Anatomy and Physiology Laboratory Manual for Nursing and Allied Health

ANATOMY AND PHYSIOLOGY LABORATORY MANUAL FOR NURSING AND ALLIED HEALTH

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INTRODUCTION

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PART I

MAIN BODY

1.

CHAPTER 1 AN INTRODUCTION TO THE HUMAN BODY

By Rajeev Chandra

Motivation

Thirteen percent of African Americans of all ages report they are in fair or poor health. Adult obesity rates for African Americans are higher than those for whites in nearly every state of the nation—37 percent of men and nearly 50 percent of women are obese.

African Americans have higher rates of diabetes, hypertension, and heart disease than other groups. Nearly 15 percent of African Americans have diabetes compared with 8 percent of whites. Asthma prevalence is also highest among blacks. Black children have a 260 percent higher emergency department visit rate, a 250 percent higher hospitalization rate, and a 500 percent higher death rate from asthma compared to white children.

African Americans experience higher incidence and mortality rates from many cancers that are amenable to early diagnosis and treatment. African-American adults with cancer are woefully underrepresented in cancer trials and are much less likely to survive prostate cancer, breast cancer, and lung cancer than their white counterparts.

In order to better understand all of the above chronic health conditions, it is very much necessary to have a basic understanding of the normal functioning of the human body. For this, it is important to know how the human body is structured and organized, or **Anatomy**; and how those structures coordinate with each other to provide normal life processes, or **Physiology**.

(Credit: Hesse, DeLoris; Cozart, Deanna; Szymik, Brett; and Nichols, Rob, "UGA Anatomy and Physiology 1 Lab Manual, 3rd Edition" (2017). Biological Sciences Open Textbooks. 13. https://oer.galileo.usg.edu/biology-textbooks/13)

Learning Objectives

Upon completion of this chapter, students should be able to:

- Describe the hierarchy of organization of the human body
- Demonstrate and describe anatomical position
- Use directional terms to precisely describe the location of structures on the human body
- Demonstrate and describe anatomical planes of section
- Identify the major body cavities and provide examples of major organs found in each

Background.

Human anatomy is the scientific study of the body's structures. In the past, anatomy has primarily been studied via observing injuries, and later by the dissection of anatomical structures of cadavers, but in the past century, computer-assisted imaging techniques have allowed clinicians to look inside the living body. Human physiology is the scientific study of the chemistry and physics of the structures of the body. Physiology explains how the structures of the body work together to maintain life. It is difficult to study structure (anatomy) without knowledge of function (physiology). The two disciplines are typically studied together because form and function are closely related in all living things.

Structural Organization of the Human Body

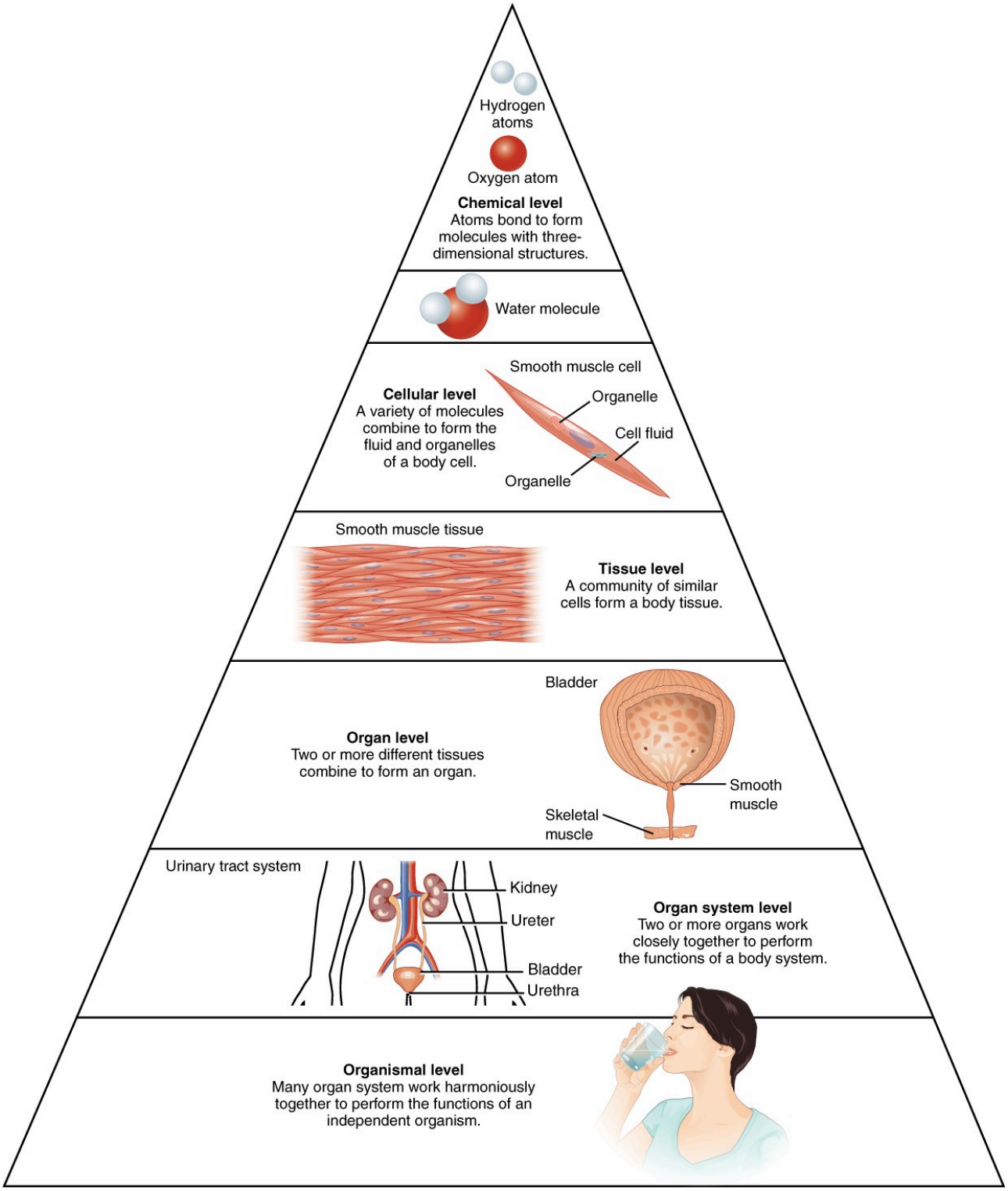


Figure. 1.2 Levels of Organization of the Structural Organization of the Human Body

The chemical level of organization includes the simplest building blocks of matter: subatomic particles, atoms and molecules. Subatomic particles (protons, neutrons, and electrons) combine to form atoms. Familiar examples of atoms include hydrogen, oxygen, carbon, nitrogen, calcium, and iron. Two or

more atoms combine to form a molecule, which includes things like water molecules, proteins, and sugars found in living things. Molecules are the chemical building blocks of all body structures.

A cell is the smallest independently functioning unit of a living organism which can include independently living single cell organisms like bacteria. All living structures within the human body 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. A tissue is a group of multiple similar cells (these cells can either be of the same cell type or can consist of a few related cell 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 that performs one or more specific functions. An organ system is a group of organs that work together to perform major functions to meet physiological needs of the body. Throughout this course we will cover a subset of the organ systems found in the human body: the integumentary, skeletal, muscular, and nervous systems.

Language of Anatomy

Anatomists and health care providers use terminology to precisely talk about the anatomy of the human body that can seem overwhelming at first. The purpose of this language is not to confuse, but rather to increase precision, efficiency, and to reduce medical errors. For example, if you tell a friend that you have a scar "above the wrist" is it located on the forearm two or three inches away from the hand? Or is it at the base of the hand? Is it on the palm-side or back-side? By using precise anatomical terminology, including anatomical position, regional terms, directional terms, body planes, and body cavities, we can eliminate ambiguity and increase precision.

Anatomical terms are made up of roots, prefixes, and suffixes. The root of a term often refers to an organ, tissue, or condition, whereas the prefix or suffix often describes the root. For example, in the disorder hypertension, the prefix "hyper-" means "high" or "over," and the root word "tension" refers to pressure, so the word "hypertension" refers to abnormally high blood pressure.

Anatomical Position

Anatomists have standardized the position of the body when it is referenced using descriptive terms to increase precision in language. Just as maps are normally oriented with north at the top, the standard body "map," called **anatomical position**, is that of the body standing upright, with 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 (see Figures 1.3 or 1.4 for an example). Using this standard position helps reduce confusion and increase precision while describing parts of the human body. It does not matter how the body being described is oriented (ex: a doctor describing their patient who is sitting on an exam table), the terms are used as if that person is in anatomical position. For example, a scar in the "anterior (front) carpal (wrist) region" would always be present on the palm side of the wrist. The term "anterior" would always be used even if the hand were palm down on a table.

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 and you may hear the terms used to describe the position of the cadavers used in this course.

Regional Terms

The human body's numerous regions have specific terms to help increase precision in language (see Figure 1.3). 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 see these terms throughout the semester as they often form the basis for many of the structures you will learn later.

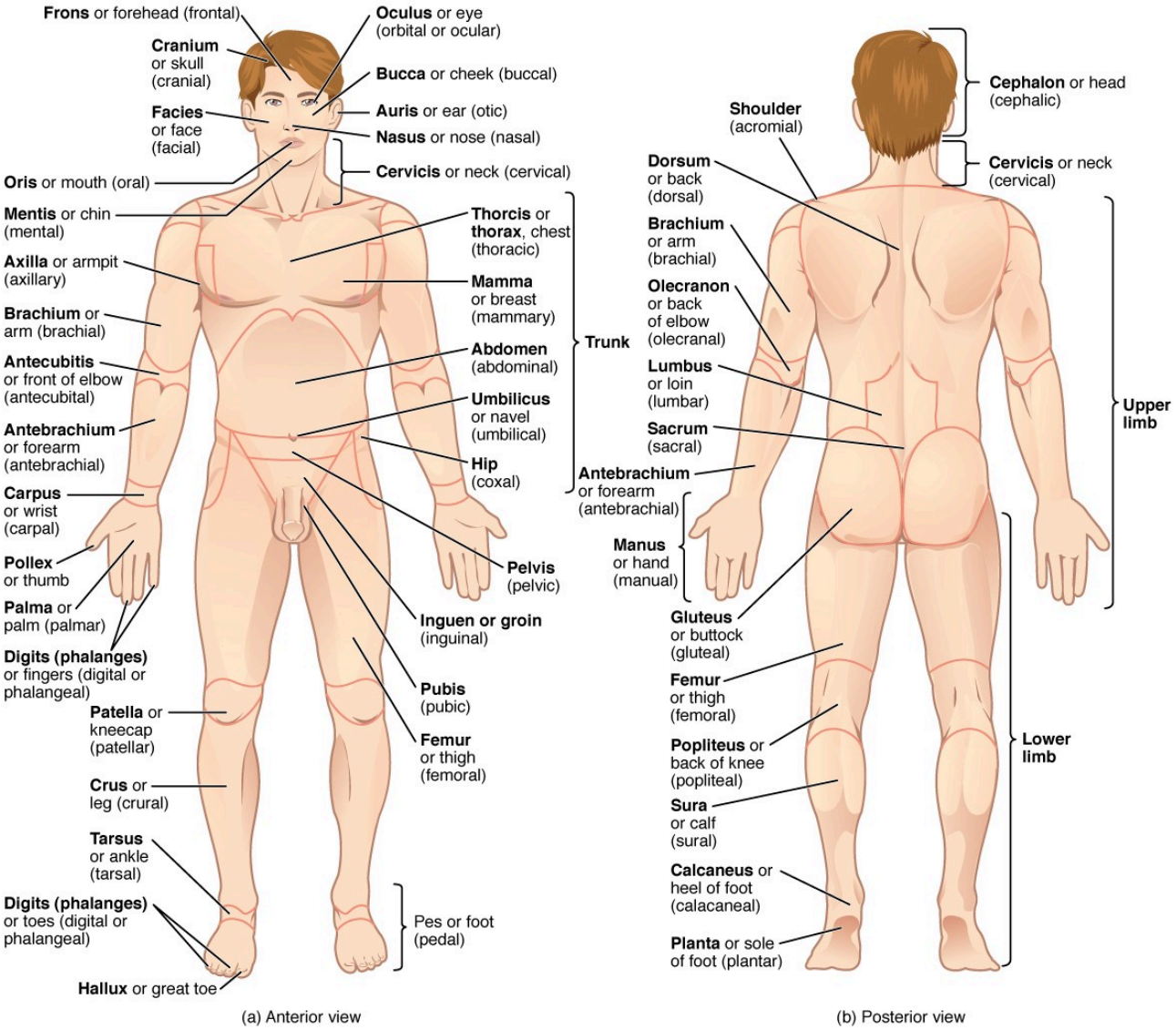


Figure 1.3 Regions of the Human Body. The human body is shown in anatomical position in an (a) anterior view and a (b) posterior view. The regions of the body are labeled in boldface.

Directional Terms

A set of specific directional anatomical terms appear throughout this and most other anatomy textbooks (Figure 1.4). These 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. Learning these terms now is critical to avoid confusion when you are studying or describing the locations of particular body parts in this course and in any future study of the human body.

- **Anterior** (or **ventral**) – Describes the front or direction toward the front of the body. For example, the toes are found on the anterior portion of the foot.
- **Posterior** (or **dorsal**) – Describes the back or direction toward the back of the body. For example, the spinal column is posterior to the sternum.
- **Superior** (or **cranial**) – Describes a position above or higher than another part of the body. For example, the eyes are superior to the mouth. Superior and cranial can often be used interchangeably though cranial is used to specifically refer to a structure near or toward the head. In quadrupeds the terms sometimes cannot be used interchangeably.
- **Inferior** (or **caudal**) – Describes a position below or lower than another part of the body. For example, the pelvis is inferior to the abdomen. Inferior and caudal can often be used interchangeably though caudal is used to specifically refer to a structure near or toward the tail (in humans, the coccyx, or lowest part of the spinal column). In quadrupeds the terms sometimes cannot be used interchangeably.
- **Lateral** – Describes the side or direction toward the side of the body. For example, the thumb is lateral to the other digits.
- **Medial** – Describes the middle or direction toward the middle of the body. For example, the big toe is the most medial toe.
- **Proximal** – Describes a position in a limb that is nearer to the point of attachment or the trunk of the body. For example, the upper arm is proximal to the wrist.
- **Distal** – Describes a position in a limb that is farther from the point of attachment or the trunk of the body. For example, the foot is distal to the thigh.
- **Superficial** – Describes a position closer to the surface of the body. For example, the skin is superficial to the bones.
- **Deep** – Describes a position farther from the surface of the body. For example, the brain is deep to the skull.
- **Contralateral** – Describes structures found on opposite sides of the body (right vs. left side). For example, the right foot is contralateral to the left arm.
- **Ipsilateral** – Describes structures found on the same side of the body. For example, the right hand and right shoulder are ipsilateral.

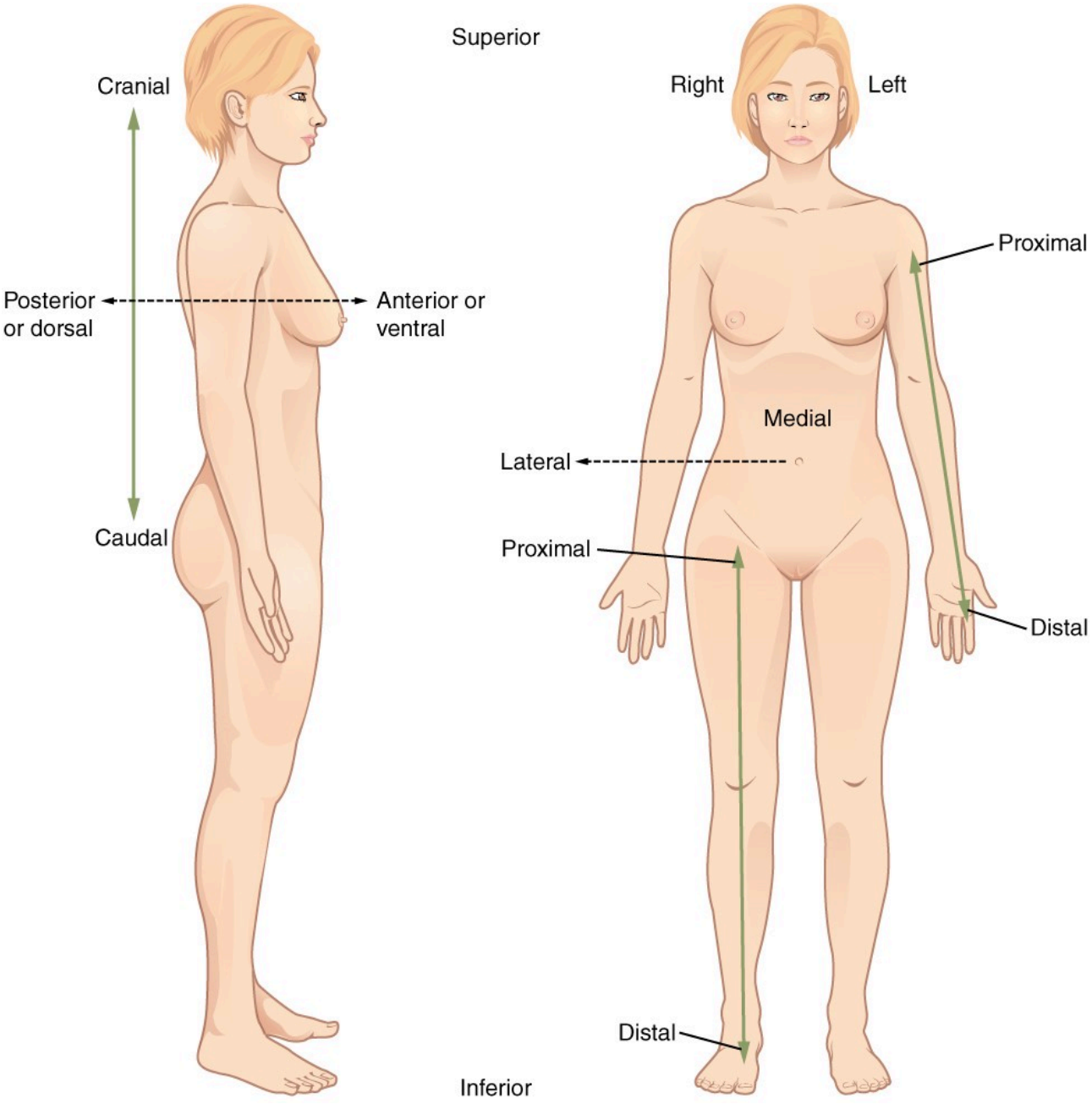


Figure 1.4 Directional Terms. The human body is shown in anatomical position in an (a) lateral view and a (b) anterior view. The arrows in green indicate the directional relationship labeled in boldface.

Body Sections & 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 which 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 (Figure 1.5).

- **Sagittal plane** – Divides the body or an organ vertically into right and left sides. If this vertical plane

runs directly down the middle of the body, it is called the midsagittal or median plane. If it divides the body into unequal right and left sides, it is called a parasagittal plane.

- **Frontal plane** – Divides the body or an organ into an anterior (front) portion and a posterior (rear) portion. The frontal plane is sometimes referred to as a coronal plane.
- **Transverse plane** – Divides the body or organ horizontally into upper and lower portions. Transverse planes produce images referred to as cross sections.

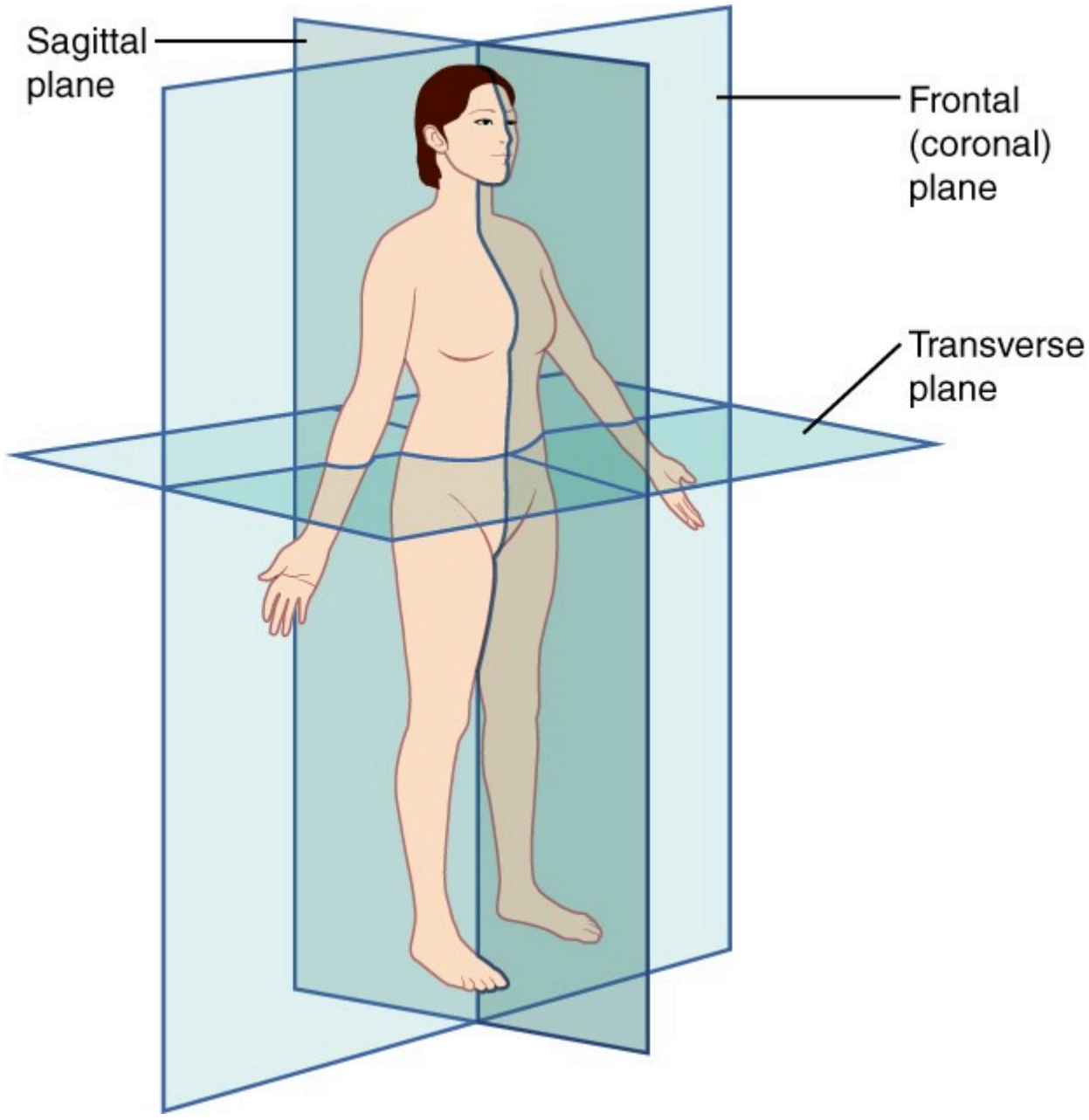


Figure 1.5 Planes of the Body. The three planes most commonly used in anatomical and medical imaging are the sagittal, frontal, and transverse planes.

Body Cavities

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 (Figure 1.6). These cavities contain delicate internal organs, and the ventral cavity allows for significant changes in the size and shape of the organs as they perform their functions. The lungs, heart, stomach, and intestines, for example, can change their shape considerably during expansion or contraction without distorting other tissues or disrupting the activity of nearby organs since they are found in cavities.

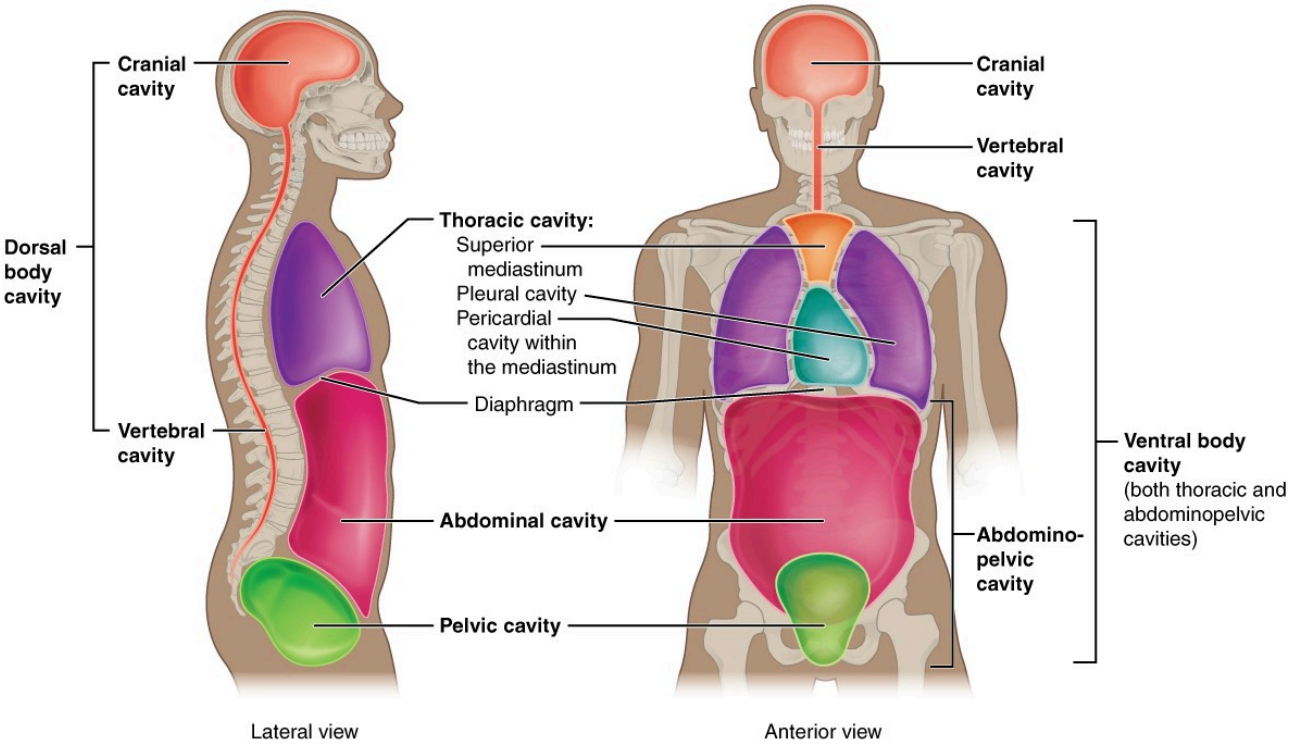


Figure 1.6 Dorsal and Ventral Body Cavities. The ventral cavity includes the thoracic and abdominopelvic cavities and their subdivisions. The dorsal cavity includes the cranial and spinal cavities.

The dorsal and ventral cavities are each subdivided into smaller cavities. In the dorsal cavity, the cranial cavity houses the brain, and the vertebral (spinal) cavity encloses the spinal cord. Just as the brain and spinal cord make up a continuous, uninterrupted structure, the cranial and spinal cavities that house them are also continuous. The brain and spinal cord are protected by the bones of the skull and vertebral column and by cerebrospinal fluid, a colorless fluid produced by the brain, which cushions the brain and spinal cord within the dorsal cavity.

The ventral cavity has two main subdivisions: the thoracic cavity and the abdominopelvic cavity. The thoracic cavity is the more superior subdivision of the anterior cavity, and it is enclosed by the rib cage. The thoracic cavity contains the lungs (each found in a pleural cavity) and the heart (found in a pericardial cavity). The diaphragm forms the floor of the thoracic cavity and separates it from the more inferior abdominopelvic cavity. The abdominopelvic cavity is the largest cavity in the body. Although no membrane physically divides the abdominopelvic cavity, it can be useful to distinguish between the abdominal cavity, the division that primarily houses the digestive organs, and the pelvic cavity, the division that primarily houses the organs of reproduction.

Abdominal Regions and Quadrants

Health care providers typically divide up the abdominal cavity into either nine regions or four quadrants in order to promote clear communication about the location of a patient's symptoms such as abdominal pain or a suspicious mass (Figure 1.7).

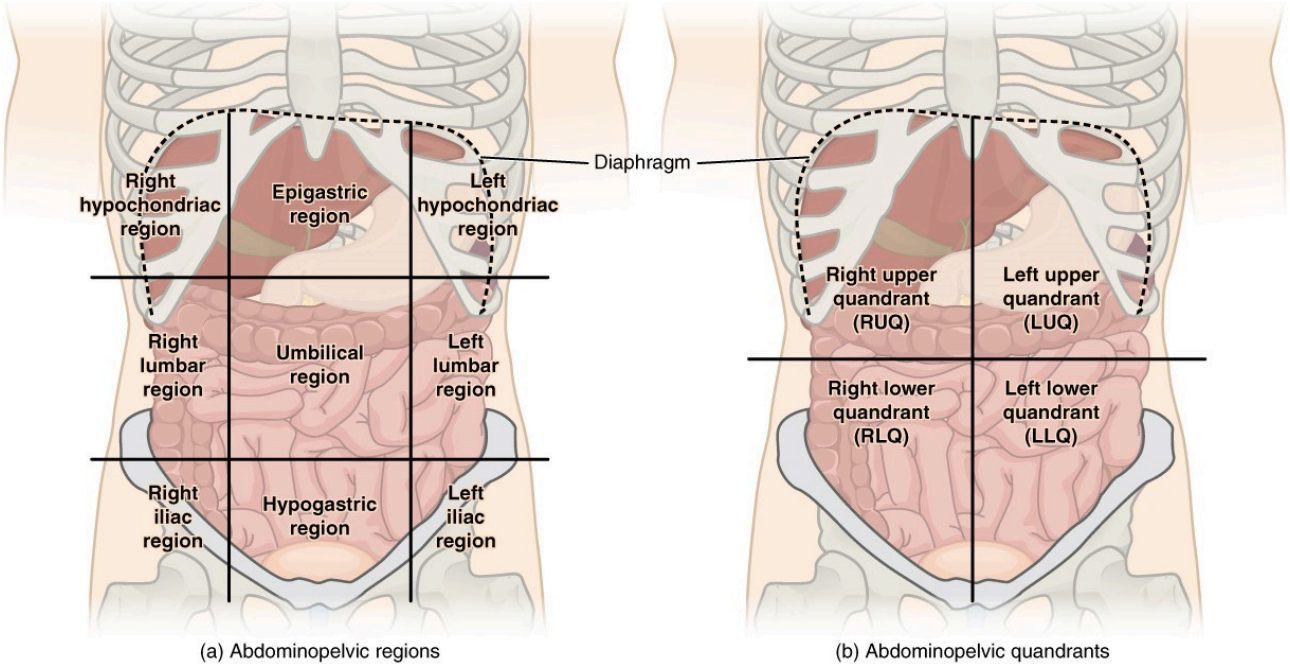


Figure 1.7 Regions and Quadrants of the Peritoneal/Abdominopelvic Cavity. There are (a) nine abdominal regions and (b) four abdominal quadrants in the peritoneal cavity.

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).

Pre-Laboratory Questions

After you review the background information in this chapter answer the following questions prior to attempting the exercises.

1. List the levels of organization in living things starting from the simplest to the most complex.
2. What is the difference between anatomy and physiology?
3. List the main regional terms used to indicate body regions in anatomy. Which body part does each represent?
4. What are the four terms used to indicate the body planes or sections in anatomy? Describe each.
5. List the main body cavities. Indicate the types of organs found in each.
6. What are the terms used for the four abdominal quadrants and nine abdominal regions?

Exercises

- Exercise 1. Describe the hierarchy of organization of the human body
- Exercise 2. Demonstrate and describe anatomical position
- Exercise 3. Use directional terms to precisely describe the location of structures on the human body
- Exercise 4. Demonstrate and describe anatomical planes of section
- Exercise 5. Identify the major body cavities and provide examples of major organs found in each

Exercise 1 Describe the hierarchy of organization of the human body

Required Materials

- None

Procedure

This activity will be completed individually or in small groups. Refer to the background information to answer the questions below.

Complete the table below by sorting the given organizational levels of the human body **from smallest to largest** and then providing a one-sentence definition of each level.

Tissue; organelle; atom; organ; organ system; cell; organism; molecule

Smallest	**Definition**
Largest	

Exercise 2 Demonstrate and describe anatomical position

Required Materials

- A lab partner
- Open space

Procedure

Using the definition of anatomical position provided in the background information, take turns with a classmate to give simple, one-movement verbal instructions to **transition from the given starting positions** so that they end up in anatomical position.

Starting Positions:

1. Lying face-up on the ground with their head, back, hands, and feet on the floor with both knees bent
2. In a seated position on the floor with their legs straight and arms folded across their chest
3. Sitting in a chair with their back to you and hands sitting in their lap
4. Standing and facing you with their legs crossed and hands in their pocket

Check Your Understanding

Write your detailed step-by-step instructions in the provided table.

Scenario	Given Instructions
1	
2	
3	
4	

Exercise 3 Use directional terms to precisely describe the location of structures on the human body

Required Materials

- Post-its
- Skeleton or torso model

Procedure

This activity will be completed individually or in small groups. Use all of the directional terms provided in the table below in an accurate context by illustrating the terms on a skeleton or torso model.

Complete the table below for each directional term.

Directional Term	Definition	Example(s)
Superior (cranial)		
Inferior (caudal)		
Medial		
Lateral		
Superficial		
Deep		
Anterior (ventral)		
Posterior (dorsal)		
Proximal		
Distal		
Ipsilateral		
Contralateral		

Exercise 4 Demonstrate and describe anatomical planes of section

Required Materials

- One pickle
- Plate
- Knife

- 4 Toothpicks
- Piece of paper

Procedure

This activity will be completed together as a class. Please do not eat the pickles.

1. Retrieve a pickle on a plate, four toothpicks, and a knife from your instructor.
2. Place the toothpicks in your pickle to serve as representations of the arms and legs.
3. Your instructor will direct you to cut your pickle along one of five planes: midsagittal (median), parasagittal, frontal (coronal), transverse (horizontal), and oblique.
4. Draw a representation of the now-visible section where you made the cut on your piece of paper.
5. Compare your drawing and pickle-sections with other groups that made that same section.
6. View the drawings of other groups that made different sections.
7. **Take a picture** of your drawing and a representative example of each of the other four sections from other groups in the class.

For each of the following questions there could be one or more than one correct answer.

Choose the body plane(s) that would allow you to see both lungs at the same time:

Midsagittal

Parasagittal

Frontal

Transverse

Oblique

Choose all possible body plane(s) that would allow you to see the brain and the spinal cord:

Midsagittal

Parasagittal

Frontal

Transverse

Oblique

Choose the body plane(s) that would allow you to see the brain but not the spinal cord:

Midsagittal

Parasagittal

Frontal

Transverse

Oblique

Choose the body plane(s) that would allow you to see the right eye but not the left eye:

Midsagittal

Parasagittal

Frontal

Transverse

Oblique

Exercise 5 Identify the major body cavities and provide examples of major organs found in each

Required Materials

- Post-its
- Large piece of paper
- Tape
- Torso model and/or a classmate

Procedure

This activity will be completed as a group.

On the large piece of paper, draw two perpendicular lines to create four quadrants (right-upper, right-lower, left-upper, and left-lower), similar to Figure 1.7.

Tape the piece of paper onto the abdomen of the torso model or a classmate

Your instructor will call out the name of a major organ and you will write the organ name on a post-it and then place the post-it in the correct quadrant.

List all of the cavities found within the dorsal body cavity.

List all of the cavities found within the ventral body cavity.

Complete the table to provide one example of an organ found in each of the following body cavities.

Body cavity	Organ Example(s)
Cranial	
Abdominal	
Pelvic	
Pleural	
Vertebral	
Pericardial	

Post-laboratory Questions

1.Name the six levels of organization of the human body.

a.

b.

c.

d.

e.

2.Describe the anatomic position using your own words?

3. If you use a midsagittal section, which organs can you divide into two equal sections? Give at least one example and demonstrate this sectioning by using a sketch of the organ.

4. Fill in the gaps below using an appropriate directional term.

- The head is located _____ to the toes.
- In the anatomic position, the thumb is located _____ to the pinky of the same hand.
- The mouth is located _____ to the eyes.

- Muscles lie _____ to the skin covering in their area.
- The tip of your nose is _____ to the top of your ears.

5. Examine the figures above and do some additional research to list all the organs that are within each of the four abdominal quadrants. Sketch and show the quadrants and the organs contained within each.

6. Make a list of the body cavities of the human body. Then, list all the organs that are found within each cavity.

7. In anatomical terminology we use specific words to define each body region. List the regional term that is used for each of the following every day language terms we use to describe these body regions:

- head
- neck
- face
- eye
- ear
- nose
- mouth
- arm
- armpit
- wrist
- finger
- chest
- breast
- thigh
- kneecap
- back of knee
- ankle
- back
- navel
- skull

2.

CHAPTER 2 THE CHEMICAL LEVEL OF ORGANIZATION

By Aylin Marz

Motivation. Every day nurses are subjected to chemicals including those found in disinfecting solutions, medications with toxic effects, various gases including those used in anesthesia, radiation producing chemicals used in treatment, as well as chemicals found in bodily fluids such as blood, saliva and urine. Generally, the **doses** or **concentrations** of these chemicals are too low to cause harm but with repeated exposures there is always additional risk of **toxicity**. Being aware of the benefit and harm of the chemicals nurses are exposed to can help reduce risk of developing diseases from these exposures.

Figure 2.1. Registered nurse retrieves medication for her patients in the emergency department. (Credit: Adopted from Medill DC, Flickr, Title: Registered nurse Jennifer Montesil retrieves medication for her patient in the emergency department at Washington Hospital Center in Washington, D.C.https://www.flickr.com/photos/56881272@N02/5815306967, CC BY 2.0 license)

The concentration of a chemical, as well as its **chemical reactivity** with the **biomolecules** within our bodies, plays a role in how it affects health. Therefore, understanding chemical reactions can help nurses avoid harm to self and patient. Different chemical characteristics allow for mixing, **dissolving**, or reactivity to occur between compatible chemicals. This concept is also important in nutrition and in understanding what type of biomolecules are needed for **energy**, healthy **growth** and **development**. Nurses informed about chemistry can help avoid harm and decide how to advocate healthy eating habits in their patients and communities.

Learning Objectives

Upon completion of the work in this chapter, students should be able to:

1. Apply concepts related to atoms and elements to solve problems on isotopes
2. Distinguish chemical reaction types such as hydrolysis degradation resulting in protein breakdown
3. Perform an enzymatic reaction determining the reactants and products
4. Apply the scientific method to determine the effect of factors affecting enzymatic activity

Background.

Life is made of chemicals which in turn are composed of various atoms composed of neutrons, protons, and electrons. There are many elements composed of atoms with different chemical properties each. Each element is determined by the number of its protons and this is called its atomic number. For example, Carbon is an element indicated with a **C** in the periodic table, and has an atomic number of **6**. The number of protons and neutrons of an atom make up its atomic mass. There are multiple versions of an element based on its mass. For example, Carbon-12 has a mass number of 12 since it has 6 protons and 6 neutrons. Carbon-14 has a mass number of 14 since it has 8 neutrons. The different versions of an element are called its **isotopes** (Figure 2.2).

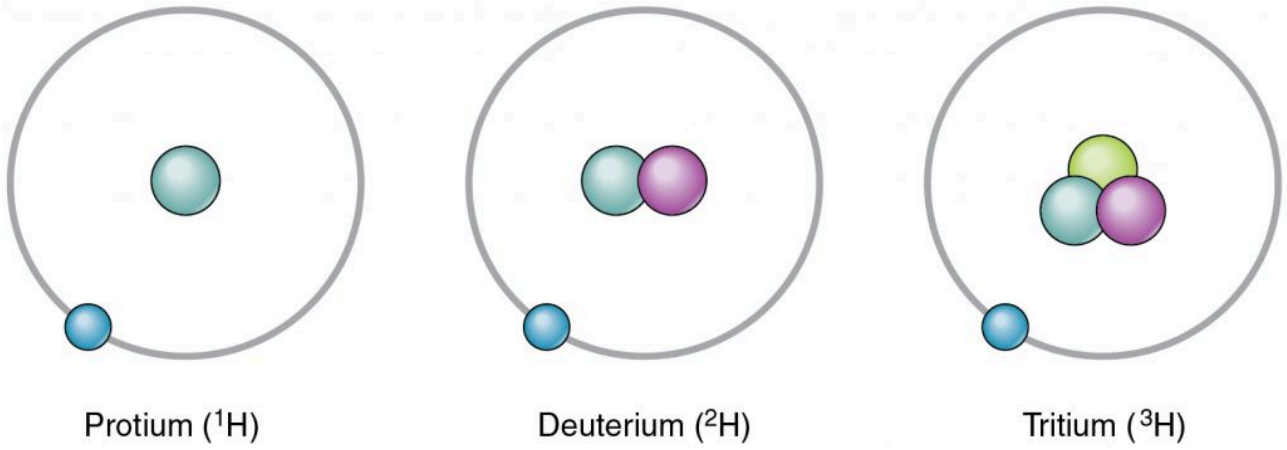


Figure 2.2. **Isotopes of Hydrogen.** Protium is the most abundant isotope of the element Hydrogen and has 1 neutron; Deuterium has two neutrons, and Tritium has three neutrons. (Credit: Adopted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

The **electrons** that orbit around the proton+neutron nucleus of an atom are negatively charged and are responsible for the interactions between different atoms. The negative charge of an electron is counteracted by the positive charge of the protons in what we call a **neutral** atom. For example, a neutral Carbon atom has 6 positively charged protons in its nucleus and 6 negatively charged electrons that orbit around the nucleus. The electrons of an atom are placed in orbitals (Figure 2.3). The first two electrons go in the innermost or first orbital, then the next 8 in the second orbital and the following 8 in the third orbital. The outermost orbital of an atom is called its **valence** orbital. The valence electrons are responsible for interactions between atoms that can result in a **chemical reaction**. The goal of a chemical reaction is to fill the valence orbital.

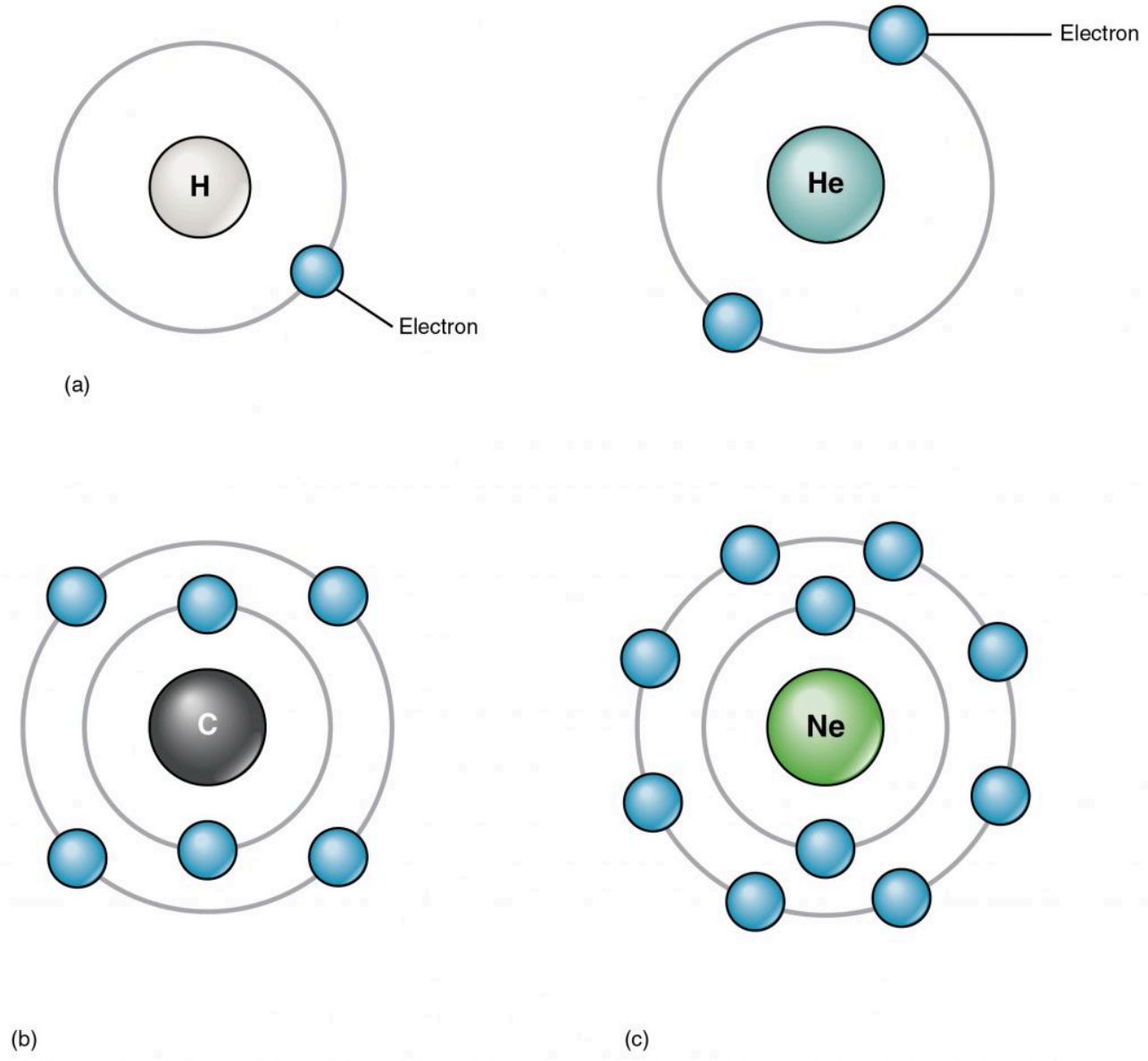
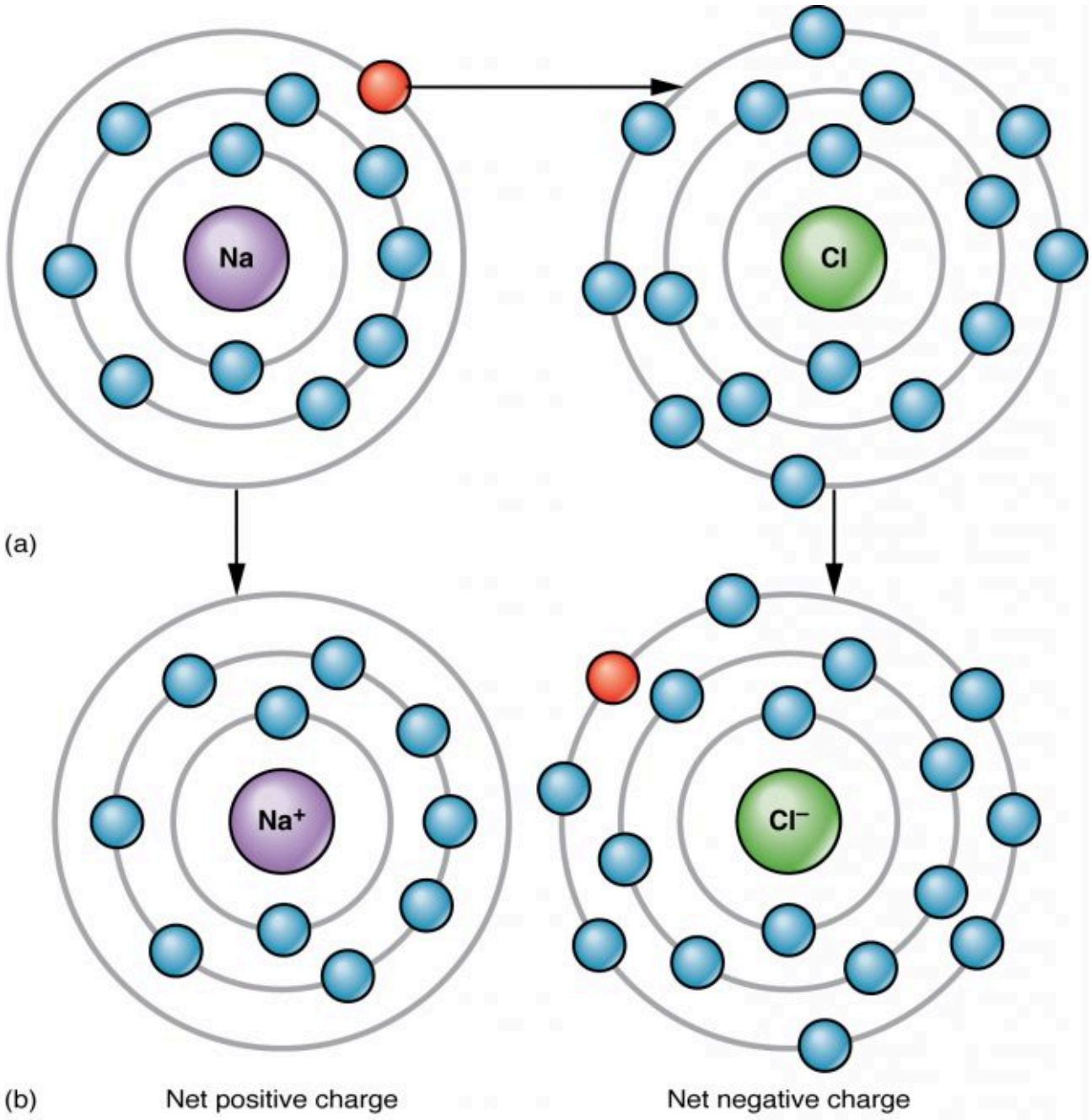


Figure 2.3 Electron Shells. Electrons orbit the atomic nucleus at distinct levels of energy called electron shells. (a) With one electron, hydrogen only half-fills its electron shell. Helium also has a single shell, but its two electrons completely fill it. (b) The electrons of carbon completely fill its first electron shell, but only half-fills its second. (c) Neon, an element that does not occur in the body, has 10 electrons, filling both of its electron shells. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0 license).

Chemical Bonds

An atom can lose or gain electrons when it interacts with another atom. If an electron is lost, then the atom becomes positively charged **ion** due to the excess of protons and is called a **cation.** If electrons are gained, then the excess negative charge renders the atom an **anion.** Chemical reactions that result in transfer of electrons from one atom to another result in attractive forces between the atoms called **ionic bonds** In the example of the ionic bonding of Sodium (Na) and Chloride (Cl) occurs by transferring an electron from Na to Cl to produce NaCl which is table salt (Figure 2.4).


Na
Cl
(a)
Na+
Cl−
(b)
Net positive charge
Net negative charge

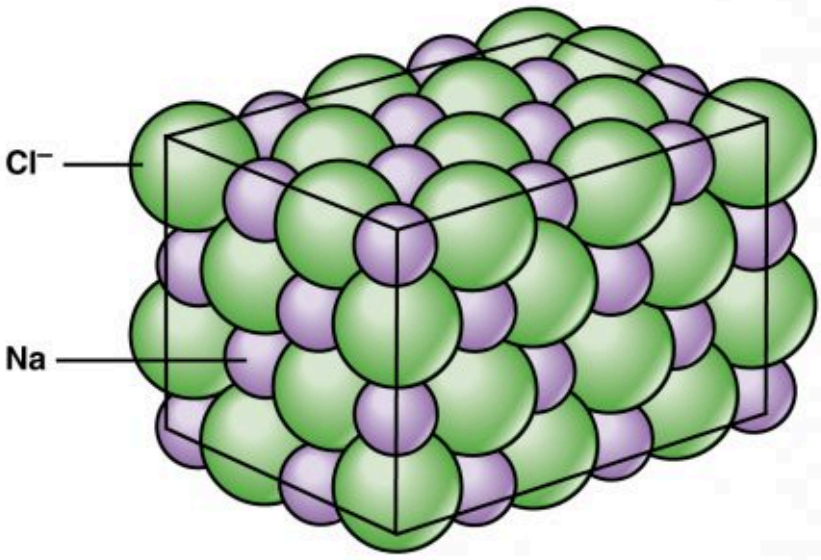
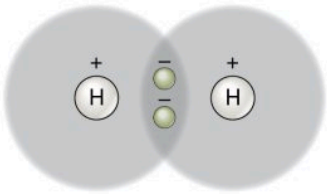

Cl−
Na
(c)

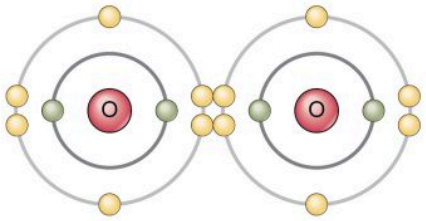
Figure 2.4. Ionic Bonding. (a) Sodium readily donates the solitary electron in its valence shell to chlorine, which needs only one electron to have a full valence shell. (b) The opposite electrical charges of the resulting sodium cation and chloride anion result in the formation of a bond of attraction called an ionic bond. (c) The attraction of many sodium and chloride ions results in the formation of large groupings called crystals. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Chemical reactions that result in sharing of electrons between atoms form attractive forces that hold the two atoms together called **covalent bonds.** Formation of bonds between atoms produces **molecules** (Figure 2.5). For example, one carbon atom covalently bonded to four hydrogens produces a molecule called methane or CH_4 that is a gas emitted by intestinal bacteria.

(a) A single covalent bond: hydrogen gas (H—H). Two atoms of hydrogen each share their solitary electron in a single covalent bond.



(b) A double covalent bond: oxygen gas (O═O). An atom of oxygen has six electrons in its valence shell; thus, two more would make it stable. Two atoms of oxygen achieve stability by sharing two pairs of electrons in a double covalent bond.



Molecule of oxygen gas (O_2)

(c) Two double covalent bonds: carbon dioxide (O═C═O). An atom of carbon has four electrons in its valence shell; thus, four more would make it stable. An atom of carbon and two atoms of oxygen achieve stability by sharing two electron pairs each, in two double covalent bonds.

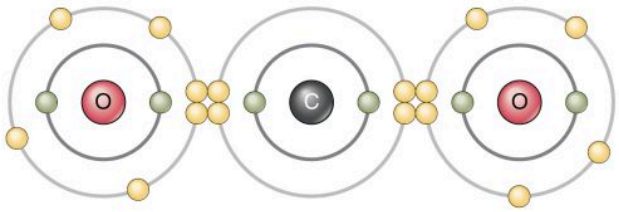


Figure 2.5 Covalent Bonding. Electrons are shared to produce (a) hydrogen gas, (b) oxygen gas, and (c) carbondioxide gas molecules. (Credit: Adopted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Many biologically relevant molecules are large and contain **monomer** units that are bonded together to form **polymers**. **Proteins** are made of amino acid monomers of which there are 20 different chemical varieties that

can be covalently bonded together (Figure 2.6). **Carbohydrates** contain monomers called **monosaccharides** such as glucose that are bonded together to form **disaccharides** such as maltose and polysaccharides such as **glycogen**. **Nucleic acids**, such as our genetic material DNA (deoxyribonucleic acid) is a long polymer made from monomers called **nucleotides**. There are many chemical types of **lipids** but the fats and oils also known as **triglycerides** are made from glycerol plus three fatty acids.

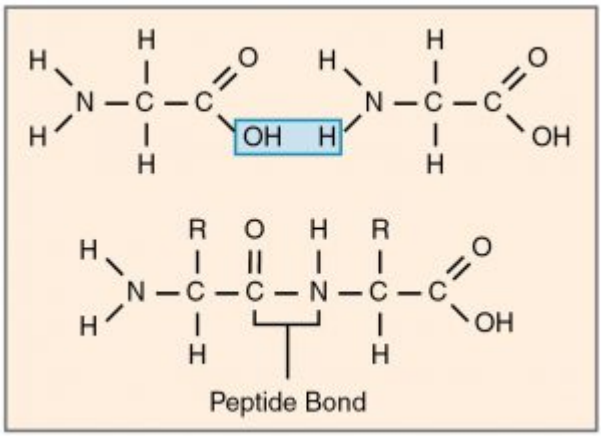


Figure 2.6. Dehydration synthesis of peptide bond in protein polymers. Different amino acids join together to form peptides, polypeptides, or proteins via dehydration synthesis. The bonds between the amino acids are peptide bonds. These bonds can be broken down in a hydrolysis reaction to produce amino acids from proteins. (Credit: Adopted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Proteins, carbohydrates, nucleic acids, triglycerides are molecules that are **broken down** during digestion into their monomeric subunits. These monomers are then absorbed into the blood and taken to cells that use them to produce energy (e.g. glucose) or to **synthesize** large molecules used in making cells structures. Making large molecules from their monomers require **dehydration synthesis** reactions in which one molecule of water is lost for each monomer bonded (Figure 2.6). When large molecules are broken down into their monomers, this requires **hydrolysis degradation** reactions in which a molecule of water is used to break each bond.

Any chemical reaction that occurs in a living organism requires the use of catalysts called **enzymes**. These are usually **proteins** that bind to the reactants or **substrates** and allow the reactants to interact more easily thereby reducing the amount of **activation energy** needed to start a reaction. To bind its substrate, an enzyme has to have a very specific three dimensional shape called its **3D structure**. An enzyme has an **active site** that fits and binds its substrate like a lock and key. Upon binding, the shape of the enzyme changes slightly to make it bind its substrate even better. This is called the **induced-fit** model (Figure 2.6).

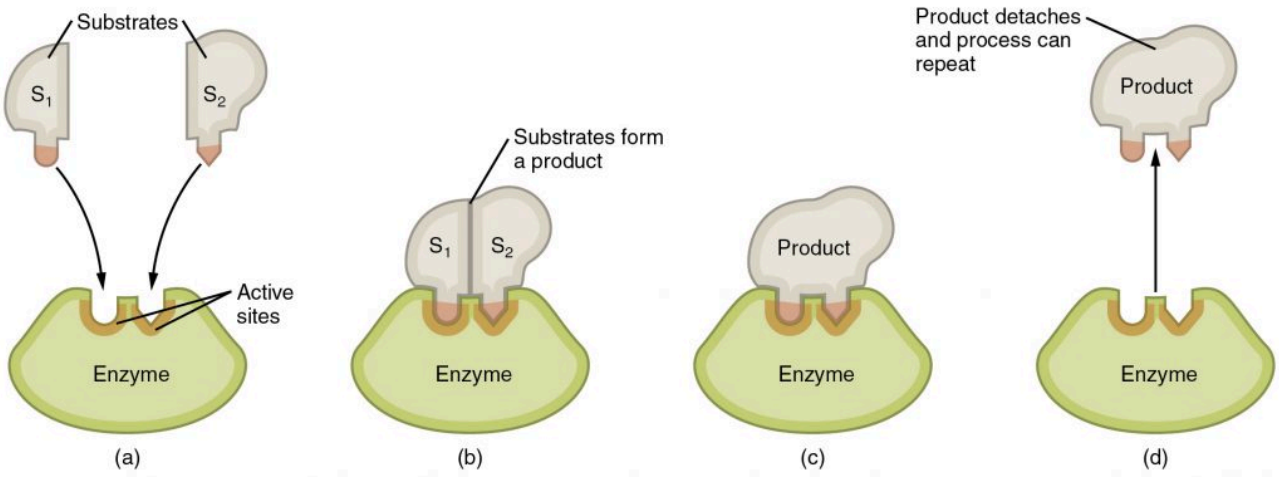


Figure 2.6 Steps in Enzymatic Reaction. According to the induced-fit model, the active site of the enzyme undergoes conformational changes upon binding with the substrate.(a) Substrates approach active sites on enzyme. (b) Substrates bind to active sites, producing an enzyme–substrate complex. (c) Changes internal to the enzyme–substrate complex facilitate interaction of the substrates. (d) Products are released and the enzyme returns to its original form, ready to facilitate another enzymatic reaction. The figure shows a dehydration synthesis reaction. Enzymes are also used in other reactions such as hydrolysis degradation reactions (Credit: Adopted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

There are factors that affect the activity of an enzyme by modifying its 3D shape. These include **co-enzymes** such as vitamins, **co-factors** such as minerals, **temperature**, and the chemical environment in which the chemical reaction occurs such as the concentration of ions such as H+ which determine the **pH**. The pH of a solution is low if the H+ concentration is high and such a solution is called **acidic**. The pH of a solution is high if the H+ concentration is low and this is a **basic or alkaline** solution. Water has neutral pH. Enzyme shape or **structure** and activity is affected by pH. For example, stomach enzymes work at acidic conditions because the stomach is really acidic. These enzymes no longer work if they find their way into the intestine which is basic.

Pre-Laboratory Questions

After you review the background information, answer the following questions prior to attempting the laboratory exercises.

1. What are the main subatomic particles making up an atom?
2. Which subatomic particle is different among various isotopes of an element?
3. What are the monomers that are covalently bonded to produce a protein polymer?
4. How do enzymes function in chemical reactions?
5. List some factors that affect the function of an enzyme.

Exercises

- Exercise 1. Radioactive Isotopes
- Exercise 2. Chemical Reaction – Breakdown of Collagen Protein
- Exercise 3. Factors Affecting Enzyme Activity

Exercise 1. Radioactive Isotopes

In the clinic, there are diagnostic methods that require giving the patient a radioactive isotope. This isotope can be traced and imaged in order to diagnose disease. What are isotopes and what makes them useful as tracers? Isotopes of an element have different atomic mass but the same chemical properties. Some isotopes are **unstable** and release high energy waves or particles that can be detected, followed and imaged, i.e. used as tracers of chemicals within the human body. These **radioactive isotopes** can also be used in treatment of disease usually because the high energy waves or particles they emit kill unwanted cells such as those of a tumor or a hyperactive thyroid gland.

In this exercise, we will explore the relationship between isotopes, atomic mass, and the number of subatomic particles using a simulation. The goal is to learn how mass number and atomic mass number (amu) relate to the number of protons, neutrons, electrons, as well as the abundance in nature of an elemental isotope. You will also see the relationship of all these to the stability of an isotope. Remember that radioactive isotopes that are useful in the clinic are the unstable isotopes.

Materials and Methods

The **tool** we will use is a simulation called "**PhET Interactive Simulation: Isotopes and Atomic Mass**". Here is the link to access it: https://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass.

- Once you get to this page, click on the arrow to begin playing the simulation.
- Then, select "Isotopes" (not Mixtures). You will get to a page that looks similar to the following **Figure 2.7.**
- You have the ability to view different elements by clicking on their symbol on the periodic table at the top right corner.
- You can add neutrons to the element by clicking and dragging one of the balls in the bowl named "Neutrons" onto the isotope. You can remove a neutron from the isotope by clicking on it and dragging it into the Neutrons bowl (bottom left corner).
- The isotope sits on a balance that allows you to select its mass number or atomic mass to view.
- The number of protons, neutrons, and electrons are displayed on the left top corner.

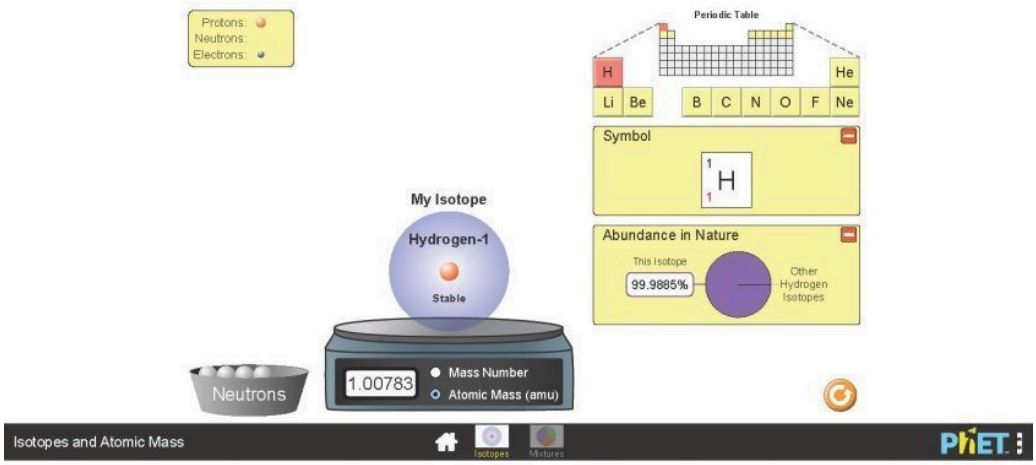


Figure 2.7 PhET simulation for observing the characteristics of an isotope by changing the number of neutrons. (Credit: Available at http://phet.colorado.edu as open educational resource under the Creative Commons Attribution license CC-BY.)

Exercise 1.1

Using the PhET interactive simulation fill out the information in the following table for **the most abundant isotope** of elements Carbon, Nitrogen, and Oxygen. The information for the element hydrogen is provided as an example.

Element name	Element Symbol	Isotope Name	Isotope Symbol	% Abundance in Nature	Atomic Number	Mass Number	Atomic Mass (amu)	Number of protons, neutrons, electrons	Stability
Hydrogen	H	Hydrogen-1	$^{1}_{1}H$	%99.9885	1	1	1.00783	1p, 0n, 1e	Stable
	C								
	N								
	O								

Exercise 1.2

Select **an element** (other than hydrogen) from the periodic table shown in this simulation. Use the interactive simulation to answer the following questions regarding your element.

- What element did you select? List its name and symbol here. Example: Hydrogen, H.
- Which isotope of this element is the most abundant in nature? What is this % abundance? Example: Hydrogen-1, %99.9885
- By adding or subtracting **neutrons** from your isotope determine all of its isotopes that exist in nature. Use the following table to list the characteristics of each of these isotopes. Hydrogen is shown as an example.

Isotope Name	**Isotope Symbol**	**% Abundance in Nature**	**Atomic Number**	**Mass Number**	**Atomic Mass (amu)**	**Number of protons, neutrons, electrons**	**Stability**
Hydrogen-1	$^{1}_{1}H$	%99.9885	1	1	1.00783	1p, 0n, 1e	Stable
Hydrogen-2 (deuterium)	$^{2}_{1}H$	%0.0115	1	2	2.01410	1p, 1n, 1e	Stable
Hydrogen-3 (tritium)	$^{3}_{1}H$	trace	1	3	3.01605	1p, 2n, 1e	Unstable

Exercise 1.3

For the following elements shown in the periodic table in this simulation determine their **unstable isotopes**. You can do this by adding or subtracting neutrons from your isotope (drag neutron balls from the bowl to your isotope to add, from the isotope to the bowl to subtract). For each unstable isotope, do a web search and determine if there is a clinical use for the isotope in diagnosis or treatment of patients. List the clinical use in the table below. Provide a web link to the information on clinical use.

Element	Unstable / Radioactive Isotopes	Clinical uses	Web links
Hydrogen (H)			
Boron (B)			
Carbon (C)			
Nitrogen (N)			
Oxygen (O)			
Fluorine (F)			

Exercise 1.4

At this point you have interacted extensively with the isotope simulation tool. Using your experience and observations come up with a hypothesis that **relates the number of neutrons to the stability of the isotope**. Design an experiment to test this hypothesis. Gather data using the simulation tool and record your data. Determine if your results support your hypothesis.

- **Hypothesis:** Based on your observation so far, what do you think is the relationship between the

number of neutrons and the stability of an isotope of an element (any element, not just a specific one)?

- **Experimental design:** How would you use the simulation to test your hypothesis? What would you change (independent variable)? What would you measure/observe (dependent variable)? What do you compare your results to (control – Hint: Would this be the stable most abundant isotope for each element)?
- **Results:** When you changed your independent variable, how did that affect your dependent variable? You can use a table here to list each element you tested. You should test all the elements available to you.
- **Conclusions:** Did the results support your initial hypothesis about the relationship between the number of neutrons and isotope stability? If the results support your hypothesis, describe the supporting results. If the results did not support your hypothesis, indicate which results contradicted your hypothesis.

Exercise 2. Chemical Reaction – Breakdown of Collagen Protein

In this exercise you will use gelatin which is the component that makes Jello solidify when it cools down. Gelatin is made of a protein called **Collagen** which also exists as filler or extracellular matrix or connective tissue protein in our bodies. Both gelatin and collagen are made of chains of amino acids. For gelatin to do its function of solidifying juices when cooled, the amino acids have to remain covalently bonded to each other. If the peptide bonds holding the amino acids together break, then gelatin will not solidify the juices. You will use an **enzyme** called **Bromelain** in this exercise that catalyzes the breakdown of the covalent bonds between the amino acids of gelatin proteins.

Materials

- Gelatin (unflavored, e.g. Knox gelatin https://www.knoxgelatine.com/basics.htm)
- Incubator at 60^{o}C
- Pineapple juice
- Transfer pipets
- Test tubes
- Test tube rack
- Test tube holder
- Test tube marker pen
- Heat block
- Beakers
- Glass stirrers
- Graduated cylinder
- Hydrochloric acid, HCl
- Sodium Hydroxide
- Water

Exercise 2.1 Preparation of the Substrate Gelatin Solution.

Follow the instructions on the gelatin package to prepare a gelatin solution that is two times more concentrated than instructed. We will call this 2X gelatin in water. For example if the package instructions say to add 100 mL of water, you add 50 mL instead. You will need boiling water, a beaker, and a graduated cylinder. Once the gelatin is dissolved, you can use it right away. Make sure to keep it warm in the 60^{o}C incubator until you are ready to use it.

Question: After you add boiling water to gelatin, do you expect the three dimensional structure of gelatin protein to be maintained? If yes, why? If not, why not? Sketch a model of what you anticipate gelatin protein structure to be before and after adding the boiling water.

Exercise 2.2 Determining Gelatin Solidification Conditions and Timeline.

The goal of this exercise is to determine how long it takes to solidify gelatin.

1. You will need three tubes with gelatin (+G) as your experimental replicates and three tubes without gelatin (-G) as control.
2. Place the tubes on the tube rack. Label three tubes as **control 1, 2, 3** and three tubes as gelatin **+G 4, 5, 6**.
3. Transfer 4 mL of water into each of the control tubes labeled 1, 2, 3.
4. Transfer 2 mL of water and 2 mL of 2X gelatin into the +G tubes 4, 5, 6. Mix by gently swirling the solution in the tubes.
5. Let all the tubes sit at benchtop.
6. Observe the tubes at 5 minute intervals until gelatin solidifies. Swirl the tubes to see if the liquid moves or not.
7. Record your observations in the table below.

Tube	Time (min)	Solid? No, Yes, Partial
1	0	
2		
3		
4		
5		
6		
1	5	
2		
3		
4		
5		
6		
1	10	
2		
3		
4		
5		
6		
1	15	
2		
3		
4		
5		
6		

Question 1. Did all your replicates in the experimental group for gelatin solidify at the same exact time? If yes, explain why you expected this to be the case? If no, what would be a reasonable explanation for why not? In the space below, sketch your tubes to show how the controls and the experimental samples looked different at the end of your observation.

Question 2. What is the independent variable in this experiment? What is the dependent variable?

Exercise 2.3 Testing the Effect of Bromelain on Gelatin Solidification.

The goal of this experiment is to determine the effect of the Bromelain enzyme on the solidification of gelatin. To achieve this, you will compare a control group in which Bromelain is absent to an experimental group in which Bromelain is present. Both groups will have gelatin under conditions that normally allow solidification as you worked out in Exercise 2.1 and 2.2. To achieve this goal, follow the steps below:

1. You will need six tubes for this experiment. Place the tubes on a rack.
2. Tubes 1, 2, 3 are control tubes that do not contain Bromelain. Measure 2 mL of 2X gelatin and 2 mL of water into each tube 1, 2, 3.
3. Tubes 4, 5, 6 are the experimental group tubes. Measure 2 mL of 2X gelatin and 2 mL of pineapple juice (Bromelain) into each tube 4, 5, 6.
4. Observe the tubes and record how long it takes them to solidify similar to what you did in Exercise 2.2. Make sure to continue your observation until your control tube contents solidify.

Tube	Time (min)	Solid? No, Yes, Partial
1	0	No
2		No
3		No
4		No
5		No
6		No
1	5	
2		
3		
4		
5		
6		
1	10	
2		
3		
4		
5		
6		
1	15	
2		
3		
4		
5		
6		

Question 1. Did all your gelatin containing tubes solidify at the same time? If yes, is that what you expected? If no, explain why you expected this result? In the space below, sketch the control and experimental tubes to show their differences at the end of the experiment.

Question 2. In this experiment, what is the independent variable? The dependent variable?

Question 3. Sketch a model that shows the enzyme-substrate interaction and the chemical reaction that occurs in the tubes that contain Bromelain. What are the reactant(s)? Product(s)?

Post-laboratory Questions

1. In Exercise 1, you explored the relationship between the number of neutrons and isotope stability. Using what you learned, explore Iodine which has an isotope used in the clinic. Specifically, radioactive Iodine-131 is used to treat overactive thyroid glands by killing cells. Use the periodic table and your knowledge of atoms and elements to answer the following:

    - What is the symbol for Iodine?
    - How many protons does Iodine-131 have?
    - How many electrons does neutral Iodine-131 have?
    - If Iodine-131 loses an electron, what will be the charge on it? Will it be an anion or cation?
    - How many neutrons does Iodine-131 have?
    - The most abundant and stable isotope of Iodine is Iodine-127. Which subatomic particle number is different between Iodine-127 and Iodine-131? How many more or less of this particle does Iodine-131 have compared to Iodine-127?

2. In Exercise 2, you showed that pineapple juice contains sufficient Bromelain enzyme to digest the collagen protein used preventing collagen from solidifying or gelling. Bromelain can work on other proteins as well. In fact, Bromelain purified from pineapple is sold in pill form as well as in cream form for various health benefits. Below you have some applications for which these pills and creams are used. For each scenario below, describe how you think Bromelain's protein degradation activity could help achieve these therapeutic effects. Then, look up information online to help you better understand how Bromelain helps with these treatments. List your reference(s).

    - Applying Bromelain cream on burns under a wound dressing:
    - Taking Bromelain to aid in digestion:
    - Bromelain taken to reduce cancer cell growth:
    - Taking Bromelain tablets to reduce blood clot formation thereby reducing plaques in arteries in cardiovascular disease:
    - Using Bromelain tablets to reduce inflammation in sinuses:
    - Taking Bromelain to help with diarrhea:

3. In Exercise 3, you used pineapple juice that contains the enzyme Bromelain. You allowed this enzyme to degrade or digest collagen which is a large protein. You then explored some physical factors such as temperature and chemical factors such as pH that affect enzyme activity. The source of your Bromelain was fresh pineapple juice. Given the factors that can affect enzyme activity, a group of nursing students get curious about the activity of Bromelain from fresh pineapple juice compared to canned pineapple juice. They set up an experiment to explore this question. Answer the following regarding the experimental design that will help compare Bromelain enzyme activity from fresh juice compared to canned juice:

- State the hypothesis that is being tested:
- What is the independent variable being altered in this experiment?
- What is the dependent variable being measured in the experiment?
- To set up the experiment you are given three groups of tubes. In each set, there are three tubes. All tubes contain the same collagen solution. In the space below, state what else you would add to each of these 9 tubes.

Group 1	Group 2	Group 3
Tube 1.	Tube 1.	Tube 1.
Tube 2.	Tube 2.	Tube 2.
Tube 3.	Tube 3	Tube 3.

- If the canned pineapple juice contains Bromelain that is less active than the enzyme from the fresh pineapple juice, what results would you expect? Use your group assignments in section "d" above to help you describe the expected results.
- What are some reasons that may render the Bromelain from the canned pineapple juice to be less active than the Bromelain enzyme from the fresh pineapple juice?

3.

CHAPTER 3 THE CELLULAR LEVEL OF ORGANIZATION

By Krishnan Prabhakaran

The Immortal Woman : Henrietta Lacks and HeLa Cells

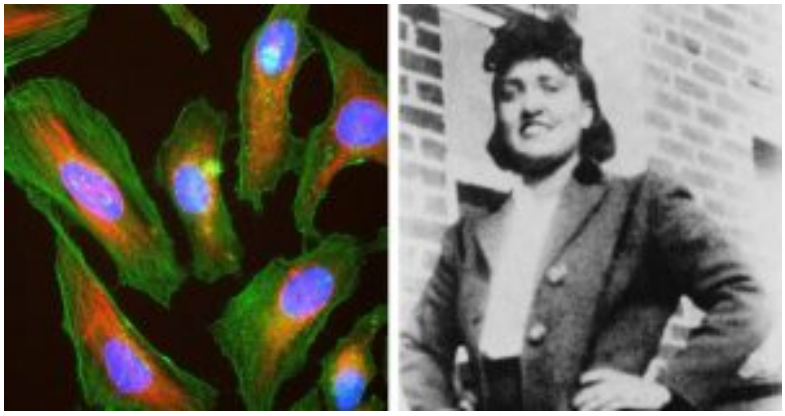


Figure 3.1 HeLa Cells: A Lasting Contribution to Biomedical Research (Credit: National Institutes of Health, Office of Science Policy. https://osp.od.nih.gov/scientific-sharing/hela-cells-landing/)

Motivation. In 1951, Henrietta Lacks, a 31-year-old African-American woman, went to Baltimore's Johns Hopkins Hospital to be treated for cervical cancer. Some of her cancer cells began being used in research due to their unique ability to continuously grow and divide in the laboratory. These so-called "immortal" cells were later named "HeLa" after the first two letters of Henrietta Lacks first and last name. Since Ms. Lacks' untimely death in 1952, HeLa cells have been a vital tool in biomedical research, leading to an increased understanding of the fundamentals of human health and disease. Some of the research involving HeLa cells also served as the underpinning of several Nobel Prize winning discoveries.

While Henrietta Lacks' story has been known in the research community for some time, it raised further awareness after the publication of the best-selling book The Immortal Life of Henrietta Lacks (Crown, 2010). To honor Ms. Lacks' and her family's continued support of biomedical research, NIH analyzed and evaluated the scientific literature involving HeLa cells and found over 110,000 publications that cited the use of HeLa cells between 1953 to 2018. This analysis further highlights the persistent impact of HeLa cells in science and medicine, proving that they have been a consistent, essential tool that has allowed researchers to expand the knowledge base in fields such as cancer biology, infectious disease, and many others.

Learning Objectives

Upon completion of the work in this chapter, students should be able to:

- Define cell & organelle

- Identify major regions of the cell (cytoplasm, nucleus, plasma membrane) on a model and/or diagram
- Summarize major functions of each major region of the cell.
- Identify typical organelles found in an animal cell and summarize major functions of each
- Summarize the major events for each part of the cell cycle (interphase and mitosis)

Background

All living matter is composed of cells. The human body contains trillions of cells. The metabolism of living organisms, all their biochemical activities, takes place within cells and as a result of cellular activity. All cells arise from other cells by cell division. All cells are surrounded by a cell membrane which encloses the cytoplasm (protoplasm) and various other internal structures. The cell membrane restricts passage of materials in and out of the cell and helps to protect the cells structural and functional integrity. Internally, floating in the cytoplasm, are various organelles (small organs), each with a specific function similar to some of the organs found in our bodies. A nucleus is found in almost all of our cells and is often the largest cellular structure present. The nucleus contains the genetic material, the chromosomes, which are made of DNA and control all metabolism. Most cells also contain mitochondria which contain most of the enzymes for extracting energy from organic foods, a chemical process called respiration.

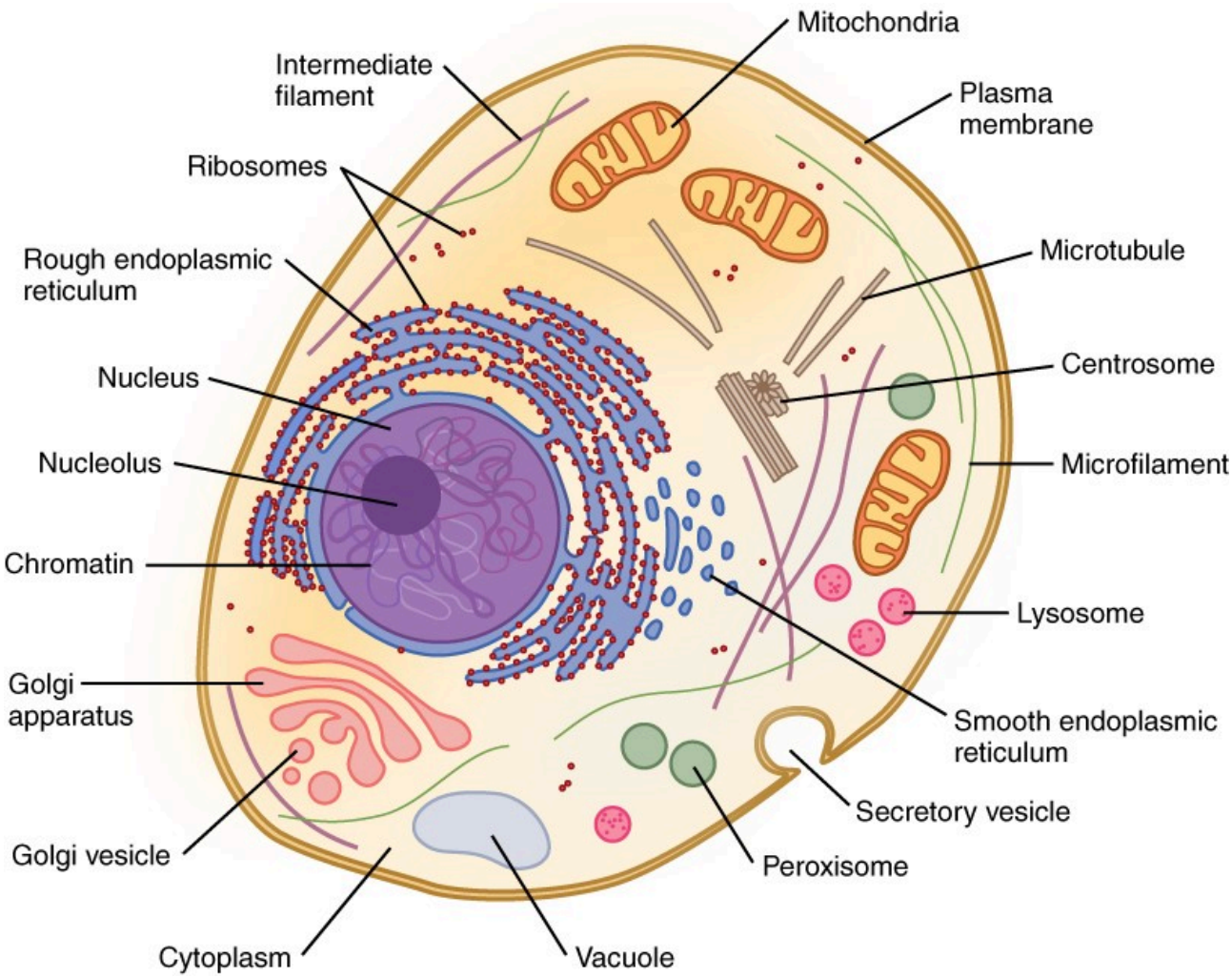


Figure 3.2 Representative human cell. This image is not indicative of any one particular type of human cell but it provides examples of the primary organelles and internal structures found in many cell types. (Credit: OpenStax Anatomy and Physiology, CC BY 4.0 license)

The Cell Membrane

Despite differences in structure and function, all living cells in multicellular organisms have a surrounding cell membrane. As the outer layer of your skin separates your body from its environment, the cell membrane (also known as the plasma membrane) separates the inner contents of a cell (intracellular) from its exterior environment (extracellular). The cell membrane provides a protective barrier around the cell and regulates which materials can pass in or out.

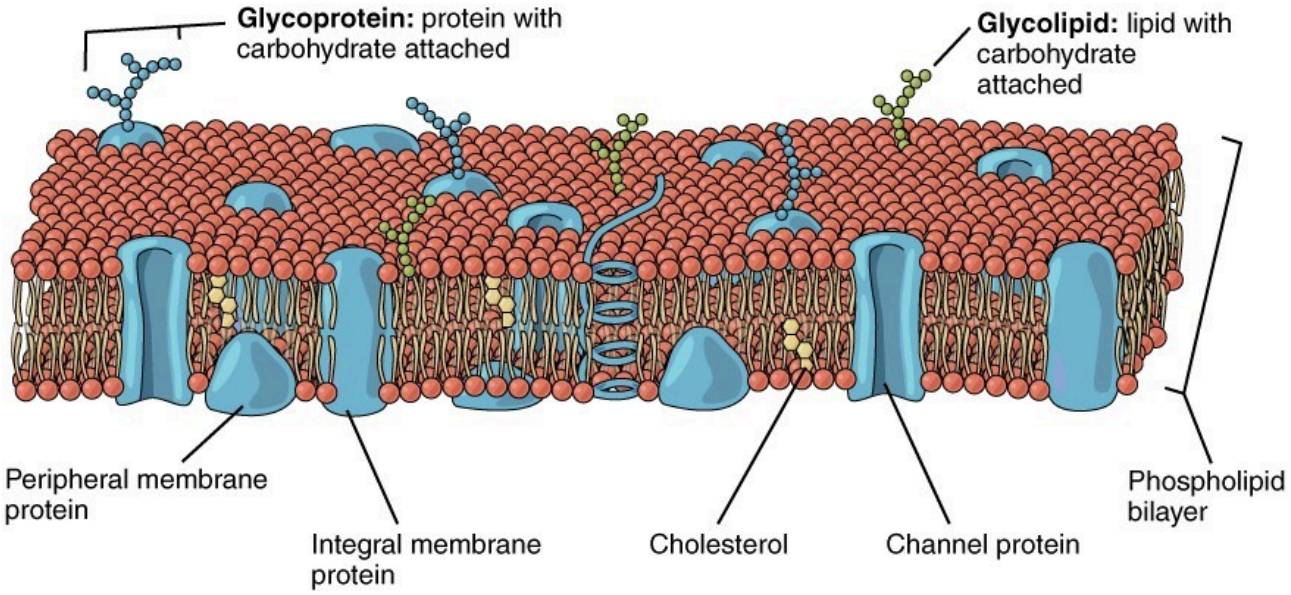


Figure 3.3 Structure of the cell membrane. The cell membrane of the cell is a phospholipid bilayer containing many different molecular components, including proteins and cholesterol, some with carbohydrate groups attached

The cell membrane is an extremely pliable and variable cell structure composed primarily of back-to-back phospholipids (the phospholipid bilayer). Cholesterol is also present, which contributes to the fluidity of the membrane, and there are various proteins embedded within the membrane that have a variety of functions. The two major structural classes of proteins are integral proteins and peripheral proteins. Integral proteins are embedded into the cell membrane and allow cells to move materials between the intracellular and extracellular environments and communicate with other cells. A channel protein is an example of an integral protein that selectively allows particular materials, such as certain ions, to pass into or out of the cell. Peripheral proteins are typically found on the inner or outer surface of the lipid bilayer but can also be attached to the internal or external surface of an integral protein. These proteins typically perform a specific function for the cell and this includes proteins that act as digestive enzymes to break down nutrients in the small intestine so that they are small enough to be absorbed by the cells.

Diffusion and Osmosis

Diffusion is the process by which molecules spread from areas of high concentration to areas of low concentration. This movement, down the concentration gradient, continues until molecules are evenly distributed. Osmosis is a special type of diffusion: the diffusion of water through a semipermeable membrane. The concentration of water is inversely related to the concentration of solute: more solute corresponds to less water and less solute corresponds to more water. This is important because osmotic vocabulary describes the solute and not the water. Hypertonic solutions contain a high concentration of solute and little water, relative to hypotonic solutions that have a low concentration of solute and therefore a higher concentration of water. The term “isotonic” is used when two areas have an equal concentration of solute: no net osmosis is occurring (Credit: biologycorner.com).

The Cytoplasm

All living cells in multicellular organisms contain an internal compartment, called the cytoplasm which includes the cytosol, organelles, and the cytoskeleton. The cytosol is the fluid component of the cytoplasm and is a jelly-like substance within the cell that includes the components necessary for cellular function. Cells also contain various membrane-enclosed cellular organelles which perform a specific function and are described further below. The cytoskeleton is a group of fibrous proteins, including microfilaments, intermediate filaments, and microtubules that helps cells maintain their structural integrity. Cytoskeletal components are also critical for cell motility, cell reproduction, and transportation of substances within the cell.

Organelles

Just as the various organs work together in harmony to perform all of a human's necessary functions, cellular organelles work together to keep the cell performing all of its important functions. Figure 3.2 shows several examples of cellular organelles whose function is summarized in Table 3.1.

Table 3.1

Organelle	**Function**
Nucleus	Contains the cell's DNA and directs cellular functions.
Mitochondrion	Converts energy storage molecules into the major energy molecule, ATP, to power cellular function
Ribosome	Protein synthesis
Rough endoplasmic reticulum	Includes ribosomes for the synthesis and modification of proteins
Smooth endoplasmic reticulum	Lipid synthesis
Golgi apparatus	Sorts, modifies, and ships products from the endoplasmic reticulum
Lysosome	Contains digestive enzymes to break down materials
Peroxisome	Contains enzymes key for lipid metabolism and chemical detoxification

The Cell Cycle

The cell cycle consists of two general phases: interphase, followed by mitosis and cytokinesis (Figure 3.4). Interphase is the period of the cell cycle during which the cell is not dividing. The majority of cells are in interphase most of the time. Mitosis is the division of genetic material, during which the cell nucleus breaks down and two new, fully functional, nuclei are formed. Cytokinesis divides the cytoplasm into two distinctive cells.

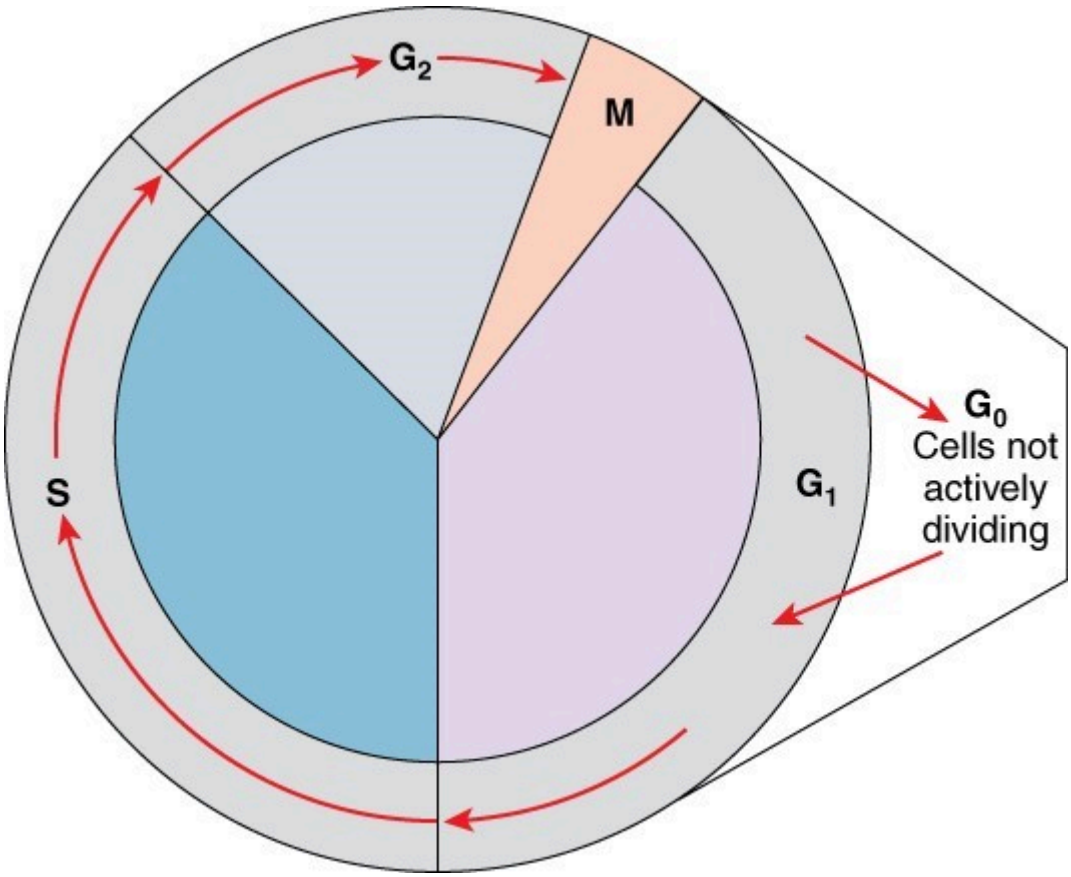


Figure 3.4 The cell cycle. The two major phases of the cell cycle include mitosis (cell division), and interphase, when the cell grows and performs all of its normal functions. Interphase is further subdivided into G1, S, and G2 phases.

Interphase

A cell grows and carries out all normal metabolic functions and processes in a period called G1 (Figure 3.4). G1 phase (gap 1 phase) is the first gap, or growth phase in the cell cycle and is the phase that varies the most in terms of duration. Cells might spend a couple of hours, or many days in this phase. For cells that will divide again, G1 is followed by replication of the DNA, during S phase. S phase (synthesis phase) is the period during which a cell replicates its DNA. After S phase, the cell proceeds through the G2 phase. The G2 phase is a second gap phase, during which the cell continues to grow and makes the necessary preparations for mitosis. S phase typically lasts between 8-10 hours and the G2 phase approximately 5 hours. Cells that have temporarily stopped dividing and are resting (a common state) and cells that have permanently ceased dividing (like nerve cells) are said to be in G0, a resting phase of the cell cycle.

Mitosis and Cytokinesis

The mitotic phase of the cell cycle typically takes between 1 and 2 hours. During this phase, a cell undergoes two major processes. First, it completes mitosis, during which the contents of the nucleus are equitably pulled apart and distributed between its two halves. Cytokinesis then occurs, dividing the cytoplasm and

cell body into two new cells. Mitosis is divided into four major stages that take place after interphase (Figure 3.5) in the following order: prophase, metaphase, anaphase, and telophase. The process is then followed by cytokinesis

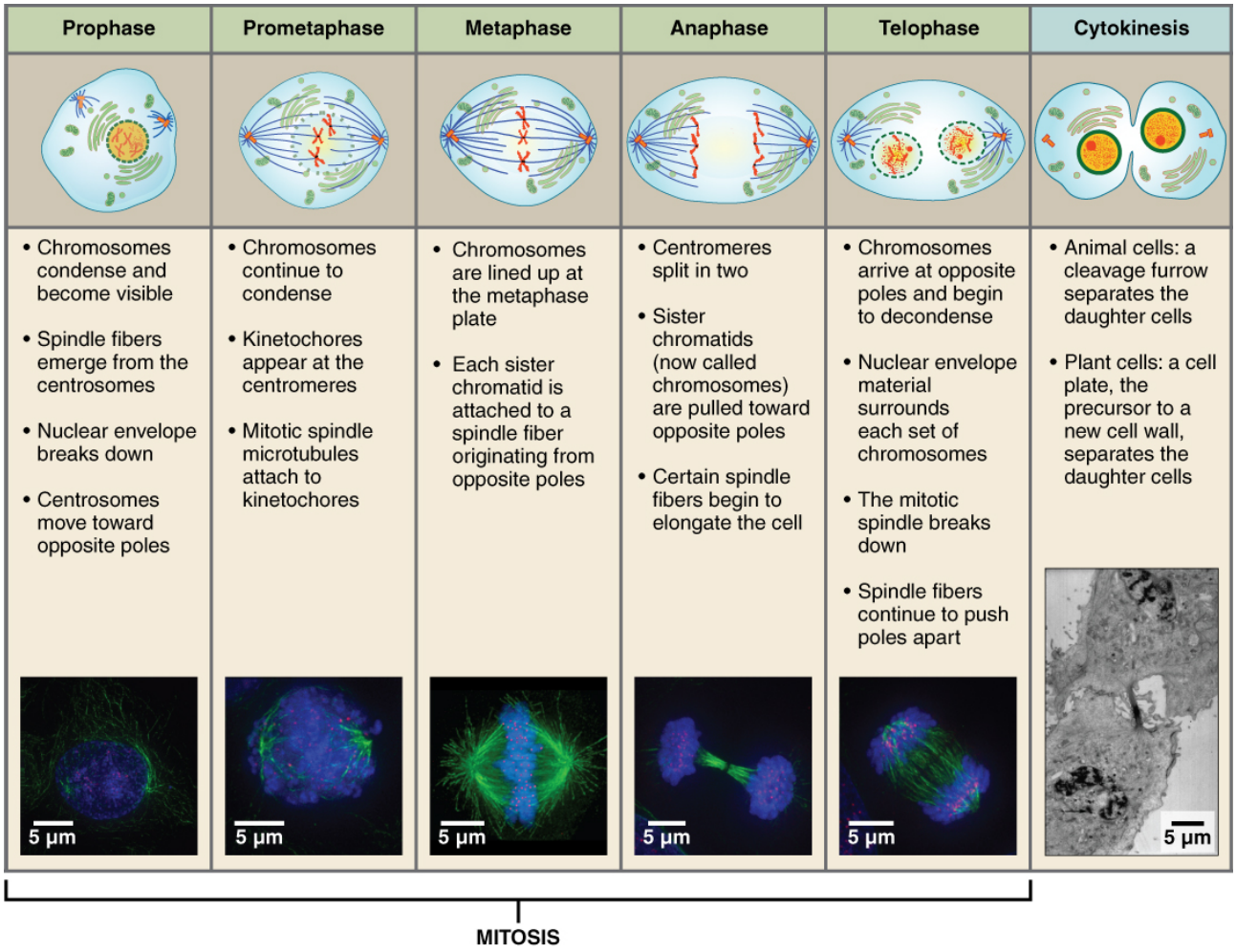


Figure 3.5 Mitosis and cytokinesis. The stages of cell division lead to the separation of identical genetic material into two new nuclei, followed by the division of the cytoplasm.

Prophase

Prophase is the first phase of mitosis, during which the loosely packed chromatin coils and condenses into visible chromosomes. During prophase, each chromosome becomes visible with its identical partner attached, forming the familiar X-shape of sister chromatids. The nucleolus disappears early during this phase, and the nuclear envelope also disintegrates. Centrosomes migrate to two different sides of the cell and microtubules begin to extend from each like long fingers from two hands extending toward each other.

Metaphase

Metaphase is the second stage of mitosis. During this stage, the sister chromatids, with their attached microtubules, line up along a linear plane in the middle of the cell. A metaphase plate forms between the

centrosomes that are now located at either end of the cell. Microtubules are now poised to pull apart the sister chromatids and bring one from each pair to each side of the cell.

Anaphase

Anaphase is the third stage of mitosis. Anaphase takes place over a few minutes, when the pairs of sister chromatids are separated from one another, forming individual chromosomes once again. Each end of the cell receives one partner from each pair of sister chromatids, ensuring that the two new daughter cells will contain identical genetic material.

Telophase

Telophase is the final stage of mitosis. Telophase is characterized by the formation of two new daughter nuclei at either end of the dividing cell. These newly formed nuclei surround the genetic material, which uncoils such that the chromosomes return to loosely packed chromatin. Nucleoli also reappear within the new nuclei, and the mitotic spindle breaks apart, each new cell receiving its own complement of DNA, organelles, membranes, and centrioles. At this point, the cell is already beginning to split in half as cytokinesis begins.

Cytokinesis

The cleavage furrow is a contractile band made up of microfilaments that forms around the midline of the cell during cytokinesis. This contractile band squeezes the two cells apart until they finally separate. Two new cells are now formed.

Microscopy

A microscope is an instrument that magnifies an object so that it may be seen by the observer. Because cells are usually too small to see with the naked eye, a microscope is an essential tool in the field of biology. In addition to magnification, microscopes also provide resolution, which is the ability to distinguish two nearby objects as separate. A combination of magnification and resolution is necessary to clearly view specimens under the microscope. The light microscope bends a beam of light at the specimen using a series of lenses to provide a clear image of the specimen to the observer.

In this lab, parts of the microscope will be reviewed. Students will learn proper use and care of the microscope.

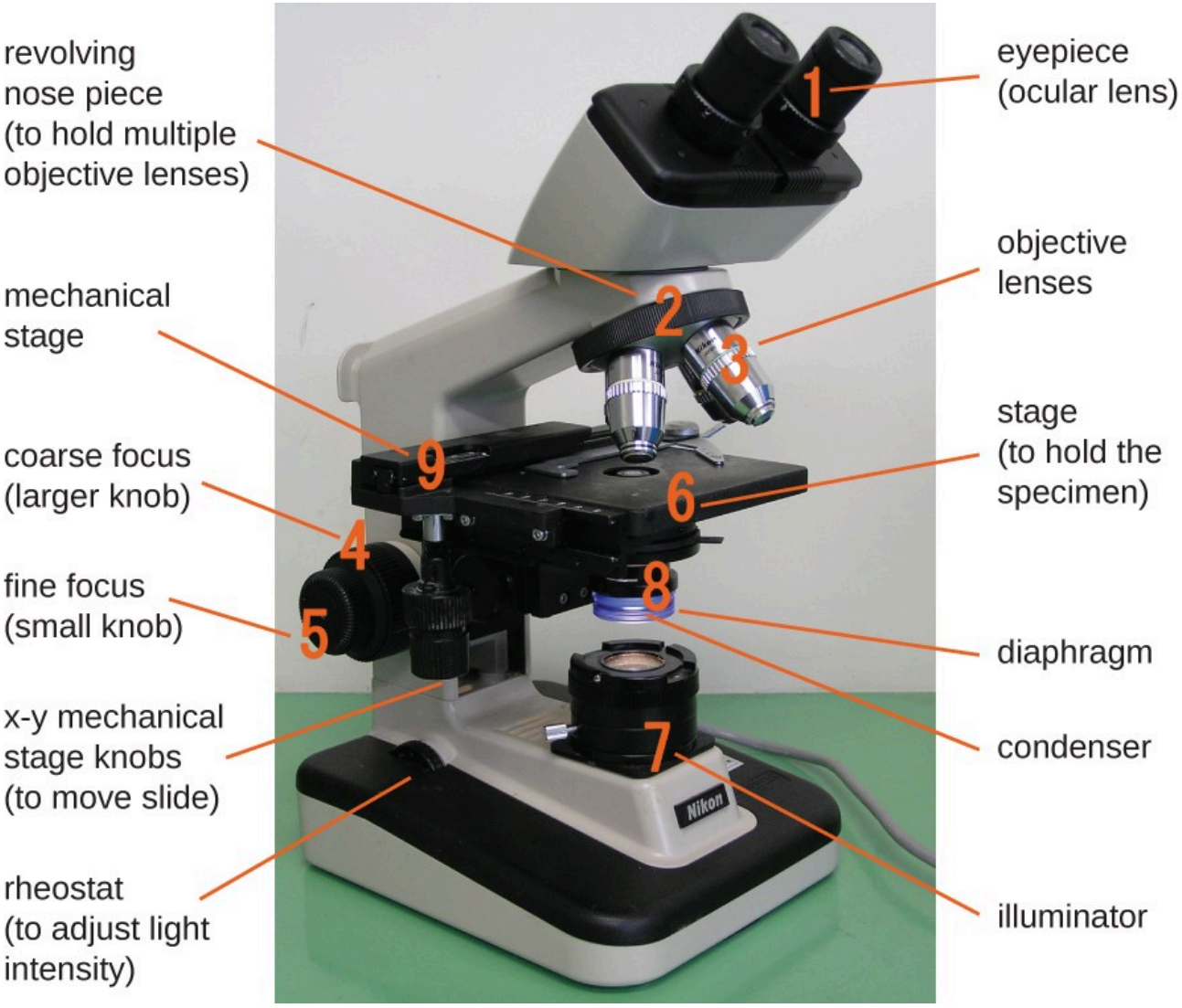


Figure 3.6. Parts of the microscope

Magnification

Your microscope has 4 objective lenses: Scanning (4x), Low (10x), High (40x), and Oil Immersion (100x). In addition to the objective lenses, the ocular lens (eyepiece) has a magnification. The total magnification is determined by multiplying the magnification of the ocular and objective lenses. The total magnification is the product of the ocular magnification times the objective magnification:

For example, if a 40◈ objective lens is selected and the ocular lens is 10◈, the total magnification would be

(40×)(10×)=400×

General Procedures

1. Make sure all backpacks, purses, etc. are off the benchtop.
2. Carry microscope by the base and arm with both hands.
3. Store with cord wrapped around microscope and the scanning objective clicked into place.

Focusing Specimens

1. Plug your microscope in to power supply and switch on illuminator.
2. Always start with the stage as low as possible and using scanning objective (4x). Odds are, you will be able to see something on this setting (sometimes it's only a color). Use the coarse knob to focus: the image may be small at this magnification, but you won't be able to find it on the higher powers without this first step. Move the mechanical stage until your focused image is also centered.
3. Once you've focused using the scanning objective, switch to the low power objective (10x). Use the coarse knob to refocus and move the mechanical stage to re-center your image. Again, if you haven't focused on this level, you will not be able to move to the next level.
4. Now switch to the high power objective (40x). At this point, ONLY use the fine adjustment knob to focus specimens.
5. If the specimen is too light or too dark, try adjusting the diaphragm.

Cleanup

1. Store microscope with the scanning objective in place and the stage in its lowest position.
2. Wrap cords around microscope. Replace slides to original slide tray
3. Replace slides to original slide tray.

Pre-Laboratory Questions

1. Which of the following is/are found in cell membranes? Select all that apply.

A. Carbohydrates
B. Phospholipids
C. Proteins
D. Cholesterol
E. All of the above are associated with the membrane

2. Which type of lipid is most important in biological membranes?

A. Waxes
B. Fats
C. Oils
D. Triglycerides
E. Phospholipids

3. In facilitated diffusion, molecules move through pores from areas of _____ concentration to areas of _____ concentration.

A. high, high
B. low, high
C. high, low

4. What structure moves the chromosomes to the correct location for cell division?

A. Microtubule

B. Nucleus
C. Centriole
D. Chromatids

Exercises

- Exercise 1. Identification of cell components on a cell model
- Exercise 2. Observing cells with a compound microscope
- Exercise 3. Diffusion through a gel
- Exercise 4. Osmosis across a membrane
- Exercise 5. Cell anatomy
- Exercise 6. Cell cycle

Exercise 1 Identification of cell components on a model

Required Materials

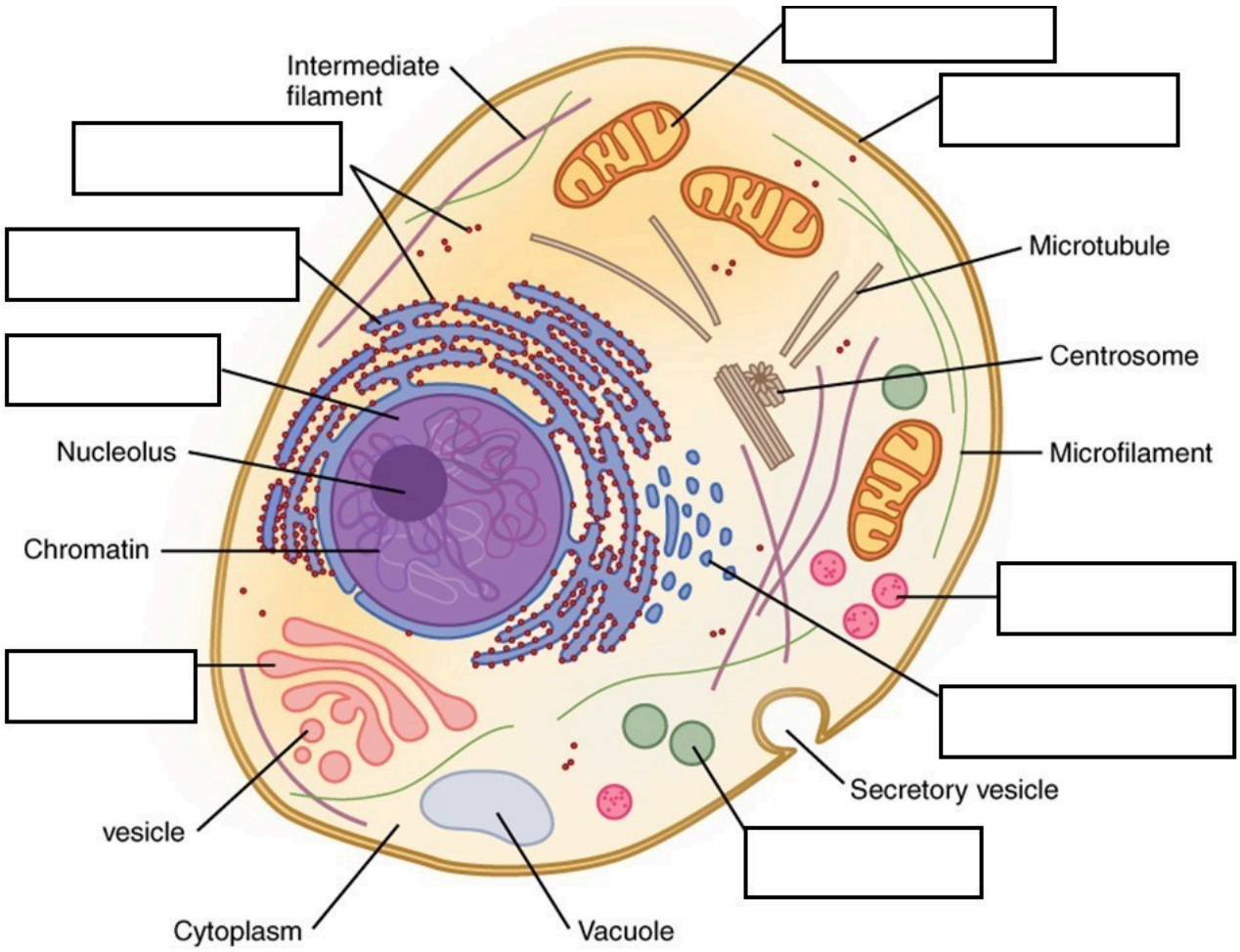
- Classroom model of an animal cell
- Post-it notes

Procedure

Study the cell model. Identify the following organelles and structures, and place a post-it note on the model to identify the structure. Additionally, label the cell figure below with the correct structure names.

-

Peroxisome	Smooth ER	Ribosome
Nucleus	Mitochondrion	Plasma membrane
Lysosome	Golgi apparatus	Rough ER



Exercise 2 Observing cells with a compound microscope

Prepare a wet mount of a human cheek cell and observe under the microscope.

Required Materials

- Compound microscope
- Methylene blue
- Microscope slide
- Coverslip
- Toothpick

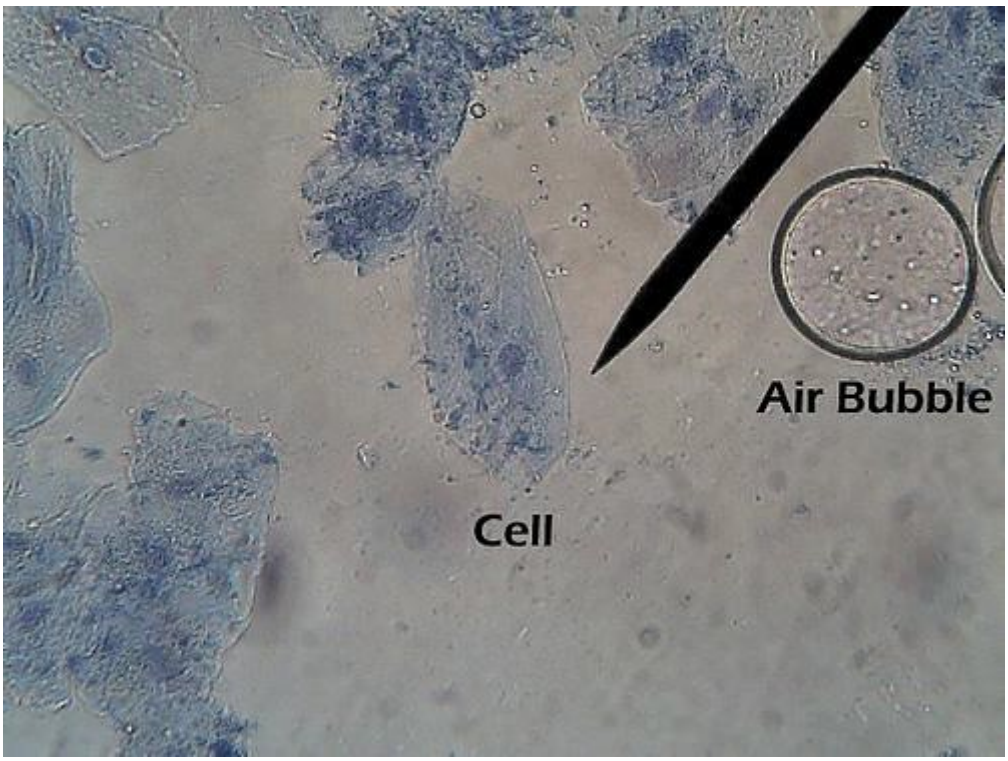
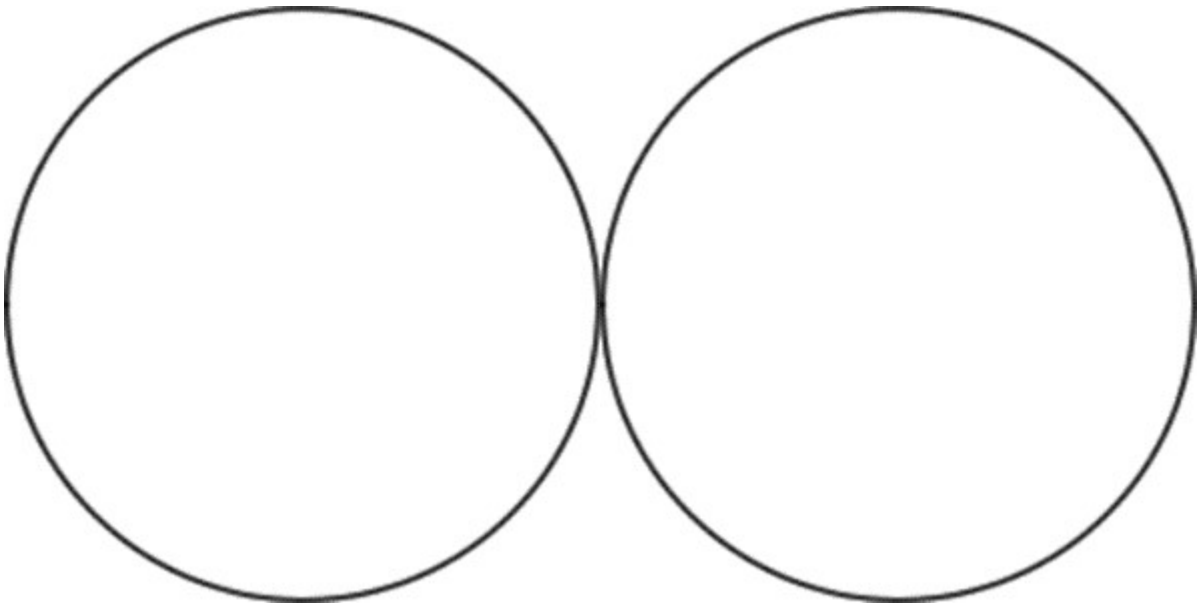


Figure 3.7 Human cheek cell stain at high power. "Cheek Cells Identified (400x)"

Procedure

1. Put a drop of methylene blue on the slide.
2. Gently scrape the inside of your cheek with the flatside of a toothpick. Scrape lightly!
3. Stir the end of the toothpick in the methylene blue stain on the slide.
4. Discard the toothpick in a trash container labeled "biohazard waste".
5. Place a coverslip onto the slide.
6. Place the prepared wet mount microscope sample onto the stage of a microscope.
7. Use the SCANNING (4x) objective to focus. You probably will not see the cells at this power.
8. Switch to low power (10x). Cells should be visible, but they will be small and look like nearly clear purplish blobs. If you are looking at something very dark purple, it is probably not a cell.
9. Once you think you have located a cell, switch to high power (40x) and refocus. Remember, do NOT use the coarse adjustment knob at this point!
10. Sketch the cell at low and high power. Label the nucleus, cytoplasm, and cell membrane of a single cell



Exercise 3 Diffusion through a gel

One factor that can affect the rate of diffusion is the size of the molecule. Larger molecules tend to move more slowly than smaller molecules. In this experiment, students will compare the diffusion rates of two dyes traveling through agar.

Required Materials

- Pre-punched agar plates
- Potassium permanganate
- Janus green
- Ruler

Procedure

1. Using the dropper, drop a single drop of potassium permanganate into one of the wells on the plate.
2. Repeat with Janus green.

1. Allow the plates to sit undisturbed for 30 minutes.
2. Which dye do you think will have the faster diffusion rate? _____
3. After 30 minutes, measure the radius of the dye front from the middle of the well and record your results.
4. Calculate the diffusion rate (mm/hr) by dividing the dye front radius by 0.5.

	Potassium permanganate	Janus Green
Molecular Weight	158g/mole	511g/mole
Radius (mm)		
Diffusion Rate		

Questions:

1. Did your outcome match your expectation? Provide an explanation for your results.
2. What are other factors that can affect the rate of diffusion?

Exercise 4 Osmosis across a membrane

Observe the movement of water across a semipermeable membrane.

Required Materials

- Dialysis bags (4 per group)
- Dental floss
- 15% sucrose solution
- 30% sucrose solution
- Triple beam balance
- Beakers
- Graduated cylinder
- Stir rods

Procedure

1. Obtain 4 strips of dialysis tubing and tie a knot in one end of each using the dental floss.
2. Pour approximately 10 mL of each solution into separate bags (see table below).
3. Fill out the table indicating the **Tonicity of Bag** (isotonic, hypotonic, hypertonic) compared to the beaker.
4. Indicate whether you expect water to move **into** or **out of** the bag under **Predicted Outcome.**

	Tube 1	Tube 2	Tube 3	Tube 4
Inside bag	water	15% sucrose	30% sucrose	water
Inside beaker	water	water	water	15% sucrose
Tonicity of Bag				
Predicted Outcome				

5. Remove most of the air from the bag (but leave a little bit of space) and tie the bag.
6. Blot the bags to remove any sugar that may have spilled; check the bags for leaks.
7. Record the weight of each baggie in the data table as **Weight at 0 min**.

Data	Tube 1	Tube 2	Tube 3	Tube 4
Weight at 0 min				
Weight at 10 min				
Weight at 20 min				
Weight at 30 min				

8. Place a bag in each beaker (be sure to keep track of which bag is in which beaker!). Fill the beakers with enough of the appropriate solution to cover your bags (refer to the above table).
9. Predict what you think will happen during the experiment.
10. Record baggie weight every 10 minutes in data table.
11. After 30 minutes, remove the bags from solution and record the final weight.

Exercise 5 Cell Anatomy

Required Materials

- None

Procedure

This activity will be completed individually or in small groups. Refer to the background information as needed to help answer the questions below.

Complete the table below to summarize the major function of each given organelle in one sentence or phrase.

Organelle	Function (one sentence or phrase)
Peroxisome	
Nucleus	
Lysosome	
Smooth ER	
Mitochondrion	
Golgi apparatus	
Ribosome	
Rough ER	

Exercise 6 Cell Cycle

Required Materials

- Classroom model of Mitosis

Procedure

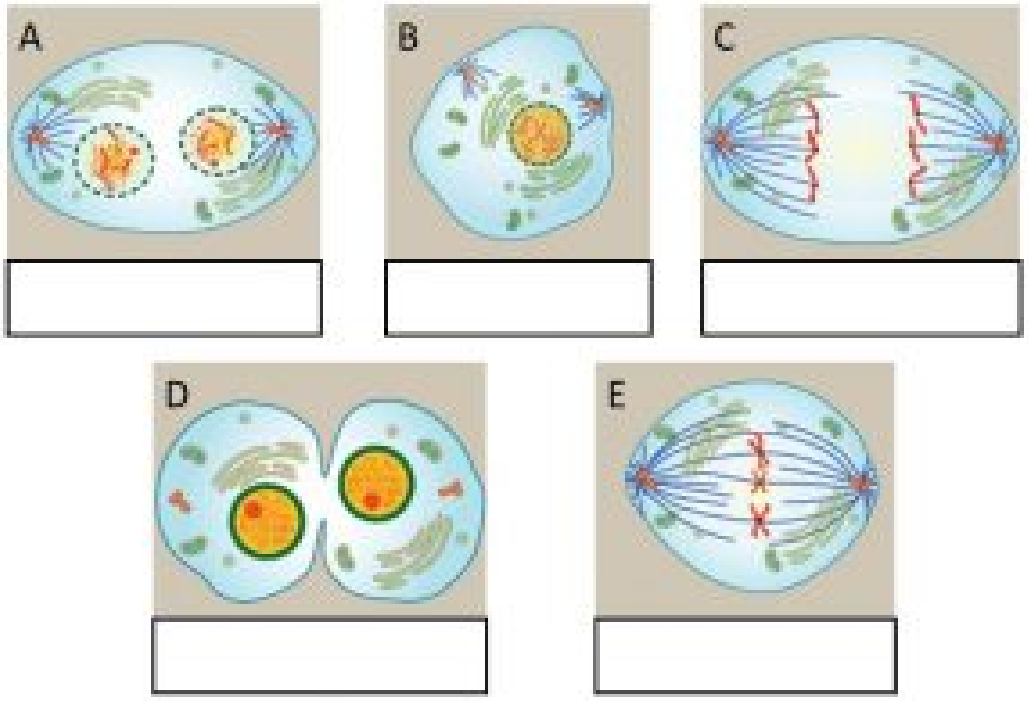
This activity will be completed individually or in small groups. Refer to the background information as needed to help answer the questions below.

A. Match the cell cycle phase to the major cellular events by completing table below with the provided cell cycle phases. Each cell cycle phase will only be used once.

S phase, G1 phase, Anaphase, Prophase, Metaphase, Telophase, Cytokinesis, G0 phase

Cell Cycle Phase	Major Cellular Events
	Sister chromatids are pulled to opposite poles
	Sister chromatids line up at middle of cell
	Chromosomes de-condense and nuclear envelopes reform
	Cleavage furrow separates daughter cells
	Significant cell growth to prepare for mitosis
	Replication of DNA
	Condensation of chromosomes
	Cells are not dividing

B. Label each of the following drawings of cells in different stages of mitosis and cytokinesis



Post-laboratory Questions

1. Nemo is a clownfish and clownfish live in the ocean. The salinity of the Nemo's ocean environment averages around 3.5%. What would happen to Nemo if he became lost and ended up in a fresh water lake?

A. Nemo would die because his cells would lose water and he would dehydrate quickly.

B. Nemo would swell and could pop if he doesn't get out of there.

C. Nemo would be fine, there wouldn't be any water movement

2. The chemical transmitter dopamine is released from a vesicle within a neuron when the vesicle fuses with the cell membrane and dumps the chemical into the extracellular space. Which type of transport mechanism is most representative of this process?

A. active transport

B. diffusion

C. exocytosis

D. endocytosis

3. The solution in beaker A is 20% of glucose and the solution in beaker B is 40% of glucose, which beaker is hypertonic?

A. beaker A

B. beaker B

4. If you connected the beakers with a tube that was permeable to water but impermeable to glucose, which way would water move?

A. From beaker A to beaker B

B. From beaker B to beaker A

C. Water would not move

4.

CHAPTER 4 THE TISSUE LEVEL OF ORGANIZATION

By Joseph D'Silva

Motivation

Diabetes is a disorder of the endocrine system. It is caused by a more-than-normal level of glucose sugar in the blood. The normal level is 70-100 mg/dL. Above 100 mg/dL, the person has an impaired blood-glucose level. There is a high incidence of diabetes among Afro-Americans. 34.2 million people of all ages—or 10.5% of the US population—has diabetes. Among African Americans, 10.9 % are affected. About 7.3 million adults aged 18 years or older are not aware of diabetes.

The amount of blood sugar in the body is regulated by insulin. This is a hormone and is secreted by cells known as the Islets of Langerhans that are located in the tissues of the pancreas. When the islets release insulin, blood sugar is controlled in the blood. When it fails to, a person develops diabetes.

To know about the pancreas is to study its histology. The histological examination of a pancreas requires that it be sectioned by using a microtome. (A microtome is an instrument. You can slice tissues as thin as 05-06 microns. A micron ((symbol u (mu)) is 1/000 mm. Look up mm lines on your ruler.) The slices of tissues can be processed through a procedure and stained with dyes. After staining and more processing they can be put on a glass slide with a cover slip on top and sealed with a sealant (Canada balsam or Permount). Once dried, the section is then examined under a compound microscope using 10 x 4, 10 x 10, or 10 x 40 magnification.

This laboratory exercise studies a section of the pancreas to identify structures in it. The structures are:

- Lobules
- Pancreatic acini
- Islets of Langerhans

See figures below and locate the (a) pancreas; (b) Islets of Langerhans; (c) Interlobular ducts, acinar cells.

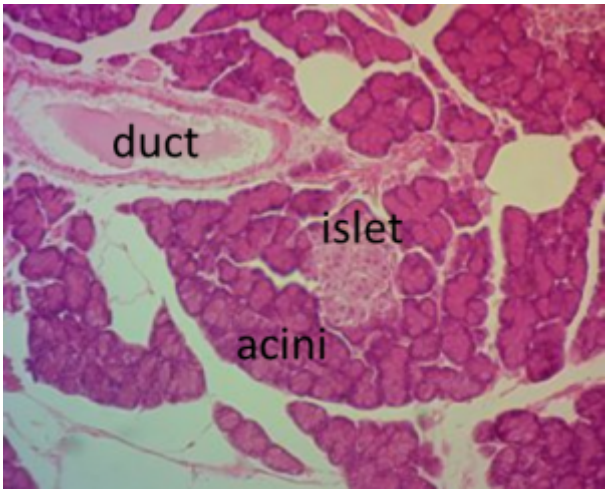


Figure 4.1. Micrograph of pancreas. 200X magnification.

Learning Objectives

Upon completion of work in this chapter, students should be able to:

- Define histology and histological tissues in general.
- Define and recognize four types of tissues on stained tissues on microscope slides.
- Describe tissues of organs.
- Explain a histologically impaired tissue.

Background

There are more than 200 different tissue types in the human body. All the organs in the body are made of tissues that are made of cells. The tissues in a body characterize organs. It would be impossible to try and remember all the tissues that are characteristic of all the organs. Therefore, histologists (cell-study specialists) have classified the 200 tissues into **four categories:** Epithelial, Connective, Muscle and Neural.

Each category of tissues has its own distinct characteristics. For example, epithelial cells are flat, cuboidal or tall. Connective tissue can be tough or fluid. Muscle tissue is made of muscle fibers (cells). Nerve tissues is made up of neurons.

Consider your skin or integument. If you cut yourself or if a surgeon makes an incision on your skin you will see tissues that are epithelial, connective, muscular and neuronal. The first layer is the epithelial tissue made up of epithelial cells. The second layer is connective. There are blood vessels and fibrous tissues there. Interspersed in the connective tissue are nerve cells. Below this are fat cells. Finally, there is a layer of muscle tissue.

In this chapter, you will learn to recognize cell types and to identify tissues. You will need to work with a microscope and study prepared slides using 40x, 100x and 400x magnification.

Epithelial Tissues

Epithelial tissue appears in sheets of cells. It covers body surfaces, lining of internal surfaces and forms glands. Cells that make up the **epithelial tissue** have an **apical** and **basal** surface (aka polarity), and lateral surfaces that include **tight junctions**. The basal layer is attached to basement membrane (connective tissue) beneath it. Another characteristic of epithelial tissue is avascularity, meaning there is no blood supply to it. Epithelial tissue is classified by **(a) shape**, and **(b) layers.**

a. Classification by shape:

Squamous – Cells are thin and flat; look like fried eggs with sunny side up or tiles on a floor or fish scales; imagine the yolk to be the **nucleus** and the white to be **cytoplasm** of epithelial cells. The nucleus is central, disc-like with cytoplasm around it. Examples are: air sacs of lungs (Figure 4.2) , blood vessels (arteries and veina), body cavity and lymphatic vessels.

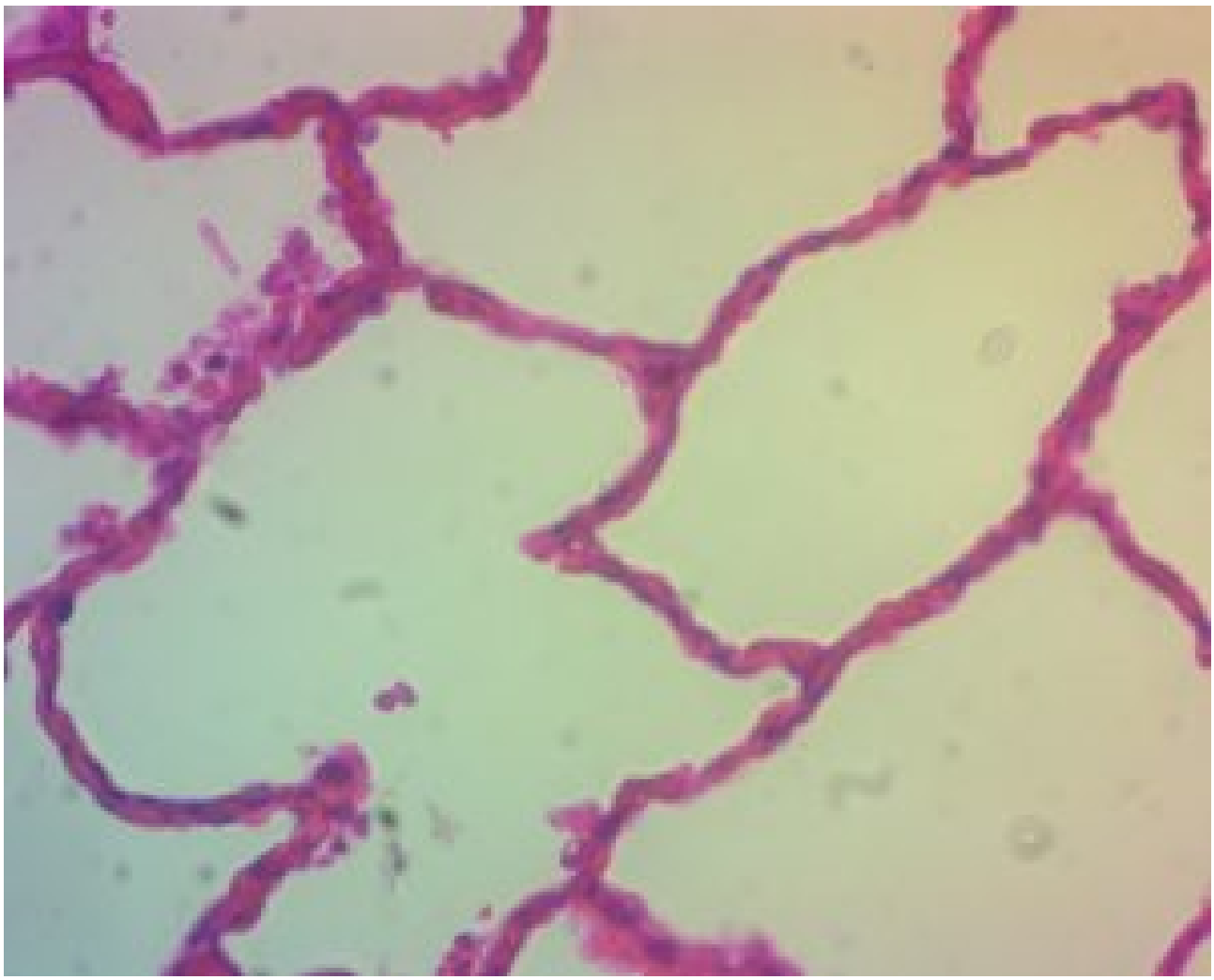


Figure 4.2 Lung Section. Squamous epithelium of the alveoli. 400X magnification. Purple, nucleus; Pink, cytoplasm.

Cuboidal – Cells are shaped like cubes with the length, breadth and height equal in size. The nucleus is situated in the cell center with cytoplasm equally distributed right round. Examples: kidney tubules, ducts of small glands (Figure 4.3), ovary surface.

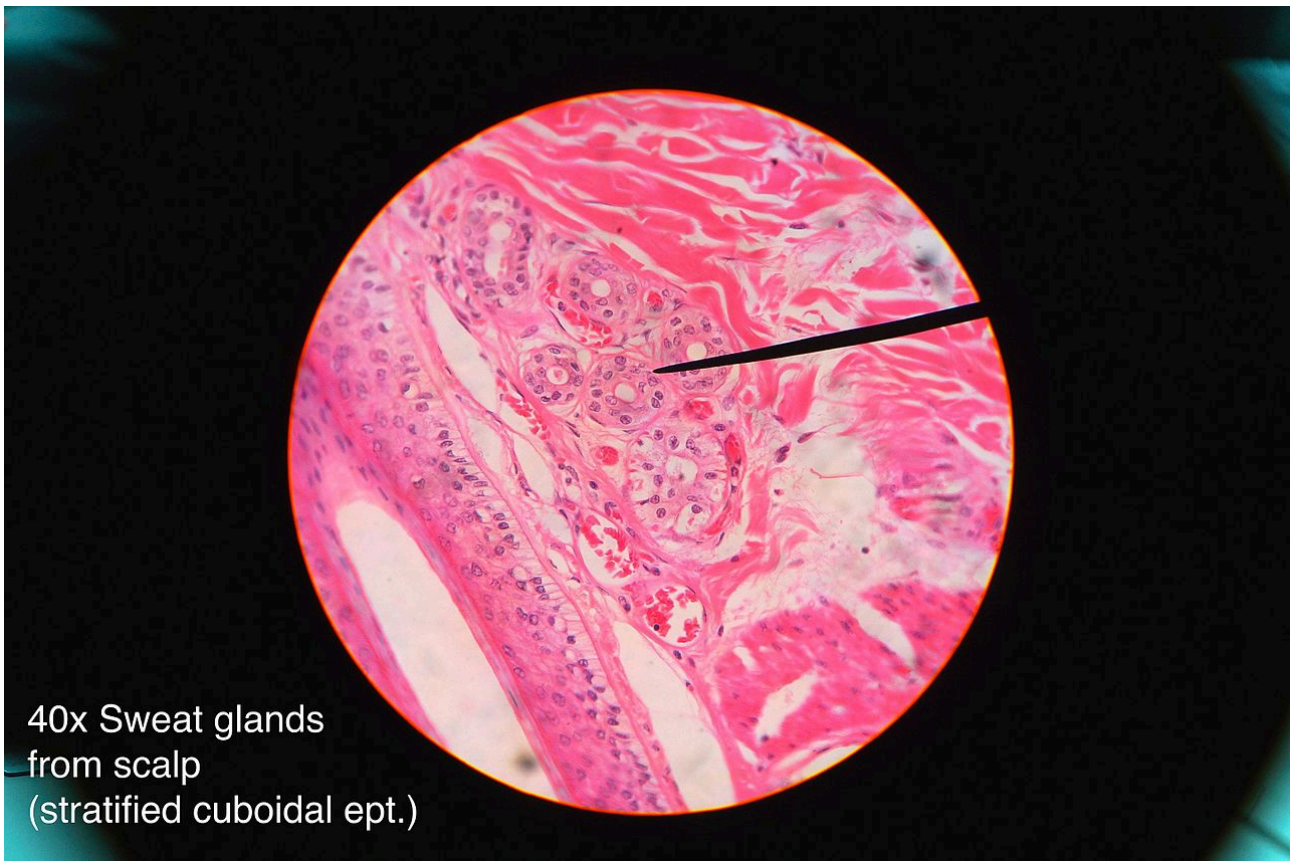


Figure 4.3. Section showing cuboidal epithelium in sweat gland. Credit: Athikhun.suw – Own work, CC BY-SA https://commons.wikimedia.org/w/index.php?curid=42368734

Columnar – Cells are shaped like tall columns. The height is longer than width. The nucleus is round or oval and is situated closer to basal surface. Nuclei may be oval/round nuclei and appear in a row. This is a characteristic feature of columnar epithelium. Examples: intestine (cells are interspersed with epithelial goblet cells) (Figure 4.4), gallbladder, uterus.

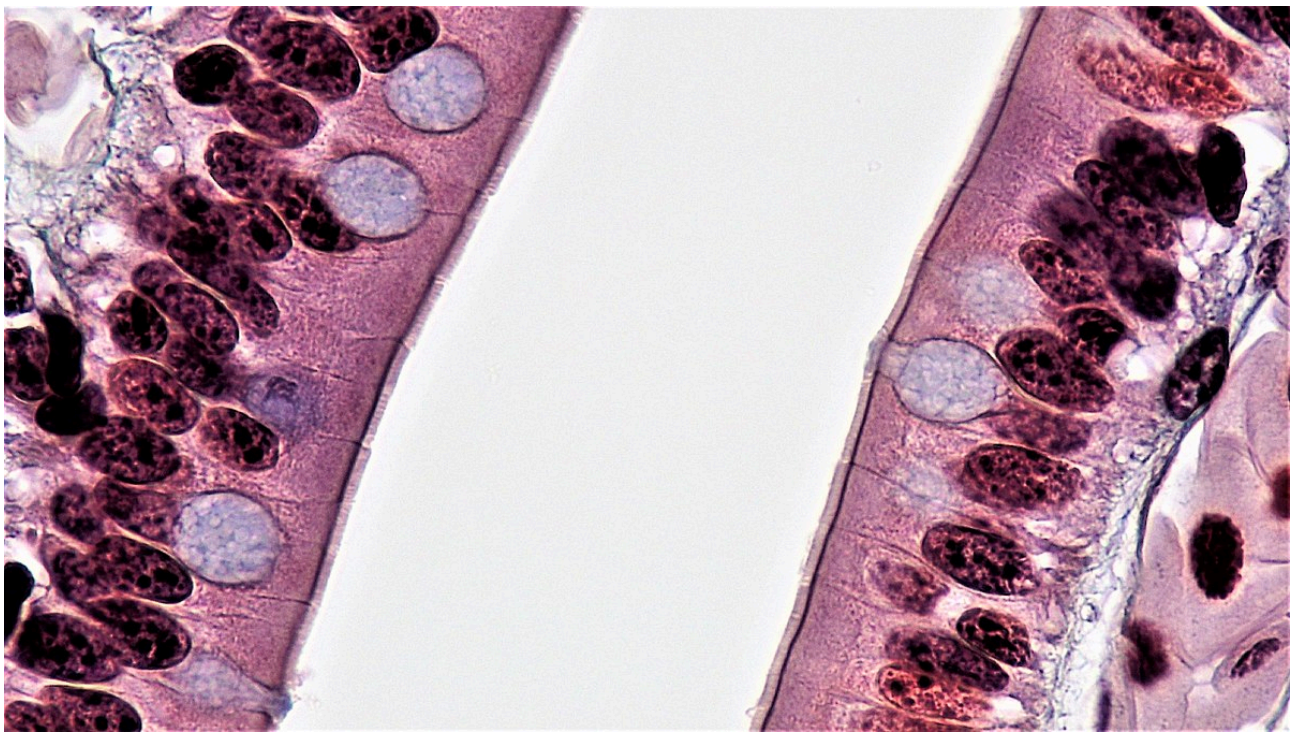


Figure 4.4. Section of mammalian gut showing columnar epithelium. File: Epithelial Tissues Simple Columnar Epithelium (27854453538) (2018) Source: Epithelial Tissues: Simple Columnar Epithelium (Wikimedia) Author: Berkshire Community College Bioscience Image Library

b. Classification by cell layers

Simple epithelium is one cell thick layer and is in direct contact with basement membrane. Its functions are absorption; diffusion, filtration or secretion. Figures 4.2, 4.3, and 4.4 all show simple epithelia.

Stratified Epithelium is two or more layers of cells thick. The deepest layer makes contact with basement membrane. Its functions are: protection/resist abrasion.

Pseudostratified Epithelium. The tissue appears in strata because cell ***nuclei*** are situated at a distance from the ***basal*** surface. But all the epithelial cells make direct contact with basement membrane. Its functions are absorption or secretion. Examples are trachea (Figure 4.5), epididymis.

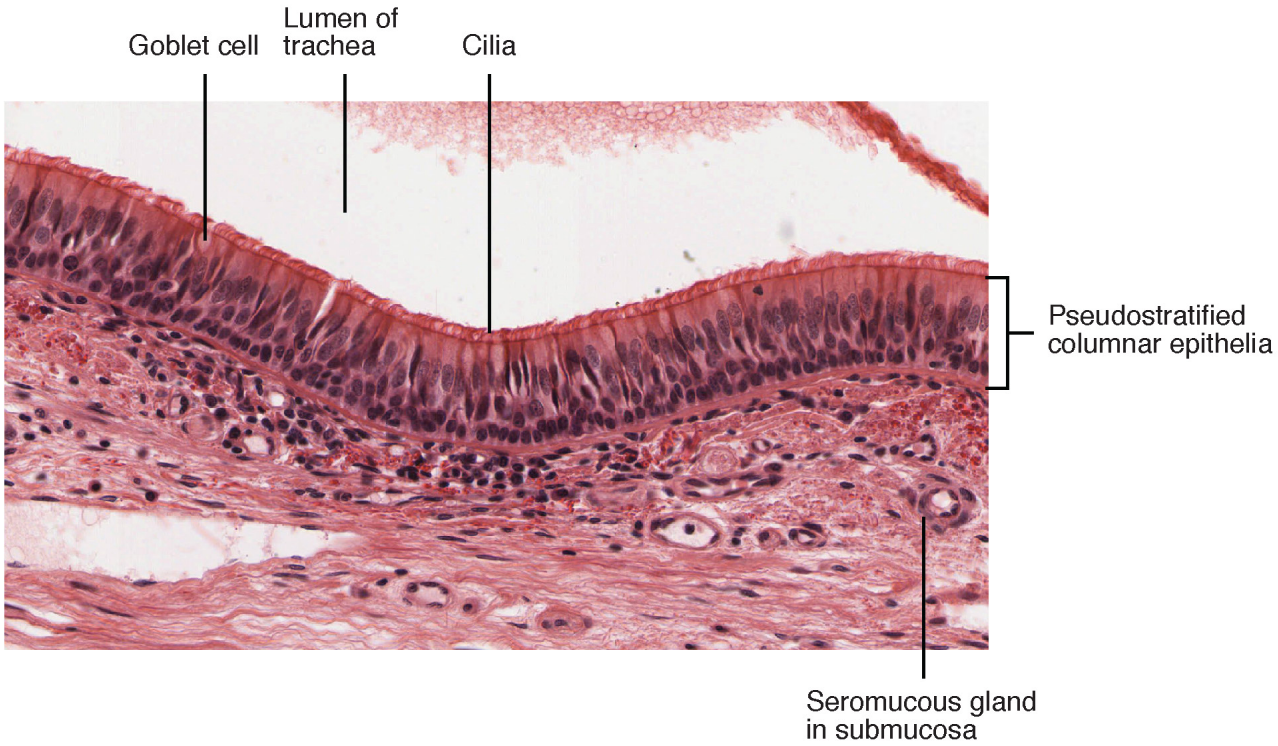


Figure 4.5 Section of trachea showing pseudostratified epithelium. Credit: Textbook OpenStax Anatomy and Physiology (2016) Source:https://cnx.org/contents/FPtK1zmh@8.25:fEI3C8Ot@10/Preface File 2308 The Trachea-b.jpg

Connective Tissues

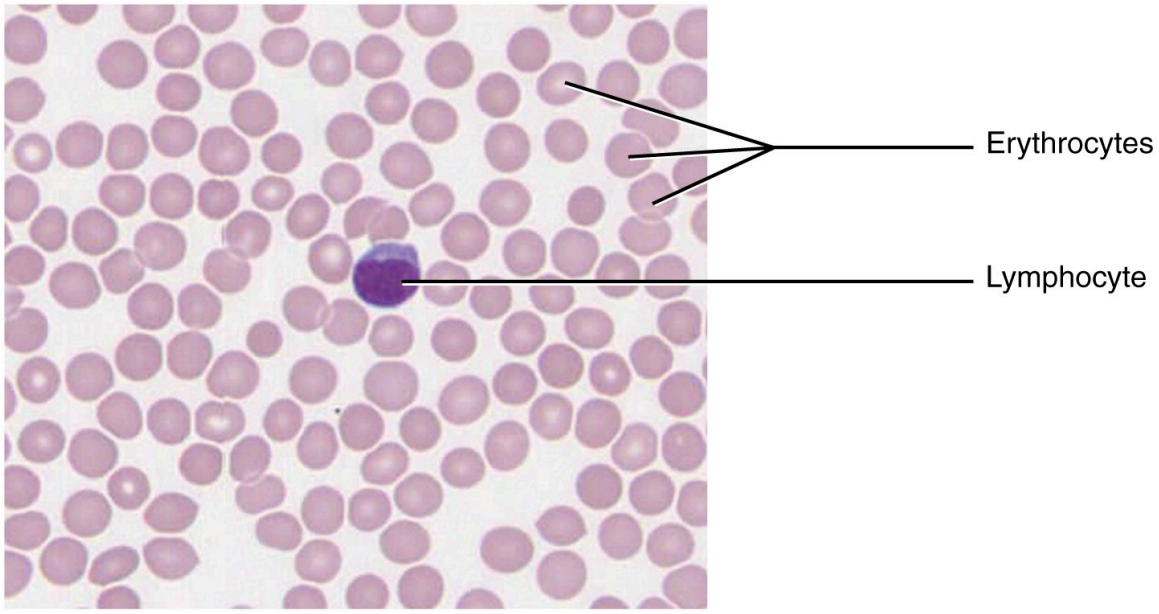


Figure 4.6. Connective tissue is fluid and shows blood with cells. (Credit: Adapted from OpenStax Anatomy and Physiology. CC-BY license)

Connective tissue is totally different from epithelial tissue. Connective tissue consists of cells plus extracellular matrix. The structure in which the cells are embedded is the extracellular matrix. For example,

blood cells are found in matrix called plasma (fluid). Extracellular matrix contains solid collagen and reticular fibers for many cells. In connective tissues, the matrix is the predominant structure with cells being sparse. The matrix consists of ground substance and protein fibers. The **ground substance** and fibers are secreted by the sparse cells. Blood (fluid), cartilage (semi-solid) and bone (solid) are connective tissues. The function of connective tissue is to connect tissues. For example, blood is pumped from the heart to all parts of the body and connects one tissue with another.

Connective Tissue Cells: Associated with connective tissue are several types of cells called fibroblasts, macrophages, adipocytes, mast cells and stem cells. They are known as resident cells because they are permanent where they be found. On the other hand, lymphocytes, plasma cells, neutrophils, eosinophils, basophils and monocytes are called wandering cells because they can move. Each cell is different from the other and has specific functions.

Classification

Connective tissue is classified as (a) Embryonic Connective Tissue; (b) Connective Tissue Proper; and, (c) Specialized Connective Tissue.

Embryonic Connective Tissue is derived from the embryo. Mesenchyme is connective tissue that is found in the embryo. Mesenchymal CT: Mesenchymal cells, ground substance and fibers make up embryonic connective tissue. The cells are few; ground substance is fluid-like and the fibers are few. Cells are spindle shaped. Mucous connective tissue is present in the umbilical cord. Wharton's jelly is the ground substance in which spindle-shaped cells are found.

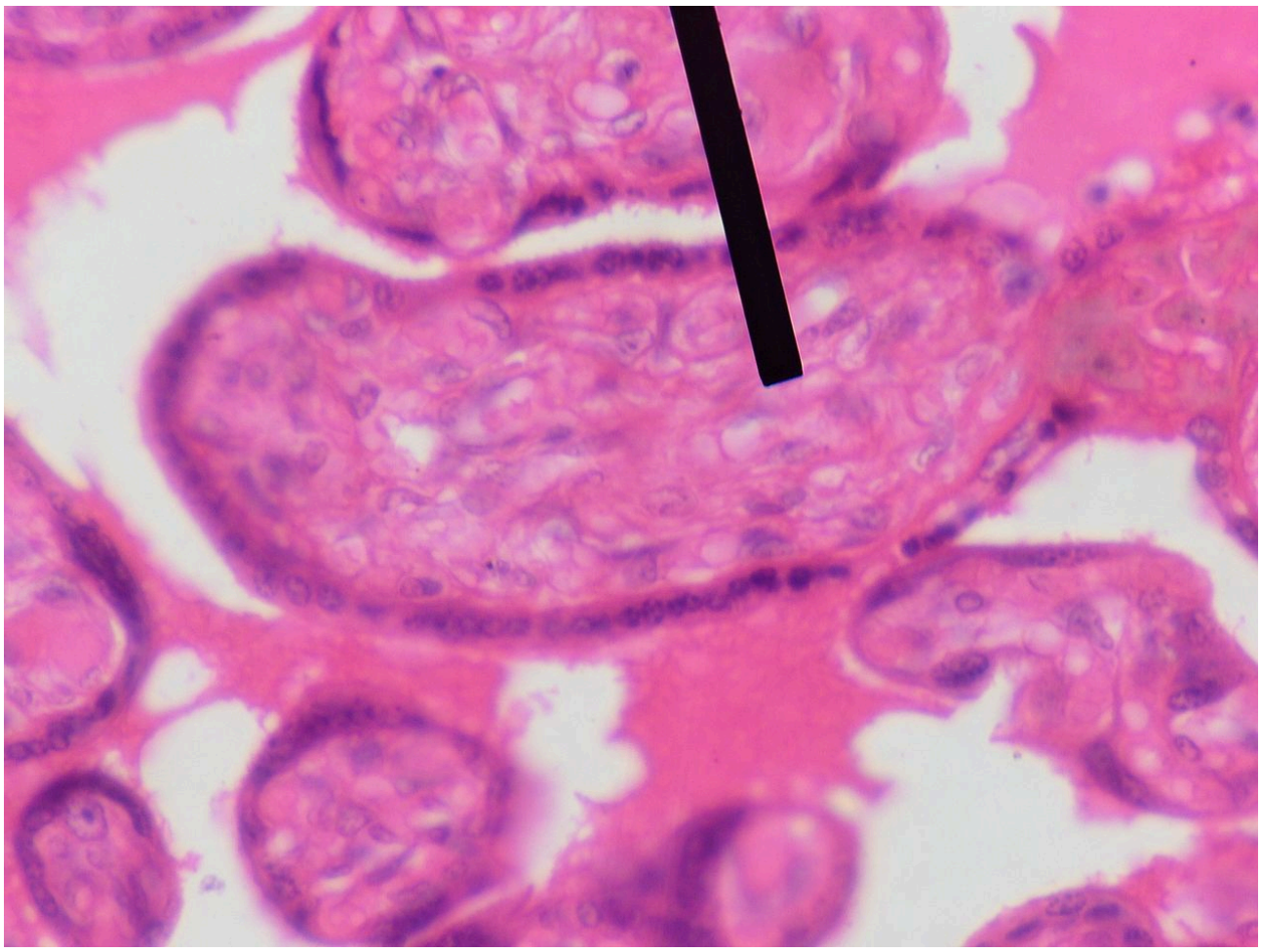


Figure 4.7 Section showing mesenchymal connective tissue. (Credit: Jpogi at Wikipedia. Public Domain license. https://commons.wikimedia.org/w/index.php?curid=50116348)

Connective Tissue Proper is different from Specialized Connective Tissue. It is divided into Loose connective tissue and Dense connective tissue. Here, you will have to identify three types of fibers: collagen , elastic and reticular fibers. Collagen and reticular fibers are made up fibrous collagen proteins whereas elastic fiber consists of fibrous elastin protein. The three types of fibers give tensile strength to tissues. Connective tissue proper contains much fibers compared to Specialized Connective Tissue.

Loose Connective Tissue does not have much collagen fibers. Ground substance occupies much of the space in the tissue. There are few transient, wandering cells. Loose connective tissue can also be described as (a) Areolar tissue; (b) Adipose (fat) tissue; and, (c) Reticular tissue. Loose connective tissue is found underneath the skin and the lining of internal surfaces.

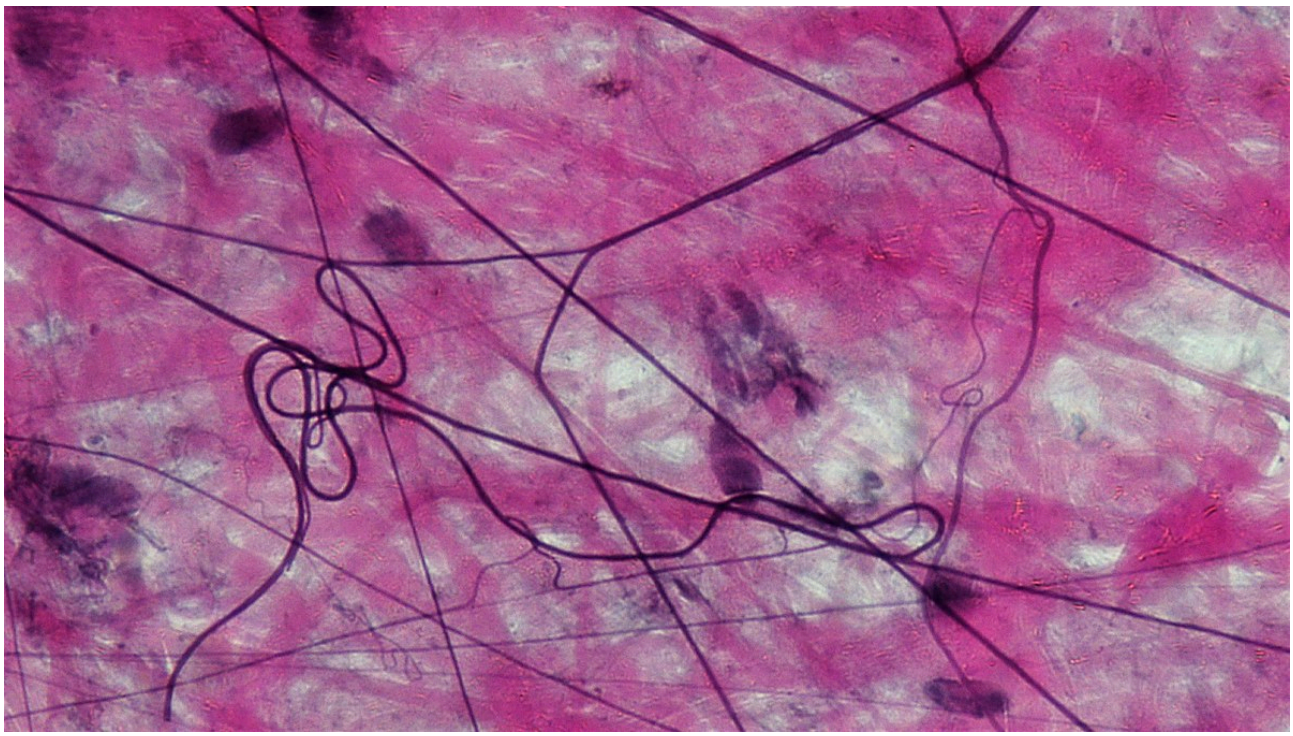


Figure 4.8. Loose connective tissue in areolar tissue. Credit: Wikimedia File Connective Tissue Loose Aerolar (41743649782). Author Berkshire Community College Bioscience Image Library

Dense Connective Tissue. As the name suggests, this tissue type is dense. It is pretty heavy with collagen fibers. Cells called fibroblasts are few. Fibroblast cells secrete the collagen fibers. Dense connective tissue is also found under the skin. Tendons, ligaments and aponeuroses are made up of dense connective tissue.

Specialized Connective Tissue. These connective tissues comprise cartilage, bone and fat tissue. Cartilage is made up of semi-solid structures (Figure 4.9) while bone is solid due to calcium salts. Fat tissue contains adipocyte cells filled with droplets of fat pushing the nucleus to the side (Figure 4.10).

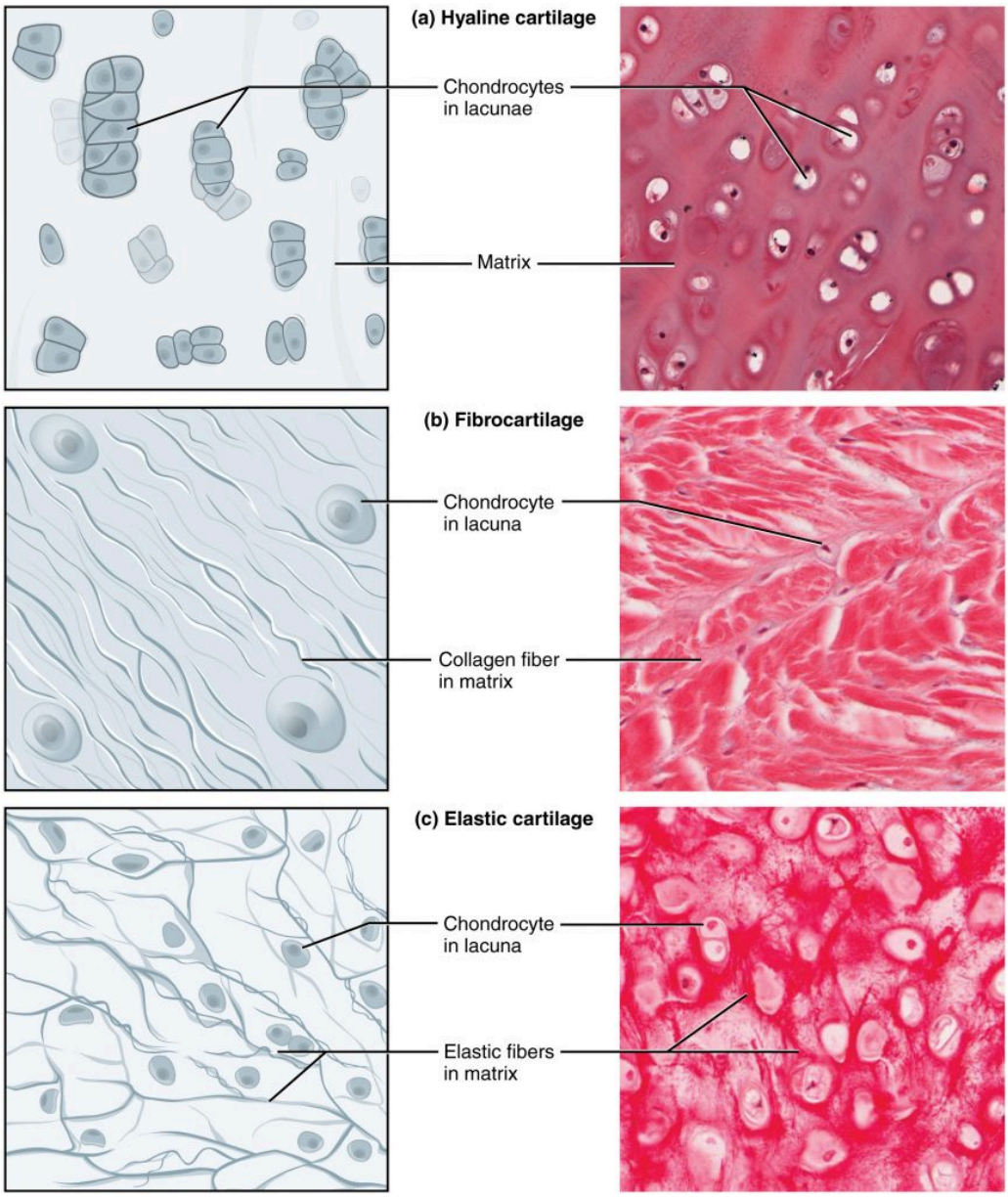


Figure 4.9. Sections showing specialized connective tissue type that is cartilage. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

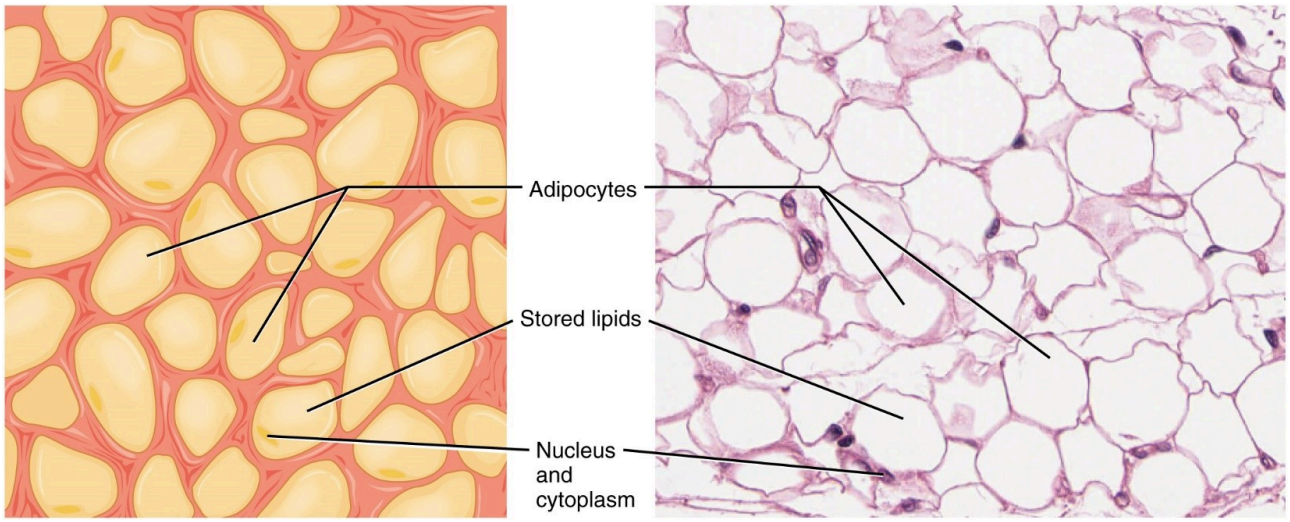
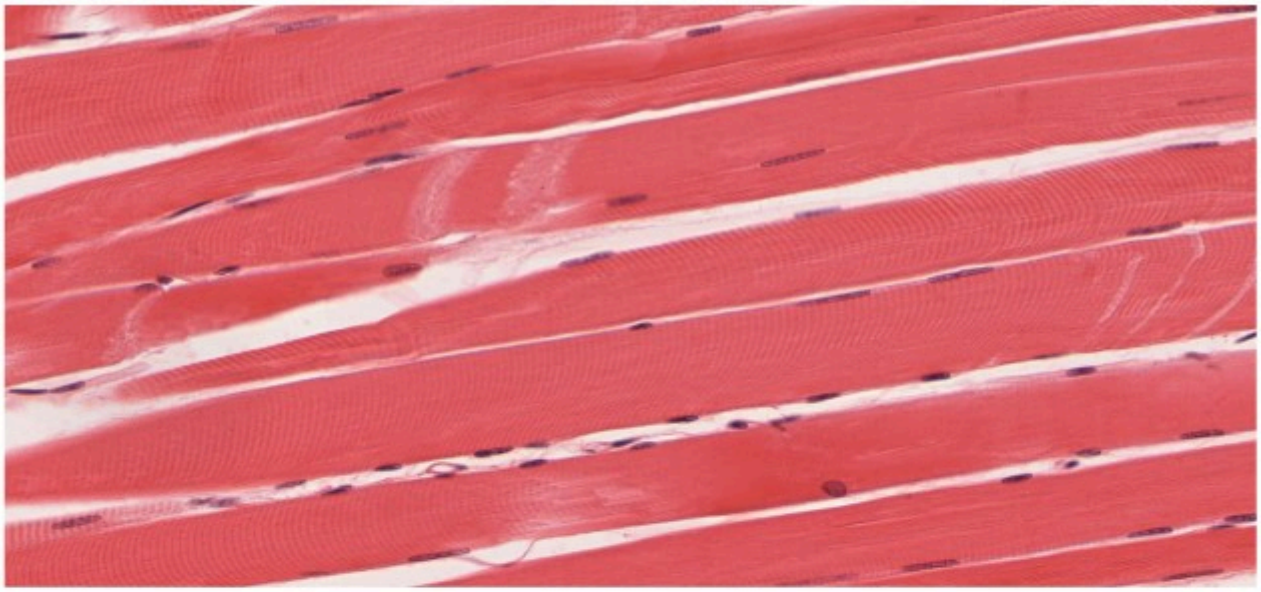


Figure. 4.10 Section showing adipose (connective) tissue. The fat cells are adipocytes that have thin cytoplasm but with a droplet of fat. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

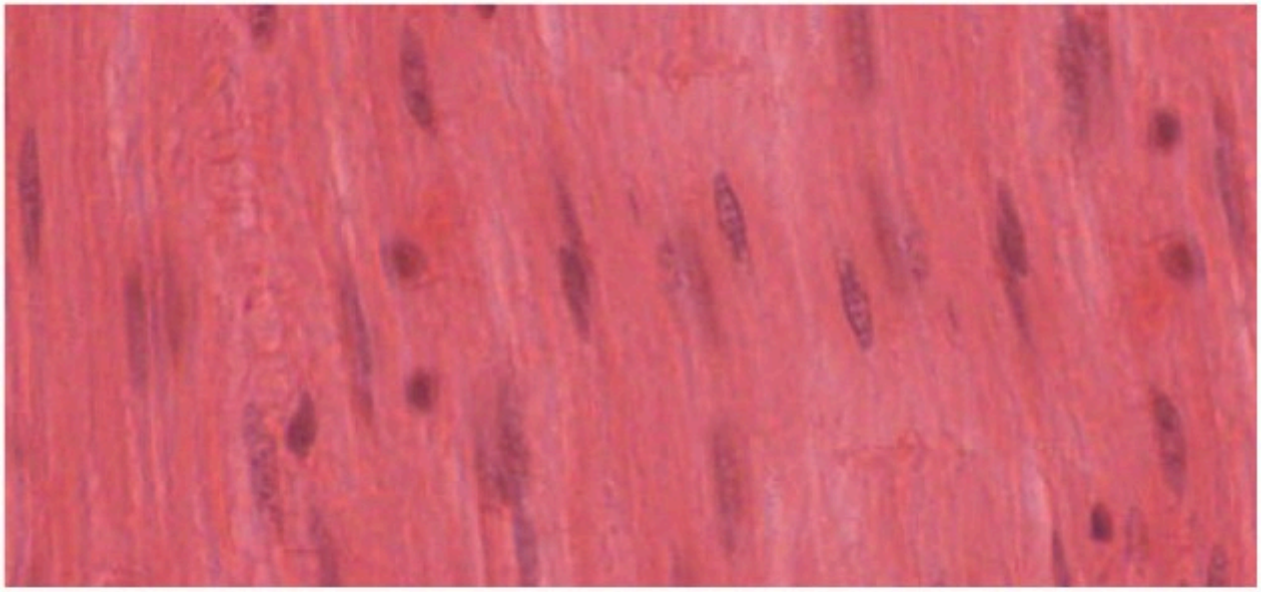
Muscle Tissues

Muscle tissue is made up of muscle cells, also known as **muscle fibers** (Please remember!). Muscle cells are different from epithelial cells and connective tissue cells. They are long (because they have to stretch), have a nucleus and make up the bulk of a human body.

There are three types of muscle cells: **skeletal, cardiac** and **smooth** (Figure 4.11). Each type is remarkably different from the other.



(a)



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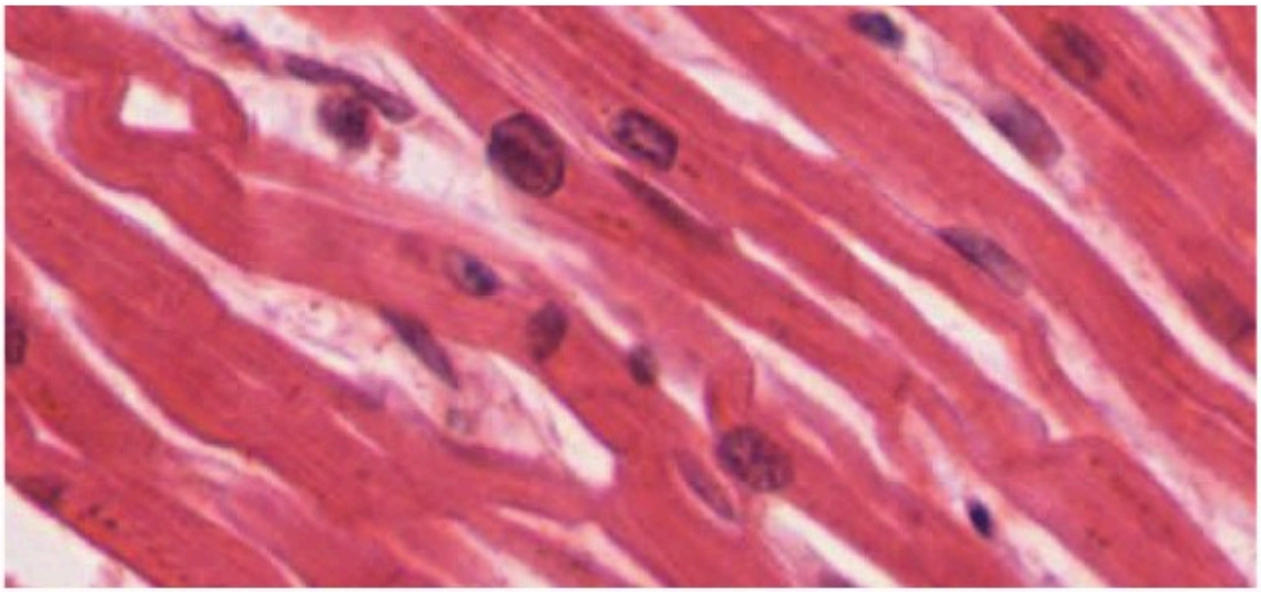


Figure 4.11 Muscle Tissue Types. (a) Skeletal, (b) Smooth, (c) Cardiac. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0)

Skeletal muscle fibers (cells) are long, have more than one nucleus (multinucleate) and striations (stripes) in the cytoplasm. Muscle cells bind bone to bone. **Cardiac muscle** fibers are branched, striated but with one nucleus per cell and have intercalated discs. Intercalated discs are unique to cardiac muscle and are junctions between the cells. Cardiac cells are found in heart tissue only. **Smooth muscle** fibers are pointed at two ends but with a bulge in the middle (spindle-shaped) with one nucleus per cell. They do not have striations or intercalated discs or branches. Smooth muscles are found in the wall of the stomach, intestine, sphincters and the eye.

Function: Skeletal muscles attach bone to bone. They move bones. Every movement in our skeletal system is made by skeletal muscles. It functions voluntary, that is, we can will our bones to move. Cardiac muscles and Smooth Muscles are involuntary; we have no control over them from the time we are born to the time we die.

Nervous Tissues

Nervous tissue is made up of large neural cells (neurons) and supporting cells (neuroglia). A **neuron** has one nucleus in its cytoplasm. The shape of nerve cells is irregular. The cytoplasm extends itself into branches. The ends of the branches come into contact with those of other nerve cells and pass on sensory stimuli. The branches that receive stimuli (such as heat, light, sound) are called dendrites. The stimuli pass through the cytoplasm and are relayed through branches known as **axons**. Axon ends synapse (form junctions) with dendrites, cell bodies, or other axons to pass on the stimuli to billions of nerve cells that are found in our brain and throughout the body. The stimuli are important to us because they allow the body to coordinate our physiological functions. **Neuroglia** (aka glial cells) are smaller cells that support and protect neurons.

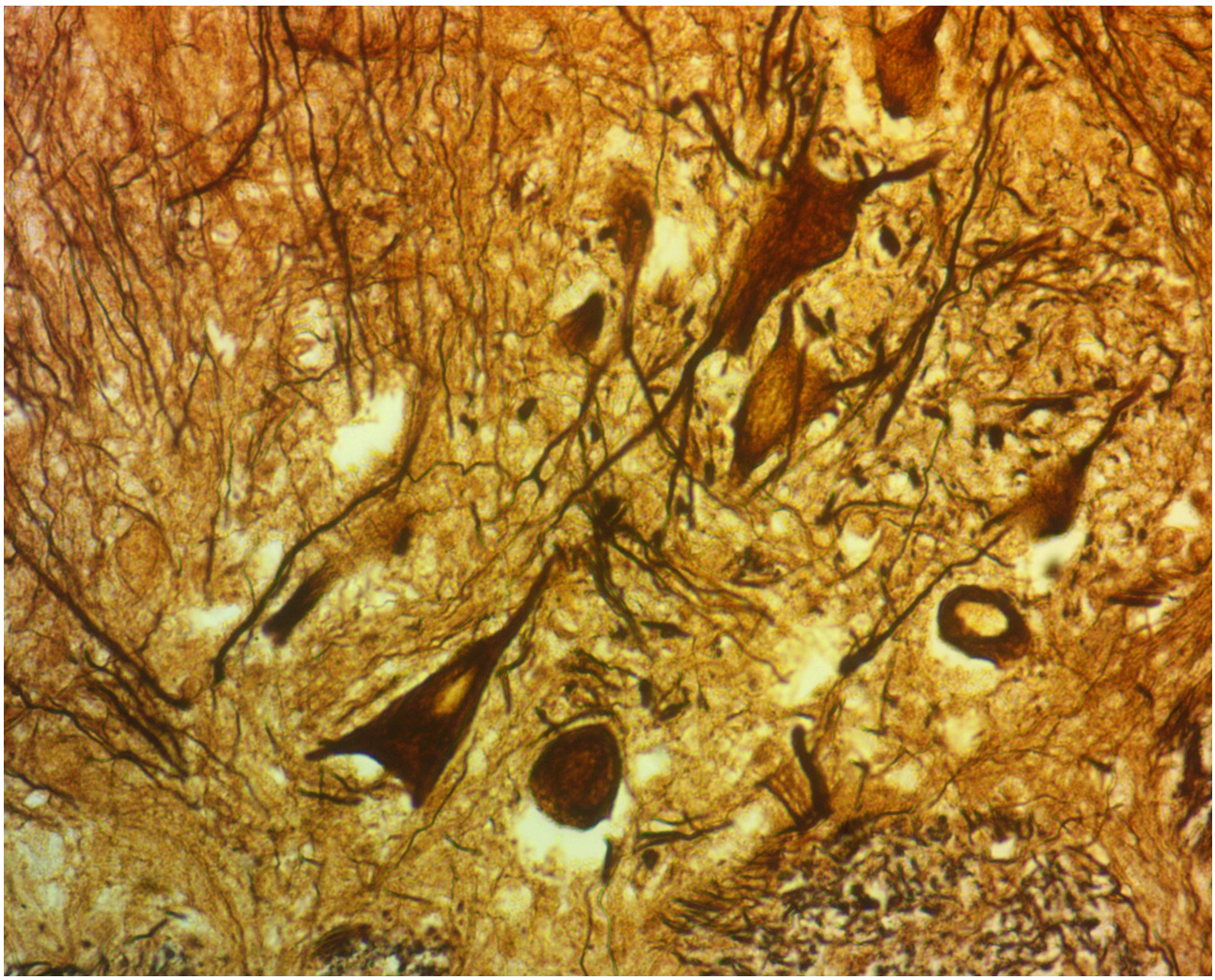


Figure 4.12 Section of spinal cord showing nervous tissue with neurons. Large triangular cell bodies of neurons, small circular glial cells, and long fibers some of which are axons are shown in dark brown.

Pre-Laboratory Questions

Review the background information sections on tissues that are provided in this chapter prior to attending the laboratory. Then, answer the following questions:

1. Define tissues.
2. List the four categories of tissues. For each category, give an example of an organ where you would find the tissue.
3. What are types of shapes that define epithelial tissues by?
4. Name epithelial tissues according to their layers. Cite one example for each.
5. Compare and contrast stratified epithelium with pseudostratified epithelium.

Exercises

- Exercise 1. Epithelial Tissues
- Exercise 2. Connective Tissues
- Exercise 3. Muscle Tissues
- Exercise 4. Neural Tissues
- Exercise 5. Histologically Impaired Tissues

Exercise 1. Epithelial Tissues

Required Materials

- Compound microscope
- Lung tissue slide
- Slide of skin from general surface showing sweat glands
- Slide of columnar epithelium from small intestine
- Trachea slide
- Adipose tissue slide
- Muscle slide with skeletal, cardiac and smooth muscle
- Spinal cord slide
- Pancreas slide

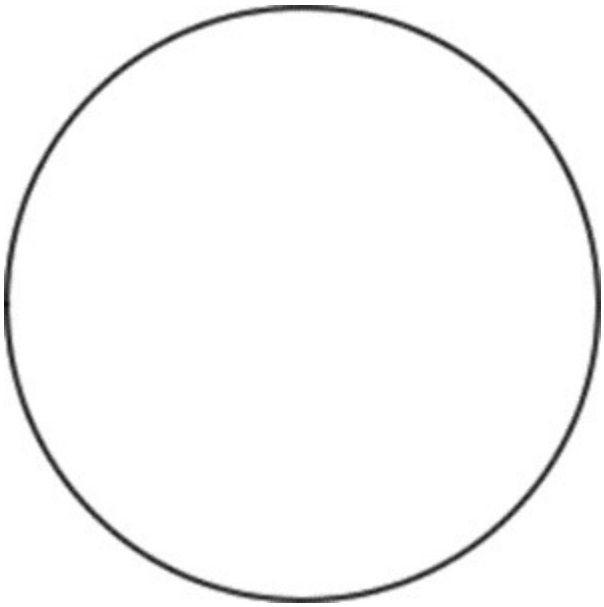
Exercise 1.1. Identification of Squamous Epithelial Tissue.

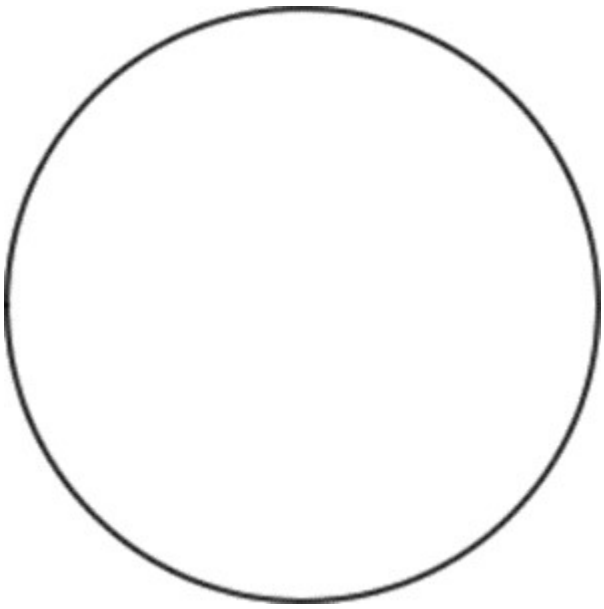
This is what you should know and remember about squamous epithelial tissue: Cells look like fried eggs with nucleus like yolk sitting on top of cytoplasm (white of egg), sunny-side up, or tiles on a floor. Filtration (glomerulus), diffusion of gases (lung tissue).

This is what you should do:

1. Ask your instructor for a prepared slide showing **lung** tissue. (Figure. 4.2.)
2. Place it on the stage of microscope and bring it into focus using low power (4 x 10 magnification).
3. Study tissue on slide. Move slide vertically and horizontally. Most of the tissue will appear as large, irregular white spaces encircled by thin layer of cells. The spaces are alveolar sacs. The cells are squamous epithelial.

4. The squamous epithelial cells are tiny but with a prominent blue (or dark) nucleus. You will not be able to see the margins of the cells because they are indistinct.
5. Change the magnification to high power (10 x 10). Study the prominent, blue or dark nuclei of the cells. Each nucleus is surrounded by cytoplasm. The plasma membrane is very thin. It will not appear as a distinct structure.
6. Identify alveolar space and nucleus of the squamous epithelial cell. Use Fig. 1.2 to assist you.
7. Draw the tissues at low and high magnification to show the cell and tissue structure as best as you can. Label nucleus, cytoplasm.

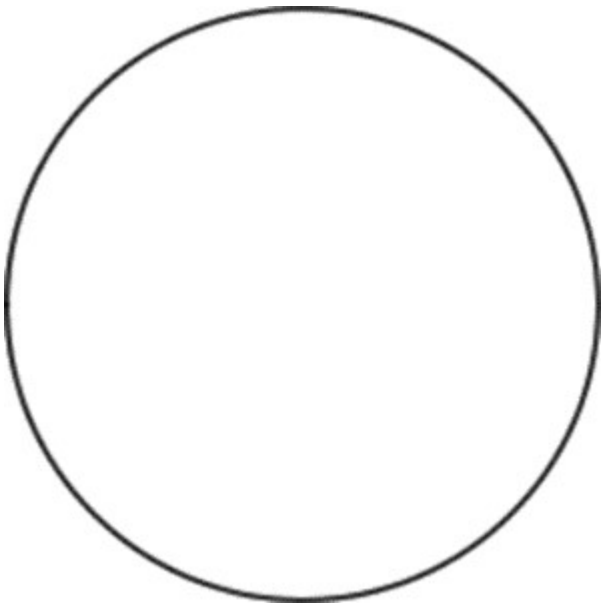


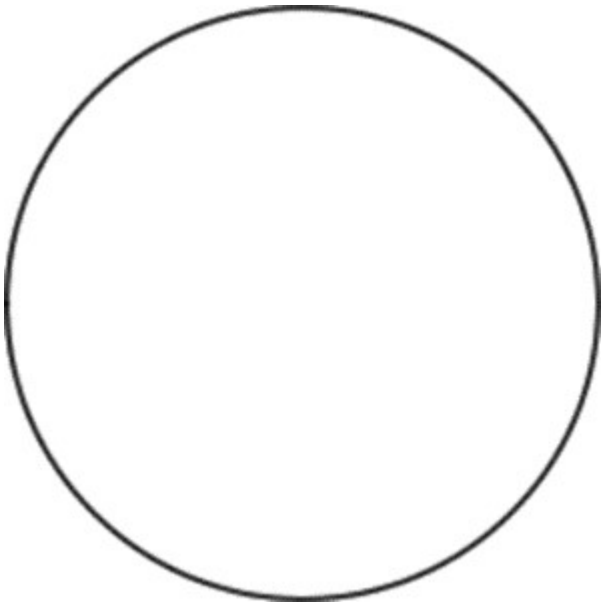


Exercise 1.2. Identification of Simple Cuboidal Epithelium

This is what you should do:

1. Ask your instructor for a slide showing **sweat gland tissue** or kidney tubule. (Figure 4.3.)
2. Place it on the stage of the microscope and bring the tissue into focus using low power (4 x 10) magnification.
3. Move slide horizontally and vertically to zoom in on cells (see black label). The space in the center of the tubule is the lumen. Cuboidal cells circle the lumen. The cells are more or less all the same shape with a large nucleus in the center. The sides of the cells are equal in length, breadth and height.
4. The side of cell facing the lumen is the apical surface. The side away from it is the basal surface.
5. Change magnification to high power (10 x 10) magnification. The cells will appear larger. The cytoplasm and nucleus now appears more distinctly.
6. Draw what you observe at low and high magnification and label lumen, nucleus, cytoplasm, apical and basal surface.





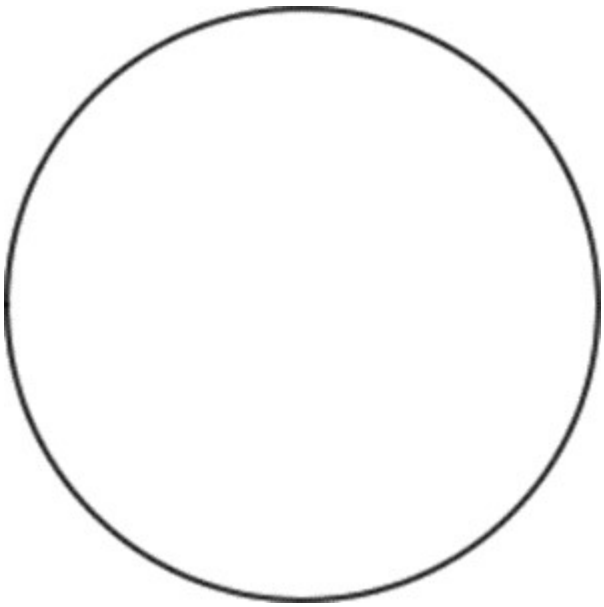
Exercise 1.3. Identification of Simple Columnar Epithelium

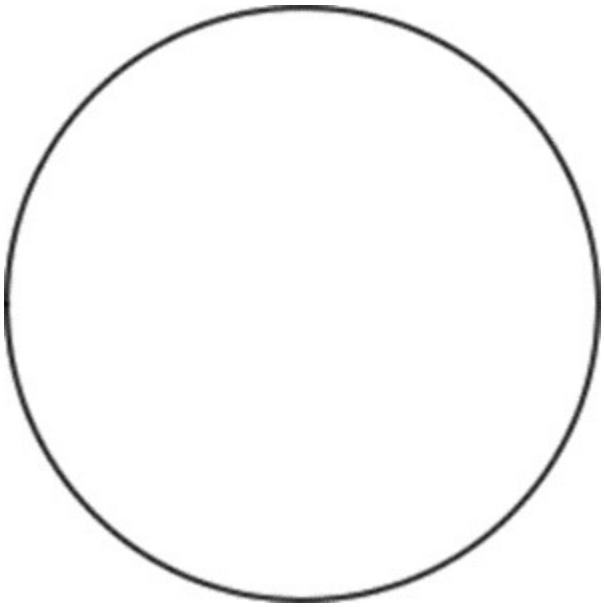
This is what you should do:

1. Ask your instructor for a slide showing **small intestine** tissue. (Figure 4.4.)
2. Place it on the stage of the microscope and bring the tissue into focus using low power (4 x 10) magnification.
3. Move slide horizontally and vertically to zoom in on a piece of the tissue that looks like a finger. The cells are numerous and colored light blue/purple with a prominent nucleus. They appear on the two sides of the intestinal tissue. The cells are taller than they are wide in shape with a large nucleus close to the base. In between the tall cells are goblet cells. They look like small vases and are filled with mucus.
4. Change magnification to high power (10 x 10) magnification. The cells will appear larger. The

cytoplasm and nucleus now appears more distinctly. The space between the two sides with cells contains blood vessels and nerve fibers.

5. Draw what you observe at low and high magnification, and label lumen, nucleus, cytoplasm, apical and basal surface.





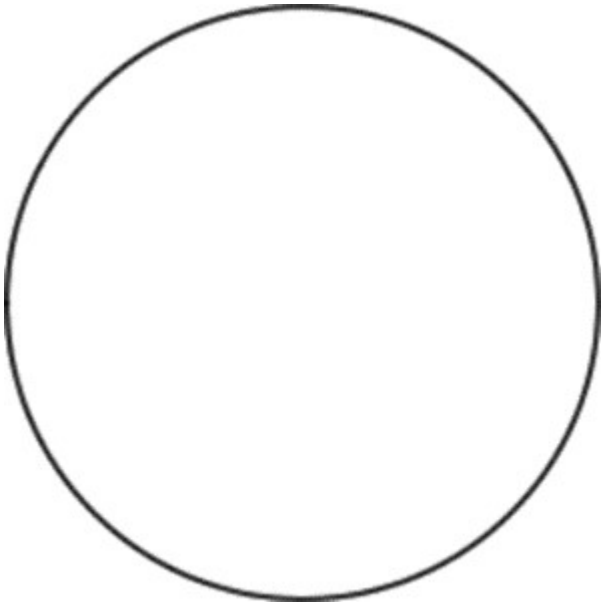
Exercise 1.4. Pseudostratified Columnar Epithelium

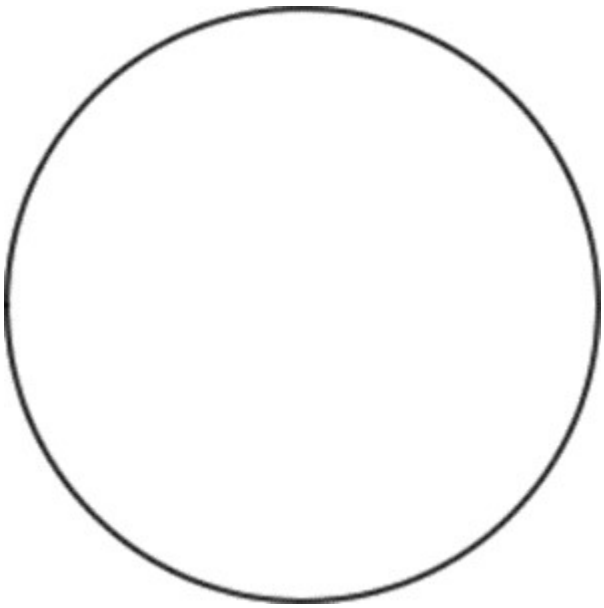
This is what you should do:

1. Ask your instructor for a slide showing **trachea**. (Figure 4.5.)
2. Place it on the stage of the microscope and bring the tissue into focus using low power (4 x 10)

magnification.

3. Move slide horizontally and vertically to zoom in on cells that appear in two or more layers. Cells are tall but blunt towards apical surface. Not all cells reach up to surface and are shorter, situated halfway between the taller ones. This gives a false impression there are two layers of cells. That is why they are called pseudostratified. The cells are numerous and colored light blue/purple with a prominent nuclei. The nuclei are prominent.
4. Change magnification to high power (10 x 10) magnification. Notice that all the cells — tall or short — all share same basement membrane.
5. Draw what you observe at low and high magnification, and label lumen, nucleus, cytoplasm, apical and basal surface.

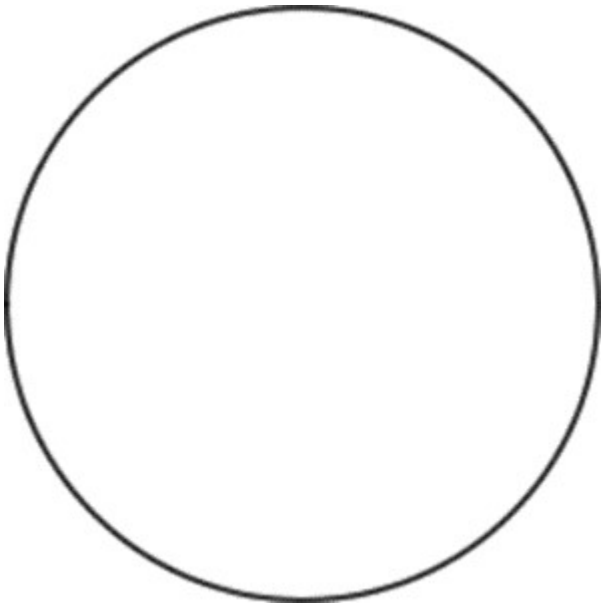


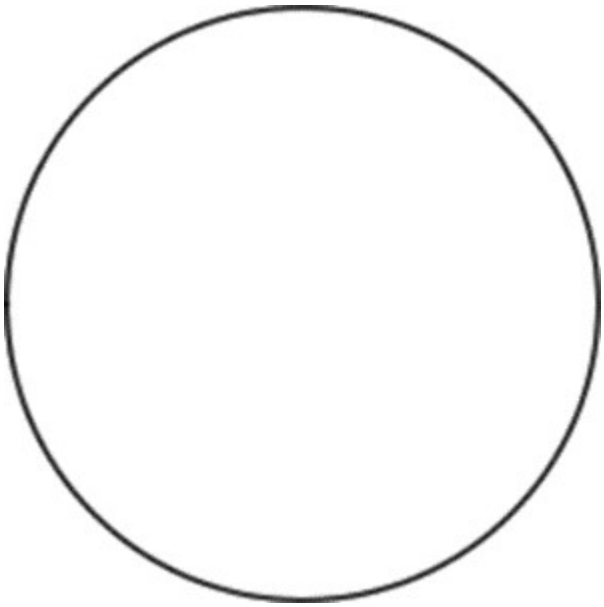


Exercise 2. Connective Tissues

This is what you should do:

1. Ask your instructor for a slide showing **adipose (fat) tissue**. (Figure 4.10.)
2. Place it on the stage of the microscope and bring the tissue into focus using low power (4 x 10) magnification.
3. Move slide horizontally and vertically to locate adipocytes (fat cells). They are white in color and are shaped like potatoes — no regular shapes. The cells are actually a thin sliver of cytoplasm colored purple with a tiny nucleus. The fat is the large white glob and occupies most of the cell space. It is amorphous.
4. Change magnification to high power (10 x 10) and notice the thin, purple cells each with its nucleus.
5. Draw what you observe at low and high magnification, and label glob of fat cell with nucleus.

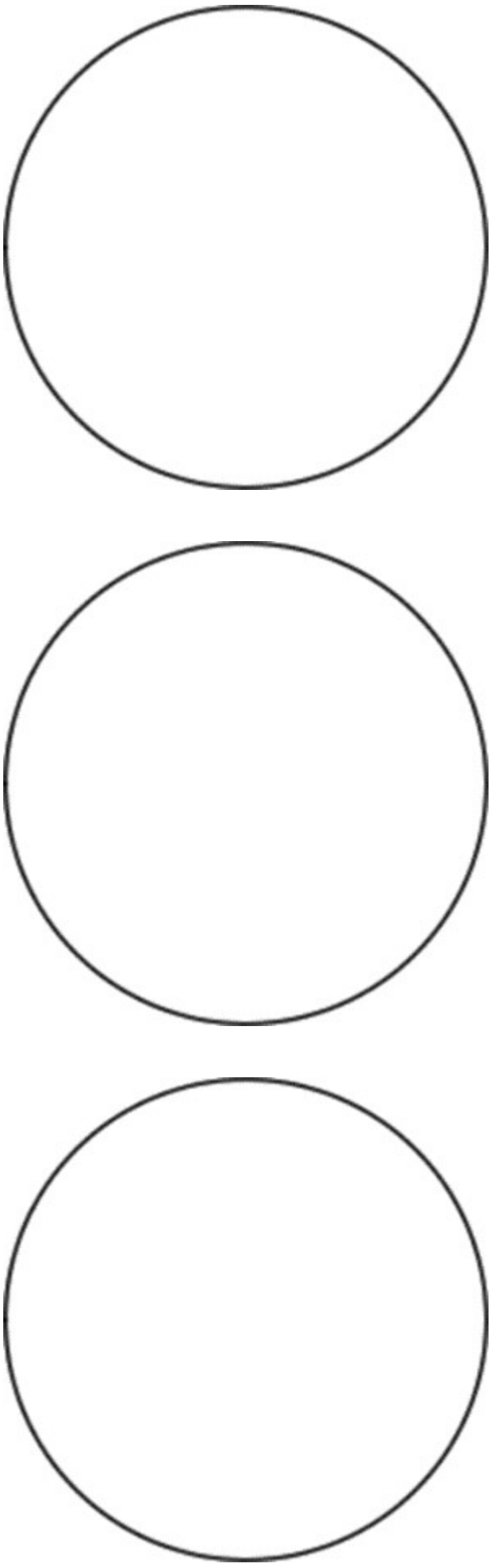


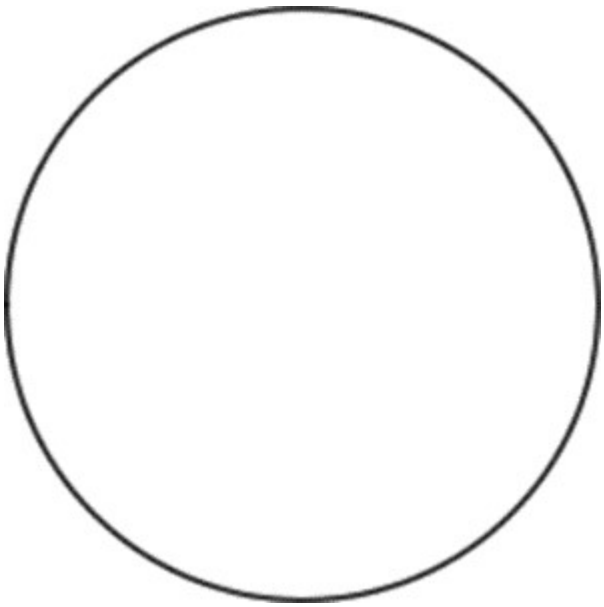


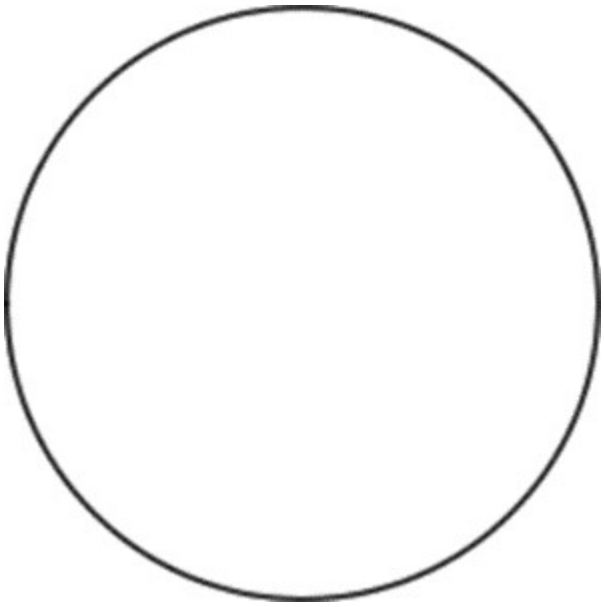
Exercise 3. Muscle Tissues

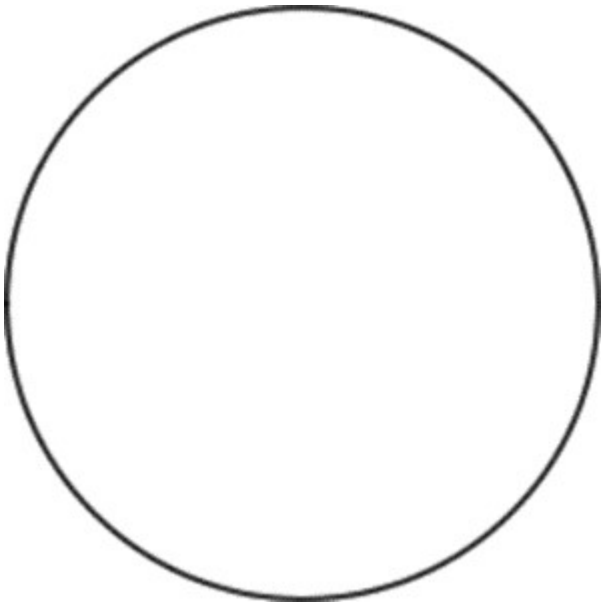
This is what you should do:

1. Ask your instructor for a slide showing **skeletal, cardiac and smooth muscle tissue**. (Figure 4.11).
2. Place the slide on the stage of the microscope and bring the tissue into focus using low power (4 x 10) magnification. Observe the three sections.
3. Change magnification to medium – (10 x 10) and high-power (10 x 40) to notice striations (skeletal and cardiac), nuclei per cell, branches and intercalated discs (cardiac) and spindle shape (smooth). Sketch at low and high magnification.
4. Skeletal muscle: Move slide horizontally and vertically to locate skeletal muscle fibers. They are long and will show striations (stripes). Notice the nuclei — more than one per cell. Sketch the fibers at low and high magnification.
5. Cardiac muscle: Notice the fibers are branched, striated and contain intercalated discs. Notice there is one nucleus per cell. Sketch the tissue at low and high magnification.
6. Smooth muscles are spindle-shaped. Cells are packed close to one another. Each cell has on nucleus. Sketch the tissue at low and high magnification.





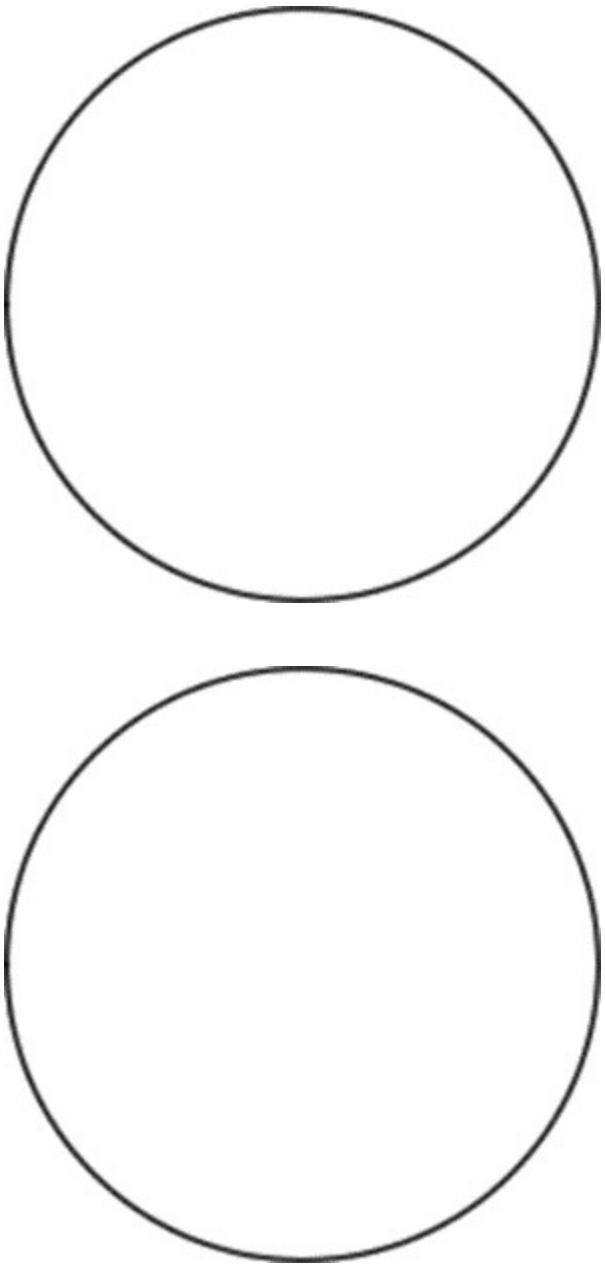




Exercise 4. Nervous Tissues

This is what you should do:

1. Ask your instructor for a **spinal cord** slide showing nervous tissue. (Figure 4.12)
2. Place it on the stage of the microscope and bring the tissue into focus using low power (4 x 10) magnification.
3. Move slide horizontally and vertically to locate neurons. They are large and blue (or dark brown) in color with no definite shape. Dendrites and axons are extensions of the cytoplasm and appear like hair. Locate dendrites that are numerous and thin. Axons are thicker and fewer in number.
4. Change magnification to high power (10 x 10). Notice neuroglial cells in cytoplasm are dense in number.
5. Draw what you observed at low and high magnification, showing neuronal cell bodies, glial cells, axons, dendrites.



Exercise 5. Histologically Impaired Tissues

At the beginning of this chapter on Tissues, we referred to diabetes. The organ that is affected is the pancreas. Notice changes in the structure of the pancreas by comparing it with normal tissue. (Figure 4.13)

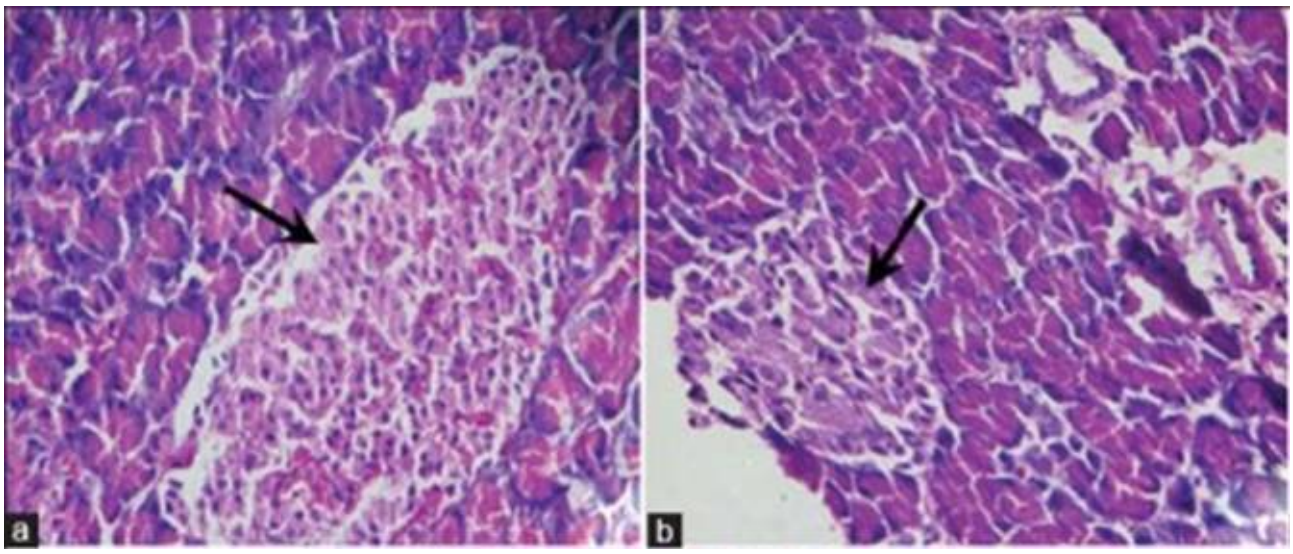
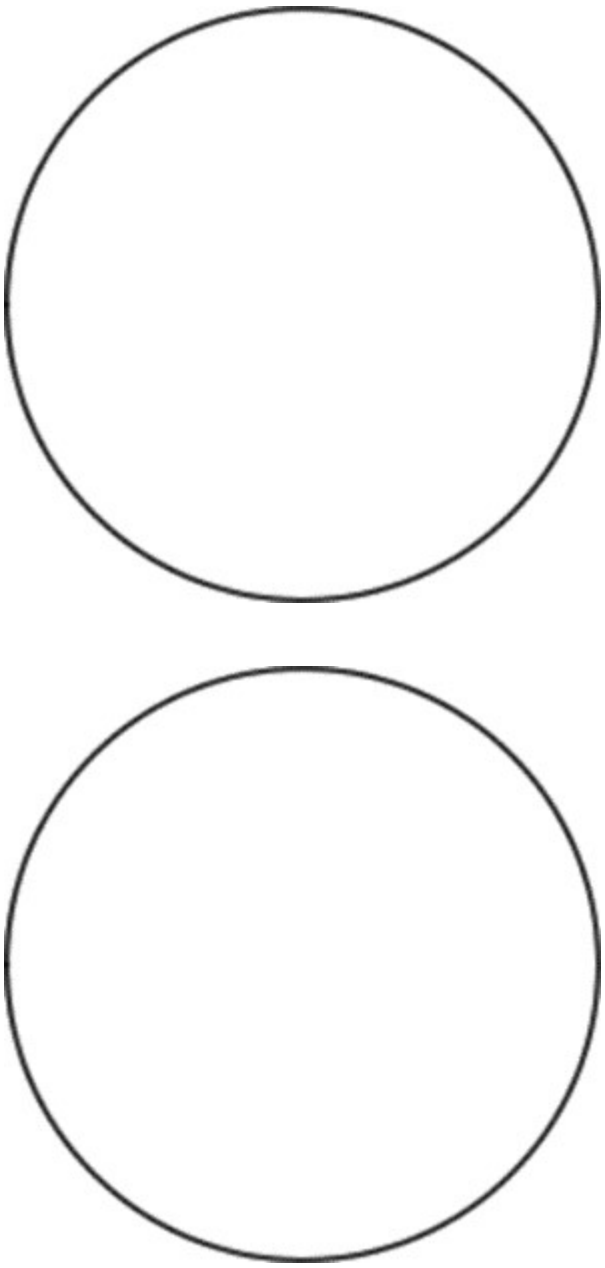


Figure 4.13 Comparison of Normal and Impaired Pancreas. (a) Control rat pancreas, (b) Diabetic rat pancreas. Arrow points to the Islets of Langerhans (Credit: Renjith RS https://www.researchgate.net/figure/Histopathology-of-pancreas-of-diabetic-rats-treated-with-Cocos-nucifera-Inflorescence-a_fig1_232742154, CC-BY-NC-SA license)

This is what you should do:

1. Ask your instructor for a **pancreas** slide.
2. Place it on the stage of the microscope and bring the tissue into focus using low power (4 x 10) magnification.
3. Move slide horizontally and vertically to locate the Islets of Langerhans, acini and ducts (Figure 4.1 and 4.13).
4. Change magnification to high power (10 x 10). Notice the epithelial cells in the islets and acini
5. Draw what you observed for this normal pancreas tissue at low and high magnification, showing islet and acinar epithelial cells.



6. How is the normal pancreas different than the diabetic pancreas in Figure 4.13? Describe the differences in the Isles of Langerhans between the normal and diabetic specimens.

Post-Laboratory Questions

1. What type of cells make up epithelial tissue? Sketch the cell to show the three different shapes that are found in epithelial tissues.
2. Epithelial tissue is characterized by (a) shape and (b) layers. Name one tissue to demonstrate shape as an example.
3. Compare lung tissue and kidney tissue. How are they different? How are they similar?
4. Sketch a pseudostratified epithelium. What is its basic characteristic?
5. Give one example each of a solid, semi-solid and fluid connective tissue. State the characteristics that define each tissue.

6. How are the three types of muscle tissues different from each other?
7. How would you identify a neuron if you saw one?

5.

CHAPTER 5 THE INTEGUMENTARY SYSTEM

By Ganesan L. Kamatchi

Motivation

Human skin is the first anatomical site a nurse examines when seeing a patient, using it as an indicator of general health such as oxygenation, nutritional status, and injury[1]. Skin color is mostly based on the pigmentation or **melanin** found in the **keratinocytes** in the **epidermis** of skin. In addition, the blood supply to the surface (redness), injury (bruising), and jaundice (yellowing) can affect skin color.

Figure 5.1. Significance of skin color in diagnosis. Many preterm babies are jaundiced and need to be treated under a UV light. This is an example of how skin color is used in diagnosis (Credit: Kurt Voelker, Flickr images, CC-BY-NC license)

Skin color of different races has led to many misconceptions in medicine. 40% of white medical students surveyed in 2016 thought that black skin is thicker than white skin therefore making black patients more resistant to pain![2] In reality, the sensory receptors called **free nerves endings** found within the **dermis** of skin detect pain and are completely unrelated to skin color which is not just black and white, but many shades in between. Let's get our facts right and serve patients of all skin color without misconceptions.

Credit:

1. Everett JS, Budescu M, Sommers MS. Making Sense of Skin Color in Clinical Care. *Clin Nurs Res*. 2012;21(4):495-516. doi:10.1177/1054773812446510
2. How we fail black patients in pain | AAMC. https://www.aamc.org/news-insights/

how-we-fail-black-patients-pain. Accessed July 22, 2020.

Learning Objectives

Upon completion of the work in this chapter on the integumentary system, students should be able to:

- Describe the layers of epidermis of thick and thin skin
- Identify the basis for skin color
- Differentiate the layers of dermis
- Explain epidermal ridges, dermal papillae and fingerprints
- Differentiate sebaceous glands, merocrine (eccrine) and apocrine sweat glands
- Identify parts of hair follicle
- Describe the structure of nail

Background.

Although you may not typically think of the skin as an organ, it is in fact made of tissues that work together as a single structure to perform unique and critical functions. The skin and its accessory structures make up the integumentary system, which provides the body with overall protection. The skin is made of multiple layers of cells and tissues, which are held to underlying structures by connective tissue. The top layer is called **epidermis** and comprises several layers of cells. The layer underneath the epidermis is called **dermis** and is made of connective tissue. The dermis is well vascularized (has numerous blood vessels) and has numerous sensory, and autonomic and sympathetic nerve fibers ensuring communication to and from the brain. The layer below the dermis is called **hypodermis**, not considered as a part of the integument, and consists of well-vascularized, loose, areolar connective tissue and adipose tissue (Figure 5.2).

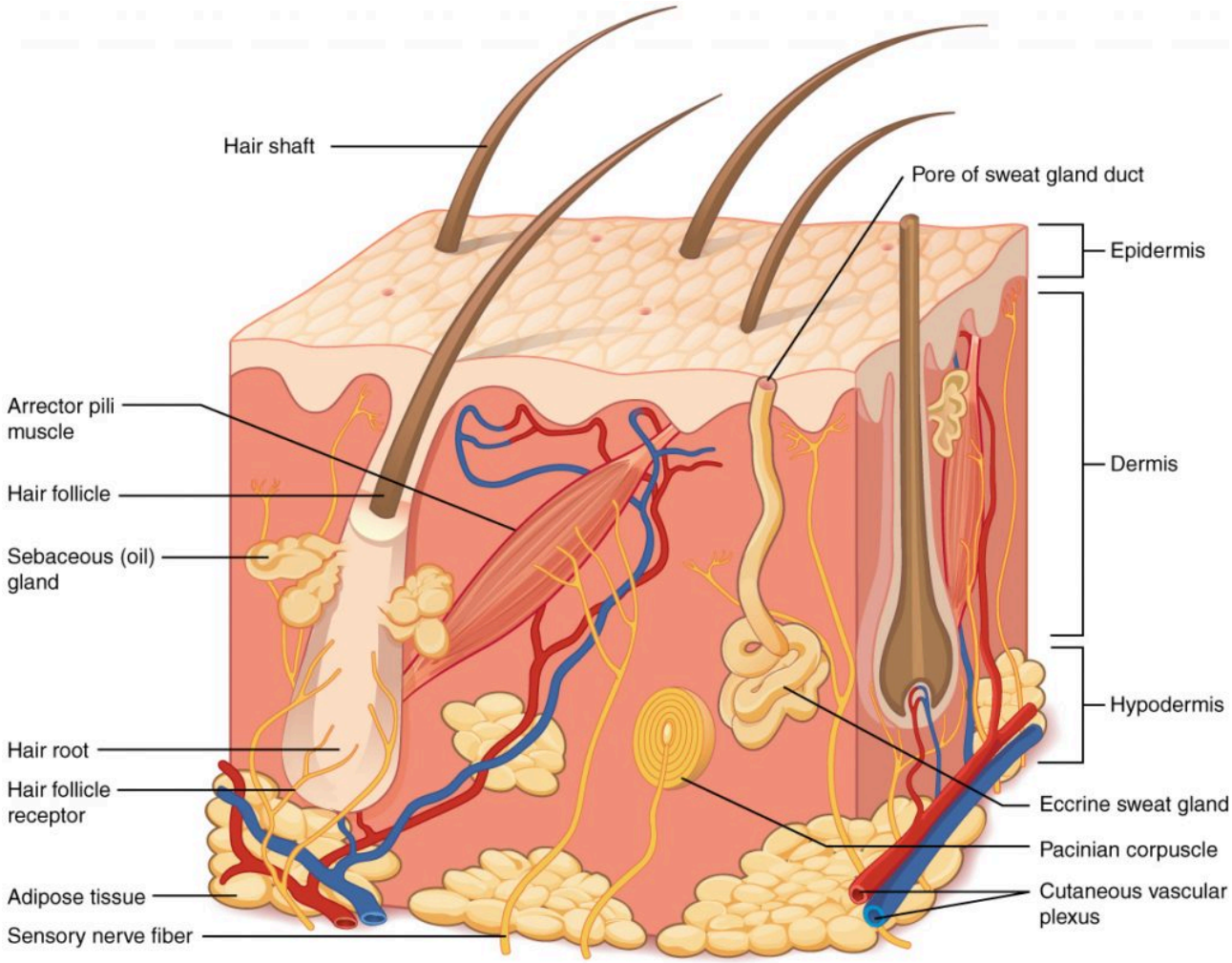


Figure 5.1 Layers of Skin. The skin is composed of two main layers: the epidermis, made of closely packed epithelial cells, and the dermis, made of dense, irregular connective tissue that houses blood vessels, hair follicles, sweat glands, and other structures. Beneath the dermis lies the hypodermis, which is composed mainly of loose connective and fatty tissues. (Credit: Adopted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

The **epidermis** is composed of keratinized, stratified squamous epithelium. It is made of four or five layers of epithelial cells, depending on its location in the body. Skin that has four layers of cells is referred to as "thin skin" (all over the body except the palms of the hand and the soles of the foot). From deep to superficial, these layers are the stratum basale, stratum spinosum, stratum granulosum, and stratum corneum. The palm and sole have an additional layer, stratum lucidum (between stratum corneum stratum granulosum) and referred to as the "thick skin" (Figure 5.3).

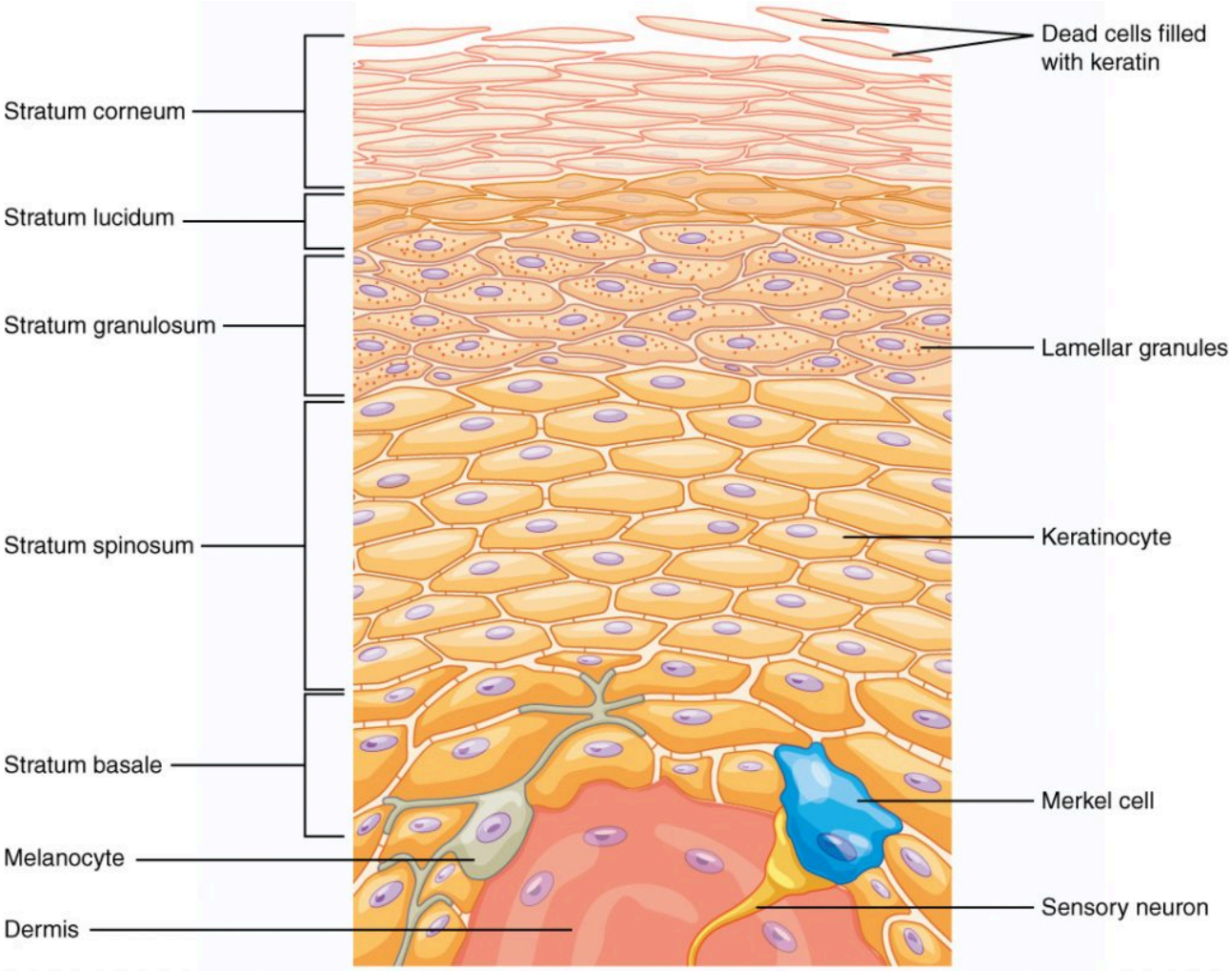


Figure 5.3. Layers of the Epidermis. The epidermis of thick skin has five layers: stratum basale, stratum spinosum, stratum granulosum, stratum lucidum, and stratum corneum.

The **color of skin** is influenced by the presence of a pigment called **melanin.** It is produced by cells called melanocytes, which are found scattered throughout the stratum basale of the epidermis. The melanin is transferred into the keratinocytes via a cellular vesicle called a melanosome (Figure 5.4).

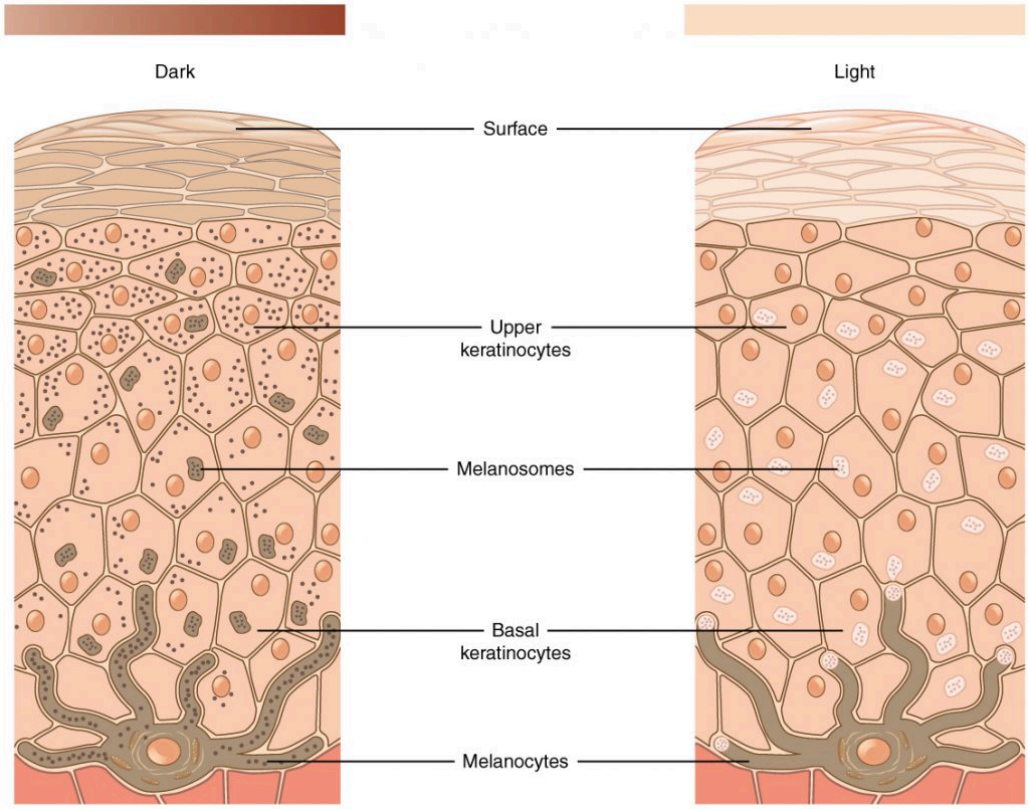


Figure 5.4 Skin Pigmentation. The relative coloration of the skin depends on the amount of melanin produced by melanocytes in the stratum basale and taken up by keratinocytes. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Hair

Accessory structures of the skin include hair, nails, sweat glands, and sebaceous glands. These structures embryologically originate from the epidermis and can extend down through the dermis into the hypodermis (Figure 5.5 and Figure 5.6).

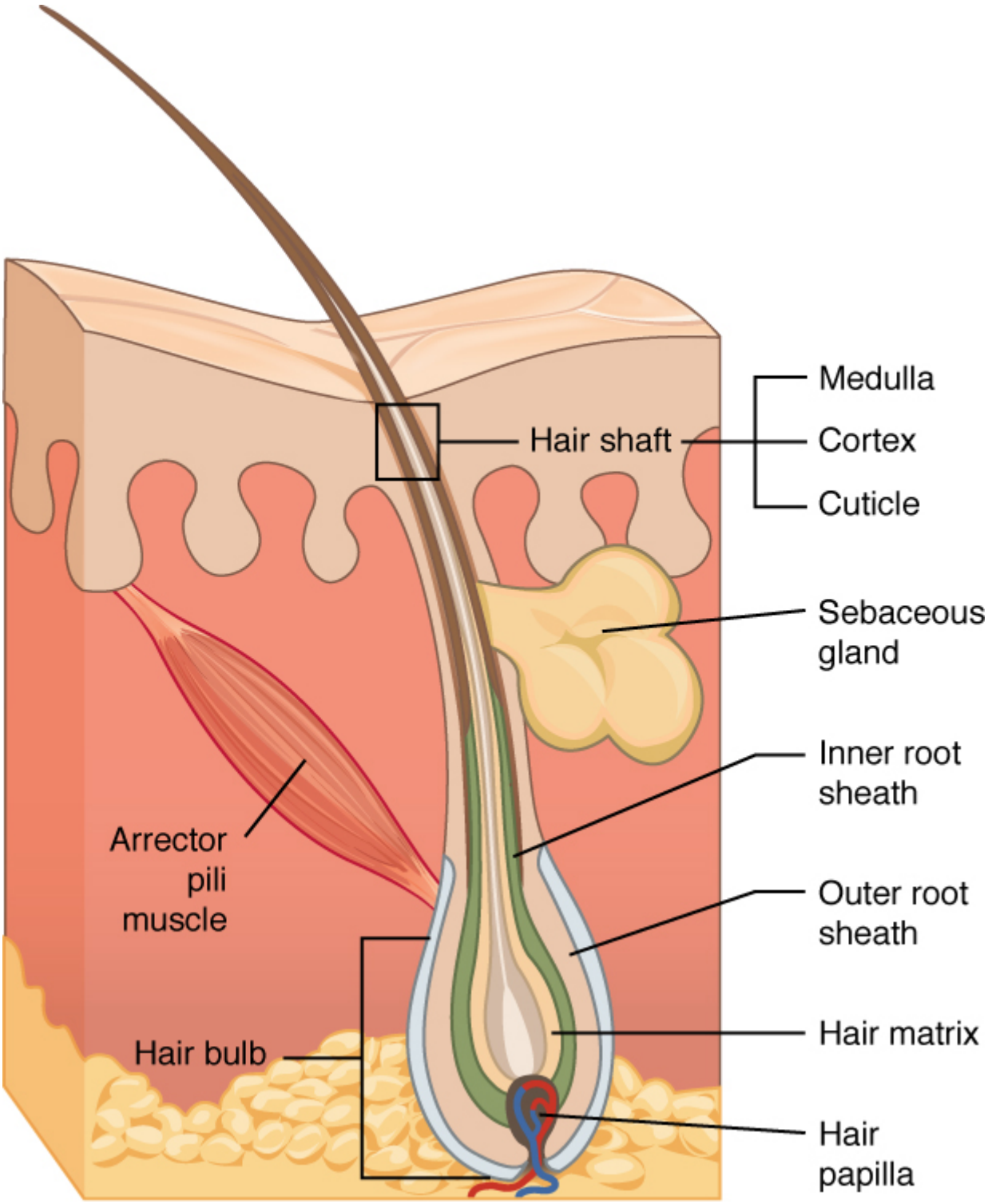


Figure 5.5 Hair. Hair follicles originate in the epidermis and have many different parts. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

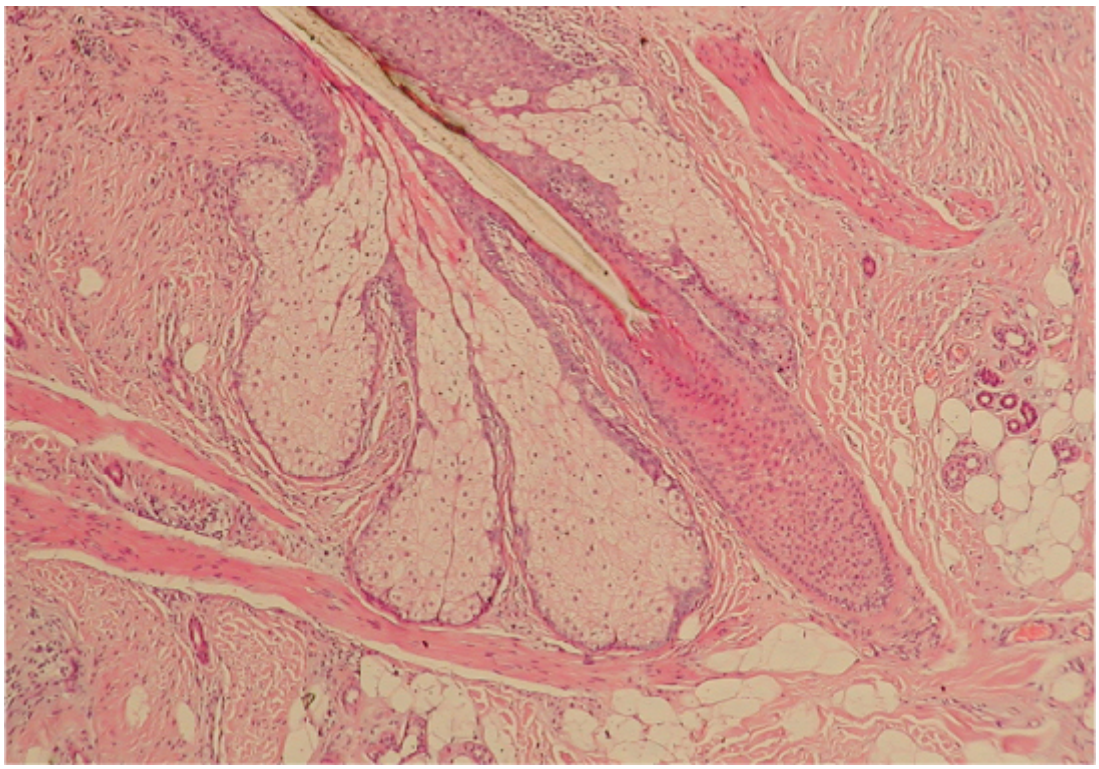


Figure 5.6 Hair Follicle. The slide shows a cross-section of a hair follicle. Basal cells of the hair matrix in the center differentiate into cells of the inner root sheath. Basal cells at the base of the hair root form the outer root sheath. LM × 4. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Sweat Glands

When the body becomes warm, sudoriferous glands (aka. sweat glands) produce sweat to cool the body. Sweat glands develop from epidermal projections into the dermis and are classified as **eccrine** sweat glands and **apocrine** sweat glands. The location of these glands and the type of sweat released by them are different. Eccrine sweat glands are the major sweat glands of the human body, responsible for temperature regulation and found in virtually all skin, with the highest density in palm and soles, then on the head, but much less on the torso and the extremities.

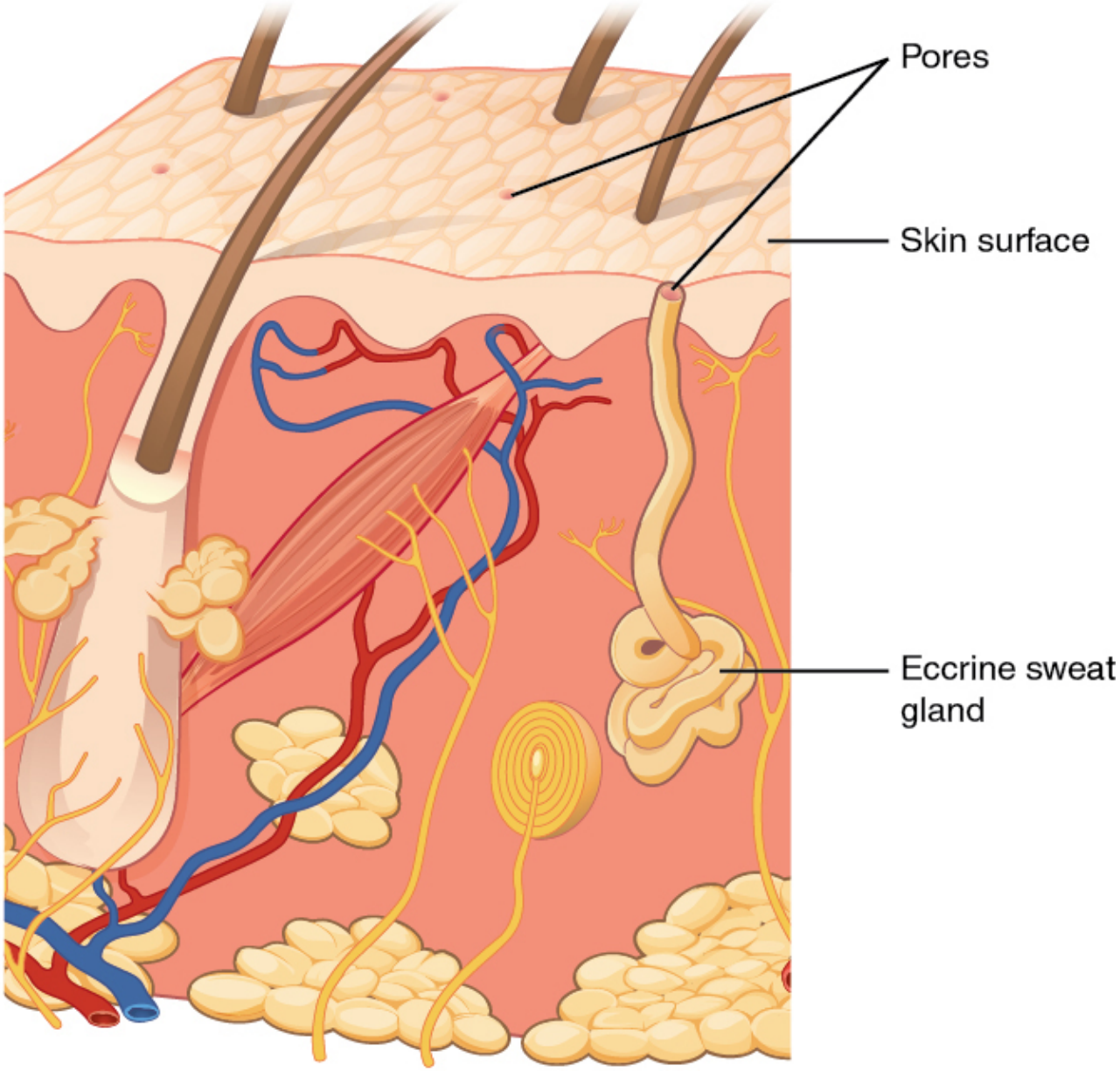


Figure 5.7 Eccrine Sweat Gland. Eccrine glands are coiled glands in the dermis that release sweat that is mostly water. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Nail

Nail is a specialized skin appendage that is a claw-like keratinous plate at the tip of the fingers and toes in most primates. Fingernails and toenails are made of a tough protective protein called alpha-keratin which is a polymer and found in the hooves, hair, claws and horns of vertebrates. The nail consists of the nail plate, the nail matrix and the nail bed below it, and the grooves surrounding it.

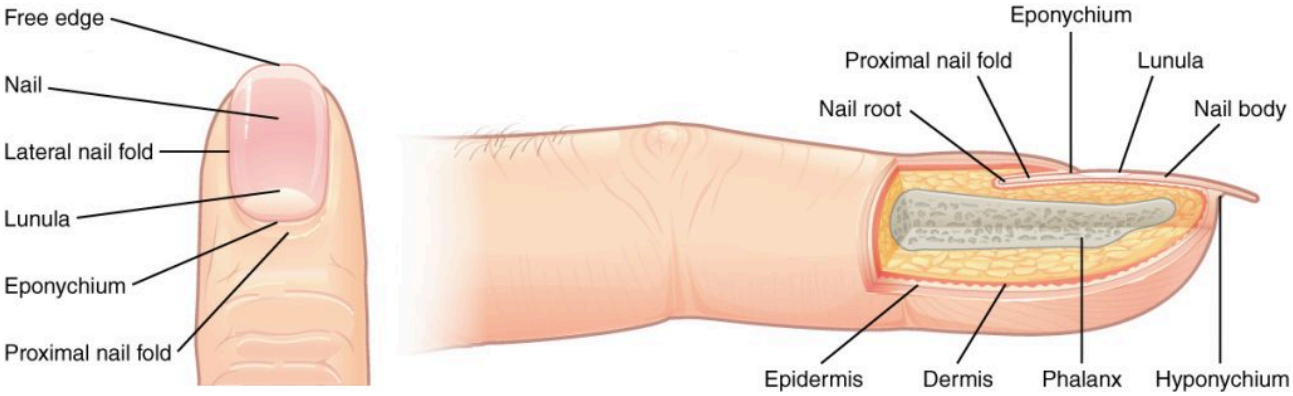


Figure 5.8 Nails. The nail is an accessory structure of the integumentary system. (Credit: Adapted from OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Pre-Laboratory Questions

Review the background information provided in the chapter and answer these questions prior to starting the exercises.

1. What are the layers of skin?
2. What is the basis for skin color?
3. Does the skin have any sense organs?
4. What are the functions of skin?
5. What are the accessory structures of skin?

Exercises

- Exercise 1 Layers of Integument
- Exercise 2 Layers of Epidermis
- Exercise 3 Skin Pigmentation
- Exercise 4 Axillaries of Skin – Hair
- Exercise 5 Axillaries of Skin – Eccrine Sweat Glands

Exercise 1 Layers of Integument

Required Materials

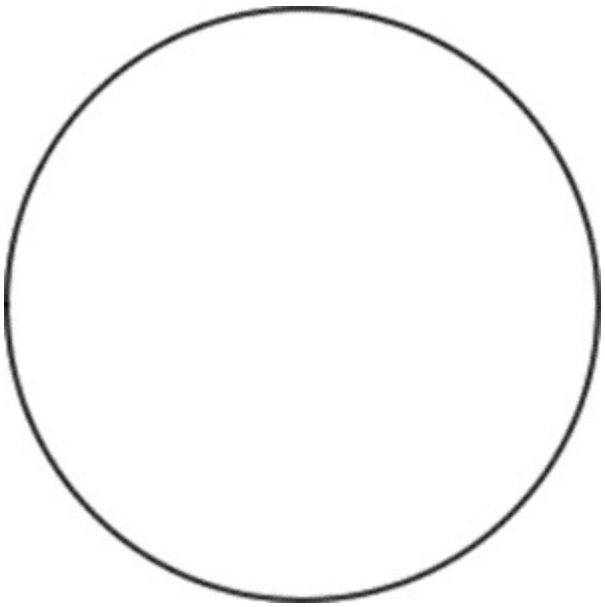
- Slide of skin
- Classroom model of skin

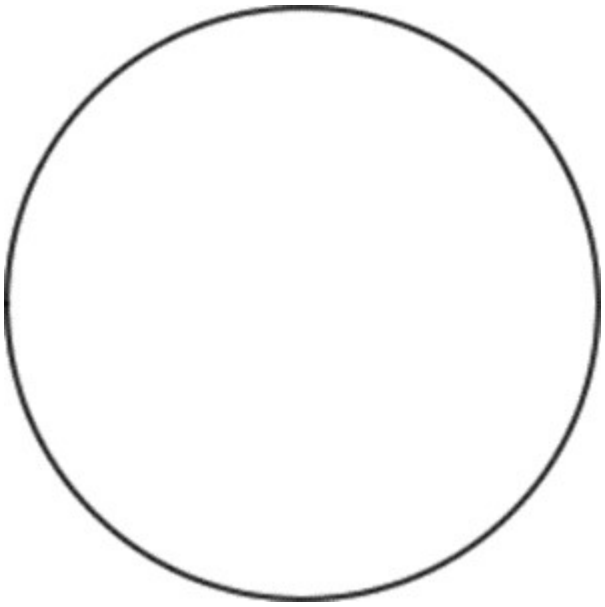
Procedure

1. Obtain a slide of skin or a model of skin.
2. Observe the organization of various layers of the skin
3. Identify

    - Epidermis
    - Dermis
    - Hypodermis and
    - Accessory structures

4. Sketch the skin and label the parts of the integument shown in Figure 5.2 above, observed at low and high magnification.





Exercise 2 Layers of Epidermis

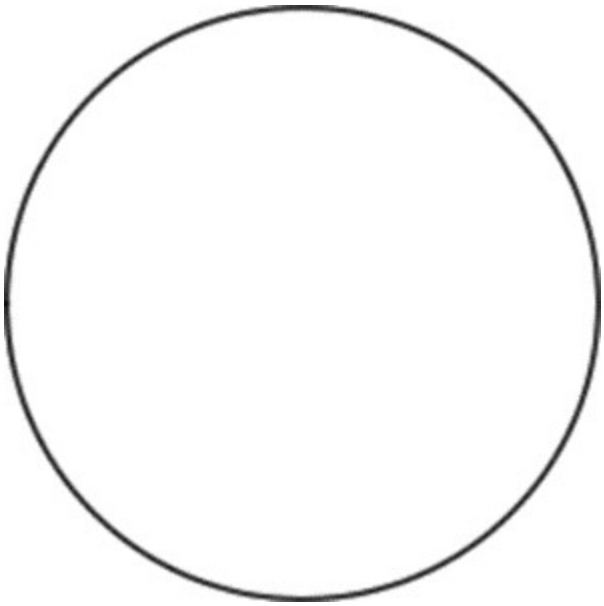
Required Materials

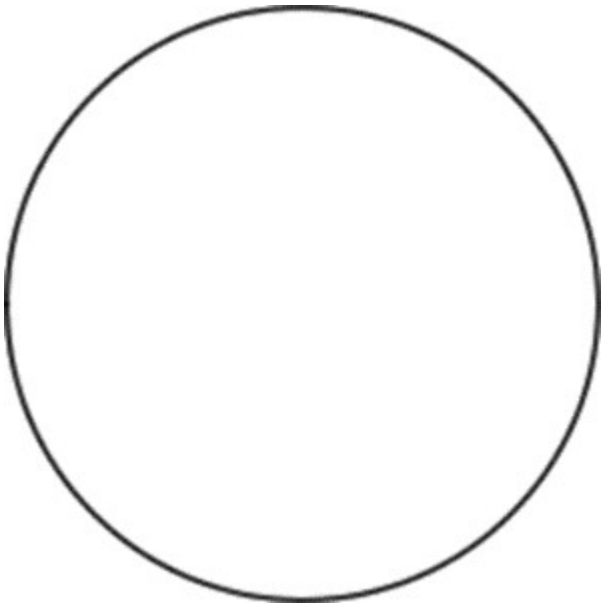
- Compound microscope
- Slide of thick skin (palmar or plantar skin)
- Skin slide (hairy skin, skin with sweatglands, etc)

Procedure

1. Obtain a slide of either "thick" or "thin" skin.
2. Place it on the stage of the microscope and scan the slide at low power.
3. Once the epithelial layer is visible in the field of view, switch to high power.

4. Examine all the layers of the epidermis and study the difference between the layers (Figure 5.3).
5. Sketch the layers as seen in the microscope and make sure to label all structures identified, observed at low and high magnification.





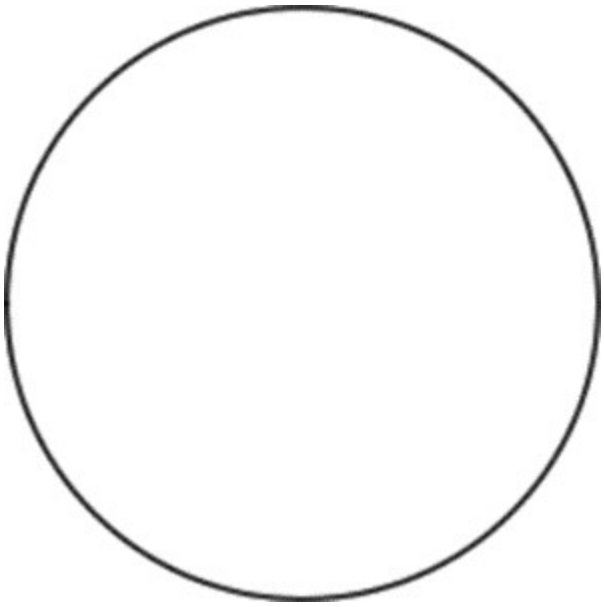
Exercise 3 Skin Pigmentation

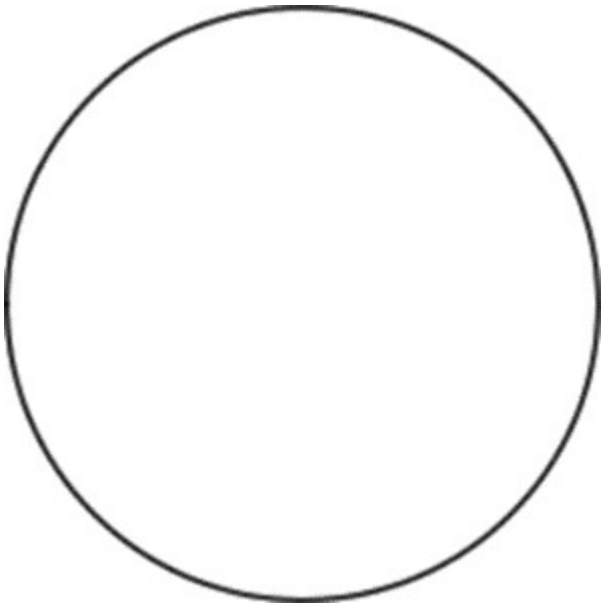
Required Materials

- Compound microscope
- Slide of pigmented skin epithelium

Procedure

1. Obtain a slide of pigmented skin.
2. Place it on the stage of the microscope and scan the slide at low power.
3. Once the layers are visible in the field of view, switch to high power.
4. Examine all the layers of the epidermis and study the pigmented layers (Figure 5.4).
5. Sketch the layers as seen in the microscope and label all relevant structures, observed at low and high magnification.





Exercise 4 Axillaries of Skin – Hair

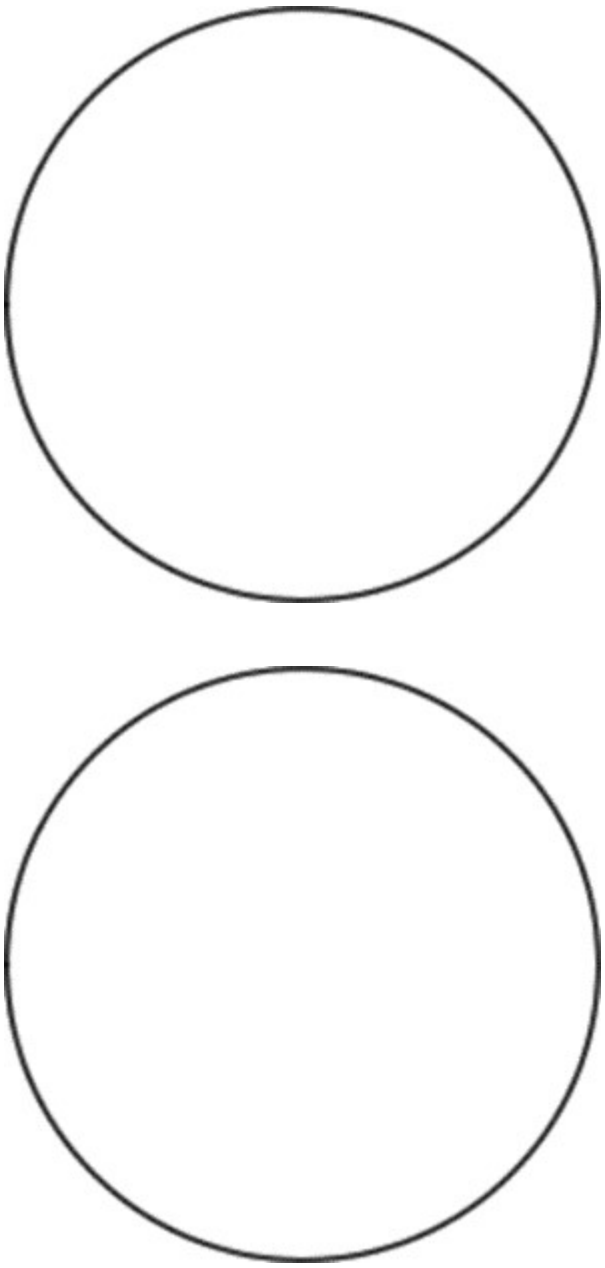
Required Materials

- Compound microscope

- Slide of scalp skin (hairy)

Procedure

1. Obtain a slide of scalp, place it on the stage of the microscope and scan the slide until a hair follicle is visible in the field of view.
2. Observe that there are three distinct regions to a hair: 1) the shaft, the portion of hair that is outside the body surface; 2) the root, the portion within the skin and 3) the bulb, the enlarged base of the hair (Figure 5.5 and 5.6).
3. Note the other accessory structures of skin such as the oil secreting sebaceous glands and the apocrine sweat glands that are connected to the hair root; and arrector pili muscle that is also attached to the hair bulb (Figure 5.5 and 5.6.
4. Sketch the skin as seen in the microscope and label the structures related to hair as well as adjacent parts, observed at low and high magnification.



Exercise 5 Axillaries of Skin – Eccrine Sweat Glands

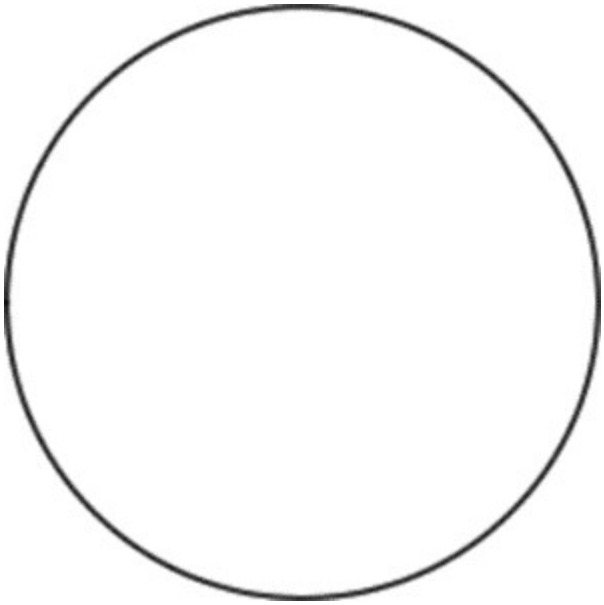
Required Materials

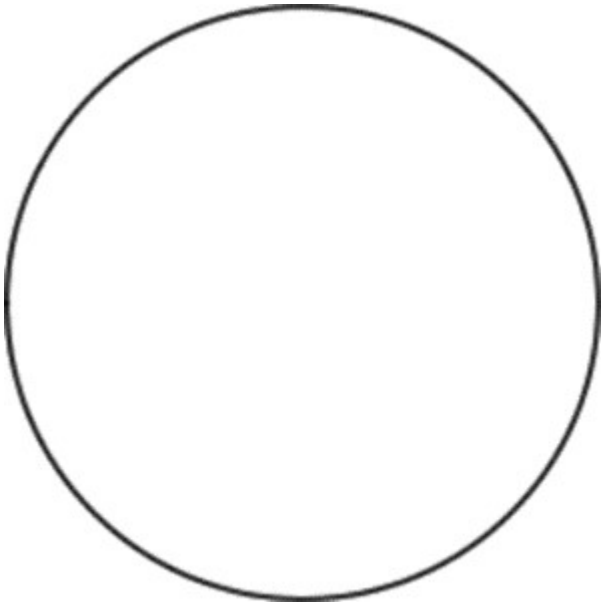
- Compound microscope
- Slide of skin from general body surface showing sweat glands

Procedure

1. Obtain a slide of skin, place it on the stage of the microscope and scan the slide until an eccrine sweat gland is visible in the field of view.
2. Observe that it originates from the dermis and the duct reaches the skin surface and the pore is exposed to the skin surface (Figure 5.7).

3. Sketch the skin area with eccrine sweat glands as seen in the microscope, observed at low and high magnification.





Exercise 6 Axillaries of Skin – Nail

Required Materials

- Compound microscope
- Slide of developing nail

Procedure

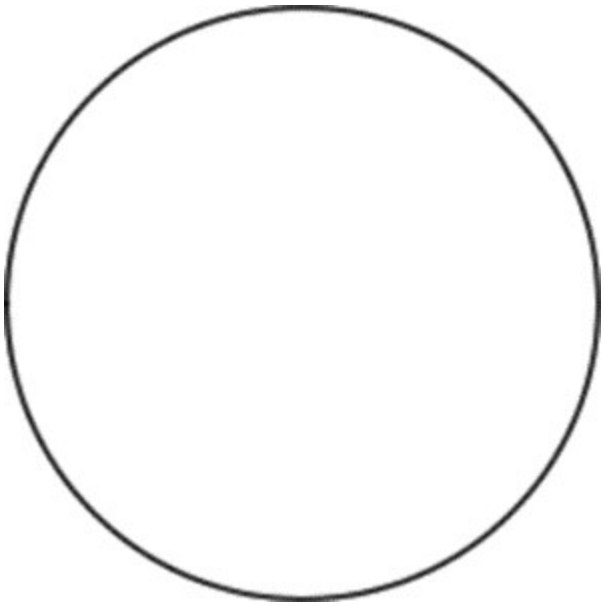
1. Obtain a slide of nail, place it on the stage of the microscope and scan it to view all the parts of the

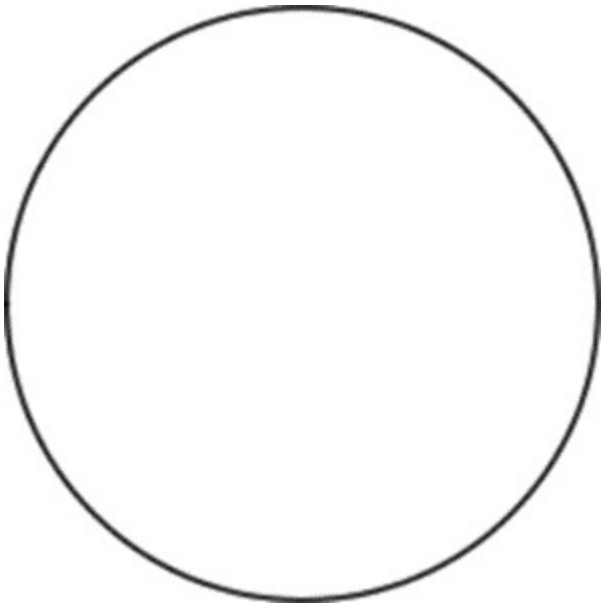
nail mentioned above

2. Identify

    - Nail plate
    - Nail matrix
    - Nail body
    - Nail root
    - Lunula

3. Sketch the nail and its parts as seen in the microscope, observed at low and high magnification.





Post-laboratory Questions

1.The papillary layer of the dermis is most closely associated with which layer of the epidermis?

A. stratum spinosum

B. stratum corneum

C. stratum granulosum

D. stratum basal

2.Eccrine sweat glands _____.

A. are present on hair

B. are present in the skin throughout the body and produce watery sweat
C. produce sebum
D. act as a moisturizer

3.Sebaceous glands _____.
A. are a type of sweat gland
B. are associated with hair follicles
C. may function in response to touch
D. release a watery solution of salt and metabolic waste

4.Similar to the hair, nails grow continuously throughout our lives. Which of the following is furthest from the nail growth center?
A. nail bed
B. hyponychium
C. nail root
D. eponychium

5.An individual using a sharp knife notices a small amount of blood where he just cut himself. Which of the following layers of skin did he have to cut into in order to bleed?
A. stratum corneum
B. stratum basale
C. papillary dermis
D. stratum granulosum

6. As you are walking down the beach, you see a dead, dry, shriveled-up fish. Which layer of your epidermis keeps you from drying out?
A. stratum corneum
B. stratum basale
C. stratum spinosum
D. stratum granulosum

7.An individual has spent too much time sun bathing. Not only is his skin painful to touch, but small blisters have appeared in the affected area. This indicates that he has damaged which layers of his skin?
A. epidermis only
B. hypodermis only
C. epidermis and hypodermis
D. epidermis and dermis

6.

CHAPTER 6 BONE TISSUE AND THE SKELETAL SYSTEM

By Ganesan L. Kamatchi

Motivation.

Healthy bones require good nutrition and lifestyle as well as a genetic component. Some bone diseases such as **osteoporosis** disproportionately affect some populations. Osteoporosis is a condition that reduces bone density by making the bones more porous or spongy. Women are more severely and frequently affected by this condition due to the dependence of bone producing and bone remodeling cells on a good balance of female hormones such as estrogen that decline over time. Alcoholism, smoking, anorexia, being of European heritage, surgical removal of ovaries, and some medications can increase risk of this painful condition called osteoporosis. Bone fractures that result from weakening of bones can be debilitating. A good diet, exercise, stopping alcohol and smoking, and some medications that help bone growth can be used for treatment of osteoporosis; but aging can't be reversed!

Figure 6.1 Elderly woman with osteoporosis showing a curved back from compression fractures of her back bones. (Credit: Wikipedia. James Hailman, MD own work, CC-BY SA license)

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Demonstrate classification of bones based on shape and size
- Label the regions of long bone gross anatomy
- Sketch and describe the microscopic anatomy of compact and spongy bone
- Describe the development of long bones based on microscopic observation

Background.

Your skeleton is a structure of living tissue that grows, repairs, and renews itself. The bones within it are dynamic and complex organs that serve several important functions, including some necessary to maintain homeostasis. Bone, or osseous tissue, is a hard, dense connective tissue that forms most of the adult skeleton, the support structure of the body. In the areas of the skeleton where bones move (for example, the ribcage and joints), cartilage, a semi-rigid form of connective tissue, provides flexibility and smooth surfaces for movement.

The skeletal system is the body system composed of bones and cartilage and performs the following critical functions for the human body:

- Supports the body
- Facilitates movement
- Protects internal organs
- Produces blood cells
- Stores and releases minerals and fat

Classification of Bones

The 206 bones that compose the adult skeleton are divided into five categories based on their shapes (Table 6.1). Their shapes and functions are related such that each categorical shape of bone has a distinct function.

Table 6.1: Classification of Bones Based on their Shape

Class of Bone	Features	Function	Examples
Long	Cylinder-like shape, longer than it is wide	Leverage	Femur, tibia, fibula, metatarsals, humerus, ulna, radius, metacarpals, phalanges
Short	Cube-like shape, approximately equal in length, width, and thickness	Provide stability, support, while allowing for some motion	Carpals, tarsals
Flat	Thin and curved	Points of attachment for muscles; protectors of internal organs	Sternum, ribs, scapulae, cranial bones
Irregular	Complex shape	Protect internal organs	Vertebrae, facial bones
Sesamoid	Small and round; embedded in tendons	Protect tendons from compressive forces	Patellae

Gross Anatomy of Bone

The structure of a long bone allows for the understanding of the gross anatomy of bone. A long bone has two parts, the long tubular shaft called diaphysis and the two wider ends, the epiphysis (Figure 6.2). The hollow region in the diaphysis is called the medullary cavity, which is filled with yellow marrow. The walls of the diaphysis are composed of dense and hard compact bone.

The epiphysis is filled with spongy bone and the space in the spongy bone is filled with red marrow. Each epiphysis meets the diaphysis at the metaphysis, the narrow area that contains the epiphyseal plate (growth plate).

The medullary cavity has a delicate membranous lining called the endosteum, where bone growth, repair, and remodeling occur. The outer surface of the bone is covered with a fibrous membrane called the periosteum which contains blood vessels, nerves, and lymphatic vessels. Tendons and ligaments also attach to bones at the periosteum. The periosteum covers the entire outer surface except where the epiphyses meet other bones to form joints.

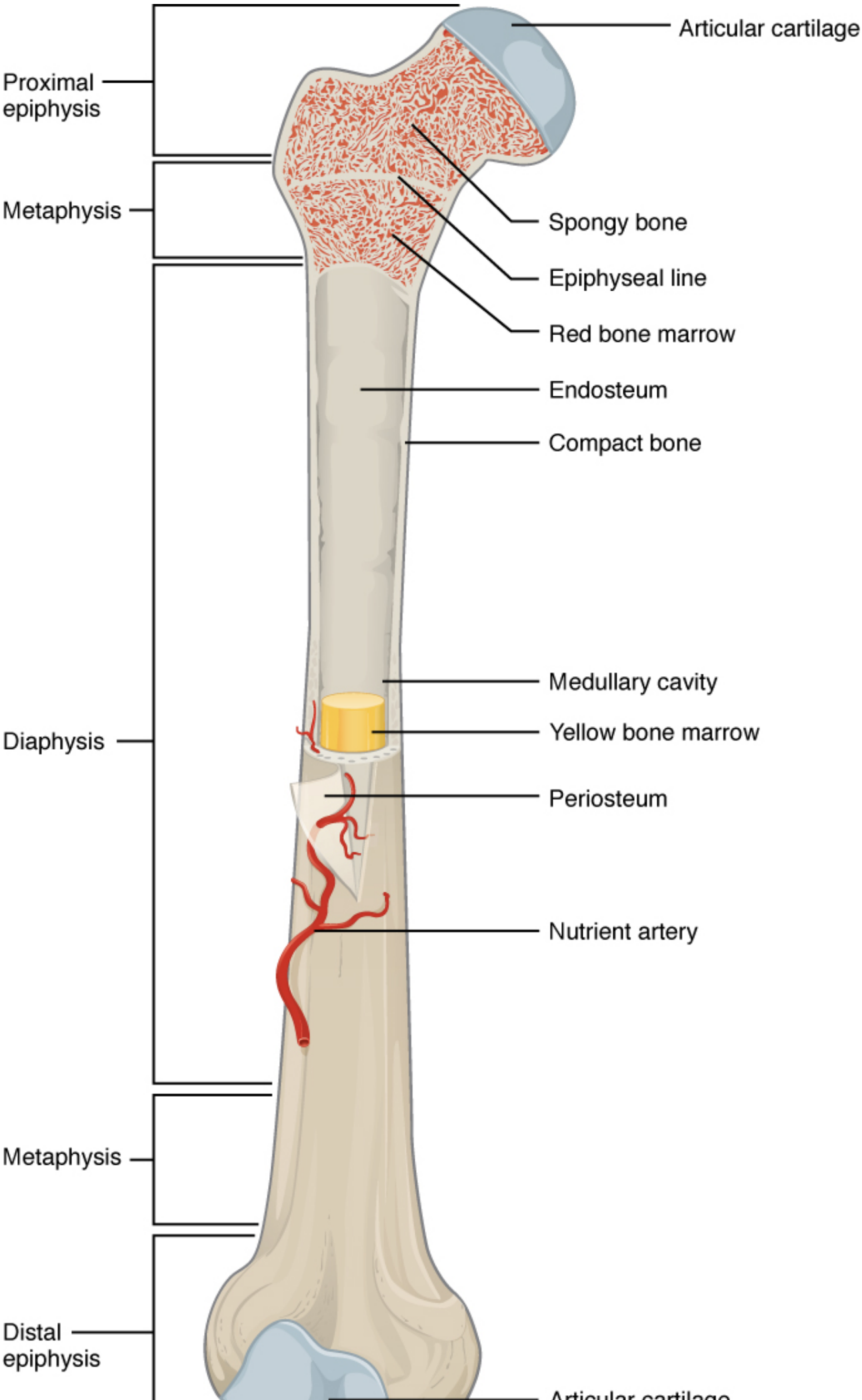

Articular cartilage
Proximal epiphysis
Metaphysis
Spongy bone
Epiphyseal line
Red bone marrow
Endosteum
Compact bone
Medullary cavity
Diaphysis
Yellow bone marrow
Periosteum
Nutrient artery
Metaphysis
Distal epiphysis
Articular cartilage

Figure 6.2 Anatomy of a Long Bone A typical long bone shows the gross anatomical characteristics of bone.

Compact Bone

Compact bone is the denser, stronger of the two types of bone tissue. The microscopic structural unit of compact bone is called an **osteon**, or Haversian system. Each osteon is composed of concentric rings of calcified matrix called lamellae. Running down the center of each osteon is the central canal, or Haversian canal, which contains blood vessels, nerves, and lymphatic vessels. These vessels and nerves branch off at right angles through a perforating canal, also known as Volkmann's canals, to extend to the periosteum and endosteum.

The osteocytes are located inside spaces called lacunae, found at the borders of adjacent lamellae. Canaliculi connect with the canaliculi of other lacunae and eventually with the central canal (Fig. 6.4). This system allows nutrients to be transported to the osteocytes and wastes to be removed from them.

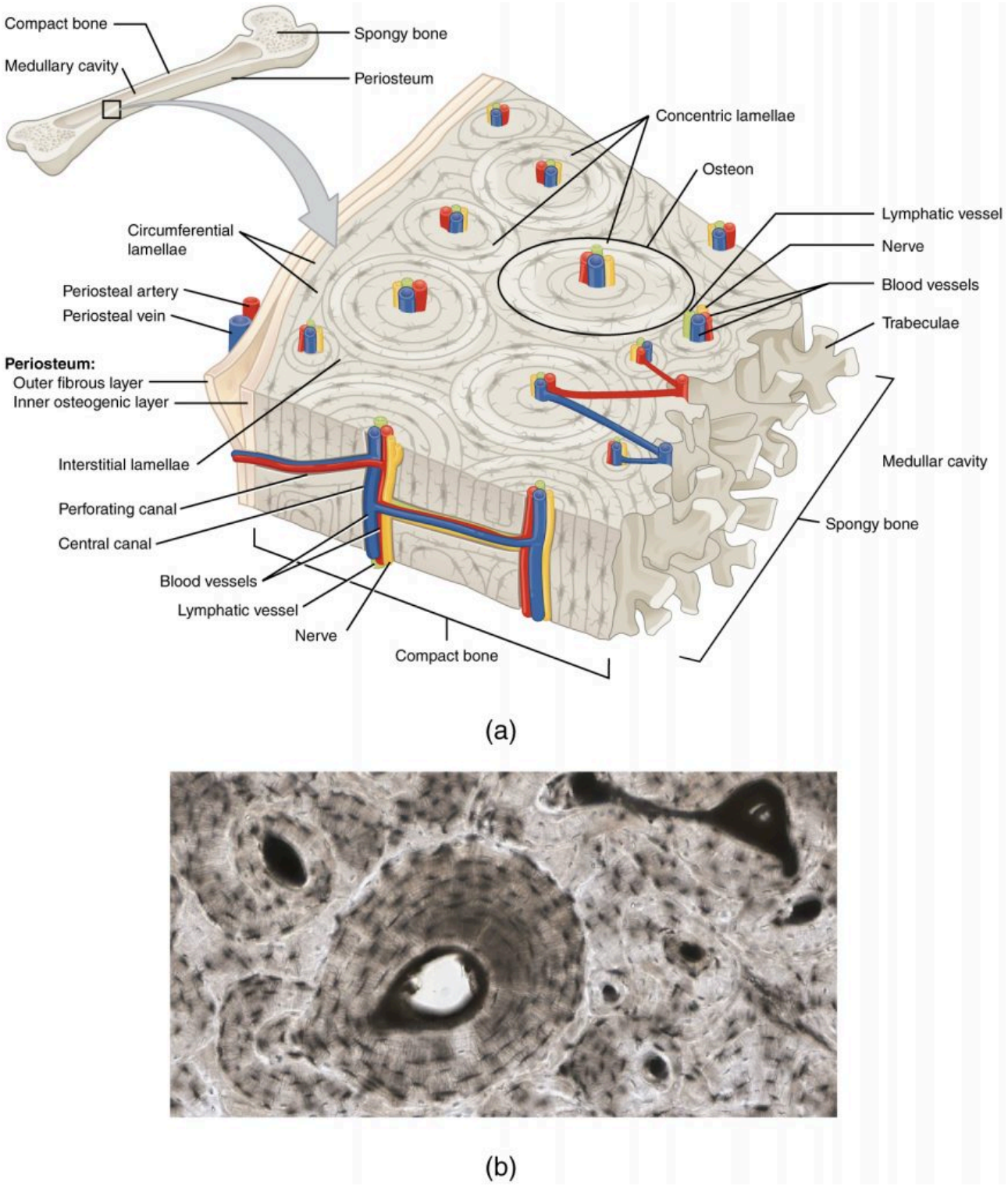


Figure 6.3 Diagram of Compact Bone. (a) This cross-sectional view of compact bone shows the basic structural unit, the osteon. (b) In this micrograph of the osteon, you can clearly see the concentric lamellae and central canals. LM × 40. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Spongy Bone

Spongy bone, also known as cancellous bone, contains osteocytes housed in lacunae, but they are not

arranged in concentric circles. Instead, the lacunae and osteocytes are found in a lattice-like network of matrix spikes called trabeculae (Figure 6.4). The trabeculae may appear to be a random network, but each trabecula forms along lines of stress to provide strength to the bone. The spaces of the trabeculated network provide balance to the dense and heavy compact bone by making bones lighter so that muscles can move them more easily. In addition, the spaces in some spongy bones contain red marrow, protected by the trabeculae, where hematopoiesis occurs.

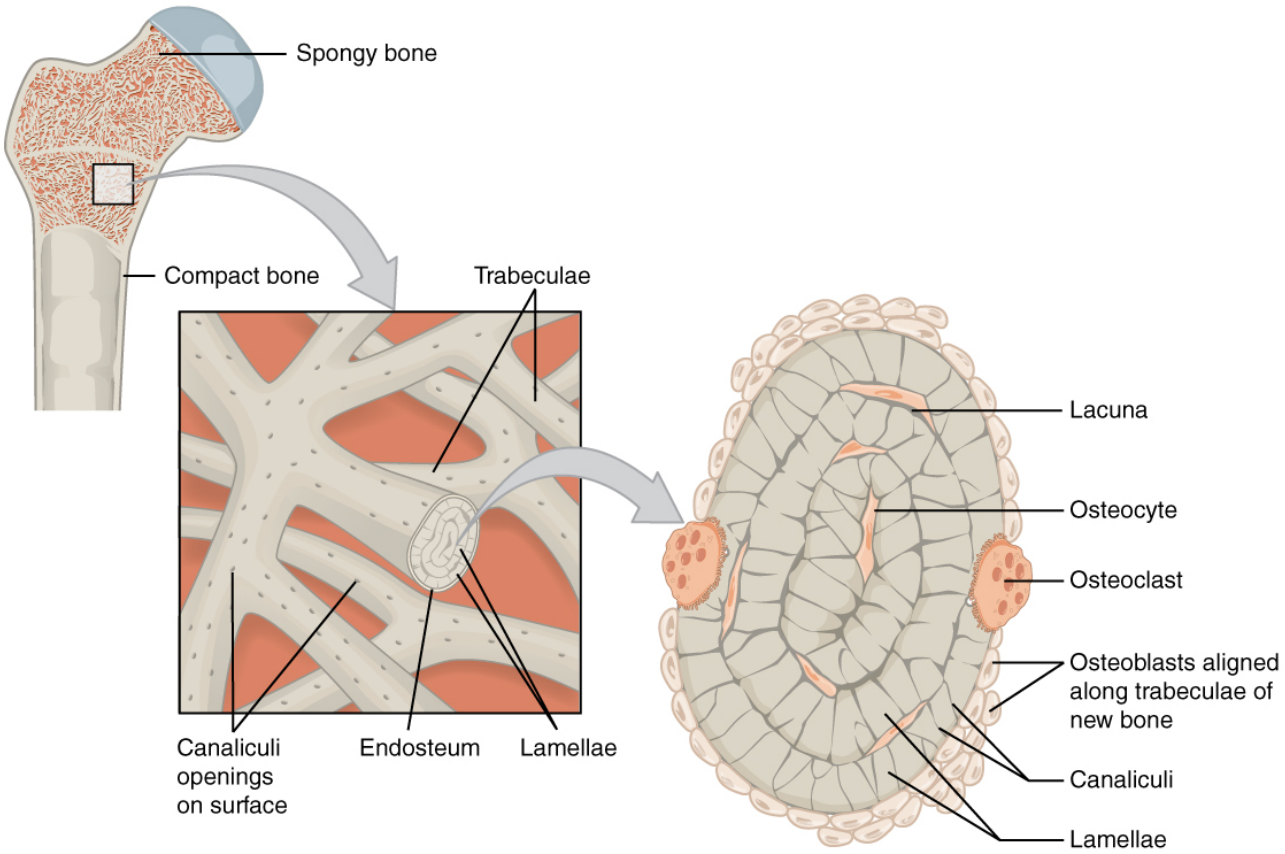


Figure 6.4 Diagram of Spongy Bone Spongy bone is composed of trabeculae that contain the osteocytes. Red marrow fills the spaces in some bones.

Bone Development

Long bones develop using endochondral ossification and flat bones develop using intramembranous ossification. Here we will focus on endochondral bone development

In endochondral ossification, bone develops by replacing hyaline cartilage. Cartilage serves as a template to be completely replaced by new bone. Endochondral ossification takes much longer than intramembranous ossification. Bones at the base of the skull and long bones form via endochondral ossification.

The epiphyseal plate is the area of growth in a long bone. It is a layer of hyaline cartilage where ossification occurs in immature bones. On the epiphyseal side of the epiphyseal plate, cartilage is formed. On the diaphyseal side, cartilage is ossified, and the diaphysis grows in length. The epiphyseal plate is composed of four zones of cells and activity (Figure 6.5). The reserve zone is the region closest to the epiphyseal end of the plate and contains small chondrocytes within the matrix.

The proliferative zone is the next layer toward the diaphysis and contains stacks of slightly larger chondrocytes. It makes new chondrocytes (via mitosis) to replace those that die at the diaphyseal end of the plate. Chondrocytes in the next layer, the zone of maturation and hypertrophy, are older and larger than those in the proliferative zone. The longitudinal growth of bone is a result of cellular division in the proliferative zone and the maturation of cells in the zone of maturation and hypertrophy.

Most of the chondrocytes in the zone of calcified matrix, the zone closest to the diaphysis, are dead because the matrix around them has calcified. Capillaries and osteoblasts from the diaphysis penetrate this zone, and the osteoblasts secrete bone tissue on the remaining calcified cartilage. Thus, the zone of calcified matrix connects the epiphyseal plate to the diaphysis. A bone grows in length when osseous tissue is added to the diaphysis.

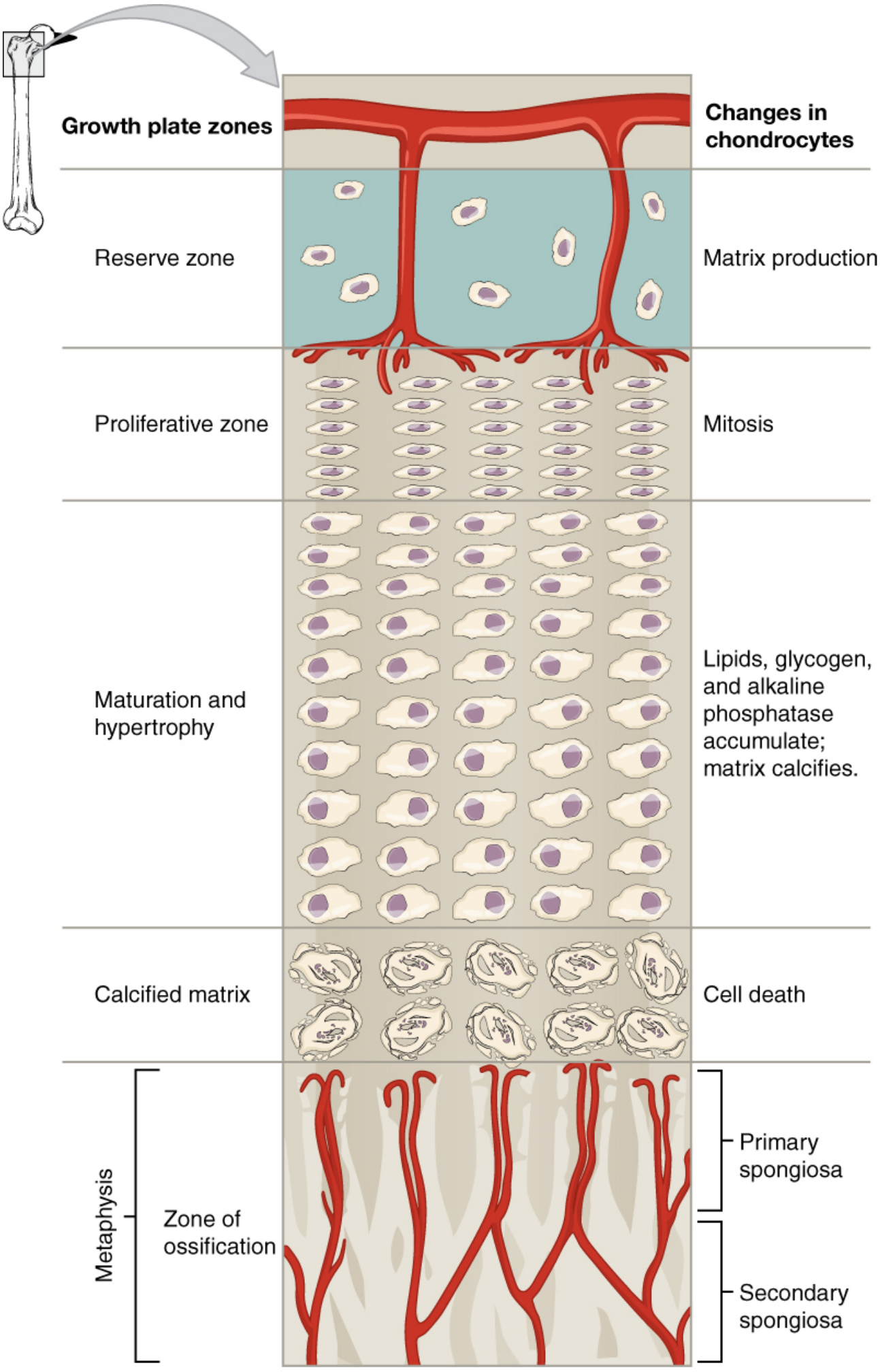

Growth plate zones
Changes in chondrocytes
Reserve zone
Matrix production
Proliferative zone
Mitosis
Maturation and hypertrophy
Lipids, glycogen, and alkaline phosphatase accumulate; matrix calcifies.
Calcified matrix
Cell death
Metaphysis
Zone of ossification
Primary spongiosa
Secondary spongiosa

Figure 6.5 Longitudinal Bone Growth The epiphyseal plate is responsible for longitudinal bone growth.

Pre-Laboratory Questions

After you review the background information, please answer the following questions.

1. What is the type of tissue, the bones made of?
2. What are the types of bone cells and where do they come from?
3. Describe the organization of osteon?
4. Describe the parts of a bone?
5. What are the functions of bone?

Exercises

- Exercise 1. Identification of Classes of Bones Based on Shape
- Exercise 2. Gross Anatomy of Bone
- Exercise 3. Compact Bone
- Exercise 4. Spongy Bone
- Exercise 5. Endochondral Bone Development

Exercise 1 Identification of Classes of Bones Based on Shape

Required Materials

- Disarticulated human skeleton

Procedure

1. Obtain the bones named in the table below and examine them for their shape properties.
2. Using **Table 6.1** above as a guide, identify the type of bone as long, short, flat, irregular, or sesamoid.

Femur	
Scapula	
Carpal	
Vertebra	
Patella	

Exercise 2 Gross Anatomy of Bone

Required Materials

- Femur from disarticulated skeleton
- Femur model showing section

Procedure

1. Obtain an intact femur or a femur that is cut along its longitudinal axis
2. Identify, sketch the bone and label the following structures.
    - Compact bone
    - Diaphysis
    - Epiphyseal line
    - Epiphysis
    - Metaphysis
    - Medullary cavity
    - Spongy bone

Exercise 3 Compact Bone

Required Materials

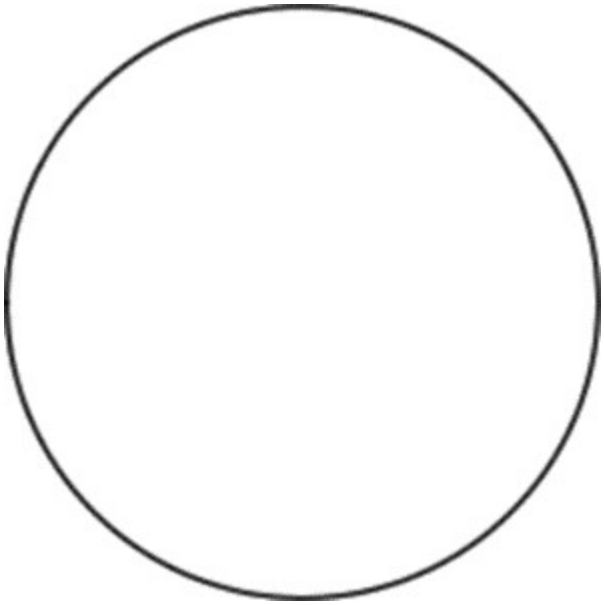
- Compound microscope
- Slide of compact bone

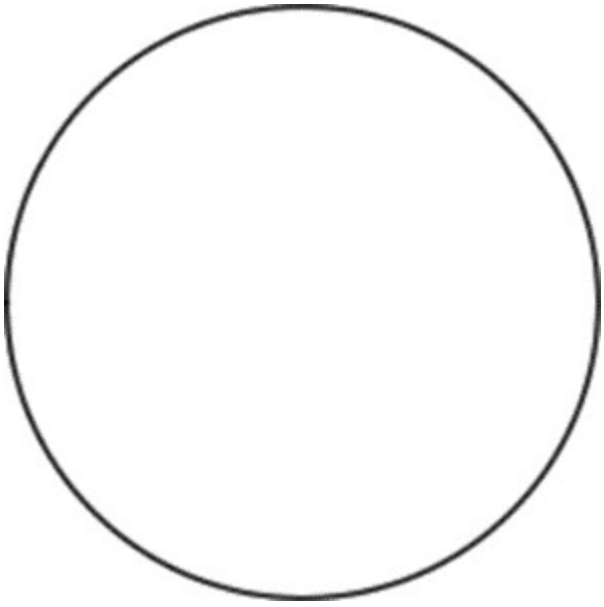
Procedure

1. Obtain a slide of compact bone.
2. Place it on the stage of the microscope and scan the slide at low power for an osteon.
3. Switch to high power magnification.
4. Identify

- Central canal
- Lacunae
- Concentric lamellae
- Canaliculi

5. Sketch the compact bone as seen in the microscope at low and high magnification in the space provided below.





Exercise 4 Spongy Bone

Required Materials

- Compound microscope

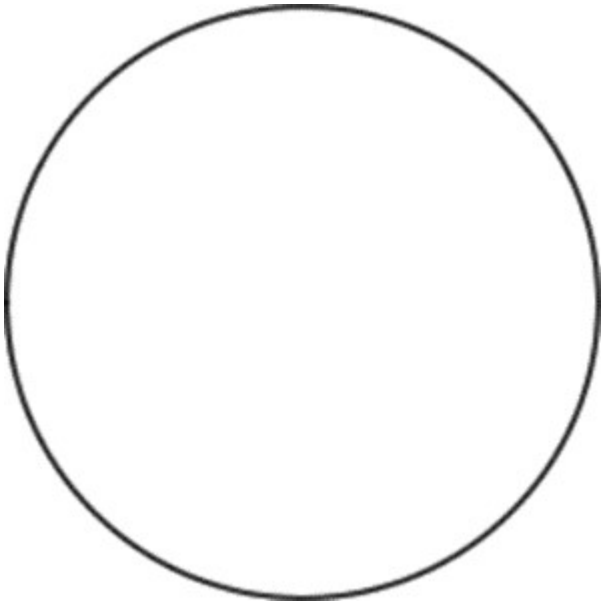
- Slide of spongy bone

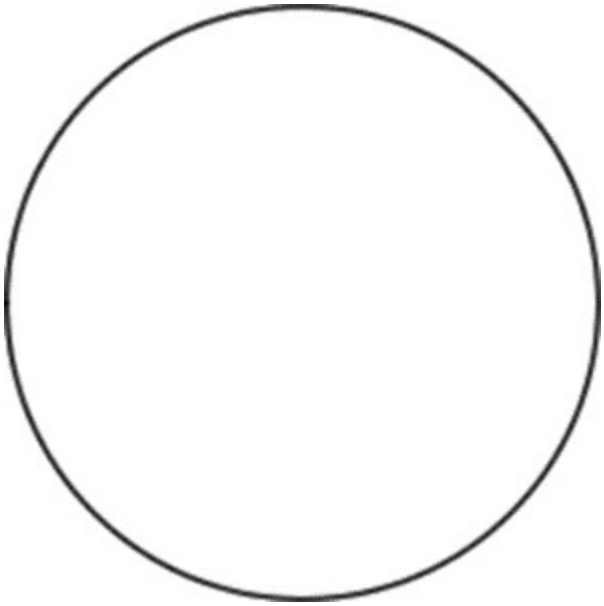
Procedure

1. Obtain a slide of spongy bone.
2. Place it on the stage of the microscope and scan for trabecula at low power.
3. Switch to high power and look for the edge of trabecula where several small cells, osteoblasts, are lined up next to each other.
4. Identify

    - Bone marrow cavity
    - Lacuna
    - Osteoblast
    - Osteoclast
    - Osteocyte
    - Trabecula

5. Sketch and label these structures as seen in the microscope at low and high magnification in the space provided.





Exercise 5 Endochondral Bone Development

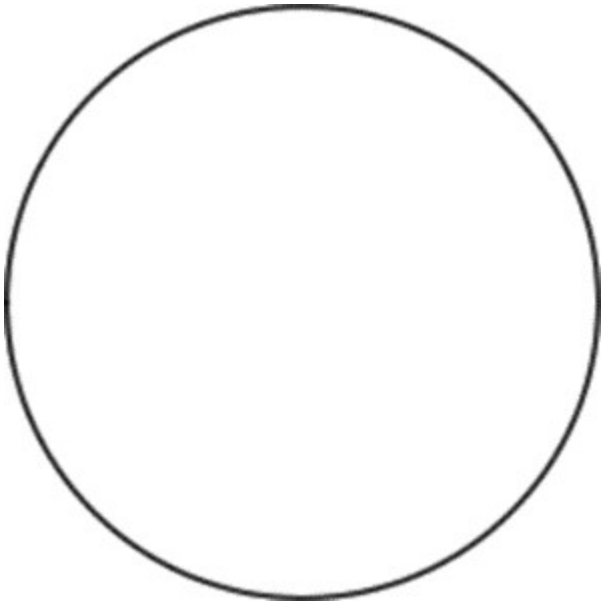
Required Materials

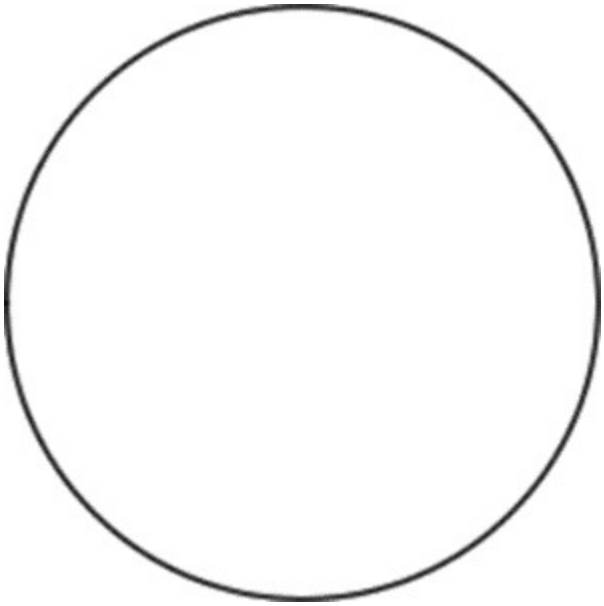
- Compound microscope
- Slide of cartilage bone ossification (developing long bone)

Procedure

1. Obtain a slide of developing long bone.

2. Place it on the stage of the microscope and scan at low power for epiphysis, diaphysis and metaphysis (epiphyseal plate is located here in the developing long bone).
3. Identify the five growth zones within the epiphyseal plate.
4. Sketch the regions and zones as seen in the microscope at low and high magnification in the space provided.





Post-laboratory Questions

1. Compare and contrast the size and shape of a femur with a carpal bone? How would you classify each and why?
2. Attempt to order the following regions of a femur from hip towards knee: Diaphysis, Epiphysis, Metaphysis, Compact Bone, Medullary Cavity, Spongy Bone. Which of these regions can you order

hip to knee? Which regions are arranged differently? Explain.

3. Compare and contrast the microscopic structure of the compact bone and spongy bone based on your observations above.
4. When you viewed the elongating epiphyseal plate of a long bone you identified a region of mitosis and a separate region of cell death. How do these biological processes each help with bone production and elongation? Explain.

7.

CHAPTER 7 AXIAL SKELETON

By Ganesan L. Kamatchi

Motivation.

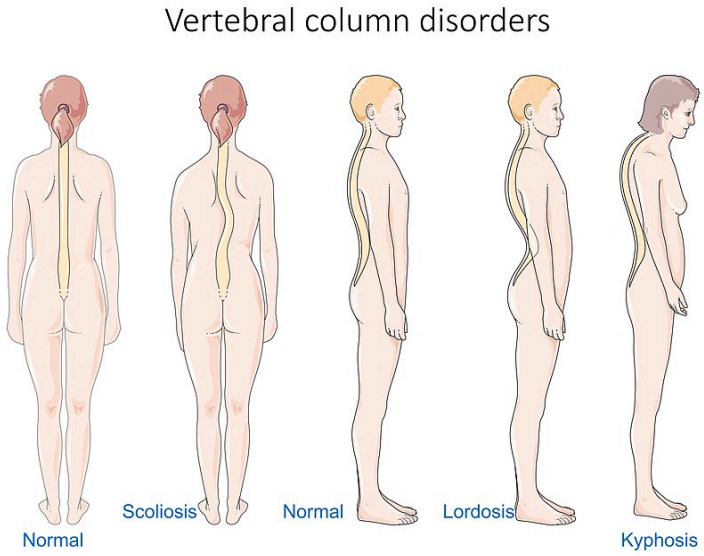


Figure 7.1 Vertebral column disorders (Credit: Wikipedia, contributed by Laboratories Servier, license CC-BY-SA)

Spinal disease refers to a condition impairing the backbone. There are many recognized spinal diseases, some more common than others. Spinal disease also includes cervical spine diseases, which are diseases in the vertebrae of the neck. A lot of flexibility exists within the cervical spine and because of that, it is common for an individual to damage that area, especially over a long period of time. Some of the common cervical spine diseases include degenerative disc disease, cervical stenosis, and cervical disc herniation. Degenerative disc disease occurs over time when the discs within each vertebra in the neck begin to fall apart and begin to disintegrate. Because each vertebra can cause pain in different areas of the body, the pain from the disease can be sensed in the back, leg, neck area, or even the arms.

When the spinal canal begins to lose its gap and gets thinner, it can cause pain in the neck, which can also cause a numb feeling in the arms and hands. Those are symptoms of cervical stenosis disease. The discs between each vertebra have fibers that can begin to deteriorate, and this can occur in cervical disc herniation. This disease is less common in younger people as it is usually a function of aging.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Identify and label the main bones and structures of the skull from multiple views
- Label and describe the five regions of the vertebral column and vertebrae within
- Identify and describe the attachments and organization of the ribs in the thoracic cage region

Background.

The skeletal system includes all of the bones, cartilages, and ligaments of the body that support and give shape to the body and body structures. The skeleton consists of the bones of the body. For adults, there are 206 bones in the skeleton. Younger individuals have higher numbers of bones because some bones fuse together during childhood and adolescence to form an adult bone. The primary functions of the skeleton are to provide a rigid, internal structure that can support the weight of the body against the force of gravity, and to provide a structure upon which muscles can act to produce movements of the body. The lower portion of the skeleton is specialized for stability during walking or running. In contrast, the upper skeleton has greater mobility and ranges of motion, features that allow you to lift and carry objects or turn your head and trunk.

In addition to providing for support and movements of the body, the skeleton has protective and storage functions. It protects the internal organs, including the brain, spinal cord, heart, lungs, and pelvic organs. The bones of the skeleton serve as the primary storage site for important minerals such as calcium and phosphate. The bone marrow found within bones stores fat and houses the blood-cell producing tissue of the body.

The skeleton is subdivided into two major divisions—the axial and appendicular.

The axial skeleton forms the vertical, central axis of the body and includes all bones of the head, neck, chest, and back (Figure 7.2). It serves to protect the brain, spinal cord, heart, and lungs. It also serves as the attachment site for muscles that move the head, neck, and back, and for muscles that act across the shoulder and hip joints to move their corresponding limbs.

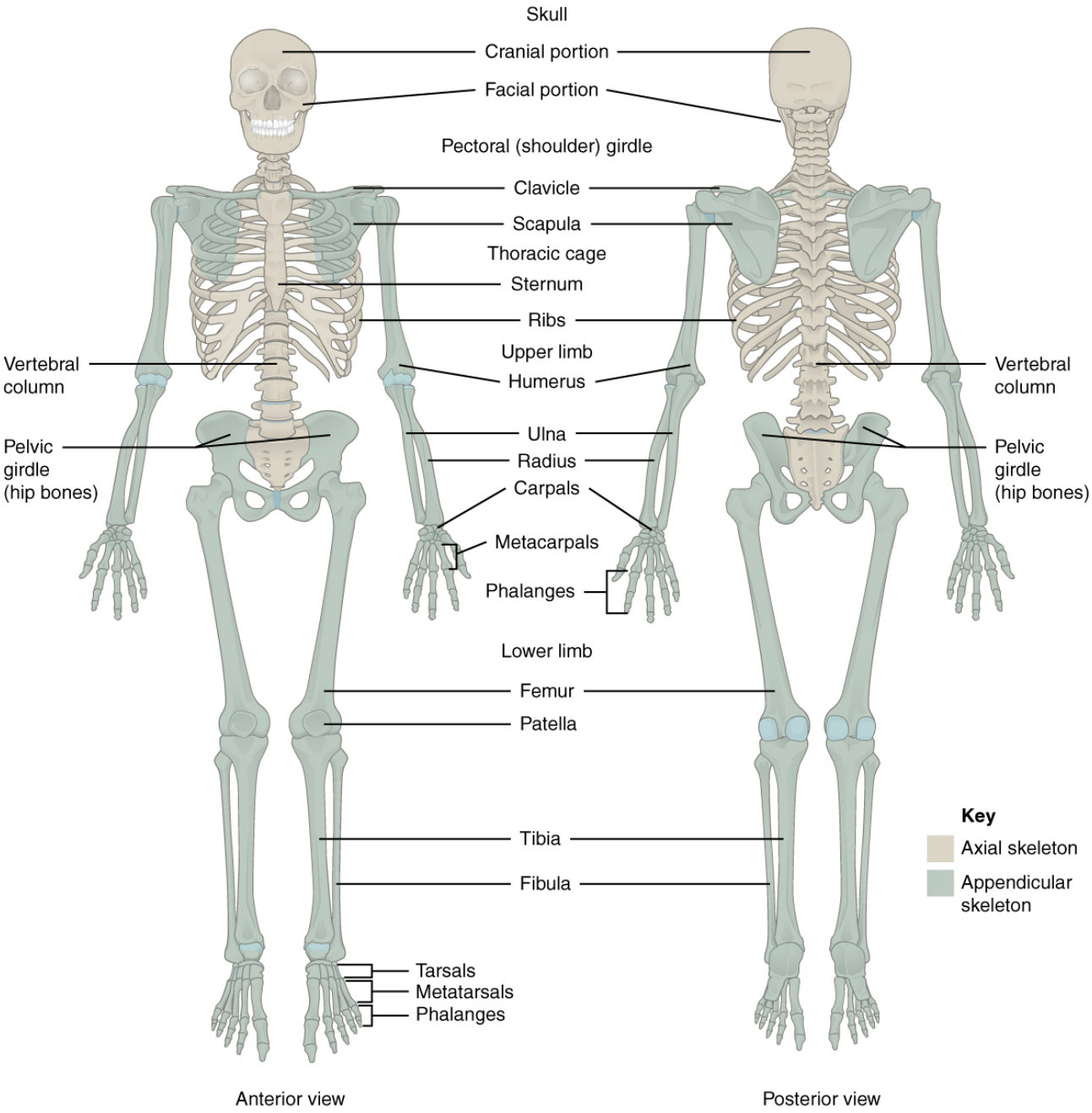


Figure 7.2 The human skeleton. Anterior and posterior views are shown as labeled. Appendicular (blue) and axial (gray).

The axial skeleton of the adult consists of 80 bones, including the skull, the vertebral column, and the thoracic cage. The skull is formed by 22 bones. Also associated with the head are an additional seven bones, including the hyoid bone and the ear ossicles (three small bones found in each middle ear). The

vertebral column consists of 24 bones, each called a vertebra, plus the sacrum and coccyx. The thoracic cage includes the 12 pairs of ribs, and the sternum, the flattened bone of the anterior chest.

Anterior View of the Skull

The anterior skull consists of the facial bones and provides the bony support for the eyes and structures of the face. This view of the skull is dominated by the openings of the orbits and the nasal cavity. Also seen are the upper and lower jaws, with their respective teeth (Figure 7.3).

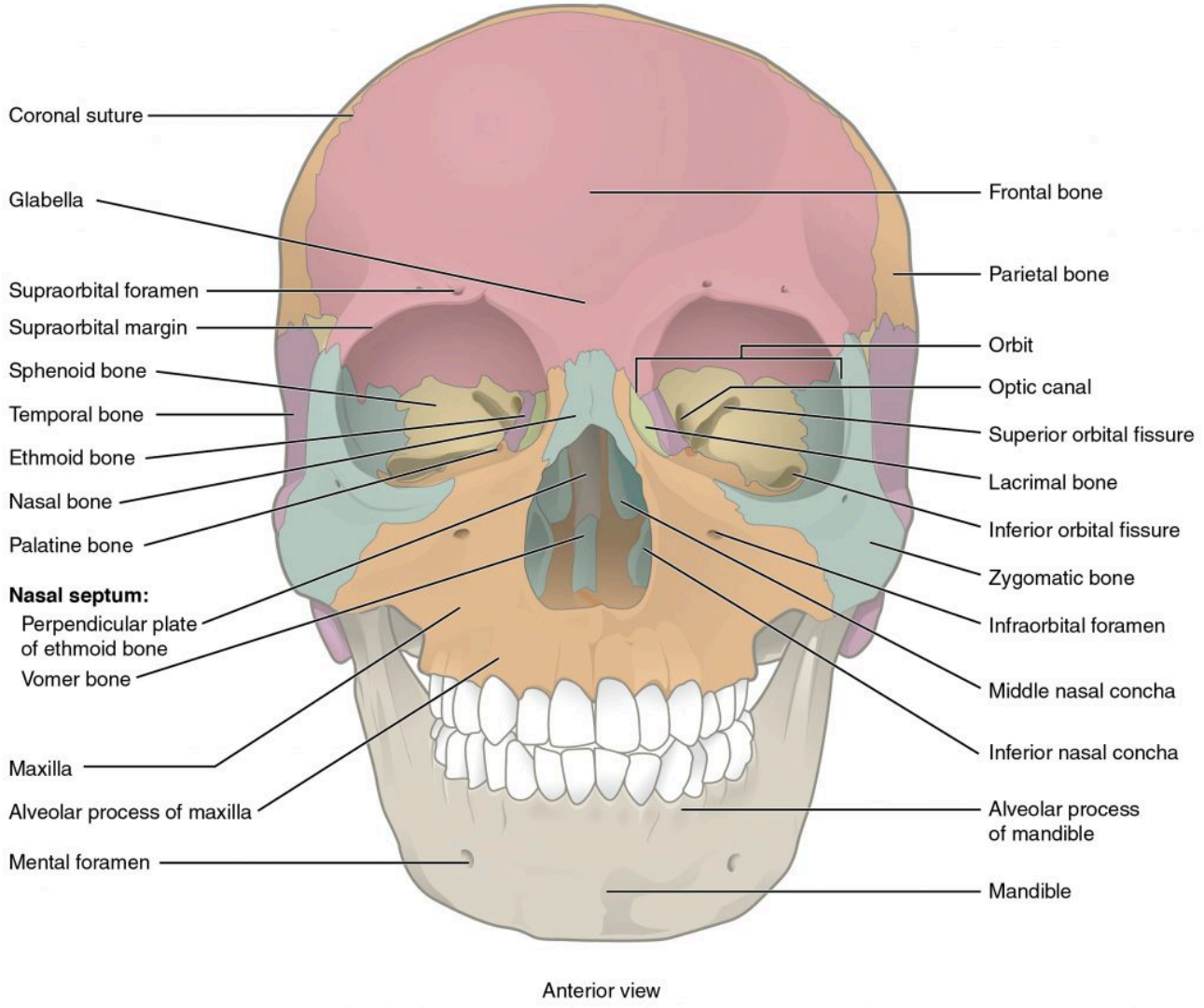


Figure 7.3 Anterior View of the Skull

The orbit is the bony socket that houses the eyeball and muscles that move the eyeball or open the upper eyelid. Inside the nasal area of the skull, the nasal cavity is divided into halves by the nasal septum. Each side of the nasal cavity is triangular in shape, with a broad inferior space that narrows superiorly. When looking into the nasal cavity from the front of the skull, three bony plates are seen projecting from each lateral wall, called superior, middle and inferior nasal conchae respectively.

Lateral View of the Skull

A view of the lateral skull is dominated by the large, rounded brain case above and the upper and lower jaws with their teeth below (Figure 7.4). Separating these areas is the bridge of bone called the zygomatic arch. One of the major muscles that pulls the mandible upward during biting and chewing arises from the zygomatic arch. On the lateral side of the brain case, above the level of the zygomatic arch, is a shallow space called the temporal fossa. Below the level of the zygomatic arch and deep to the vertical portion of the mandible is another space called the infratemporal fossa. Both the temporal fossa and infratemporal fossa contain muscles that act on the mandible during chewing.

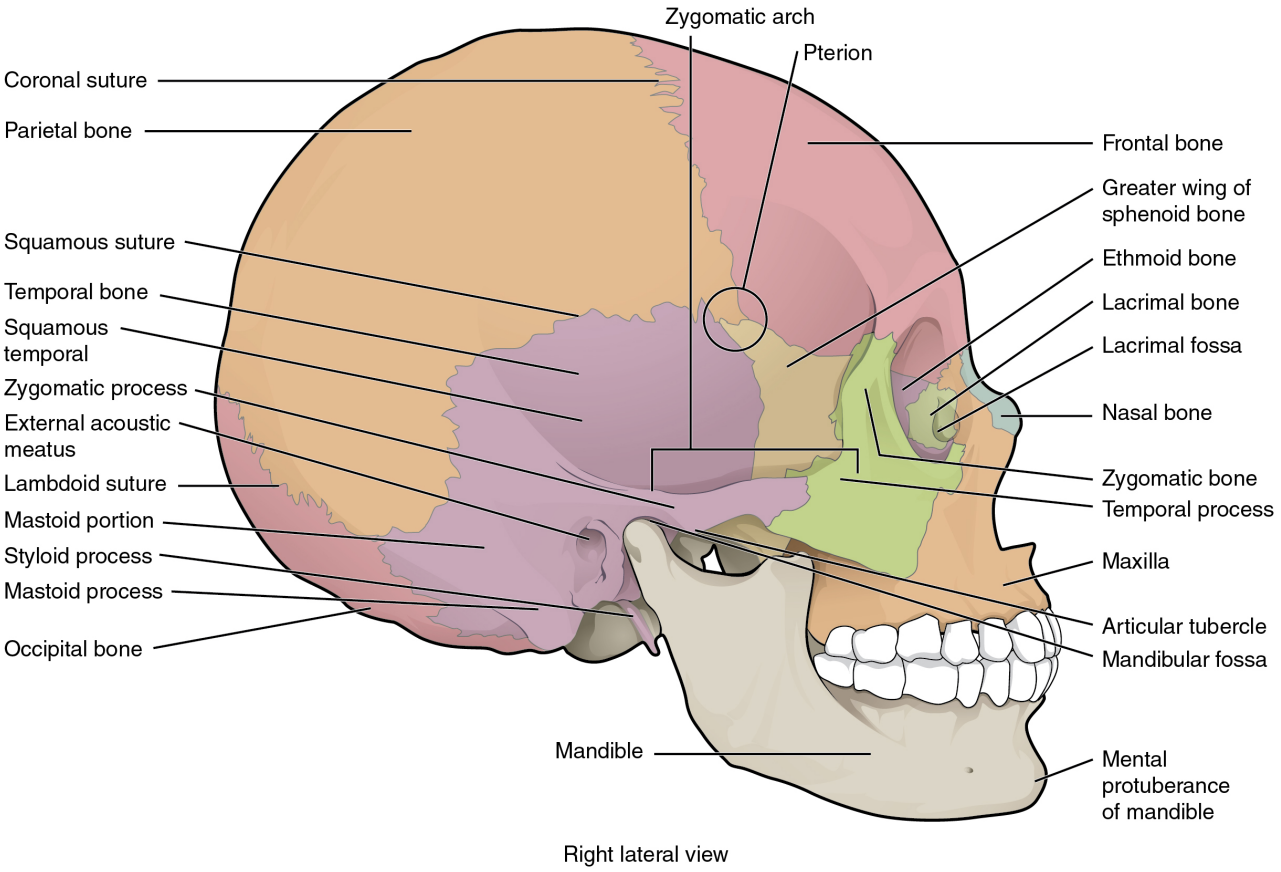


Figure 7.4 Lateral View of the Skull The lateral skull shows the large, rounded brain case, zygomatic arch, and the upper and lower jaws. The zygomatic arch is formed jointly by the zygomatic process of the temporal bone and the temporal process of the zygomatic bone. The shallow space above the zygomatic arch is the temporal fossa. The space inferior to the zygomatic arch and deep to the posterior middle is the infratemporal fossa.

Posterior View of Skull

Parietal, temporal and occipital bones form the posterior side of the skull. The occipital bone is the single bone that forms the posterior skull and posterior base of the cranial cavity (Figure 7.5). On its outside surface, at the posterior midline, is a small protrusion called the external occipital protuberance, which serves as an attachment site for a ligament of the posterior neck. Lateral to either side of this bump is a superior nuchal line (nuchal = "nape" or "posterior neck"). The nuchal lines represent the most superior point at which muscles of the neck attach to the skull, with only the scalp covering the skull above these

lines. On the base of the skull, the occipital bone contains the large opening of the foramen magnum, which allows for passage of the spinal cord as it exits the skull. On either side of the foramen magnum is an oval-shaped occipital condyle. These condyles form joints with the first cervical vertebra and thus support the skull on top of the vertebral column.

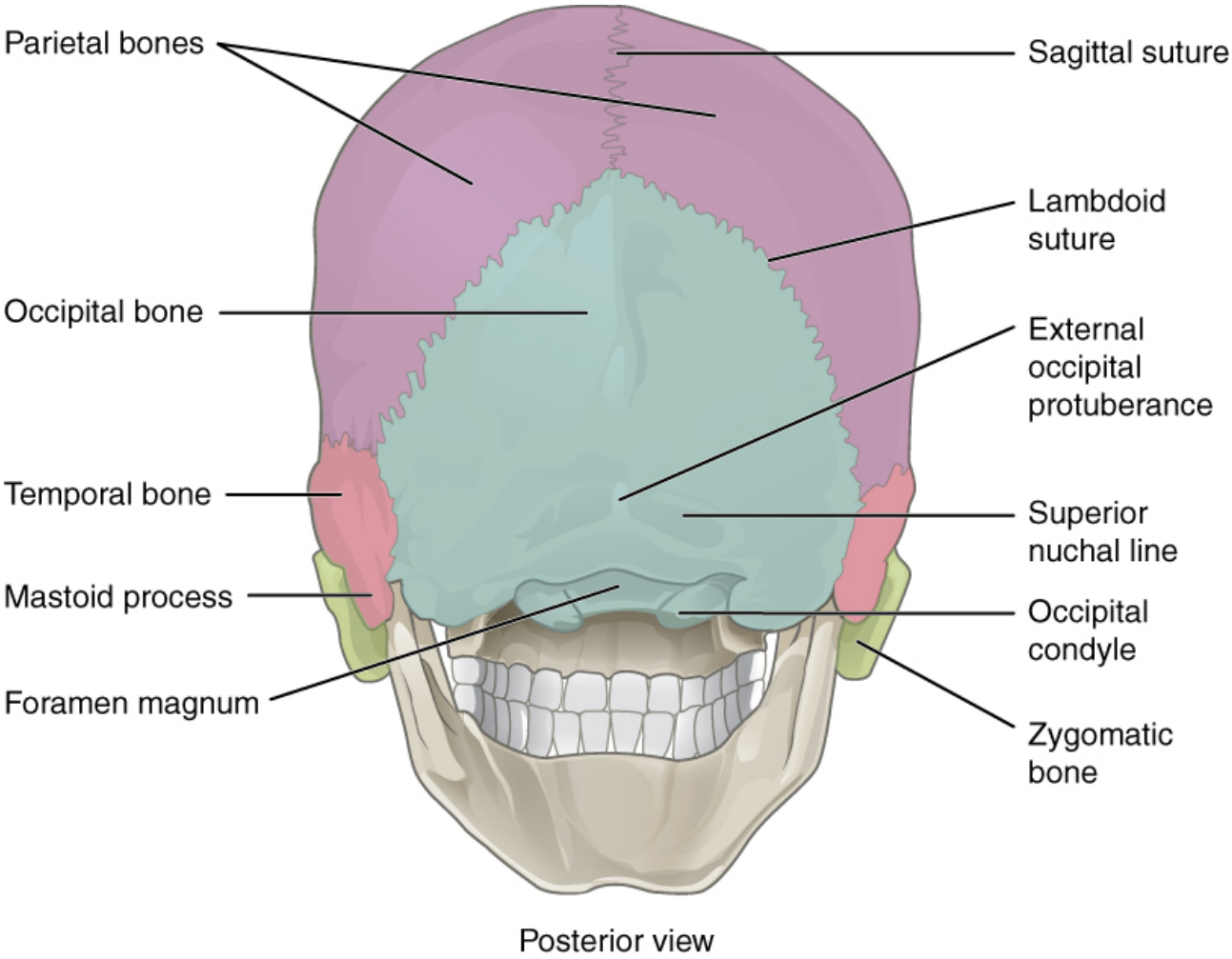


Figure 7.5 Posterior View of the Skull. The two parietal bones, two temporal bones and the single occipital bone form the posterior side of the skull. Occipital bone has the opening for the spinal cord, the foramen magnum.

Superior View of Cranial Floor

The base of skull, also known as the cranial base or the cranial floor, is the most inferior area of the skull. It is composed of the endocranium and the lower parts of the skull roof. There are three depressions called cranial fossa is formed by the floor of the cranial cavity. They are anterior cranial fossa, housing the projecting frontal lobes of the brain; middle cranial fossa, separated from the posterior fossa by the clivus and the petrous crest and the posterior cranial fossa, between the foramen magnum and tentorium cerebelli, containing the brainstem and cerebellum (Figure 7.6).

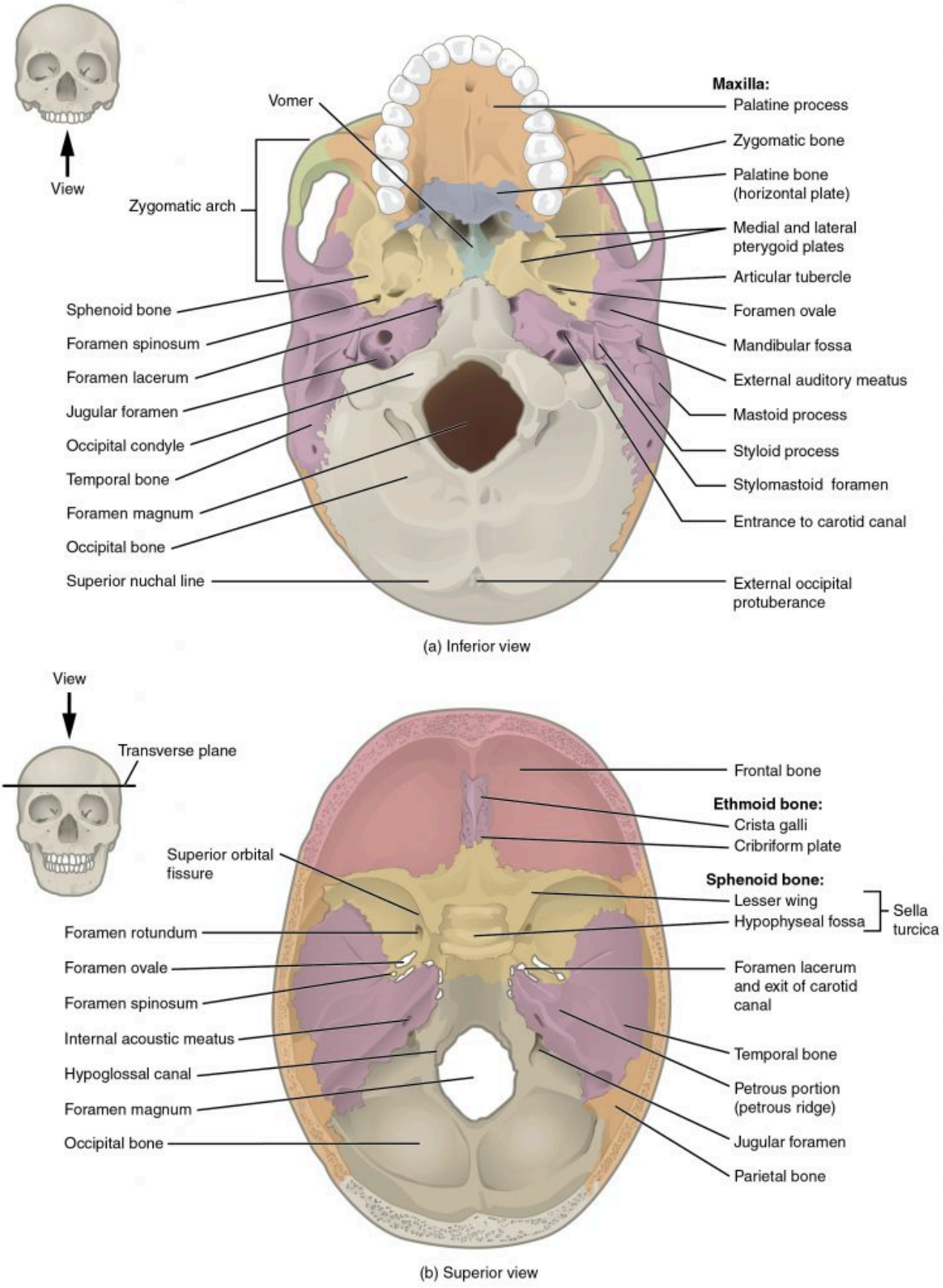


Figure 7.6 Inferior and Superior Views of the Skull. The inside/superior floor of the cranial cavity is formed by the frontal, ethmoid, sphenoid, temporal, and occipital bones. The lesser wing of the sphenoid bone separates the anterior and middle cranial fossae. The petrous ridge (petrous portion of temporal bone) separates the middle and posterior cranial fossae.

Vertebral Column

The adult vertebral column consists of 24 vertebrae, plus the sacrum (5 vertebrae) and coccyx (4 vertebrae). The vertebrae are divided into five regions: cervical C1–C7 vertebrae, thoracic T1–T12 vertebrae, lumbar L1–L5 vertebrae, sacral S1-S5 vertebrae (fused) and coccygeal Co1-Co4 vertebrae (fused). The vertebral column is curved, with two primary curvatures (thoracic and sacrococcygeal curves) and two secondary curvatures (cervical and lumbar curves). (Figure 7.7). A typical vertebra is shown in Figure 7.8.

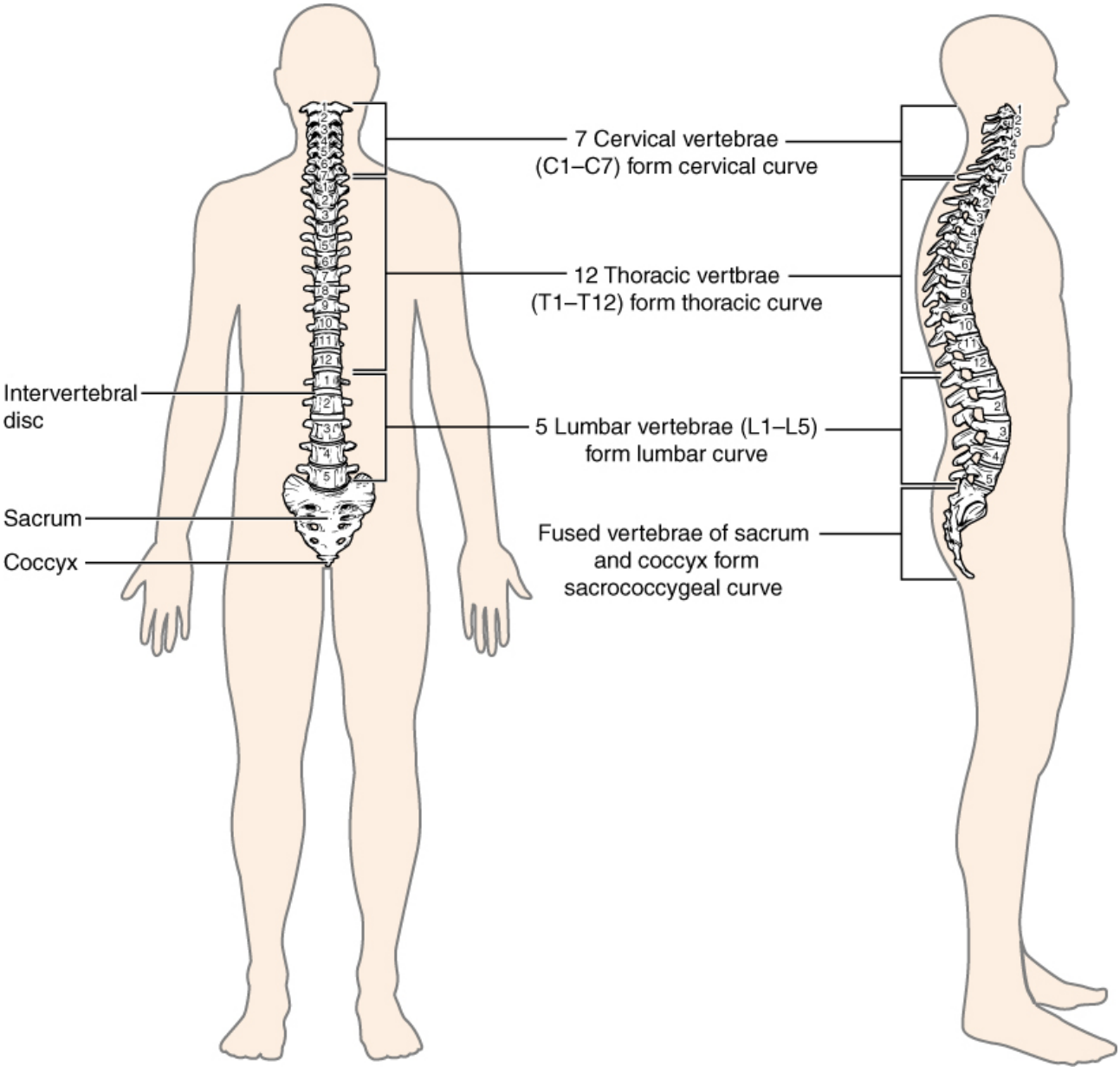


Figure 7.7 The Vertebral Column

Vertebra

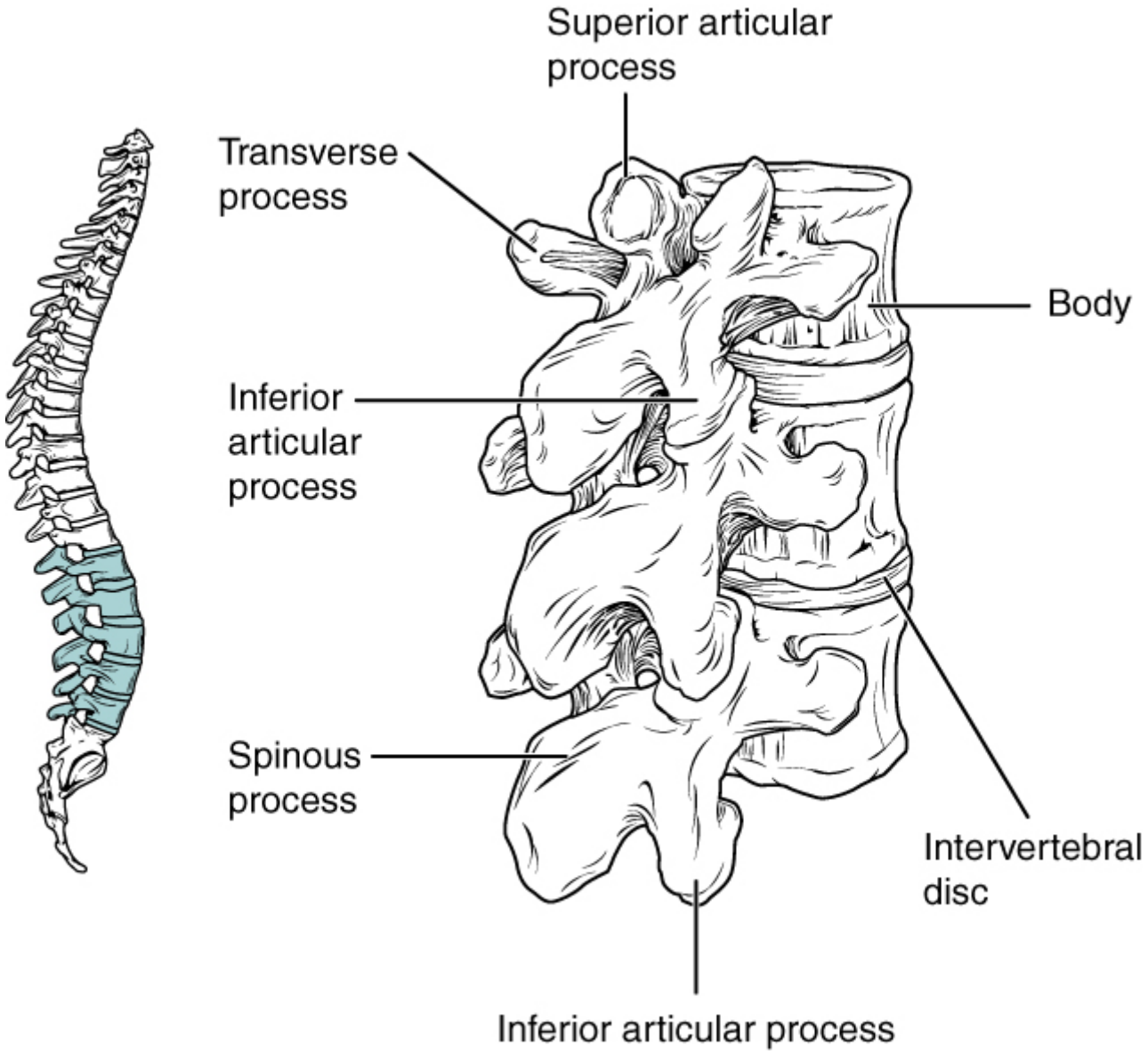


Figure 7.8 Typical Vertebral Structures (Lumbar)

The Thoracic Cage

The thoracic cage is formed by the sternum and 12 pairs of ribs with their costal cartilages. The ribs are anchored posteriorly to the 12 thoracic vertebrae. The sternum consists of the manubrium, body, and xiphoid process. The ribs are classified as true ribs (1–7) and false ribs (8–12). The last two pairs of false ribs are also known as floating ribs (11–12). (Figure 7.9)

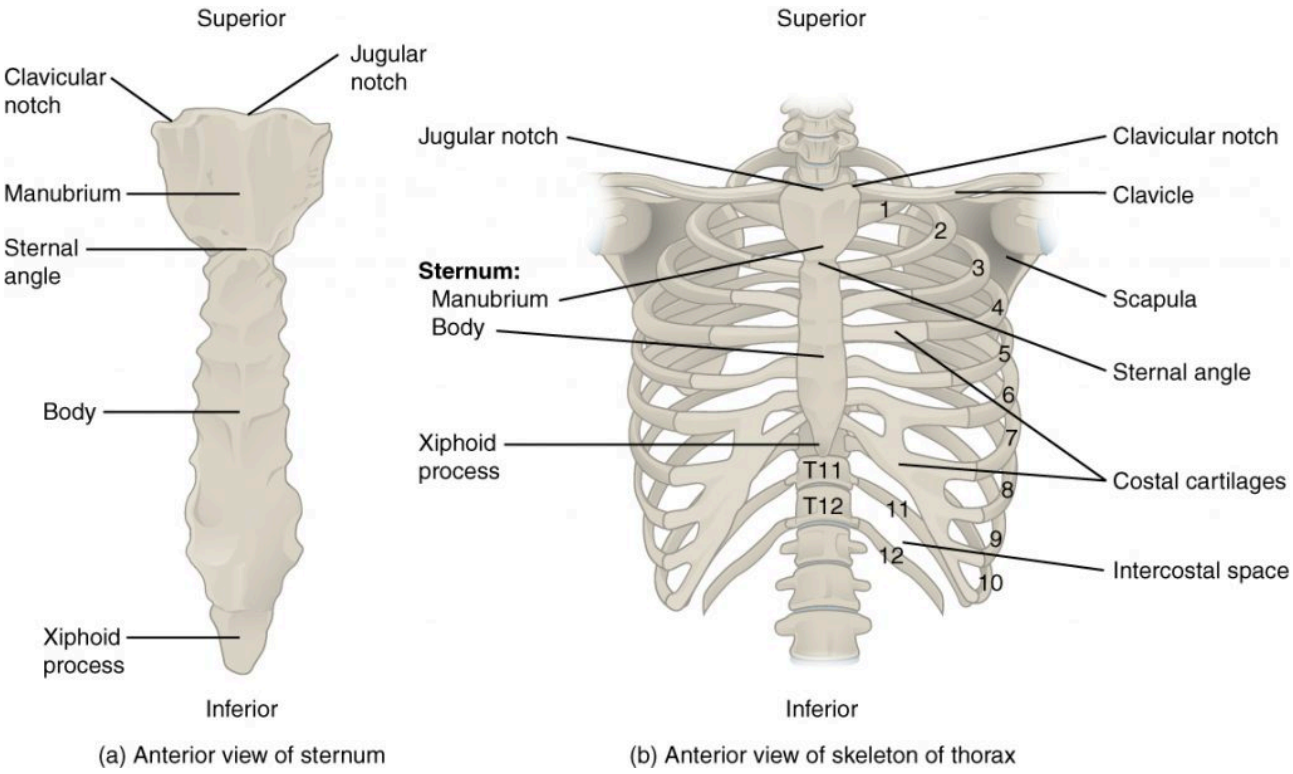


Figure 7.9 The Thoracic Cage. The ribs are numbered 1 – 12. The thoracic vertebrae are labeled T11, T12

Pre-Laboratory Questions

After reviewing the background information, please answer these pre-laboratory questions.

1. What are the components of the axial skeleton?
2. List the names of the flat bones of the skull.
3. Name the five regions of the vertebral column.
4. What are the three types of ribs based on their attachments?

Exercises

Type your exercises here.

- Exercise 1 Anterior View of the Skull
- Exercise 2 Lateral View of the Skull
- Exercise 3 Posterior View of Skull

- Exercise 4 Superior View of Cranial Floor
- Exercise 5 Vertebral Column
- Exercise 6 Thoracic Cage

Exercise 1 Anterior View of the Skull

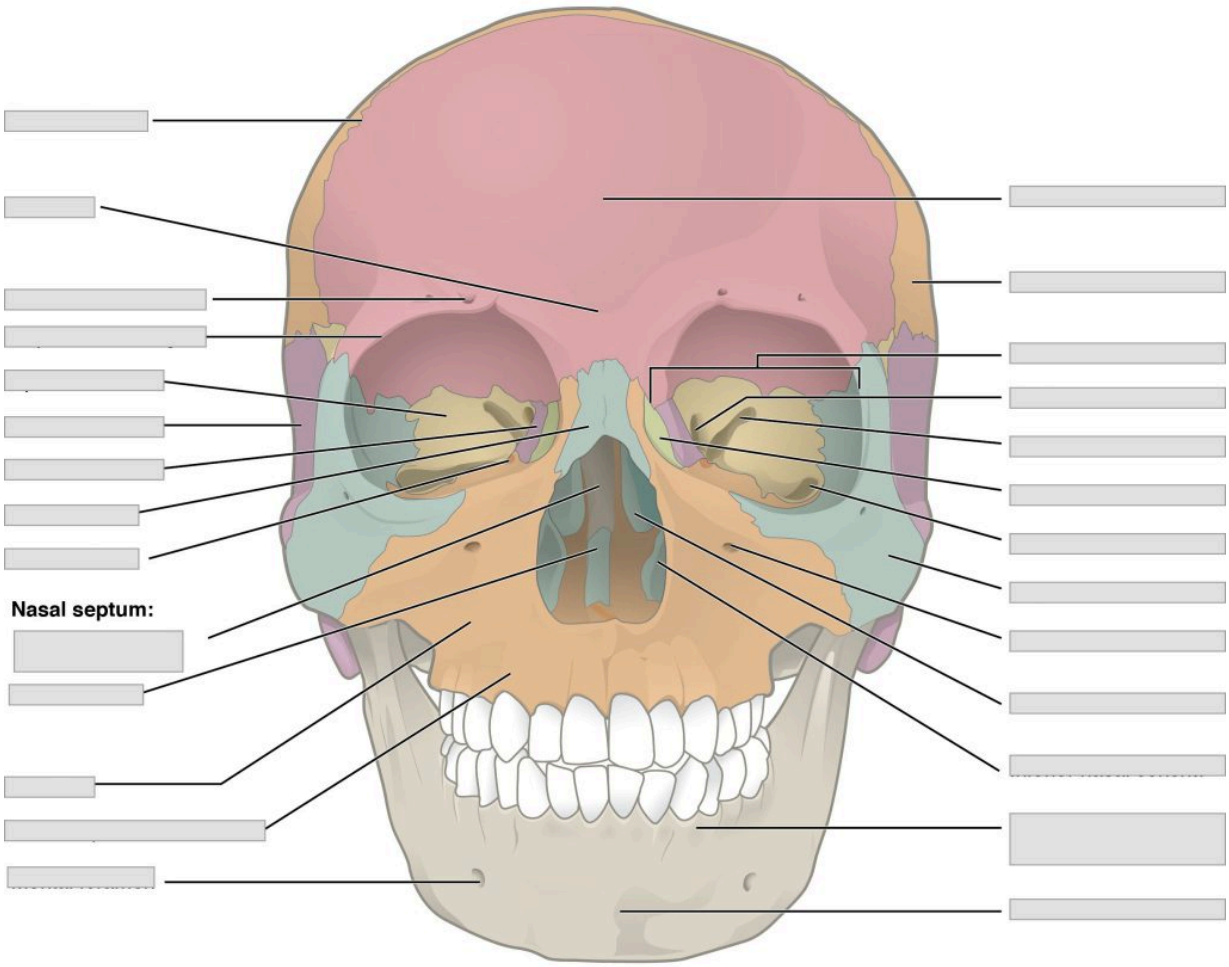
Required Materials

- Skull models
- Poster of the skeletal system

Procedure

1. Obtain a skull model and observe its structures from the anterior side (Figure 7.3)
2. Identify the structures listed below on the skull and label the structures on the image below.

· Alveolar processes	· Optic canal
· Frontal bone	· Parietal bone
· Inferior nasal concha	· Perpendicular plate of ethmoid
· Inferior orbital fissure	· Sphenoid bone
· Infraorbital foramen	· Superior orbital fissure
· Lacrimal bone	· Supraorbital foramen
· Mandible	· Supraorbital margin
· Maxilla	· Temporal bone
· Mental protuberance	· Vomer
· Nasal bone	· Zygomatic bone



Anterior view

Exercise 2 Lateral View of the Skull

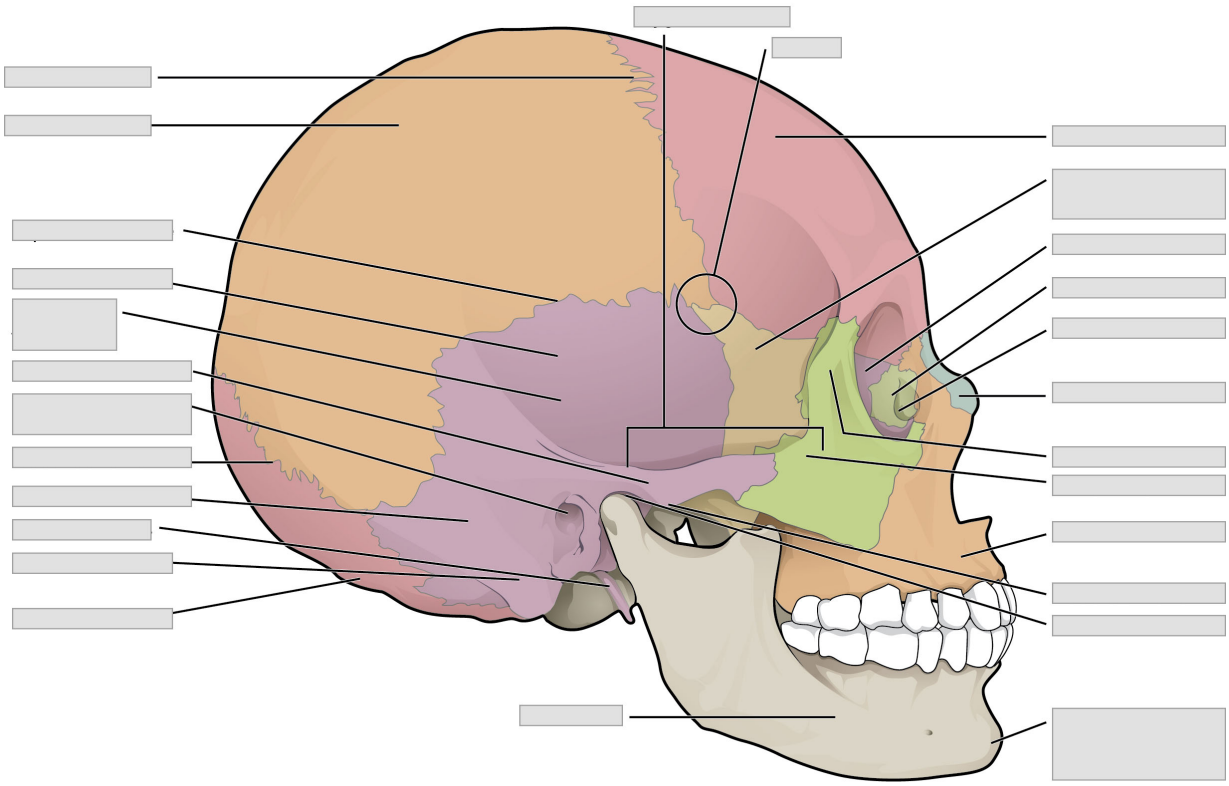
Required Materials

- Skull models
- Poster of the skeletal system

Procedure

1. Obtain a skull model and observe its structures from the lateral side (Figure 7.4)
2. Identify the structures listed below on the skull and label the structures on the image below.

· Coronal suture	· Mental protuberance
· Ethmoid bone	· Nasal bone
· External acoustic meatus	· Occipital bone
· Frontal bone	· Parietal bone
· Greater wing of sphenoid bone	· Pterion
· Lacrimal bone	· Squamous part of temporal
· Lacrimal fossa	· Squamous suture
· Lambdoid suture	· Styloid process
· Mandible	· Temporal process
· Mastoid process	· Zygomatic bone
· Maxilla	· Zygomatic process



Right lateral view

Exercise 3 Posterior View of Skull

Required Materials

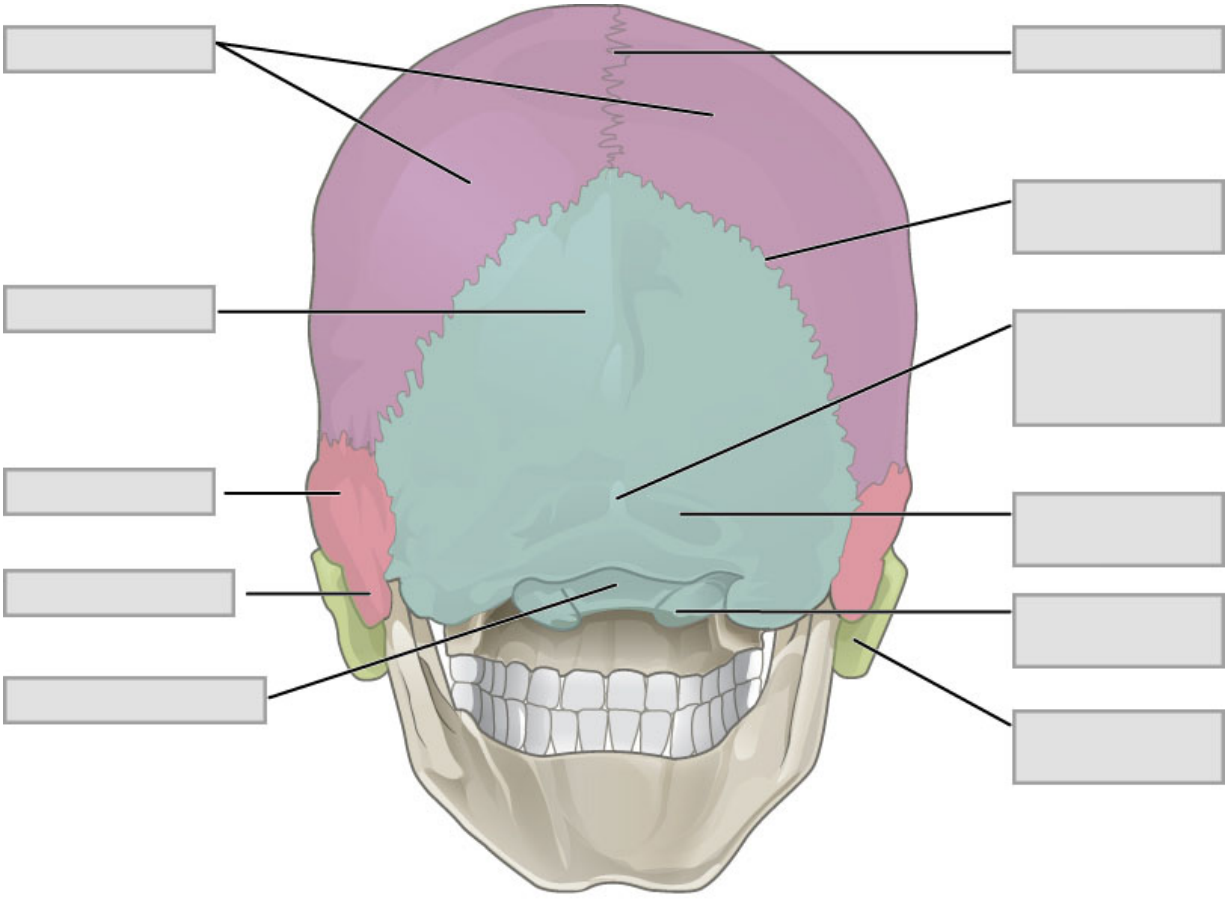
- Skull models

- Poster of the skeletal system

Procedure

1. Obtain a skull model and observe its structures from the posterior side (Figure 7.5)
2. Identify the structures listed below on the skull and label the structures on the image below.

· External occipital protuberance	· Parietal bone
· Foramen magnum	· Sagittal suture
· Lambdoid suture	· Superior nuchal line
· Mastoid process	· Temporal bone
· Occipital bone	· Zygomatic bone
· Occipital condyle	



Posterior view

Exercise 4 Superior View of Cranial Floor

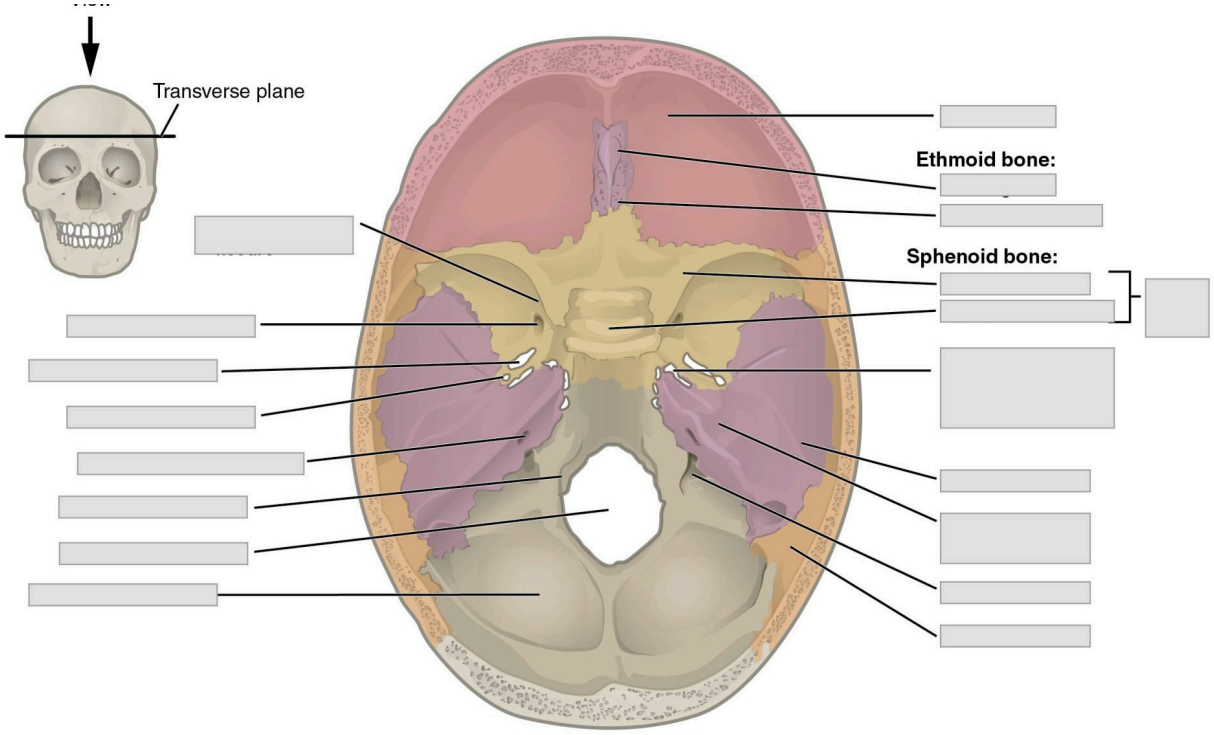
Required Materials

- Skull models
- Poster of the skeletal system

Procedure

1. Obtain a skull cut along its transverse plane and observe its structures from the cranial floor (Figure 7.6 b).
2. Identify the structures listed below on the skull and label the structures on the image below.

· Ethmoid bone	· Jugular foramen
· Foramen magnum	· Occipital bone
· Foramen ovale	· Parietal bone
· Foramen spinosum	· Sphenoid bone
· Frontal bone	· Temporal bone
· Internal acoustic meatus	



Exercise 5 Vertebral Column

Required Materials

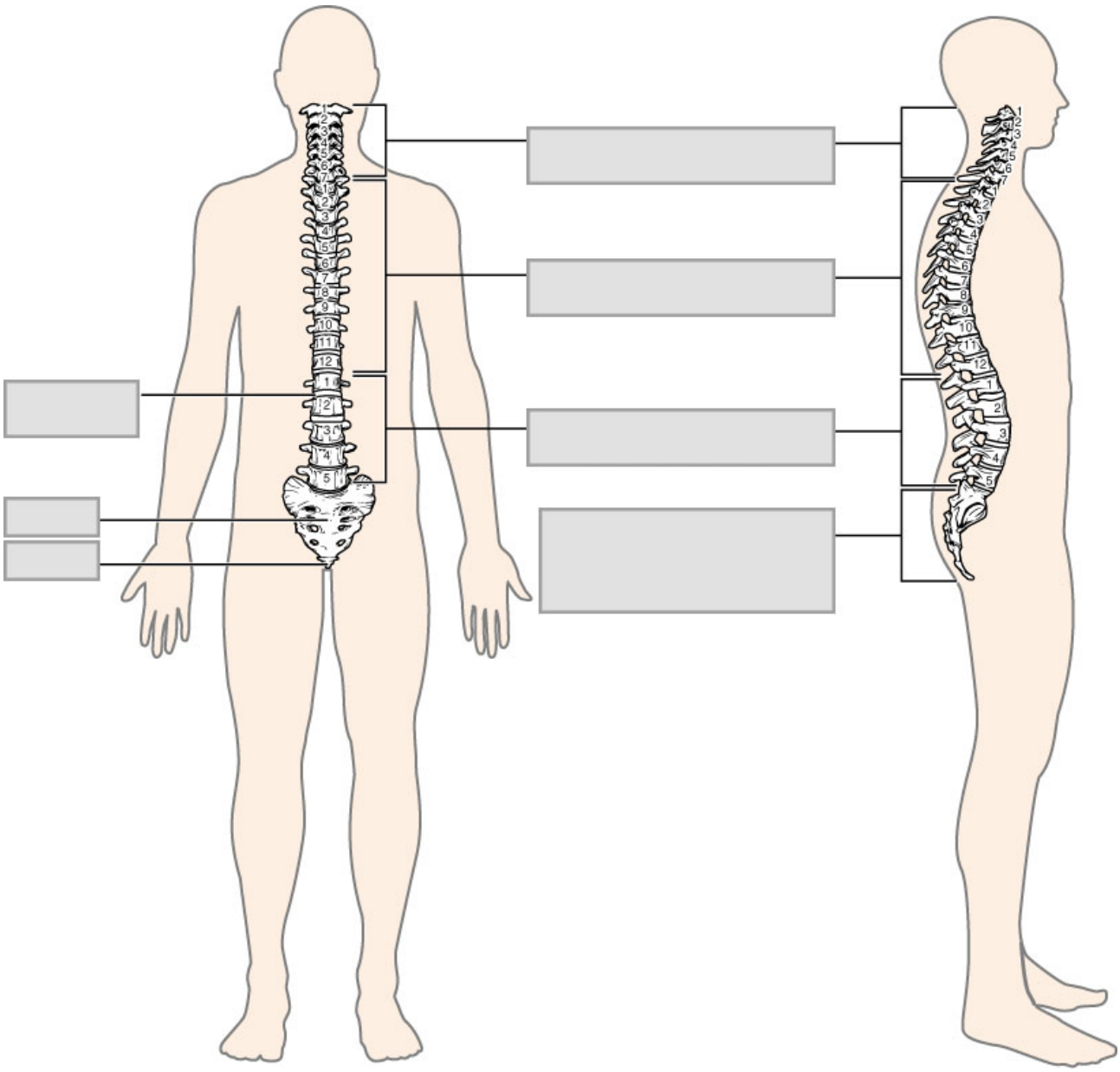
- Vertebral column model
- Vertebra on model or articulated skeleton model

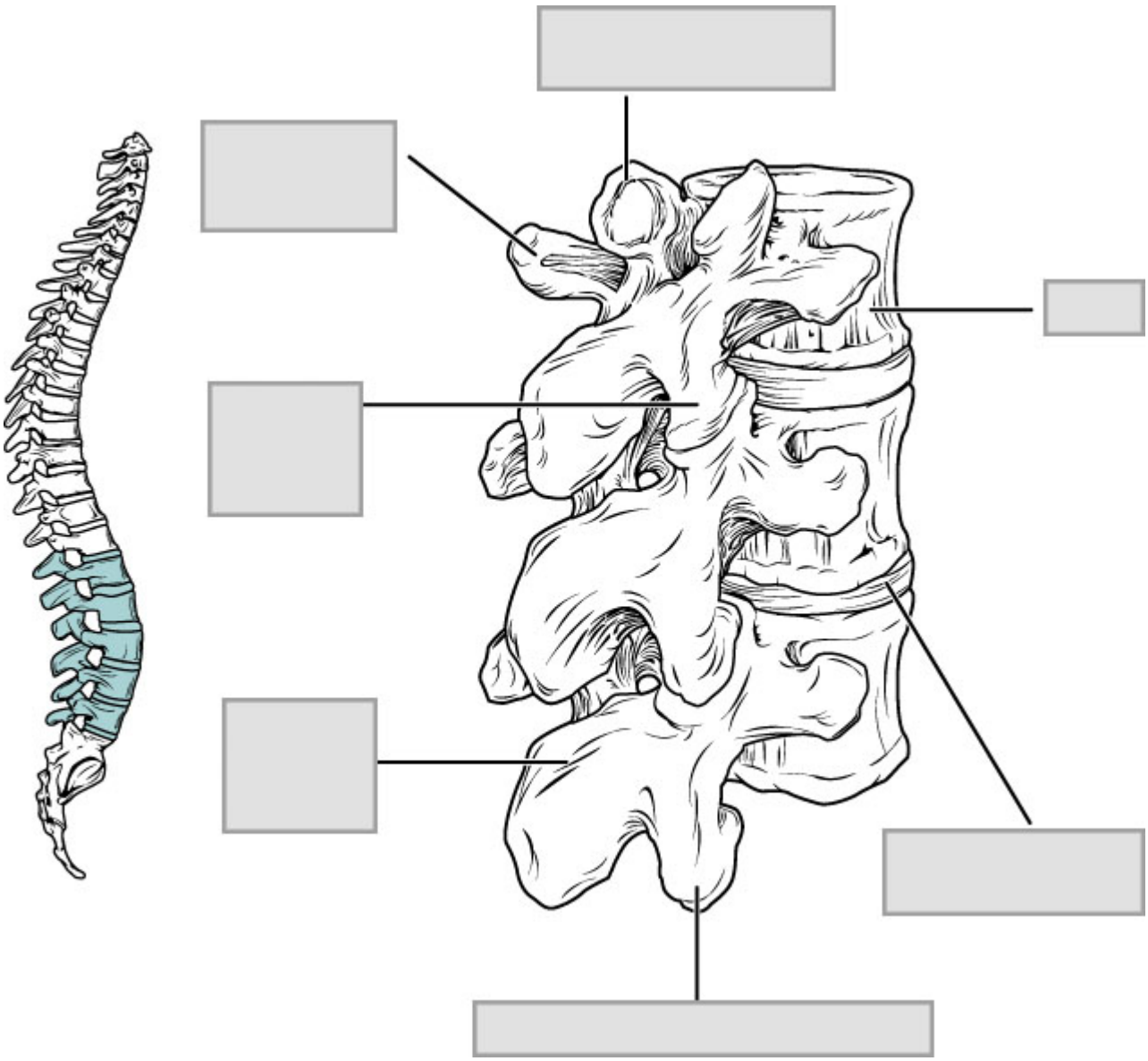
- Vertebra from the disarticulated skeleton
- Poster of the skeletal system

Procedures

1. Obtain a model of vertebral column and observe its structures (Figure 7.7 and 7.8).
2. Identify the structures on the list below and label them on the given vertebral column and vertebra below.

·	Body	·	Sacral curvature
·	Cervical curvature	·	Sacrum
·	Cervical vertebrae	·	Spinous process
·	Coccygeal vertebrae	·	Superior articular process
·	Lamina	·	Thoracic curvature
·	Lumbar curvature	·	Thoracic vertebrae
·	Lumbar vertebrae	·	Transverse process
·	Pedicle	·	Vertebral foramen





Exercise 6 Thoracic Cage

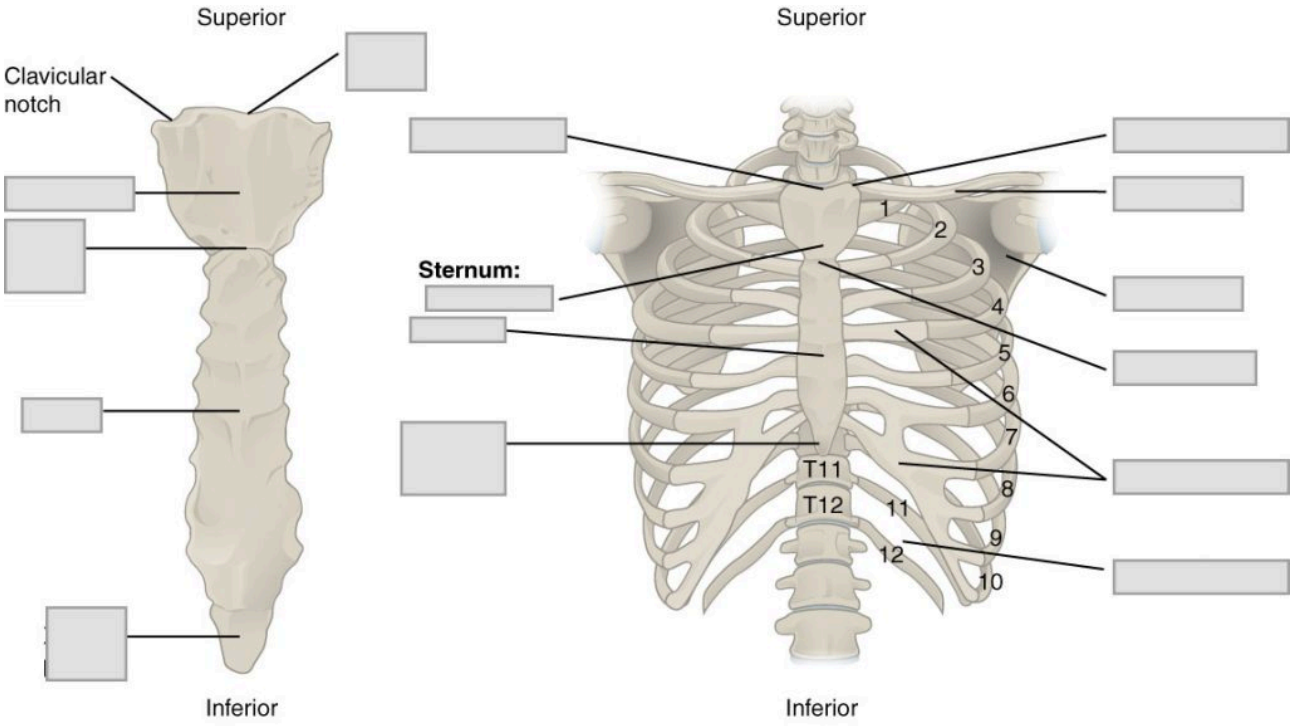
Required Materials

- Thoracic cage model
- Articulated skeleton
- Poster of the skeletal system

Procedure

1. Obtain a model of thoracic cage or the whole skeleton and identify its parts (Figure 7.9).
2. Identify the structures on the list below and label on the figure given.

- Costal cartilage
- False ribs
- Floating ribs
- Intercostal space
- Ribs 1-12



Post-laboratory Questions

1. If you are observing the skull from above a person's head, what are the bones and structures you would be able to see? List these and describe their locations with respect to each other using anatomical terms.
2. Scoliosis, lordosis, and kyphosis are disorders of the vertebral column shown in the firs part of this chapter. Examine the figure given.
    1. For each disorder, identify the part of the vertebral column shown to be affected.
    2. How many vertebrae are in each of these regions you ID'd for each disorder?
3. In open heart surgery, the sternum is cut through and ribs are spread apart to access the heart.
    1. List the regions of the sternum cut (from neck to belly).
    2. By cutting the sternum, which ribs would be affected directly? Indirectly?

8.

CHAPTER 8 THE APPENDICULAR SKELETON

By Ganesan L. Kamatchi

Motivation.

Figure 8.1 Hip Hop Dancers The appendicular skeleton consists of the upper and lower limb bones, the bones of the hands and feet, and the bones that anchor the limbs to the axial skeleton; all important for living and dancing. Credit: Openverse, by by caribb, license CC BY-NC-ND

Gorham-Stout disease is a rare and enigmatic condition involving various skeletal locations. It is also called massive bone disease, vanishing bone disease, phantom bone disease, massive osteolysis, Gorham–Stout syndrome and Gorham's disease. It is characterized by destruction of osseous matrix and proliferation of vascular structures with benign origin. Despite the extensive investigation of the pathogenetic mechanisms of the disease, its

etiology of GSD is poorly understood and the cause of excessive bone resorption in GSD patients has not been clarified. Several studies proposed that the abnormal proliferation of endothelial-lined vessels could promote bone resorption. Bone normally do not have lymphatic vessels and the presence of lymphatics in GSD patients have been confirmed histologically and biochemically. Gorham-Stout disease can affect any part of the skeleton, but the pelvis, long bones, and shoulder girdles are the most frequently involved [Kaissi et al., Medicines (Basel) 6: 54, 2019].

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Identify and label the pectoral girdle bone structures in the clavicle and scapula samples provided
- Identify the bones of the upper limbs and label their structures
- Label the bones and structures within the pelvic girdle after identifying on an articulated skeleton
- Identify the bones of the lower limbs and label these and their associated structures

Background.

Your skeleton provides the internal supporting structure of the body. The adult axial skeleton consists of 80 bones that form the head and body trunk. Attached to this are the limbs, whose 126 bones constitute the appendicular skeleton (Figure 8.2). These bones are divided into two groups: the bones that are located within the limbs themselves, and the girdle bones that attach the limbs to the axial skeleton. The bones of the shoulder region form the pectoral girdle, which anchors the upper limb to the thoracic cage of the axial skeleton. The lower limb is attached to the vertebral column by the pelvic girdle.

Because of our upright stance, different functional demands are placed upon the upper and lower limbs. Thus, the bones of the lower limbs are adapted for weight-bearing support and stability, as well as for body locomotion via walking or running. In contrast, our upper limbs are not required for these functions. Instead, our upper limbs are highly mobile and can be utilized for a wide variety of activities. The large

range of upper limb movements, coupled with the ability to easily manipulate objects with our hands and opposable thumbs, has allowed humans to construct the modern world in which we live.

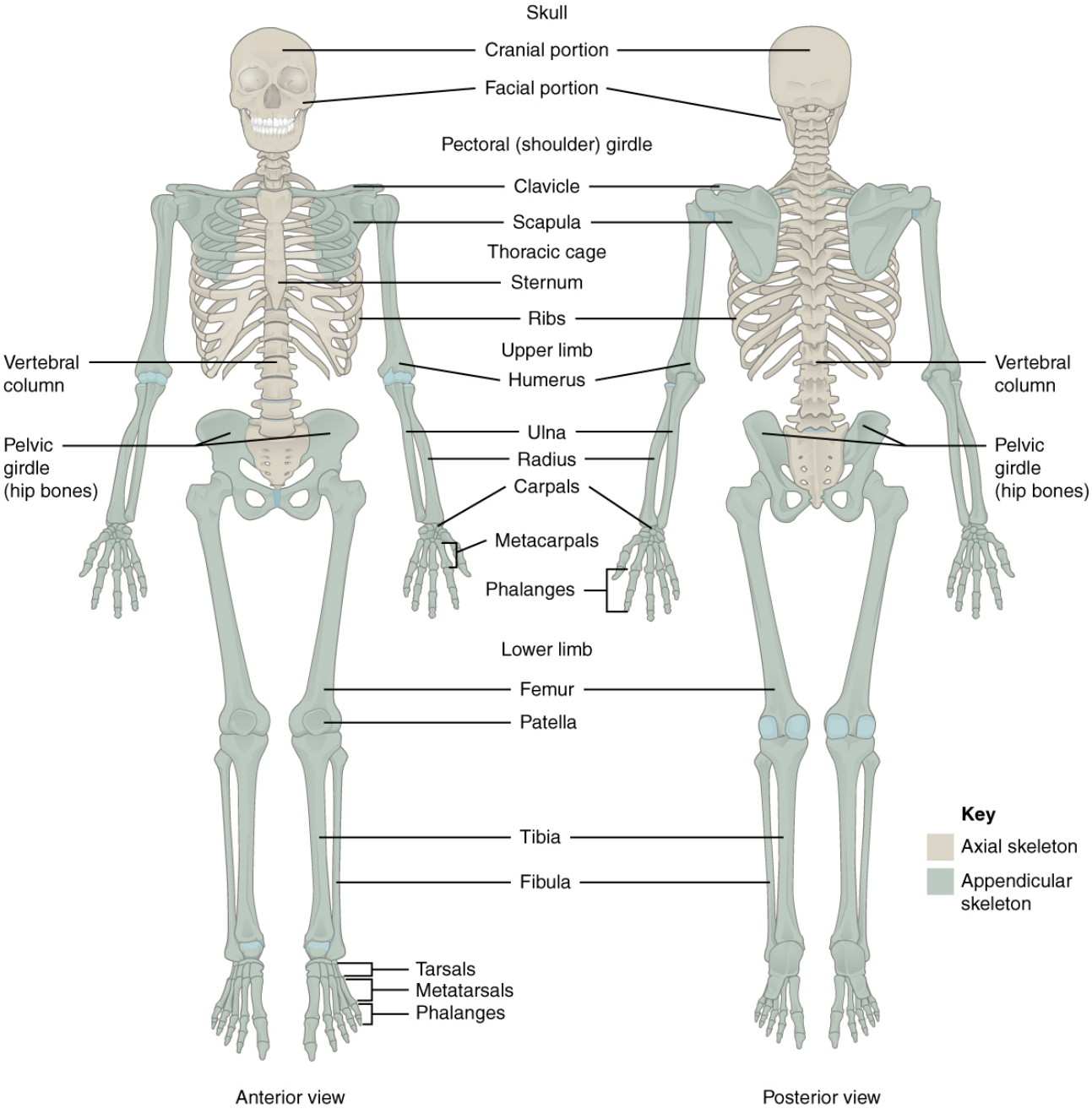


Figure 8.2 Axial and Appendicular Skeleton The axial skeleton supports the head, neck, back, and chest and thus forms the vertical axis of the body. It consists of the skull, vertebral column (including the sacrum and coccyx), and the thoracic cage, formed by the ribs and sternum. The appendicular skeleton is made up of all bones of the upper and lower limbs.

The Clavicle

The clavicle is the only long bone that lies in a horizontal position in the body (see Figure 8.3). The clavicle has several important functions. First, anchored by muscles from above, it serves as a strut that extends laterally to support the scapula. This in turn holds the shoulder joint superiorly and laterally from the body trunk, allowing for maximal freedom of motion for the upper limb. The clavicle also

transmits forces acting on the upper limb to the sternum and axial skeleton. Finally, it serves to protect the underlying nerves and blood vessels as they pass between the trunk of the body and the upper limb.

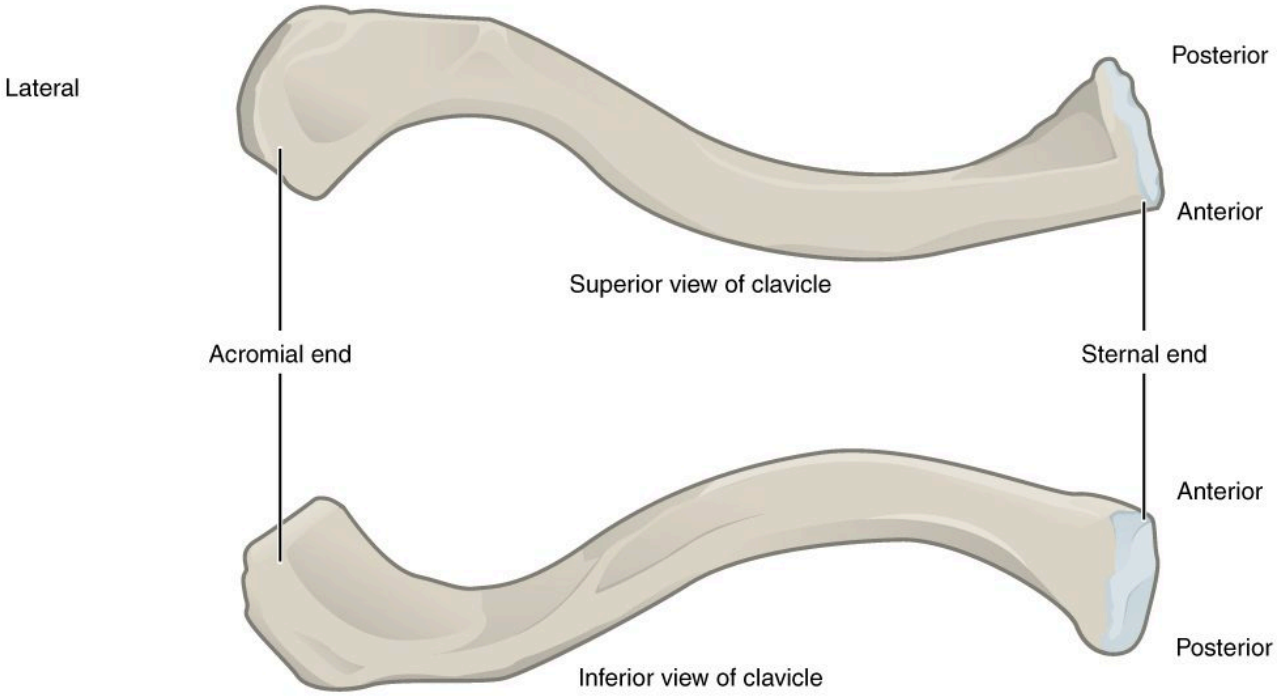


Figure 8.3 Right Clavicle. The clavicle is a part of pectoral girdle; superior view and inferior view

The Scapula

The scapula is also part of the pectoral girdle and thus plays an important role in anchoring the upper limb to the body (Figure 8.4). The scapula is located on the posterior side of the shoulder. It is surrounded by muscles on both its anterior (deep) and posterior (superficial) sides, and thus does not articulate with the ribs of the thoracic cage. Scapula forms the shoulder joint or glenohumeral joint involving articulation between the glenoid cavity of the scapula and the head of the humerus.

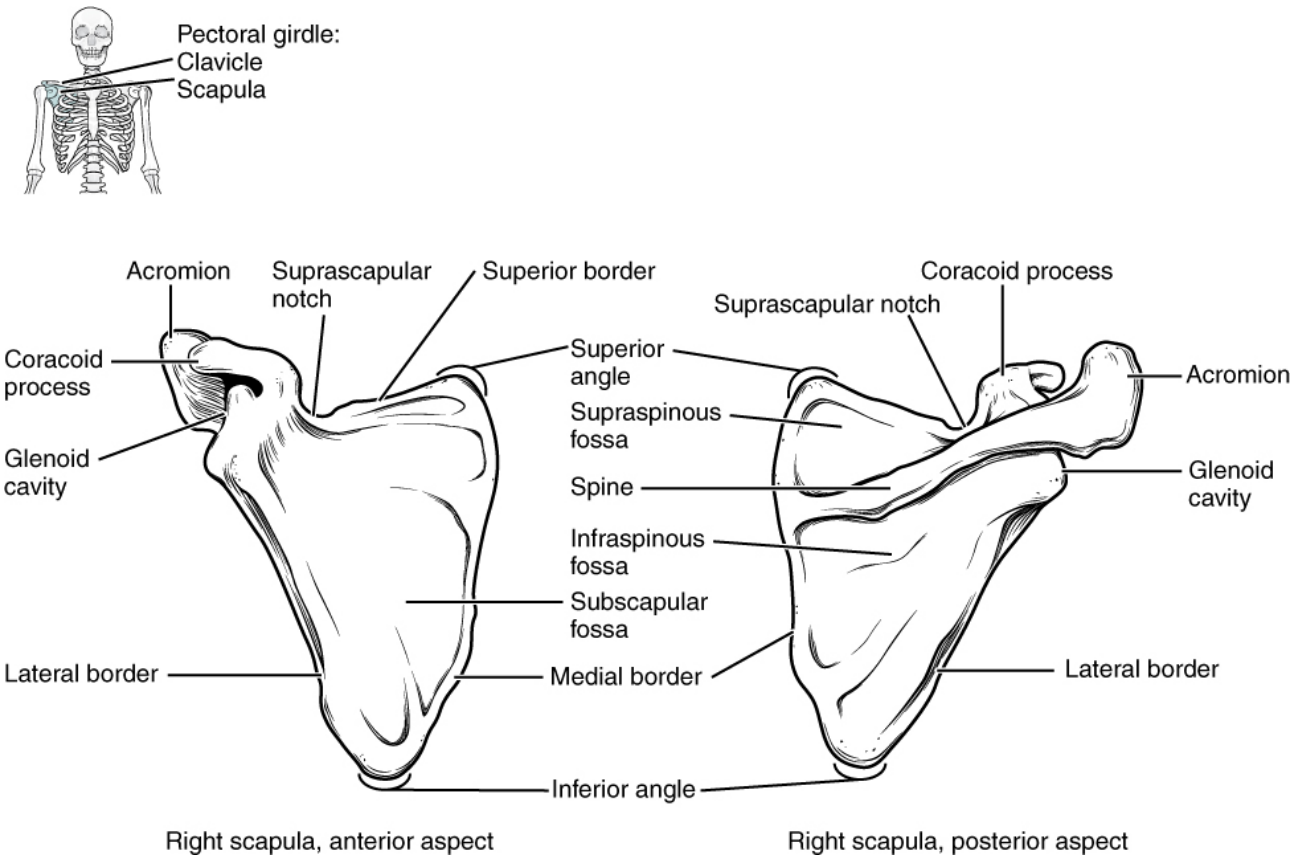


Figure 8.4 Right Scapula anterior view and posterior view

The Upper Limb

Each upper limb contains 30 bones. This includes the humerus, radius, ulna, carpals, metacarpals and the phalanges.

The Humerus

The upper limb is divided into three regions. These consist of the arm, located between the shoulder and elbow joints; the forearm, which is between the elbow and wrist joints; and the hand, which is located distal to the wrist. The humerus is the single bone of the upper arm region (Figure 8.5). At its proximal end is the head of the humerus. This is the large, round, smooth region that faces medially. The head articulates with the glenoid cavity of the scapula to form the glenohumeral (shoulder) joint.

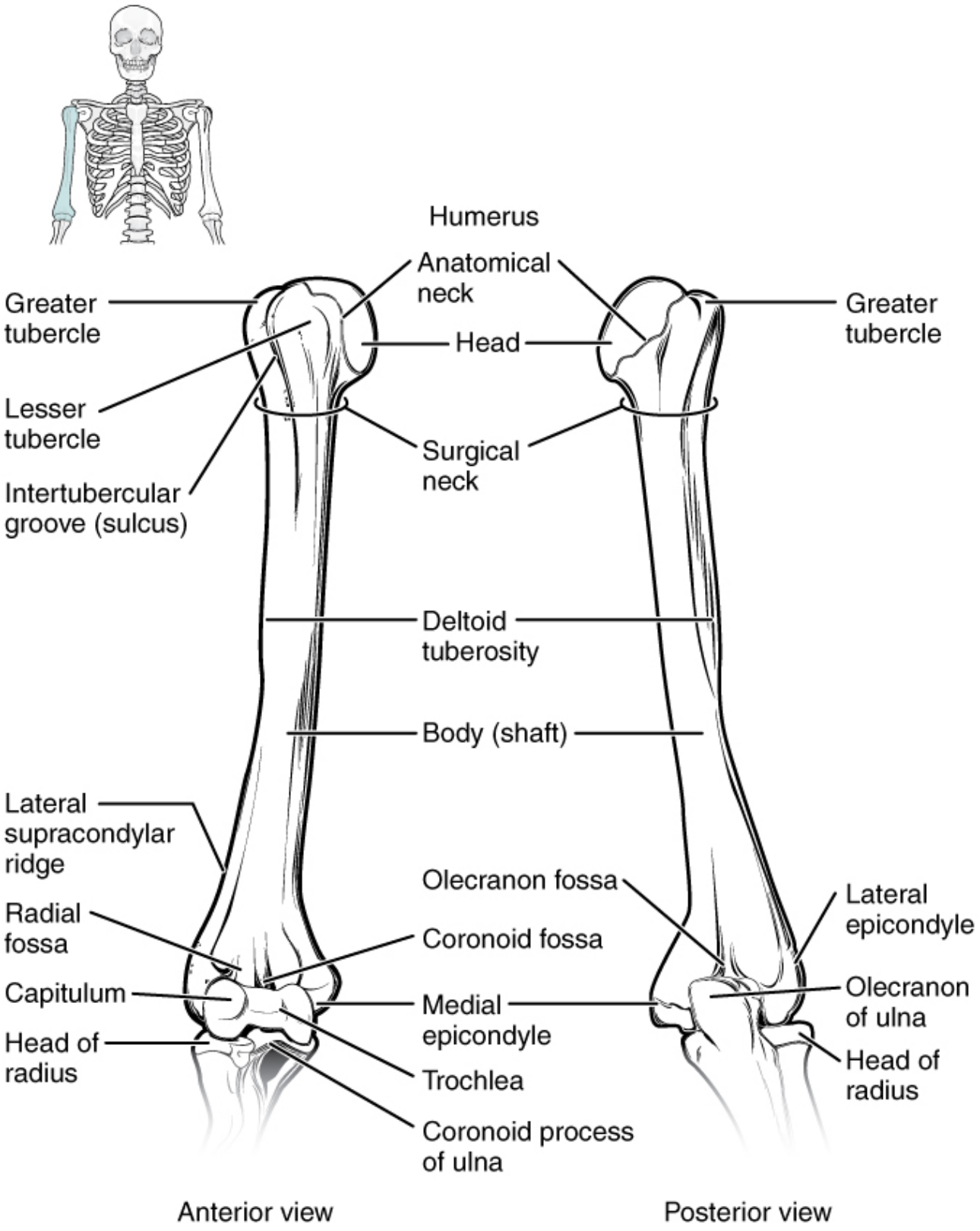


Figure 8.5 Humerus The humerus is the single bone of the upper arm region. It articulates with the radius and ulna bones of the forearm to form the elbow joint. Anterior and posterior view shown.

The Ulna and Radius

The ulna is the medial bone of the forearm. It runs parallel to the radius, which is the lateral bone of the forearm (Figure 8.6). The proximal end of the ulna resembles a crescent wrench with its large, C-shaped

trochlear notch. This region articulates with the trochlea of the humerus as part of the elbow joint. The inferior margin of the trochlear notch is formed by a prominent lip of bone called the coronoid process of the ulna. The posterior and superior portions of the proximal ulna make up the olecranon process, which forms the bony tip of the elbow.

The radius runs parallel to the ulna, on the lateral (thumb) side of the forearm (see Figure 8.6). The head of the radius is a disc-shaped structure that forms the proximal end. The neck of the radius is the narrowed region immediately below the expanded head. The shaft of the radius is slightly curved and has a small ridge along its medial side. The distal end of the radius has a smooth surface for articulation with two carpal bones to form the radiocarpal joint or wrist joint.

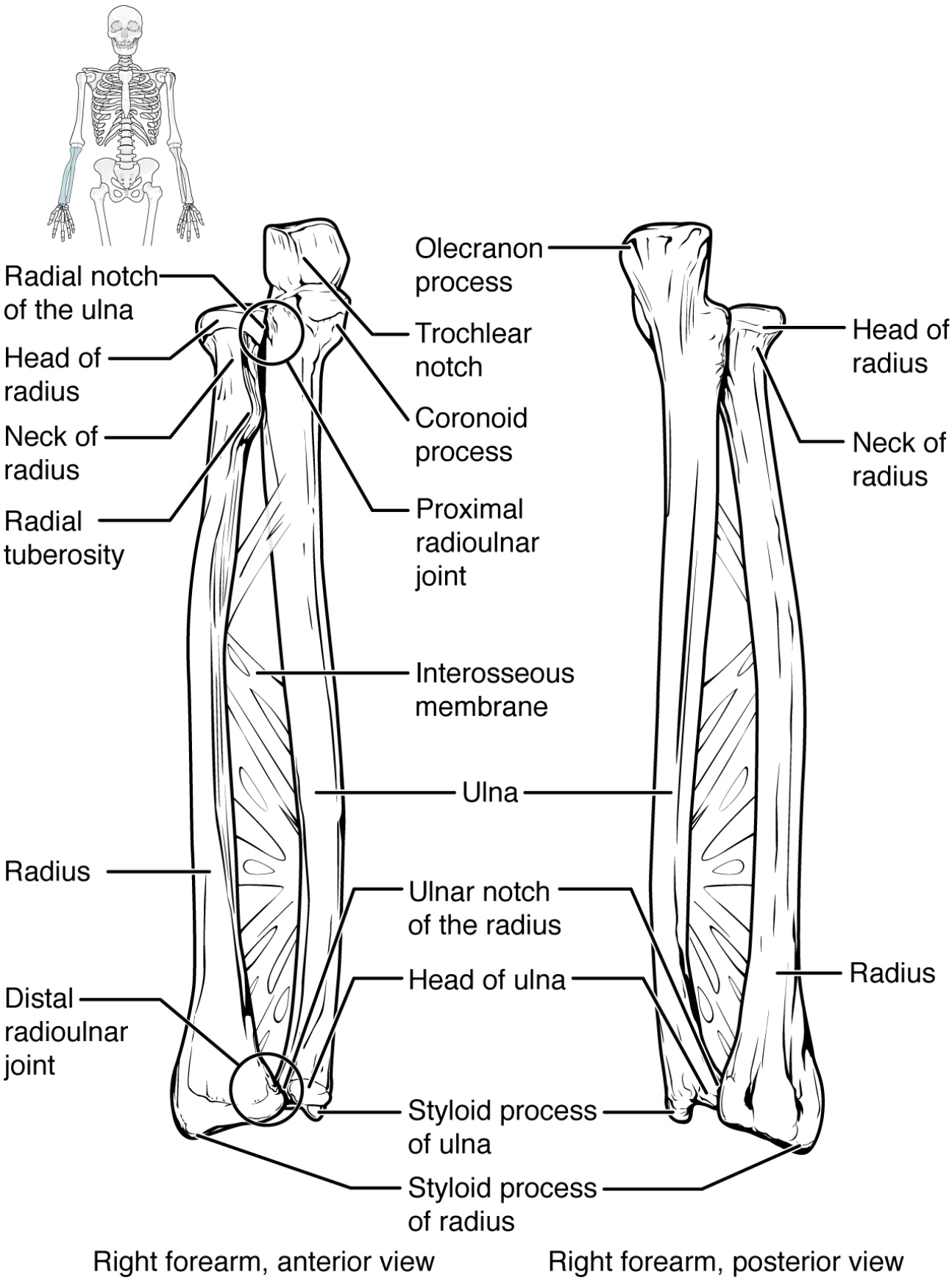


Figure 8.6 Right Ulna and Radius The ulna is located on the medial side of the forearm, and the radius is on the lateral side. These bones are attached to each other by an interosseous membrane. a, anterior view b, posterior view

Bones of the Wrist and Hand

The wrist and base of the hand are formed by a series of eight small carpal bones (Figure 8.7). The carpal bones are arranged in two rows, forming a proximal row of four carpal bones and a distal row of four carpal bones. The bones in the proximal row, running from the lateral (thumb) side to the medial side, are the scaphoid, lunate, triquetrum and pisiform bones. The distal bones (lateral to medial) are the trapezium, trapezoid, capitate and hamate bones.

The palm of the hand contains five elongated metacarpal bones. These bones lie between the carpal bones of the wrist and the bones of the fingers and thumb (see Figure 8.7). The proximal end of each metacarpal bone articulates with one of the distal carpal bones.

The fingers and thumb contain 14 bones, each of which is called a phalanx bone, named after the ancient Greek phalanx. The thumb (pollex) is digit number 1 and has two phalanges, a proximal phalanx, and a distal phalanx bone (see Figure 8.7). Digits 2 (index finger) through 5 (little finger) have three phalanges each, called the proximal, middle, and distal phalanx bones.

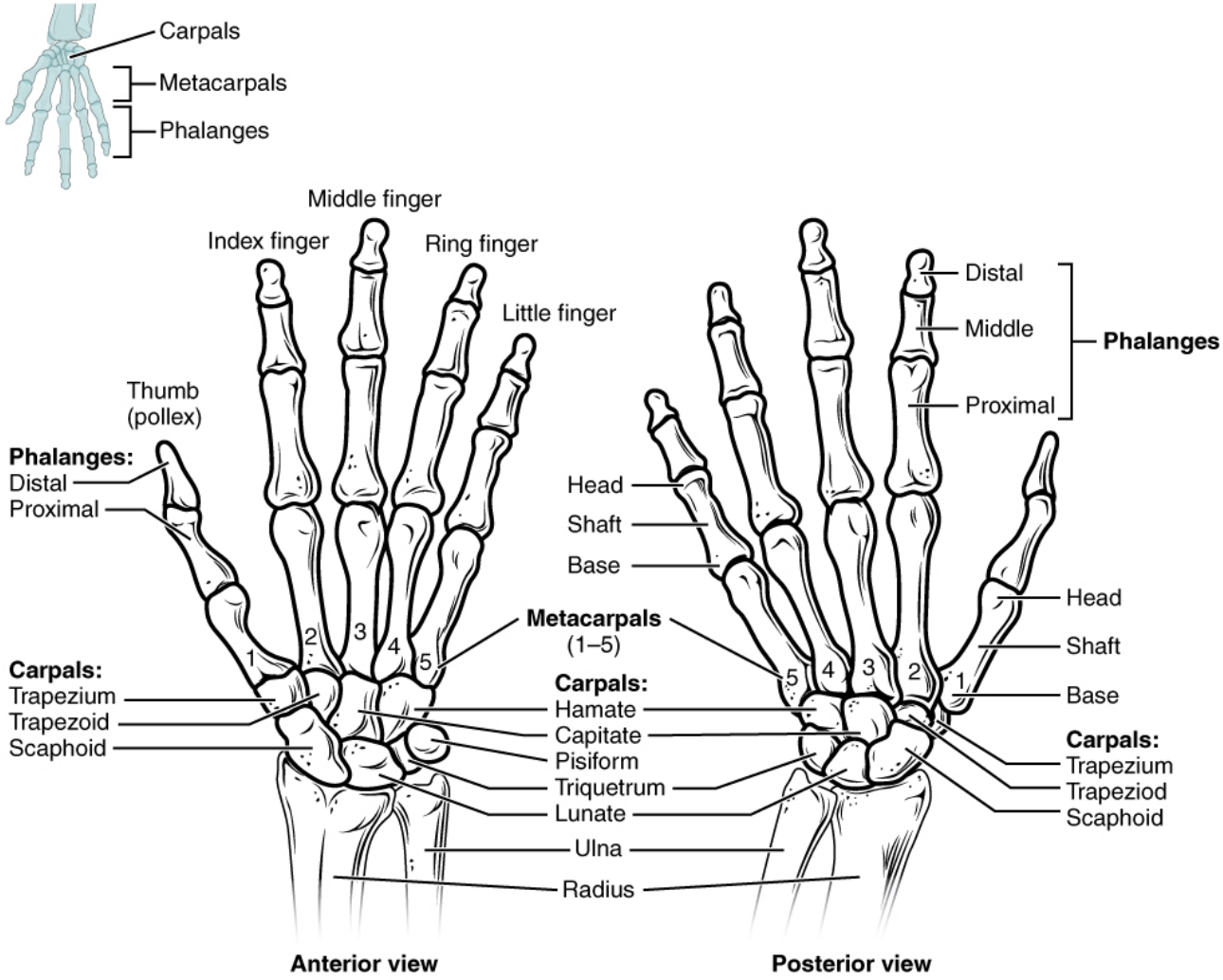


Figure 8.7 Bones of the Wrist and Hand The eight carpal bones form the base of the hand. These are arranged into proximal and distal rows of four bones each. The metacarpal bones form the palm of the hand. The thumb and fingers consist of the phalanx bones. Left hand shown.

Bones of the Pelvic Girdle

The pelvic girdle (hip girdle) is formed by a single bone, the hip bone or coxal bone, which serves as the attachment point for each lower limb. Each hip bone, in turn, is firmly joined to the axial skeleton via its attachment to the sacrum of the vertebral column. The right and left hip bones also converge anteriorly to attach to each other (Figure 8.8).

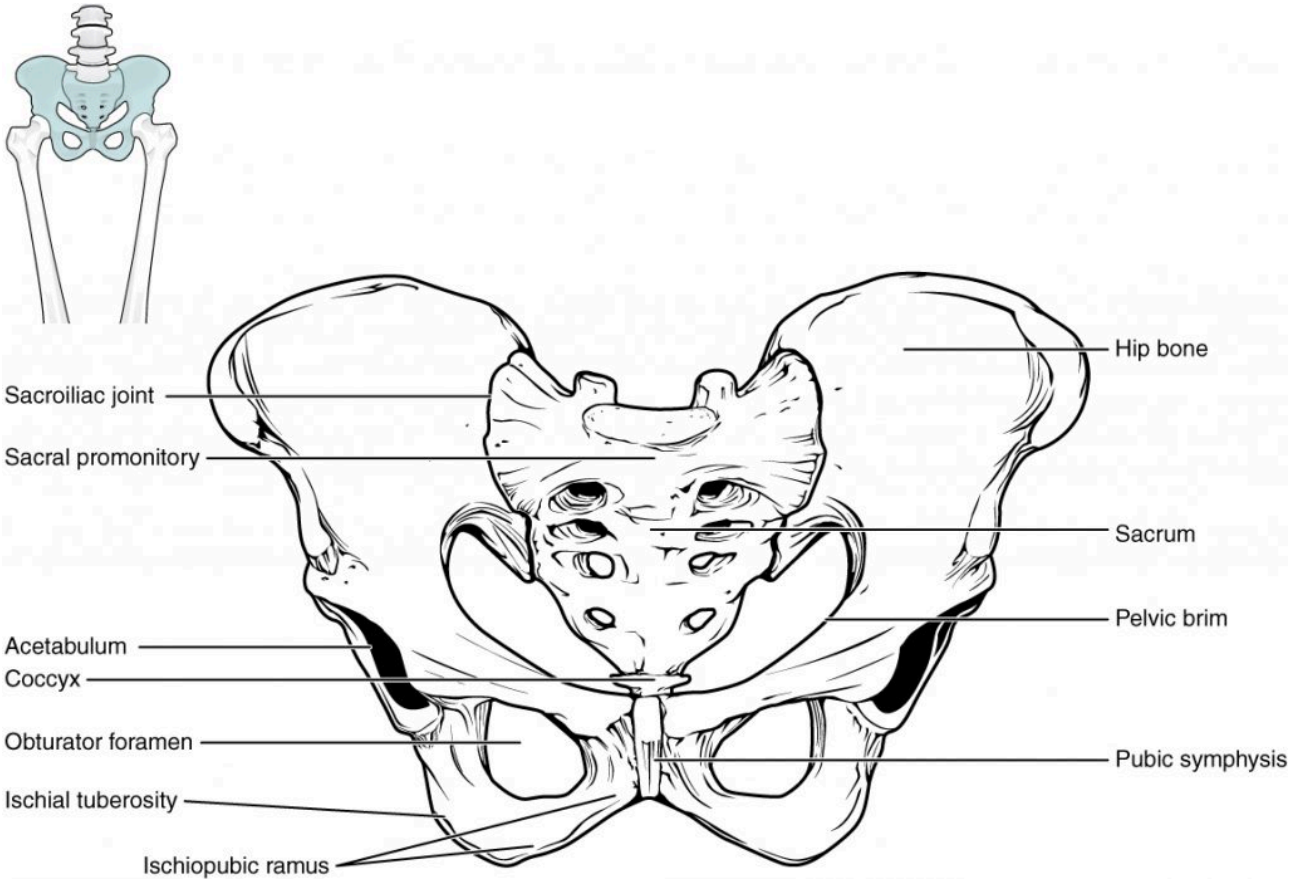


Figure 8.8 Pelvis The pelvic girdle is formed by a single hip bone. The hip bone attaches the lower limb to the axial skeleton through its articulation with the sacrum. The right and left hip bones, plus the sacrum and the coccyx, together form the pelvis.

Os Coxa

The hip bone, or coxal bone, forms the pelvic girdle portion of the pelvis. The paired hip bones are the large, curved bones that form the lateral and anterior aspects of the pelvis. Each adult hip bone is formed by three separate bones that fuse together during the late teenage years. These bony components are the ilium, ischium, and pubis (Figure 8.9).

The ilium is the fan-like, superior region that forms the largest part of the hip bone. It is firmly united to the sacrum at the largely immobile sacroiliac joint (see Figure 8.8). The ischium forms the posteroinferior region of each hip bone. It supports the body when sitting. The pubis forms the anterior portion of the hip bone. The pubis curves medially, where it joins to the pubis of the opposite hip bone at a specialized joint called the pubic symphysis.

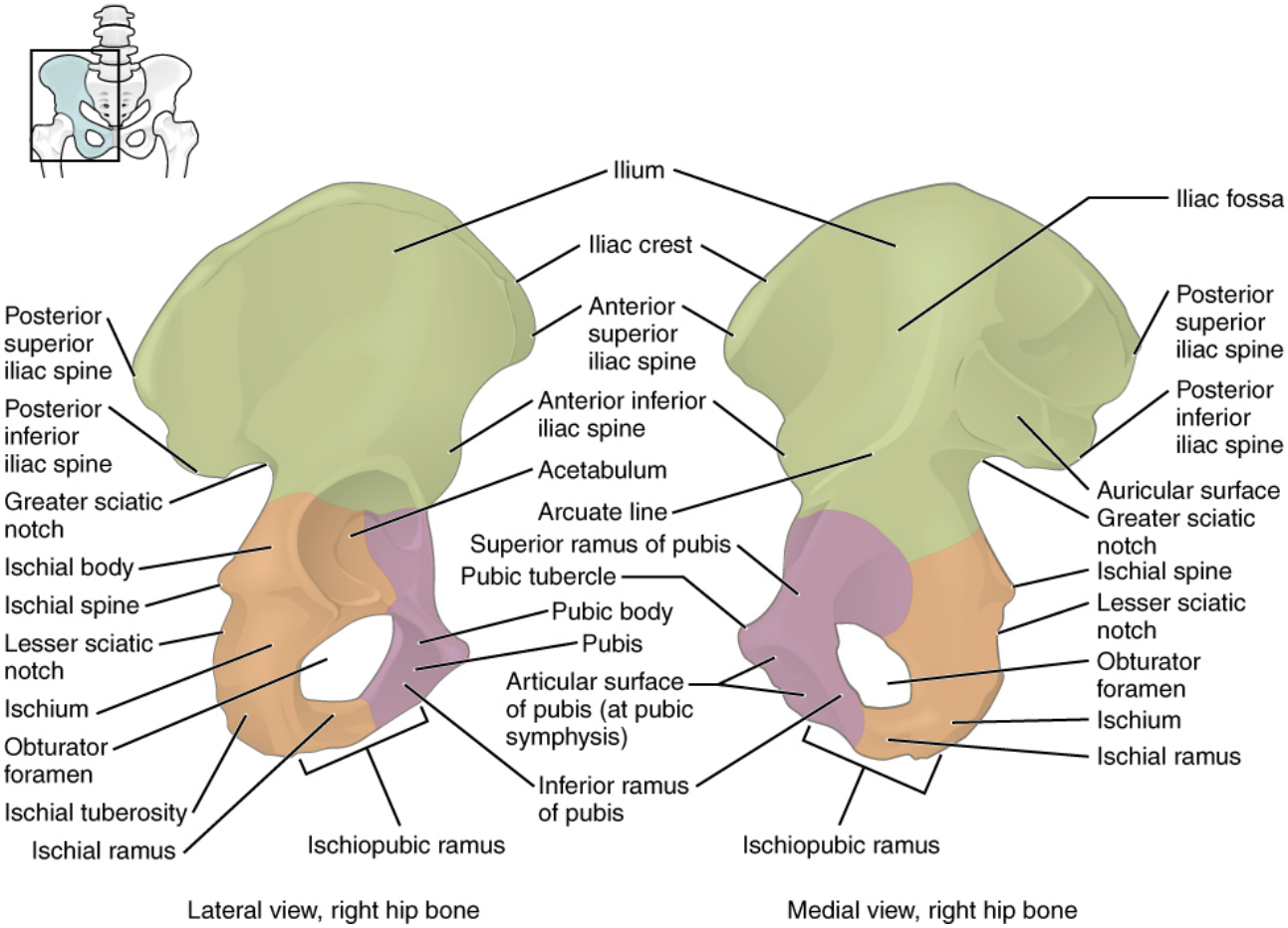


Figure 8.9 The Hip Bone (Os Coxa) The adult hip bone consists of three regions. The ilium forms the large, fan-shaped superior portion, the ischium forms the posteroinferior portion, and the pubis forms the anteromedial portion; lateral view and medial view of right hip bone.

Male and Female Pelvis

The differences between the adult female and male pelvis relate to function and body size. In general, the bones of the male pelvis are thicker and heavier, adapted for support of the male's heavier physical build and stronger muscles. The greater sciatic notch of the male hip bone is narrower and deeper than the broader notch of females. Because the female pelvis is adapted for childbirth, it is wider than the male pelvis, as evidenced by the distance between the anterior superior iliac spines (Figure 8.10). The ischial tuberosities of females are also farther apart, which increases the size of the pelvic outlet. Because of this increased pelvic width, the subpubic angle is larger in females (greater than 80 degrees) than it is in males (less than 70 degrees). The female sacrum is wider, shorter, and less curved, and the sacral promontory projects less into the pelvic cavity, thus giving the female pelvic inlet (pelvic brim) a more rounded or oval shape compared to males. The lesser pelvic cavity of females is also wider and more shallow than the narrower, deeper, and tapering lesser pelvis of males. Because of the obvious differences between female and male hip bones, this is the one bone of the body that allows for the most accurate sex determination.

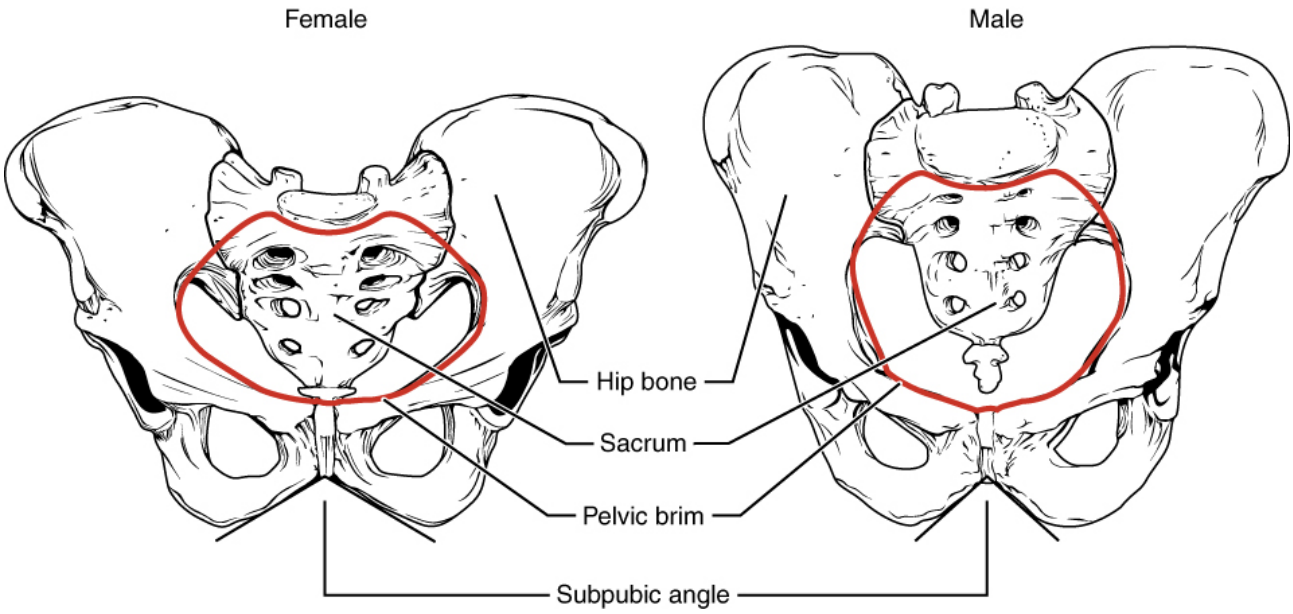


Figure 8.10 Male and Female Pelvis The female pelvis is adapted for childbirth and is broader, with a larger subpubic angle, a rounder pelvic brim, and a wider and shallower lesser pelvic cavity than the male pelvis. Left, female pelvis and right, male pelvis.

The Lower Limb

Each lower limb contains 30 bones. This includes the femur, patella, tibia, fibula, tarsals, metatarsals and the phalanges.

The Lower Limb

The Femur

The femur, or thigh bone, is the single bone of the thigh region (Figure 8.11). It is the longest and strongest bone of the body, and accounts for approximately one-quarter of a person's total height. The rounded, proximal end is the head of the femur, which articulates with the acetabulum of the hip bone to form the hip joint. The narrowed region below the head is the neck of the femur. The elongated shaft of the femur has a slight anterior bowing or curvature. The distal end of the femur has medial and lateral bony expansions. On the lateral side, the smooth portion that covers the distal and posterior aspects of the lateral expansion is the lateral condyle of the femur. The roughened area on the outer, lateral side of the condyle is the lateral epicondyle of the femur. Similarly, the smooth region of the distal and posterior medial femur is the medial condyle of the femur, and the irregular outer, medial side of this is the medial epicondyle of the femur. The combination of the medial and lateral condyles with the patellar surface gives the distal end of the femur a horseshoe (U) shape.

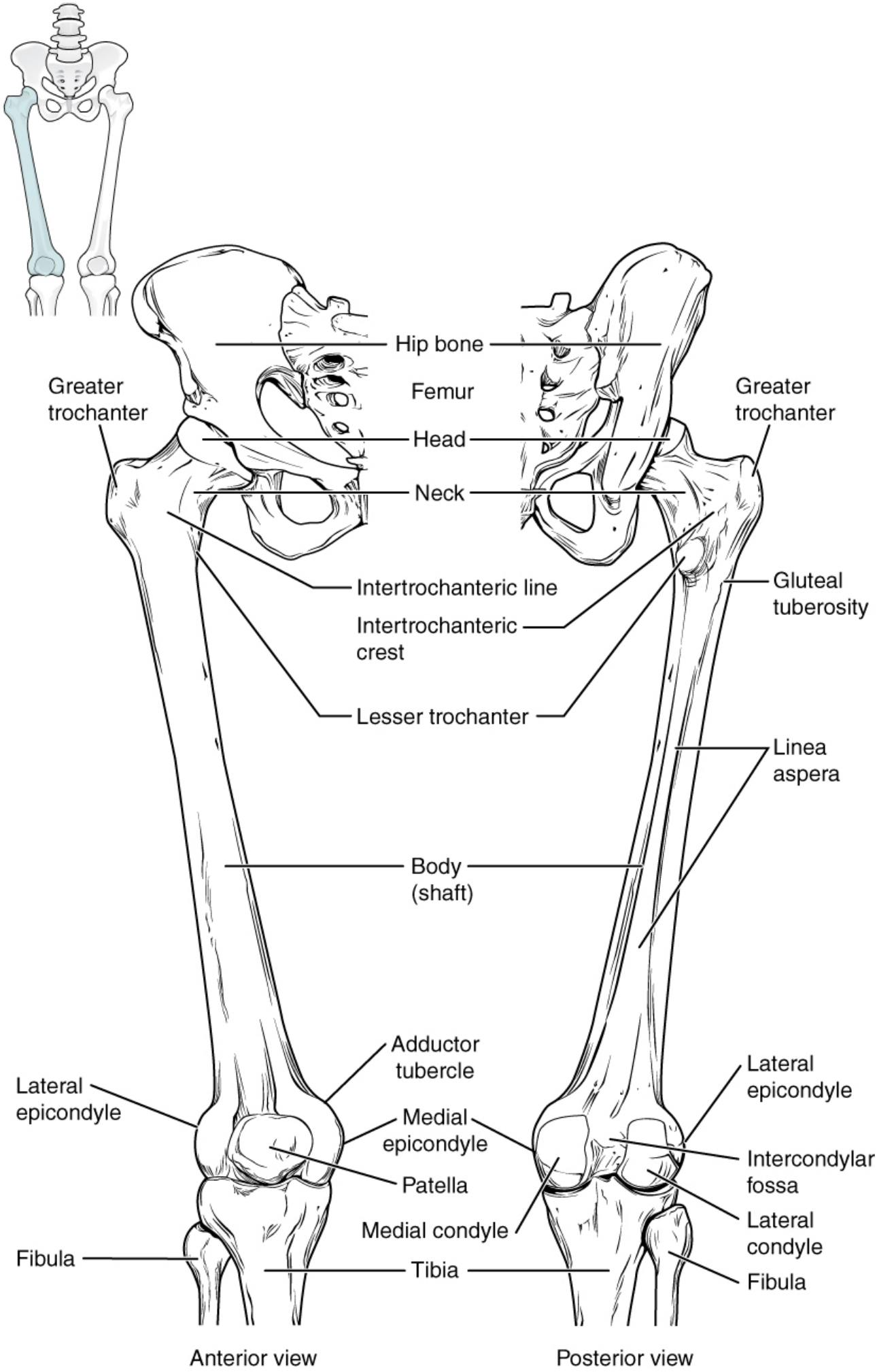

Hip bone
Femur
Greater trochanter
Head
Neck
Greater trochanter
Intertrochanteric line
Intertrochanteric crest
Gluteal tuberosity
Lesser trochanter
Linea aspera
Body (shaft)
Adductor tubercle
Lateral epicondyle
Medial epicondyle
Lateral epicondyle
Patella
Intercondylar fossa
Medial condyle
Lateral condyle
Fibula
Tibia
Fibula
Anterior view
Posterior view

Figure 8.11 Femur The femur is the single bone of the thigh region. It articulates superiorly with the hip bone at the hip joint, and inferiorly with the tibia at the knee joint. The patella only articulates with the distal end of the femur.

The Tibia and Fibula

The tibia (shin bone) is the medial bone of the leg and is larger than the fibula, with which it is paired (Figure 8.12). The tibia is the main weight-bearing bone of the lower leg and the second longest bone of the body, after the femur. The proximal end of the tibia is greatly expanded. The two sides of this expansion form the medial condyle of the tibia and the lateral condyle of the tibia.

The fibula is the slender bone located on the lateral side of the leg (see Figure 8.12). It serves primarily for muscle attachments and thus is largely surrounded by muscles. The head of the fibula is the small, knob-like, proximal end of the fibula. The distal end of the fibula forms the lateral malleolus, which forms the easily palpated bony bump on the lateral side of the ankle.

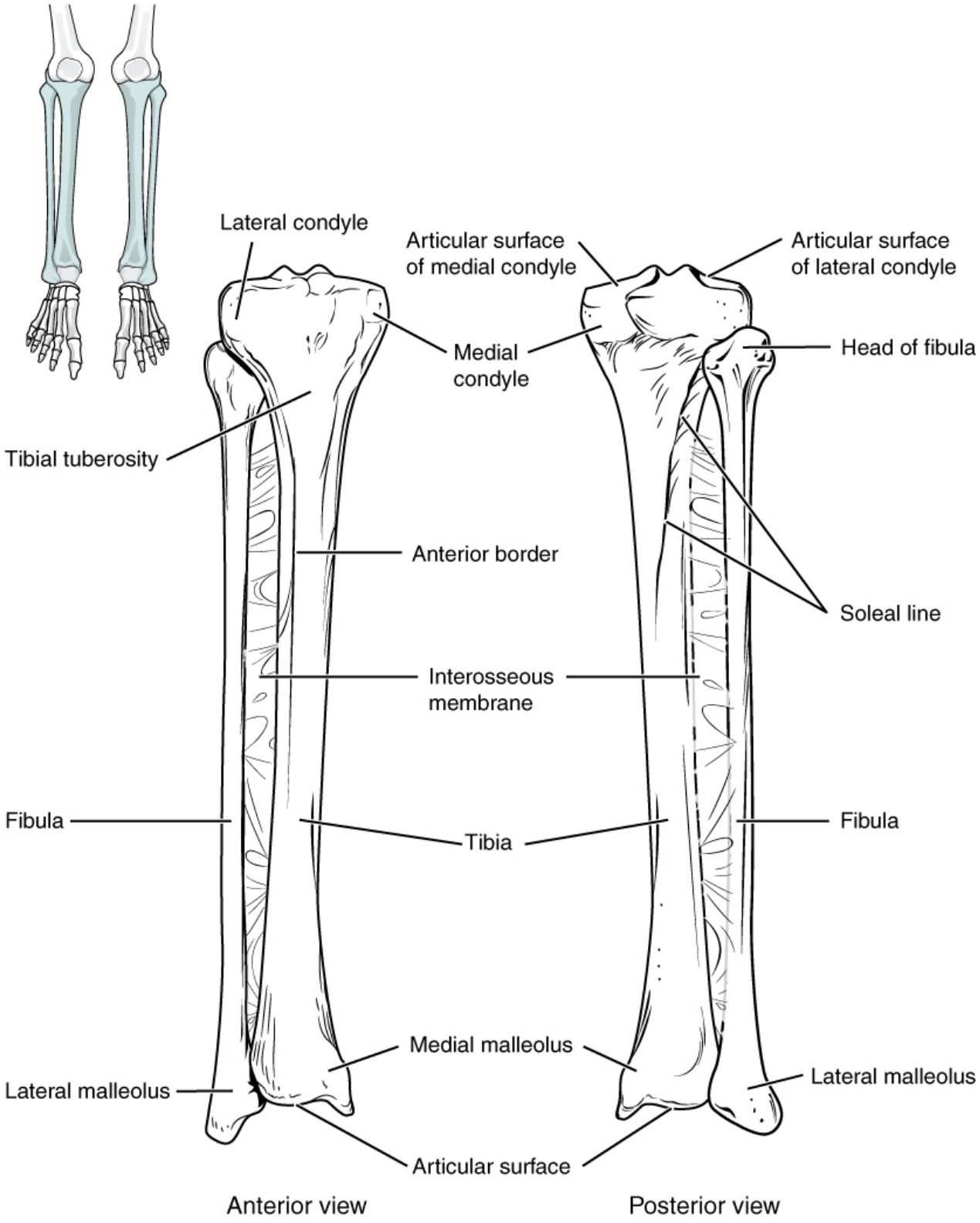


Figure 8.12 Tibia and Fibula The tibia is the larger, weight-bearing bone located on the medial side of the leg. The fibula is the slender bone of the lateral side of the leg and does not bear weight. Anterior view and posterior view of the right leg are shown.

Bones of the Ankle and Foot

The posterior half of the foot is formed by seven tarsal bones (Figure 8.13). The most superior bone is the talus. This has a relatively square-shaped, upper surface that articulates with the tibia and fibula to

form the ankle joint. fibula. Inferiorly, the talus articulates with the calcaneus (heel bone), the largest bone of the foot, which forms the heel.

The anterior half of the foot is formed by the five metatarsal bones, which are located between the tarsal bones of the posterior foot and the phalanges of the toes (see Figure 8.13). These elongated bones are numbered 1–5, starting with the medial side of the foot. The first metatarsal bone is shorter and thicker than the others. The second metatarsal is the longest.

The toes contain a total of 14 phalanx bones (phalanges), arranged in a similar manner as the phalanges of the fingers (see Figure 8.13). The toes are numbered 1–5, starting with the big toe (hallux). The big toe has two phalanx bones, the proximal and distal phalanges. The remaining toes all have proximal, middle, and distal phalanges.

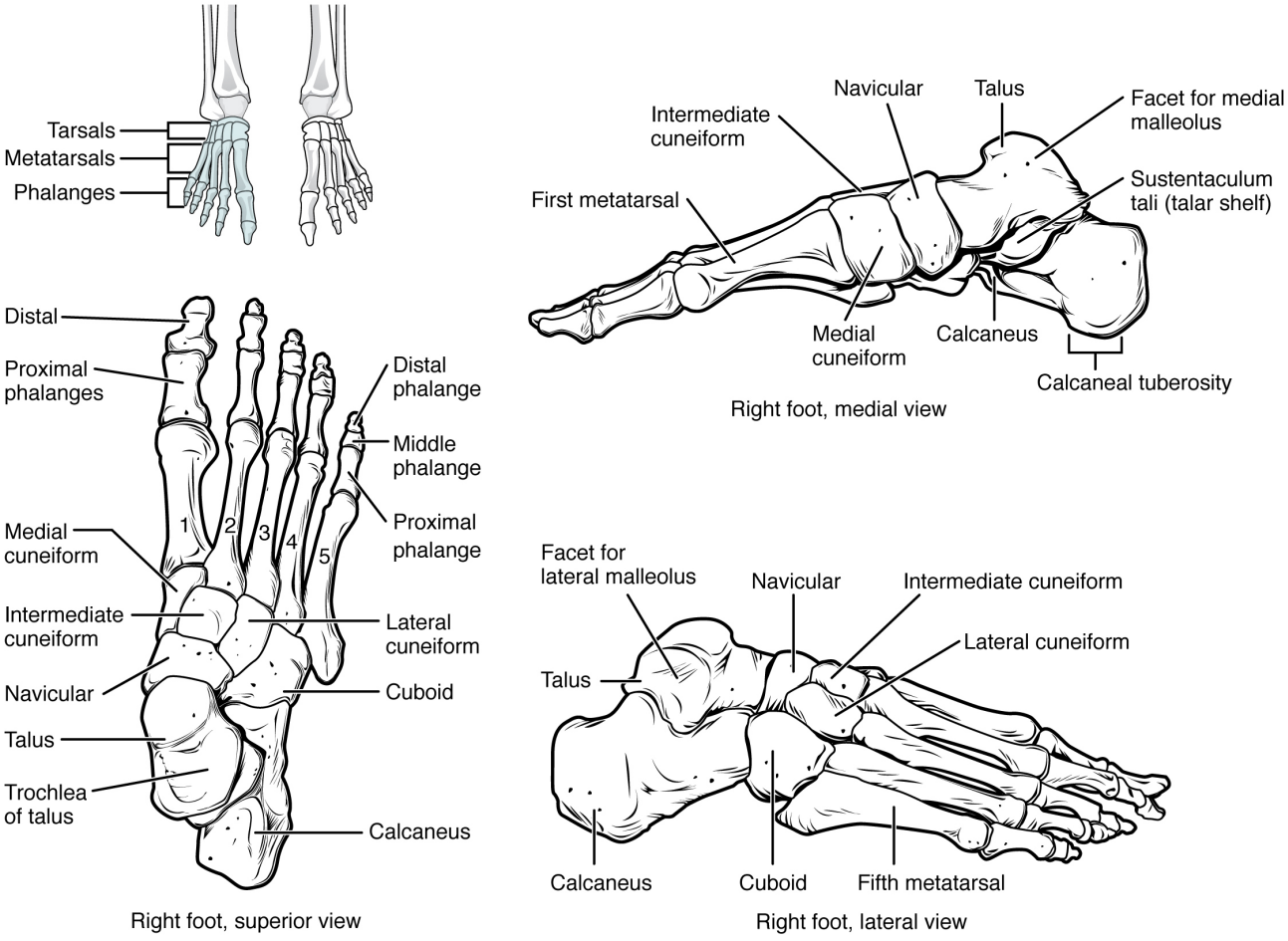


Figure 8.13 Bones of the Foot The bones of the foot are divided into three groups. The posterior foot is formed by the seven tarsal bones. The mid-foot has the five metatarsal bones. The toes contain the phalanges.

Pre-Laboratory Questions

After reading the background information please answer these pre-laboratory questions.

1. Name the main bones of the appendicular skeleton.
2. What are the main bones in the pectoral girdle?
3. Name the bones of the pelvic girdle.
4. Name the long bones in the upper and lower limbs.
5. What are the main wrist and finger bones called?
6. What are the main ankle, foot and toe bones called?

Exercises

- Exercise 1 The Clavicle
- Exercise 2 The Scapula
- Exercise 3 The Upper Limb – Humerus
- Exercise 4 The Upper Limb – Ulna and Radius
- Exercise 5 Wrist and Hand
- Exercise 6 The Hip Bone (Ox Coxa)
- Exercise 7 Male and Female Pelvis
- Exercise 8 The Lower Limb – Femur
- Exercise 9 The Lower Limb – Tibia and Fibula
- Exercise 10 Ankle and Foot

Exercise 1 The Clavicle

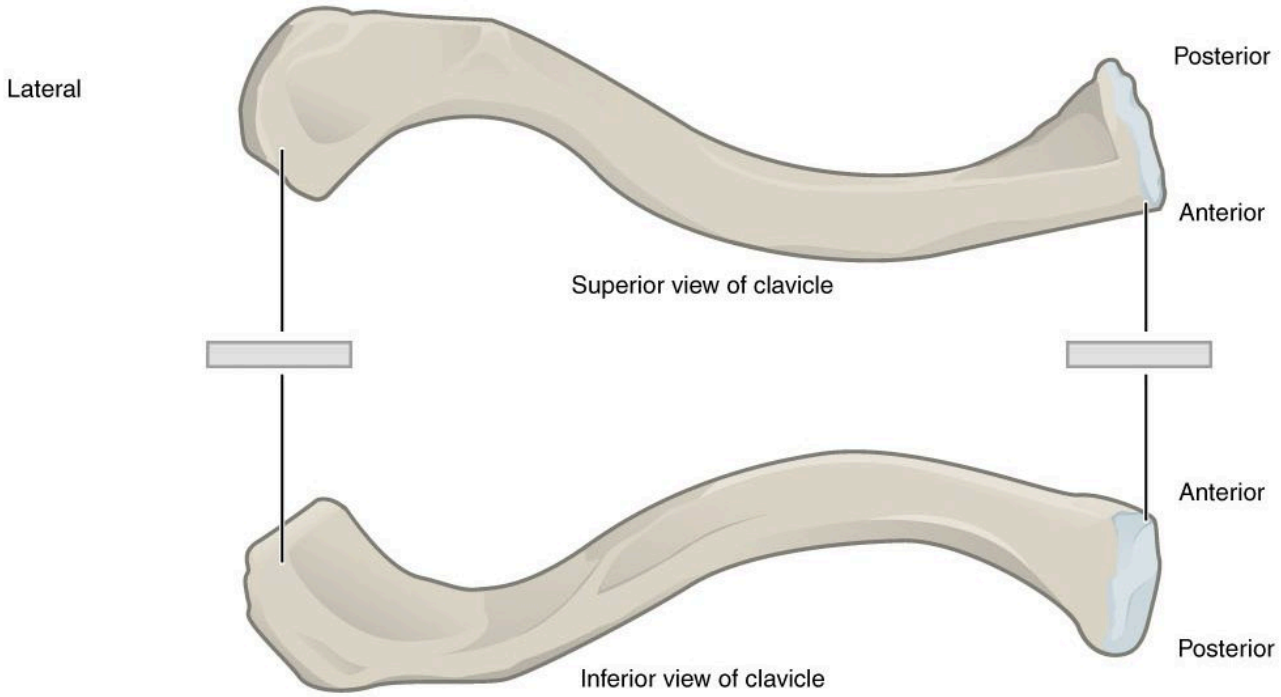
Required Materials

- Clavicle from the disarticulated bones of the skeleton model
- Poster of the skeletal system

Procedure

1. Obtain a clavicle and observe its structures from all sides (Figure 8.3)
2. Identify the structures on the list below and label these on the figure given.

· Acromial end	· Shaft
· Coronoid tubercle	· Sternal end
· Costal tuberosity	



Exercise 2 The Scapula

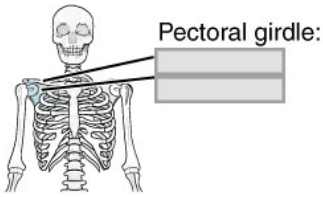
Required Materials

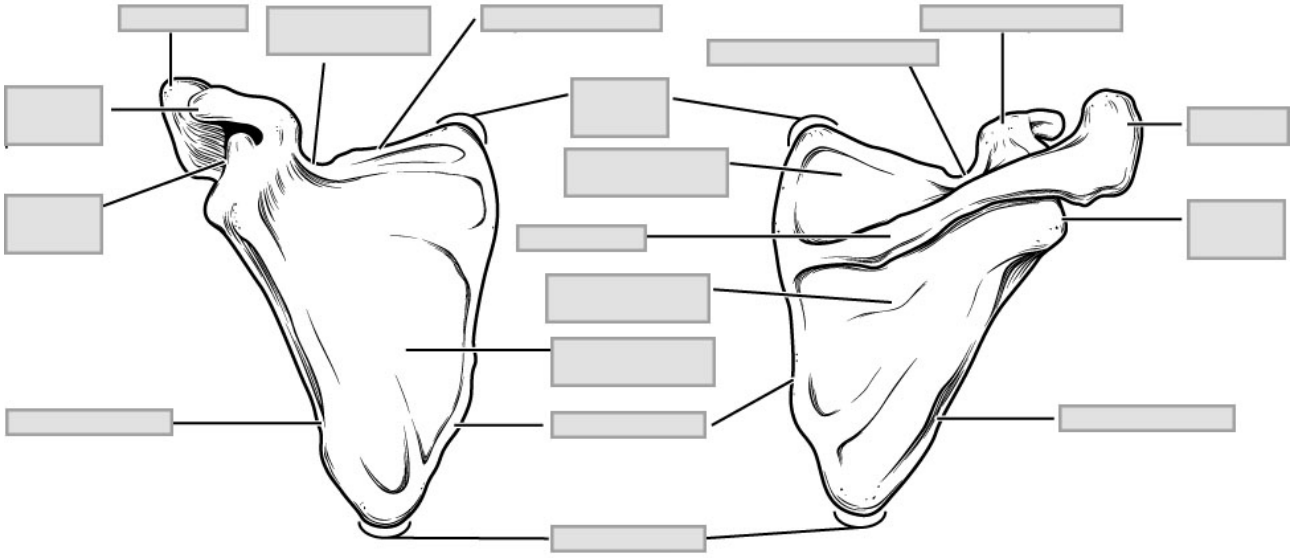
- Scapula from the disarticulated bones of the skeleton model
- Poster of the skeletal system

Procedure

1. Obtain a scapula and observe its structures from all sides (Figure 8.4)
2. Identify the structures on the list below and label these on the figure given.

·	Acromion	·	Spine
·	Glenoid cavity	·	Subscapular space
·	Infraglenoid tubercle	·	Supraglenoid tubercle
·	Infraspinous process	·	Superior angle
·	Inferior angle	·	Superior border
·	Lateral border	·	Suprascapular notch
·	Medial border	·	Supraspinous fossa





Right scapula, anterior aspect

Right scapula, posterior aspect

Exercise 3 The Upper Limb – Humerus

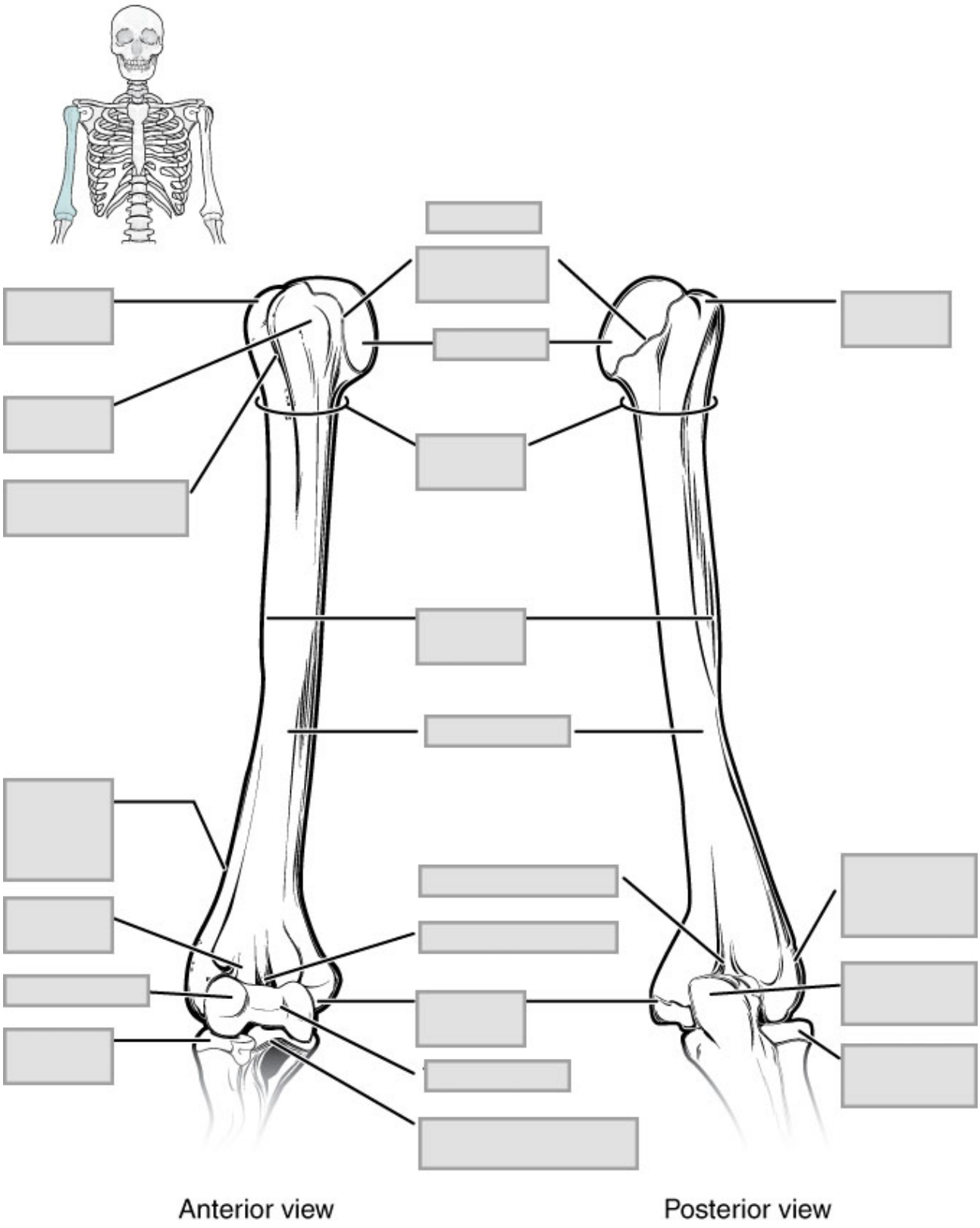
Required Materials

- Humerus from the disarticulated bones of the skeleton model
- Poster of the skeletal system

Procedure

1. Obtain a humerus and observe its structures from all sides (Figure 8.5)
2. Identify the structures on the list below and label these on the figure given.

· Anatomical neck	· Lesser tubercle
· Capitulum	· Lateral supracondylar ridge
· Coronoid fossa	· Medial epicondyle
· Deltoid tuberosity	· Olecranon fossa
· Greater tubercle	· Radial fossa
· Head	· Shaft
· Intertubercular groove	· Supracondylar ridges
· Lateral epicondyle	· Surgical neck



Exercise 4 The Upper Limb – Ulna and Radius

Required Materials

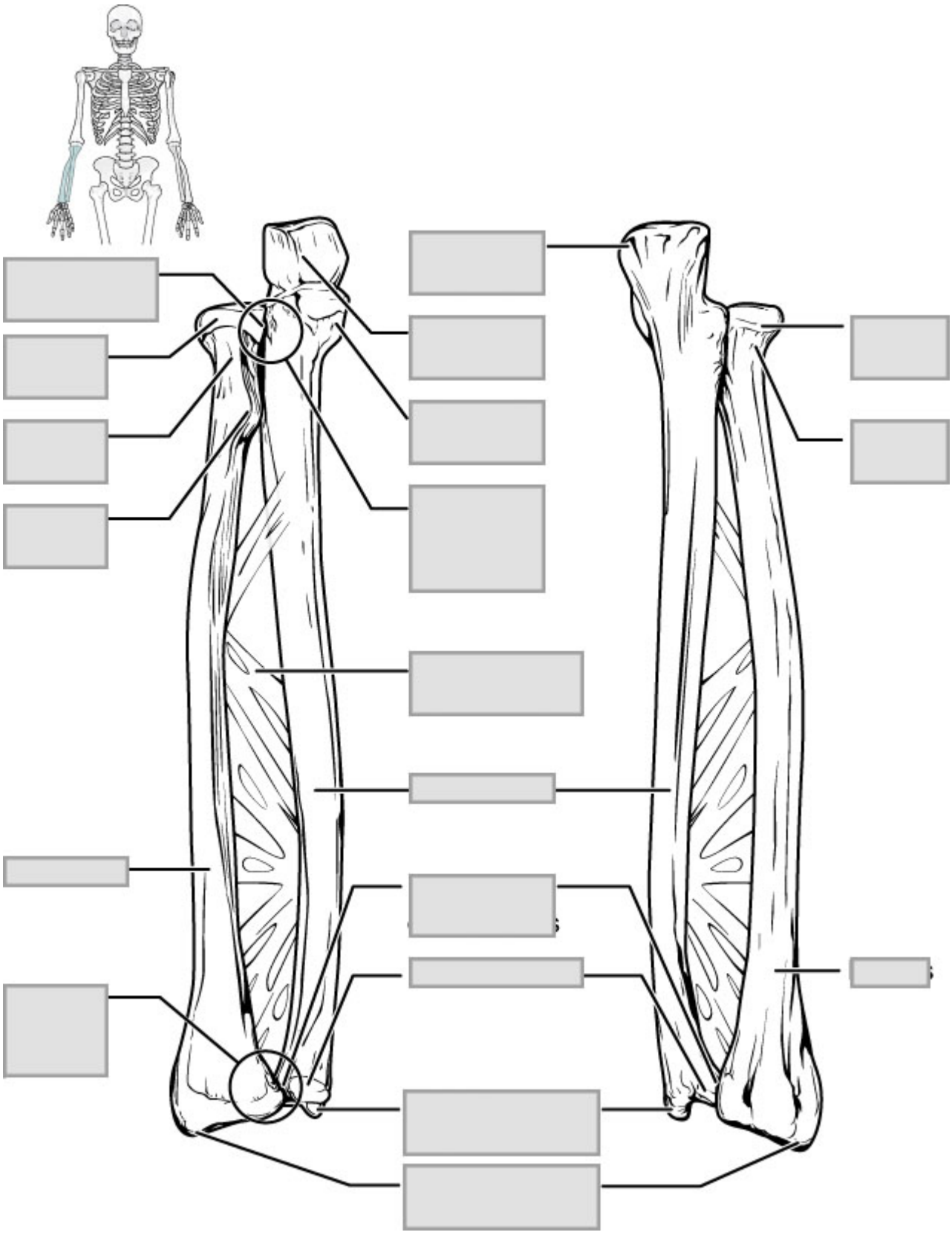
- Radius from the disarticulated bones of the skeleton model

- Ulna from the disarticulated bones of the skeleton model
- Poster of the skeletal system

Procedure

1. Obtain a radius and an ulna and observe its structures from all sides (Figure 8.6)
2. Identify the structures on the list below and label these on the figure given.

·	Coronoid process	·	Radial tuberosity
·	Head of radius	·	Radius
·	Head of ulna	·	Styloid process of radius
·	Neck of radius	·	Styloid process of ulna
·	Olecranon process	·	Trochlear notch
·	Radial notch of ulna	·	Ulna



Exercise 5 Wrist and Hand

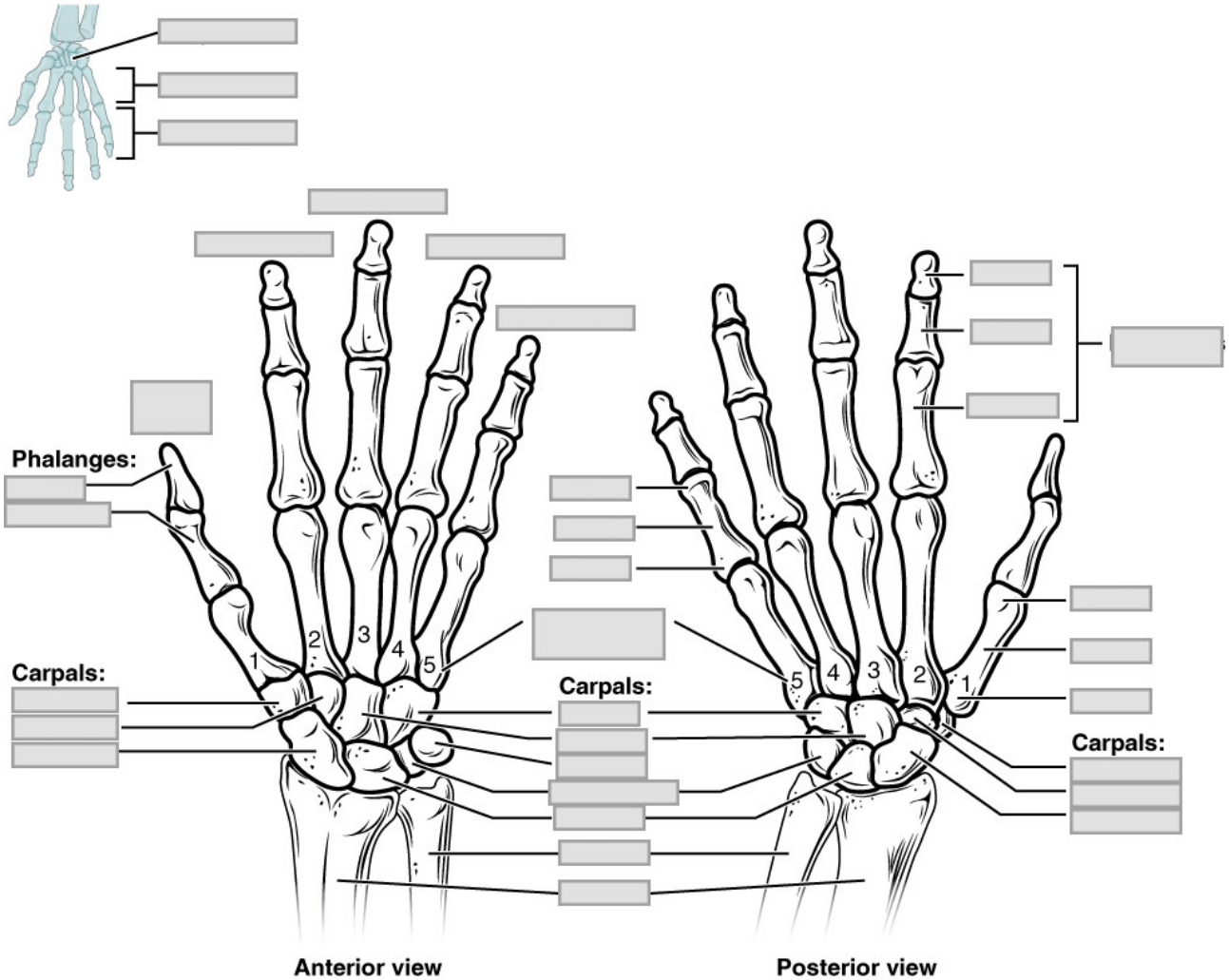
Required Materials

- Wrist and hand from the disarticulated bones of the skeleton model
- Wrist and hand on the articulated skeleton model
- Poster of the skeletal system

Procedure

1. Examine the bones of the wrist and hand from the whole skeleton or a model and observe their structures from all sides (Figure 8.7)
2. Identify the structures on the list below and label these on the figure given.

· Carpals	· Metacarpal IV
· Distal phalanx	· Metacarpal V
· Distal phalanx (pollex)	· Middle phalanx
· Metacarpal I	· Proximal phalanx
· Metacarpal II	· Proximal phalanx (pollex)
· Metacarpal III	



Exercise 6 The Hip Bone (Ox Coxa)

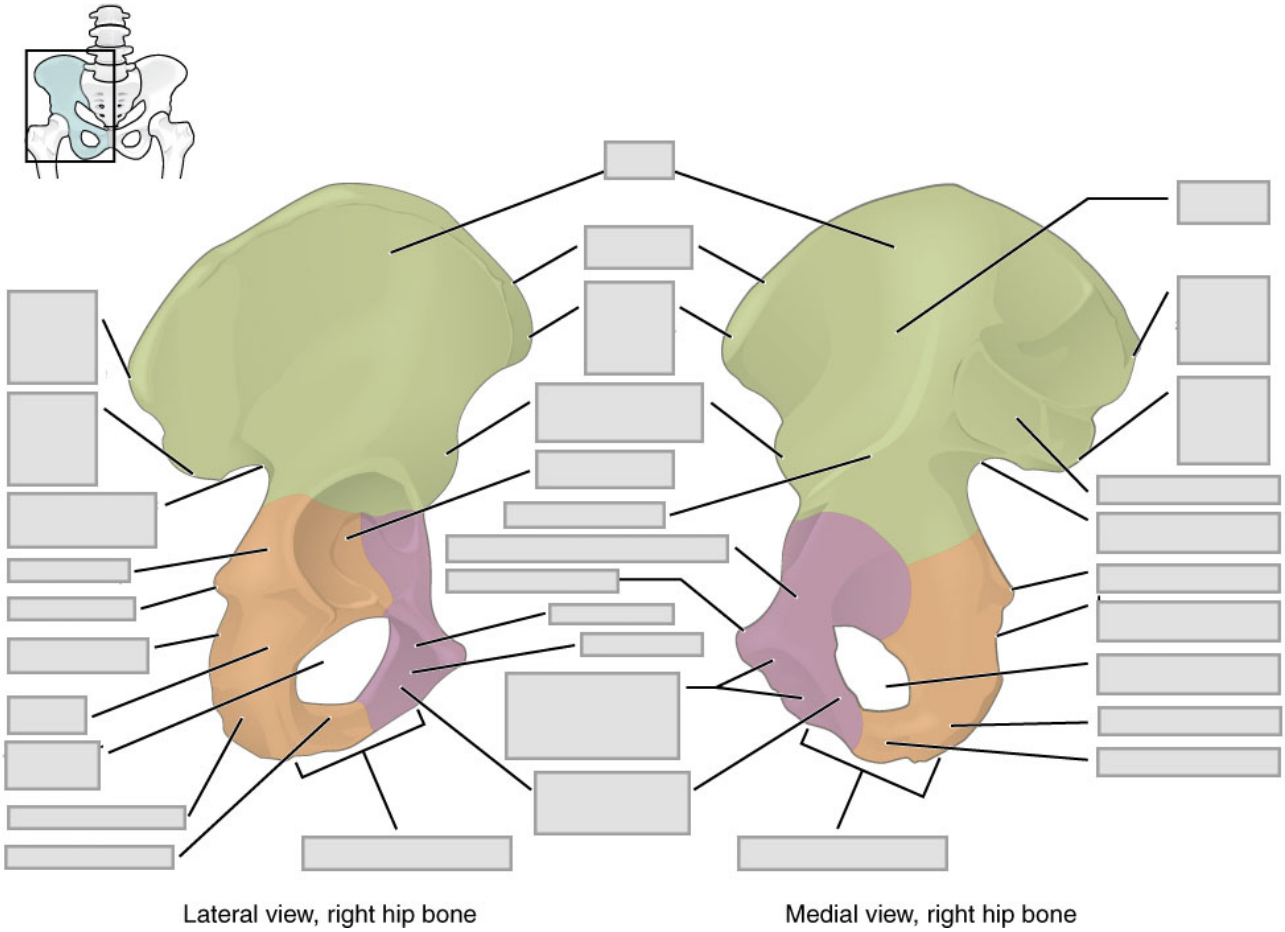
Required Materials

- Hip bone from the disarticulated bones of the skeleton model
- Hip bone on the articulated skeleton model
- Poster of the skeletal system

Procedure

1. Examine the hip bone from the whole skeleton or a model and observe their structures from all sides (Figure 8.9)
2. Identify the structures on the list below and label these on the figure given.

· Acetabulum	· Ischial sciatic notch
· Anterior inferior iliac spine	· Ischial spine
· Anterior superior iliac spine	· Ischial tuberosity
· Arcuate line	· Ischium
· Arcuate surface	· Lesser sciatic notch
· Greater sciatic notch	· Obturator foramen
· Iliac crest	· Posterior inferior iliac spine
· Iliac fossa	· Posterior superior iliac spine
· Ilium	· Pubic body
· Ischial body	· Pubis



Lateral view, right hip bone

Medial view, right hip bone

Exercise 7 Male and Female Pelvis

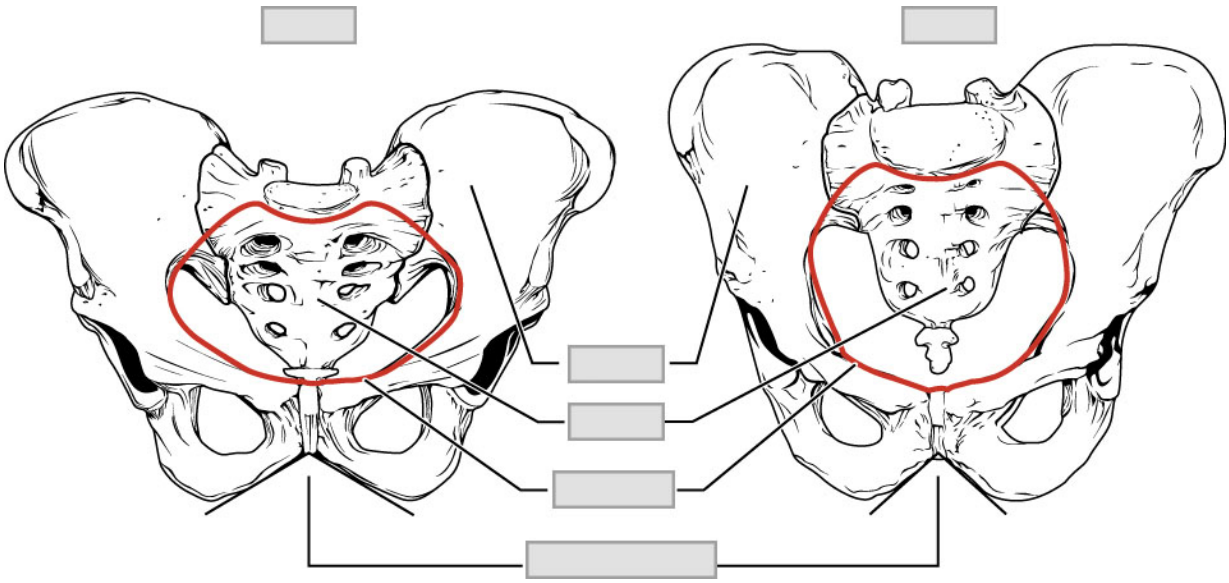
Required Materials

- None

Procedure

1. Examine both the male and female pelvises and observe their structures from all sides (Figure 8.10)
2. Identify the structures in the list below and label these on the figure given.

· Hip bone	· Pelvic inlet
· Obturator foramen	· Sacrum
· Pelvic brim	· Subpubic angle



Exercise 8 The Lower Limb – Femur

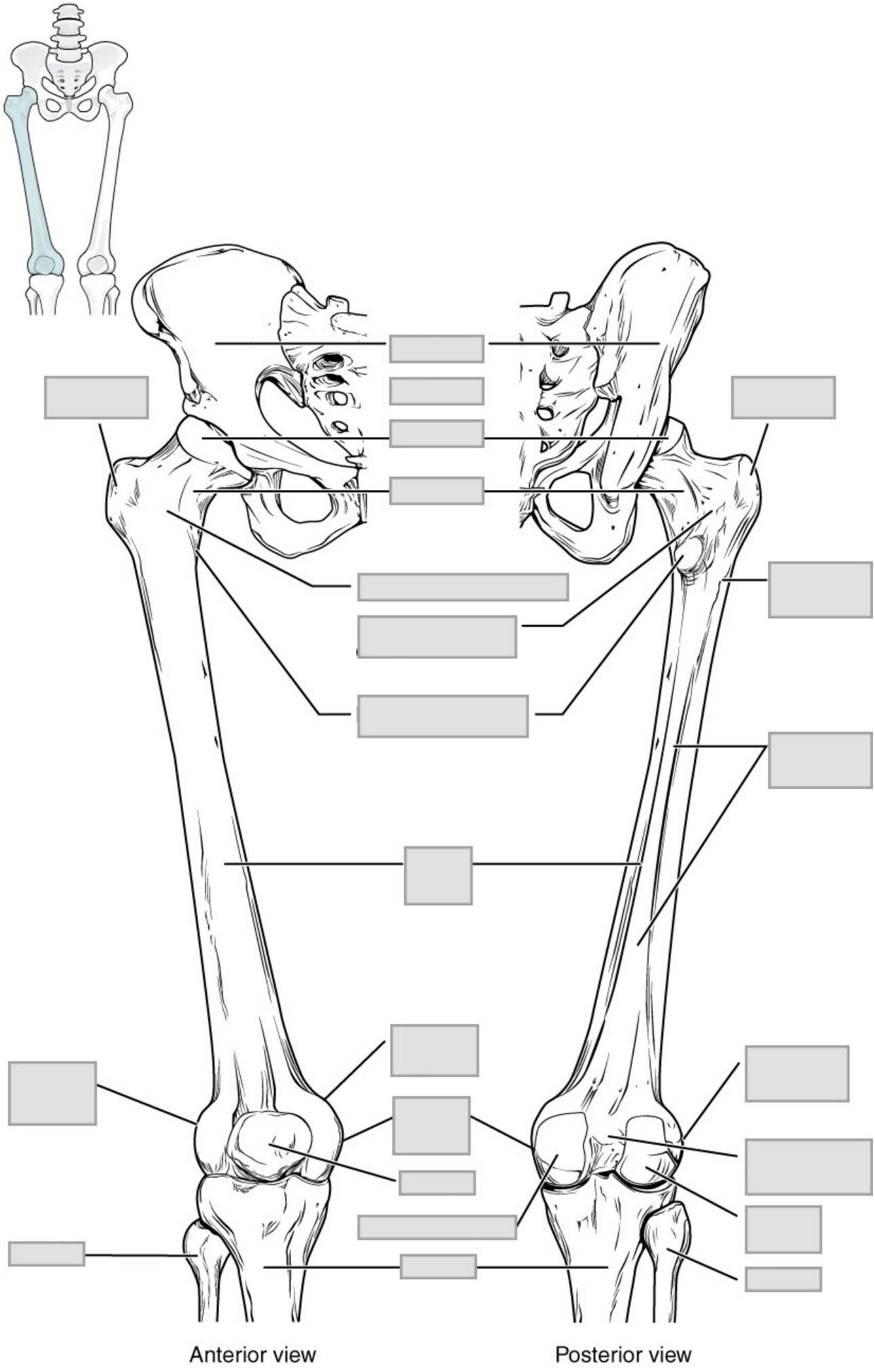
Required Materials

- Femur from disarticulated skeleton model
- Femur on articulated skeleton model
- Poster of the skeletal system

Procedure

1. Examine an isolated femur and observe its parts from all sides (Figure 8.11)
2. Identify the structures in the list below and label these on the figure given.

· Body (shaft)	· Lateral epicondyle
· Gluteal tuberosity	· Medial condyle
· Greater trochanter	· Medial epicondyle
· Head	· Neck
· Lateral condyle	


Anterior view
Posterior view

Exercise 9 The Lower Limb – Tibia and Fibula

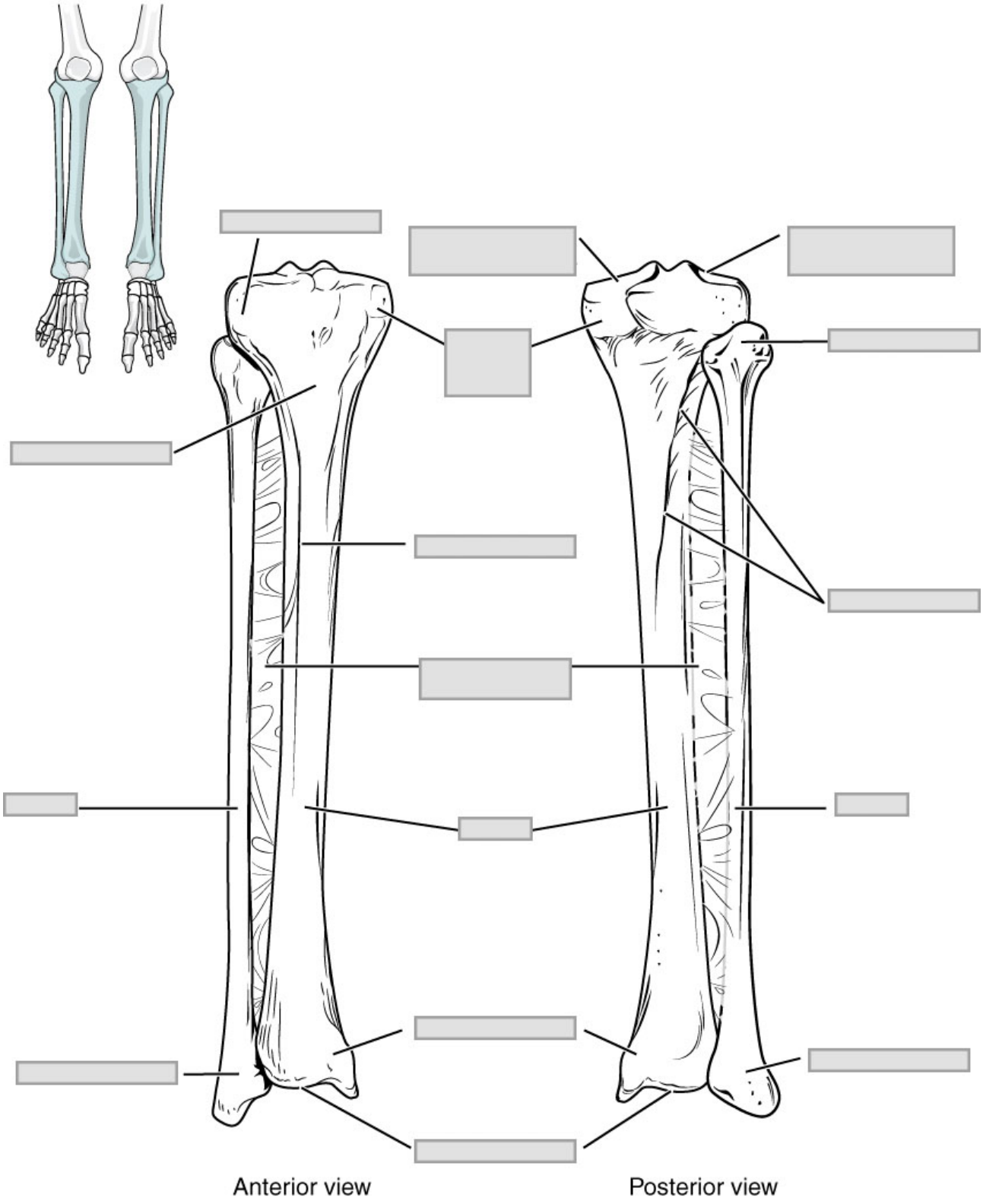
Required Materials

- Tibia and fibula from disarticulated skeleton model
- Tibia and fibula on articulated skeleton model
- Poster of the skeletal system

Procedure

1. Examine an isolated tibia and a fibula and observe its parts from all sides (Figure 8.12)
2. Identify the structures in the list below and label these on the figure given.

· Articular surface	· Lateral malleolus
· Articular surface of lateral epicondyle	· Medial condyle
· Fibula	· Medial malleolus
· Head of fibula	· Tibia
· Interosseous membrane	· Tibial tuberosity
· Lateral condyle	



Exercise 10 Ankle and Foot

Required Materials

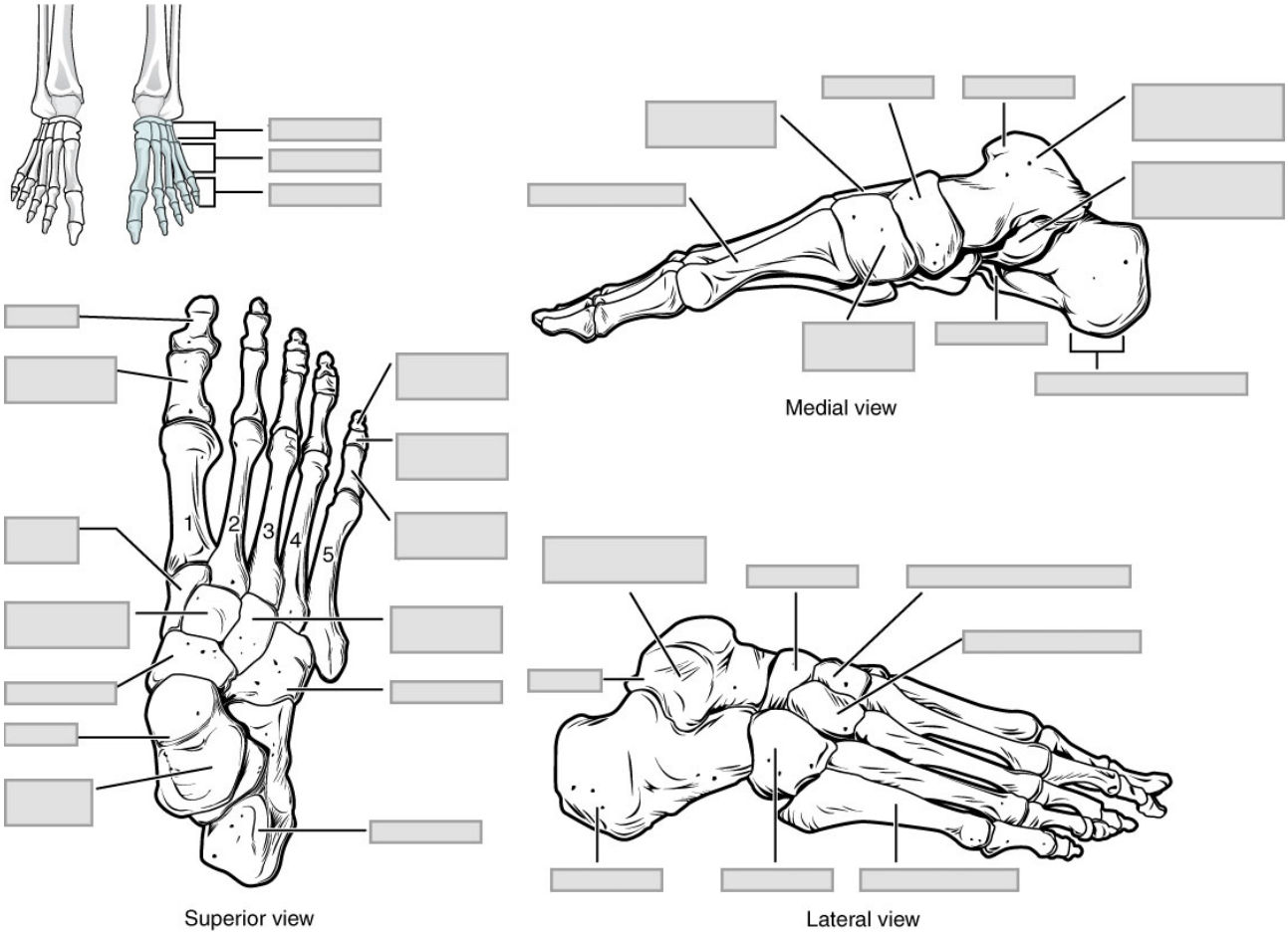
- Foot and ankle bones from disarticulated skeleton model
- Foot and ankle on articulated skeleton model

- Poster of the skeletal system

Procedure

1. Examine the foot and ankle bones from the models and observe its parts from all sides (Figure 8.13)
2. Identify the structures in the list below and label these on the figure given.

Calcaneus	Metatarsal 4
Distal phalanges	Metatarsal 5
Metatarsal 1	Middle phalanges
Metatarsal 2	Proximal phalanges
Metatarsal 3	Talus



Post-laboratory Questions

1. What are some similar features of the upper limb and lower limb long bones?
2. How are the two main bone types of the pectoral girdle (clavicle and scapula) different than the main bones of the pelvic girdle?

3. Compare the organization of the hand bones and foot bones. What are some similarities and differences?

9.

CHAPTER 9 JOINTS

By Ganesan L. Kamatchi

Motivation.

Figure 9.1 Sports Magic Without healthy joints, body movements would be painful or impossible. Artifacts, sculptures, photos and life-sized video projections convey the historical impact on and off the playing field of black athletes on U.S. society. Smithsonian Institution, National Museum of African American History and Culture, Washington, DC. (Credit: "Sports Magic" by the U.S. Department of State on Openverse. Photo by Tim Brown. , license CC-BY-SA)

Osteoarthritis is a type of joint disease that results from breakdown of joint cartilage and underlying bone. The most common symptoms are joint pain and stiffness. Usually, the symptoms progress slowly over years. Initially they may occur only after exercise but can become constant over time. Other symptoms may include joint swelling, decreased range of

motion, and, when the back is affected, weakness or numbness of the arms and legs. The most commonly involved joints are the two near the ends of the fingers and the joint at the base of the thumbs; the knee and hip joints; and the joints of the neck and lower back. Joints on one side of the body are often more affected than those on the other. The symptoms can interfere with work and normal daily activities. Unlike some other types of arthritis, only the joints, not internal organs, are affected. Osteoarthritis is the most common form of arthritis, affecting about 237 million people, or 3.3% of the world's population. In the United States, 30 to 53 million people are affected. It becomes more common as people become older.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Define and classify articulations
- Classify fibrous joints with examples
- Describe and classify cartilaginous joints
- Describe and classify synovial joints
- Describe the types of movements possible in synovial joints

Background.

The adult human body has 206 bones, and with the exception of the hyoid bone in the neck, each bone is connected to at least one other bone. Joints are the location where bones come together. Many joints allow for movement between the bones. At these joints, the articulating surfaces of the adjacent bones can move smoothly against each other. However, the bones of other joints may be joined to each other by connective tissue or cartilage. These joints are designed for stability and provide for little or no movement. Importantly, joint stability and movement are related to each other. This means that stable joints allow for little or no mobility between the adjacent bones. Conversely, joints that provide the most movement between bones are the least stable. Understanding the relationship between joint structure and function will help to explain why particular types of joints are found in certain areas of the body.

The articulating surfaces of bones at stable types of joints, with little or no mobility, are strongly united to each other. For example, most of the joints of the skull are held together by **fibrous** connective tissue and do not allow for movement between the adjacent bones. This lack of mobility is important because the skull bones serve to protect the brain. Similarly, other joints united by fibrous connective tissue allow for very little movement, which provides stability and weight-bearing support for the body. For example, the tibia and fibula of the leg are tightly united to give stability to the body when standing. At other joints, the bones are held together by **cartilage**, which permits limited movements between the bones. Thus, the joints of the vertebral column only allow for small movements between adjacent vertebrae, but when added together, these movements provide the flexibility that allows your body to twist, or bend to the front, back, or side. In contrast, at joints that allow for wide ranges of motion, the articulating surfaces of the bones are not directly united to each other. Instead, these surfaces are enclosed within a **space filled with lubricating fluid**, which allows the bones to move smoothly against each other. These joints provide greater mobility, but since the bones are free to move in relation to each other, the joint is less stable. Most of the joints between the bones of the appendicular skeleton are this freely moveable type of joint. These joints allow the muscles of the body to pull on a bone and thereby produce movement of that body region. Your ability to kick a soccer ball, pick up a fork, and dance the tango depend on mobility at these types of joints.

Fibrous Joints

At a fibrous joint, the adjacent bones are directly connected to each other by fibrous connective tissue, and thus the bones do not have a joint cavity between them (Figure 9.2 a-c). The gap between the bones may be narrow or wide. There are three types of fibrous joints. A **suture** is the narrow fibrous joint found between most bones of the skull. At a **syndesmosis** joint, the bones are more widely separated but are held together by a narrow band of fibrous connective tissue called a ligament or a wide sheet of connective tissue called an interosseous membrane. This type of fibrous joint is found between the shaft regions of the long bones in the forearm and in the leg. Lastly, a **gomphosis** is the narrow fibrous joint between the roots of a tooth and the bony socket in the jaw into which the tooth fits.

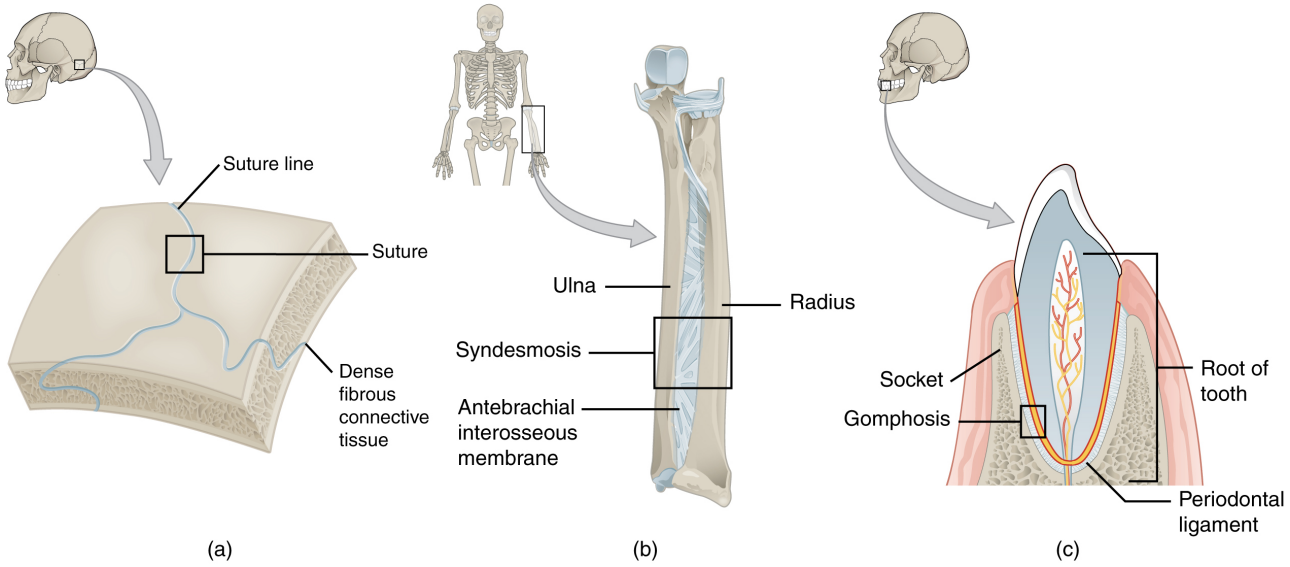


Figure 9.2 Fibrous Joints Fibrous joints form strong connections between bones. (a) **Sutures** join most bones of the skull. (b) An interosseous membrane forms a **syndesmosis** between the radius and ulna bones of the forearm. (c) A **gomphosis** is a specialized fibrous joint that anchors a tooth to its socket in the jaw.

Cartilagenous Joints

As the name indicates, at a cartilaginous joint, the adjacent bones are united by cartilage, a tough but flexible type of connective tissue. These types of joints lack a joint cavity and involve bones that are joined together by either hyaline cartilage or fibrocartilage (Figure 9.3 a-b). There are two types of cartilaginous joints. A **synchondrosis** is a cartilaginous joint where the bones are joined by hyaline cartilage. Also classified as a synchondrosis are places where bone is united to a cartilage structure, such as between the anterior end of a rib and the costal cartilage of the thoracic cage, or in the epiphyseal plate of a growing long bone. The second type of cartilaginous joint is a **symphysis**, where the bones are joined by fibrocartilage. The pubic portions of the right and left hip bones of the pelvis are joined together by fibrocartilage, forming the pubic symphysis. An intervertebral disc unites the bodies of adjacent vertebrae within the vertebral column. Intervertebral discs are made of fibrocartilage and thereby structurally form a symphysis type of cartilaginous joint.

Cartilaginous joints are also functionally classified as either a synarthrosis or an amphiarthrosis joint.

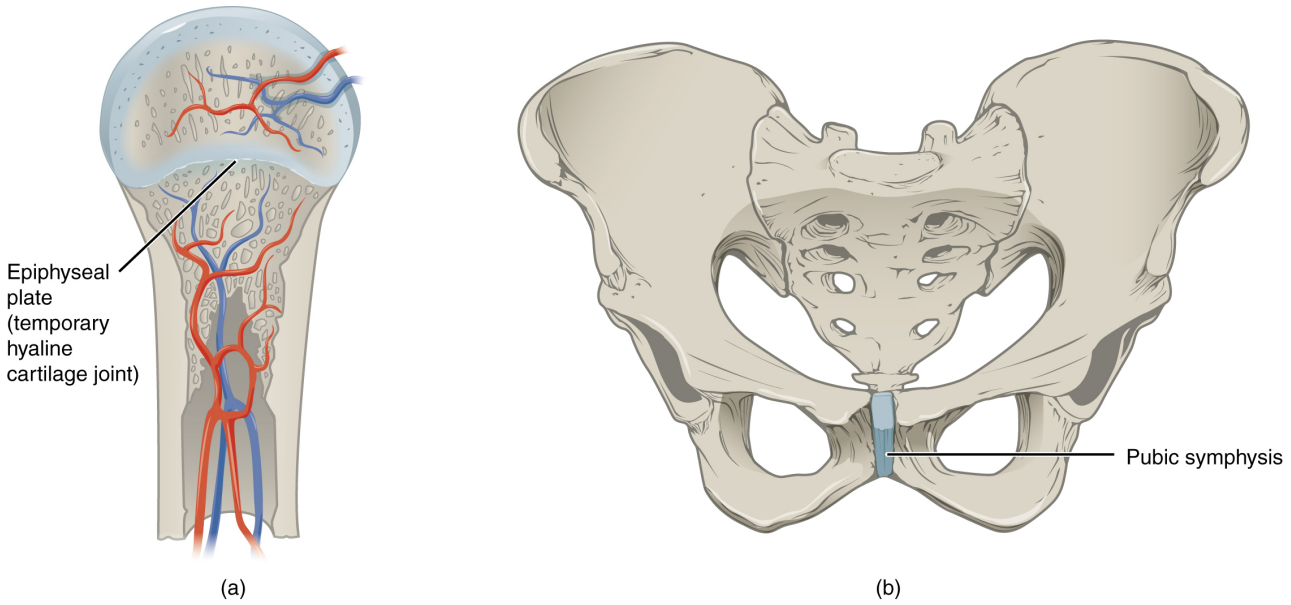


Figure 9.3 Cartilaginous Joints At cartilaginous joints, bones are united by hyaline cartilage to form a synchondrosis or by fibrocartilage to form a symphysis. (a) The hyaline cartilage of the epiphyseal plate (growth plate) forms a synchondrosis that unites the shaft (diaphysis) and end (epiphysis) of a long bone and allows the bone to grow in length. (b) The pubic portions of the right and left hip bones of the pelvis are joined together by fibrocartilage, forming the pubic symphysis.

Synovial Joints

Synovial joints are the most common type of joint in the body (Figure 9.4). A key structural characteristic for a synovial joint that is not seen at fibrous or cartilaginous joints is the presence of a joint cavity. This fluid-filled space is the site at which the articulating surfaces of the bones contact each other. Also unlike fibrous or cartilaginous joints, the articulating bone surfaces at a synovial joint are not directly connected to each other with fibrous connective tissue or cartilage. This gives the bones of a synovial joint the ability to move smoothly against each other, allowing for increased joint mobility.

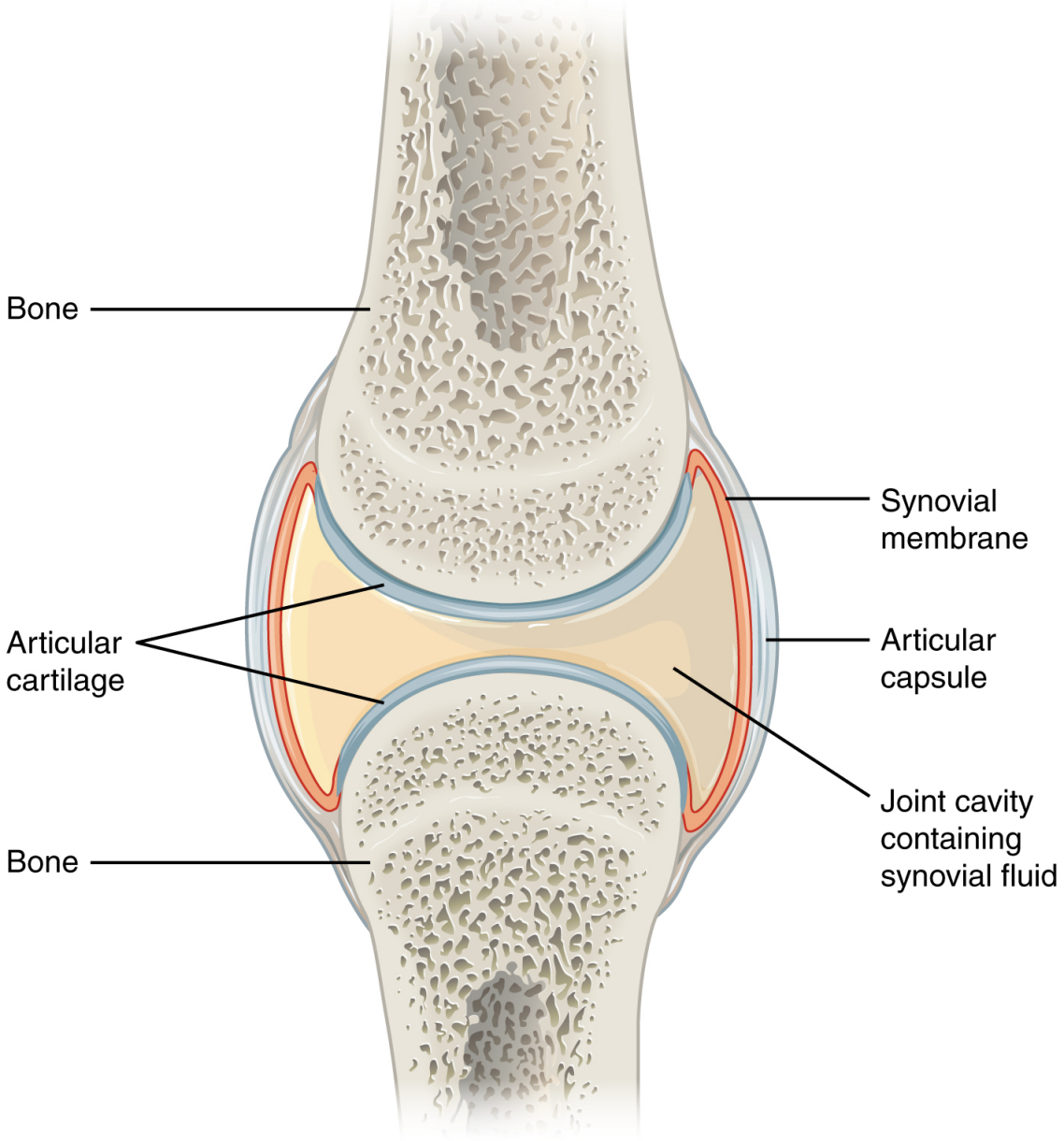


Figure 9.4 Synovial Joints Synovial joints allow for smooth movements between the adjacent bones. The joint is surrounded by an articular capsule that defines a joint cavity filled with synovial fluid. The articulating surfaces of the bones are covered by a thin layer of articular cartilage. Ligaments support the joint by holding the bones together and resisting excess or abnormal joint motions.

Synovial joints are characterized by the presence of a joint cavity. The walls of this space are formed by the articular capsule, a fibrous connective tissue structure that is attached to each bone just outside the area of the bone's articulating surface. The bones of the joint articulate with each other within the joint cavity.

Friction between the bones at a synovial joint is prevented by the presence of the articular cartilage, a thin layer of hyaline cartilage that covers the entire articulating surface of each bone. However, unlike at a cartilaginous joint, the articular cartilages of each bone are not continuous with each other. Instead, the articular cartilage acts like a Teflon® coating over the bone surface, allowing the articulating bones to move smoothly against each other without damaging the underlying bone tissue. Lining the inner surface of the

articular capsule is a thin synovial membrane. The cells of this membrane secrete synovial fluid (synovia = "a thick fluid"), a thick, slimy fluid that provides lubrication to further reduce friction between the bones of the joint. This fluid also provides nourishment to the articular cartilage, which does not contain blood vessels. The ability of the bones to move smoothly against each other within the joint cavity, and the freedom of joint movement this provides, means that each synovial joint is functionally classified as a diarthrosis.

Outside of their articulating surfaces, the bones are connected together by ligaments, which are strong bands of fibrous connective tissue. These strengthen and support the joint by anchoring the bones together and preventing their separation. Ligaments allow for normal movements at a joint, but limit the range of these motions, thus preventing excessive or abnormal joint movements. Ligaments are classified based on their relationship to the fibrous articular capsule. An extrinsic ligament is located outside of the articular capsule, an intrinsic ligament is fused to or incorporated into the wall of the articular capsule, and an intracapsular ligament is located inside of the articular capsule.

At many synovial joints, additional support is provided by the muscles and their tendons that act across the joint. A tendon is the dense connective tissue structure that attaches a muscle to bone. As forces acting on a joint increase, the body will automatically increase the overall strength of contraction of the muscles crossing that joint, thus allowing the muscle and its tendon to serve as a "dynamic ligament" to resist forces and support the joint. This type of indirect support by muscles is very important at the shoulder joint, for example, where the ligaments are relatively weak.

A few synovial joints of the body have a fibrocartilage structure located between the articulating bones. This is called an articular disc, which is generally small and oval-shaped, or a meniscus, which is larger and C-shaped. These structures can serve several functions, depending on the specific joint. In some places, an articular disc may act to strongly unite the bones of the joint to each other. Examples of this include the articular discs found at the sternoclavicular joint or between the distal ends of the radius and ulna bones. At other synovial joints, the disc can provide shock absorption and cushioning between the bones, which is the function of each meniscus within the knee joint. Finally, an articular disc can serve to smooth the movements between the articulating bones, as seen at the temporomandibular joint. Some synovial joints also have a fat pad, which can serve as a cushion between the bones.

Additional structures located outside of a synovial joint serve to prevent friction between the bones of the joint and the overlying muscle tendons or skin. A bursa (plural = bursae) is a thin connective tissue sac filled with lubricating liquid. They are located in regions where skin, ligaments, muscles, or muscle tendons can rub against each other, usually near a body joint (Figure 9.5).

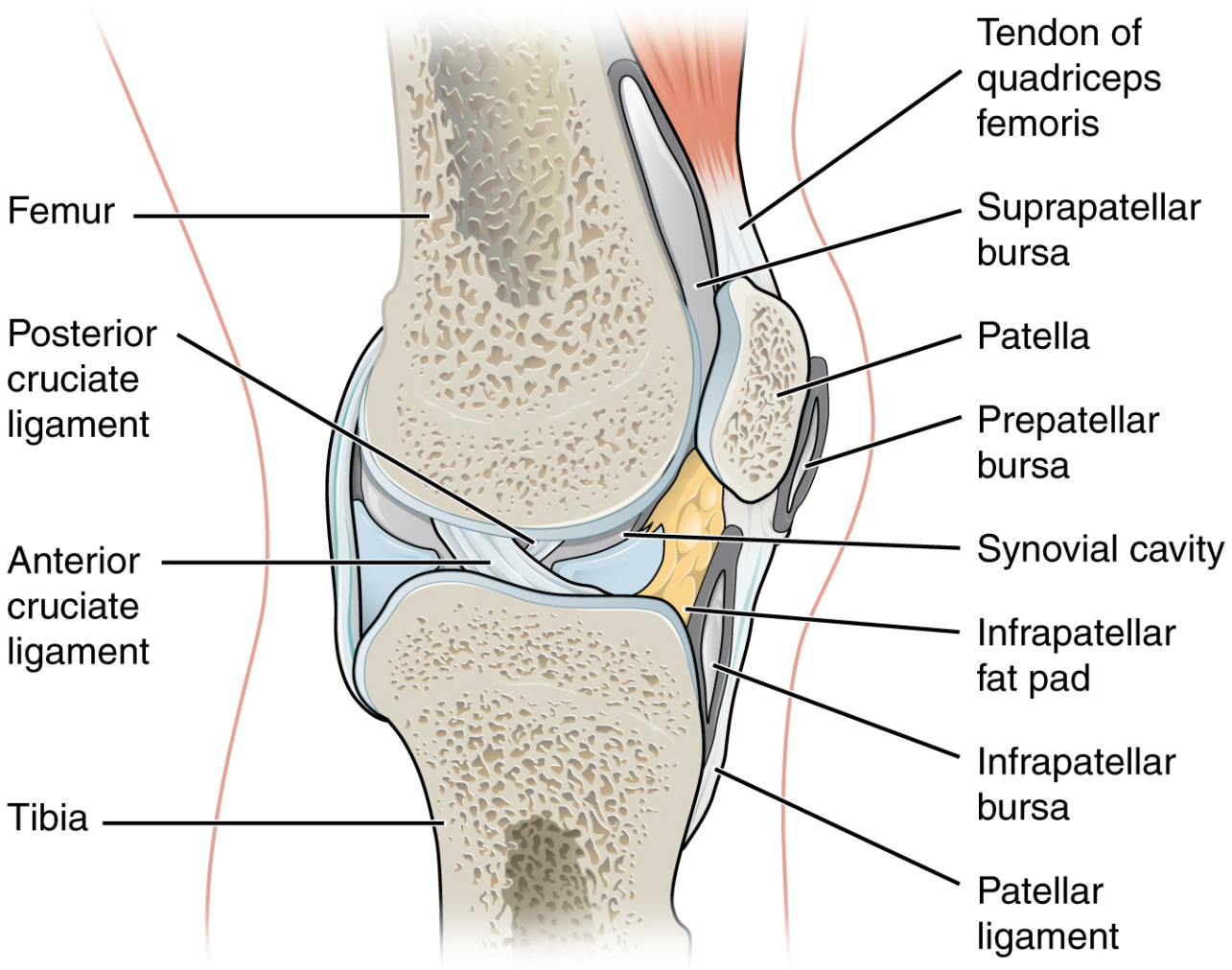


Figure 9.5 Bursae Bursae are fluid-filled sacs that serve to prevent friction between skin, muscle, or tendon and an underlying bone. Three major bursae and a fat pad are part of the complex joint that unites the femur and tibia of the leg.

Bursae reduce friction by separating the adjacent structures, preventing them from rubbing directly against each other. Bursae are classified by their location. A subcutaneous bursa is located between the skin and an underlying bone. It allows skin to move smoothly over the bone. Examples include the prepatellar bursa located over the kneecap and the olecranon bursa at the tip of the elbow. A submuscular bursa is found between a muscle and an underlying bone, or between adjacent muscles. These prevent rubbing of the muscle during movements. A large submuscular bursa, the trochanteric bursa, is found at the lateral hip, between the greater trochanter of the femur and the overlying gluteus maximus muscle. A subtendinous bursa is found between a tendon and a bone. Examples include the subacromial bursa that protects the tendon of shoulder muscle as it passes under the acromion of the scapula, and the suprapatellar bursa that separates the tendon of the large anterior thigh muscle from the distal femur just above the knee.

A tendon sheath is similar in structure to a bursa, but smaller. It is a connective tissue sac that surrounds a muscle tendon at places where the tendon crosses a joint. It contains a lubricating fluid that allows for smooth motions of the tendon during muscle contraction and joint movements.

Classification of Synovial Joints

Synovial joints are subdivided based on the shapes of the articulating surfaces of the bones that form each joint. The six types of synovial joints are pivot, hinge, condyloid, saddle, plane, and ball-and socket-joints (Figure 9.6).

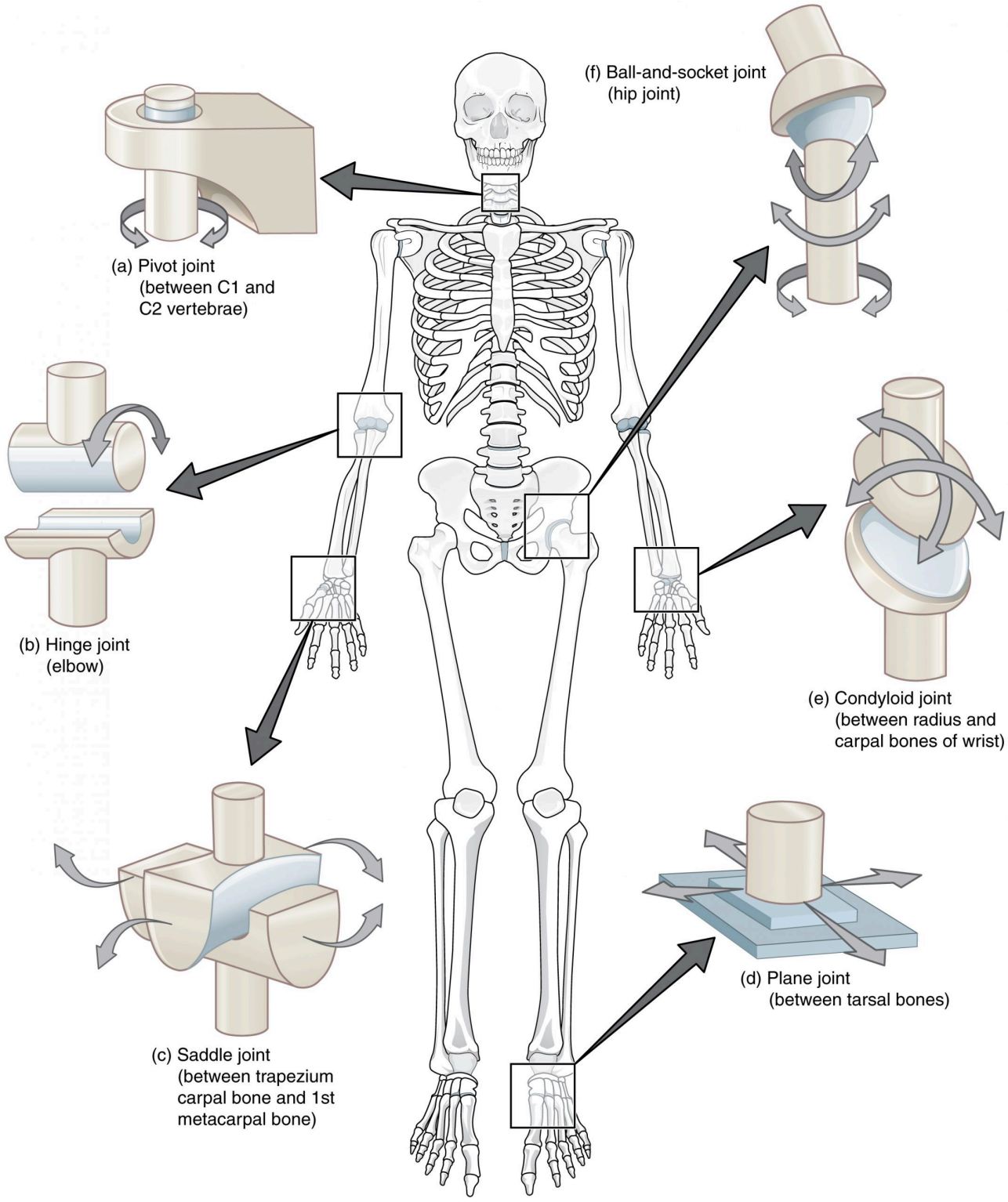


Figure 9.6 Types of Synovial Joints The six types of synovial joints allow the body to move in a variety of ways. (a) **Pivot joints** allow for rotation around an axis, such as between the first and second cervical vertebrae, which allows for side-to-side rotation of the head. (b) The **hinge joint** of the elbow works like a door hinge. (c) The articulation between the trapezium carpal bone and the first metacarpal bone at the base of the thumb is a **saddle joint**. (d) **Plane joints**, such as those between the tarsal bones of the foot, allow for limited gliding movements between bones. (e) The radiocarpal joint of the wrist is a **condyloid joint**. (f) The hip and shoulder joints are the only **ball-and-socket joints** of the body.

Pivot Joint

At a pivot joint, a rounded portion of a bone is enclosed within a ring formed partially by the articulation with another bone and partially by a ligament (see Figure 9.6a). The bone rotates within this ring. Since the rotation is around a single axis, pivot joints are functionally classified as a uniaxial diarthrosis type of joint. An example of a pivot joint is the atlantoaxial joint, found between the C1 (atlas) and C2 (axis) vertebrae. Here, the upward projecting dens of the axis articulates with the inner aspect of the atlas, where it is held in place by a ligament. Rotation at this joint allows you to turn your head from side to side. A second pivot joint is found at the proximal radioulnar joint. Here, the head of the radius is largely encircled by a ligament that holds it in place as it articulates with the radial notch of the ulna. Rotation of the radius allows for forearm movements.

Hinge Joint

In a hinge joint, the convex end of one bone articulates with the concave end of the adjoining bone (see Figure 9.6b). This type of joint allows only for bending and straightening motions along a single axis, and thus hinge joints are functionally classified as uniaxial joints. A good example is the elbow joint, with the articulation between the trochlea of the humerus and the trochlear notch of the ulna. Other hinge joints of the body include the knee, ankle, and interphalangeal joints between the phalanx bones of the fingers and toes.

Saddle Joint

At a saddle joint, both of the articulating surfaces for the bones have a saddle shape, which is concave in one direction and convex in the other (see Figure 9.6c). This allows the two bones to fit together like a rider sitting on a saddle. Saddle joints are functionally classified as biaxial joints. The primary example is the first carpometacarpal joint, between the trapezium (a carpal bone) and the first metacarpal bone at the base of the thumb. This joint provides the thumb the ability to move away from the palm of the hand along two planes. Thus, the thumb can move within the same plane as the palm of the hand, or it can jut out anteriorly, perpendicular to the palm. This movement of the first carpometacarpal joint is what gives humans their distinctive "opposable" thumbs. The sternoclavicular joint is also classified as a saddle joint.

Plane Joint

At a plane joint (gliding joint), the articulating surfaces of the bones are flat or slightly curved and of approximately the same size, which allows the bones to slide against each other (see Figure 9.6d). The motion at this type of joint is usually small and tightly constrained by surrounding ligaments. Based only on their shape, plane joints can allow multiple movements, including rotation. Thus plane joints can be functionally classified as a multiaxial joint. However, not all of these movements are available to every plane joint due to limitations placed on it by ligaments or neighboring bones. Thus, depending upon the specific joint of the body, a plane joint may exhibit only a single type of movement or several movements. Plane joints are found between the carpal bones (intercarpal joints) of the wrist or tarsal bones (intertarsal joints) of the foot, between the clavicle and acromion of the scapula (acromioclavicular joint), and between the superior and inferior articular processes of adjacent vertebrae (zygapophysial joints).

Condyloid Joint

At a condyloid joint (ellipsoid joint), the shallow depression at the end of one bone articulates with a rounded structure from an adjacent bone or bones (see Figure 9.6e). The knuckle (metacarpophalangeal)

joints of the hand between the distal end of a metacarpal bone and the proximal phalanx bone are condyloid joints. Another example is the radiocarpal joint of the wrist, between the shallow depression at the distal end of the radius bone and the rounded scaphoid, lunate, and triquetrum carpal bones. In this case, the articulation area has a more oval (elliptical) shape. Functionally, condyloid joints are biaxial joints that allow for two planes of movement. One movement involves the bending and straightening of the fingers or the anterior-posterior movements of the hand. The second movement is a side-to-side movement, which allows you to spread your fingers apart and bring them together, or to move your hand in a medial-going or lateral-going direction.

Ball-and-Socket Joint

The joint with the greatest range of motion is the ball-and-socket joint. At these joints, the rounded head of one bone (the ball) fits into the concave articulation (the socket) of the adjacent bone (see Figure 9.6f). The hip joint and the glenohumeral (shoulder) joint are the only ball-and-socket joints of the body. At the hip joint, the head of the femur articulates with the acetabulum of the hip bone, and at the shoulder joint, the head of the humerus articulates with the glenoid cavity of the scapula.

Ball-and-socket joints are classified functionally as multiaxial joints. The femur and the humerus are able to move in both anterior-posterior and medial-lateral directions and they can also rotate around their long axis. The shallow socket formed by the glenoid cavity allows the shoulder joint an extensive range of motion. In contrast, the deep socket of the acetabulum and the strong supporting ligaments of the hip joint serve to constrain movements of the femur, reflecting the need for stability and weight-bearing ability at the hip.

Pre-Laboratory Questions

After you complete reviewing the Background information provided, please answer the following questions prior to doing the lab exercises.

1. What is the functional classification of joints?

A) synarthroses.
B) amphiarthroses.
C) diarthroses.
D) all of the above.

2. What is the structural classification of joints?

A) fibrous joint.
B) cartilaginous joint.
C) synovial joint.

D) all of the above.

3. What is the most common type of joint in the human body?

A) fibrous joints.
B) cartilaginous joints.
C) synovial joints.

4. Fibrous joints belong to which functional type of joints?

A) synarthroses.
B) amphiarthroses.
C) diarthroses.

5. What is the only movable bone in the human skull?

A) mandible.
B) frontal.
C) parietal.
D) occipital.

Exercises

- Exercise 1 Fibrous Joints
- Exercise 2 Cartilagenous Joints
- Exercise 3 Synovial Joints

Exercise 1 Fibrous Joints

Exercise 1a. Suture

Required Materials

- Skull models

- Poster of the skeletal system

Procedure

1. Examine a skull model and study the suture joints between the bones of the skull (Figure 9.2a).
2. Identify the structures in the list below and label these on the figure given.

·	Frontal bone	·	Name of suture 3
·	Name of suture 1	·	Parietal bone
·	Name of suture 2	·	Occipital bone

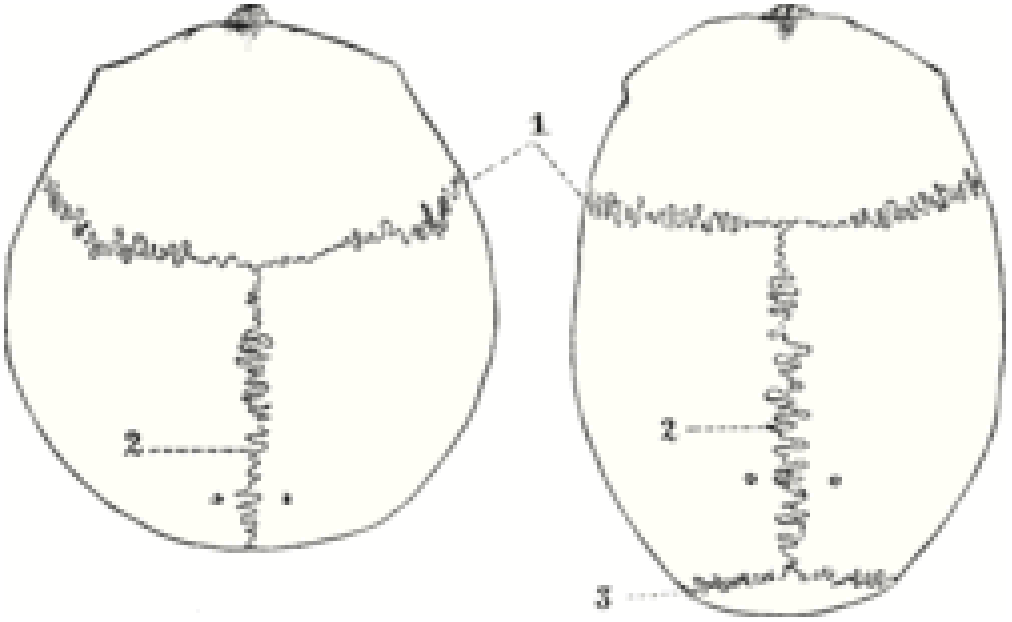


Image credit: Wikipedia. By Julius Collmann, License, Public Domain

Exercise 1b. Syndesmosis

Required Materials

- Articulated skeleton model
- Poster of the skeletal system

Procedures

1. Examine the whole skeleton and observe the joint between the radius and ulna and its parts from all sides (Figure 9.2b)
2. Identify the structures in the list below and label these on the figure given.

·	Antebrachial interosseous membrane	·	Ulna
·	Radius		

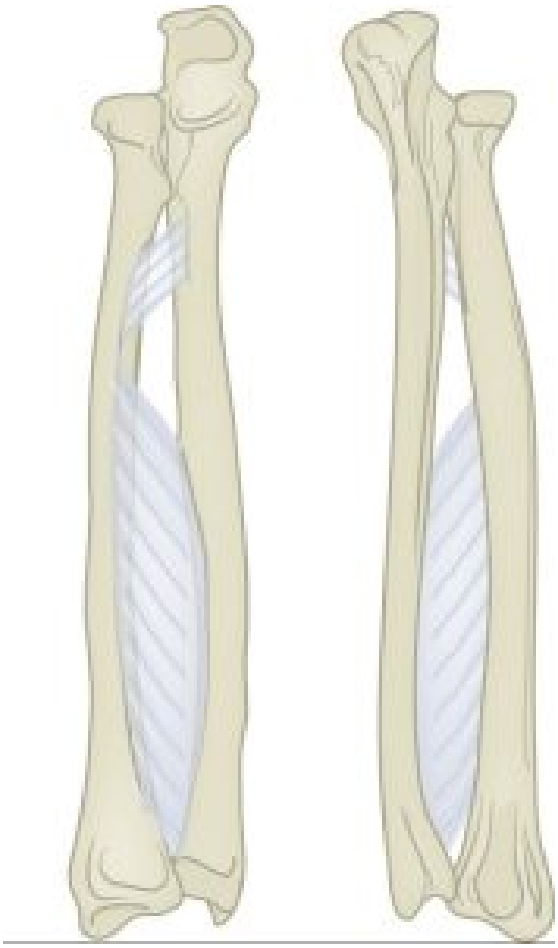


Image credit: "Slagter – Drawing Radius and ulna separate and with interosseous membrane – no labels" at AnatomyTOOL.org by Ron Slagter, LUMC, license: Creative Commons Attribution-NonCommercial-ShareAlike

Exercise 1c. Gomphosis

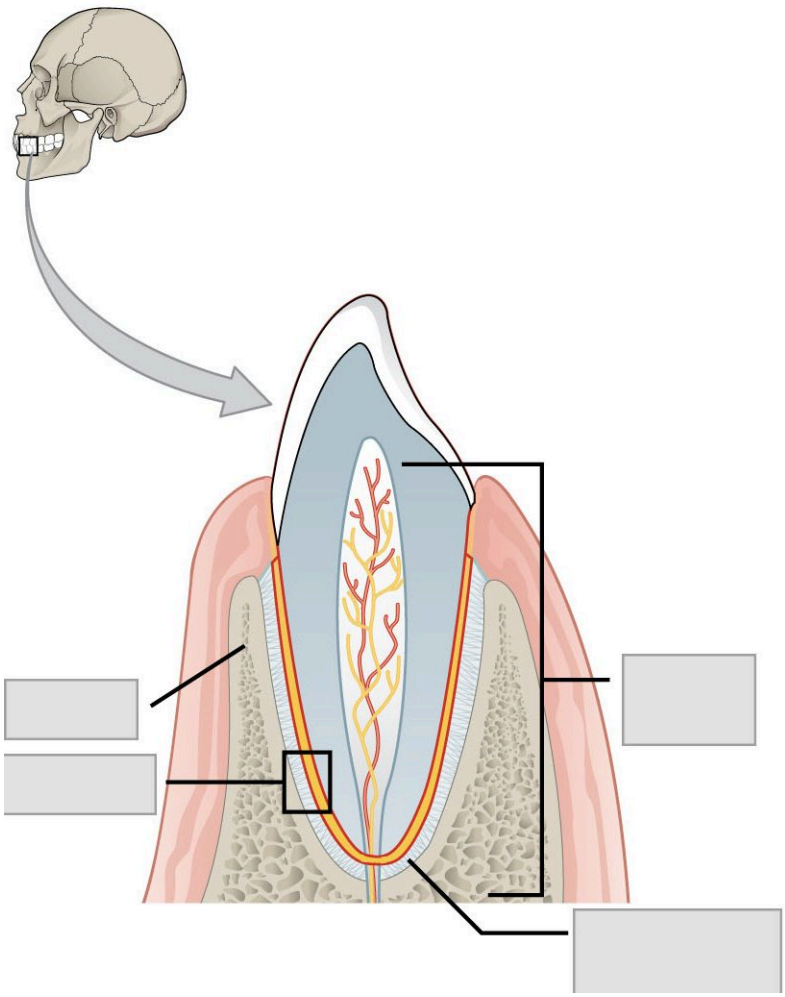
Required Materials

- Tooth in the human digestive system model
- Model of Half of the Human Head
- Median Section of the Head Model
- Skull model
- Poster of the skeletal system

Procedure

1. Examine a model of gomphosis joint and observe its parts from all sides (Figure 9.2c)
2. Identify the structures in the list below and label them in the figure given.

·	Alveolar process of mandible	·	Periodontal ligament
·	Gomphosis	·	Root of tooth



Exercise 2 Cartilaginous Joints

Exercise 2a. Synchondrosis

In a long bone, the hyaline cartilage of the epiphyseal plate (growth plate) forms a synchondrosis that unites the shaft (diaphysis) and end (epiphysis) of the bone and allows the bone to grow in length. The costochondral joint between the first rib and the manubrium of the sternum also forms a synchondrosis.

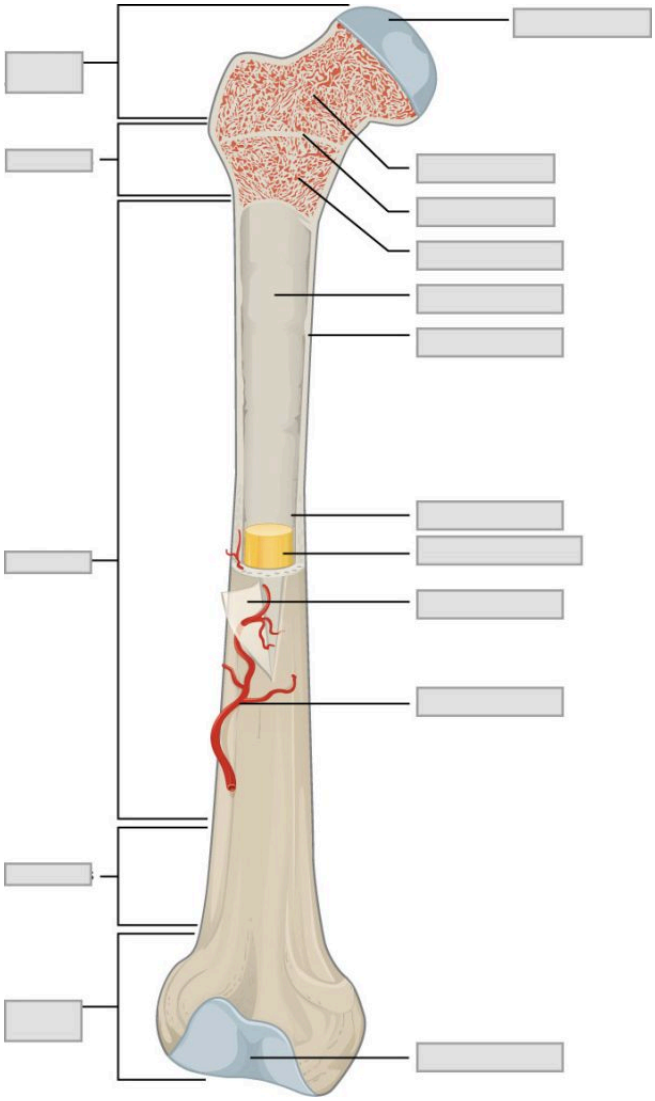
Required Materials

- Rib cage on articulated skeleton
- Cut long bones on bone tissue model
- Poster of the skeletal system

Procedure

1. Examine a longitudinal section of a long bone and the rib cage and study the synchondrosis joint.
2. Identify the structures in the list below and label these on the figures given.

· Body	· First rib
· Clavicle	· Manubrium
· Diaphysis	· Clavicle
· Epiphyseal plate	· Xiphoid process
· Epiphysis	



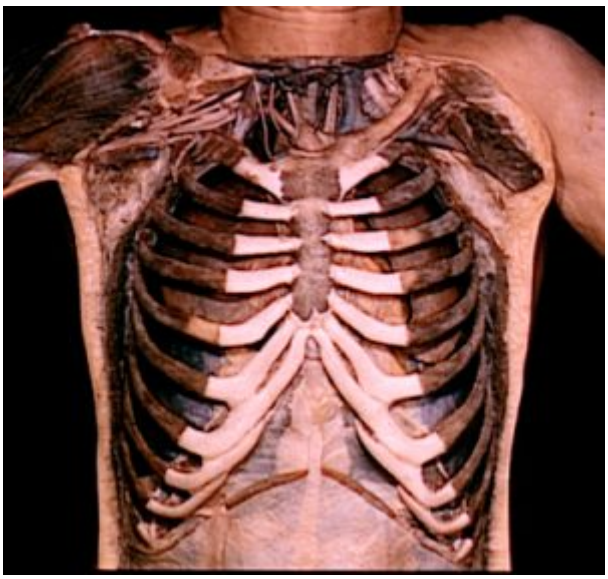


Image Credit: Bassett Collection of Stereoscopic Images of Human Anatomy, Image #116-2, license CC-BY-SA

Exercise 2b. Symphysis

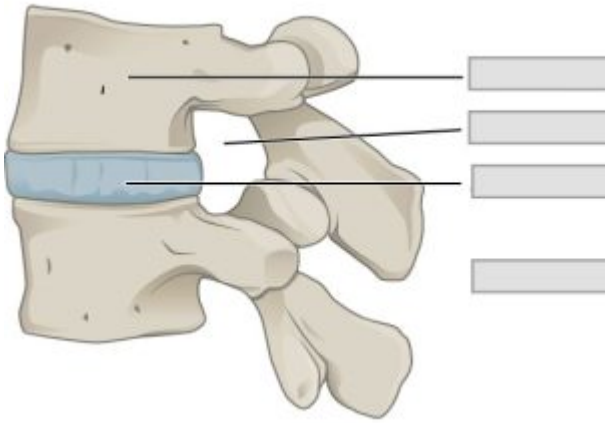
Required Materials

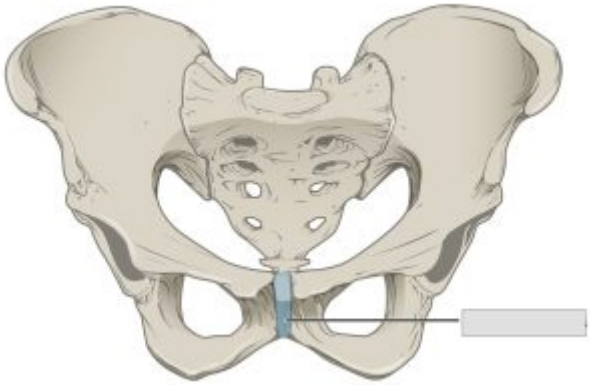
- Flexible vertebrate column model (with pelvic girdle)
- Poster of the skeletal system

Procedure

1. Examine a pelvic girdle and vertebral column and study the symphysis joint (Figure 9.3).
2. Identify the structures in the list below and label them on the figures given.

· Acetabulum	· Ischium
· Coccyx	· Pubic symphysis
· Iliac crest	· Pubis
· Ilium	· Sacrum
· Intervertebral disc	· Vertebral body





Exercise 3 Synovial Joints

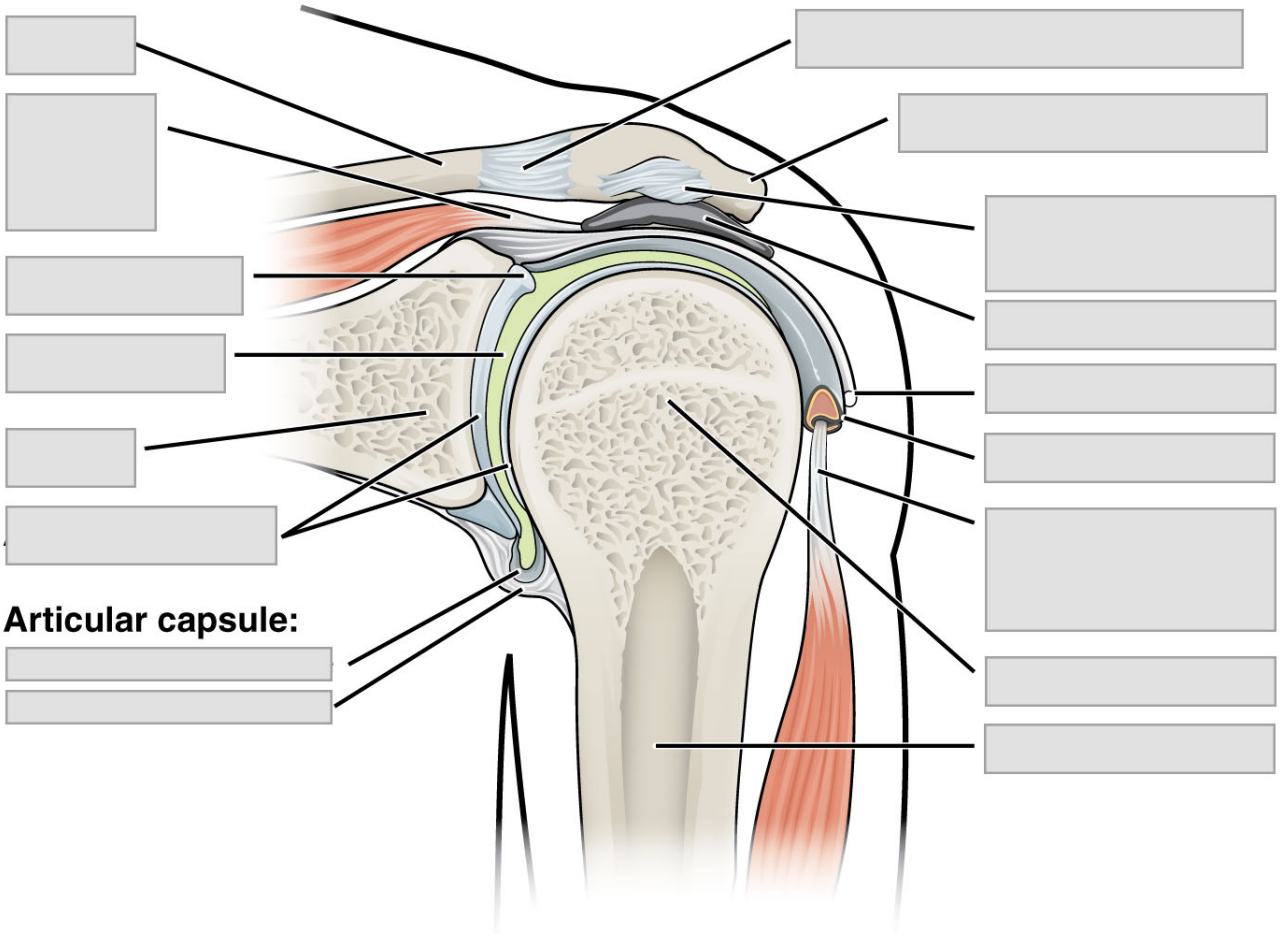
Required Materials

- Miniature functional joints model set
- Articulated skeleton
- Skeletal system poster

Procedure

1. Examine a model of the shoulder joint or the shoulder joint of a skeleton and study the structure of ball-and-socket joint (Figure 4, 5, and 6f).
2. Identify the structures in the list below and label these in the figure given.

- Acromioclavicular joint
- Acromion of scapula
- Articular capsule – synovial membrane
- Articular capsule – fibrous membrane
- Articular capsule
- Articular cartilage
- Clavicle
- Coracoacromial ligament
- Glenoid cavity
- Glenoid labrum
- Head of humerus
- Humerus
- Tendon of supraspinatus muscle
- Scapula
- Subacromial bursa
- Tendon of biceps brachii muscles (long head)
- Tendon sheath



Post-laboratory Questions

1. A synarthrosis is

A) always made of cartilage.
B) a joint that has a capsule.
C) a joint within a fetus that ossifies during early development.

D) immobile.
E) slightly mobile.

2. Which of the following joints contain an interosseous membrane?

A) gomphosis.
B) suture.
C) syndesmosis.

3. A synarthrotic joint would have

A) high mobility and high stability.
B) high mobility and low stability.
C) low mobility and low stability.
D) low mobility and high stability.

4. Functionally, a gomphosis is categorized as a

A) cartilagenous joint.
B) diarthrosis.
C) synarthrosis.
D) synovial joint.

5. In fibrous joints, the articulating surfaces are held together by

A) dense regular connective tissue.
B) areolar connective tissue.
C) dense irregular
D) fibrocartilage.
E) articular cartilage.

6. Structurally, a syndesmosis is a _____ joint; functionally, it is a _____

A) cartilagenous; diarthrosis
B) cartilagenous; amphiarthrosis
C) fibrous; amphiarthrosis
D) fibrous; synarthrosis

E) ball and socket; pivot

7. Sutures are joints that are found

A) throughout the axial and appendicular skeletons.
B) between all bones and teeth of the skull.
C) between certain bones of the skull.
D) only where a facial bone articulates with a cranial bone.

8. The interosseous membrane between the radius and the ulna is an example of a

A) synchondrosis.
B) suture.
C) synostosis.
D) synarthrosis.
E) syndesmosis.

9. The pubic symphysis is classified as a

A) cartilaginous joint and an amphiarthrosis.
B) fibrous joint and a synarthrosis.
C) synovial joint and a diarthrosis.
D) cartilaginous joint and a synarthrosis.
E) fibrous joint and an amphiarthrosis.

10. What type of cartilage is located between the bones in a symphysis?

A) elastic cartilage
B) reticular cartilage
C) hyaline cartilage
D) fibrocartilage

11. What type of cartilage do the intervertebral discs belong to?

A) elastic cartilage

B) reticular cartilage
C) hyaline cartilage
D) fibrocartilage

12. What type of cartilage do the costochondral cartilages belong to?

A) elastic cartilage
B) reticular cartilage
C) hyaline cartilage
D) fibrocartilage

13. An articular capsule is present in

A) fibrous joints.
B) fibrous joints and cartilaginous joints.
C) synovial joints.
D) fibrous joints and synovial joints.
E) all joints.

14. Fluid-filled sacs that cushion synovial joints are called

A) fat pads.
B) articular discs.
C) bursae.
D) menisci.
E) diarthroses.

15. Synovial fluid is

A) a watery fluid produced by capsular ligaments.
B) an oily fluid produced by the synovial membrane.
C) a watery fluid produced by hyaline cartilage.
D) an oily fluid produced by articular cartilage.

16. The largest and most complex synovial joint is the

A) mandibular joint
B) carpal joint
C) elbow joint
D) knee joint
E) finger joints

17. Which joint is the most easily dislocated?

A) mandibular joint.
B) carpal joint.
C) shoulder joint.
D) knee joint.
E) hip joint.

10.

CHAPTER 10 MUSCLE TISSUE

By Joseph D'Silva

Motivation.

Muscles really stand out in athletes. You cannot miss them. The athletes we see here are Shaq O'Neil, Serena Williams and LeBron James. Their skeletal muscles stand out as you can see from the pictures below.

Figure 10.1. Shaquille O'Neal, Serena Williams, and LeBron James. (Credit: Wikimedia)

But athletes suffer injuries to their muscles. You can relate to them because you have seen them carried off the court or field on stretchers. Think of an athlete you have seen because he injured a hamstring muscle! Sports medicine and physiotherapy are huge nowadays. As more and more athletes compete, there will be more muscle injuries and you can contemplate building a career in sports medicine for yourself.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Identify and define muscle fiber.
- State the organelles located in the muscle fiber.
- Compare and contrast skeletal, cardiac and smooth muscle fibers.
- Define neuromuscular junction and state its function.

Background.

We have skeletal muscles in our own bodies (maybe not as big as the athletes' above!). The flesh we are made up of contains muscle tissue and is attached to bones. Muscles are needed to move our body parts. They move our skeleton, heart and gastrointestinal tract. There are three types of muscles: **skeletal**, **cardiac** and **smooth**. Cardiac muscle is in our heart and smooth muscles are located in the walls of our stomach and intestine as well as other tubular organs.

Skeletal muscle functions to help us to move bones. We can will them to do that voluntarily. However, cardiac and smooth muscles are beyond our control and function involuntarily from the time we are in the womb until we pass away. Skeletal muscles need our attention for many reasons. One of them is to maintain posture. Also, to lift weights, anchor ourselves, plant our feet. With age, muscle tone can be lost. Particularly, the elderly skeletal muscles need attention because they do not use their muscles as much as they should resulting in muscle loss. There are also disorders of the musculo-skeletal system that can be debilitating.

To know about muscles, you have to study their histology first. That is, you have to look at muscle tissue under the microscope. Once you know that, you can study the large muscles that stand out in our body. In this chapter, you will learn to identify skeletal, cardiac and smooth muscles.

Skeletal muscles contain tissues that are made up of muscle cells aka muscle fiber (Figure 10.2).

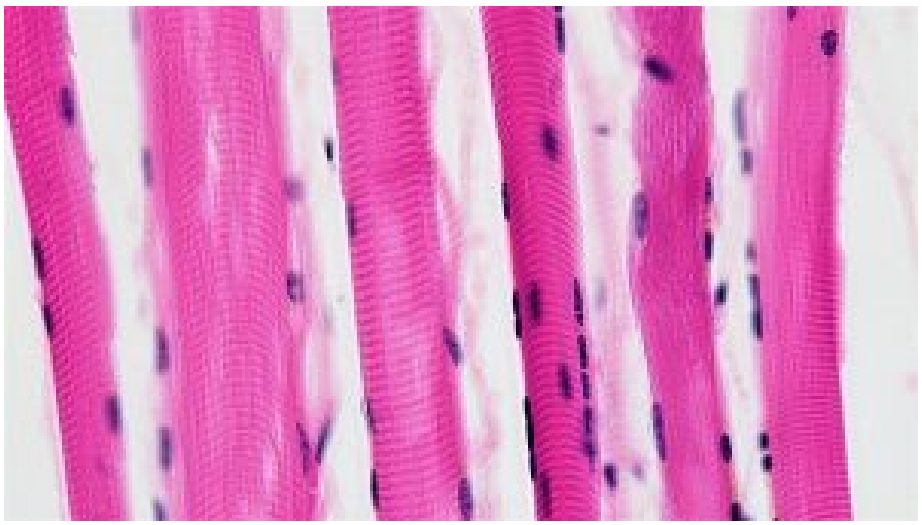


Figure 10.2. Showing skeletal muscle. Notice the striations and multinucleate cytoplasm. The nuclei are dark in color. (Credit: Wikimedia)

Each muscle fiber has a cell membrane (sarcolemma), cell cytoplasm (sarcoplasm) and nucleus. The cytoplasm is dotted with organelles (Figure 10.3): Golgi apparatus, endoplasmic (sarcoplasmic) reticulum, mitochondria, ribosomes, lysosomes, myofibrils and myofilaments, triads, A-band, I-band (Figure 10.4 and 10.5). Each of the many organelles has a particular function. But as a whole they produce relaxation and contraction in muscle tissue.

The sarcolemma is the membrane that covers the muscle cell (Figure 10.3). The cell contains cytoplasm in which myofibrils are very prominent. The myofibrils are surrounded by mitochondria and endoplasmic reticulum. There are three structures around the myofibrils that form the triad: terminal cisterna, T-tubule and sarcoplasmic reticulum (Figure 10.4). The myofibrils contain two protein structures known as myosin and actin. The sarcomere is a unit of structure and function in the muscle cell. It runs from one I-band to another with the A-band in the middle. The I-band and A-band can only be observed with an electron microscope. The A-band is dark. The I-band is light (Figure 10.5). When the sarcomere shortens reducing the distance between the two Z discs, the muscle contracts (Figure 10.5).

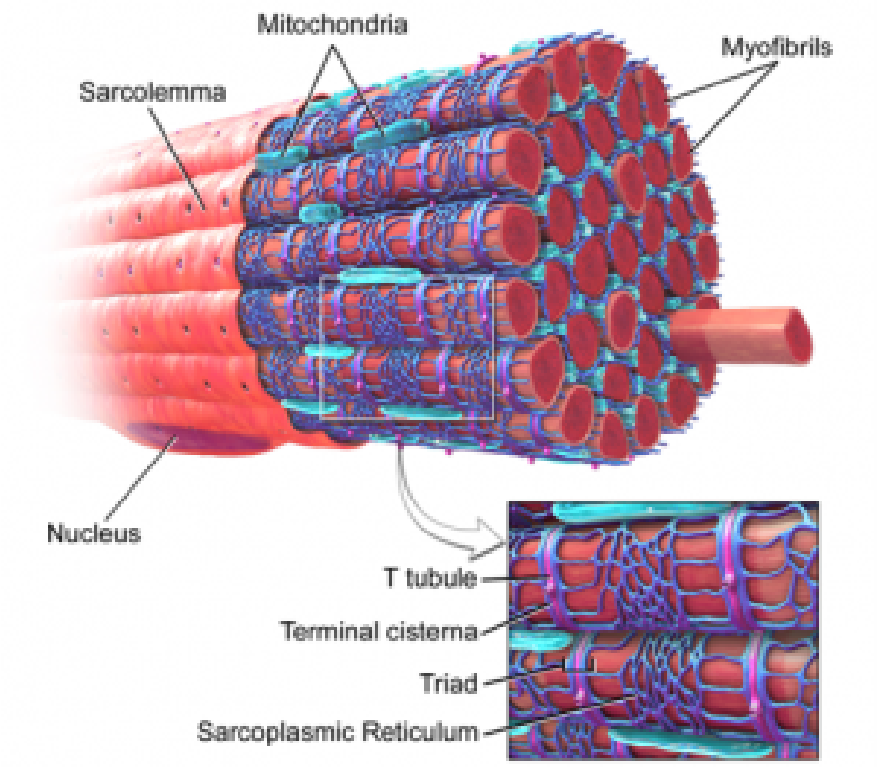


Figure 10.3. Muscle fiber is a cell containing sarcoplasm and organelles shown in this figure. (Credit: Wikimedia)

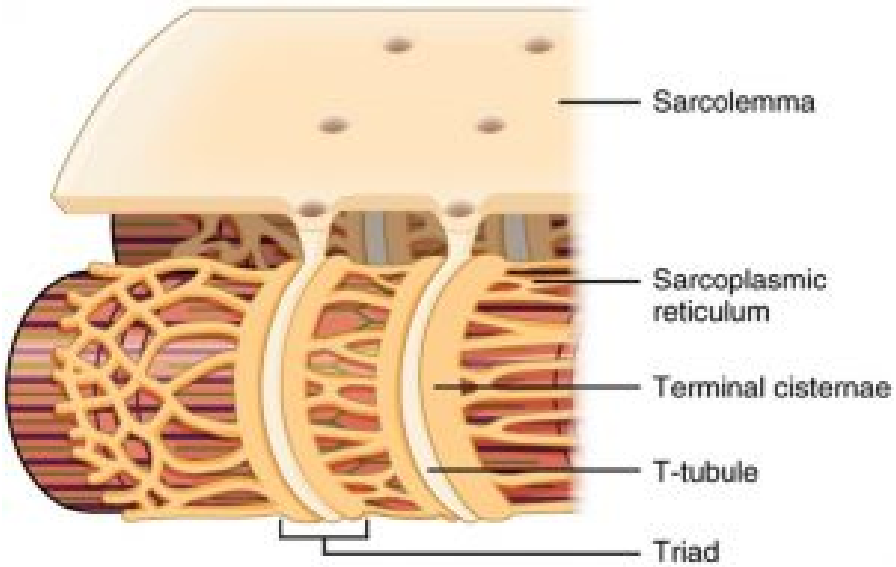


Figure 10.4. The sarcoplasmic reticulum, terminal cisternae and T-tubule are shown here forming the triad. (Credit: OpenStax https://cnx.org/contents)

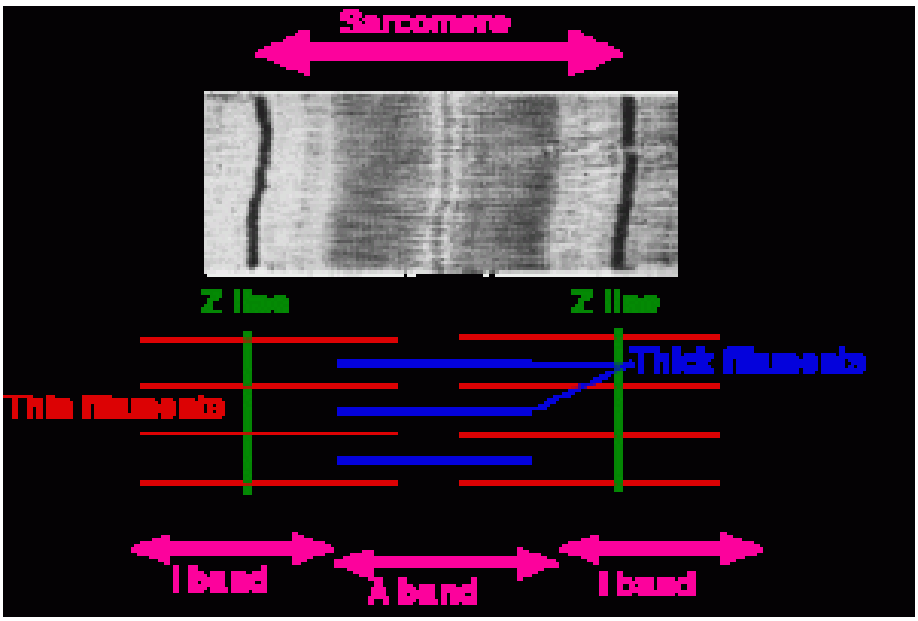


Figure 10. 5. The sarcomere is shown here with its I and A bands. Note that the A bands are dark and the I bands are light. (Credit: Wikimedia)

There are structural and functional differences between the three types of muscles. Skeletal muscle fibers can be identified by their multinucleate cytoplasm and striations (Figure 10.2) . Skeletal muscles move bones. Cardiac muscle fibers have one nucleus per cell, branched striations and intercalated disk (Figure 10.6). Cardiac muscles are found in the heart where they squeeze it to pump blood. Smooth muscles do not have striations. They are spindle-shaped with one nucleus in each cell (Figure 10.7). Smooth cells are found mostly in the gastrointestinal tract where they move the stomach and intestine as well as in the walls of other tubular organs such as the urinary tract and reproductive tract, helping move materials along within these tubes.

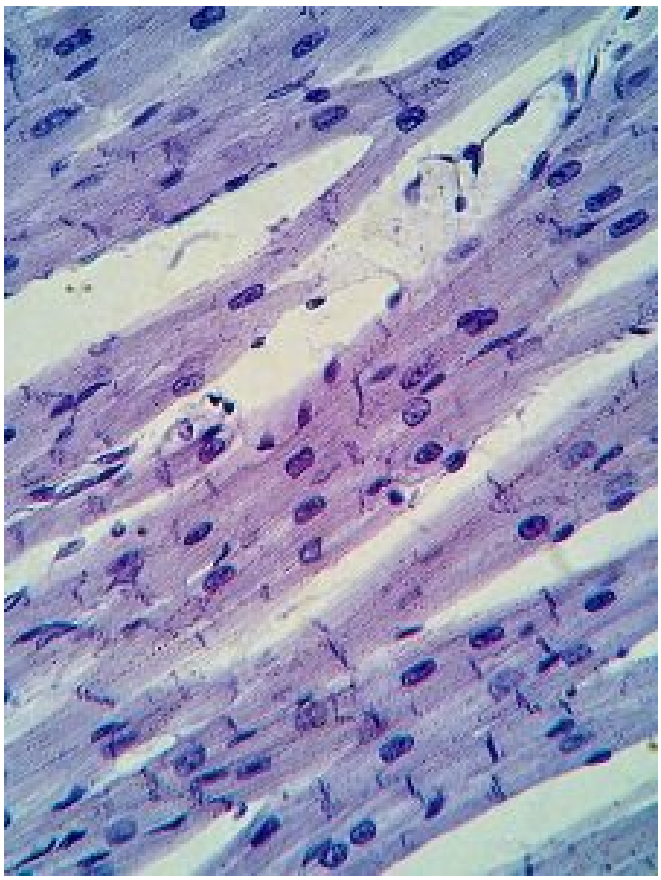


Figure 10.6. Cardiac muscles. Notice striations, intercalated disks (bands), single nucleus in a cell. The cells are also branched. (Credit: Wikimedia)

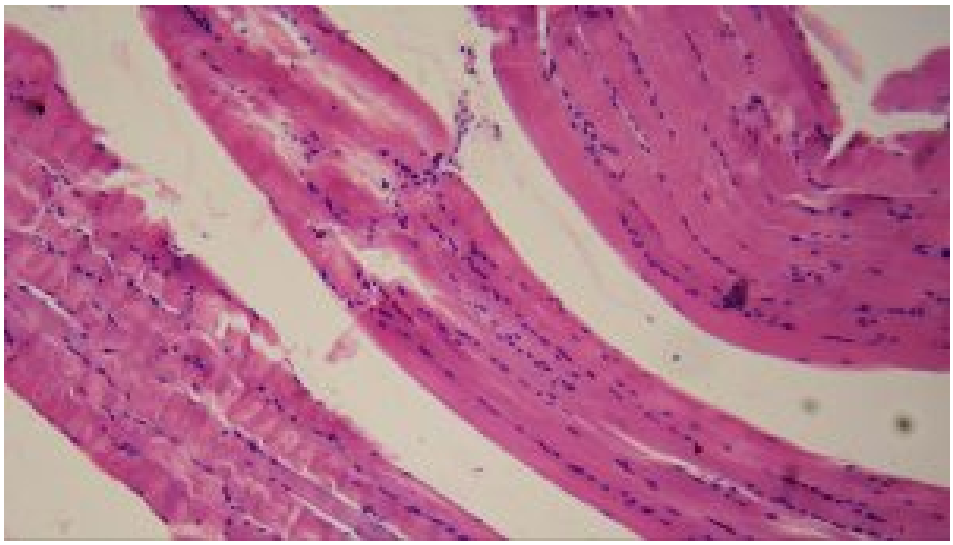


Figure 10.7. Smooth muscle. Unlike skeletal and cardiac muscle fibers, there are no striations. There is one nucleus per nucleus. (Credit: Wikimedia)

The nervous system and muscular system work closely together to maintain proper muscle contraction

and relaxation. Skeletal muscles are innervated by motor neurons we can voluntarily activate or inactivate (Figure 10.8). The axon ends from the neuron send signals to the motor end plate of the sarcolemma of the skeletal muscle fiber to contract and relax the muscles. A neurotransmitter (chemical) called acetylcholine is released from the axon into the space between the neuron and muscle fiber (synaptic cleft). The neurotransmitter then binds cell surface proteins on the sarcolemma to initiate events for muscle contraction.

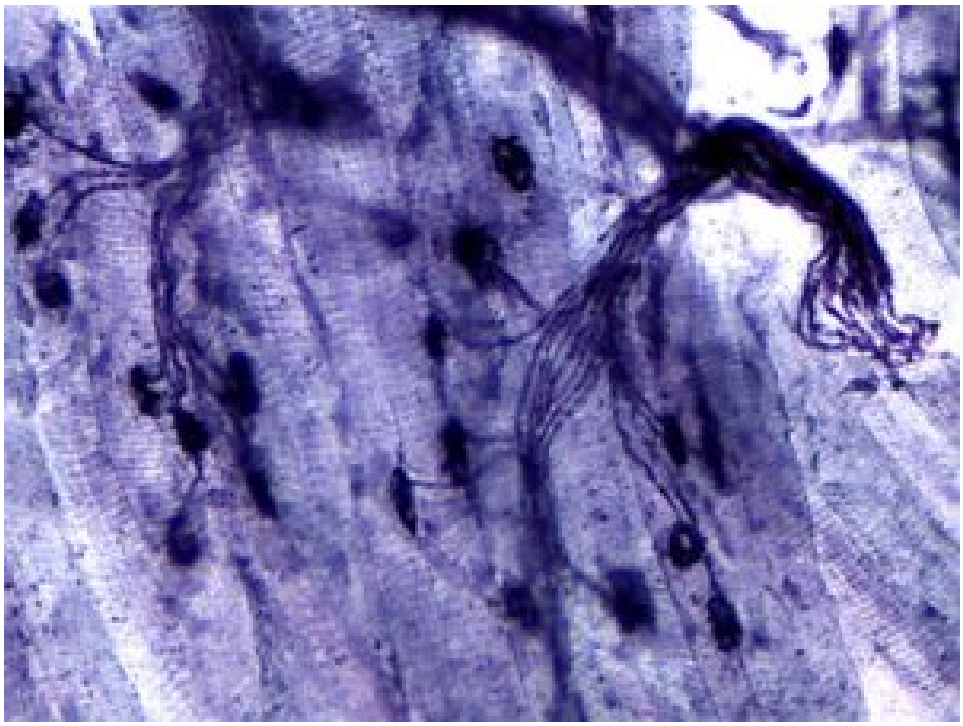


Figure 10.8. The neuromuscular junction is the attachment of the axon of a nerve cell to the motor end plate of a muscle cell. (Credit: Wikimedia)

Pre-Laboratory Questions

1. The sarcomere is a unit of structure in the muscle fiber. Describe the structure of a sarcomere. Use diagrams and electron micrographs to help you.
2. The sarcomere is also a unit of function. How can you relate the function of the sarcomere to the movement of a muscle, say biceps?
3. Define a (a) skeletal muscle, (b) smooth, and (c) cardiac muscle.
4. Create a concept map listing events that occur in a neuromuscular junction when dendrites receive a stimulus such as a pin prick.

Exercises

- Exercise 1. Identify the microscopic features of skeletal muscle
- Exercise 2. Identify the organelles found in a muscle fiber
- Exercise 3. Identify cardiac muscle tissue
- Exercise 4. Identify smooth muscle tissue
- Exercise 5. Describe neuromuscular junction

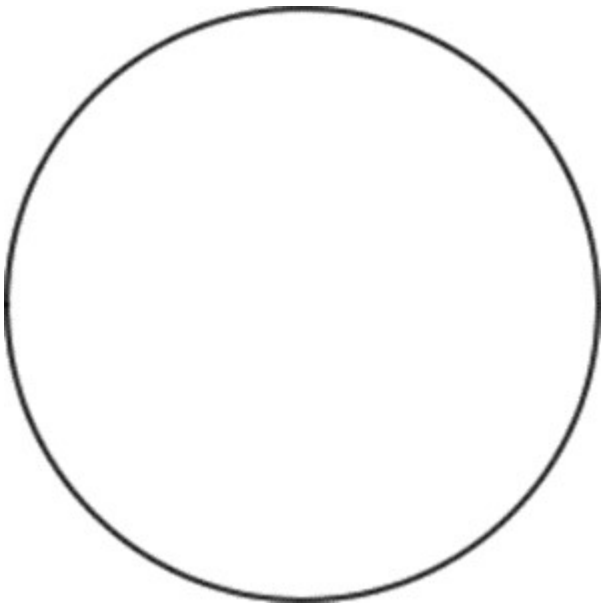
Exercise 1. Identify the microscopic features of skeletal muscle

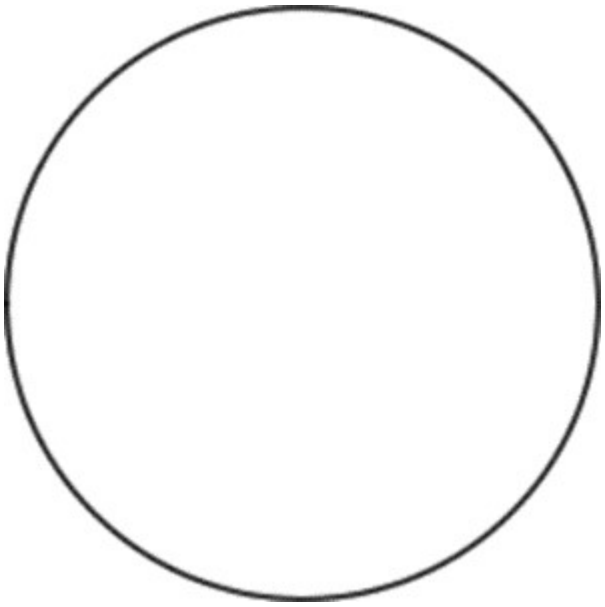
Required Materials

- Compound microscope
- Skeletal muscle slide

Procedure

1. Obtain a slide of the skeletal muscle (Figure 10.2)
2. Using a compound microscope focus on the tissue using the 4x objective.
3. Switch to the low magnification 10x objective lens and scan the slide showing skeletal muscle.
4. Repeat your observations high magnification of the 40x objective.
5. Notice the dark nuclei. They are more than one in each cell and are located to a side in the sarcoplasm.
6. Observe the striations that appear as light and dark bands. Striations and multinuclei define skeletal muscle fiber.
7. Sketch what you observed at low and high magnification and label the main structures.





Exercise 2. Identify the organelles found in a muscle fiber

Required Materials

- 3D Model of the Sarcomere
- Post-it notes

Procedure

1. Observe a 3-dimensional model of the sarcomere.
2. Use your post-it notes to label on the model the organelles in the sarcoplasm: sarcolemma, sarcoplasm, nucleus, sarcomere, myofibrils, myofilaments and triad (Figure 10.3, 10.4, 10.5)
3. Take a picture of the model with your post-it notes attached. Insert in the space below.

(Alternatively, you can draw a picture of the sarcomere and label this figure with the structures indicated.)

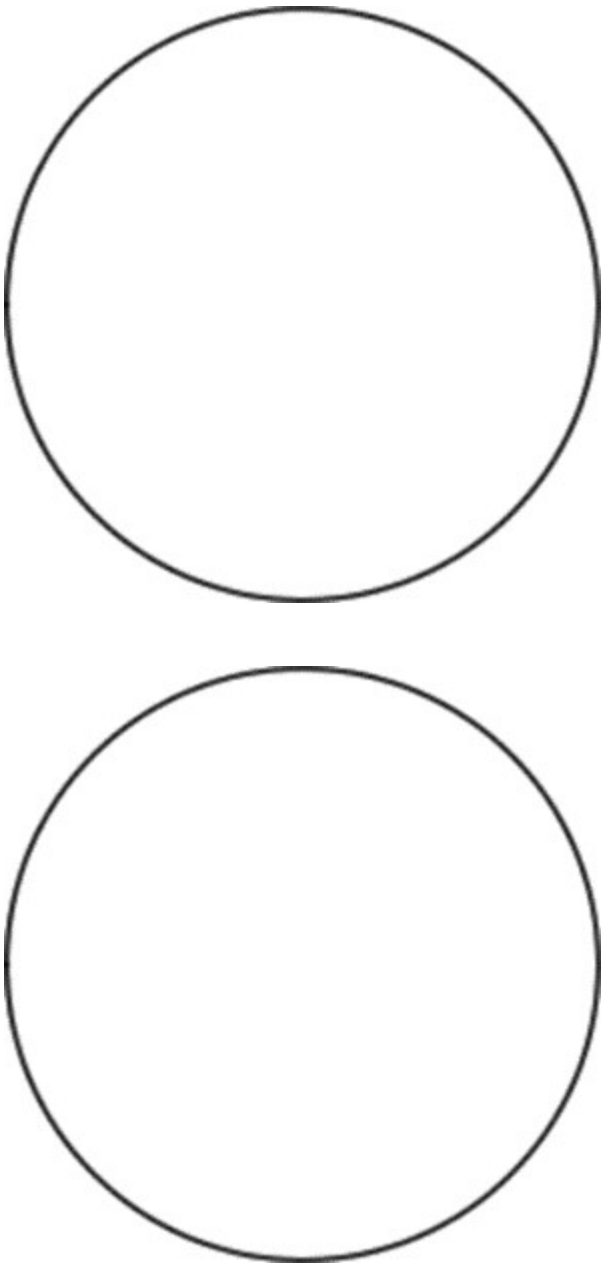
Exercise 3. Identify cardiac muscle tissue magnification.

Required Materials

- Compound microscope
- Cardiac muscle slide

Procedure

1. Obtain a slide of the cardiac muscle (Figure 10.6)
2. Using a compound microscope focus on the tissue using the 4x objective.
3. Switch to the low magnification 10x objective lens and scan the slide showing cardiac muscle.
4. Repeat your observations high magnification of the 40x objective.
5. Notice striations, intercalated disks (bands), single nucleus in a cell. The cells are also branched.
6. Sketch what you observed at low and high magnification and label the main structures.



Exercise 4. Identify smooth muscle tissue

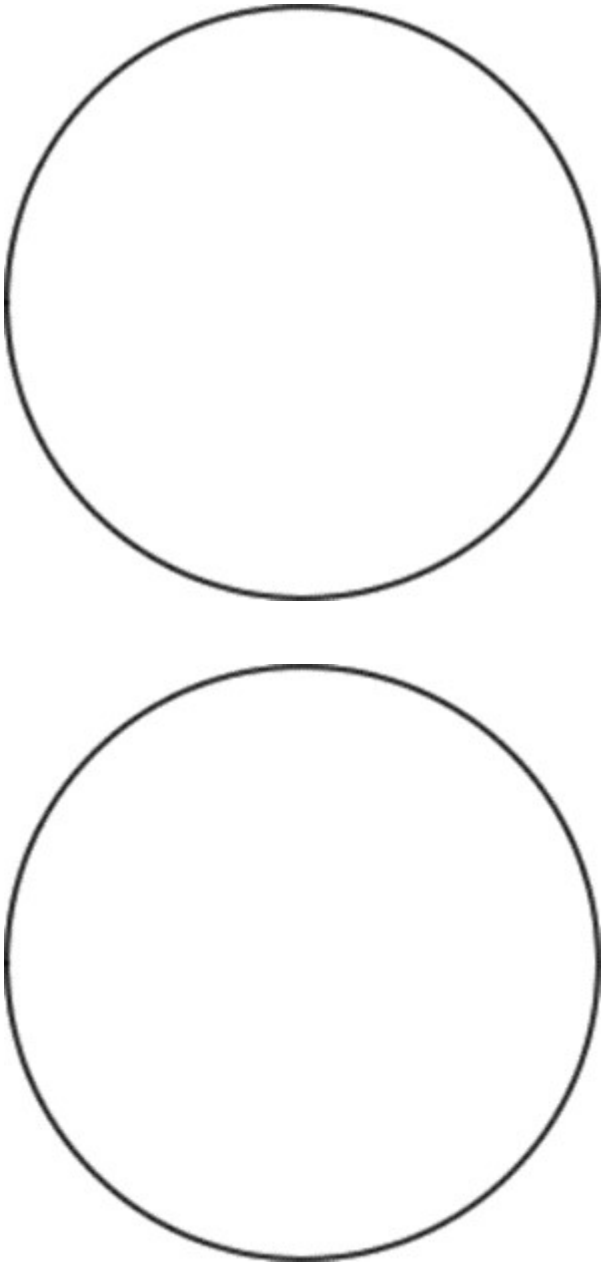
Required Materials

- Compound microscope
- Smooth muscle slide

Procedure

1. Obtain a slide of the smooth muscle (Figure 10.7)
2. Using a compound microscope focus on the tissue using the 4x objective.
3. Switch to the low magnification 10x objective lens and scan the slide showing smooth muscle.
4. Repeat your observations high magnification of the 40x objective.

5. Unlike skeletal and cardiac muscle fibers, there are no striations. There is one nucleus per nucleus.
6. Sketch what you observed at low and high magnification and label the main structures.



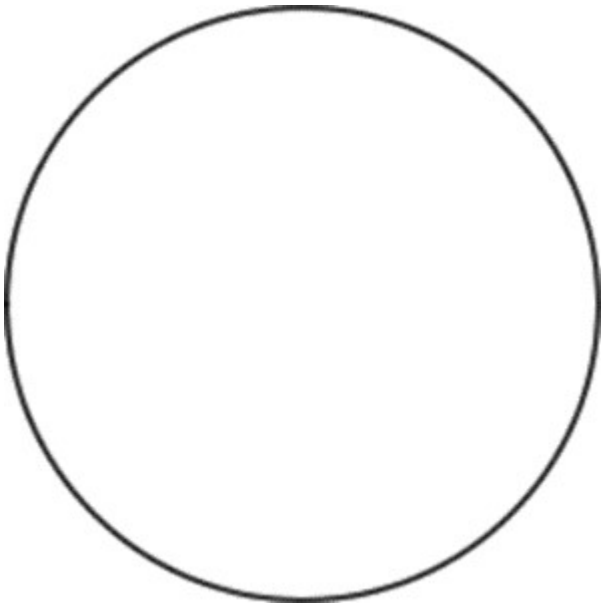
Exercise 5. Describe neuromuscular junction.

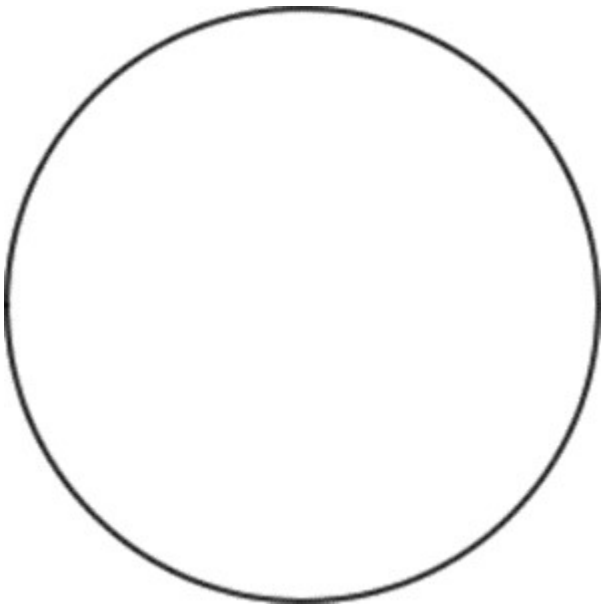
Required Materials

- Compound microscope
- Neuromuscular spindle slide

Procedure

1. Obtain a slide that shows skeletal muscle tissue with a nerve cell. The axons of nerve cells (neurons) touch the sarcolemma and stimulate it to relax and contract (Figure 10.8)
2. Using a compound microscope focus on the tissue using the 4x objective.
3. Switch to the low magnification 10x objective lens and scan the slide showing axon ends and motor end plate.
4. Repeat your observations high magnification of the 40x objective.
5. Notice the nerves, axon ends, striated muscle fibers, and the motor end plate.
6. Sketch what you observed at low and high magnification and label the main structures.





Post-laboratory Questions

1. Construct a table with three columns. Now, describe similarities and dissimilarities in structure (a) between skeletal muscle and smooth muscle; (b) smooth and cardiac muscle; (c) skeletal muscle and cardiac muscle.

	Similarities	Dissimilarities
Question (a) skeletal vs. smooth		
Question (b) smooth vs. cardiac		
Question (c) skeletal vs. cardiac		

2. Draw a muscle fiber and label:
   a. Myofilament
   b. Sarcoplasmic reticulum
   c. T-tubule
   d. Triad

3. Fill in the blanks:

a. Myofilament plays a role in _____

b. The sarcoplasmic reticulum functions to _____

c. The T-tubule can be defined as _____

d. The triad is a set of structures that _____

4. The synaptic cleft is a _____ between the _____ and _____

5. Acetylcholine is a neurotransmitter located in _____

6. Explain what happens when acetylcholine is released into the synaptic cleft.

7. What is the function of dendrites? What is the function of axons?

11.

CHAPTER 11 THE MUSCULAR SYSTEM

By Joseph D'Silva

Motivation.

Figure 11.1. U.S. Army World Class Athlete Program Spc. Faruk Sahin (Credit: Wikimedia)

Have you ever noticed how skeletal muscles stand out in most men compared to most women? Men are more heavily built and it has to do with genetics and DNA! The build comes from those muscles that are attached to bone or bones. Skeletal muscles make up the muscular system. Each muscle has a name. For every muscle, there is a point of origin in a bone and an insertion in another. Skeletal muscles are bound to bone by tendons. But ligaments bind muscles to muscles. This is important to know. Basically, skeletal muscles

move our body. But injuries such as sprain, tear, contusion can occur. A sprain is a damage to muscle fibers. In sports medicine, the patients are athletes that can suffer from tendinitis and pulled hamstrings.

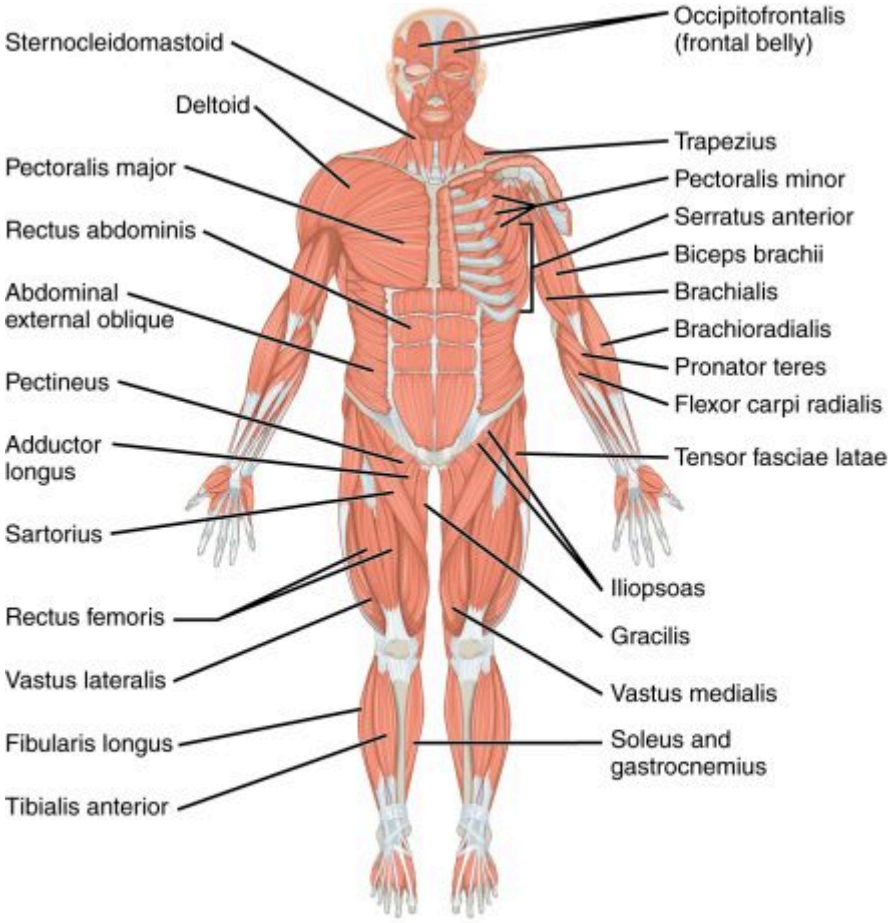
Learning Objectives

Upon completion of the work in this chapter students should be able to:

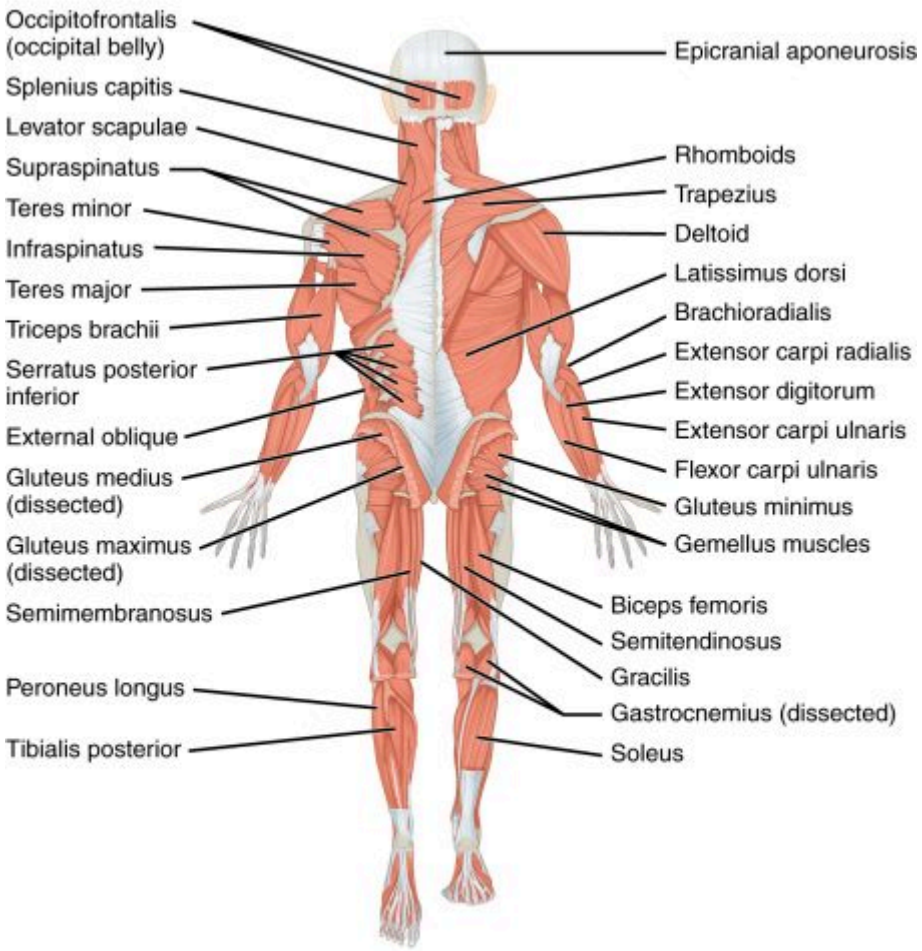
- Identify facial muscles, name them and state their functions.
- Name and identify thoracic muscles.
- Identify muscles of the abdominal wall.
- Identify appendicular muscles of the pectoral girdle.
- List muscles of the lower limb.

Background.

Muscles are tissues that stand out in our bodies. We are all familiar with them. You already know the name of the muscle on your forearm. It is the biceps. Two particular features of your muscles is that each one of them has a name and a function. The names identify them. Muscles bind bone to bone. Relax a muscle and the bone will extend out. Contract a muscle and it will pull up the bone to which it is attached. The point on the bone where the muscle becomes attached and cannot be moved is the origin. Where it attaches to a bone and moves the bone is the point of insertion. Major muscles of the body (Figure 11.2)are especially noticeable in people that exercise regularly and in athletes.



Major muscles of the body.
Right side: superficial; left side: deep (anterior view)



Major muscles of the body.
Right side: superficial; left side: deep (posterior view)

Figure 11.2 Major muscles of the body

Some muscles that you will need to identify along with their functions are facial, thoracic, abdominal, pelvic girdle, upper and lower limbs. These are sets of muscles and they have particular functions.

Facial Muscles

There are several of them (Figure 11.3). The names are in Latin. So...remembering them and pronouncing them will be a challenge: buccinator, mentalis, orbicularis oris, orbicularis oculi, platysma and zygomaticus. The buccinators are your cheek muscles. The muscles on your chin are mentalis. Orbicularis oris are your upper and lower lip muscles. The muscles around your eyes are obicularis oculi. The muscle under your lower jaw is the platysma. Zygomaticus is a muscle on either side of your mouth. Each muscle has one or more functions.

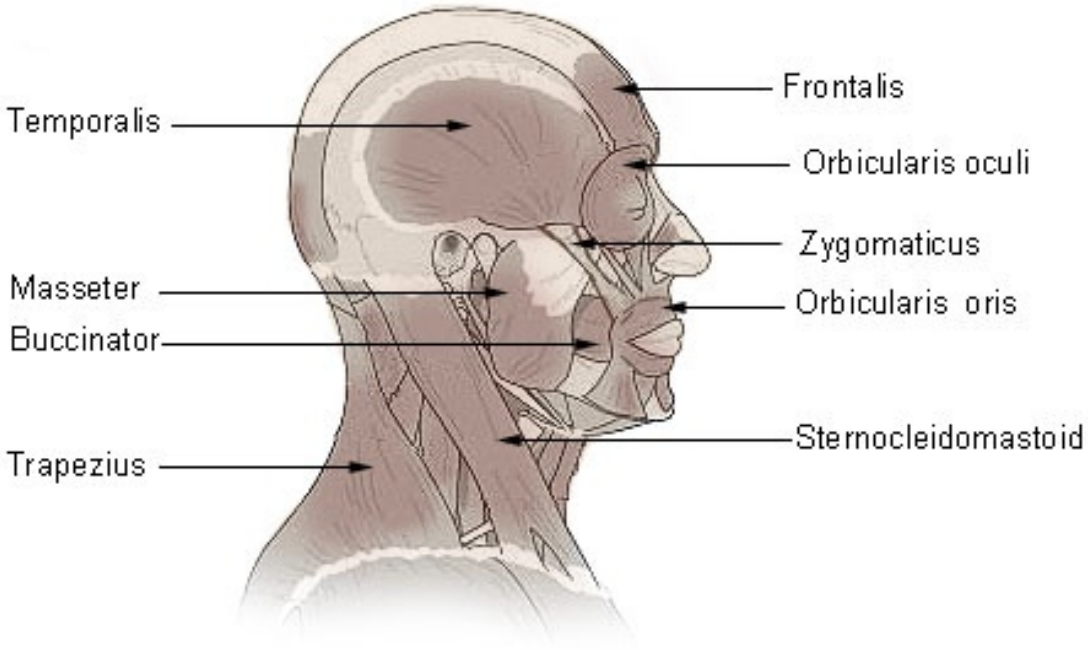


Figure 11.3. The facial muscles shown in this figure are the buccinator, orbicularis oris, orbicularis oculi. (Credit: Wikimedia)

Thoracic Muscles

The diaphragm is a sheet of muscles beneath your thoracic basket or rib cage (Figure 11.4 and 11.5). The external and intercostalis are muscles situated in between your costae or ribs (Figure 11.6 and 11.7). Together, the three sets of muscles assist us to breathe in (inspiration) and breathe out (expiration) during alveolar respiration. They act to elevate and expand the rib cage and thus the lungs become elevated. During expiration, the rib cage becomes reduced in size.

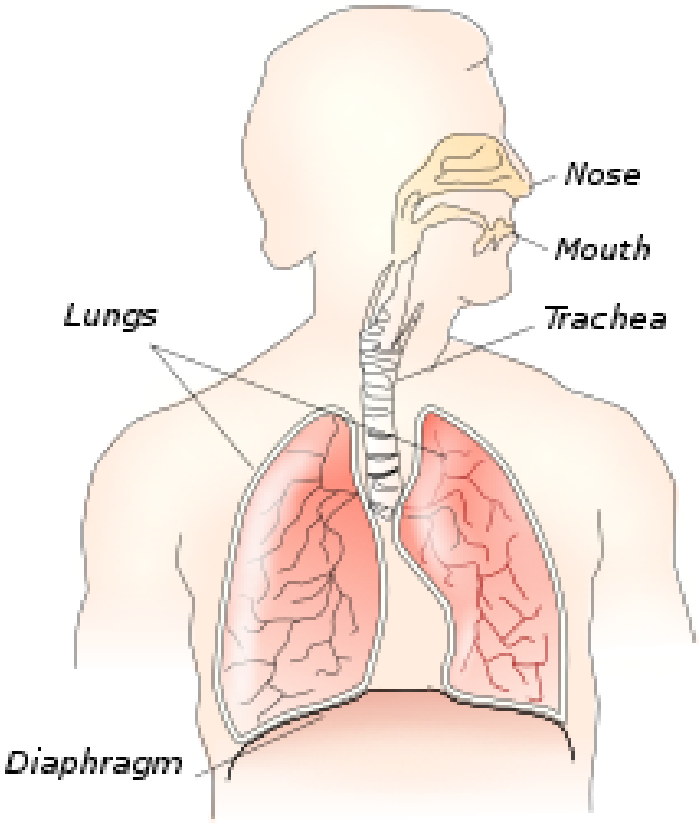


Figure 11.4 Diaphragm. Anterior view. Credit: Wikimedia

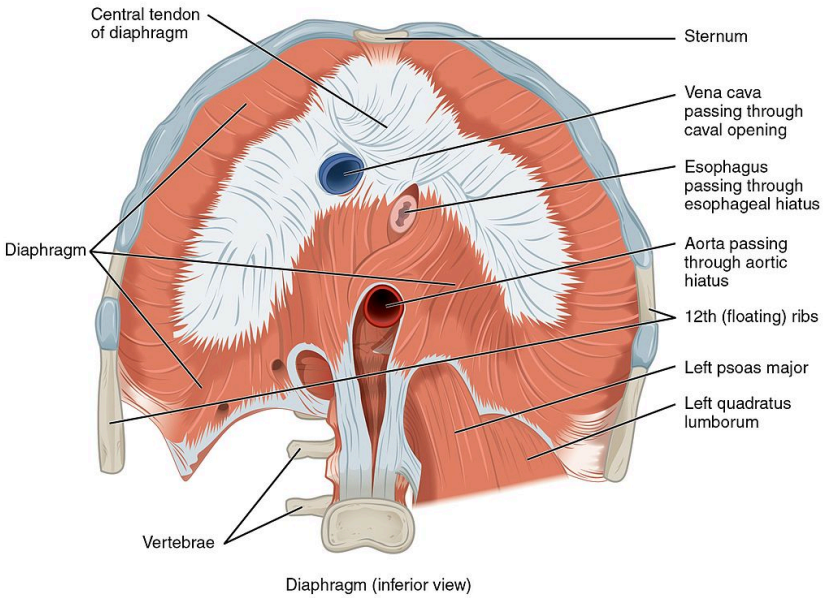


Figure 11.5 Diaphragm. Inferior View. Credit: Wikimedia

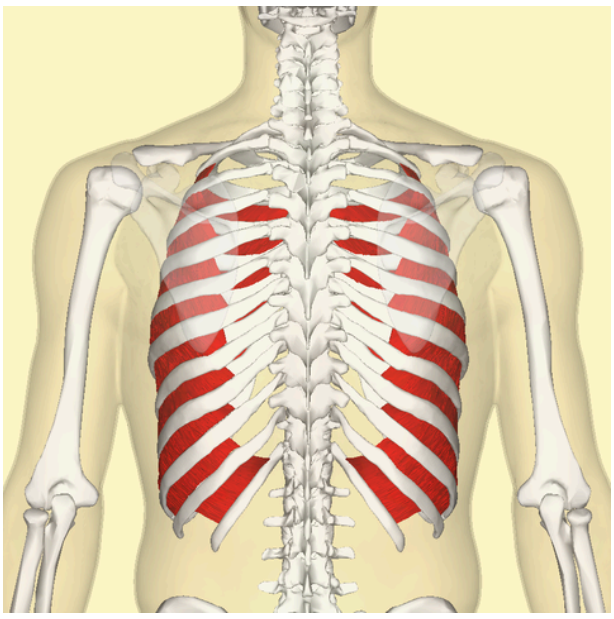


Figure 11.6 Internal Intercostal Muscles.
Posterior View. Credit: Wikimedia

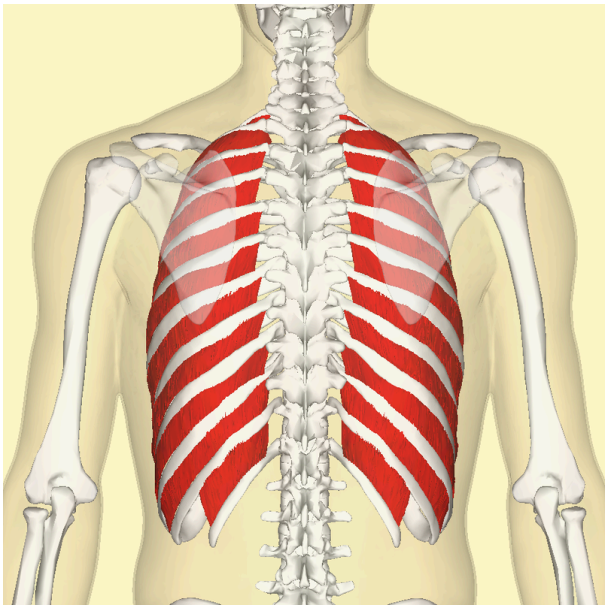


Figure 11.7 Internal Intercostal Muscles.
Posterior View. Credit: Wikimedia

Muscles of the Abdomen

The muscles that cover the abdominal cavity are the abdominal muscles (Figure 11.8 and 11.9). Located between the ribs and the pelvis, they are sheets of flat muscles and are prominent. The muscles are the external obliques, the internal obliques, the transversus abdominis, and the rectus abdominis. The external obliques are situated on the lateral sides of the abdomen. The paired rectus abdominis run vertically from

pelvis to the xiphoid process and ribs. The internal obliques runs laterally. The transversus abdominis muscle is deep to the internal oblique muscle.

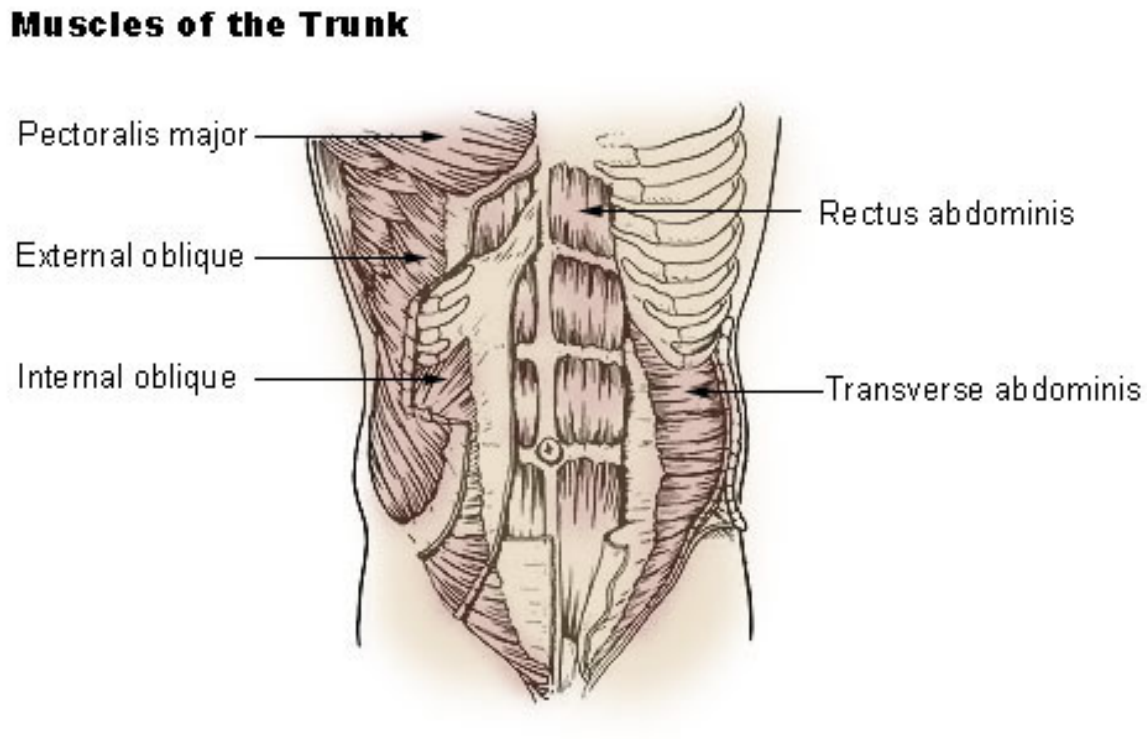


Figure 11.8 Abdominal muscles. Anterior view. Credit: Wikipedia.

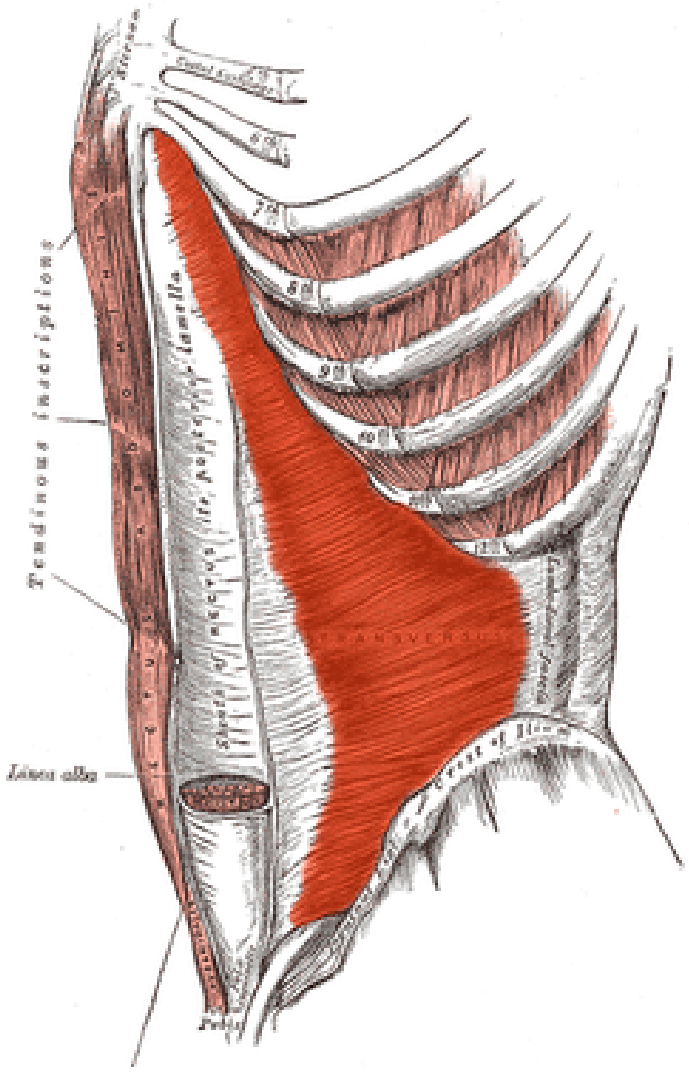


Figure 11.9 Transverse abdominus shown in red. Lateral view of left side of body. Credit: Wikipedia.

Pectoral Muscles

The pectoral muscles (Figure 11.10, 11.11 and 11.12) are attached to the pectoral girdle. The pectoralis major is the set of fan-shaped prominent muscles on the chest. Its origin is in the clavicle, sternum and abdomen. It inserts in the tubercle of the humerus bone. The pectoralis minor is deep to the pectoralis major. Its origin is the 3rd to 5th rib. The insertion is in coracoid process of the scapula. The serratus anterior muscle originates in the first to 8th rib. It inserts in the scapula. The trapezius is a large muscle originating in the C7 to T12 vertebrae. Its insertion is in the clavicle and scapula. The rhomboid muscle is broad and originates in the thoracic vertebrae T2-T5. It inserts in the scapula. The latissimus dorsi is a broad, flat muscle. It has several points of origin: T7-T12, thoracolumbar fascia, iliac crest and scapula. Its insertion is in the humerus. The teres major originates in the lateral border of the scapula and inserts in the humerus.

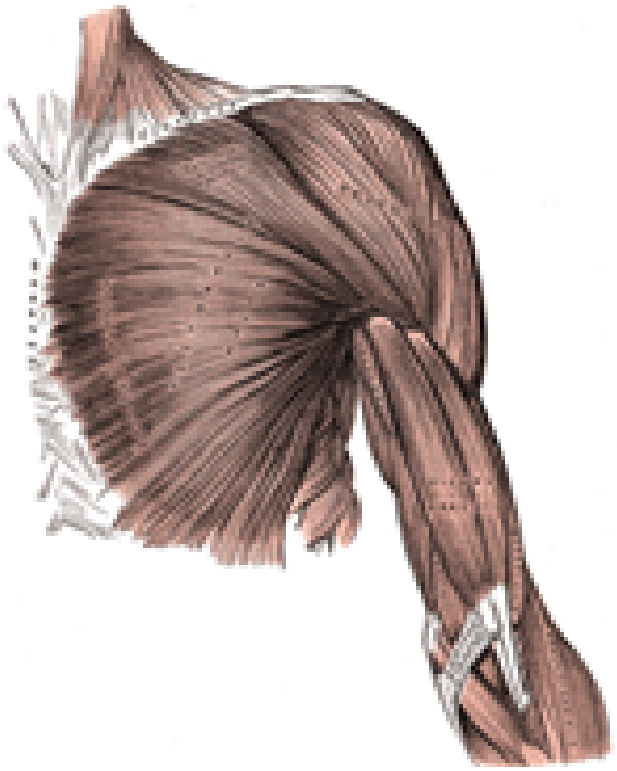


Figure 11.10 Pectoral muscles. Anterior view.
Credit: Wikipedia

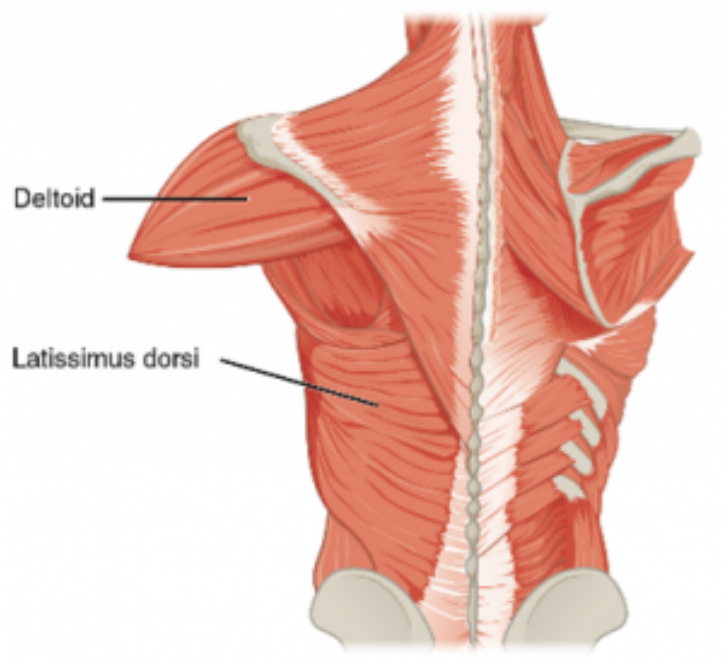


Figure 11.11 Latissimus dorsi. Dorsal view.

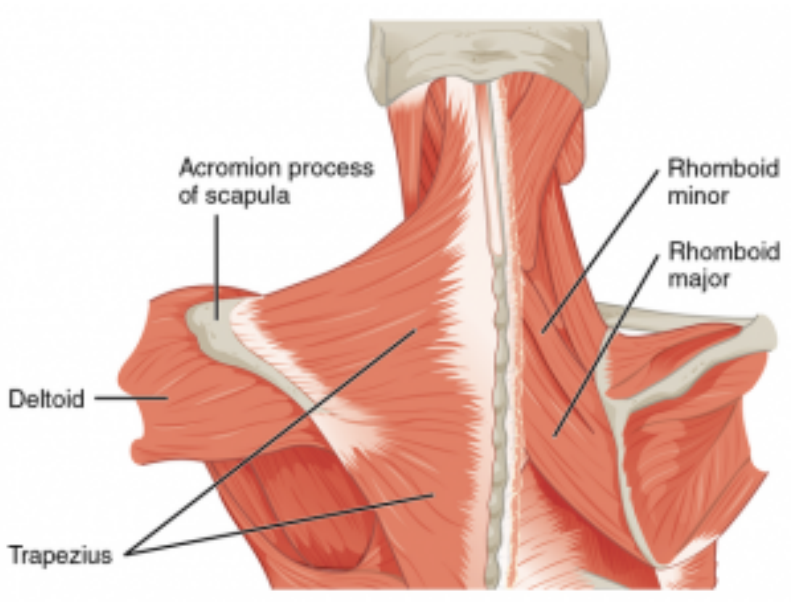


Figure 11.12 Rhomboid, trapezius. Dorsal view.

Example of Lower Limb Muscles – Gluteus Maximus, Sartorius, Hamstring Muscles

The gluteus maximus (Figure 11.13) is the largest, fleshy muscle dorsally. It extends from the hips (sacrum, ileum and fascia) to the femur. The gluteus minimus is a triangular shaped muscle located deep to the gluteus maximus. It originates in the ilium and inserts in the greater tuberosity of the femur. Gluteus medius originates in the ileum and inserts in the greater trochanter of the femur. Review the skeleton bones.

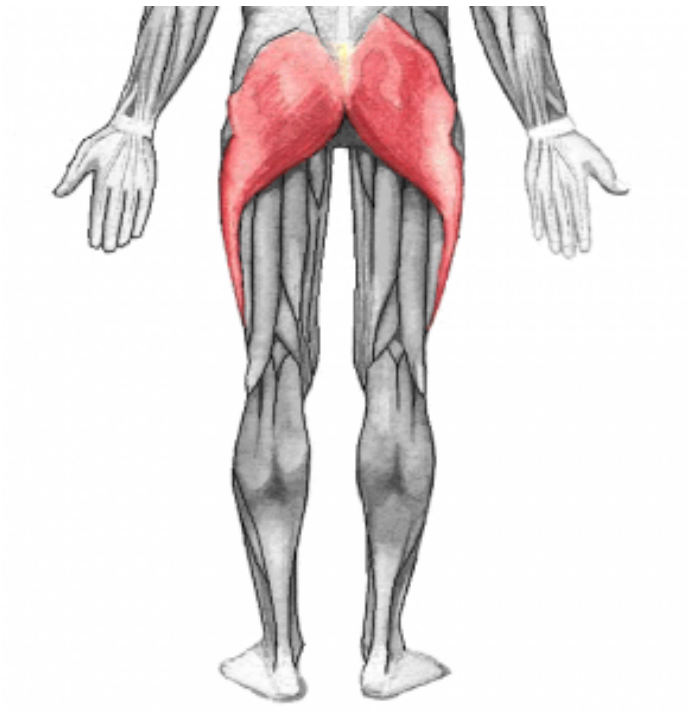


Figure 11.13 Gluteus maximus muscle. Posterior view. Credit: Wikipedia

Sartorius

The sartorius muscle (Figure 11.14) is a belt-like muscle that extends diagonally from the anterior superior iliac spine to the proximal end of tibia below medial condyle. It crosses from hip to knee joints. The origin is in the iliac bone and insertion in the tibia. It is the longest muscle in the body. The muscle is referred to as a tailor's muscle because they used to sit cross-legged to sew on a sewing machine.

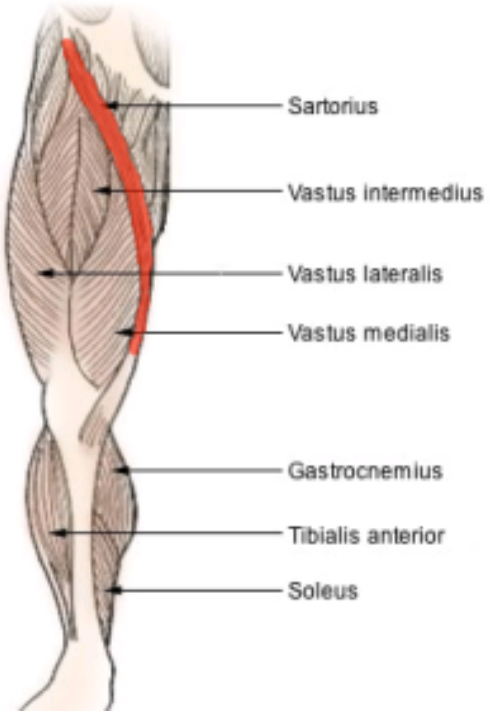


Figure 11.14 Sartorius muscle. Anterior view.
Credit: Wikipedia

Hamstring Muscles

The hamstring muscles are a set of three muscles (Figure 11.15): semi-tendinosus, biceps femoris and semi-membranosus. They all have their origin in the ischium. The insertion is in the tibia and fibula. The hamstrings connect bones of the pelvis, knees and lower leg. The biceps femoris is long. It starts in the thigh and attaches to the fibula. It is laterally situated. The semimembranosus begins at the pelvis and ends in the tibia. The semitendinosus lies between the semimembranosus and biceps femoris. It is the longest of the three muscles. The hamstring muscles are an important set of muscles if only because sports people injure them.

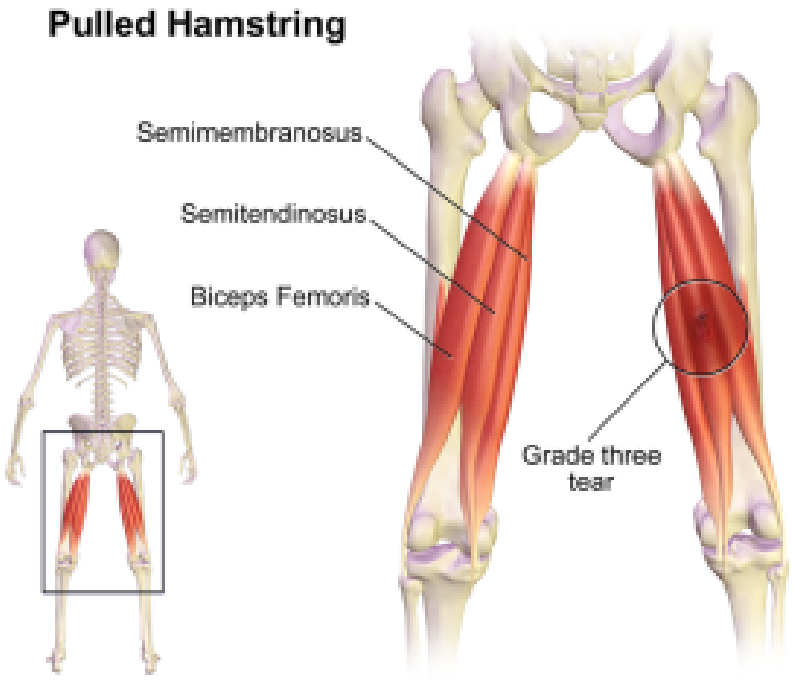


Figure 11.15 Pulled hamstring muscles. Showing location of hamstrings. Posterior view. Credit: Wikipedia.

Pre-Laboratory Questions

1. Name and identify facial muscles: buccinator, mentalis, orbicularis oris, orbicularis oculi, zygomaticus and platysma. Where is the origin and insertion of each muscle? What are their functions? Complete table below: Origin/Insertion/Function.
2. Name and identify thoracic muscles: diaphragm, external intercostalis, internal intercostalis. What are their functions?
3. List muscles of the abdominal wall: external oblique, internal oblique, rectus abdominis, transverse abdominis. What are their functions?
4. List muscles of the pectoral girdle: pectoralis minor, serratus anterior, pectoralis major, trapezius. rhomboid major, latissimus dorsi and teres major. What are their points of origin and insertion? What is their function?
5. List muscles of the upper limb: deltoid, biceps brachii, brachialis, triceps brachii.
6. List muscles of the lower limb: Gluteus maximus, gluteus minimus, sartorius, rectus femoris, vastus intermedius, vastus lateralis and vastus medialis. What are their points of origin and insertion? What are their functions.

Exercises

- Exercise 1 Name and identify facial muscles
- Exercise 2 Identification of thoracic muscles
- Exercise 3 Identification of muscles of the abdomen
- Exercise 4 Identification of pectoral muscles
- Exercise 5 Identification of muscles of lower limb

Exercise 1. Name and identify facial muscles

Required Materials

- Human Muscle Model (life size)
- Male Muscular Figure
- Mini Human Muscular Figure
- The Muscular System Poster
- Post-it notes

Procedure

1. Feel these muscles on your face (Figure 11.3): buccinators, mentalis, orbicularis oris, orbicularis oculi, platysma, zygomaticus. Ask your instructor to show the model on the table that displays muscles. Use the model to identify each muscle. Blow up your mouth as if you were blowing up a balloon. The cheek muscles are the buccinators.

2. Mentalis muscle is the lower lip muscle. Feel it. Now, use your lower lip to pout. The mentalis muscle helps you to pout. Identify the mentalis muscle on the model on demonstration.

3. Orbicularis oris is the set of muscles around your mouth. Protrude your lips as if you are kissing. Orbicularis muscles help you to do that. Purse your lips. “Orb” means “globe”, “round”. “Oris” means “opening”.

4. Run your fingers around your eyelid. The muscle you will feel is the orbicularis oculi muscle. It helps you to close your eyes. “Oculus” means a round window.

5. Platysma is a flat sheet of muscles extending from below the chin to the top of the throat. You can feel this muscle if you stretch your chin to look up at the ceiling.

6. Zygomaticus muscle is attached to the zygomaticus bone. It forms an angle with the upper lip. Together with the buccinator, it helps to form speech and facial expressions. Smile or laugh….and it is these set of muscles that will go into action.

7. Label the muscles you found on the muscle model using post-it notes. Take a picture. Alternatively, you can draw and label these muscles below.

8. Make a chart showing functions of the buccinators, orbicularis oris, orbicularis oculi, platysma and zygomaticus.

Muscle Type	**Function**
Buccinators	
Orbicularis oris	
Orbicularis sculi	
Platysma	
Zygomaticus	

Exercise 2. Identification of thoracic muscles

Required Materials

- Human Muscle Model (life size)
- Male Muscular Figure
- Mini Human Muscular Figure
- The Muscular System Poster
- Post-it notes

Procedure

1. Run your fingers down to the end of the thoracic basket and tuck them in to feel the diaphragm (Figure 11.4 and 11.5). it is the muscle that separates your thoracic cavity from your abdominal

cavity. Identify it on the model on demonstration. Ask your instructor to point it out to you.

2. The intercostal muscles are located in-between the ribs (Figure 11.6 and 11.7). Put your fingers to the sides of your thoracic basket also to feel the external intercostal muscles. The intercostal muscles are deep to the external intercostals.
3. Use the post-it notes to label these muscles on the models. Take a picture and insert it below. Alternatively, you can draw and label these muscles on your drawing.

Exercise 3. Identification of muscles of the abdomen

Required Materials

- Human Muscle Model (life size)
- Male Muscular Figure
- Mini Human Muscular Figure
- The Muscular System Poster
- Post-it notes

Procedure

1. Feel the muscles covering the abdomen (Figure 11.8 and 11.9). You may not be able to identify them. But use the model to study the four muscles: external oblique, internal oblique, rectus abdominis and transverse abdominis. To locate the transversus abdominis muscle, feel the side of your abdomen just where the pelvic bone is located. Contract the muscle and hold for 5-6 seconds. The rectus abdominis can be felt by running the fingers from below the xiphoid process to the pelvis.
2. Make a chart showing the origin and insertion of the external obliques, the internal obliques, the transversus abdominis, and the rectus abdominis (Hint: Consider the sternum, ribs, pubic bones).

	Origin	**Insertion**
external obliques		
internal obliques		
transverse abdominis		
rectus abdominis		

3. Use the post-it notes to label these muscles on the models. Take a picture and insert below. Alternatively, you can draw and label these muscles below.

Exercise 4. Identification of pectoral muscles

Required Materials

- Human Muscle Model (life size)
- Male Muscular Figure
- Mini Human Muscular Figure
- The Muscular System Poster
- Post-it notes

Procedure

1. The pectoralis major muscle is best seen in the model on demonstration (Figure 11.2). Study its origin and insertion. The pectoralis minor and serratus major can also be viewed on the model.
2. The trapezius, rhomboid (Figure 11.12) and latissimus dorsi (Figure 11.11) can best be felt by

placing your hands on the dorsal / posterior aspect of your body.

3. Use the post-it notes to label these muscles on the model. Take a picture and insert it below. Alternatively, you can draw and label these muscles below.

Exercise 5. Identification of muscles of the lower limb

Required Materials

- Human Muscle Model (life size)
- Male Muscular Figure
- Mini Human Muscular Figure
- The Muscular System Poster
- Post-it notes

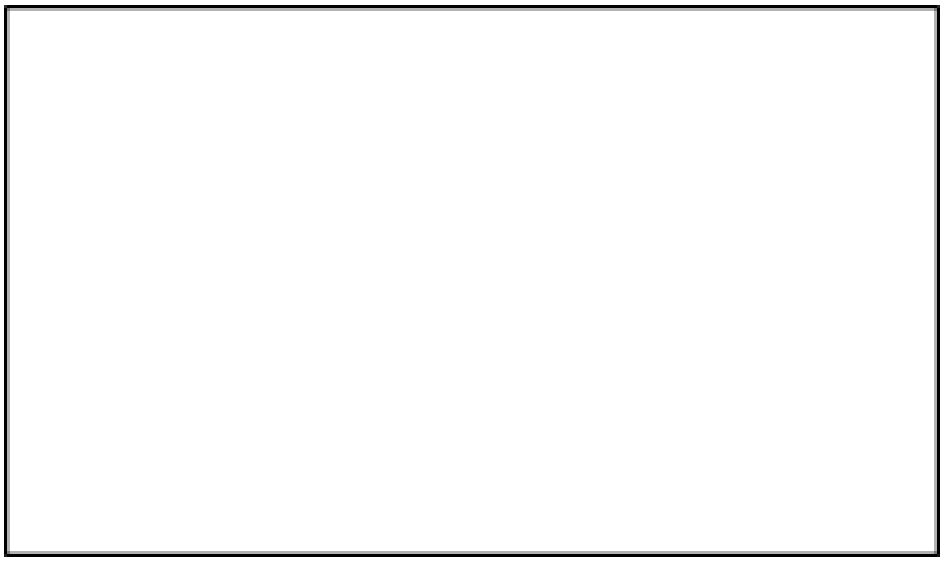
Procedure

1. You can feel the gluteus muscle with your hands. The gluteus maximus muscle is your buttock (Figure 11.13).
2. With your hands, feel the ileum, sacrum and coccyx of your pelvic bones. These are the three bones where the gluteus maximus muscle originates. They insert on the tuberosity of the femur which you can also feel. Now, trace the muscle on the demonstration model.
3. For the sartorius muscle (Figure 11.14), You can sit cross-legged on the floor. Or, you can cross one

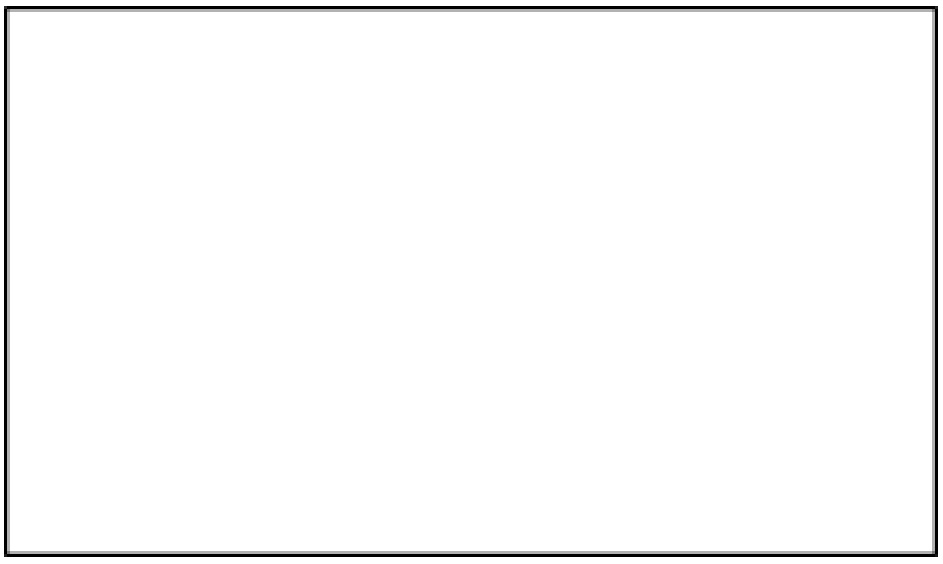
leg over the other sitting on a stool. Using your thumbs, feel the width of the sartorius muscle in your inner thigh. Now run the two thumbs along the edges of the muscle to the knee/ hips. By doing this, you will be feeling the sartorius muscle from the hip to the tibia.

4. The hamstring muscles (Figure 11.15) These can be felt easily by your fingers and hand. Feel them by placing your hands to the back of your thighs. They run along the length of the femur.
5. Use the post-it notes to label these muscles on the model. Take a picture and insert it below. Alternatively, you can draw and label these muscles below. For gluteus maximus and hamstrings, use the posterior view. For sartorius, use the anterior view.

Posterior view of lower limb muscles:



Anterior view of lower limb muscles:



Post-laboratory Questions

1. What is the common name for the buccinator muscles?

2. What are the muscles that form your upper and lower lips, eyes?
3. If male person was shaving the underside of his maxillary region by stretching it and looking upwards, what is the muscle he would be feeling?
4. State the functions of the (a) latissimus dorsi and (b) trapezius muscles.
5. Name the origin of the pectoralis major muscle.
6. What is the tailor's muscle? Why is it so called?
7. Where do the hamstring muscles originate and insert?

12.

CHAPTER 12 THE NERVOUS SYSTEM AND NERVOUS TISSUE

By Aylin Marz

Motivation.

Drug addiction is a health issue that devastates individuals as well as whole communities including some African American communities. Risk factors that increase someone's chance of becoming an addict are not fully understood but these include environmental and genetics factors that affect the *nervous system*. Addiction is a disease of the nervous system. Being addicted to a drug like cocaine changes the chemistry of the brain down to the level of the neurotransmitter chemicals that send signals between neurons. Dopamine is the feel good neurotransmitter that activates the pleasure centers of the brain in everyone but the amounts of it become too high in addicts. Understanding how the nervous system works to transmit signals and control these signals can help understand diseases like addiction and why they are so difficult to treat. As a health professional dealing with athletes who may have gotten hooked on opioids prescribed to them after surgery or trying to deal with whole communities devastated by addiction as a nurse in your community, it is crucial to know the biology and chemistry of the nervous system.

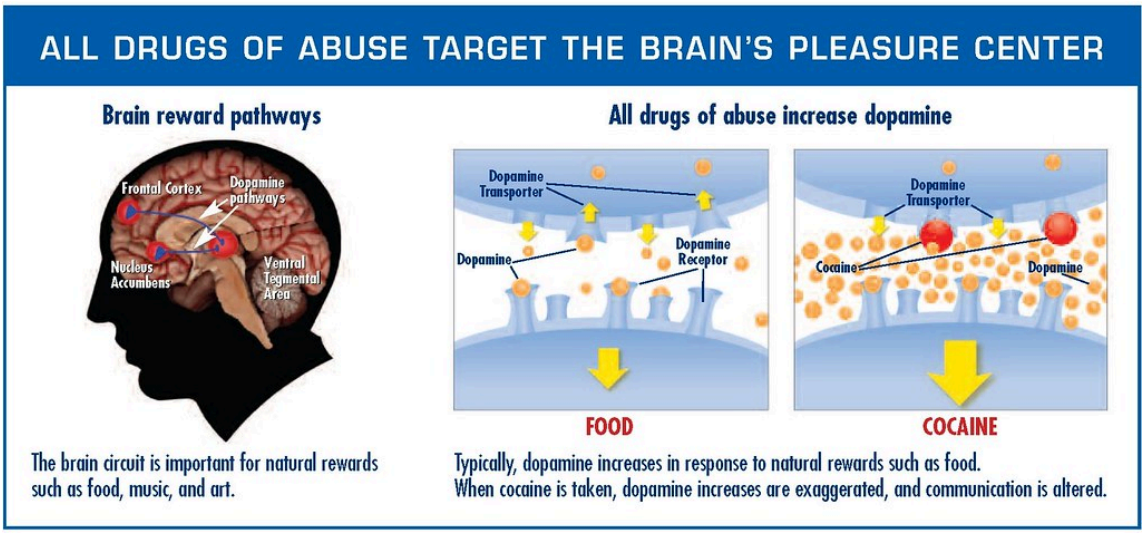


Figure 12.1 Drugs of abuse target dopamine neurotransmitter in brain's pleasure centers.
(Credit: "Drugs of Abuse" by National Institutes of Health (NIH) is marked with CC PDM 1.0)

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Create a 3D model of a typical multipolar neuron to label structures such as dendrites, cell body, axon, myelin sheath and organelles such as the nucleus and mitochondria
- Perform microscopy to identify the gray and white matter areas and the neurons and glial cells within these areas using a spinal cord section
- Demonstrate an understanding of how action potentials are generated by interpreting the effects of mutant or blocked voltage-gated Na^+ or K^+ channels on action potentials
- Explain how a neurotransmitter works by identifying what goes wrong with the neurotransmitter dopamine in addiction

Background.

Basic Structure and Function of the Nervous System

The nervous system can be separated into divisions on the basis of anatomy and physiology. The anatomical divisions are the central and peripheral nervous systems (aka CNS and PNS, respectively). The CNS is the brain and spinal cord. The PNS is everything else. Functionally, the nervous system can be divided into those regions that are responsible for sensation, those that are responsible for integration, and those that are responsible for generating responses. All of these functional areas are found in both the central and peripheral anatomy.

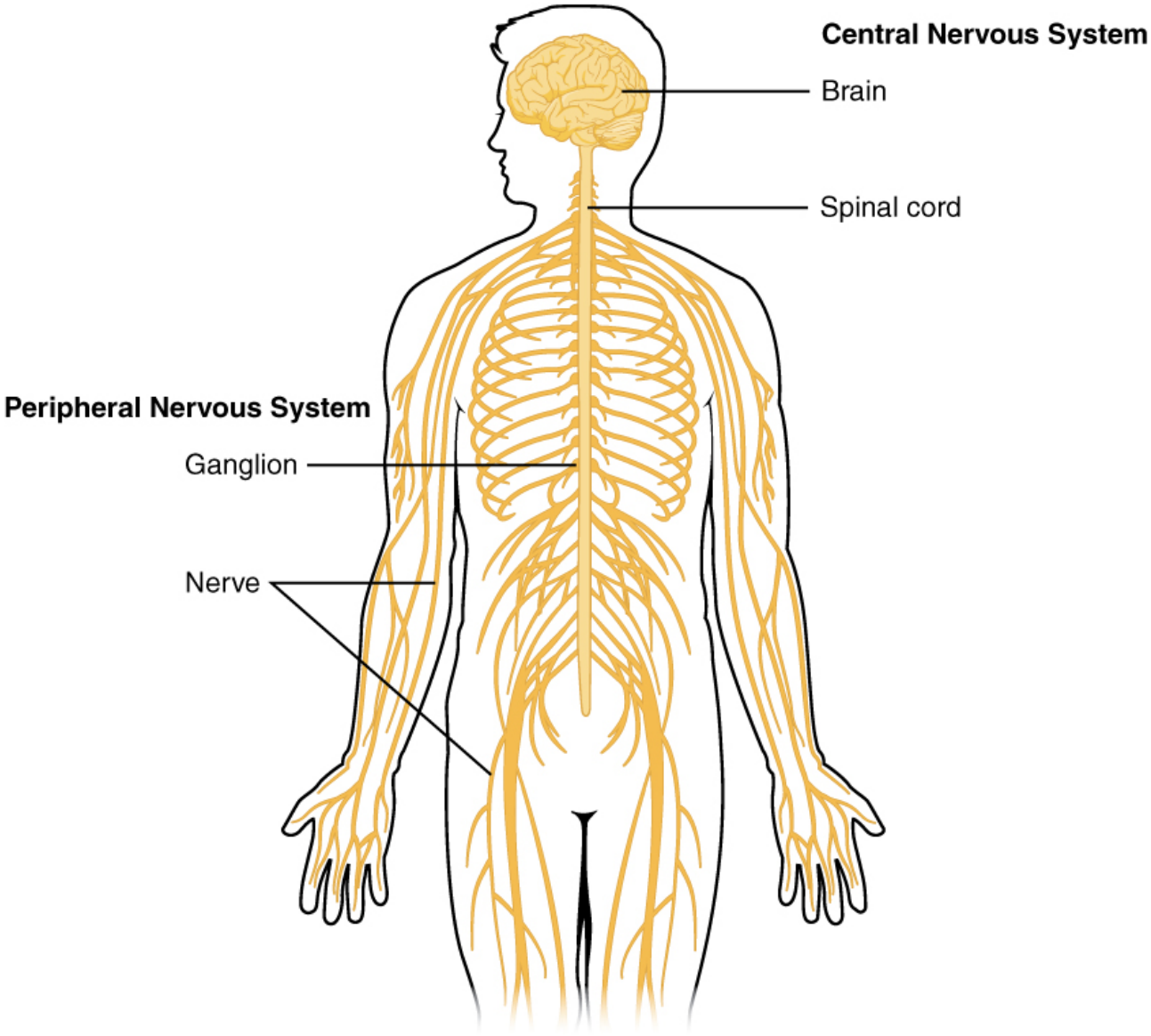


Figure 12.2 Central Nervous System (CNS) and Peripheral Nervous System (PNS). (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Considering the anatomical regions of the nervous system, there are specific names for the structures within each division. A localized collection of neuron cell bodies is referred to as a *nucleus* in the CNS

and as a *ganglion* in the PNS. A bundle of axons is referred to as a *tract* in the CNS and as a *nerve* in the PNS. Whereas nuclei and ganglia are specifically in the central or peripheral divisions, axons can cross the boundary between the two. A single axon can be part of a nerve and a tract. The name for that specific structure depends on its location.

Nervous tissue can also be described as *gray matter* and *white matter* on the basis of its appearance in unstained tissue. These descriptions are more often used in the CNS. Gray matter is where nuclei are found and white matter is where tracts are found. In the PNS, ganglia are basically gray matter and nerves are white matter.

The nervous system can also be divided on the basis of how it controls the body. The *somatic nervous system (SNS)* is responsible for functions that result in moving skeletal muscles. Any sensory or integrative functions that result in the movement of skeletal muscle would be considered somatic. The *autonomic nervous system (ANS)* is responsible for functions that affect cardiac or smooth muscle tissue, or that cause glands to produce their secretions. Autonomic functions are distributed between central and peripheral regions of the nervous system. The sensations that lead to autonomic functions can be the same sensations that are part of initiating somatic responses. Somatic and autonomic integrative functions may overlap as well.

A special division of the nervous system is the *enteric nervous system*, which is responsible for controlling the digestive organs. Parts of the autonomic nervous system overlap with the enteric nervous system. The enteric nervous system is exclusively found in the periphery because it is the nervous tissue in the organs of the digestive system.

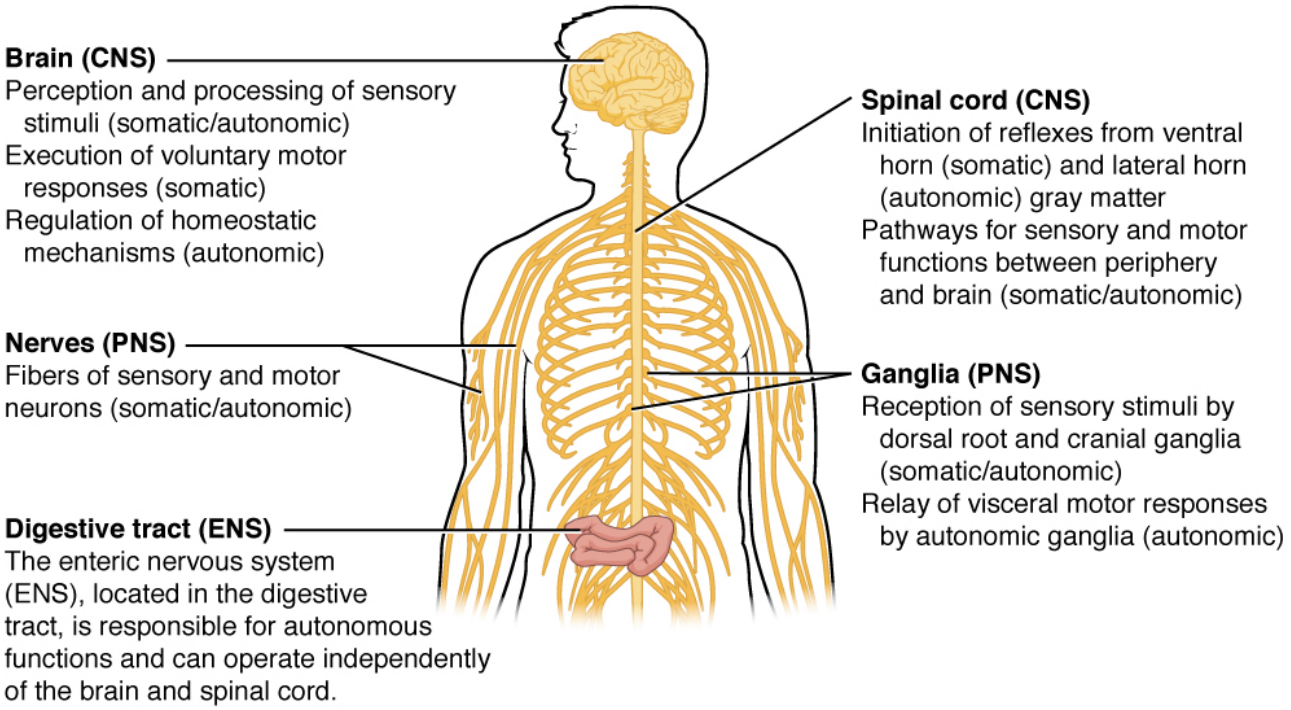


Figure 12.3 Functional regions of the nervous system. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Nervous Tissue

Nervous tissue contains two major cell types, *neurons* and *glial cells*. Neurons are the cells responsible for communication through electrical signals. Glial cells are supporting cells, maintaining the environment around the neurons.

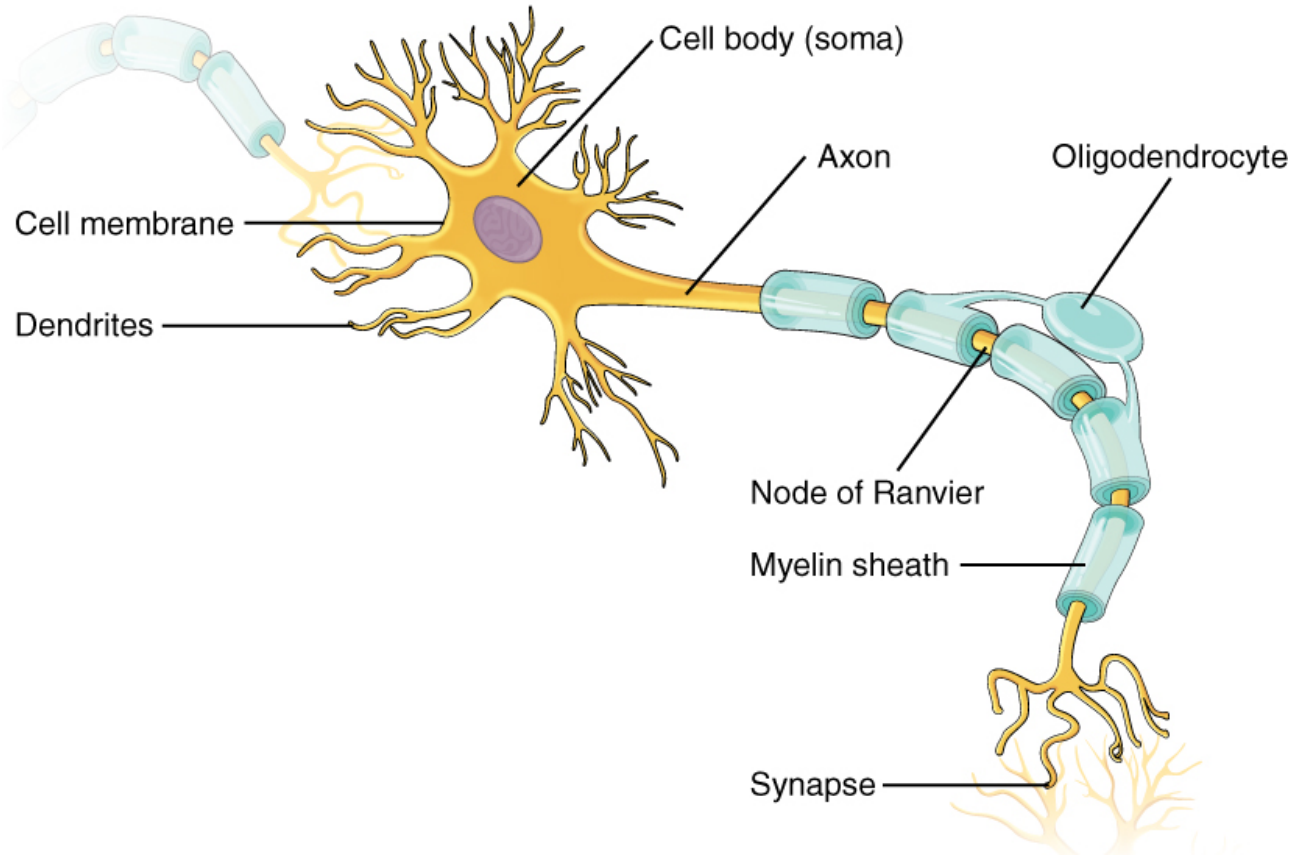


Figure 12.4 A multipolar neuron. Dendrites receive information from other neurons. The cell body integrates the signals and starts an action potential which travels down the axon. The figure shows a myelinated axon but some neurons are not myelinated. Synapses with other neurons occur at the ends of axons as shown. Oligodendrocyte is a type of glial cells that provides the myelin (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Neurons are polarized cells, based on the flow of electrical signals along their membrane. Signals are received at the *dendrites*, are passed along the *cell body*, and propagate along the *axon* towards the target, which may be another neuron, muscle tissue, or a gland. Many axons are insulated by a lipid-rich substance called *myelin*. Specific types of glial cells provide this insulation.

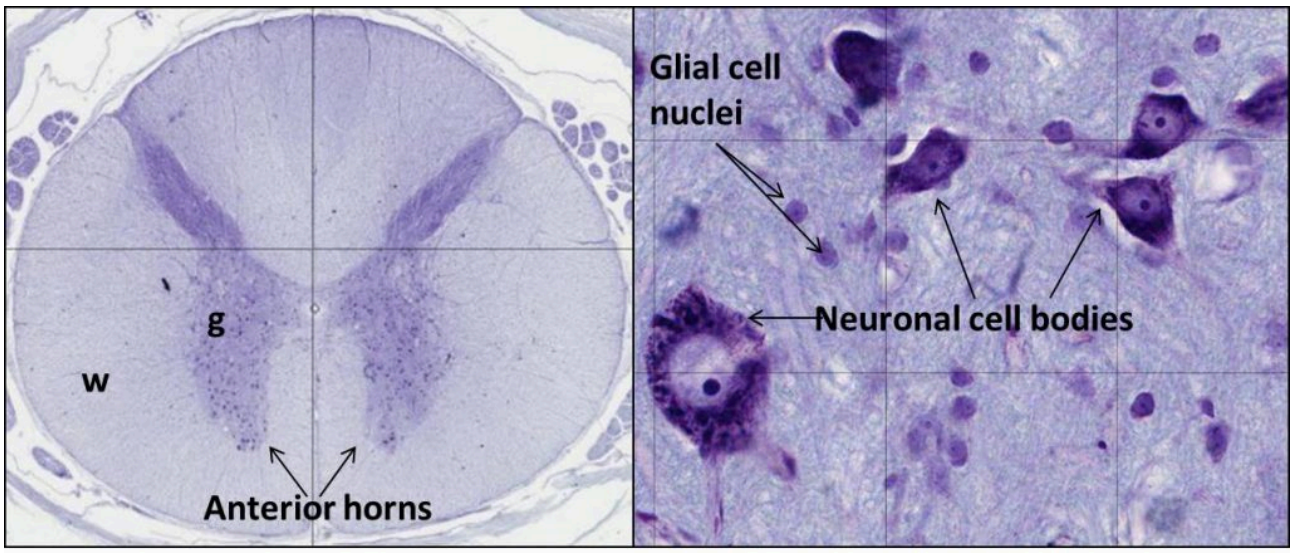


Figure 12.5 Spinal cord cross section. Low magnification image of the cross section of spinal cord with Nissl stain (left) shows the white matter areas with myelinated axons (w) and gray matter areas (g) containing unmyelinated axons, cell bodies and dendrites. High magnification image from the right anterior horn shows the neuronal cell bodies (dark purple) as well as the smaller nuclei of a multitude of glial cells. (Credit: Histology Lab Manual – Columbia University, CC-BY-SA license)

Several types of *glial cells* are found in the nervous system, and they can be categorized by the anatomical division in which they are found. In the CNS, *astrocytes*, *oligodendrocytes*, *microglia*, and *ependymal cells* are found. Astrocytes are important for maintaining the chemical environment around the neuron and are crucial for regulating the blood-brain barrier. Oligodendrocytes are the myelinating glia in the CNS. Microglia act as phagocytes and play a role in immune surveillance. Ependymal cells are responsible for filtering the blood to produce cerebrospinal fluid, which is a circulatory fluid that performs some of the functions of blood in the brain and spinal cord because of the blood brain barrier or BBB. In the PNS, *satellite cells* are supporting cells for the neurons, and *Schwann cells* produce myelin to insulate peripheral axons.

The Function of Nervous Tissue

Sensation starts with the activation of a sensory ending, such as the thermoreceptor in the skin sensing the temperature of the water. The sensory endings in the skin initiate an electrical signal that travels along the sensory axon within a nerve into the spinal cord, where it synapses with a neuron in the gray matter of the spinal cord. The temperature information represented in that electrical signal is passed to the next neuron by a chemical signal that diffuses across the small gap of the synapse and initiates a new electrical signal in the target cell. That signal travels through the sensory pathway to the brain, passing through the thalamus, where conscious perception of the water temperature is made possible by the cerebral cortex. Following integration of that information with other cognitive processes and sensory information, the brain sends a command back down to the spinal cord to initiate a motor response by controlling a skeletal muscle. The motor pathway is composed of two cells, the upper motor neuron and the lower motor neuron. The upper motor neuron has its cell body in the cerebral cortex and synapses on a cell in the gray matter of the spinal

cord. The lower motor neuron is that cell in the gray matter of the spinal cord and its axon extends into the periphery where it synapses with a skeletal muscle in a neuromuscular junction.

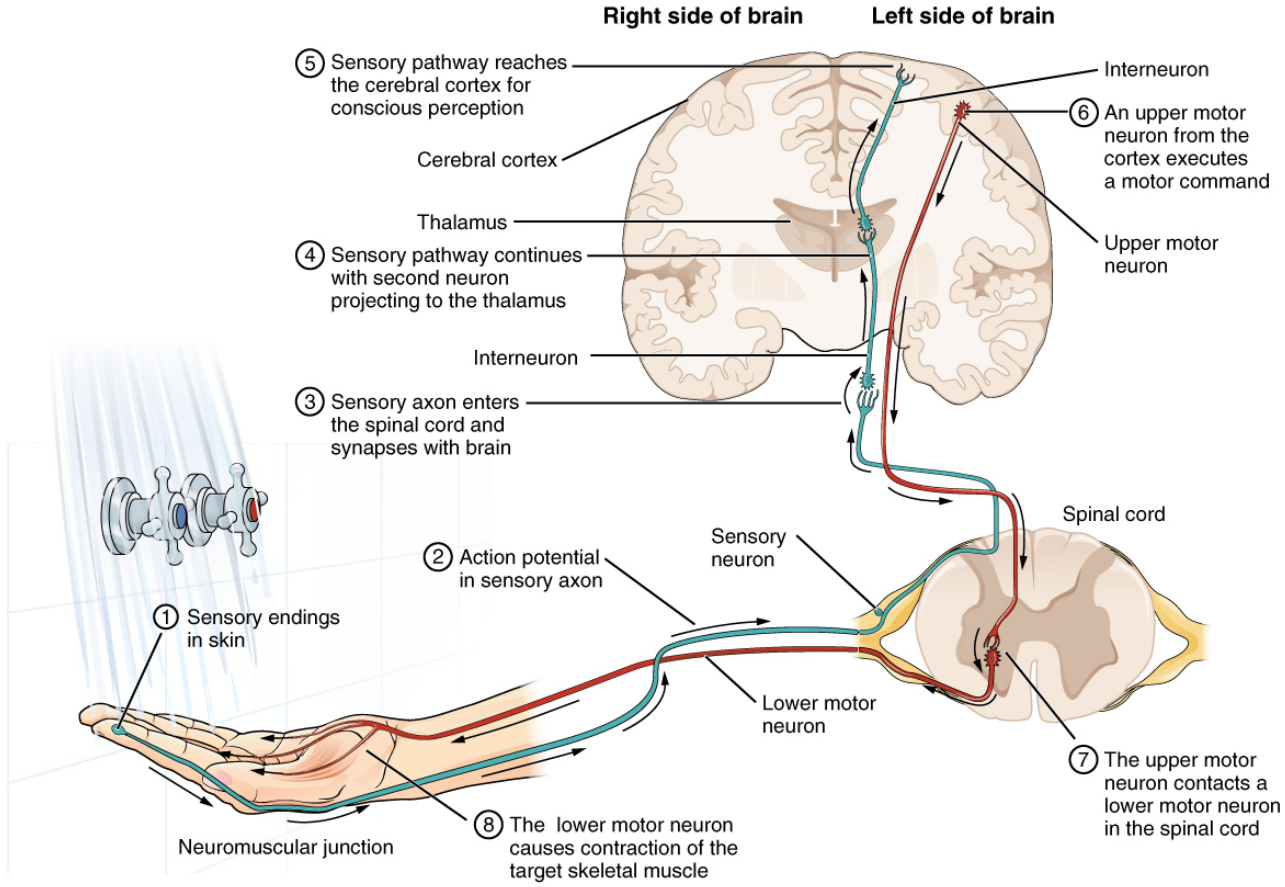


Figure 12.6 Example of Sensory, Motor and Integration Functions of the Nervous Tissues. Sensory nerve endings in the skin (receptors) send information to a sensory neuron which synapses with an interneuron in the brain after passing through the spinal cord. In the brain, another synapse sends the sensory information to the part of the brain that provides conscious perception. In response, an upper neuron in the brain is activated and sends a signal to the lower motor neuron in the spinal cord which in turn activates a skeletal muscle to contract in response. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

The Action Potential

The nervous system is characterized by electrical signals that are sent from one area to another. Whether those areas are close or very far apart, the signal must travel along an axon. The basis of the electrical signal is the controlled distribution of ions across the membrane. Transmembrane ion channels regulate when ions can move in or out of the cell, so that a precise signal is generated. This signal is the action potential which has a very characteristic shape based on voltage changes across the membrane in a given time period.

The membrane is normally at rest with established Na+ and K+ concentrations on either side. A stimulus will start the depolarization of the membrane, and voltage-gated channels will result in further depolarization followed by repolarization of the membrane. A slight overshoot of hyperpolarization marks the end of the action potential. While an action potential is in progress, another cannot be generated under the same conditions. While the voltage-gated Na+ channel is inactivated, absolutely no action potentials

can be generated. Once that channel has returned to its resting state, a new action potential is possible, but it must be started by a relatively stronger stimulus to overcome the K+ leaving the cell.

The action potential travels down the axon as voltage-gated ion channels are opened by the spreading depolarization. In unmyelinated axons, this happens in a *continuous* fashion because there are voltage-gated channels throughout the membrane. In myelinated axons, propagation is described as *saltatory* because voltage-gated channels are only found at the nodes of Ranvier and the electrical events seem to "jump" from one node to the next. Saltatory conduction is faster than continuous conduction, meaning that myelinated axons propagate their signals faster. The diameter of the axon also makes a difference as ions diffusing within the cell have less resistance in a wider space.

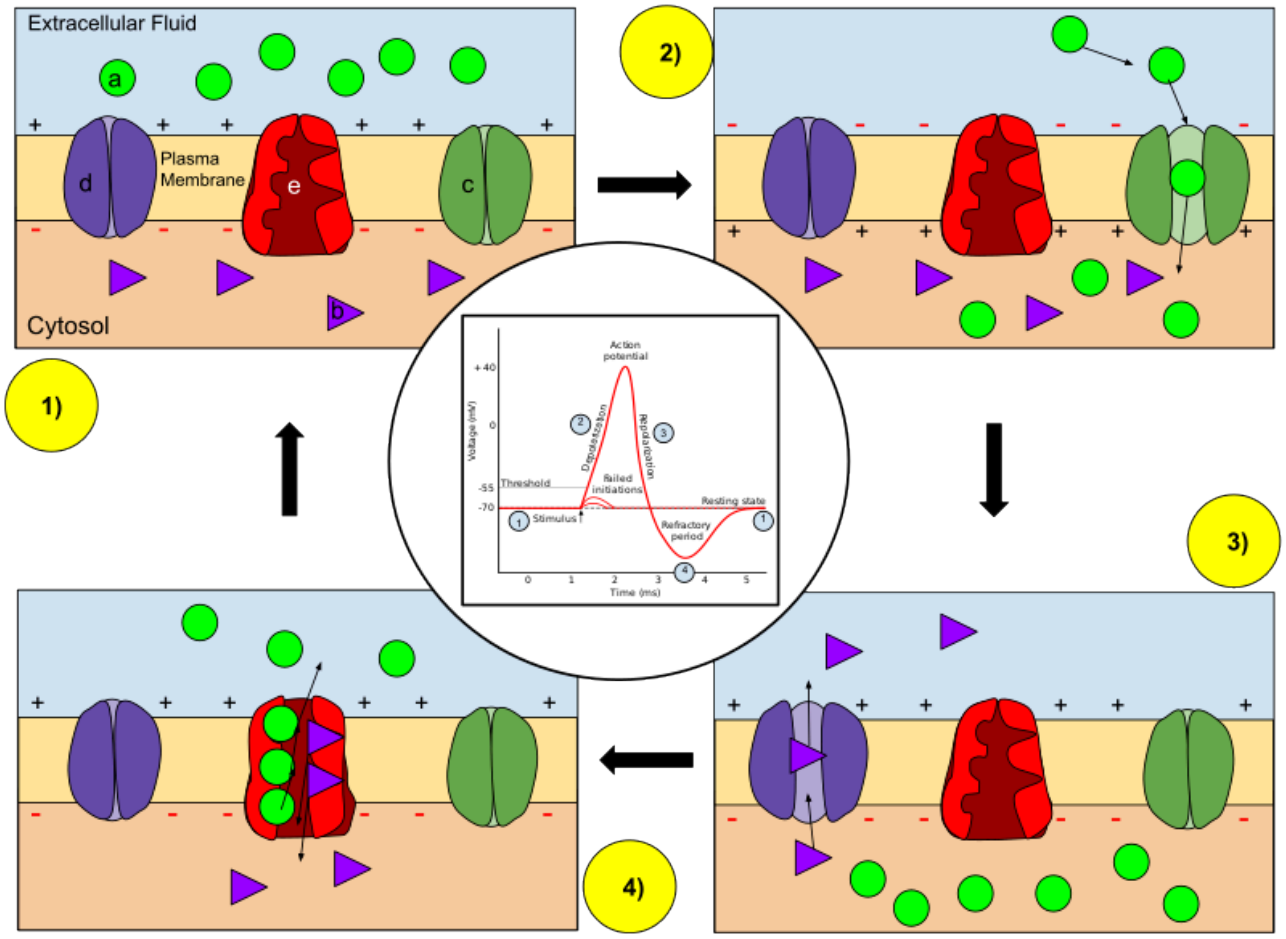


Figure 12.7 Generation of an Action Potential. (Key: (a) Sodium (Na+) ion (b) Potassium (K+) ion (c) Sodium channel (d) Potassium channel (e) Sodium-Potassium Pump. Credit: Wikimedia, by CThompson02, CC-BY-SA 4.0 license)

In the stages of an action potential, the permeability of the membrane of the neuron changes. At the **resting state (1)**, sodium and potassium ions are unable to pass through the membrane, and the neuron has a negative charge inside (mainly due to the large proteins that are negatively charged, as well as the lower amount of positive K+ ions inside the neuron). Once the action potential is triggered, the **depolarization (2)** of the neuron activates the sodium channel, allowing sodium ions to pass through the membrane of the neuron and results in a positive charge in the neuron and a negative charge in the

extracellular fluid. After the action potential is reached, the neuron begins **repolarization (3)**, where the sodium channels close and the potassium channels open, allowing potassium ions to cross the membrane and flood into the extracellular fluid, resulting in a positive charge in the extracellular fluid and a negative charge that is below the resting potential of the neuron. Finally, the membrane potential returns to the resting state as the potassium channels close during the **refractory period (4)**. The sodium-potassium pump works to maintain the concentration gradient over time by exchanging three sodium ions per two potassium ions across the plasma membrane.

View the Action Potential Animation for animated information.

Communication between Neurons

The basis of the electrical signal within a neuron is the *action potential* that propagates down the axon. For a neuron to generate an action potential, it needs to receive input from another source, either another neuron or a sensory stimulus. That input will result in opening ion channels in the neuron, resulting in a *graded potential* based on the strength of the stimulus. Graded potentials can be depolarizing or hyperpolarizing and can summate to affect the probability of the neuron reaching threshold.

Graded potentials can be the result of sensory stimuli. If the sensory stimulus is received by the dendrites of a sensory neuron, such as the sensory neuron ending in the skin, the graded potential is called a *generator potential* because it can directly generate the action potential in the initial segment of the axon. If the sensory stimulus is received by a specialized sensory receptor cell, the graded potential is called a *receptor potential*. Graded potentials produced by interactions between neurons at synapses are called *postsynaptic potentials (PSPs)*. A depolarizing graded potential at a synapse is called an *excitatory PSP (EPSP)*, and a hyperpolarizing graded potential at a synapse is called an *inhibitory PSP (IPSP)*. Summation of EPSPs and IPSPs determine if the membrane reaches the *threshold depolarization level of -55 mV* from the resting potential of -70 mV.

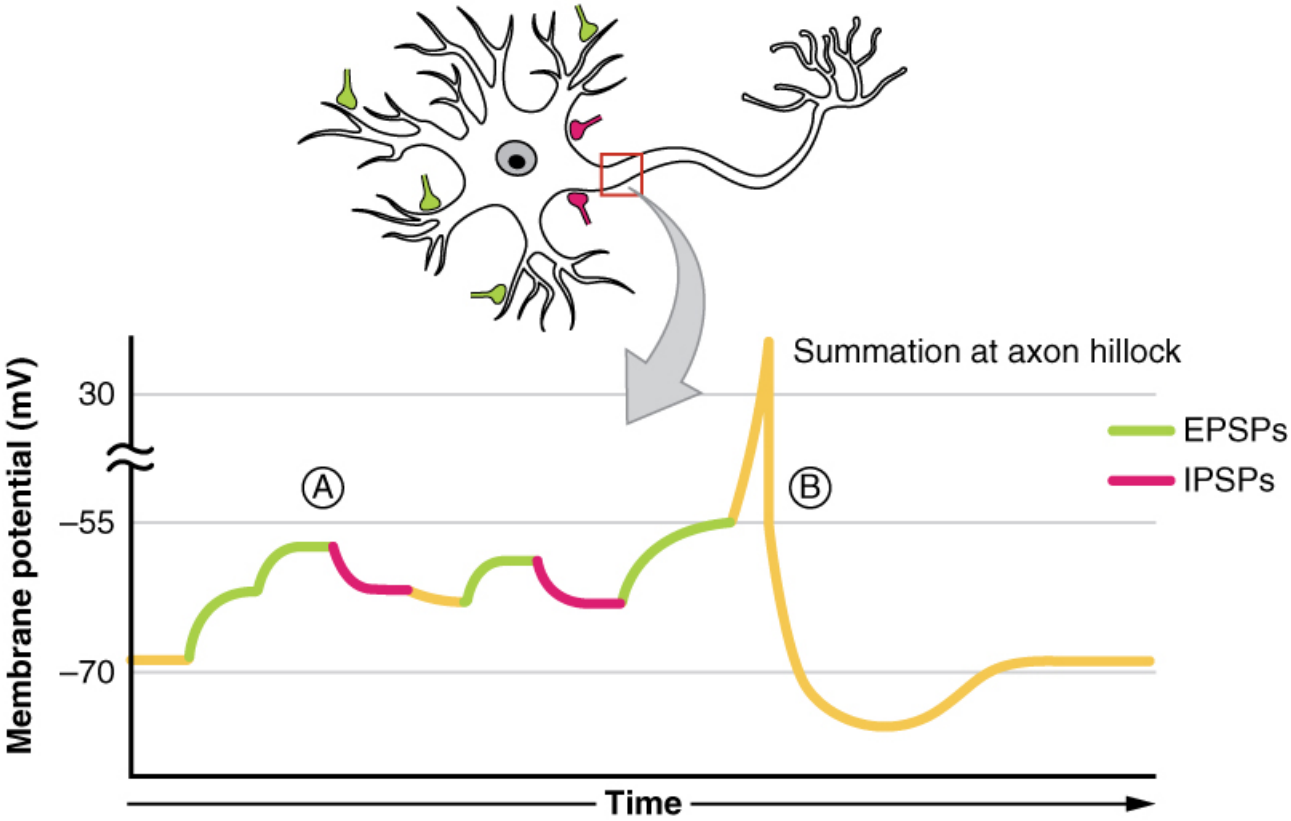


Figure 12.8 Summation of EPSPs and IPSPs. Summation of the excitatory EPSPs help towards reaching the threshold, whereas the inhibitory IPSPs move the membrane further away from the threshold. If the threshold of -55mV is reached at the axon hillock (red square on the neuron) then an action potential is initiated. The figure shows summation of PSPs over time (graph) as well as over space (multiple synapses on the neuron figure).

Synapses are the contacts between neurons, which can either be chemical or electrical in nature. Chemical synapses are far more common. At a chemical synapse, neurotransmitter is released from the presynaptic element and diffuses across the synaptic cleft. The neurotransmitter binds to a receptor protein and causes a change in the postsynaptic membrane (the PSP). The neurotransmitter must be inactivated or removed from the synaptic cleft so that the stimulus is limited in time.

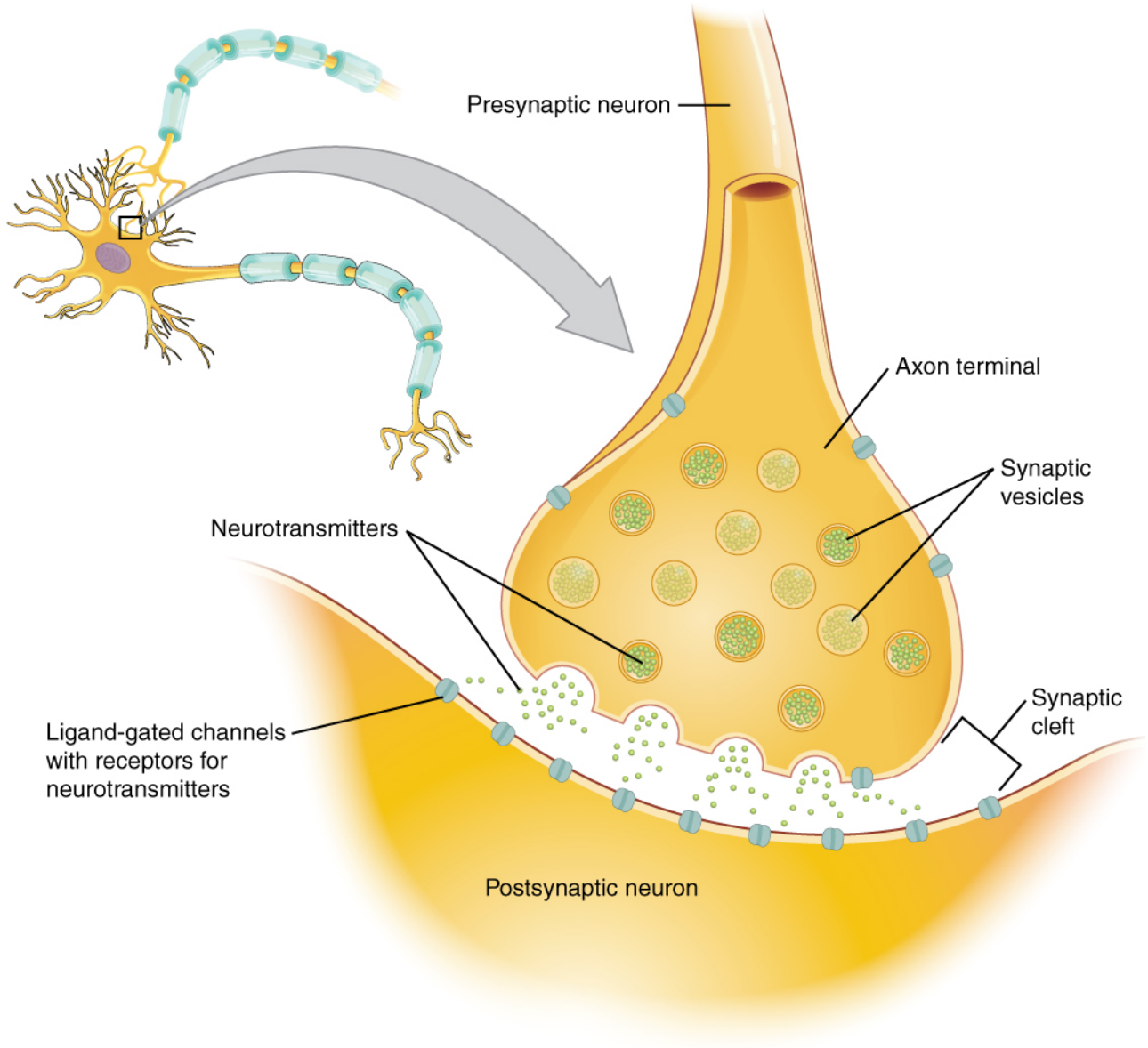


Figure 12.9 The Chemical Synapse. The action potential reaches the presynaptic neuronal end and opens the voltage-gated calcium channels bringing in calcium. The calcium is used by the synaptic vesicles carrying the neurotransmitter to fuse with the membrane and release the neurotransmitter into the synaptic cleft. The neurotransmitter binds ligand-gated channels on the postsynaptic membrane. If the binding brings in sodium Na+ it depolarizes or produces an excitatory PSP. If the binding opens a chloride channel bringing in Cl- it hyperpolarizes producing an inhibitory PSP. The neurotransmitter is removed from the synaptic cleft either enzymatically or by reuptake to the presynaptic neuron.

The particular characteristics of a synapse vary based on the *neurotransmitter* system produced by that neuron. The cholinergic system which uses acetylcholine (ACh) as a neurotransmitter is found at the neuromuscular junction and in certain places within the nervous system. Amino acids, such as glutamate, glycine, and gamma-aminobutyric acid (GABA) are used as neurotransmitters. Other neurotransmitters are the result of amino acids being enzymatically changed, as in the biogenic amines such as dopamine (reward neurotransmitter), or being covalently bonded together, as in the neuropeptides.

Pre-Laboratory Questions

After you review the Background information above, answer the following pre-laboratory questions before starting your lab exercises:

1. What are the two anatomical divisions of the nervous system?
2. List the three main functions of nervous system tissues.
3. What do we call main functional cell types that transmit electrical signals in the nervous system?
4. How is an action potential generated?
5. Explain how signal is transmitted from a presynaptic to a postsynaptic neuron at the synapse.

Exercises

- Exercise 1 Create a 3D model of a multipolar neuron and label its structures and organelles
- Exercise 2 Sketch and identify neural tissue components by spinal cord section microscopy
- Exercise 3 Interpret effects on action potential of changes to voltage-gated Na^+ channels
- Exercise 4 Predict the effect of manipulating the neurotransmitter dopamine on addiction

Exercise 1 Create a 3D model of a multipolar neuron and label its structures and organelles

Required Materials

- Plaster (multiple colors)
- Wired threads (multiple colors)
- Styrofoam balls
- Straws
- Wooden sticks
- Water color paint
- Plates
- Colorful Markers
- Construction paper

- Labeling Tape
- Labeling Pins
- Scissors
- Neuron models

Procedure

1. Your task is to generate as complete a 3D model as possible. You may need to make more than one model to demonstrate both the gross structures and the smaller organelle type structures and detail within the neuron. When you are finished, you should have labelled the following structures on your 3D model.
2. As you build your model, make sure to use the pins and labeling tape to carefully label as many of the above structures as possible. Have fun! When finished, present your model to your instructor. Leave the model or models on the instructor's table or side bench for further examination.
3. Take a picture of the labeled models and paste them below (and in the Post-laboratory Questions section).

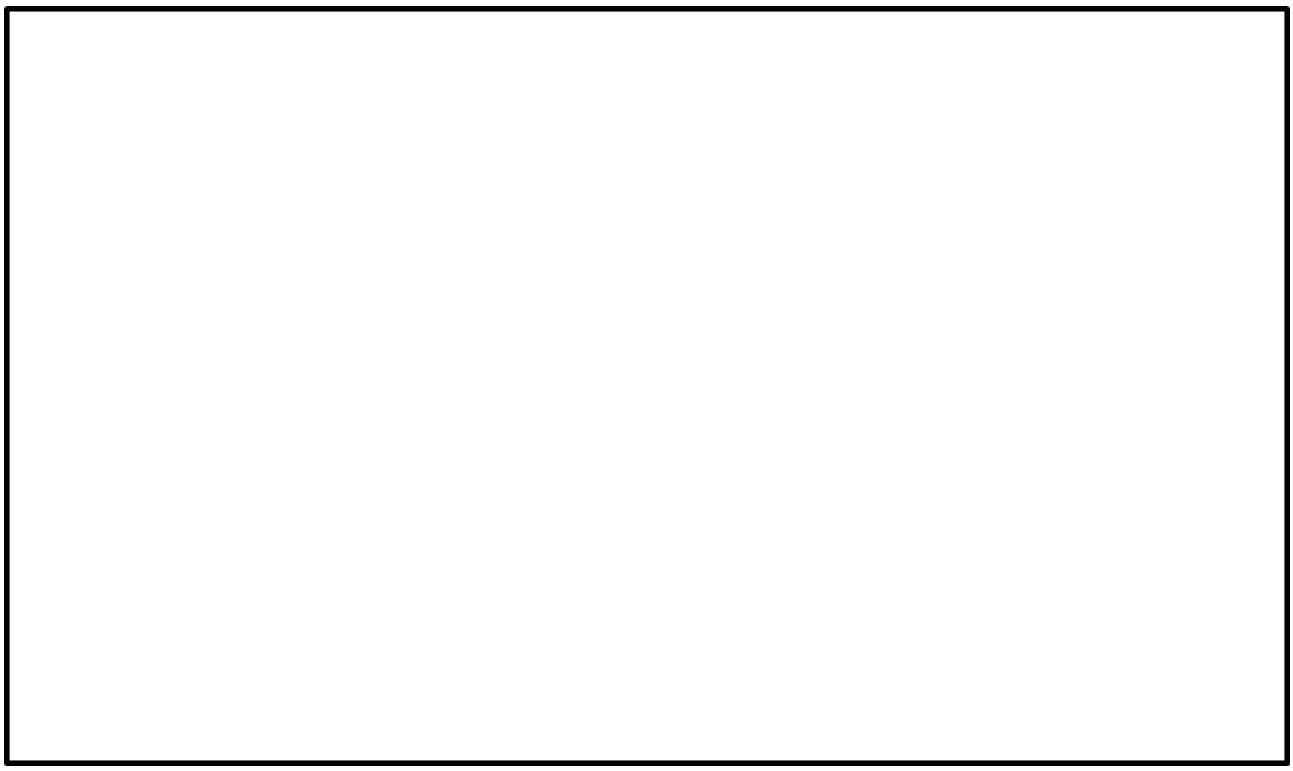
Gross structures:

- Dendrites
- Cell body
- Axon hillock
- Axon
- Myelin
- Nodes of Ranvier
- Synaptic knobs

Internal detail:

- Nucleus
- Nucleolus
- Cell membrane
- Cytoplasm
- Mictochondria
- Endoplasmic reticulum
- Golgi apparatus
- Cytoskeleton
- Axoplasm
- Axon cytoskeleton
- Synaptic vesicles with neurotransmitter

- Voltage-gated Na+ channels
- Voltage-gated K+ channels
- Voltage-gated Ca+ channels
- Ligand-gated Na+ channels
- Ligand-gated Cl- channels



Exercise 2 Sketch and identify neural tissue components by spinal cord section microscopy

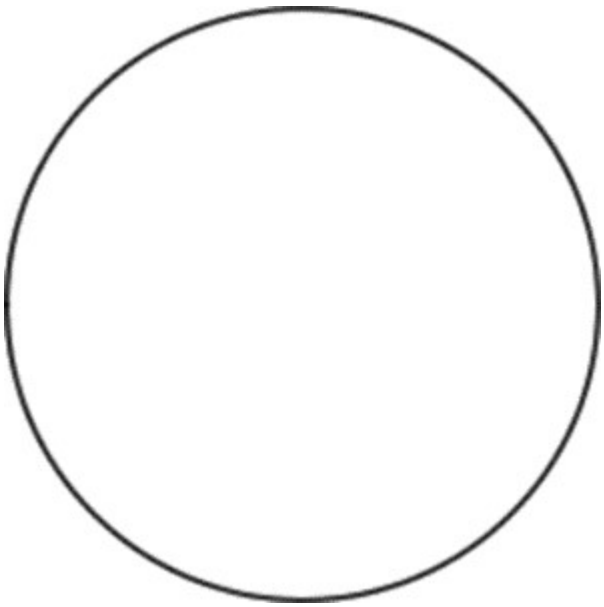
Required Materials

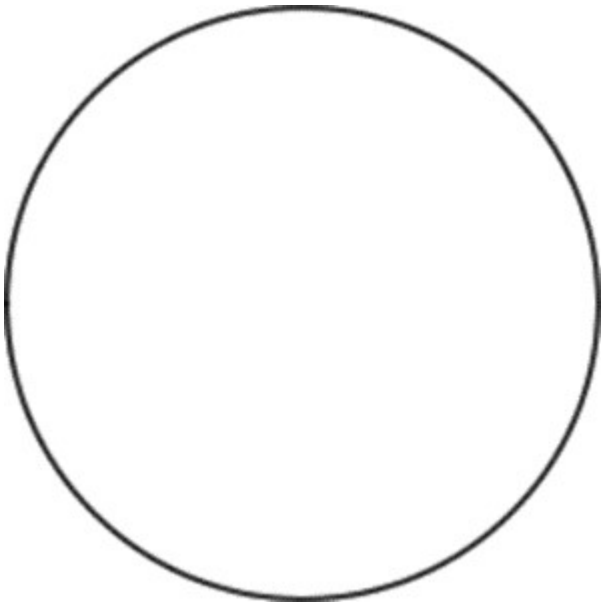
- A slide of the cross section of the spinal cord
- A light microscope with 4x, 10x, 40x, and 100x objectives and 10x ocular objective
- Lens cleaning fluid
- Lens paper
- Microscope immersion oil

Procedure

1. Nervous system tissues contain neurons that transmit electrical signals and glial cells that have supportive functions. In this exercise, you will examine the microscopic structure of the spinal cord which is part of the CNS (Figure 12.5). This will enable you to identify white and gray matter areas at low magnification, as well as neurons, myelinated axons, and glial cells at high magnification.

2. Observe the spinal cord section using the lowest objective magnification (4x). Identify the white matter and gray matter areas of the spinal cord. Also identify the ventral (anterior) and dorsal (posterior) horns that are part of the gray matter.
3. Observe neurons and glial cells at high magnification (10x, then 40x, and possibly with oil at 100x). Before you change your objective from 4x, first determine whether you should be looking in the gray matter or white matter areas. Then, move your slide to the correct matter area. Scan that area at higher magnification to find neuronal cell bodies and glial cell nuclei.
4. Observe cross sections of myelinated axons at high magnification (10x, then 40x, and possibly with oil at 100x). First decide if you need to be examining the gray matter or white matter areas of the spinal cord section. Then, move into the appropriate area. Scan your slide to see if you can recognize a myelinated axon cross section which looks like a white halo around a dark circle.
5. Sketch the low and high magnification images of the spinal cord section below and label all of these structures on them using the space below.





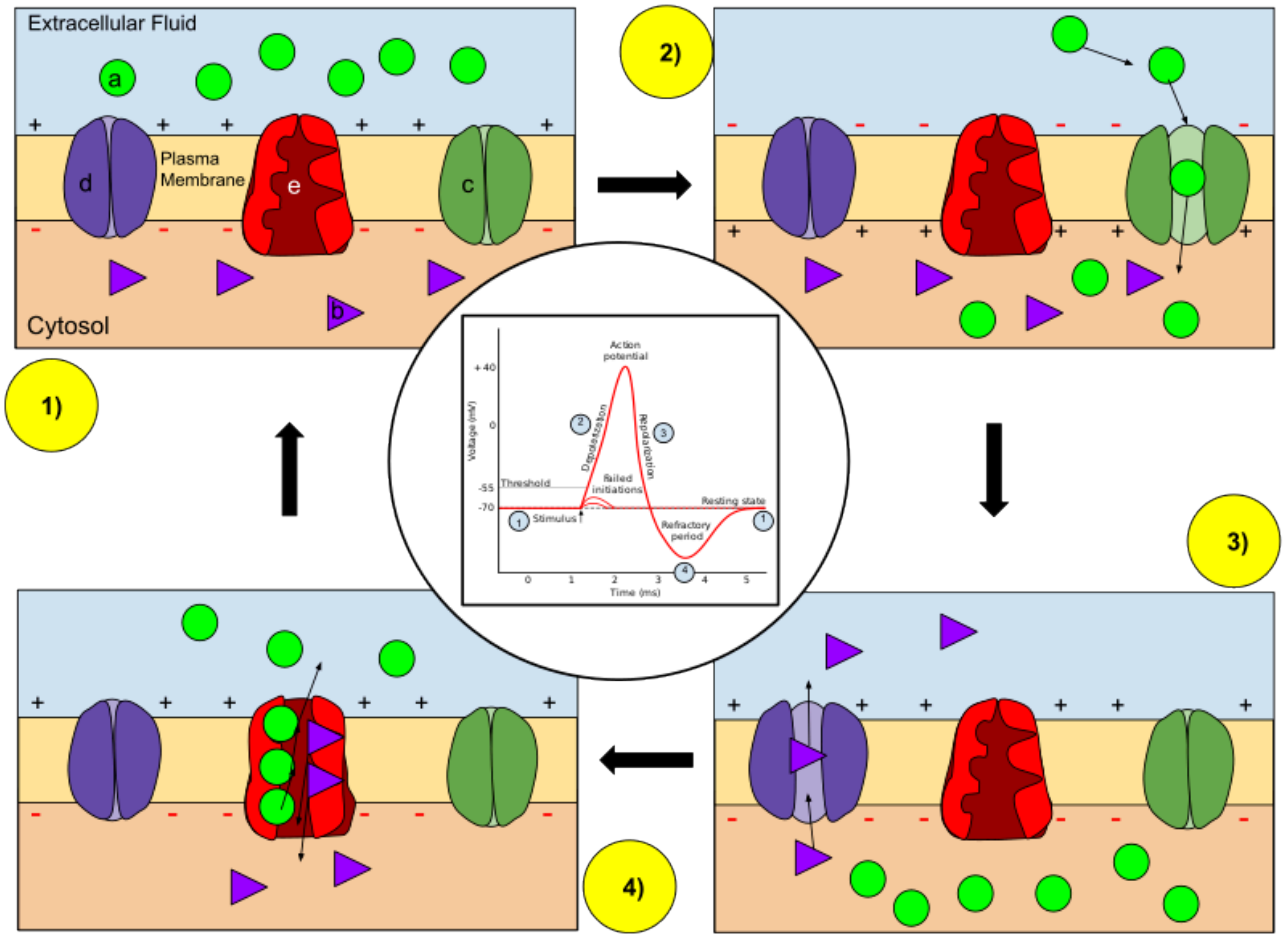
Exercise 3 Interpret effects on action potential of changes to voltage-gated Na^+ channels

Required Materials

- Scenario: Lidocaine is a local anesthetic or numbing agent which prevents sensory neurons from sending pain signals to the brain. Lidocaine achieves its numbing effect by binding to and reversibly blocking voltage gated sodium Na^+ channels. What "reversible" blocking means is that once the Lidocaine levels are reduced, the sodium Na^+ channel function gets back to normal. Tetrodotoxin is another sodium Na^+ channel blocker. However, tetrodotoxin is considered to be a neurotoxin. It is a naturally occurring toxin found in pufferfish, porcupine fish, ocean sunfish, and triggerfish. Unlike lidocaine, when tetrodotoxin blocks the sodium channel, this is not reversible. In this exercise, we will predict how these chemicals affect the initiation and progression of the action potentials down a

neuron.

- Model of <u>action potential:</u> We will use the figure of action potential generation displayed in **Figure 12.7** as a model



Key: **(a)** Sodium (Na+) ion **(b)** Potassium (K+) ion **(c)** Sodium channel **(d)** Potassium channel **(e)** Sodium-Potassium Pump.

Proceduer

1. Lidocaine is applied to a patient's skin before a minor procedure to enable local numbing. Think of a sensory neuron that is activated to transmit pain information to the brain from this area. If the nurse cuts into the skin without adding the Lidocaine, then the neuron will be activated as shown in Figure 12.7 and above. It will generate an action potential that will be transmitted down the neuron. What will happen to the steps 1 – 4 shown in the figure above if Lidocaine is used to numb the patient? Draw steps 1-4, as well as the action potential graph shown in the middle to display the changes expected by applying Lidocaine.

2. What will happen after a few hours in which Lidocaine diffuses out of the area? Will the neuron go back to normal action potential generation as shown in Figure 12.7? Explain.

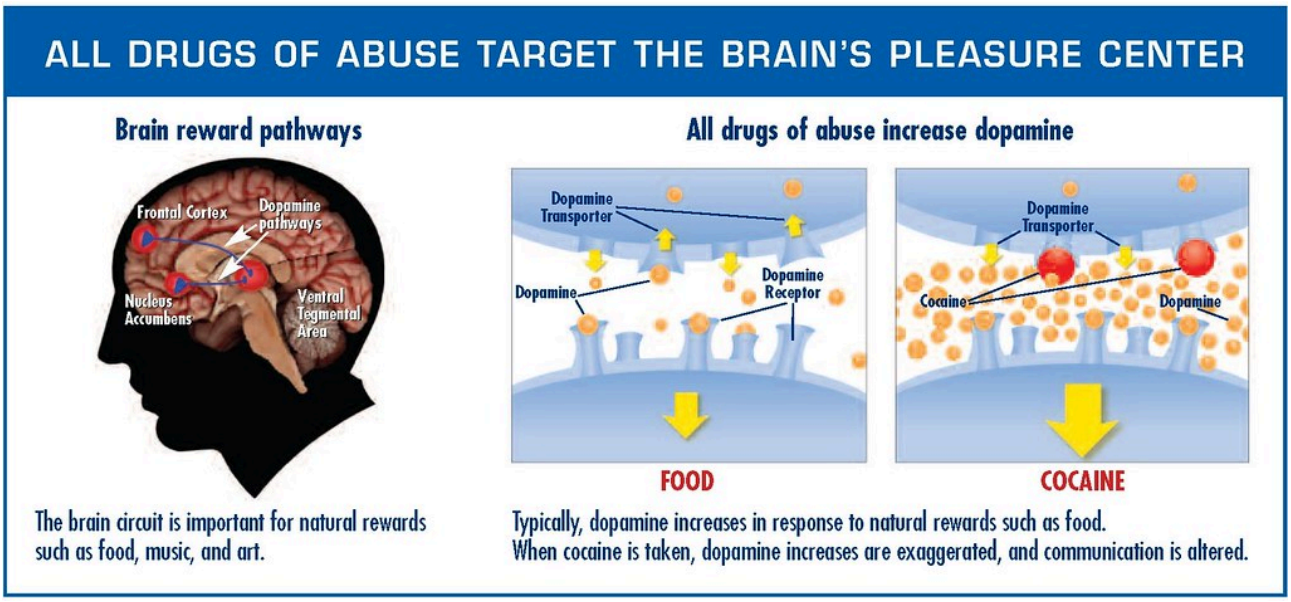
3. If you have a patient who ate pufferfish containing Tetrodotoxin, what do you expect will happen to each of the patient's exposed neurons? Will each neuron be able to generate an action potential? For Figure 12.7 now draw what will happen to steps 1 – 4 and the action potential graph in the presence of Tetrodotoxin.

4. Can Tetrodotoxin be used as a local numbing agent like Lidocaine is? Explain.

Exercise 4 Predict the effect of manipulating the neurotransmitter dopamine on addiction

Required Materials

- Scenario: We will go back to **Figure 12.1** to revisit the issue of drug abuse or addiction. After having gone through the chapter, you now know that dopamine is a neurotransmitter released as a chemical in response to an action potential in the presynaptic neuron. Once it is released, dopamine binds receptors on the postsynaptic neuron's cell membrane to generate excitatory PSPs or inhibitory PSPs. Whether the effect is an ESPS or ISPS depends on the type of dopamine receptor on the postsynaptic cell membrane. In this exercise you will explore this synaptic pathway comparing it in normal and addicted brains. You will also think of creative ways in which you can develop medication to treat drug addiction. How can you normalize the dopamine pathways in an addict's brain?
- Model of dopamine in drug addiction: We will use the **Figure 12.1** model showing the changes in dopamine at the synapse that occur in drug addiction.



Procedure

1. On the figure above, label the presynaptic and postsynaptic cells and the synaptic cleft.

2. In response to cocaine, there is clearly much more dopamine (orange dots) in the synaptic cleft. Using the figure, explain what caused this increase in dopamine level in response to cocaine (compared to what happens in the normal case in response to food). Which process did cocaine block?

3. As shown in response to cocaine, the issue that starts addiction has to do with the fact that dopamine persists and continues to signal to the postsynaptic cell highly activating the pleasure or reward centers of the brain for extended periods of time.

If you could develop a chemical treatment to prevent this from occurring, how would you go about it? In other words, what are some ways you can prevent dopamine from accumulating in the presence of cocaine?

Post-laboratory Questions

1. In Exercise 1 you built a 3D model or 3D models of a multipolar neuron. Please answer the following questions related to this exercise.

a. Take a picture of the fully labeled model(s) and paste the picture(s) below.

b. As you built this model, what were some things that you weren't sure of regarding the model? Did you have questions about the ratio of the cell body to the length of the axon for example? Do you think this would be the same for all multipolar neurons? Discuss.

c. Multipolar neurons are motor neurons that transmit information from the central nervous system to skeletal muscles. Think of all the skeletal muscles in your body that you move on purpose. Think of their distance from the brain's motor centers. Would you expect the length of the axon of a motor neuron controlling your eyelid muscles to be the same as one controlling you foot muscles? Explain. Use drawing to help answer your question.

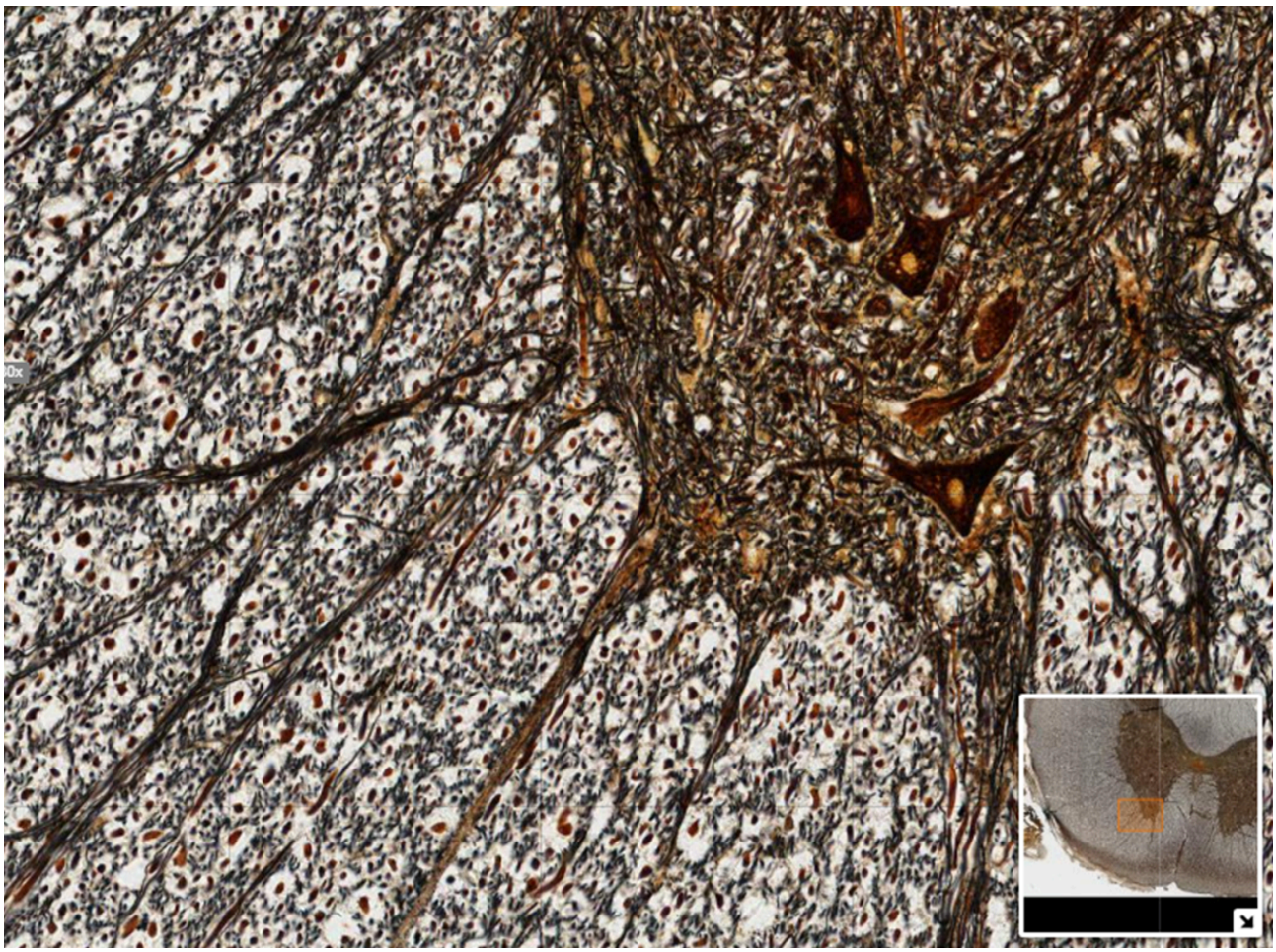
d. Did you have any difficulty deciding how wide the diameter of the axon needed to be? Do you think all multipolar neurons have the same diameter or do you expect some to be wider and some narrower? If some neuronal axons are wider, would that help move the action potential down the length of it? Explain.

2. In Exercise 2, you sketched and identified neural tissue components by spinal cord section microscopy. Using the same concepts related to the content of gray matter and white matter and your knowledge of neurons and glial cells, answer the following questions related to another spinal cord section, this time stained with silver stain rather than the Nissl stain used in the slides you observed.

a. Label the following on the low magnification micrograph of the spinal cord below: **gray matter, white matter, anterior horns, posterior horns.**

(Credit: Histology Lab Manual – Columbia University, CC-BY-SA 4.0)

b. In the high magnification image of the same silver stained spinal cord section as above, find and label the following: **neuronal cell body, glial cell, myelinated axon.**

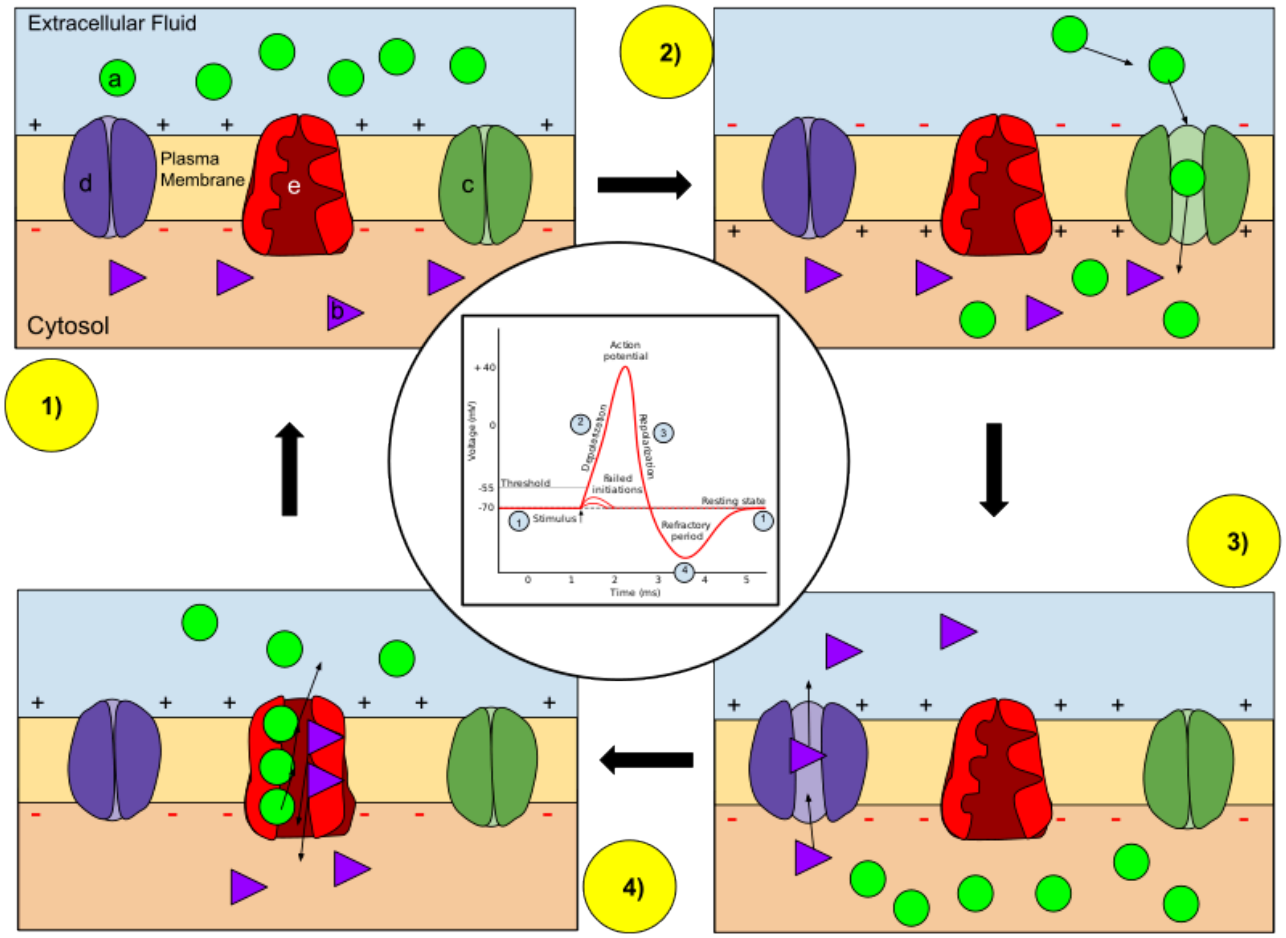


(Credit: Histology Lab Manual – Columbia University, CC-BY-SA 4.0)

3. In Exercise 3, you explored the effects on action potential of changes to voltage-gated Na^+ channels by the local numbing agent Lidocaine and the neurotoxin Tetrodotoxin. Using the same logic and applying your knowledge of how action potentials are generated as shown in **Figure 12.7** answer the following questions related to blocking the voltage-gated potassium K^+ channel in a neuron.

You are told that your patient has been stung by a scorpion and the scorpion venom contains a potassium K^+ channel blocker. There are four steps in the action potential model below. Explain which of these four steps will be affected by blocking the potassium channel and what the effect will be.

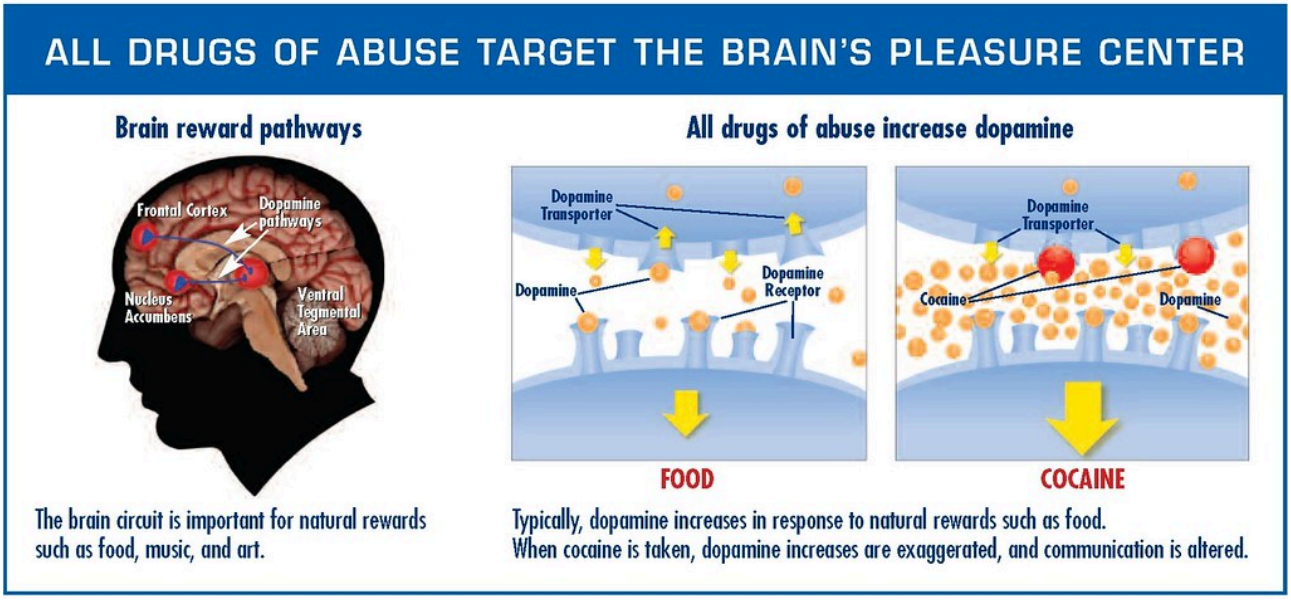
- **(1) Stimulus to reach threshold?**
- **(2) Depolarization?**
- **(3) Repolarization?**
- **(4) Hyperpolarization?**



4. In Exercise 4 you examined ways of manipulating the neurotransmitter dopamine to reduce its effects on addiction. You did this because you were shown that drugs of abuse like cocaine result in an increase in the amount of dopamine therefore heightening the sensation of pleasure for sustained periods of time.

In some patients who suffer from depression, the opposite situation exists: The levels of dopamine becomes too low and therefore the patients do not feel pleasure or get feelings of enjoyment when they should.

a. Draw the synapses comparing the normal reaction to food with the reaction of a depressed person to food (similar to Figure 12.1) showing the levels of dopamine in each.



b. One of the medications that is used to treat depression is a dopamine re-uptake inhibitor. Re-uptake refers to what the dopamine transporters in the figure above do. Explain how a re-uptake inhibitor of dopamine helps a depressed person feel better.

c. Given what you know about the effect of cocaine (and other drugs of abuse) on dopamine and its relation to depression, how do you explain the term "self-medicating" as it refers to use of drugs of abuse and depression?

13.

CHAPTER 13 ANATOMY OF THE NERVOUS SYSTEM

By Krishnan Prabhakaran

Motivation.

Parkinson's disease is a brain disorder that causes unintended or uncontrollable movements, such as shaking, stiffness, and difficulty with balance and coordination. Symptoms usually begin gradually and worsen over time. As the disease progresses, people may have difficulty walking and talking. They may also have mental and behavioral changes, sleep problems, depression, memory difficulties, and fatigue.

While virtually anyone could be at risk for developing Parkinson's, some research studies suggest this disease affects *more men than women*. It's unclear why, but studies are underway to understand factors that may increase a person's risk. One clear risk is age: Although most people with Parkinson's first develop the disease *after age 60*, about 5% to 10% experience onset before the age of 50. Early-onset forms of Parkinson's are often, but not always, inherited, and some forms have been linked to specific gene mutations.

The most prominent signs and symptoms of Parkinson's disease occur when nerve cells in the basal ganglia (Figure 13.1) , an area of the brain that controls movement, become impaired and/or die. Normally, these nerve cells, or neurons, produce an important brain chemical known as dopamine. When the neurons die or become impaired, they produce less dopamine, which causes the movement problems associated with the disease. Scientists still do not know what causes the neurons to die.

People with Parkinson's disease also lose the nerve endings that produce norepinephrine, the main chemical messenger of the sympathetic nervous system, which controls many functions of the body, such as heart rate and blood pressure. The loss of norepinephrine might help explain some of the non-movement features of Parkinson's, such as fatigue, irregular blood pressure, decreased movement of food through the digestive tract, and sudden drop in blood pressure when a person stands up from a sitting or lying position.

Some cases of Parkinson's disease appear to be hereditary and a few cases can be traced to

specific genetic mutations. While genetics is thought to play a role in Parkinson's, in most cases the disease does not seem to run in families. Many researchers now believe that Parkinson's results from a combination of genetic and environmental factors, such as exposure to toxins.

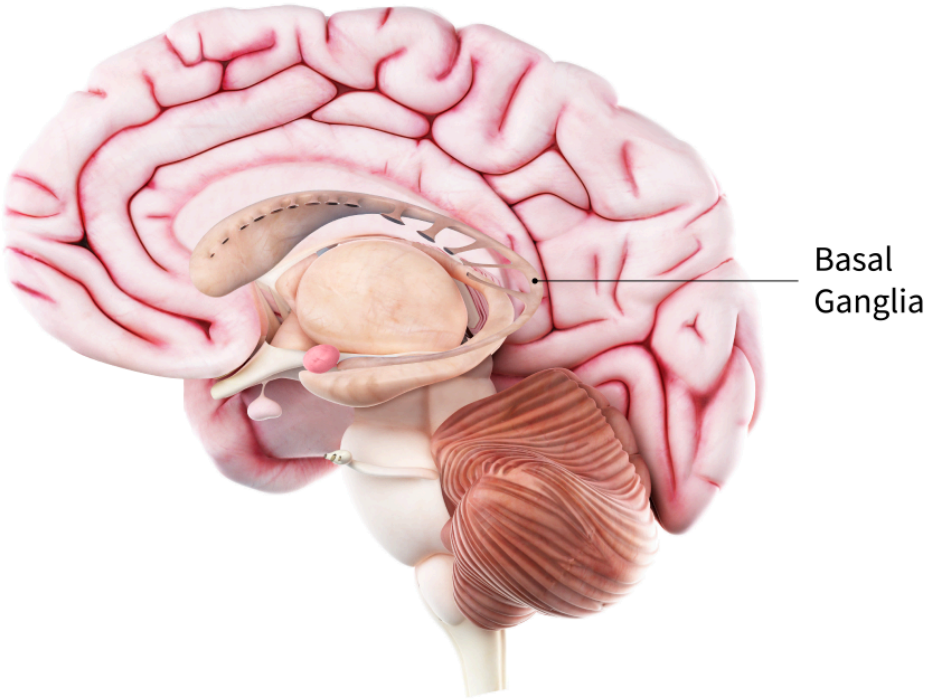


Figure 13.1 Basal ganglia region of brain affected by Parkinson's disease.
Credit: National Institutes of Health National Institute on Aging (NIA) is the originator and NIA's Web site (www.nia.nih.gov) is the source, license Public Domain.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Describe the composition of gray and white matter and provide examples of brain structures made of each.

- Describe and identify the brain meninges: dura mater, arachnoid mater, & pia mater.
- Define the following structural features of the brain: gyrus, sulcus, fissure.
- Identify brain structures on a dissected brain specimen, model, or diagram.
- Identify cranial nerves on a model or diagram and describe functions of each.
- Identify and define anatomical features of the spinal cord on a model or diagram for both longitudinal view and cross-sectional views.
- Apply learning outcome 1 to describe the fundamental principles of sensory and motor signaling pathways within the spinal cord.

Background.

The nervous system can be divided into two major regions: the central and peripheral nervous systems. The central nervous system (CNS) is the brain and spinal cord, and the peripheral nervous system (PNS) is everything else (Figure 13.2). The brain is contained within the cranial cavity of the skull, and the spinal cord is contained within the vertebral cavity of the vertebral column. It is a bit of an oversimplification to say that the CNS is what is inside these two cavities and the peripheral nervous system is outside of them, but that is one way to start to think about it. There are some elements of the peripheral nervous system that are within the cranial or vertebral cavities. The peripheral nervous system is so named because it is on the periphery—meaning beyond the brain and spinal cord. Depending on different aspects of the nervous system, the dividing line between central and peripheral is not necessarily universal.

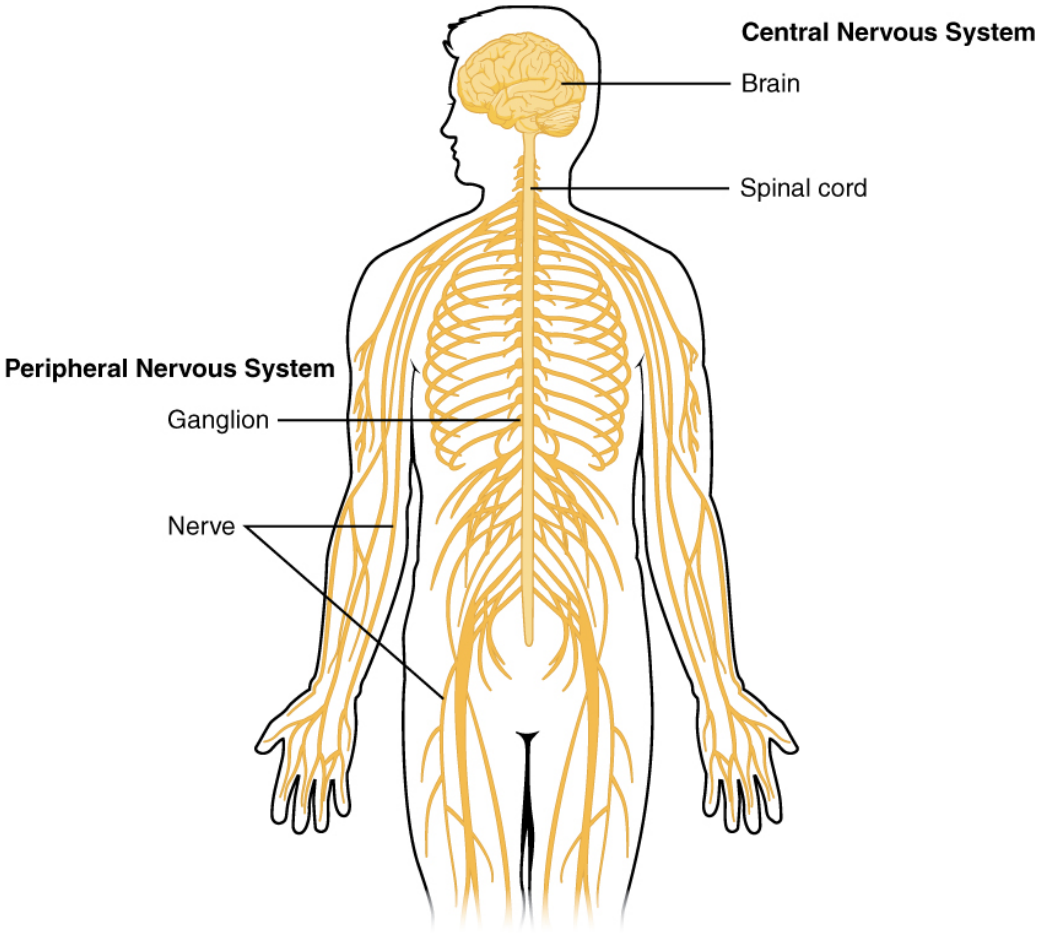


Figure 13.2 Central and peripheral nervous system. CNS, brain and spinal cord; PNS Nerves and ganglia

Nervous Tissue Structures

Nervous tissue, present in both the CNS and PNS, contains two basic types of cells: neurons and glial cells. A glial cell is one of a variety of cells that provide a framework of tissue that supports the neurons and their activities and will not be considered further in this lab. The neuron is the more functionally important of the two, in terms of the communicative function of the nervous system.

Neurons are cells and therefore have a soma, or cell body, but they also have notable extensions of the cell; each extension is generally referred to as a process. There is one important process that nearly all neurons have called an axon, which is the fiber that connects a neuron with its target. Another type of process that branches off from the soma is the dendrite. Dendrites are responsible for receiving most of the input from other neurons. Looking at nervous tissue, there are regions that predominantly contain cell bodies and regions that are largely composed of axons. These two regions within nervous system structures are referred to as gray matter (the regions with many cell bodies and dendrites) or white matter (the regions with many axons). The colors ascribed to these regions are what would be seen in unstained, nervous tissue (Figure 13.3). Gray matter is not necessarily gray. It can be pinkish because of blood content, or even slightly tan, depending on how long the tissue has been preserved. White matter is white because axons are insulated by a lipid-rich substance called myelin. Lipids can appear as white material, much like the fat on a

raw piece of meat. Gray matter may have that color ascribed to it because next to the white matter, it is just darker— hence, gray.

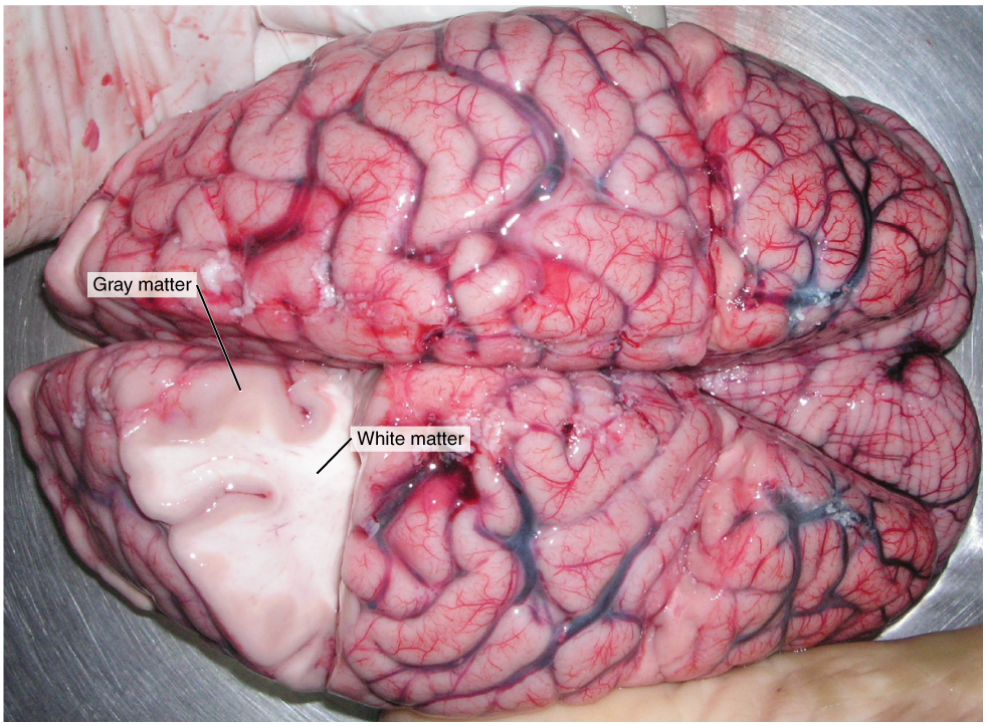


Figure 13.3 Gray Matter and White Matter. A brain removed during an autopsy, with a partial section removed, shows white matter surrounded by gray matter. Gray matter makes up the outer cortex of the brain. (https://commons.wikimedia.org/w/index.php?curid=6745926)

The cell bodies of neurons or axons are often located in discrete anatomical structures that are named. Those names are specific to whether the structure is central or peripheral. A localized collection of neuron cell bodies in the CNS is referred to as a nucleus. In the PNS, a cluster of neuron cell bodies is referred to as a ganglion. A notable exception to this naming convention is a group of nuclei in the central nervous system that were once called the basal ganglia before "ganglion" became accepted as a description for a peripheral structure. Some sources refer to this group of nuclei as the "basal nuclei" which helps avoid confusion.

Terminology applied to bundles of axons also differs depending on location. A bundle of axons, or fibers, found in the CNS is called a tract whereas the same thing in the PNS would be called a nerve. Please note that both can be used to refer to the same bundle of axons. When those axons are in the PNS, the term is nerve, but if they are in the CNS, the term is tract. One example of this is the axons that project from the nervous tissue in the retina into the brain. Axons leaving the eye are called the optic nerve but as soon as they enter the cranium they are referred to as the optic tract.

The Meninges

The outer surface of the brain is covered by a series of membranes composed of connective tissue called the meninges, which protect the brain (Figure 13.4). There are three major meningeal layers; the dura mater, the arachnoid mater and the pia mater.

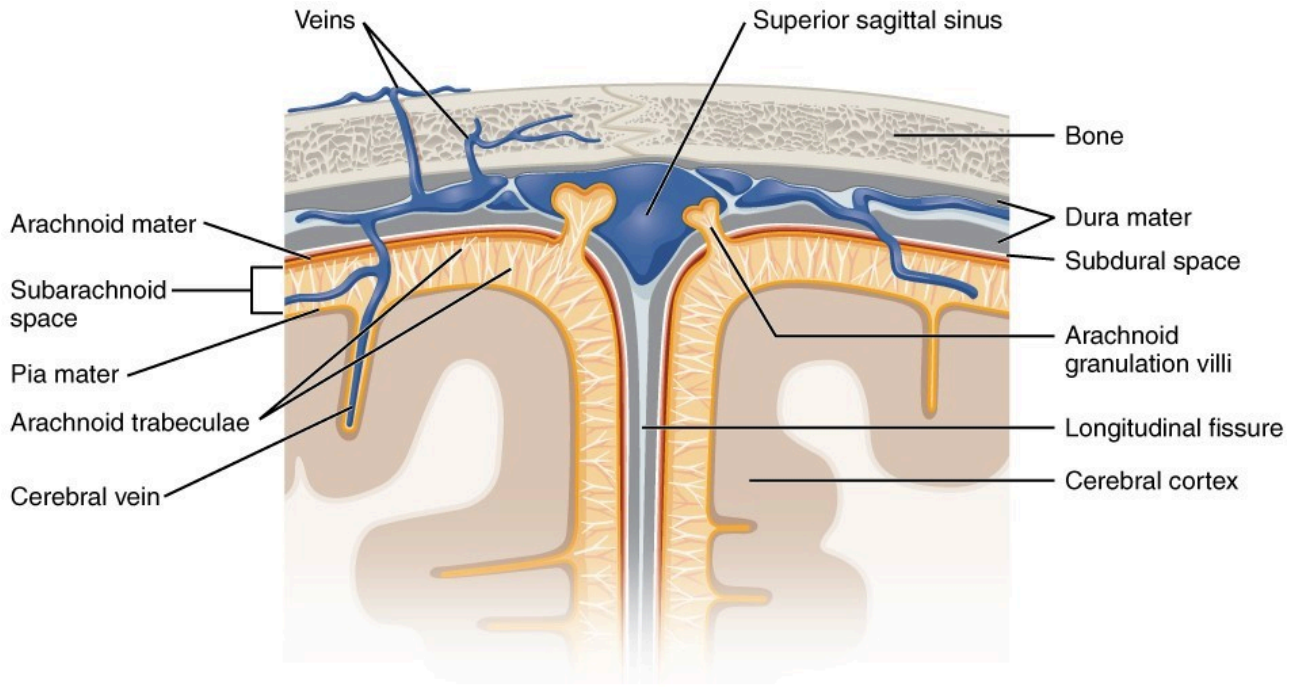


Figure 13.4 Meningeal Layers. The layers of the meninges in are shown, with the dura mater adjacent to the inner surface of the cranium, the pia mater adjacent to the surface of the brain, and the arachnoid and subarachnoid space between them.

Dura mater

Like a thick cap covering the brain, the dura mater is a tough outer covering. It is a thick fibrous layer and a strong protective sheath over the entire brain and spinal cord. It is anchored to the inner surface of the cranium and to the very end of the vertebral cavity. The name comes from the Latin for "tough mother" to represent its physically protective role. It encloses the entire CNS and the major blood vessels that enter the cranium and vertebral cavity.

Arachnoid mater

The middle layer of the meninges is the arachnoid, named for the spider-web–like extensions between it and the pia mater. The arachnoid defines a sac-like enclosure around the CNS. The branching extensions are found in the subarachnoid space, which is filled with circulating CSF (cerebrospinal fluid). The arachnoid emerges into the dural sinuses as the arachnoid granulations, where the CSF is filtered back into the blood for drainage from the nervous system. The subarachnoid space is filled with circulating CSF, which also provides a liquid cushion to the brain and spinal cord. Like clinical blood work, a sample of CSF can be withdrawn to find chemical evidence of neuropathology or metabolic traces of the biochemical functions of nervous tissue.

Pia mater

Directly adjacent to the surface of the CNS is the pia mater, a thin fibrous membrane that extends into every convolution of gyri and sulci in the cerebral cortex (contours of the brain) and other grooves and indentations. It is thought to have a continuous layer of cells providing a fluid-impermeable membrane. The name pia mater comes from the Latin for "tender mother," suggesting the thin membrane is a gentle covering for the brain.

Brain Anatomy

The brain and the spinal cord make up the central nervous system, and they represent the main organs of the nervous system. While the spinal cord is a single structure, the adult brain is described in terms of four major regions: the cerebrum, the diencephalon, the brain stem, and the cerebellum.

Cerebrum

The iconic gray mantle of the human brain, which appears to make up most of the mass of the brain, is the cerebrum (Figure 13.5) The wrinkled outer portion is the cerebral cortex, and the rest of the structure is beneath that outer covering. There is a large separation between the two sides of the cerebrum called

the longitudinal fissure which separates the cerebrum into two distinct halves, a right and left cerebral hemisphere. Deep within the cerebrum, the white matter of the corpus callosum provides the major pathway for communication between the two hemispheres of the cerebral cortex. Many of the higher neurological functions, such as memory, emotion, and consciousness, are the result of cerebral function.

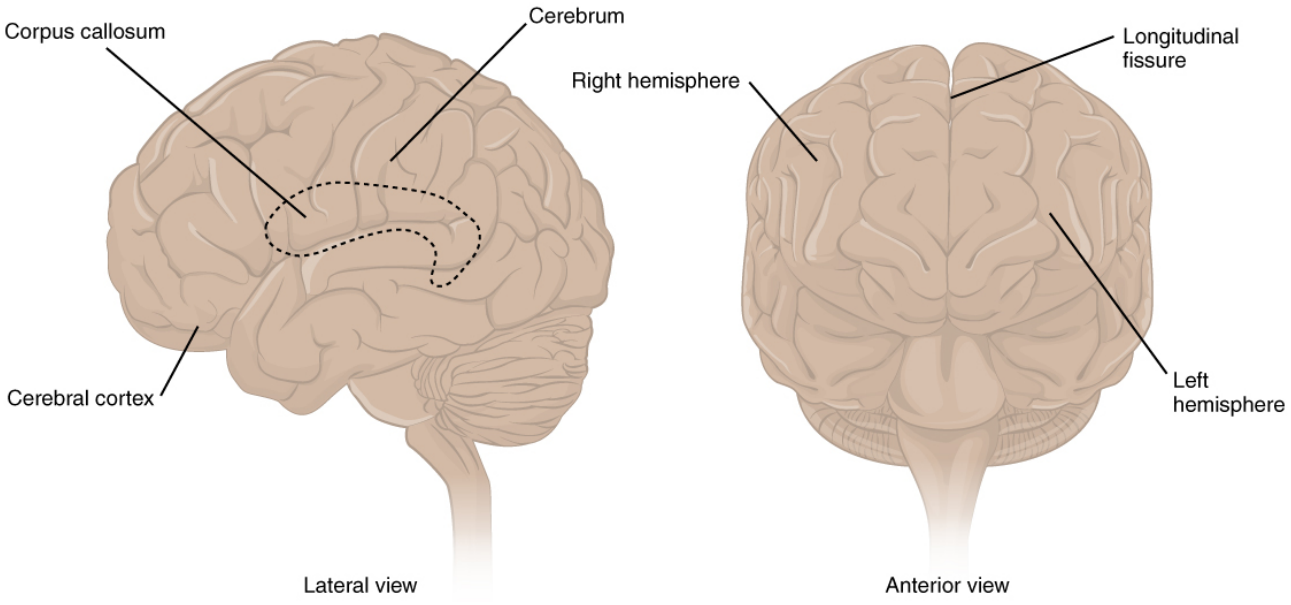


Figure 13.5 The Cerebrum with its two hemispheres separated by the longitudinal fissure.

Cerebral cortex

The cerebrum is covered by a continuous layer of gray matter that wraps around either side of the forebrain— the cerebral cortex. This thin, extensive region of wrinkled gray matter is responsible for the higher functions of the nervous system. A gyrus (plural = gyri) is the ridge of one of those wrinkles, and a sulcus (plural = sulci) is the groove between two gyri. The pattern of these folds of tissue can be used to indicate specific regions of the cerebral cortex.

The folding of the cortex maximizes the amount of gray matter in the cranial cavity. During embryonic development, the telencephalon is a structure that eventually develops into the cerebrum. As the telencephalon expands within the skull, the brain goes through a regular course of growth that results in everyone's brain having a similar pattern of folds. The surface of the brain can be mapped based on the

locations of large gyri and sulci. Using these landmarks, the surface of the cortex can be separated into four major regions, or lobes (Figure 13.6). The lateral sulcus that separates the temporal lobe from the other regions is one such landmark. Superior to the lateral sulcus are the parietal and frontal lobes, which are separated from each other by the central sulcus. The posterior region of the cortex is the occipital lobe, which has no obvious anatomical border between it and the parietal or temporal lobes on the lateral surface of the brain. From the medial surface, an obvious landmark separating the parietal and occipital lobes is called the parieto-occipital sulcus. The fact that there is no obvious anatomical border between these lobes is consistent with the functions of these regions being interrelated.

The frontal lobe is responsible for complex functions including motor functions (planning and executing movements via commands sent to the spinal cord and periphery) and, within the prefrontal cortex, aspects of personality via influencing motor responses involved in decision-making. The other lobes are responsible for sensory functions. The parietal lobe is where somatosensation is processed. The occipital lobe is where visual processing begins, although the other parts of the brain can contribute to visual function. The temporal lobe contains the cortical area for auditory processing and also has regions crucial for memory formation.

Located deep within the lateral sulcus is a fifth lobe of the brain called the insular lobe. The function of the insular lobe is not very well understood, however, evidence suggests that it is involved in several processes like motor-control, homeostasis and self awareness. It has also been linked to addiction and a variety of neuropsychiatric disorders.

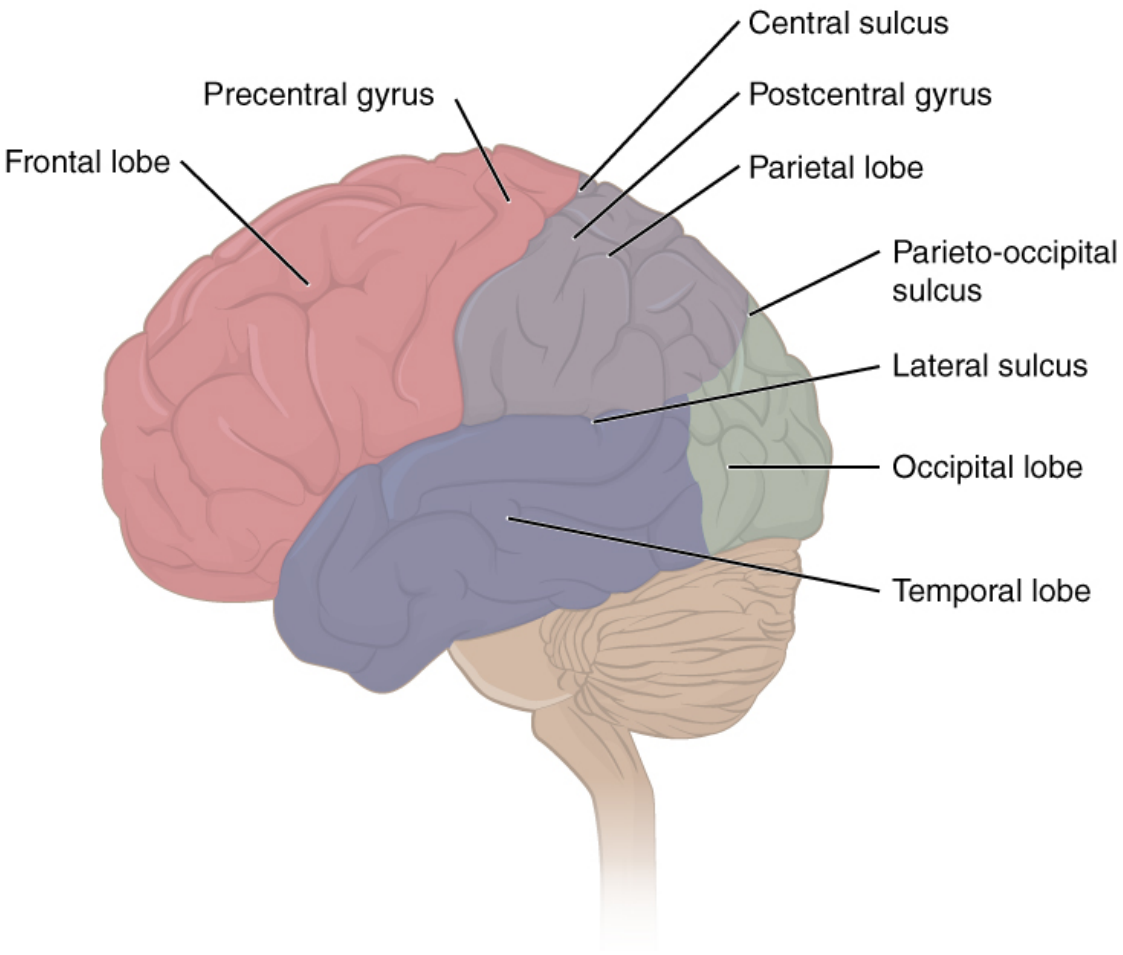


Figure 13.6 Lobes of the cerebral cortex. Insular cortex is not shown.

Subcortical gray matter

Beneath the cerebral cortex are sets of nuclei known as subcortical nuclei that augment cortical processes. The nuclei of the basal forebrain modulate the overall activity of the cortex, possibly leading to greater attention to sensory stimuli. The hippocampus and amygdala are medial-lobe structures that, along with the adjacent cortex, are involved in long-term memory formation and emotional responses.

The basal nuclei are a set of nuclei in the cerebrum responsible for comparing cortical processing with the general state of activity in the nervous system to influence the likelihood of movement taking place. The major structures of the basal nuclei that control movement are the caudate, putamen, and globus pallidus, which are located deep in the cerebrum. The caudate is a long nucleus that follows the basic C-shape of the cerebrum from the frontal lobe, through the parietal and occipital lobes, into the temporal lobe. The putamen is mostly deep in the anterior regions of the frontal and parietal lobes. Together, the caudate and putamen are called the striatum. The globus pallidus is a layered nucleus that lies just medial to the putamen; they are called the lenticular nuclei because they look like curved pieces fitting together like lenses. The globus pallidus has two subdivisions, the external and internal segments, which are lateral and medial, respectively. These nuclei can be seen via a frontal section of the brain (Figure 13.7).

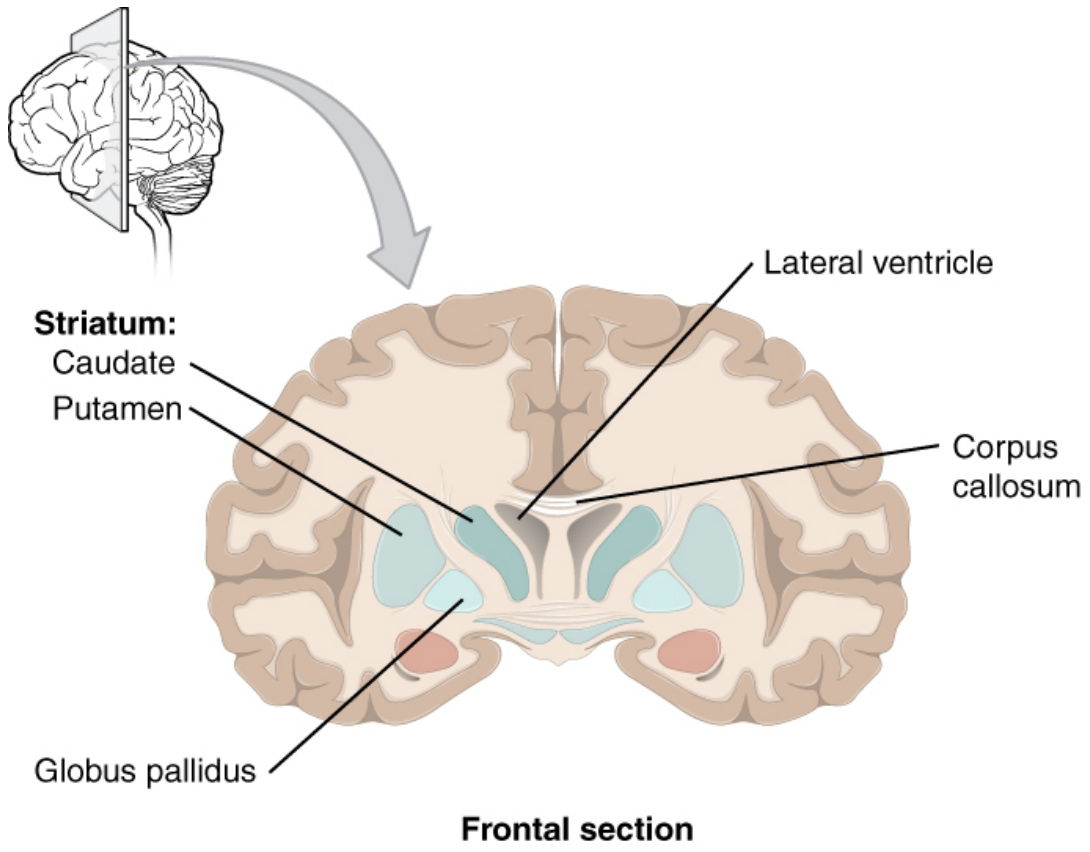


Figure 13.7 Frontal section of cerebral cortex and basal nuclei

Diencephalon

The diencephalon is the connection between the cerebrum and the nearly all of the nervous system and has two major regions: the thalamus and the hypothalamus (Figure 13.8). Most of the brain, the spinal cord, and the PNS send information to the cerebrum through the diencephalon. Output from the cerebrum passes back through the diencephalon to the periphery. The single exception is the system associated with olfaction, or the sense of smell, which connects directly with the cerebrum.

The thalamus is a collection of nuclei that relay information between the cerebral cortex and the periphery, spinal cord, or brain stem. All sensory information, except for olfaction, passes through the thalamus before processing by the cortex. The thalamus does not just pass the information on, it also processes that information. The cerebrum and basal nuclei also send motor information to the thalamus which usually involves interactions between the cerebellum and other nuclei in the brain stem as well.

Inferior and slightly anterior to the thalamus is the hypothalamus, the other major region of the diencephalon. The hypothalamus is a collection of nuclei that are largely involved in regulating homeostasis. The hypothalamus is the executive region in charge of the autonomic nervous system and the endocrine system through its regulation of the anterior pituitary gland. Other parts of the hypothalamus are involved in memory and emotion as part of the limbic system.

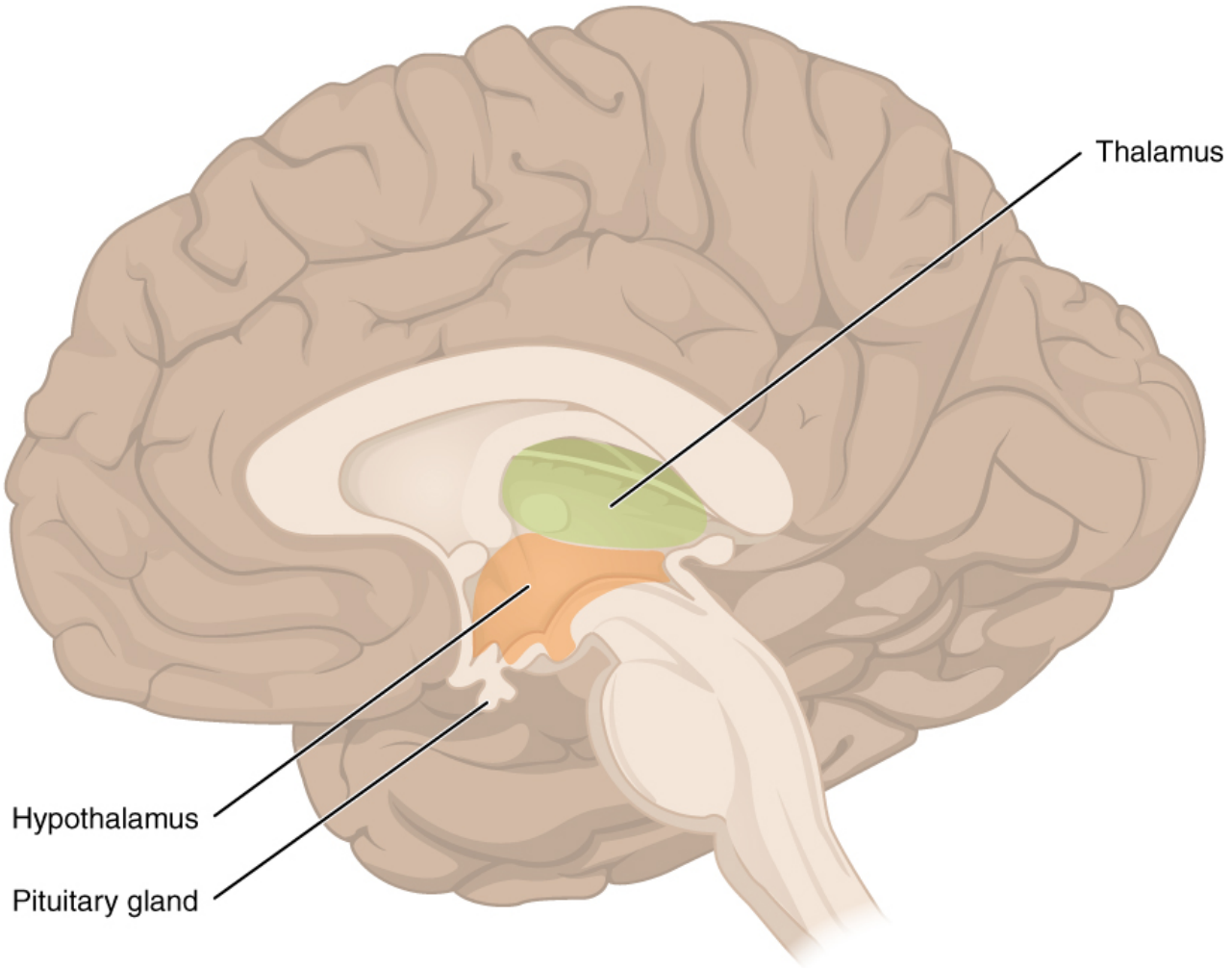


Figure 13.8 The Diencephalon. The diencephalon is composed primarily of the thalamus and hypothalamus. The hypothalamus is inferior and anterior to the thalamus, culminating in a sharp angle to which the pituitary gland is attached.

Brain stem

The midbrain and hindbrain (composed of the pons and the medulla) are collectively referred to as the brain stem (Figure 13.9). The structure emerges from the ventral surface of the forebrain as a tapering cone that connects the brain to the spinal cord. Attached to the brain stem, but considered a separate region of the adult brain, is the cerebellum. The midbrain coordinates sensory representations of the visual, auditory, and somatosensory perceptual information. The pons is the main connection with the cerebellum. The pons and the medulla regulate several crucial functions, including the cardiovascular and respiratory systems and rates. The cranial nerves (described below) connect through the brain stem and provide the brain with the sensory input and motor output associated with the head and neck, including most of the special senses. The major ascending and descending pathways between the spinal cord and brain, specifically the cerebrum, pass through the brain stem.

The midbrain is a small region between the thalamus and pons. The upper portion of the midbrain is composed of four bumps known as the colliculi (singular = colliculus), which means "little hill" in Latin.

The inferior colliculus is the inferior pair of these enlargements and is part of the auditory brain stem pathway. Neurons of the inferior colliculus project to the thalamus, which then sends auditory information

to the cerebrum for the conscious perception of sound. The superior colliculus is the superior pair and combines sensory information about visual space, auditory space, and somatosensory space. Activity in the superior colliculus is related to orienting the eyes to a sound or touch stimulus.

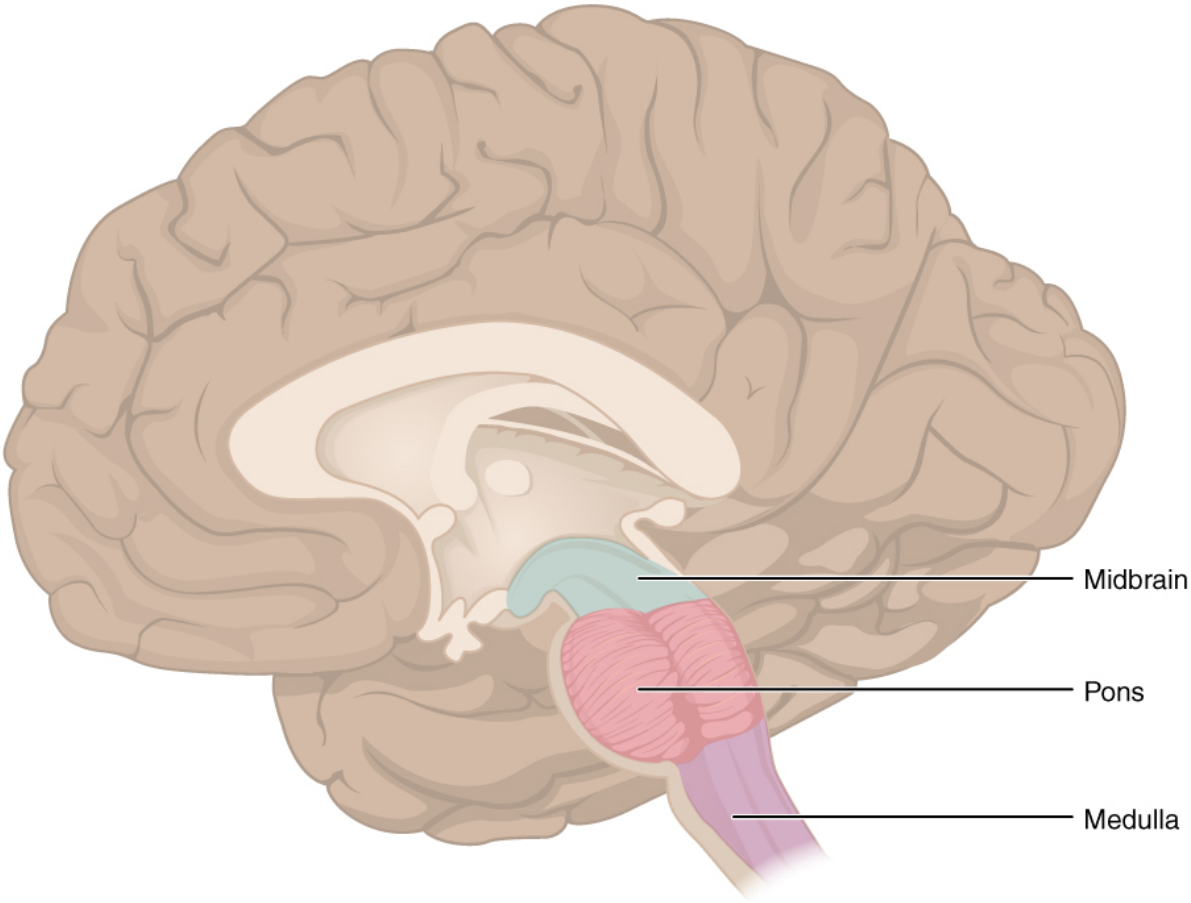


Figure 13.9 The Brain Stem. The brain stem comprises three regions: the midbrain, the pons, and the medulla

Cerebellum

The cerebellum, as the name suggests, is the "little brain" and accounts for approximately 10 percent of the mass of the brain. It is covered in gyri and sulci like the cerebrum, and looks like a miniature version of that part of the brain (Figure 13.10). The cerebellum is largely responsible for comparing information from the cerebrum with sensory feedback from the periphery through the spinal cord.

Descending fibers from the cerebrum have branches that connect to neurons in the pons. Those neurons project into the cerebellum, providing the cerebellum with the same motor information that is sent to the spinal cord. Sensory information from the periphery, which enters through spinal or cranial nerves, also projects to a nucleus in the medulla known as the inferior olive. Fibers from this nucleus enter the cerebellum and are compared with the descending commands from the cerebrum. For example, if the cerebrum sends a command down to the spinal cord to initiate walking, a copy of that motor command is sent to the cerebellum. Sensory feedback from the muscles and joints, proprioceptive information about the movements of walking, and sensations of balance are sent to the cerebellum through the inferior olive and then the cerebellum integrates all of that information. If walking is not coordinated, perhaps because

the ground is uneven or a strong wind is blowing, then the cerebellum sends out a corrective command to compensate for the difference between the original command from the cerebrum and the sensory feedback from the periphery. The output of the cerebellum is into the midbrain, which then sends a descending input to the spinal cord to correct motor information going to skeletal muscles.

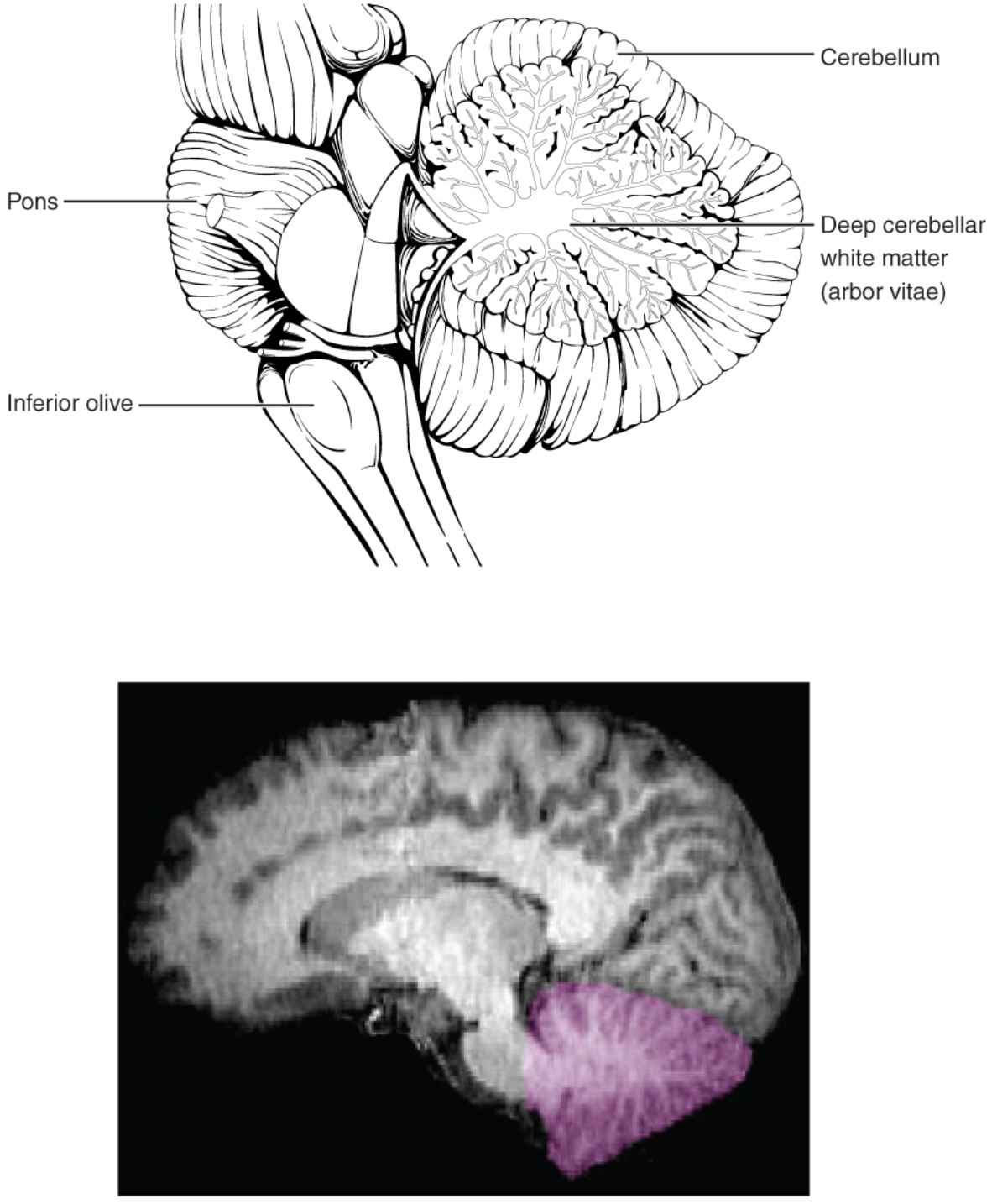


Figure 13.10 The Cerebellum. The cerebellum is situated on the posterior surface of the brain stem.

Cranial Nerves

The nerves attached to the brain are the cranial nerves, which are primarily responsible for the sensory

and motor functions of the head and neck (one of these nerves targets organs in the thoracic and abdominal cavities as part of the parasympathetic nervous system) (Figure 13.11, Table 13.1). There are twelve cranial nerves, which are designated CNI through CNXII for "Cranial Nerve," using Roman numerals for 1 through 12.

The olfactory nerve (I) and optic nerve (II) are responsible for the sense of smell and vision, respectively. The oculomotor nerve (III) is responsible for eye movements by controlling four of the extraocular muscles. It is also responsible for lifting the upper eyelid when the eyes point up, and for pupillary constriction. The trochlear nerve (IV) and the abducens nerve (VI) are both responsible for eye movement but do so by controlling different extraocular muscles. The trigeminal nerve (V) is responsible for cutaneous sensations of the face and controlling the muscles of mastication. The facial nerve (VII) is responsible for the muscles involved in facial expressions, as well as part of the sense of taste and the production of saliva.

The vestibulocochlear nerve (VIII) is responsible for the senses of hearing and balance. The glossopharyngeal nerve (IX) is responsible for controlling muscles in the oral cavity and upper throat, as well as part of the sense of taste and the production of saliva. The vagus (X) nerve is responsible for contributing to homeostatic control of the organs of the thoracic and upper abdominal cavities via autonomic neurons. The spinal accessory nerve (XI) is responsible for controlling the muscles of the neck, along with cervical spinal nerves. The hypoglossal nerve (XII) is responsible for controlling the muscles of the lower throat and tongue.

The cranial nerves can be classified as sensory nerves, motor nerves, or a combination of both, meaning that the axons in these nerves can originate out of sensory ganglia external to the cranium or motor nuclei within the brain stem. Sensory axons enter the brain to synapse in a nucleus. Motor axons connect to skeletal muscles of the head or neck. Three of the nerves are solely composed of sensory fibers; five are strictly motor; and the remaining four are mixed nerves that contain both sensory and motor fibers. The first, second, and eighth nerves are purely sensory (olfactory (CNI), optic (CNII), and vestibulocochlear (CNVIII) nerves). The three eye-movement nerves are all motor (oculomotor (CNIII), trochlear (CNIV), and abducens (CNVI)). The spinal accessory (CNXI) and hypoglossal (CNXII) nerves are also strictly motor. The remainder of the nerves (trigeminal (CNV), facial (CNVII), glossopharyngeal (CNIX), and vagus (CNX) nerves) contain both sensory and motor fibers and are often related to each other. The trigeminal and facial nerves both concern the face; one is primarily associated the sensations and the other primarily associated with the muscle movements. The facial and glossopharyngeal nerves are both responsible for conveying gustatory, or taste, sensations as well as controlling salivary glands. The vagus nerve is involved in visceral responses to taste, namely the gag reflex.

An important learning outcome for this lesson is to understand and describe the functions of cranial nerves. While this can feel a lot of information to commit to memory, it is possible by using memory tools like mnemonics. There are many mnemonics others have created that can quickly be found via an internet search. However, the best way to remember a mnemonic, is to make your own with personally-relatable information (i.e. movies, sports, friends names, etc.).

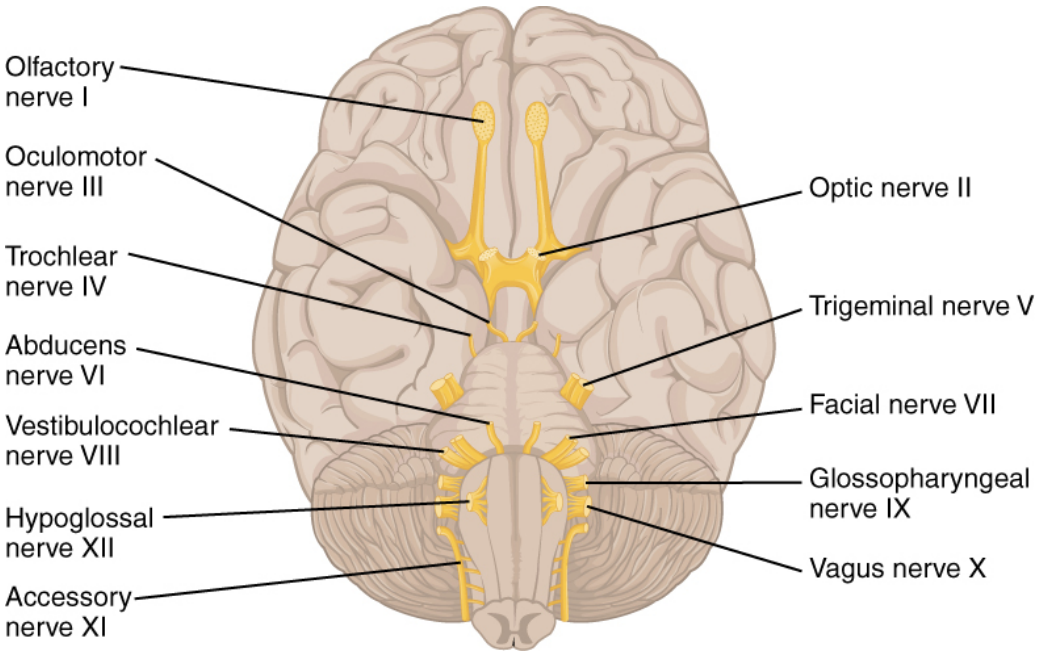


Figure 13.11 The Cranial Nerves. The anatomical arrangement of the roots of the cranial nerves observed from an inferior view of the brain.

Table 13.1 The Cranial Nerves

Number	Name	Type	Function(s)
I	Olfactory	Sensory	• Sensory information from the nose.
II	Optic	Sensory	• Sensory information from the eyes.
III	Oculomotor	Motor	• Motor information to most rectus and inferior oblique muscles to cause eye movement.
IV	Trochlear	Motor	• Motor information to superior oblique muscle for eye movement.
V	Trigeminal	Both	• Sensory information from and motor information to the face. • Motor information for chewing.
VI	Abducens	Motor	• Motor information to lateral rectus muscle to cause eye movement.
VII	Facial	Both	• Sensory information from anterior part of the tongue. • Motor information to the face. • Innervates lacrimal, salivary and other glands.
VIII	Vestibulocochlear	Sensory	• Sensory information from the ear for hearing and equilibrium.
IX	Glossopharyngeal	Both	• Sensory information from posterior part of the tongue. • Motor information to tongue and throat.
X	Vagus	Both	• Sensory information from abdomen, thorax, neck and root of tongue. • Motor information to heart, digestive organs, spleen and kidneys.
XI	Accessory	Motor	• Motor information for swallowing.
XII	Hypoglossal	Motor	•Motor information to the tongue.

The Spinal Cord

Anatomy of Spinal Cord

In an adult, the spinal cord is about eighteen inches long and extends from the foramen magnum of the skull to approximately the first lumbar vertebra and is divided into regions that correspond to regions of the vertebral column (Figure 13.12). The name of each spinal cord region corresponds to the level at which spinal nerves pass through the intervertebral foramina. Immediately adjacent to the brain stem is the cervical region, followed by the thoracic, then the lumbar, and finally the sacral region. The spinal cord has two areas where the diameter of the spinal cord is enlarged because of increased neural structures associated with the appendages. The cervical enlargement is caused by nerves moving to and from the arms and is located from approximately C3 through T2. The lumbar enlargement is caused by nerves moving to and from the legs and is located from about T7 through T11 (Figure 13.12).

The spinal cord does not extend the full length of the vertebral column because the spinal cord does not grow significantly longer after the first or second year while the skeleton continues to grow. As the vertebral

column continues to grow, spinal nerves grow with it and result in a long bundle of nerves that resembles a horse's tail, called the cauda equina (Figure 13.12). Some of the largest neurons of the spinal cord extend from the cauda equina including the motor neuron that causes contraction of the big toe which is located in the sacral region of the spinal cord. This motor neuron's axon reaches all the way to the belly of that muscle which can be over a meter in distance in a tall person. The neuronal cell body that maintains that long fiber is also necessarily quite large, possibly several hundred micrometers in diameter, making it one of the largest cells in the body. Immediately superior to the cauda equina, the spinal cord terminates at the medullary cone (also known as the conus medullaris) at approximately vertebra L1. Beyond the medullary cone, the meninges that cover the spinal cord (discussed below) continue as a thin, delicate strand of tissue called the terminal filum, which anchors the spinal cord to the coccyx.

31 pairs of spinal nerves extend from the spinal cord and each pair is named for the level of the spinal cord from which each pair emerges. There are eight pairs of cervical nerves designated C1 to C8, twelve thoracic nerves designated T1 to T12, five pairs of lumbar nerves designated L1 to L5, five pairs of sacral nerves designated S1 to S5, and one pair of coccygeal nerves. The first nerve, C1, emerges between the first cervical vertebra and the occipital bone. The second nerve, C2, emerges between the first and second cervical vertebrae. The same occurs for C3 to C7, but C8 emerges between the seventh cervical vertebra and the first thoracic vertebra. For the thoracic and lumbar nerves, each one emerges between the vertebra that has the same designation and the next vertebra in the column. The sacral nerves emerge from the sacral foramina along the length of that unique vertebra.

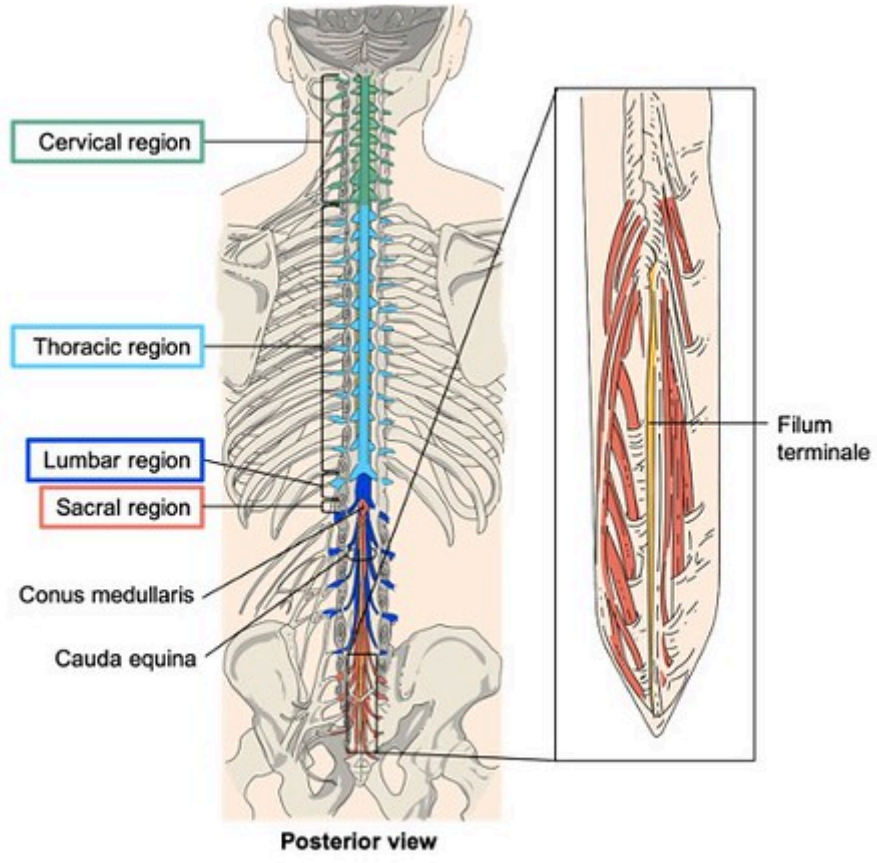


Figure 13.12 Gross Anatomy of the Spinal Cord The spinal cord is divided into four regions: cervical, thoracic, lumbar and sacral. The sacral region has a tapered end called the conus medullaris. The bundle of axons inferior to the conus medullaris is the cauda equina. The cauda equina is anchored to the coccyx by the filum terminale, a thin strand of pia mater. (Image credit: "Spinal Cord" by Chiara Mazzasette is a derivative from the original work of Daniel Donnelly and is licensed by CC BY 4.0)

The Meninges (of the Spinal Cord)

The spinal cord and brain are covered by the meninges which are a continuous, layered unit of tissues that provide support and protection to the delicate structures of the nervous system. The meninges include three layers: the dura mater, arachnoid mater, and pia mater (Figure 13.4). The outermost layer, the dura mater, is anchored to the inside of the vertebral cavity. It is thick and "dura"ble, providing protection and support to the spinal cord. The arachnoid mater is the thin middle layer, connecting the dura mater to the pia mater. The arachnoid mater gets its name from its web-like appearance and is connected to the pia mater through tiny fibrous extensions that span the subarachnoid space between the two layers. The innermost pia mater is in direct contact with the spinal cord and brain. It is thin and rich in blood vessels, although the pia mater is thicker and less vascular in the spinal cord than in the brain.

The subarachnoid space is filled with cerebrospinal fluid (CSF) which protects the CNS by providing cushioning. In order to test for disease or dysfunction in the central nervous system, CSF may be removed and analyzed via a procedure called a spinal tap or lumbar puncture (Figure 13.13). Because of the close proximity between the meninges and nervous tissue, this procedure is typically done at the end of the spinal cord, where the terminal filum extends from the inferior end of CNS at the upper lumbar region to the

sacral end of the vertebral column. Because the spinal cord does not extend through the lower lumbar region of the vertebral column, a needle can be inserted in this region through the dura and arachnoid layers to withdraw CSF with minimal risk of damaging the nervous tissue of the spinal cord. One example of a disease commonly diagnosed via lumbar puncture is meningitis, which is an inflammation of the meninges caused by either a viral or bacterial infection. Symptoms include fever, chills, nausea, vomiting, sensitivity to light, soreness of the neck, and severe headache. More serious are the possible neurological symptoms, such as changes in mental state including confusion, memory deficits, other dementia-type symptoms, hearing loss, and even death due to the close proximity of the infection to nervous system structures.

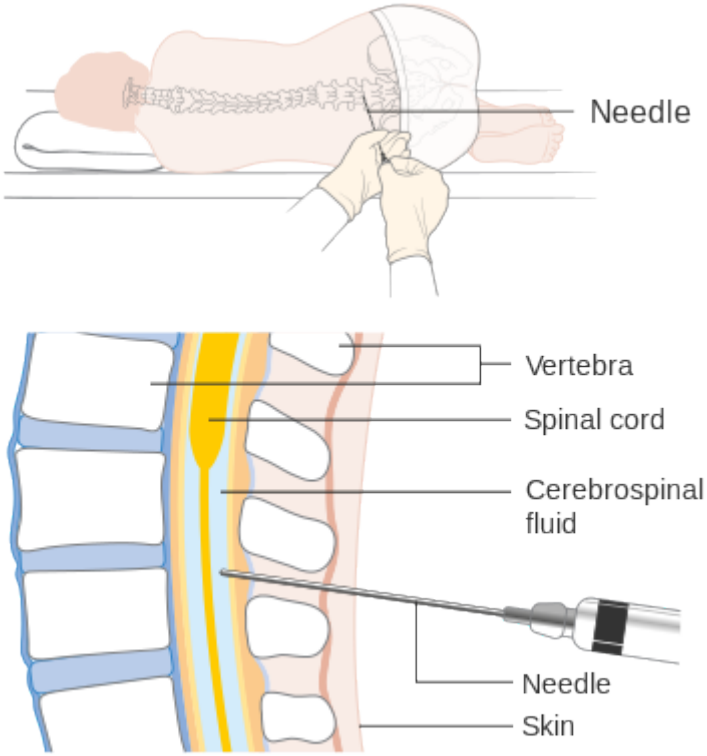


Figure 13.13 Lumbar Puncture. Removal of the CSF via insertion of a needle into the subarachnoid space between the arachnoid mater and pia mater. (Credit: Cancer Research UK / Wikimedia Commons)

Cross-sectional Anatomy of the Spinal Cord

Each section of the spinal cord has its associated spinal nerves forming two nerve routes that include a combination of incoming sensory axons and outgoing motor axons. For example, the radial nerve contains fibers of cutaneous sensation in the arm, as well as motor fibers that move muscles in the arm. The sensory axons that form a part of the radial nerve enter the spinal cord as the posterior (dorsal) nerve root, whereas the motor fibers emerge as the anterior (ventral) nerve root (Figure 13.14). The cell bodies of sensory neurons are grouped together at the posterior (dorsal) root ganglion, causing an enlargement of that portion of the spinal nerve. Note that it is common to see the terms dorsal and ventral used interchangeably with posterior and anterior, particularly in reference to nerves and the structures of the spinal cord.

Inside the spinal cord, the anterior and posterior nerve roots form the gray matter of the spinal cord. In cross section (Figure 13.14), the distribution of gray matter of the spinal cord is often compared to an inkblot test or butterfly, with the spread of the gray matter, subdivided into regions referred to as horns, on one side replicated on the other. The posterior horn receives information from the posterior nerve root and is therefore responsible for sensory processing, while the anterior horn sends out motor signals to the anterior nerve root to move skeletal muscles. The lateral horn, which is only found in the thoracic, upper lumbar, and sacral regions, is a key component of the sympathetic division of the autonomic nervous system. The anterior median fissure marks the anterior midline and the posterior median sulcus marks the posterior midline. Each side of the gray matter is connected by the gray commissure and located in the center of the gray commissure is the central canal, which runs the length of the spinal cord. The central canal is continuous with the ventricular system of the brain and transports nutrients to the spinal cord.

Comparable to the gray matter being separated into horns, the white matter of the spinal cord is separated into columns. Ascending tracts of nervous system fibers in these columns carry sensory information from the periphery to the brain, whereas descending tracts carry motor commands from the brain to the periphery. Looking at the spinal cord longitudinally, the columns extend along its length as continuous bands of white matter. In cross-section, the posterior columns can be seen between the two posterior horns of gray matter, whereas the anterior columns are bounded by the anterior horns. The white matter on either side of the spinal cord, between the posterior horn and the anterior horn, are the lateral columns. The posterior columns are composed of axons of ascending tracts, whereas the anterior and lateral columns are composed of many different groups of axons of both ascending and descending tracts.

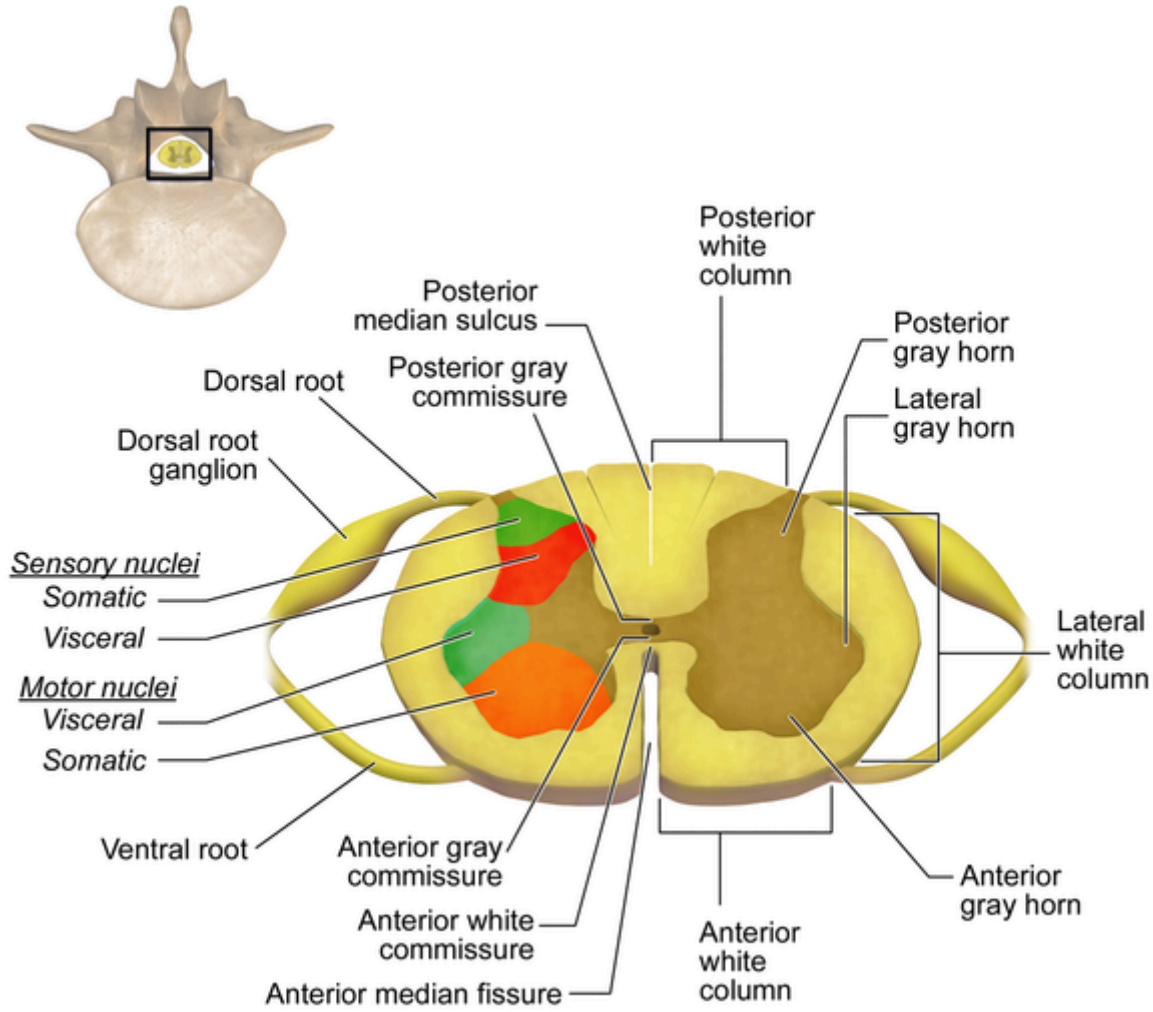


Figure 13.14 Cross section of spinal cord. Credit: BruceBlaus, Wikimedia, license CC-BY-SA.

Spinal Nerve Plexuses

Spinal nerves extend outward from the vertebral column to innervate the periphery. The nerves in the periphery are not straight continuations of the spinal nerves, but rather the reorganization of the axons in those nerves to follow different courses. Axons from different spinal nerves will come together to form a peripheral nerve. This occurs at four places along the length of the vertebral column, each identified as a nerve plexus which have previously been described in the context of the peripheral nerves. Focusing on the relationship to spinal nerves, two nerve plexuses are found at the cervical level, one at the lumbar level, and one at the sacral level (Figure 13.15). The cervical plexus is composed of axons from spinal nerves C1 through C5 and branches into nerves in the posterior neck and head, as well as the phrenic nerve, which connects to the diaphragm at the base of the thoracic cavity. The other plexus from the cervical level is the brachial plexus. Spinal nerves C4 through T1 reorganize through this plexus to give rise to the nerves of the arms (ex: radial nerve), as the name brachial suggests. The lumbar plexus arises from all the lumbar spinal nerves and gives rise to nerves innervating the pelvic region and the anterior leg (ex: femoral nerve). The sacral plexus comes from the lower lumbar nerves L4 and L5 and the sacral nerves S1 to S4. The most significant systemic nerve to come from this plexus is the sciatic nerve, which is a combination of the

tibial nerve and the fibular nerve. Spinal nerves of the thoracic region, T2 through T11, are not part of the plexuses but rather emerge and give rise to the intercostal nerves, which innervate the intercostal muscles found in between ribs.

Table 13.2 Nerve plexuses

	Associated Spinal Nerves	Major Associated Peripheral Nerves
Cervical	C1-5	Phrenic
Brachial	C5-T1	Radial, median, ulnar, musculocutaneous, axillary
Lumbar	L1-4	Femoral, obturator
Sacral	L4-S4	Sciatic

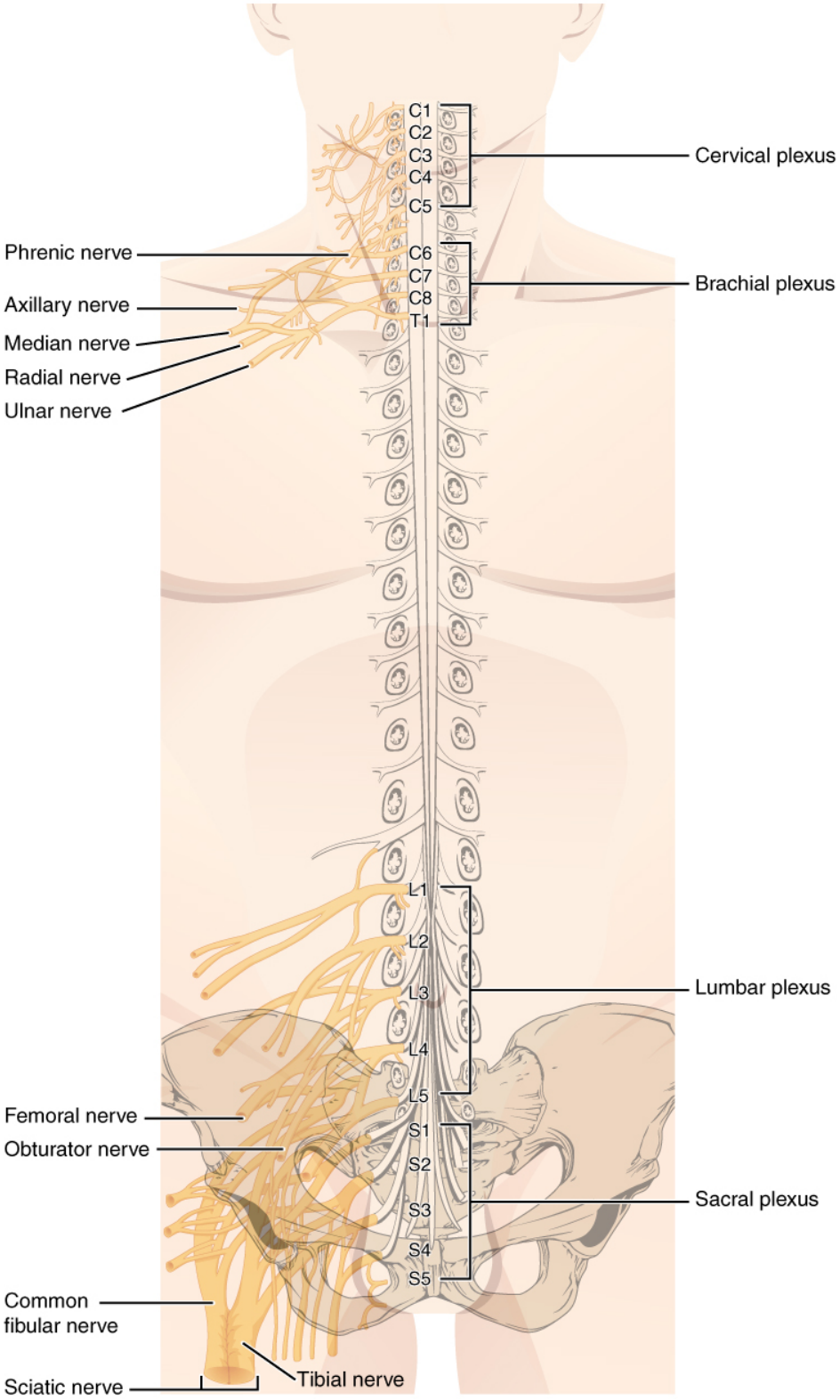
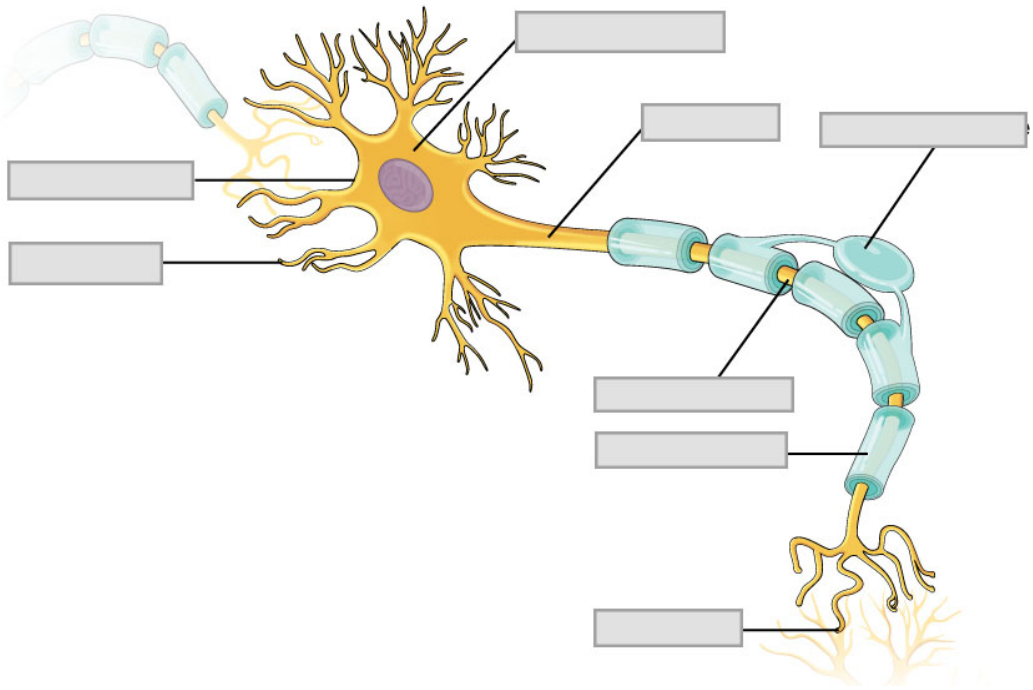


Figure 13.15 Nerve plexuses of the body.

Pre-Laboratory Questions

1. Identify the parts of a typical neuron: Axon, cell body, dendrites , nucleus, axon terminals.



2. Which of the following is *not* a function of the nervous system?

A. stimulate muscles and glands
B. contribute to homeostatic feedback loops
C. produce quick effects by electrochemical mechanisms
D. release chemicals into the bloodstream for distribution throughout the body

3. Which part of the brain has noticeable superior and lateral gyri (folds) that increase surface area for cortical gray matter?

A. midbrain
B. pons
C. cerebellum
D. brainstem
E. left and right hemispheres

4. In addition to meninges, fluid-filled spaces help protect the brain nervous tissue. The subarachnoid space would be found between which two meninges?

A. arachnoid and pia mater
B. dura mater and arachnoid mater
C. dura mater and pia mater

5. Which of the following is not important for creating the Blood-brain barrier (BBB)?

A. tight ependymal cell junctions
B. basement membrane
C. tight endothelial (capillary wall epithelium) cell junctions

D. ependymal cilia

Exercises

- Exercise 1 Gray and white mater composition and brain areas
- Exercise 2 Identification of brain meninges: dura mater, arachnoid mater, & pia mater
- Exercise 3 Identification of brain structures on a dissected brain specimen, model, or diagram
- Exercise 4 Identification of cranial nerves
- Exercise 5 Anatomical features of the spinal cord on a model or diagram

Exercise 1 Gray and white mater composition and brain areas

Required materials

- None

Procedure

1. This activity will be completed individually or in small groups. Refer to the background information to answer the question below.
2. Define the following terms and provide examples of each in the central nervous system

Terms	Definition	Examples in CNS
Gray mater		
White mater		

Exercise 2 Identification of brain meninges: dura mater, arachnoid mater, & pia mater

Required materials

- None

Procedure

1. This activity will be completed individually or in small groups. Refer to the background information to answer the questions below.
2. Categorize the following terms and provide a one line definition for each of them. For the meninges, also rank them from the most superficial layer to the deepest layer.

Gyri, pia mater, sulcus, arachnoid mater, fissure, dura mater

Brain meninges	Definition
Superficial–	
Deepest–	
Brain structures	**Definition**

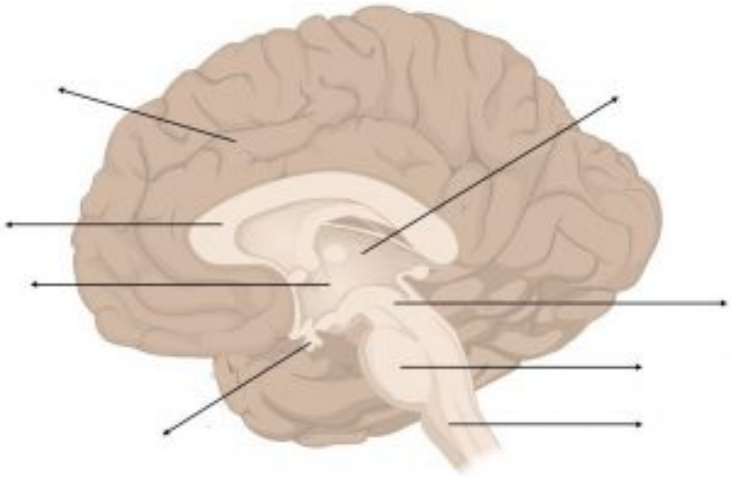
Exercise 3 Identification of brain structures on a dissected brain specimen, model, or diagram

Required materials

- Gloves
- Dissection tray
- Dissection instruments
- Sheep brain specimen (or cow brain specimen)
- T-pins for labeling
- Labeling tape
- Sheep brain bismount model
- Brain Cavities Model
- Brain Ventricles Model
- Classic Human Brain Model
- Nervous System on Board Model
- Brain poster
- Nervous system poster

Procedure

1. The first activity will be completed individually.
2. Refer to the background information and label the following diagram with the appropriate



structures.
3. The brain dissection activity will be completed in groups of 3-4 in the lab. Please read the following steps carefully before you begin.

    - Place the brain specimen in the tray, dorsal side up (Figure 13.16).

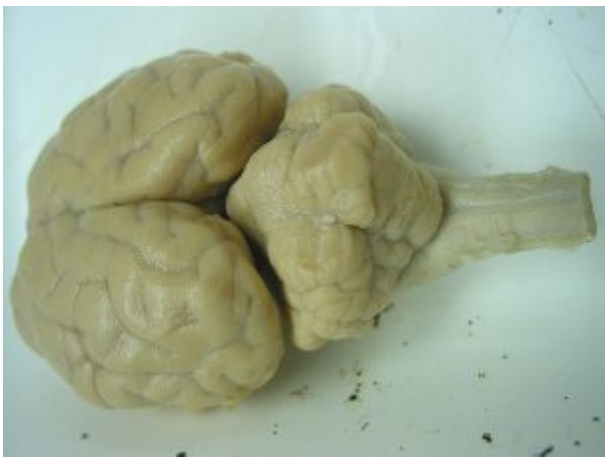


Figure 13.16 Sheep brain. Dorsal side up. Credit: Aaron Bornstein, Wikimedia, license CC-BY.

- Identify the cerebrum, the longitudinal fissure and the two hemispheres of the brain. You can also locate examples of gyri, sulci and the different lobes of the cerebrum.

- Place the brain in the tray ventral side up (Figure 13.17) and identify the cerebellum, pons, medulla and optic chiasma.

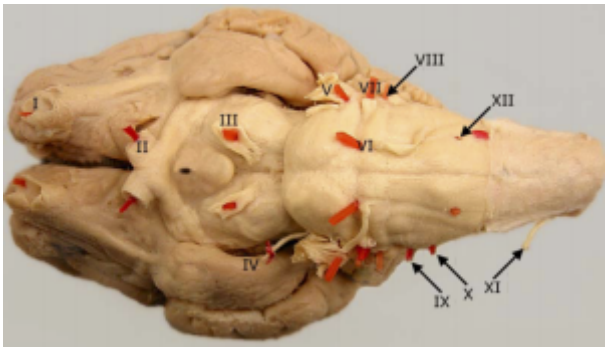


Figure 13.17 Sheep brain. Ventral side up. Cranial nerves numbered. Credit: Thomas Fletcher am, Wikimedia, license CC-BY-SA.

- Place the brain on the tray, dorsal side up. Locate the longitudinal fissure and gently try to widen it with your fingers (Figure 13.18).

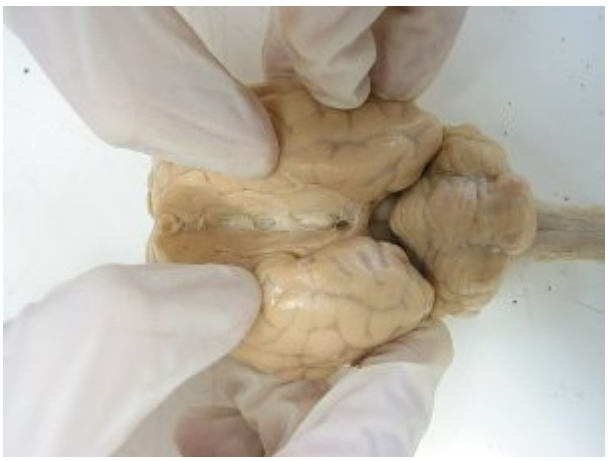


Figure 13.18 Sheep brain with longitudinal fissure widened. Credit: Aaron Bornstein, Wikimedia, license CC-BY

- Insert a scalpel in the fissure and cut through the brain into two longitudinal halves (Figure 13.19).

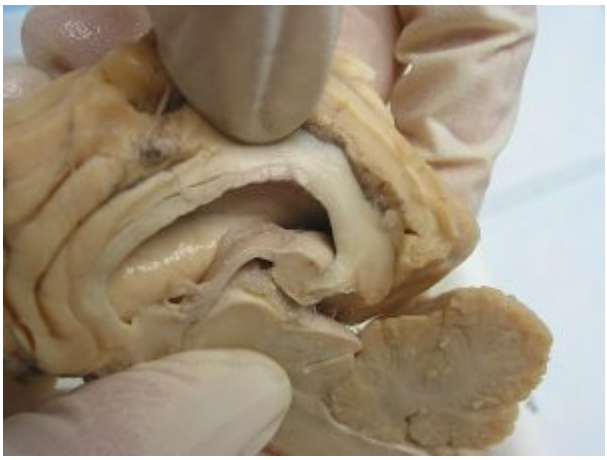


Figure 13.19 Sheep brain cut through the longitudinal fissure into two halves. Credit: Arron Bernstein, Wikimedia, license CC-BY.

- With the cut sides facing up, identify the thalamus, hypothalamus, pineal body, pons and medulla.
- Locate the corpus collosum and lateral ventricles.
- Observe the cut surface of the cerebellum and try to identify the tree like structure made of white mater called arbor vitae or "tree of life".
- Compare the structures that you see in your dissected samples to those from other groups.
- Your instructor will help you identify the same structures on a dissected human brain.
- Using T-pins and labeling tape, label all the regions of the brain you identified. Take a picture (or pictures) and insert in the space below.

- When you are done observing and taking pictures of the sheep brain specimen, dispose it off in the biohazard bin and clean the dissecting tray, T-pins and dissection instruments.

Exercise 4 Identification of cranial nerves

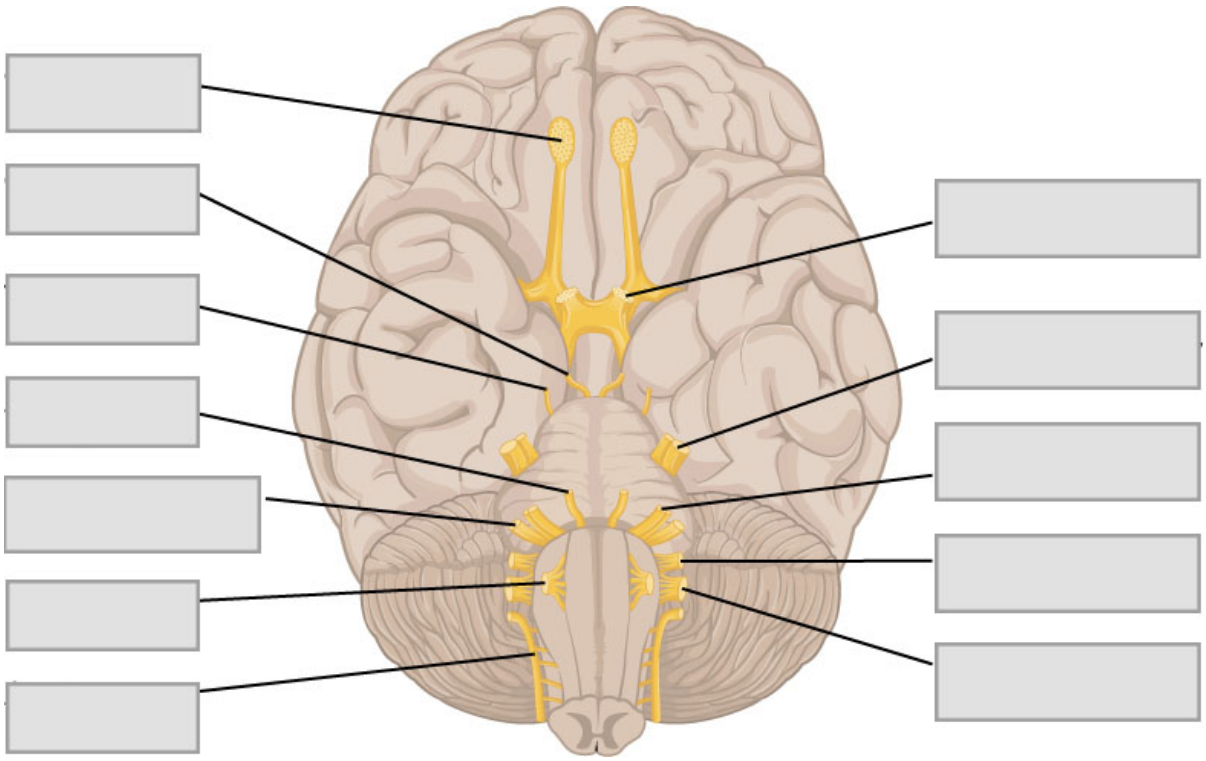
Required materials

- None

Procedure

1. This activity will be completed individually. Refer to the background information to answer the questions below.
2. For each cranial nerve:

    - Use the summary table (Table 13.1) as your source for this information.
    - Identify and label this diagram with appropriate cranial nerves. Identify by both name and number on diagram.



- Fill in the blanks to complete the table.
  - Identify by both **name** and **number**.
  - Provide one example of a **function**.
  - Identify whether each nerve carries sensory information, motor information, or both **types** of information.

Name	Number	Type	Function
Vestibulocochlear			
	V		
		Both	Motor information to the face.
Oculomotor			

	X		

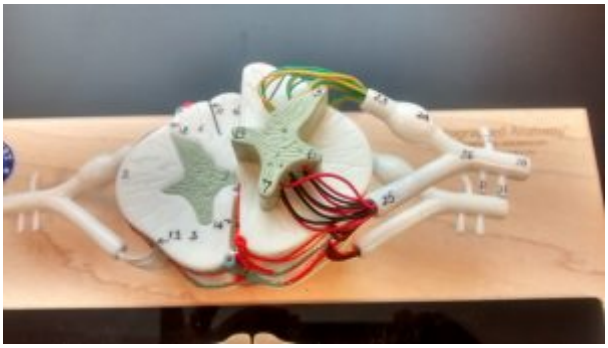
Exercise 5 Anatomical features of the spinal cord ona model or diagram

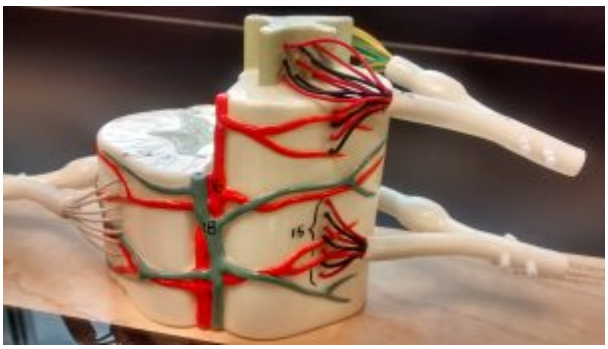
Required Materials

- Spinal cord cross section model
- Nervous System on Board model
- The nervous system poster
- Muscular system poster

Procedure

1. Identify and define anatomical features of the spinal cord on a model or diagram for both longitudinal view and cross-sectional views.





Identify the following features on the spinal cord model. Then draw diagrams (cross section and longitudinal section) to label and show these below.

- Posterior (dorsal) median sulcus
- Anterior (ventral) median fissure
- Posterior (dorsal) horn
- Anterior (ventral) horn
- Lateral horn
- Gray commissure
- Posterior (dorsal) root
- Posterior (dorsal) root ganglion
- Anterior (ventral) root
- Posterior (dorsal) column
- Anterior (ventral) column
- Lateral column
- Central canal
- Pia mater
- Arachnoid mater
- Subarachnoid space
- Dura mater
- Spinal nerve

2. Name the layers of the meninges is from superficial to deep:
3. Fill in the following table:

Example of a Muscle Innervated by Nerve	**Nerve**	**Nerve Plexus**
		Cervical
Triceps brachii		
	Ulnar	
Flexor carpi radialis		
	Musculocutaneous	
Deltoid		
	Femoral	
Adductor Longus		
		Sacral

4. Number the pathway in order from receiving a sensory signal to exciting a muscle via motor nerves:

____ Anterior root
____ Sensory nerve innervating the muscle
____ Anterior Ramus
____ Descending tracts of white matter
____ Posterior horn ____ Brain

____ Posterior root
____ Motor nerve innervating the muscle
____ Ascending tracts of white matter
____ Posterior ramus
____ Anterior horn
____ Posterior root ganglion

Post-laboratory Questions

1. Which of the following gray or white matter brain structures is correctly paired with its description?

A. projection tracts: receive sensory input and process information locally
B. association tracts: cells with unmyelinated connections within part of the CNS
C. commissural tracts: connects right and left hemisphere
E. neocortex: tracts extending from higher to lower regions of the brain
E. stellate cells: connect different parts within the same hemisphere

2. Which part of the forebrain plays a major role in homeostasis through both the endocrine system and autonomic nervous system?

A. insula
B. corpus callosum
C. hypothalamus
D. precentral gyrus
E. basal nuclei

3. Which part of the cerebral cortex contains the visual center?

A. temporal lobe
B. occipital lobe
C. frontal lobe
D. parietal lobe
E. insula lobe

4. Which of the cranial nerves does *not* have a sensory component?

A. Facial (VII)
B. Trochlear (IV)
C. Vestibulocochlear (VIII)
D. Olfactory (I)
E. Optic (II)

5. Which of the plexuses would be involved in breathing and movement of the head?

A. coccygeal

B. brachial

C. sacral

D. lumbar

E. cervical

14.

CHAPTER 14 THE SOMATIC NERVOUS SYSTEM

By Rajeev Chandra

Motivation.

When high temperature is sensed in the skin, a reflexive withdrawal is initiated by the muscles of the arm. Sensory neurons are activated by a stimulus, which is sent to the central nervous system, and a motor response is sent out to the skeletal muscles that control this movement. This mechanism allows us to avoid getting burned in order to avoid life threatening burns as shown in the figure. Our somatic nervous system is responsible for conscious sensory and voluntary motor functions. As such, it is there to protect us from the harms that exist in the environment so we can maintain homeostasis and good health.

Figure 14.1 Caring for burned soldier. Capt. Jabari White leans on a therapy table as burn therapist Alicia White works on flexing his arm. White suffered burns over more than 60 percent of his body when his vehicle was hit by a roadside bomb. Photo by Elaine Wilson, US Army, flickr, license CC-BY.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Describe the components of the somatic nervous system
- Name the modalities and submodalities of the sensory systems
- Distinguish between general and special senses
- Describe regions of the central nervous system that contribute to somatic functions
- Explain the stimulus-response motor pathway

Background.

The somatic nervous system is traditionally considered a division within the peripheral nervous system. However, this misses an important point: somatic refers to a functional division, whereas peripheral refers to an anatomic division. The somatic nervous system is responsible for our conscious perception of the environment and for our voluntary responses to that perception by means of skeletal muscles. Peripheral sensory neurons receive input from environmental stimuli, but the neurons that produce motor responses originate in the central nervous system. The distinction between the structures (i.e., anatomy) of the peripheral and central nervous systems and functions (i.e., physiology) of the somatic and autonomic systems can most easily be demonstrated through a simple reflex action. When you touch something hot, you pull your hand away (if you can). Sensory receptors in the skin sense extreme temperature and the early signs of tissue damage. This triggers an action potential, which travels along the sensory fiber from the skin, through the dorsal spinal root to the spinal cord, and directly activates a ventral horn motor neuron. That neuron sends a signal along its axon to excite the biceps brachii, causing contraction of the muscle and flexion of the forearm at the elbow to withdraw the hand from the hot stove. The withdrawal reflex has more components, such as inhibiting the opposing muscle and balancing posture while the arm is forcefully withdrawn.

The basic withdrawal reflex explained above includes sensory input (the painful stimulus), central processing (the synapse in the spinal cord), and motor output (activation of a ventral motor neuron that causes contraction of the biceps brachii). Expanding the explanation of the withdrawal reflex can include inhibition of the opposing muscle, or cross extension, either of which increase the complexity of the example by involving more central neurons. A collateral branch of the sensory axon would inhibit another ventral horn motor neuron so that the triceps brachii do not contract and slow the withdrawal down. The cross extensor reflex provides a counterbalancing movement on the other side of the body, which requires another collateral of the sensory axon to activate contraction of the extensor muscles in the contralateral limb.

A more complex example of somatic function is conscious muscle movement. For example, reading of this text starts with visual sensory input to the retina, which then projects to the thalamus, and on to the cerebral cortex. A sequence of regions of the cerebral cortex process the visual information, starting in the primary visual cortex of the occipital lobe, and resulting in the conscious perception of these letters. Subsequent cognitive processing results in understanding of the content. As you continue reading, regions of the cerebral cortex in the frontal lobe plan how to move the eyes to follow the lines of text. The output from the cortex causes activity in motor neurons in the brain stem that cause movement of the extraocular muscles through the third, fourth, and sixth cranial nerves. This example also includes sensory input (the retinal projection to the thalamus), central processing (the thalamus and subsequent cortical activity), and motor output (activation of neurons in the brain stem that lead to coordinated contraction of extraocular muscles).

There are two ways to consider how the nervous system is divided functionally. First, the nervous system can be divided based on the fundamental functions of the nervous system which are sensation,

integration, and response. Second, control of the body can be classified as either autonomic or somatic—divisions that are largely defined by the structures involved in the generation of a response.

The autonomic nervous system (ANS) is primarily responsible for involuntary control of the body, usually for the sake of homeostasis (regulation of the internal environment) of most internal organ systems. Key stimuli for autonomic functions can come from sensory structures found in either external or internal environments. ANS motor output extends to smooth and cardiac muscle as well as glandular epithelial tissue. For example, sweat glands are controlled by the ANS to regulate the body's internal temperature. When you are hot, the ANS stimulates the sweat glands to secrete sweat which cools your body down to maintain homeostasis with regard to body temperature.

The somatic nervous system (SNS) is primarily responsible for voluntary motor responses via skeletal muscles. The senses of the body interact with stimuli from the external environment and our body responds primarily via voluntary muscle movement. The term "voluntary" suggests that there is a conscious decision to make a movement. However, some aspects of the somatic system use voluntary muscles without conscious control. One example is the ability of our breathing to switch to unconscious control while we are focused on another task. However, those same muscles that are responsible for the basic process of breathing are also utilized for speech, which is entirely voluntary. Additionally, skeletal muscle responses via the SNS can be reflexive in nature, such as when a doctor uses a reflex hammer to tap your patellar tendon during a physical or when you jump or scream when startled. Other motor responses, such as riding a bike, become automatic (in other words, unconscious) as a person learns and masters motor skills (referred to as habit learning or procedural memory).

A major role of sensory receptors is to help us learn about the environment around us, or about the state of our internal environment. Stimuli from varying sources, and of different types, are received and changed into the electrochemical signals of the nervous system. This occurs when a stimulus changes the cell membrane potential of a sensory neuron. The stimulus causes the sensory cell to produce an action potential that is relayed into the central nervous system (CNS), where it is integrated with other sensory information—or sometimes higher cognitive functions—to become a conscious perception of that stimulus. The central integration may then lead to a motor response.

Describing sensory function with the term sensation or perception is a deliberate distinction. Sensation is the activation of sensory receptor cells at the level of the stimulus. Perception is the central processing of sensory stimuli into a meaningful pattern. Perception is dependent on sensation, but not all sensations are perceived. Receptors are the cells or structures that detect sensations. A receptor cell is changed directly by a stimulus. A transmembrane protein receptor is a protein in the cell membrane that mediates a physiological change in a neuron, most often through the opening of ion channels or changes in the cell signaling processes. Transmembrane receptors are activated by chemicals called ligands. For example, a molecule in food can serve as a ligand for taste receptors. Other transmembrane proteins, which are not accurately called receptors, are sensitive to mechanical or thermal changes. Physical changes in these proteins increase ion flow across the membrane, and can generate an action potential or a graded potential in the sensory neurons.

Sensory Receptors

Stimuli in the environment activate specialized receptor cells in the peripheral nervous system. Different types of stimuli are sensed by different types of receptor cells. Receptor cells can be classified into types on the basis of three different criteria: cell type, position, and function. Receptors can be classified structurally on the basis of cell type and their position in relation to stimuli they sense. They can also be classified functionally on the basis of the transduction of stimuli, or how the mechanical stimulus, light, or chemical changed the cell membrane potential.

Structural Receptor Types

The cells that interpret information about the environment can be either (1) a neuron that has a free nerve ending, with dendrites embedded in tissue that would receive a sensation; (2) a neuron that has an encapsulated ending in which the sensory nerve endings are encapsulated in connective tissue that enhances their sensitivity; or (3) a specialized receptor cell, which has distinct structural components that interpret a specific type of stimulus (Figure 14.2). The pain and temperature receptors in the dermis of the skin are examples of neurons that have free nerve endings. Also located in the dermis of the skin are lamellated corpuscles, neurons with encapsulated nerve endings that respond to pressure and touch. The cells in the retina that respond to light stimuli are an example of a specialized receptor, a photoreceptor.

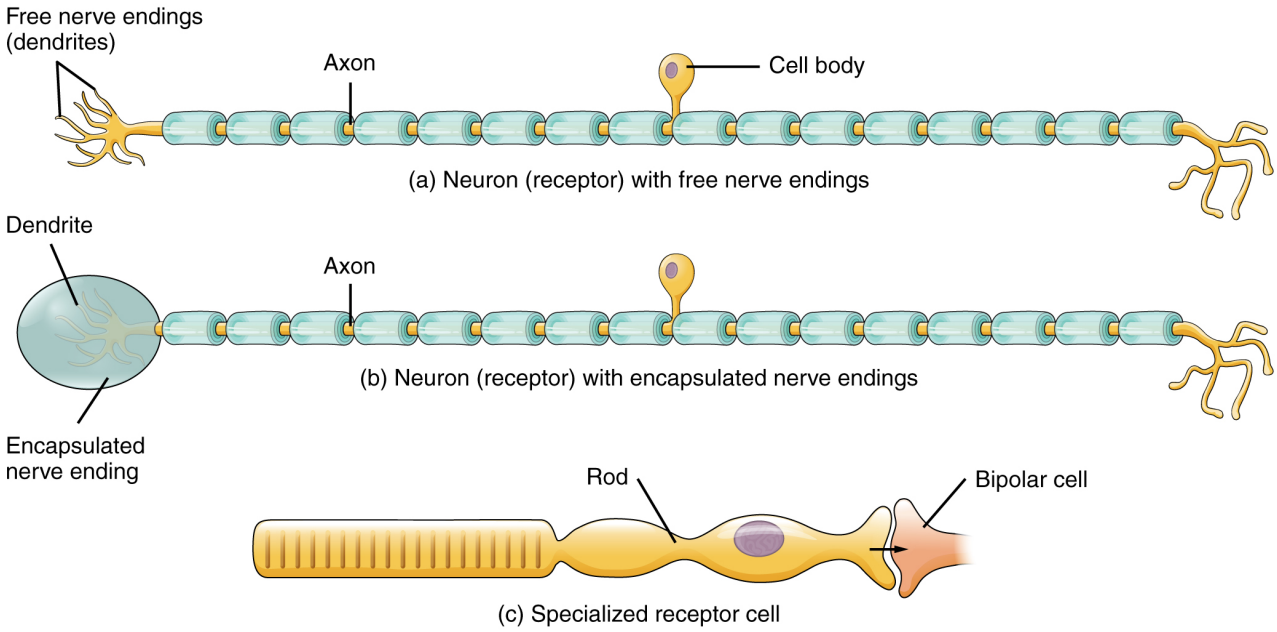


Figure 14.2 Receptor Classification by Cell Type Receptor cell types can be classified on the basis of their structure. Sensory neurons can have either (a) free nerve endings or (b) encapsulated endings. Photoreceptors in the eyes, such as rod cells, are examples of (c) specialized receptor cells. These cells release neurotransmitters onto a bipolar cell, which then synapses with the optic nerve neurons..

Another way that receptors can be classified is based on their location relative to the stimuli. An exteroceptor is a receptor that is located near a stimulus in the external environment, such as the somatosensory receptors that are located in the skin. An interoceptor is one that interprets stimuli from internal organs and tissues, such as the receptors that sense the increase in blood pressure in the aorta or

carotid sinus. Finally, a proprioceptor is a receptor located near a moving part of the body, such as a muscle, that interprets the positions of the tissues as they move.

Functional Receptor Types

A third classification of receptors is by how the receptor transduces stimuli into membrane potential changes. Stimuli are of three general types. Some stimuli are ions and macromolecules that affect transmembrane receptor proteins when these chemicals diffuse across the cell membrane. Some stimuli are physical variations in the environment that affect receptor cell membrane potentials. Other stimuli include the electromagnetic radiation from visible light. For humans, the only electromagnetic energy that is perceived by our eyes is visible light. Some other organisms have receptors that humans lack, such as the heat sensors of snakes, the ultraviolet light sensors of bees, or magnetic receptors in migratory birds.

Receptor cells can be further categorized on the basis of the type of stimuli they transduce. Chemical stimuli can be interpreted by a chemoreceptor that interprets chemical stimuli, such as an object's taste or smell. Osmoreceptors respond to solute concentrations of body fluids. Additionally, pain is primarily a chemical sense that interprets the presence of chemicals from tissue damage, or similar intense stimuli, through a nociceptor. Physical stimuli, such as pressure and vibration, as well as the sensation of sound and body position (balance), are interpreted through a mechanoreceptor. Another physical stimulus that has its own type of receptor is temperature, which is sensed through a thermoreceptor that is either sensitive to temperatures above (heat) or below (cold) normal body temperature.

Sensory Modalities

Ask anyone what the senses are, and they are likely to list the five major senses—taste, smell, touch, hearing, and sight. However, these are not all of the senses. The most obvious omission from this list is balance. Also, what is referred to simply as touch can be further subdivided into pressure, vibration, stretch, and hair-follicle position, on the basis of the type of mechanoreceptors that perceive these touch sensations. Other overlooked senses include temperature perception by thermoreceptors and pain perception by nociceptors.

Within the realm of physiology, senses can be classified as either general or specific. A general sense is one that is distributed throughout the body and has receptor cells within the structures of other organs. Mechanoreceptors in the skin, muscles, or the walls of blood vessels are examples of this type. General senses often contribute to the sense of touch, as described above, or to proprioception (body movement) and kinesthesia (body movement), or to a visceral sense, which is most important to autonomic functions. A special sense is one that has a specific organ devoted to it, namely the eye, inner ear, tongue, or nose.

Each of the senses is referred to as a sensory modality. Modality refers to the way that information is encoded, which is similar to the idea of transduction. The main sensory modalities can be described on the basis of how each is transduced. The chemical senses are taste and smell. The general sense that is usually referred to as touch includes chemical sensation in the form of nociception, or pain. Pressure, vibration, muscle stretch, and the movement of hair by an external stimulus, are all sensed by mechanoreceptors. Hearing and balance are also sensed by mechanoreceptors. Finally, vision involves the activation of photoreceptors.

Listing all the different sensory modalities, which can number as many as 17, involves separating the five major senses into more specific categories, or submodalities, of the larger sense. An individual sensory

modality represents the sensation of a specific type of stimulus. For example, the general sense of touch, which is known as somatosensation, can be separated into light pressure, deep pressure, vibration, itch, pain, temperature, or hair movement.

Gustation (Taste)

Only a few recognized submodalities exist within the sense of taste, or gustation. Until recently, only four tastes were recognized: sweet, salty, sour, and bitter. Research at the turn of the 20th century led to recognition of the fifth taste, umami, during the mid-1980s. Umami is a Japanese word that means "delicious taste," and is often translated to mean savory. Very recent research has suggested that there may also be a sixth taste for fats, or lipids.

Gustation is the special sense associated with the tongue. The surface of the tongue, along with the rest of the oral cavity, is lined by a stratified squamous epithelium. Raised bumps called papillae (singular = papilla) contain the structures for gustatory transduction. There are four types of papillae, based on their appearance (Figure 14.3): circumvallate, foliate, filiform, and fungiform. Within the structure of the papillae are taste buds that contain specialized gustatory receptor cells for the transduction of taste stimuli. These receptor cells are sensitive to the chemicals contained within foods that are ingested, and they release neurotransmitters based on the amount of the chemical in the food. Neurotransmitters from the gustatory cells can activate sensory neurons in the facial, glossopharyngeal, and vagus cranial nerves.

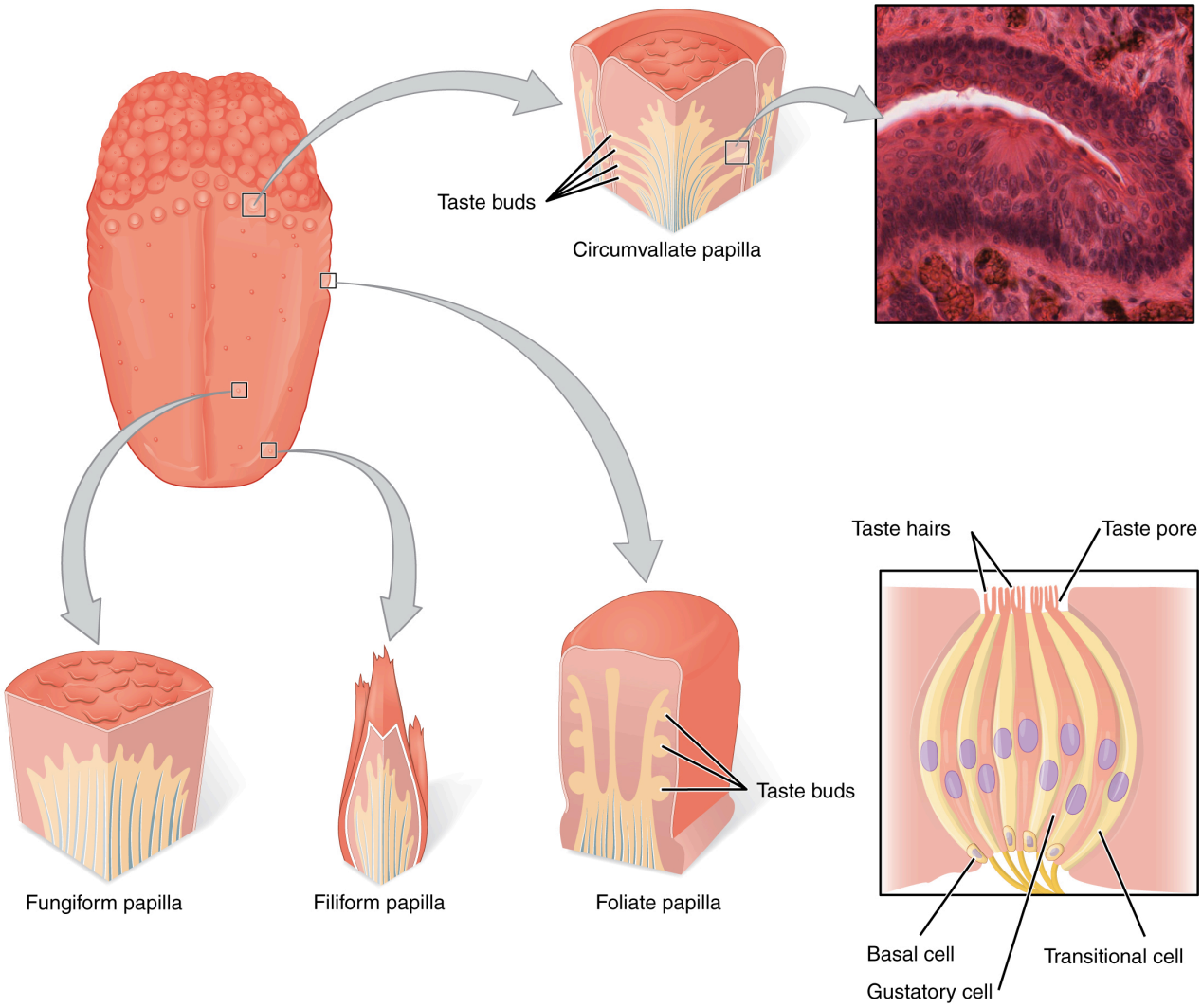


Figure 14.3 The Tongue. The tongue is covered with small bumps, called papillae, which contain taste buds that are sensitive to chemicals in ingested food or drink. Different types of papillae are found in different regions of the tongue. The taste buds contain specialized gustatory receptor cells that respond to chemical stimuli dissolved in the saliva. These receptor cells activate sensory neurons that are part of the facial and glossopharyngeal nerves. LM × 1600 (Micrograph provided by the Regents of University of Michigan Medical School © 2012).

Salty taste is simply the perception of sodium ions (Na+) in the saliva. When you eat something salty, the salt crystals dissociate into the component ions Na+ and Cl–, which dissolve into the saliva in your mouth. The Na+ concentration becomes high outside the gustatory cells, creating a strong concentration gradient that drives the diffusion of the ion into the cells. The entry of Na+ into these cells results in the depolarization of the cell membrane and the generation of a receptor potential.

Sour taste is the perception of H+ concentration. Just as with sodium ions in salty flavors, these hydrogen ions enter the cell and trigger depolarization. Sour flavors are, essentially, the perception of acids in our food. Increasing hydrogen ion concentrations in the saliva (lowering saliva pH) triggers progressively stronger graded potentials in the gustatory cells. For example, orange juice—which contains citric acid—will taste sour because it has a pH value of approximately 3. Of course, it is often sweetened so that the sour taste is masked.

The first two tastes (salty and sour) are triggered by the cations Na+ and H+. The other tastes result from food molecules binding to a G protein–coupled receptor. A G protein signal transduction system ultimately leads to depolarization of the gustatory cell. The sweet taste is the sensitivity of gustatory cells to the presence of glucose dissolved in the saliva. Other monosaccharides such as fructose, or artificial sweeteners such as aspartame (NutraSweet™), saccharine, or sucralose (Splenda™) also activate the sweet receptors. The affinity for each of these molecules varies, and some will taste sweeter than glucose because they bind to the G protein–coupled receptor differently.

Bitter taste is similar to sweet in that food molecules bind to G protein–coupled receptors. However, there are a number of different ways in which this can happen because there are a large diversity of bitter-tasting molecules. Some bitter molecules depolarize gustatory cells, whereas others hyperpolarize gustatory cells. Likewise, some bitter molecules increase G protein activation within the gustatory cells, whereas other bitter molecules decrease G protein activation. The specific response depends on which molecule is binding to the receptor.

One major group of bitter-tasting molecules are alkaloids. Alkaloids are nitrogen containing molecules that are commonly found in bitter-tasting plant products, such as coffee, hops (in beer), tannins (in wine), tea, and aspirin. By containing toxic alkaloids, the plant is less susceptible to microbe infection and less attractive to herbivores.

Therefore, the function of bitter taste may primarily be related to stimulating the gag reflex to avoid ingesting poisons. Because of this, many bitter foods that are normally ingested are often combined with a sweet component to make them more palatable (cream and sugar in coffee, for example). The highest concentration of bitter receptors appear to be in the posterior tongue, where a gag reflex could still spit out poisonous food.

The taste known as umami is often referred to as the savory taste. Like sweet and bitter, it is based on the activation of G protein–coupled receptors by a specific molecule. The molecule that activates this receptor is the amino acid L-glutamate. Therefore, the umami flavor is often perceived while eating protein-rich foods. Not surprisingly, dishes that contain meat are often described as savory.

Once the gustatory cells are activated by the taste molecules, they release neurotransmitters onto the dendrites of sensory neurons. These neurons are part of the facial and glossopharyngeal cranial nerves, as well as a component within the vagus nerve dedicated to the gag reflex. The facial nerve connects to taste buds in the anterior third of the tongue. The glossopharyngeal nerve connects to taste buds in the posterior two thirds of the tongue. The vagus nerve connects to taste buds in the extreme posterior of the tongue, verging on the pharynx, which are more sensitive to noxious stimuli such as bitterness.

Olfaction (Smell)

Like taste, the sense of smell, or olfaction, is also responsive to chemical stimuli. The olfactory receptor neurons are located in a small region within the superior nasal cavity (Figure 14.4). This region is referred to as the olfactory epithelium and contains bipolar sensory neurons. Each olfactory sensory neuron has dendrites that extend from the apical surface of the epithelium into the mucus lining the cavity. As airborne molecules are inhaled through the nose, they pass over the olfactory epithelial region and dissolve into the mucus. These odorant molecules bind to proteins that keep them dissolved in the mucus and help

transport them to the olfactory dendrites. The odorant–protein complex binds to a receptor protein within the cell membrane of an olfactory dendrite. These receptors are G protein–coupled, and will produce a graded membrane potential in the olfactory neurons.

The axon of an olfactory neuron extends from the basal surface of the epithelium, through an olfactory foramen in the cribriform plate of the ethmoid bone, and into the brain. The group of axons called the olfactory tract connect to the olfactory bulb on the ventral surface of the frontal lobe. From there, the axons split to travel to several brain regions. Some travel to the cerebrum, specifically to the primary olfactory cortex that is located in the inferior and medial areas of the temporal lobe. Others project to structures within the limbic system and hypothalamus, where smells become associated with long-term memory and emotional responses. This is how certain smells trigger emotional memories, such as the smell of food associated with one's birthplace. Smell is the one sensory modality that does not synapse in the thalamus before connecting to the cerebral cortex. This intimate connection between the olfactory system and the cerebral cortex is one reason why smell can be a potent trigger of memories and emotion.

The nasal epithelium, including the olfactory cells, can be harmed by airborne toxic chemicals. Therefore, the olfactory neurons are regularly replaced within the nasal epithelium, after which the axons of the new neurons must find their appropriate connections in the olfactory bulb. These new axons grow along the axons that are already in place in the cranial nerve.

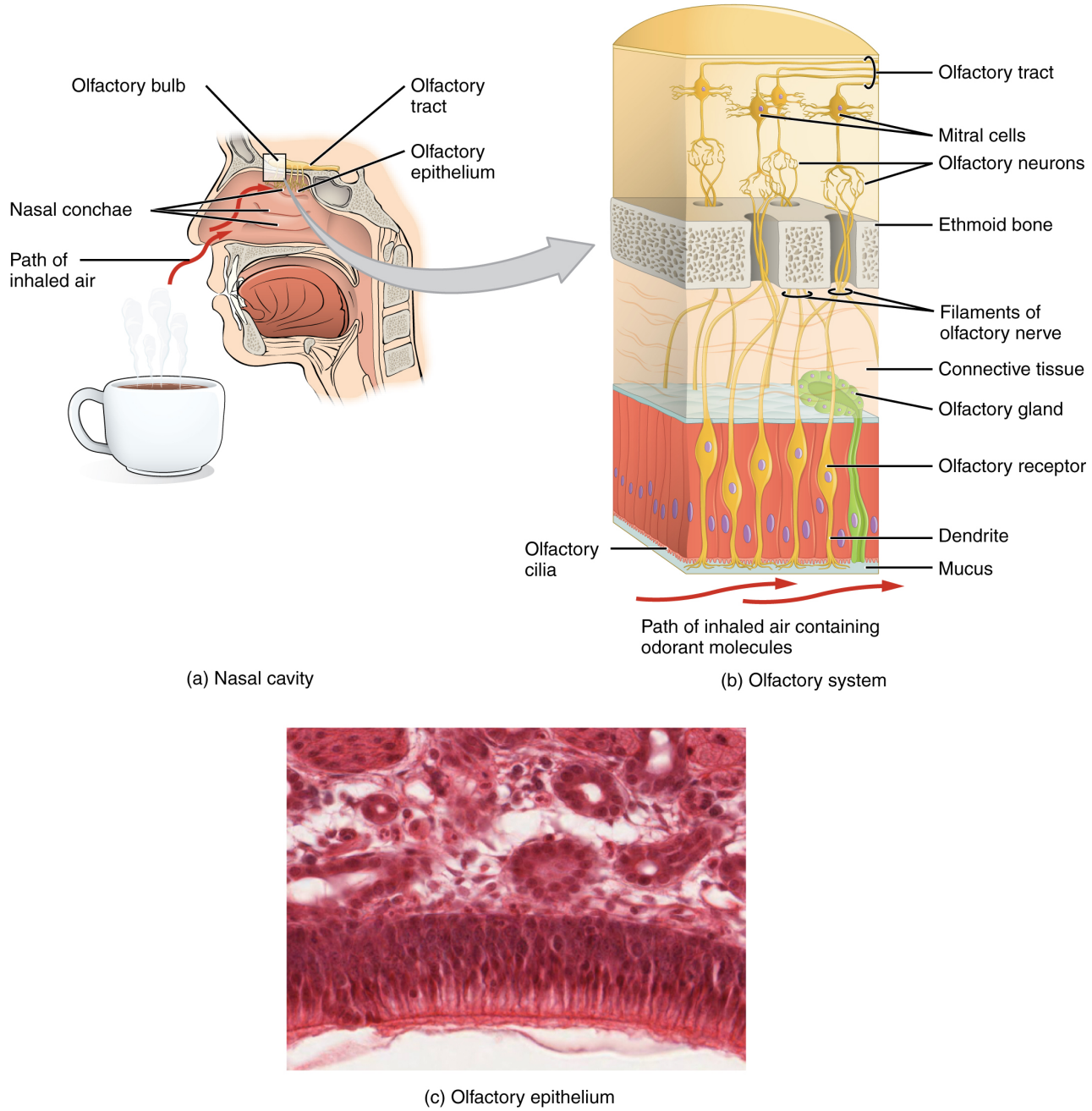


Figure 14.4 The Olfactory System. (a) The olfactory system begins in the peripheral structures of the nasal cavity. (b) The olfactory receptor neurons are within the olfactory epithelium. (c) Axons of the olfactory receptor neurons project through the cribriform plate of the ethmoid bone and synapse with the neurons of the olfactory bulb (tissue source: simian). LM × 812. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Audition (Hearing)

Hearing, or audition, is the transduction of sound waves into a neural signal that is made possible by the structures of the ear (Figure 14.5). The large, fleshy structure on the lateral aspect of the head is known as the auricle. Some sources will also refer to this structure as the pinna, though that term is more appropriate for a structure that can be moved, such as the external ear of a cat. The C-shaped curves of the auricle direct sound waves toward the auditory canal. The canal enters the skull through the external auditory meatus of

the temporal bone. At the end of the auditory canal is the tympanic membrane, or ear drum, which vibrates after it is struck by sound waves. The auricle, ear canal, and tympanic membrane are often referred to as the external ear. The middle ear consists of a space spanned by three small bones called the ossicles. The three ossicles are the malleus, incus, and stapes, which are Latin names that roughly translate to hammer, anvil, and stirrup. The malleus is attached to the tympanic membrane and articulates with the incus. The incus, in turn, articulates with the stapes. The stapes is then attached to the inner ear, where the sound waves will be transduced into a neural signal. The middle ear is connected to the pharynx through the Eustachian tube, which helps equilibrate air pressure across the tympanic membrane. The tube is normally closed but will pop open when the muscles of the pharynx contract during swallowing or yawning.

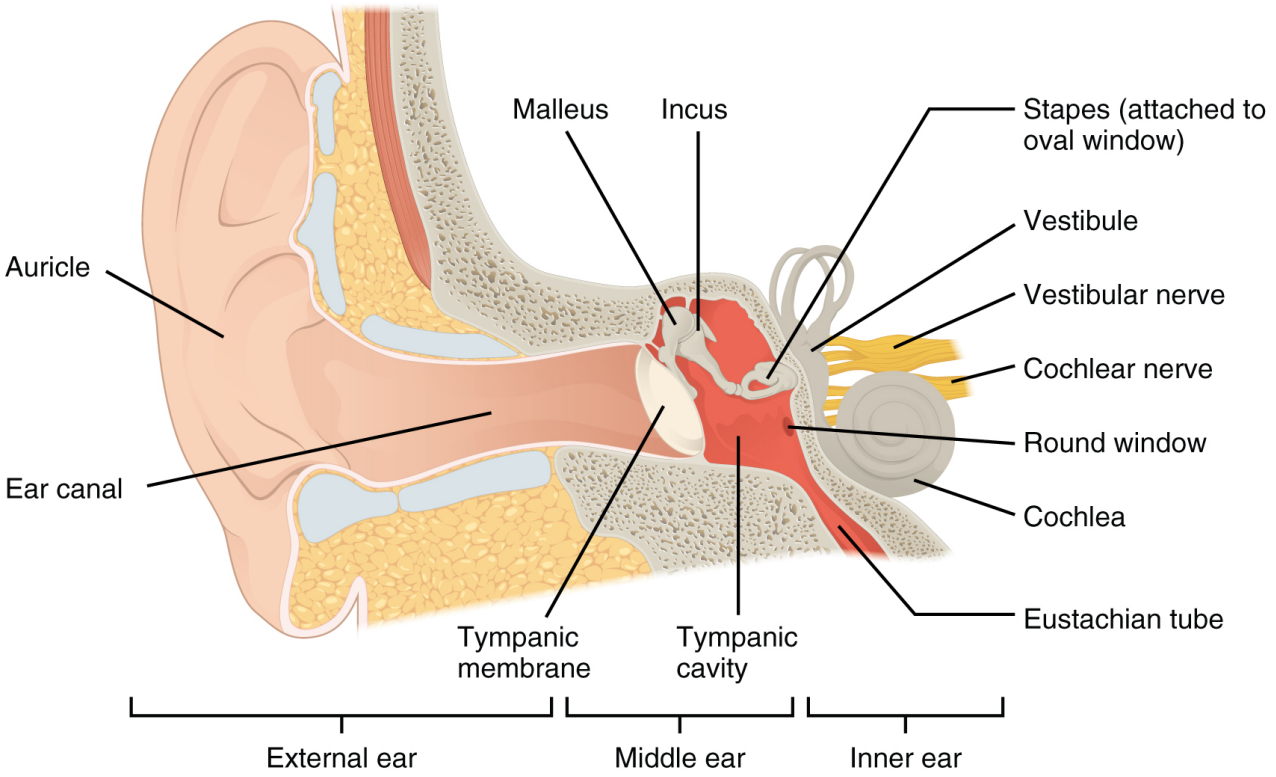


Figure 14.5 Structures of the Ear The external ear contains the auricle, ear canal, and tympanic membrane. The middle ear contains the ossicles and is connected to the pharynx by the Eustachian tube. The inner ear contains the cochlea and vestibule, which are responsible for audition and equilibrium, respectively.

The inner ear is often described as a bony labyrinth, as it is composed of a series of canals embedded within the temporal bone. It has two separate regions, the cochlea and the vestibule, which are responsible for hearing and balance, respectively. The neural signals from these two regions are relayed to the brain stem through separate fiber bundles. However, these two distinct bundles travel together from the inner ear to the brain stem as the vestibulocochlear nerve. Sound is transduced into neural signals within the cochlear region of the inner ear, which contains the sensory neurons of the spiral ganglia. These ganglia are located within the spiral-shaped cochlea of the inner ear. The cochlea is attached to the stapes through the oval window.

The oval window is located at the beginning of a fluid-filled tube within the cochlea called the scala vestibuli. The scala vestibuli extends from the oval window, travelling above the cochlear duct, which is the central cavity of the cochlea that contains the sound-transducing neurons. At the uppermost tip of the cochlea, the scala vestibuli curves over the top of the cochlear duct. The fluid-filled tube, now called the scala tympani, returns to the base of the cochlea, this time travelling under the cochlear duct. The scala tympani ends at the round window, which is covered by a membrane that contains the fluid within the scala. As vibrations of the ossicles travel through the oval window, the fluid of the scala vestibuli and scala tympani moves in a wave-like motion. The frequency of the fluid waves match the frequencies of the sound waves (Figure 14.6). The membrane covering the round window will bulge out or pucker in with the movement of the fluid within the scala tympani.

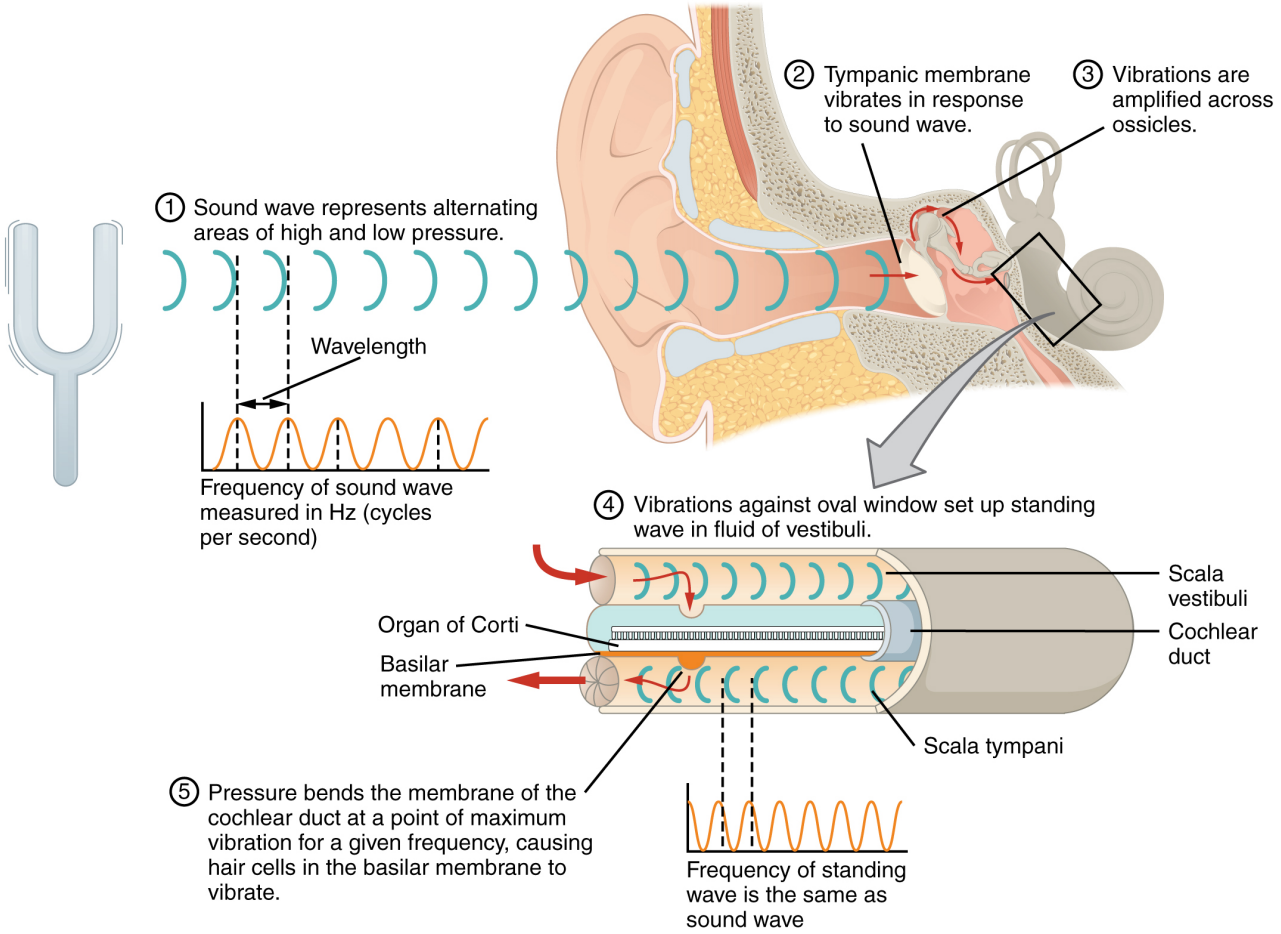


Figure 14.6 Transmission of Sound Waves to Cochlea A sound wave causes the tympanic membrane to vibrate. This vibration is amplified as it moves across the malleus, incus, and stapes. The amplified vibration is picked up by the oval window causing pressure waves in the fluid of the scala vestibuli and scala tympani. The complexity of the pressure waves is determined by the changes in amplitude and frequency of the sound waves entering the ear.

A cross-sectional view of the cochlea shows that the scala vestibuli and scala tympani run along both sides of the cochlear duct (Figure 14.7). The cochlear duct contains several organs of Corti, which tranduce the wave motion of the two scala into neural signals. The organs of Corti lie on top of the basilar membrane, which is the side of the cochlear duct located between the organs of Corti and the scala tympani. As the

fluid waves move through the scala vestibuli and scala tympani, the basilar membrane moves at a specific spot, depending on the frequency of the waves. Higher frequency waves move the region of the basilar membrane that is close to the base of the cochlea. Lower frequency waves move the region of the basilar membrane that is near the tip of the cochlea.

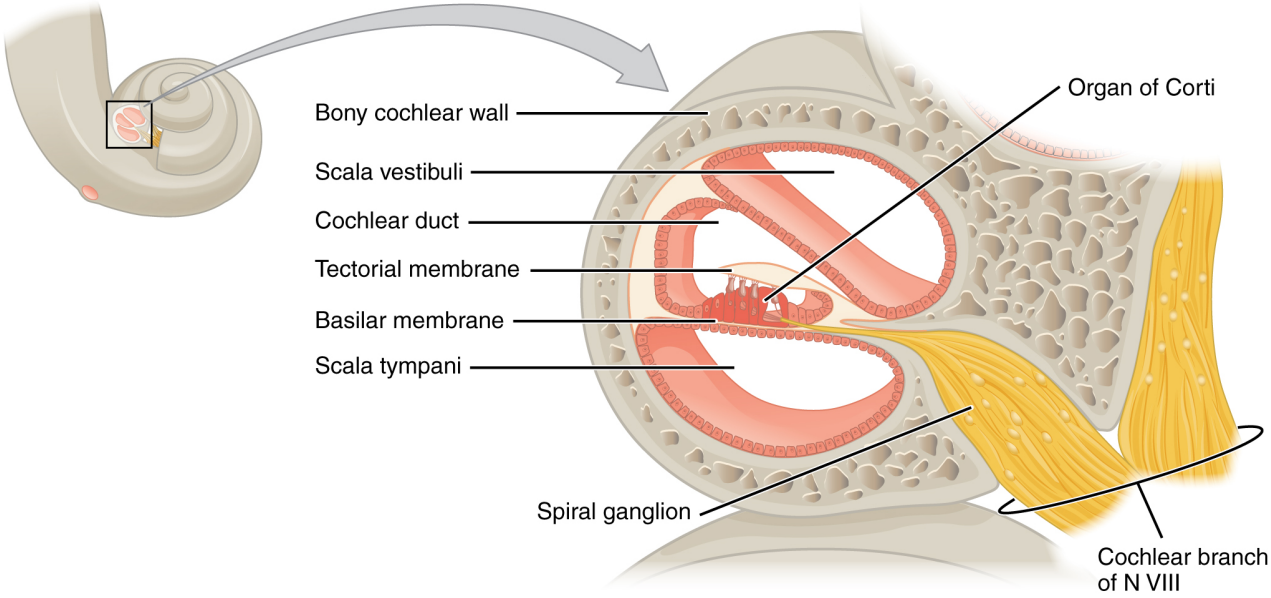


Figure 14.7 Cross Section of the Cochlea. The three major spaces within the cochlea are highlighted. The scala tympani and scala vestibuli lie on either side of the cochlear duct. The organ of Corti, containing the mechanoreceptor hair cells, is adjacent to the scala tympani, where it sits atop the basilar membrane.

The organs of Corti contain hair cells, which are named for the hair-like stereocilia extending from the cell's apical surfaces (Figure 14.8). The stereocilia are an array of microvilli-like structures arranged from tallest to shortest. Protein fibers tether adjacent hairs together within each array, such that the array will bend in response to movements of the basilar membrane. The stereocilia extend up from the hair cells to the overlying tectorial membrane, which is attached medially to the organ of Corti. When the pressure waves from the scala move the basilar membrane, the tectorial membrane slides across the stereocilia. This bends the stereocilia either toward or away from the tallest member of each array. When the stereocilia bend toward the tallest member of their array, tension in the protein tethers opens ion channels in the hair cell membrane. This will depolarize the hair cell membrane, triggering nerve impulses that travel down the afferent nerve fibers attached to the hair cells. When the stereocilia bend toward the shortest member of their array, the tension on the tethers slackens and the ion channels close. When no sound is present, and the stereocilia are standing straight, a small amount of tension still exists on the tethers, keeping the membrane potential of the hair cell slightly depolarized.

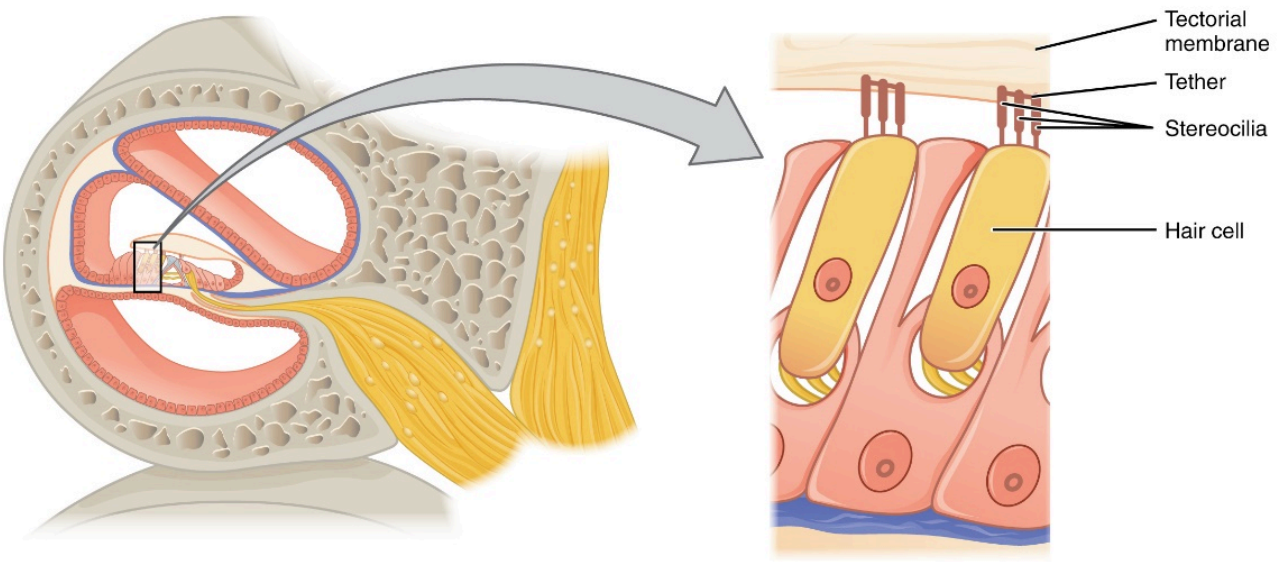


Figure 14.8 Hair Cell The hair cell is a mechanoreceptor with an array of stereocilia emerging from its apical surface. The stereocilia are tethered together by proteins that open ion channels when the array is bent toward the tallest member of their array, and closed when the array is bent toward the shortest member of their array.

Cochlea and Organ of Corti

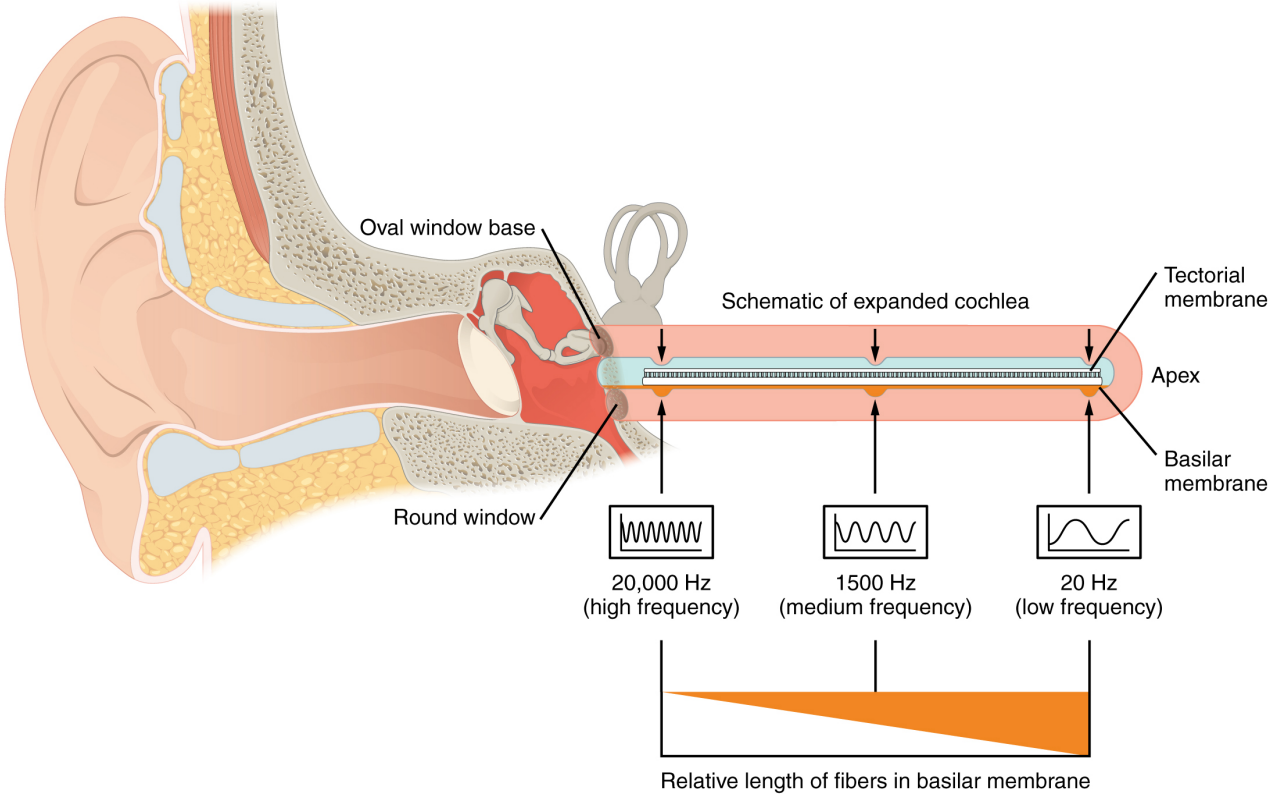


Figure 14.9 Frequency Coding in the Cochlea The standing sound wave generated in the cochlea by the movement of the oval window deflects the basilar membrane on the basis of the frequency of sound. Therefore, hair cells at the base of the cochlea are activated only by high frequencies, whereas those at the apex of the cochlea are activated only by low frequencies.

Watch this video to learn more about how the structures of the ear convert sound waves into a neural signal by moving the "hairs," or stereocilia, of the cochlear duct. Specific locations along the length of the duct encode specific frequencies, or pitches. The brain interprets the meaning of the sounds we hear as music, speech, noise, etc. Which ear structures are responsible for the amplification and transfer of sound from the external ear to the inner ear?

Watch this animation to learn more about the inner ear and to see the cochlea unroll, with the base at the back of the image and the apex at the front. Specific wavelengths of sound cause specific regions of the basilar membrane to vibrate, much like the keys of a piano produce sound at different frequencies. Based on the animation, where do frequencies—from high to low pitches—cause activity in the hair cells within the cochlear duct?

Equilibrium (Balance)

Along with audition, the inner ear is responsible for encoding information about equilibrium, the sense of balance. A similar mechanoreceptor—a hair cell with stereocilia—senses head position, head movement, and whether our bodies are in motion. These cells are located within the vestibule of the inner ear. Head position is sensed by the utricle and saccule, whereas head movement is sensed by the semicircular canals. The neural signals generated in the vestibular ganglion are transmitted through the vestibulocochlear nerve to the brain stem and cerebellum.

The utricle and saccule are both largely composed of macula tissue (plural = maculae). The macula is composed of hair cells surrounded by support cells. The stereocilia of the hair cells extend into a viscous gel called the otolithic membrane (Figure 14.10). On top of the otolithic membrane is a layer of calcium carbonate crystals, called otoliths. The otoliths essentially make the otolithic membrane top-heavy. The otolithic membrane moves separately from the macula in response to head movements. Tilting the head causes the otolithic membrane to slide over the macula in the direction of gravity. The moving otolithic membrane, in turn, bends the sterocilia, causing some hair cells to depolarize as others hyperpolarize. The exact position of the head is interpreted by the brain based on the pattern of hair-cell depolarization.

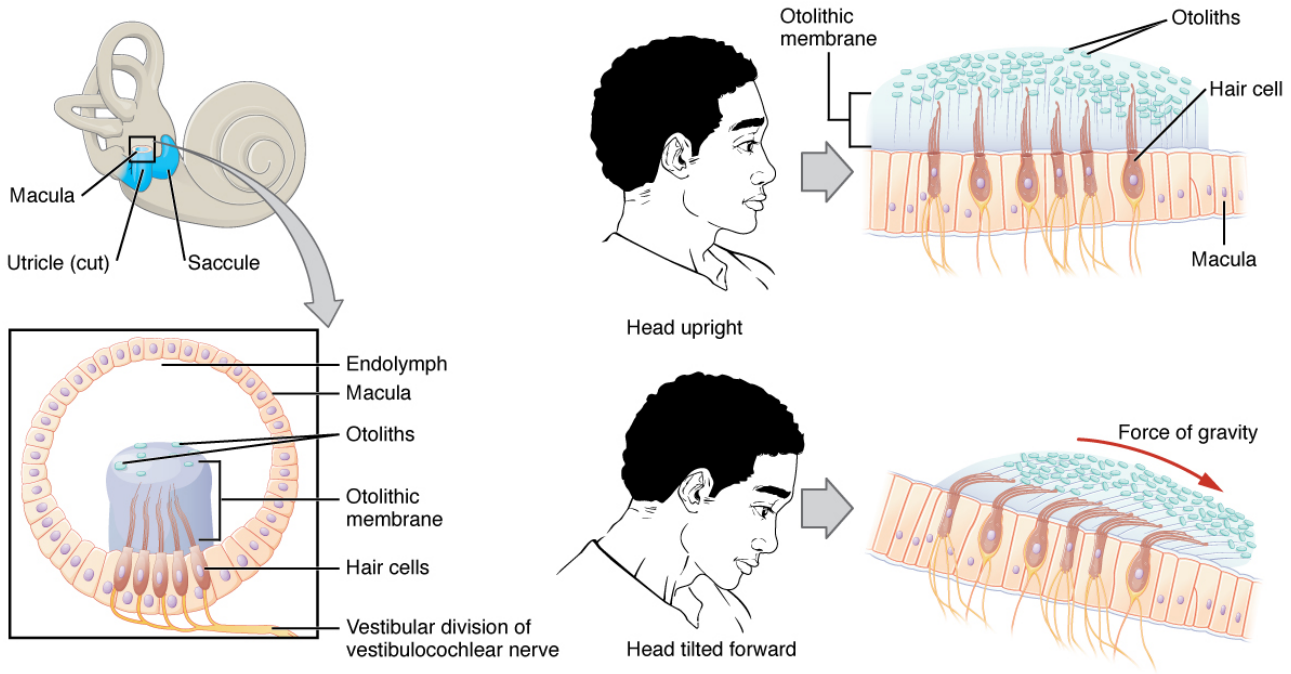


Figure 14.10 Linear Acceleration Coding by Maculae The maculae are specialized for sensing linear acceleration, such as when gravity acts on the tilting head, or if the head starts moving in a straight line. The difference in inertia between the hair cell stereocilia and the otolithic membrane in which they are embedded leads to a shearing force that causes the stereocilia to bend in the direction of that linear acceleration.

The semicircular canals are three ring-like extensions of the vestibule. One is oriented in the horizontal plane, whereas the other two are oriented in the vertical plane. The anterior and posterior vertical canals are oriented at approximately 45 degrees relative to the sagittal plane. The base of each semicircular canal, where it meets with the vestibule, connects to an enlarged region known as the ampulla. The ampulla contains the hair cells that respond to rotational movement, such as turning the head while saying "no." The stereocilia of these hair cells extend into the cupula, a membrane that attaches to the top of the ampulla. As the head rotates in a plane parallel to the semicircular canal, the fluid lags, deflecting the cupula in the direction opposite to the head movement. The semicircular canals contain several ampullae, with some oriented horizontally and others oriented vertically. By comparing the relative movements of both the horizontal and vertical ampullae, the vestibular system can detect the direction of most head movements within three-dimensional (3-D) space.

Somatosensation (Touch)

Somatosensation is considered a general sense, as opposed to the special senses discussed in this section. Somatosensation is the group of sensory modalities that are associated with touch, proprioception, and interoception. These modalities include pressure, vibration, light touch, tickle, itch, temperature, pain, proprioception, and kinesthesia. This means that its receptors are not associated with a specialized organ, but are instead spread throughout the body in a variety of organs. Many of the somatosensory receptors are

located in the skin, but receptors are also found in muscles, tendons, joint capsules, ligaments, and in the walls of visceral organs.

Two types of somatosensory signals that are transduced by free nerve endings are pain and temperature. These two modalities use thermoreceptors and nociceptors to transduce temperature and pain stimuli, respectively. Temperature receptors are stimulated when local temperatures differ from body temperature. Some thermoreceptors are sensitive to just cold and others to just heat. Nociception is the sensation of potentially damaging stimuli. Mechanical, chemical, or thermal stimuli beyond a set threshold will elicit painful sensations. Stressed or damaged tissues release chemicals that activate receptor proteins in the nociceptors. For example, the sensation of heat associated with spicy foods involves capsaicin, the active molecule in hot peppers. Capsaicin molecules bind to a transmembrane ion channel in nociceptors that is sensitive to temperatures above 37°C. The dynamics of capsaicin binding with this transmembrane ion channel is unusual in that the molecule remains bound for a long time. Because of this, it will decrease the ability of other stimuli to elicit pain sensations through the activated nociceptor. For this reason, capsaicin can be used as a topical analgesic, such as in products such as Icy Hot™.

If you drag your finger across a textured surface, the skin of your finger will vibrate. Such low frequency vibrations are sensed by mechanoreceptors called Merkel cells, also known as type I cutaneous mechanoreceptors. Merkel cells are located in the stratum basale of the epidermis. Deep pressure and vibration is transduced by lamellated (Pacinian) corpuscles, which are receptors with encapsulated endings found deep in the dermis, or subcutaneous tissue. Light touch is transduced by the encapsulated endings known as tactile (Meissner) corpuscles. Follicles are also wrapped in a plexus of nerve endings known as the hair follicle plexus. These nerve endings detect the movement of hair at the surface of the skin, such as when an insect may be walking along the skin. Stretching of the skin is transduced by stretch receptors known as bulbous corpuscles. Bulbous corpuscles are also known as Ruffini corpuscles, or type II cutaneous mechanoreceptors.

Other somatosensory receptors are found in the joints and muscles. Stretch receptors monitor the stretching of tendons, muscles, and the components of joints. For example, have you ever stretched your muscles before or after exercise and noticed that you can only stretch so far before your muscles spasm back to a less stretched state? This spasm is a reflex that is initiated by stretch receptors to avoid muscle tearing. Such stretch receptors can also prevent over-contraction of a muscle. In skeletal muscle tissue, these stretch receptors are called muscle spindles. Golgi tendon organs similarly transduce the stretch levels of tendons. Bulbous corpuscles are also present in joint capsules, where they measure stretch in the components of the skeletal system within the joint. The types of nerve endings, their locations, and the stimuli they transduce are presented in Table 14.1.

Table 14.1			
Mechanoreceptors of Somatosensation *No corresponding eponymous name.			
Name	**Historical (eponymous) name**	**Location(s)**	**Stimuli**
Free nerve endings	*	Dermis, cornea, tongue, joint capsules, visceral organs	Pain, temperature, mechanical deformation
Mechanoreceptors	Merkel's discs	Epidermal–dermal junction, mucosal membranes	Low frequency vibration (5–15 Hz)
Bulbous corpuscle	Ruffini's corpuscle	Dermis, joint capsules	Stretch
Tactile corpuscle	Meissner's corpuscle	Papillary dermis, especially in the fingertips and lips	Light touch, vibrations below 50 Hz
Lamellated corpuscle	Pacinian corpuscle	Deep dermis, subcutaneous tissue	Deep pressure, high-frequency vibration (around 250 Hz)
Hair follicle plexus	*	Wrapped around hair follicles in the dermis	Movement of hair
Muscle spindle	*	In line with skeletal muscle fibers	Muscle contraction and stretch
Tendon stretch organ	Golgi tendon organ	In line with tendons	Stretch of tendons

Vision

Vision is the special sense of sight that is based on the transduction of light stimuli received through the eyes. The eyes are located within either orbit in the skull. The bony orbits surround the eyeballs, protecting them and anchoring the soft tissues of the eye (Figure 14.11). The eyelids, with lashes at their leading edges, help to protect the eye from abrasions by blocking particles that may land on the surface of the eye. The inner surface of each lid is a thin membrane known as the palpebral conjunctiva. The conjunctiva extends over the white areas of the eye (the sclera), connecting the eyelids to the eyeball. Tears are produced by the lacrimal gland, located beneath the lateral edges of the nose. Tears produced by this gland flow through the lacrimal duct to the medial corner of the eye, where the tears flow over the conjunctiva, washing away foreign particles.

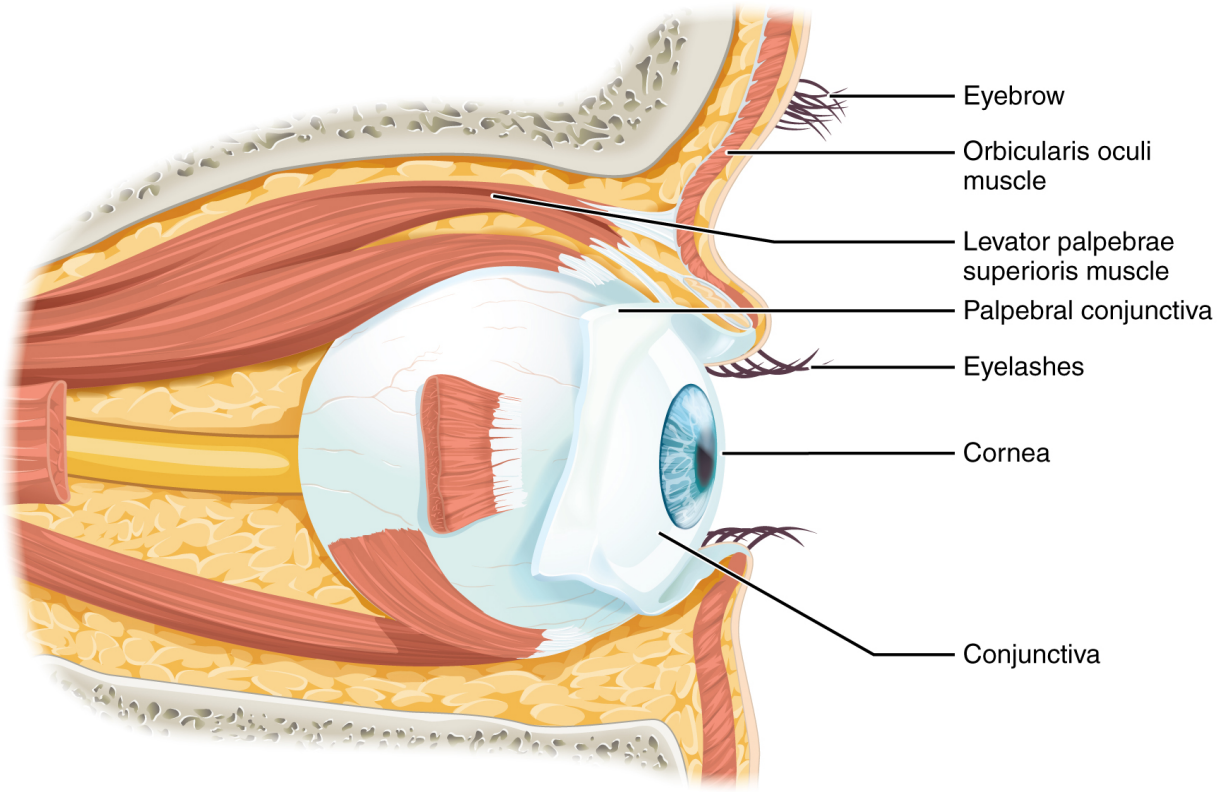


Figure 14.11 The Eye in the Orbit The eye is located within the orbit and surrounded by soft tissues that protect and support its function. The orbit is surrounded by cranial bones of the skull.

Movement of the eye within the orbit is accomplished by the contraction of six extraocular muscles that originate from the bones of the orbit and insert into the surface of the eyeball (Figure 14.12). Four of the muscles are arranged at the cardinal points around the eye and are named for those locations. They are the superior rectus, medial rectus, inferior rectus, and lateral rectus. When each of these muscles contract, the eye to moves toward the contracting muscle. For example, when the superior rectus contracts, the eye rotates to look up. The superior oblique originates at the posterior orbit, near the origin of the four rectus muscles. However, the tendon of the oblique muscles threads through a pulley-like piece of cartilage known as the trochlea. The tendon inserts obliquely into the superior surface of the eye. The angle of the tendon through the trochlea means that contraction of the superior oblique rotates the eye medially. The inferior oblique muscle originates from the floor of the orbit and inserts into the inferolateral surface of the eye. When it contracts, it laterally rotates the eye, in opposition to the superior oblique. Rotation of the eye by the two oblique muscles is necessary because the eye is not perfectly aligned on the sagittal plane. When the eye looks up or down, the eye must also rotate slightly to compensate for the superior rectus pulling at approximately a 20-degree angle, rather than straight up. The same is true for the inferior rectus, which is compensated by contraction of the inferior oblique. A seventh muscle in the orbit is the levator palpebrae superioris, which is responsible for elevating and retracting the upper eyelid, a movement that usually occurs in concert with elevation of the eye by the superior rectus (see Figure 14.12).

The extraocular muscles are innervated by three cranial nerves. The lateral rectus, which causes abduction of the eye, is innervated by the abducens nerve. The superior oblique is innervated by the trochlear nerve. All of the other muscles are innervated by the oculomotor nerve, as is the levator palpebrae

superioris. The motor nuclei of these cranial nerves connect to the brain stem, which coordinates eye movements.

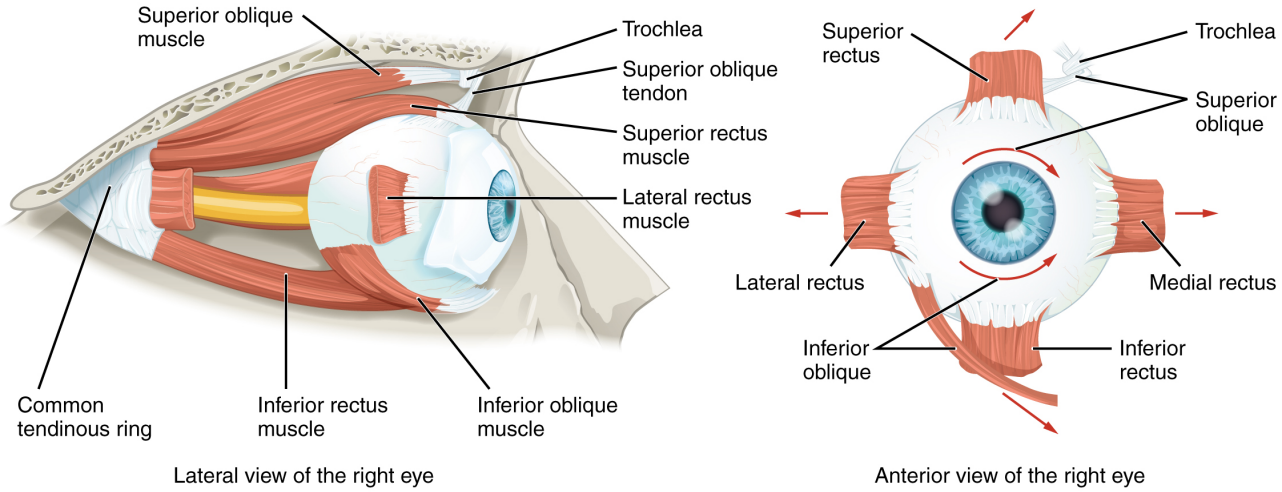


Figure 14.12 Extraocular Muscles The extraocular muscles move the eye within the orbit.

The eye itself is a hollow sphere composed of three layers of tissue. The outermost layer is the fibrous tunic, which includes the white sclera and clear cornea. The sclera accounts for five sixths of the surface of the eye, most of which is not visible, though humans are unique compared with many other species in having so much of the "white of the eye" visible (Figure 14.13). The transparent cornea covers the anterior tip of the eye and allows light to enter the eye. The middle layer of the eye is the vascular tunic, which is mostly composed of the choroid, ciliary body, and iris. The choroid is a layer of highly vascularized connective tissue that provides a blood supply to the eyeball. The choroid is posterior to the ciliary body, a muscular structure that is attached to the lens by suspensory ligaments, or zonule fibers. These two structures bend the lens, allowing it to focus light on the back of the eye. Overlaying the ciliary body, and visible in the anterior eye, is the iris—the colored part of the eye. The iris is a smooth muscle that opens or closes the pupil, which is the hole at the center of the eye that allows light to enter. The iris constricts the pupil in response to bright light and dilates the pupil in response to dim light. The innermost layer of the eye is the neural tunic, or retina, which contains the nervous tissue responsible for photoreception.

The eye is also divided into two cavities: the anterior cavity and the posterior cavity. The anterior cavity is the space between the cornea and lens, including the iris and ciliary body. It is filled with a watery fluid called the aqueous humor. The posterior cavity is the space behind the lens that extends to the posterior side of the interior eyeball, where the retina is located. The posterior cavity is filled with a more viscous fluid called the vitreous humor.

The retina is composed of several layers and contains specialized cells for the initial processing of visual stimuli. The photoreceptors (rods and cones) change their membrane potential when stimulated by light energy. The change in membrane potential alters the amount of neurotransmitter that the photoreceptor cells release onto bipolar cells in the outer synaptic layer. It is the bipolar cell in the retina that connects a photoreceptor to a retinal ganglion cell (RGC) in the inner synaptic layer. There, amacrine cells additionally contribute to retinal processing before an action potential is produced by the RGC. The axons

of RGCs, which lie at the innermost layer of the retina, collect at the optic disc and leave the eye as the optic nerve (see Figure 14.13). Because these axons pass through the retina, there are no photoreceptors at the very back of the eye, where the optic nerve begins. This creates a "blind spot" in the retina, and a corresponding blind spot in our visual field.

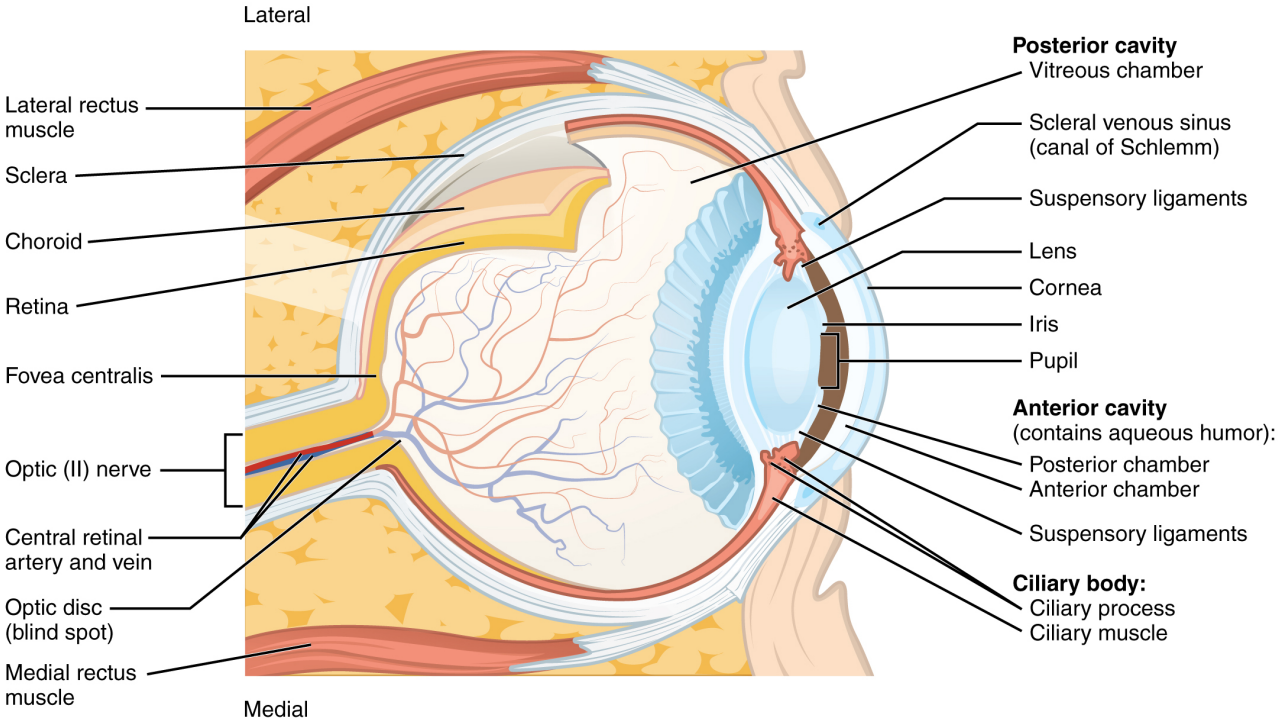


Figure 14.13 Structure of the Eye The sphere of the eye can be divided into anterior and posterior chambers. The wall of the eye is composed of three layers: the fibrous tunic, vascular tunic, and neural tunic. Within the neural tunic is the retina, with three layers of cells and two synaptic layers in between. The center of the retina has a small indentation known as the fovea.

Note that the photoreceptors in the retina (rods and cones) are located behind the axons, RGCs, bipolar cells, and retinal blood vessels. A significant amount of light is absorbed by these structures before the light reaches the photoreceptor cells. However, at the exact center of the retina is a small area known as the fovea. At the fovea, the retina lacks the supporting cells and blood vessels, and only contains photoreceptors. Therefore, visual acuity, or the sharpness of vision, is greatest at the fovea. This is because the fovea is where the least amount of incoming light is absorbed by other retinal structures (see Figure 14.13). As one moves in either direction from this central point of the retina, visual acuity drops significantly. In addition, each photoreceptor cell of the fovea is connected to a single RGC. Therefore, this RGC does not have to integrate inputs from multiple photoreceptors, which reduces the accuracy of visual transduction. Toward the edges of the retina, several photoreceptors converge on RGCs (through the bipolar cells) up to a ratio of 50 to 1. The difference in visual acuity between the fovea and peripheral retina is easily evidenced by looking directly at a word in the middle of this paragraph. The visual stimulus in the middle of the field of view falls on the fovea and is in the sharpest focus. Without moving your eyes off that word, notice that words at the beginning or end of the paragraph are not in focus. The images in your peripheral vision are focused by the peripheral retina, and have vague, blurry edges and words that are not as clearly identified.

As a result, a large part of the neural function of the eyes is concerned with moving the eyes and head so that important visual stimuli are centered on the fovea.

Light falling on the retina causes chemical changes to pigment molecules in the photoreceptors, ultimately leading to a change in the activity of the RGCs. Photoreceptor cells have two parts, the inner segment and the outer segment (Figure 14.14). The inner segment contains the nucleus and other common organelles of a cell, whereas the outer segment is a specialized region in which photoreception takes place. There are two types of photoreceptors—rods and cones—which differ in the shape of their outer segment. The rod-shaped outer segments of the rod photoreceptor contain a stack of membrane-bound discs that contain the photosensitive pigment rhodopsin. The cone-shaped outer segments of the cone photoreceptor contain their photosensitive pigments in infoldings of the cell membrane. There are three cone photopigments, called opsins, which are each sensitive to a particular wavelength of light. The wavelength of visible light determines its color. The pigments in human eyes are specialized in perceiving three different primary colors: red, green, and blue.

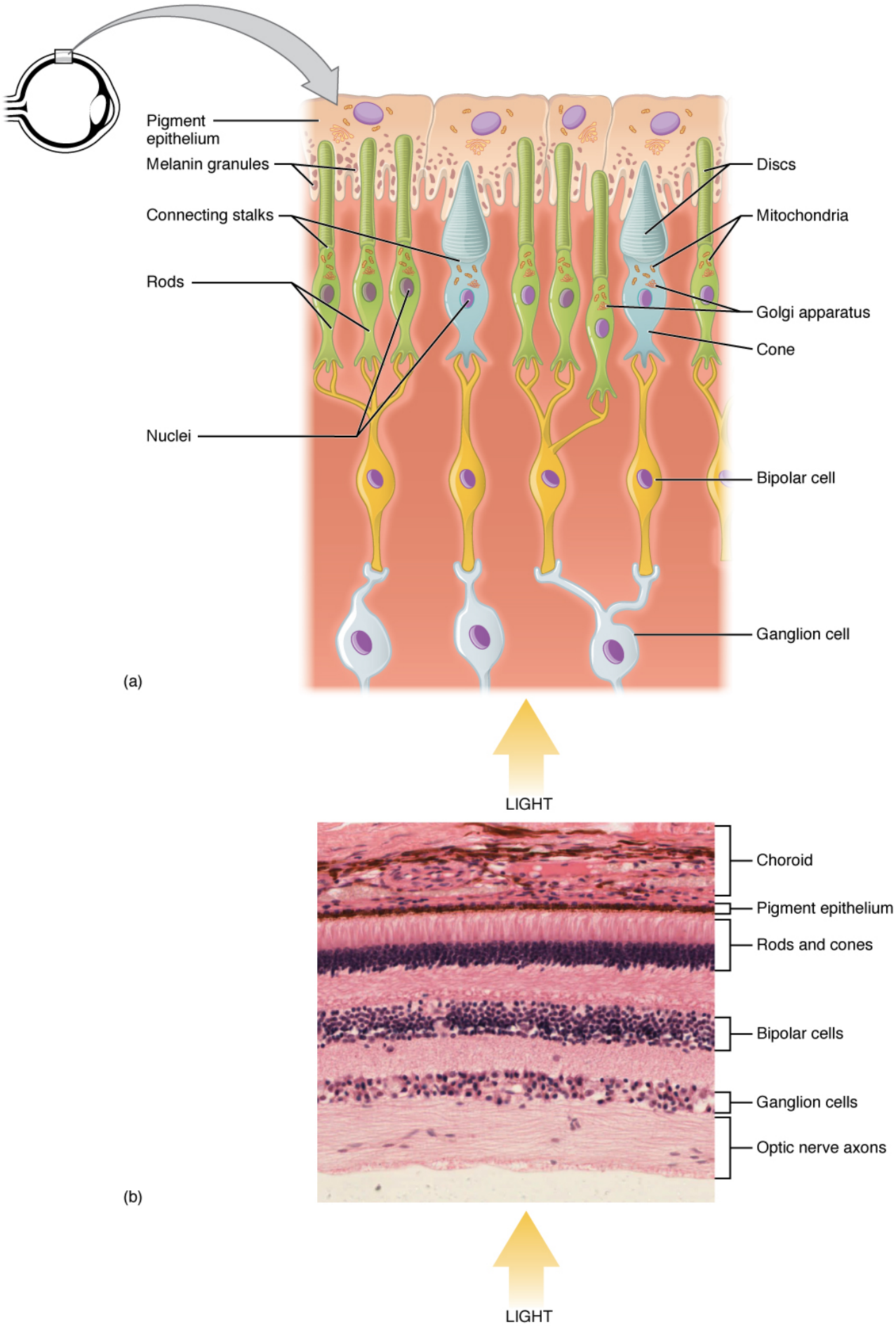

Pigment epithelium
Melanin granules
Connecting stalks
Rods
Nuclei
Discs
Mitochondria
Golgi apparatus
Cone
Bipolar cell
Ganglion cell
(a)
LIGHT
Choroid
Pigment epithelium
Rods and cones
Bipolar cells
Ganglion cells
Optic nerve axons
(b)
LIGHT

Figure 14.14 Photoreceptors (a) All photoreceptors have inner segments containing the nucleus and other important organelles and outer segments with membrane arrays containing the photosensitive opsin molecules. Rod outer segments are long columnar shapes with stacks of membrane-bound discs that contain the rhodopsin pigment. Cone outer segments are short, tapered shapes with folds of membrane in place of the discs in the rods. (b) Tissue of the retina shows a dense layer of nuclei of the rods and cones. LM × 800. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

At the molecular level, visual stimuli cause changes in the photopigment molecule that lead to changes in membrane potential of the photoreceptor cell. A single unit of light is called a photon, which is described in physics as a packet of energy with properties of both a particle and a wave. The energy of a photon is represented by its wavelength, with each wavelength of visible light corresponding to a particular color. Visible light is electromagnetic radiation with a wavelength between 380 and 720 nm. Wavelengths of electromagnetic radiation longer than 720 nm fall into the infrared range, whereas wavelengths shorter than 380 nm fall into the ultraviolet range. Light with a wavelength of 380 nm is blue whereas light with a wavelength of 720 nm is dark red. All other colors fall between red and blue at various points along the wavelength scale.

Opsin pigments are actually transmembrane proteins that contain a cofactor known as retinal. Retinal is a hydrocarbon molecule related to vitamin A. When a photon hits retinal, the long hydrocarbon chain of the molecule is biochemically altered. Specifically, photons cause some of the double-bonded carbons within the chain to switch from a *cis* to a *trans* conformation. This process is called photoisomerization. Before interacting with a photon, retinal's flexible double-bonded carbons are in the *cis* conformation. This molecule is referred to as 11-*cis*-retinal. A photon interacting with the molecule causes the flexible double-bonded carbons to change to the *trans*– conformation, forming all-*trans*-retinal, which has a straight hydrocarbon chain (Figure 14.15).

The shape change of retinal in the photoreceptors initiates visual transduction in the retina. Activation of retinal and the opsin proteins result in activation of a G protein. The G protein changes the membrane potential of the photoreceptor cell, which then releases less neurotransmitter into the outer synaptic layer of the retina. Until the retinal molecule is changed back to the 11-*cis*-retinal shape, the opsin cannot respond to light energy, which is called bleaching. When a large group of photopigments is bleached, the retina will send information as if opposing visual information is being perceived. After a bright flash of light, afterimages are usually seen in negative. The photoisomerization is reversed by a series of enzymatic changes so that the retinal responds to more light energy.

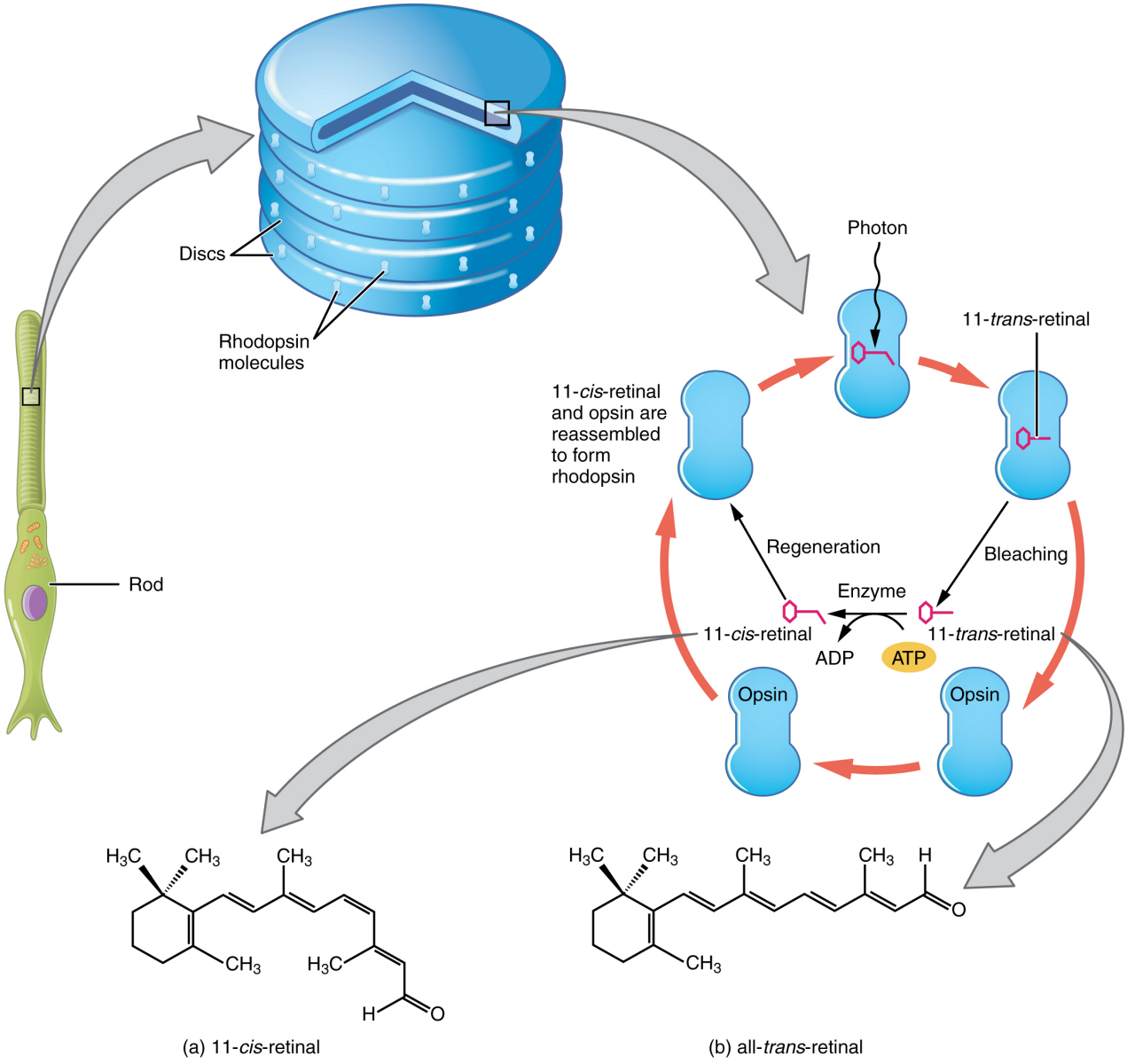


Figure 14.15 Retinal Isomers The retinal molecule has two isomers, (a) one before a photon interacts with it and (b) one that is altered through photoisomerization.

The opsins are sensitive to limited wavelengths of light. Rhodopsin, the photopigment in rods, is most sensitive to light at a wavelength of 498 nm. The three color opsins have peak sensitivities of 564 nm, 534 nm, and 420 nm corresponding roughly to the primary colors of red, green, and blue (Figure 14.16). The absorbance of rhodopsin in the rods is much more sensitive than in the cone opsins; specifically, rods are sensitive to vision in low light conditions, and cones are sensitive to brighter conditions. In normal sunlight, rhodopsin will be constantly bleached while the cones are active. In a darkened room, there is not enough light to activate cone opsins, and vision is entirely dependent on rods. Rods are so sensitive to light that a single photon can result in an action potential from a rod's corresponding RGC.

The three types of cone opsins, being sensitive to different wavelengths of light, provide us with color vision. By comparing the activity of the three different cones, the brain can extract color information from visual stimuli. For example, a bright blue light that has a wavelength of approximately 450 nm would

activate the "red" cones minimally, the "green" cones marginally, and the "blue" cones predominantly. The relative activation of the three different cones is calculated by the brain, which perceives the color as blue. However, cones cannot react to low-intensity light, and rods do not sense the color of light. Therefore, our low-light vision is—in essence—in grayscale. In other words, in a dark room, everything appears as a shade of gray. If you think that you can see colors in the dark, it is most likely because your brain knows what color something is and is relying on that memory.

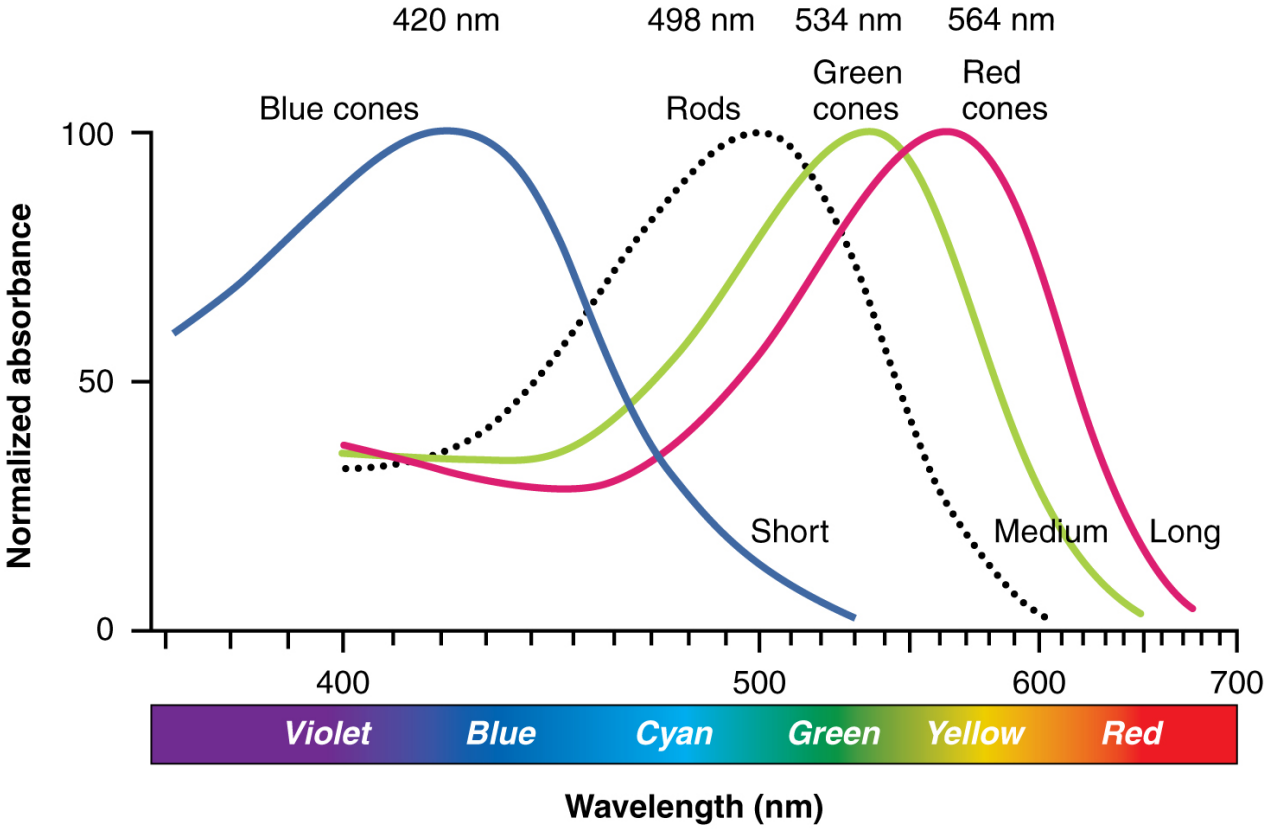


Figure 14.16 Comparison of Color Sensitivity of Photopigments Comparing the peak sensitivity and absorbance spectra of the four photopigments suggests that they are most sensitive to particular wavelengths.

Watch this video to learn more about a transverse section through the brain that depicts the visual pathway from the eye to the occipital cortex. The first half of the pathway is the projection from the RGCs through the optic nerve to the lateral geniculate nucleus in the thalamus on either side. This first fiber in the pathway synapses on a thalamic cell that then projects to the visual cortex in the occipital lobe where "seeing," or visual perception, takes place. This video gives an abbreviated overview of the visual system by concentrating on the pathway from the eyes to the occipital lobe. The video makes the statement (at 0:45) that "specialized cells in the retina called ganglion cells convert the light rays into electrical signals." What aspect of retinal processing is simplified by that statement? Explain your answer.

Sensory Nerves

Once any sensory cell transduces a stimulus into a nerve impulse, that impulse has to travel along axons to reach the CNS. In many of the special senses, the axons leaving the sensory receptors have a

topographical arrangement, meaning that the location of the sensory receptor relates to the location of the axon in the nerve. For example, in the retina, axons from RGCs in the fovea are located at the center of the optic nerve, where they are surrounded by axons from the more peripheral RGCs.

Spinal Nerves

Generally, spinal nerves contain afferent axons from sensory receptors in the periphery, such as from the skin, mixed with efferent axons travelling to the muscles or other effector organs. As the spinal nerve nears the spinal cord, it splits into dorsal and ventral roots. The dorsal root contains only the axons of sensory neurons, whereas the ventral roots contain only the axons of the motor neurons. Some of the branches will synapse with local neurons in the dorsal root ganglion, posterior (dorsal) horn, or even the anterior (ventral) horn, at the level of the spinal cord where they enter. Other branches will travel a short distance up or down the spine to interact with neurons at other levels of the spinal cord. A branch may also turn into the posterior (dorsal) column of the white matter to connect with the brain. For the sake of convenience, we will use the terms ventral and dorsal in reference to structures within the spinal cord that are part of these pathways. This will help to underscore the relationships between the different components. Typically, spinal nerve systems that connect to the brain are contralateral, in that the right side of the body is connected to the left side of the brain and the left side of the body to the right side of the brain.

Cranial Nerves

Cranial nerves convey specific sensory information from the head and neck directly to the brain. For sensations below the neck, the right side of the body is connected to the left side of the brain and the left side of the body to the right side of the brain. Whereas spinal information is contralateral, cranial nerve systems are mostly ipsilateral, meaning that a cranial nerve on the right side of the head is connected to the right side of the brain. Some cranial nerves contain only sensory axons, such as the olfactory, optic, and vestibulocochlear nerves. Other cranial nerves contain both sensory and motor axons, including the trigeminal, facial, glossopharyngeal, and vagus nerves (however, the vagus nerve is not associated with the somatic nervous system). The general senses of somatosensation for the face travel through the trigeminal system.

Pre-Laboratory Questions

1. What type of receptor cell is responsible for transducing pain stimuli?

   A. mechanoreceptor
   B. nociceptor
   C. osmoreceptor
   D. photoreceptor

2. Which of these cranial nerves is part of the gustatory system?

A. olfactory
B. trochlear
C. trigeminal
D. facial

3. Which submodality of taste is sensitive to the pH of saliva?

A. umami
B. sour
C. bitter
D. sweet

4. Axons from which neuron in the retina make up the optic nerve?

A. amacrine cells
B. photoreceptors
C. bipolar cells
D. retinal ganglion cells

5. What type of receptor cell is involved in the sensations of sound and balance?

A. photoreceptor
B. chemoreceptor
C. mechanoreceptor
D. nociceptor

Exercises

- Exercise 1 Identify and label eye structures on a model or diagram.
- Exercise 2 Cow eye dissection
- Exercise 3 Identify and label ear structures on a model or diagram

Exercise 1

Required Materials

1. Colored tape or post-it notes
2. Sharpie or marker
3. Eye models
4. Ox eye bismount model

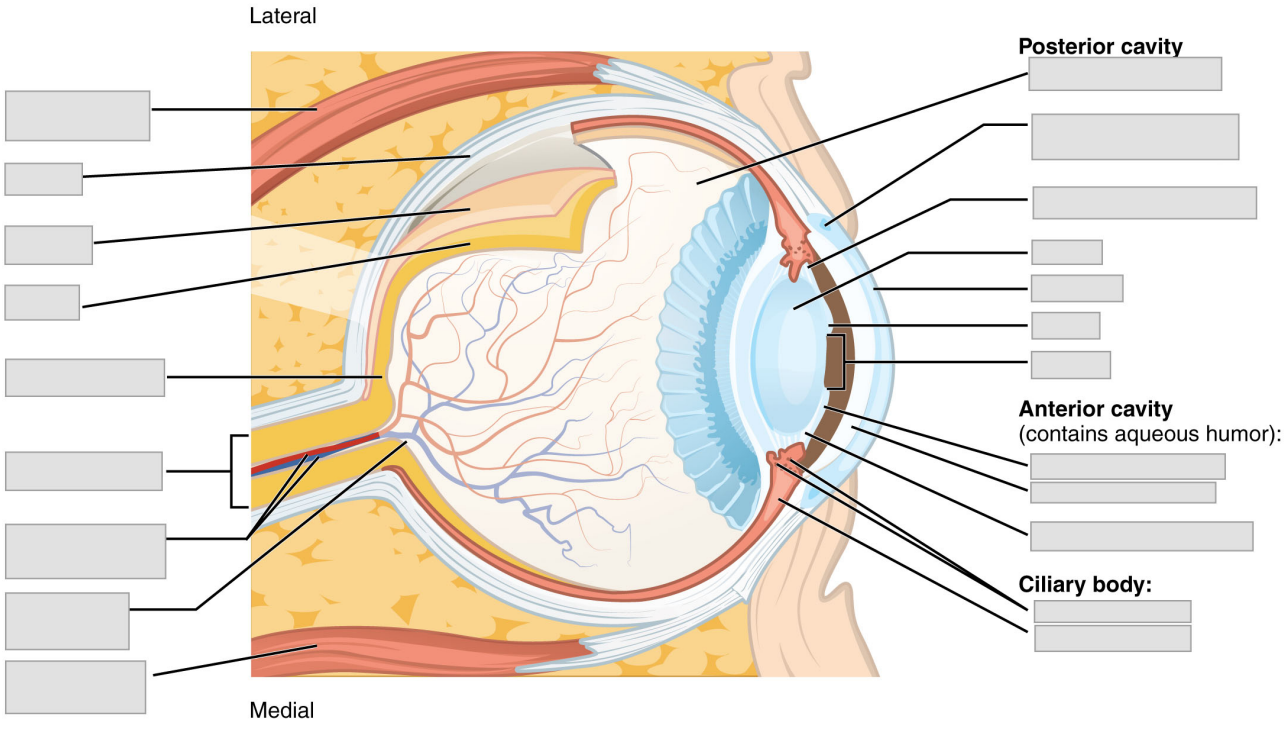
Procedure

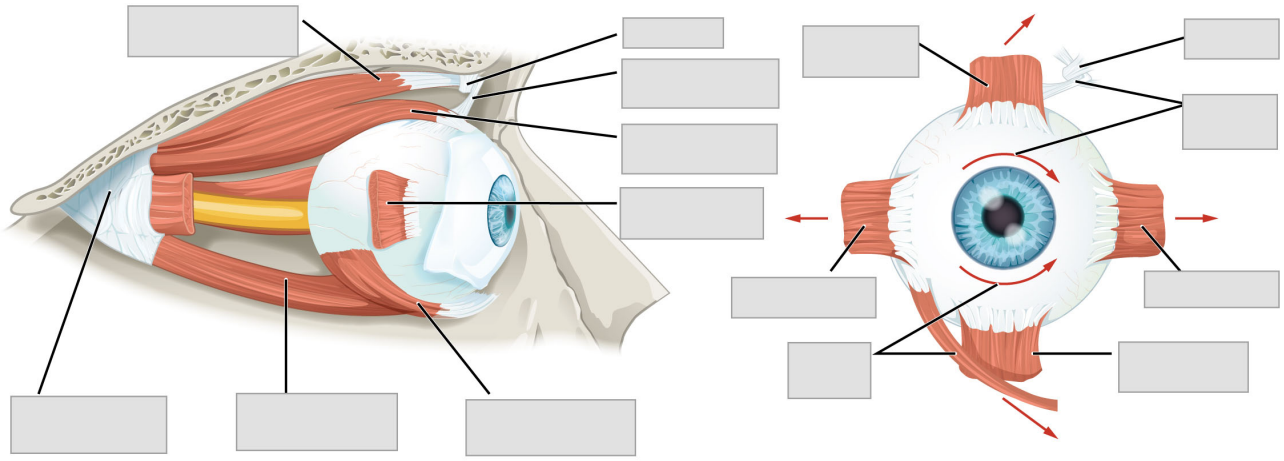
1. First, This activity requires you to label the structures of the eye on a model. You are provided a list of terms below and you are expected to use every term provided. Using colored tape or post-it notes, please write the number that corresponds to the term from the list and place them on your model.
2. Once finished, take pictures of your models with your labels on them. Insert the pictures in the space provided below.

List of Terms:

Eye -Internal		**Eye – External & Accessories**
Anterior portion Sclera Cornea Anterior chamber Aqueous humor Iris Pupil Posterior chamber Lens Ciliary body Suspensory ligament	**Posterior portion** Posterior cavity Vitreous humor Retina Fovea centralis Macula lutea Optic disc Tapetum lucidum Choroid Optic nerve	Lateral rectus muscle Medial rectus muscle Superior rectus muscle Inferior rectus muscle Superior oblique muscle Inferior oblique muscle Pupil Iris Sclera Lacrimal caruncle

3. Label the following figures by using the List of Terms given in the table above.





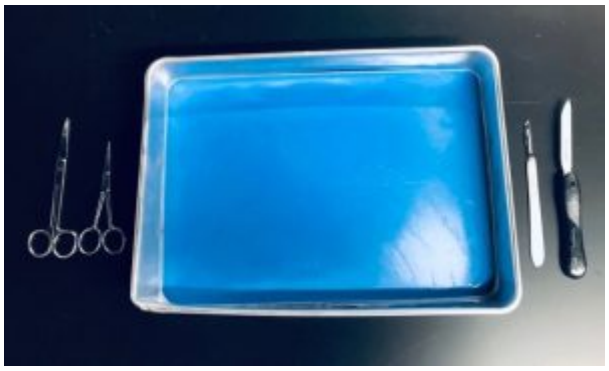
Lateral view of the right eye

Anterior view of the right eye

Exercise 2 Cow eye dissection

Required Materials (Provided)

- Preserved cow's eye
- Single-edged razor blade or scalpel
- Dissection scissors
- Dissection tray
- Forceps
- Gloves
- Paper towels
- Plastic trash bag
- Ox eye bismount model



Procedure

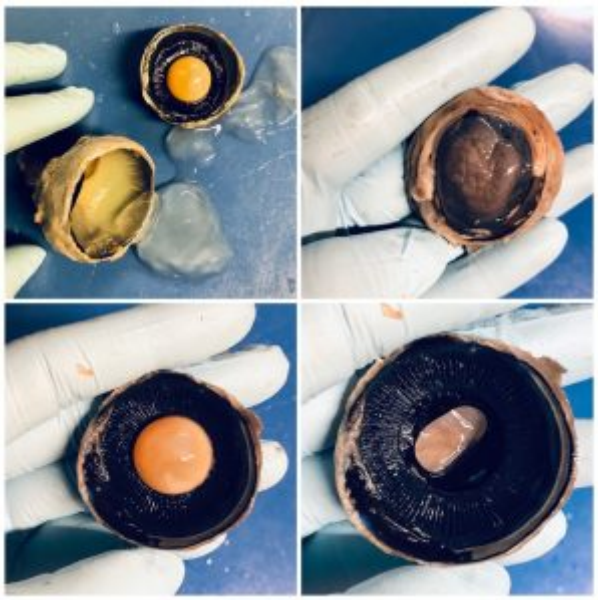
1. The cow eyes functionally and structurally similar to the human eye. During this activity, you will dissect a cow eye, identify several structures of a cow eye and learn their functions.
2. Your goal is to dissect and identify and describe external and internal eye structures on a dissected eye.
3. As you go through the procedure of dissection below, take pictures so you can insert them in the

space provided and label them to identify the main structures of the eye.

4. You will complete this activity in dissection lab as group of 3-4. Please read the following steps carefully before you begin and while doing dissection.

    - Put on your personal protective gloves and get a cow eye from your TA.
    - Place the preserved cow eye on a dissecting tray.
    - Examine the external features of the eye.
    - Cut away all the thick fat and the muscle surrounding the eyeball. Avoid cutting the tough optic nerve on the back of the eye.

    - Remove the vitreous humor and lens from the anterior portion of the eye to examine the iris and pupil.



- Compile the pictures of the eye you took as you dissected it, insert the pictures below and label the eye structures.

Exercise 3 Identify and label ear structures on a model or diagram

Required Materials

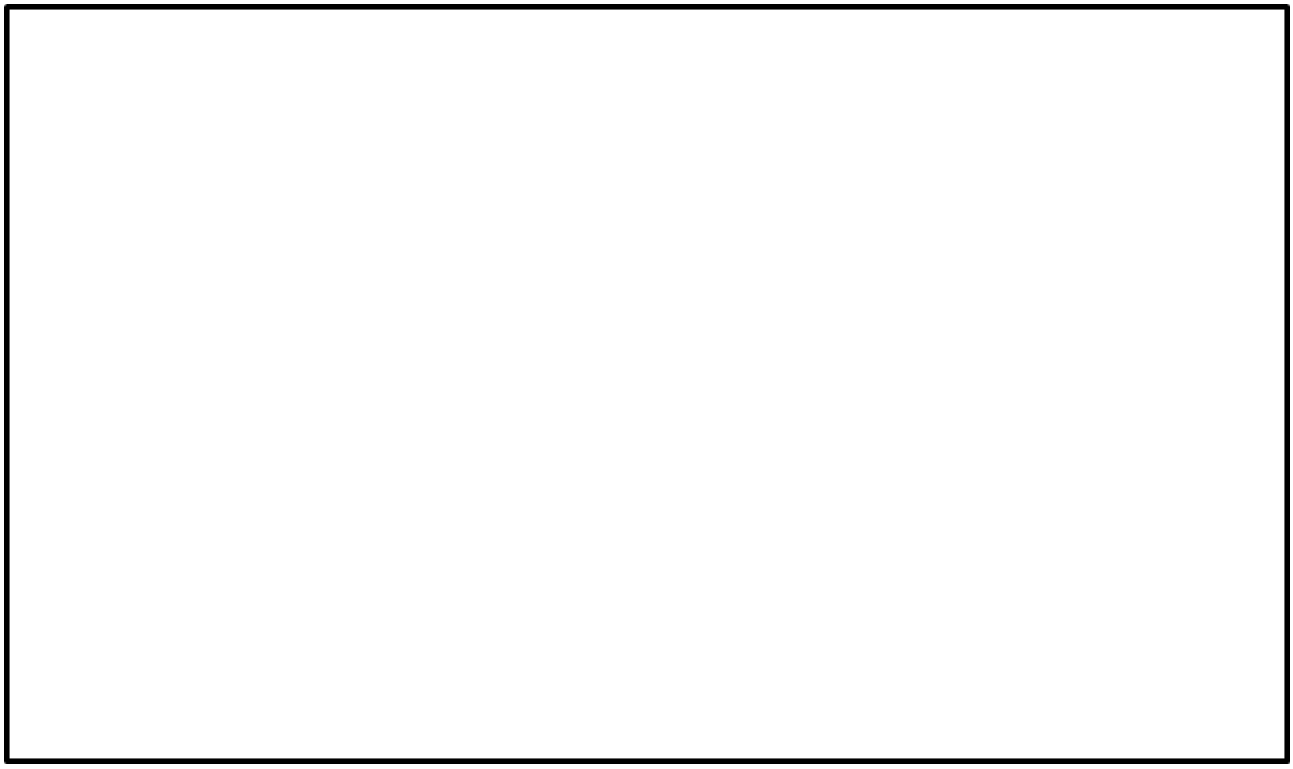
- Colored tape or post-it notes
- Sharpie or marker
- Ear models

Procedure

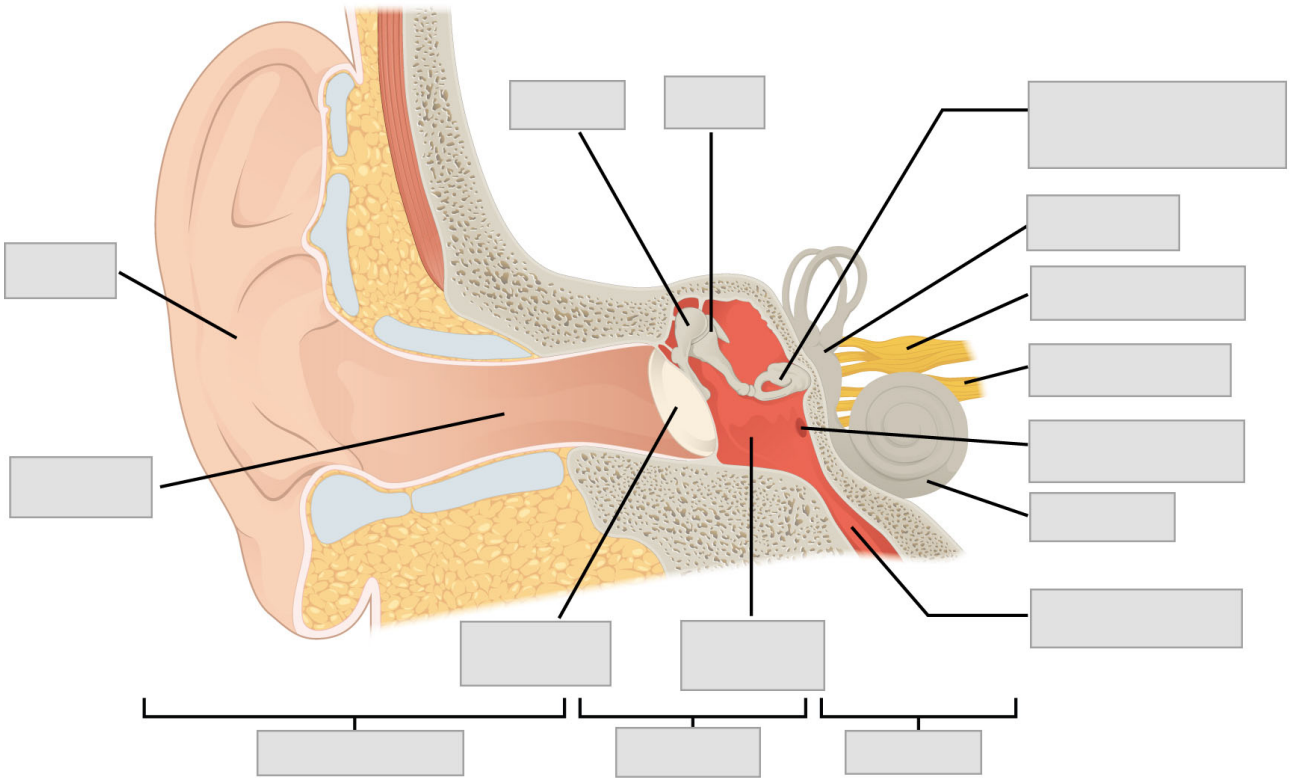
1. This activity requires you to label the structures of the ear on a model. You are provided a list of terms below and you are expected to use every term provided. Using colored tape or post-it notes, please write the number that corresponds to the term from the list and place them on your model.
2. As you complete labeling the model, take pictures and insert these in the space provided below.

List of Terms:

External & Middle Ear	**Inner Ear**
Pinna (auricle) Auditory canal (external acoustic meatus) Tympanic membrane Auditory (Eustachian) tube Malleus Incus Stapes Oval window	Round window Cochlea Cochlear nerve Vestibule Anterior semicircular duct Posterior semicircular duct Lateral semicircular duct Vestibular nerve



3. Label the following figure by using the List of Terms in the table above.



Post-laboratory Questions

1. Light first enters the eye through the lens.

   True
   False

2. What is the white layer that surrounds eye?

   A. Cornea
   B. Retina
   C. Ciliary body
   D. Sclera

3. Fill in the blank with the appropriate words.

Structure	***Function***
	creates electrical impulses that are sent to the brain
External muscles	
	pigmented structure which controls diameter of pupil
Fovea	
	protects eyes against infection
Ciliary body	
	the jelly-like substance filling the central cavity of the eye
Lens	
	contains light-sensitive cells – allows us to see details clearly
Optic nerve	

4. What is the function of the inner ear?

A. Direct sound waves to the tympanic membrane.

B. Transforms sound waves into vibrations

C. Connects the middle ear with the nasopharynx

D. Transmit vibrations to the brain

5. Fill in the blank with the appropriate words.

Structure	***Function***
Vestibule	
	transmits the electrical impulses generated for hearing to brain
Pinna	
	connects the middle ear to the nasopharynx
Tympanic membrane	
	transfers the vibration of the auditory ossicles to the cochlea
Vestibular nerve	
	transforms the sound in neural impulses
Auditory canal	
	transmits the sound vibrations from the eardrum to the inner ear

15.

CHAPTER 15 THE AUTONOMIC NERVOUS SYSTEM

By Krishnan Prabhakaran

Motivation

Abnormal functioning of the autonomic nervous system can be life threatening and there is a specific term for it: **dysautonomia.** Dysregulation of the autonomic nervous system can produce the apparent malfunction of the organs it regulates. For this reason, dysautonomia patients often present with numerous, seemingly unrelated maladies.

Symptoms are wide ranging and can include problems with the regulation of heart rate, blood pressure, body temperature and perspiration. Other symptoms include fatigue, lightheadedness, feeling faint or passing out (syncope), weakness and cognitive impairment.

Autonomic dysfunction can occur as a secondary condition of another disease process, like diabetes, or as a primary disorder where the autonomic nervous system is the only system impacted. These conditions are often misdiagnosed.

Over one million Americans are impacted with a primary autonomic system disorder. The more common forms of these conditions include Postural Orthostatic **Tachycardia** Syndrome POTS / Orthostatic Intolerance OI (Figure 15.1) , Neurocardiogenic Syncope NCS, Pure Autonomic Failure PAF and Multiple Systems Atrophy MSA.

Figure 15.1 Hand of a person with Postural Orthostatic Tachycardia Syndrome (POTS) and dysautonomia exhibiting blood pooling after standing for too long in cold weather. Photo by Yitzilitt on Wikimedia Commons, license CC-BY-SA.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Compare and contrast the sympathetic and parasympathetic divisions of the nervous system
- Differentiate between the functions, target organs and neurotransmitters used by the sympathetic and parasympathetic divisions of the autonomic nervous system

Background.

The Autonomic Nervous System

The autonomic nervous system is tied into emotional responses and the fight-or-flight response sounds like a panic attack. In the modern world, these sorts of reactions are associated with anxiety as much as with response to a threat. It is engrained in the nervous system to respond like this. In fact, the adaptations of the autonomic nervous system probably predate the human species and are likely to be common to all mammals, and perhaps shared by many animals. However, the autonomic nervous system is not just about responding to threats. Besides the fight-or-flight response, there are the responses referred to as "rest and digest". The digestive system has a big job to do. Much of the function of the autonomic system is based on the connections within an autonomic, or visceral, reflex."

The Autonomic Nervous System at Work

Jayla is sitting, having an outdoor lunch with friends when a large spider lands on her plate. She immediately freezes, the food in her mouth begins to feel like a wad of dry hay, and she nearly gags as she tries to swallow it. She feels her heart race and pounding in her chest. After swallowing her food, it seems stuck in her throat and chest.

In this scenario, Jayla had been sitting, relaxed and enjoying a meal. In this relaxed state, the body would have a heart rate that is at rest, active peristalisis (activity in muscles of the digestive system), ample activity in salivary glands and in digestive gland secretions, and bronchi that are not dilated. In this relaxed state, food can be easily processed due to ample amounts of saliva and digestive enzymes in the saliva released by the salivary glands into the mouth.. Salivation also facilitates swallowing by providing lubrication to the back of the throat and the esophagus. In this relaxed state, digestive fluids and enzymes in the intestines are actively produced and secreted so that food can be further processed and broken down (catabolized) for absorption of nutrients and glucose. While relaxed, Jayla's heart beats imperceptibly and her breathing is deep.

With the sudden appearance of the spider, the rate of Jayla's heart beat becomes more rapid, and it contracts more powerfully. In this vigilant state, Jayla senses her rapid heart rate as well as the increased force of the contraction of her heart. She also senses a shift to rapid, shallow breathing that she tries to control. Her food seems lodged near the back of her throat as she struggles to swallow her food safely.

Within seconds of seeing the spider, Jayla's body systems shifted from reflecting calm to a state of panic and hyper-vigilance. These responses to the external threat prepare Jayla to either fight or flee the situation. In the hyper-vigilant state, Jayla's pupils widen, she sweats and more blood is pumped through her blood vessels which permits more blood, chemicals, and hormones to flow to her skeletal muscles and respiratory system. As you can see, the effects on organ systems when in either of the states, relaxed or hyper-vigilant, are nearly opposite. These two states are controlled by two subsets of neural pathways that are part of the peripheral nervous system.

The autonomic nervous system is divided into the sympathetic nervous system and the parasympathetic

nervous system. It is the complementarity of these two latter branches of the autonomic nervous system that drove the physiological changes in the "Spider Sat Down Beside Her" scenario above.

As evident from the impact of the sight of the spider on Jayla's ability to eat her meal, activity in the parasympathetic system is associated with a relaxing meal; on the other hand, activity in the sympathetic system is associated with alertness and vigilance. In keeping with the complementary functionality of the two systems, they have been given nick names. The parasympathetic branch works for "rest and repose" (also commonly known as "rest and digest"); the sympathetic branch is known for the "fight or flight" response (variously also known as "fight, flight or freeze;" "hyperarousal;" "acute stress").

Comparison of Somatic Motor and Autonomic Nervous Systems

FEATURE	SNS	ANS
EFFECTOR	Skeletal muscle	Glands, smooth a
GENERAL FUNCTION	Conscious or unconscious	Unconscious, affe
EFFECTOR RESPONSE	Skeletal muscle contraction	Effector stimulate
NEURON ARRANGEMENT (CNS TO EFFECTOR)	One only	Two: CNS to au (postganglionic n
CELL BODY LOCATION	Motor nuclei of cranial nerves or ventral horn of spinal cord	Preganglionic in a postganglionic in
NUMBER OF SYNAPSES	One: Between motor neuron and effector	Two: Between pr effector
AXON MYELINATION	Yes	Preganglionic = y
NEUROTRANSMITTER	Acetylcholine	Preganglionic neu Postganglionic ne
RECEPTOR TYPE	Nicotinic	Autonomic gangl Effectors =

General Information on the Autonomic Nervous System

- Consists of **motor (=efferent) neurons** and peripheral nerves that transmit to visceral effectors of the body (*e.g.*, glands, smooth muscle, cardiac muscle)
- Involves sensory neurons that function for somatic division also
- Acts automatically and involuntarily
- Functions primarily to **maintain homeostatic conditions** (mainly by autonomic reflexes, although emotions can have effects also)
- Composed of organizational network of **ganglia** which serve as synaptic centers between **preganglionic neurons** with cell bodies in CNS (transmit from CNS to ganglia) and **postganglionic neurons** with cell bodies in ganglia (transmit from ganglia to effectors)

Divisions of the Autonomic Nervous System

A. Sympathetic (=thoracolumbar) Division

General information

- "Fight-or-flight" (=energy expenditure) division
- Arises from all thoracic and first two lumbar spinal nerves

General functions

- Stimulates**:** heart rate, intestinal sphincter constriction, urinary bladder relaxation, dilation of pupils of eyes, sweat secretion, erection of hair
- Inhibits: stomach and intestinal movements, bronchial muscles

Anatomy

- Sympathetic ganglia (=vertebral) = lie on either side lateral to ventral surface of spinal cord from second cervical vertebra to coccyx (resembling a chain of beads)
    - Preganglionic neuron axons (between spinal cord and ganglion) small in diameter and myelinated = white ramus communicants
    - Usually synapse with several postganglionic neurons
- Possible *routes of exit* of sympathetic axons
    - Spinal nerves
        - Preganglionic axons synapse with postganglionic neurons at same level their axons enter sympathetic chain—**or**—may pass superiorly or inferiorly and synapse with postganglionic neurons at different levels from where their axons enter the chain
        - Postganglionic axons leave chain and pass through **gray ramus communicants** and reenter spinal nerve
        - Innervate sweat glands, smooth muscle in blood vessels of skin or bones, and arrector pili in skin
    - Sympathetic nerves
        - After preganglionic neurons synapse as described for spinal nerves, postganglionic axons leave chain in a **sympathetic nerve**
        - Innervate heart muscle, thoracic blood vessel smooth muscle, smooth muscle of esophagus and lungs and, from a sympathetic nerve plexus near the carotid artery, the head and neck sweat glands, salivary glands, smooth muscle in blood vessels, the eye, and arrector pili
    - Splanchnic nerves
        - Some preganglionic axons originating at T5-12 enter chain ganglia but exit at the same or

different level, without synapsing, as **splanchnic nerves** going to **collateral (=prevertebral) ganglia** to synapse with postganglionic neurons
        - Collateral ganglia are in the abdomen close to where major arteries (for which they are named) arise from the abdominal aorta: **celiac, superior mesenteric, and inferior mesenteric**
        - Innervate abdominopelvic structures: smooth muscle in walls of blood vessels and organs or glands (*e.g.*, pancreas, liver, prostate)
    - Innervation of adrenal medulla
        - Composed only of preganglionic neurons whose axons synapse with cells of adrenal medulla
        - Eighty percent of cells secrete **epinephrine** and twenty percent secrete **norepinephrine** into blood stream
        - Enhances and prolongs effect of sympathetic division; permits effect to reach organs otherwise not involved (due to lack of sympathetic innervation)

B. Parasympathetic Division (=craniosacral)–think "vagus"

General information

- "Repose-and-repair" (=restorative)
- Arises from brainstem nuclei and S2-S4

General functions

- initiates **effects generally antagonistic to sympathetic division**

Anatomy

- **Parasympathetic (=terminal) ganglia** = lie in or near their effectors (preganglionic axons tend to synapse with only one or few postganglionic neurons)
- **Nerves**
    - Oculomotor = smooth muscles in eyes
    - Facial and glossopharyngeal = salivary glands
    - Vagus (contains 75% of all parasympathetic fibers) = heart, lungs, esophagus, stomach, pancreas, liver, small intestine, and upper colon
    - S2-S4 = urinary bladder, lower colon, rectum, and reproductive organs

Physiology of the Autonomic Nervous System

Neurotransmitters

- **Acetylcholine**
  - Secreted by **cholinergic axons**
  - Includes all autonomic preganglionic axons and all parasympathetic postganglionic axons
- **Norepinephrine**
  - Secreted by **adrenergic axons**
  - Includes nearly all sympathetic postganglionic axons (**Exception** = some that innervate sweat glands)
  - *Effectors break down norepinephrine and epinephrine **more slowly** than acetylcholine; therefore, the effects of these neurotransmitters **last longer than acetylcholine**.

Receptors

  - **Cholinergic** = respond to acetylcholine
    - **Nicotinic**
      - Always leads to **excitatory response**
      - All autonomic postganglionic neurons and skeletal muscle cells
    - **Muscarinic**
      - may be **excitatory** (*g.*, smooth muscle in wall of stomach) or **inhibitory** (*e.g.*, heart muscle)
  - **Adrenergic** = respond to norepinephrine or epinephrine
  - o **Types**
    - **Alpha (α)**
    - **Beta (ß)** = more sensitive to epinephrine than to norepinephrine
      - ***Beta blockers** bind beta receptors to reduce rate and strength of heart contraction; this, in turn, reduces blood pressure.
  - o **Responses** = may be inhibitory or excitatory in either case
    - Norepinephrine **excitatory** at beta receptors in heart muscle but **inhibitory** at beta receptors in stomach wall smooth muscle
    - Epinephrine from adrenal medulla stimulates both alpha and beta receptors about equally, but norepinephrine stimulates alpha more than beta

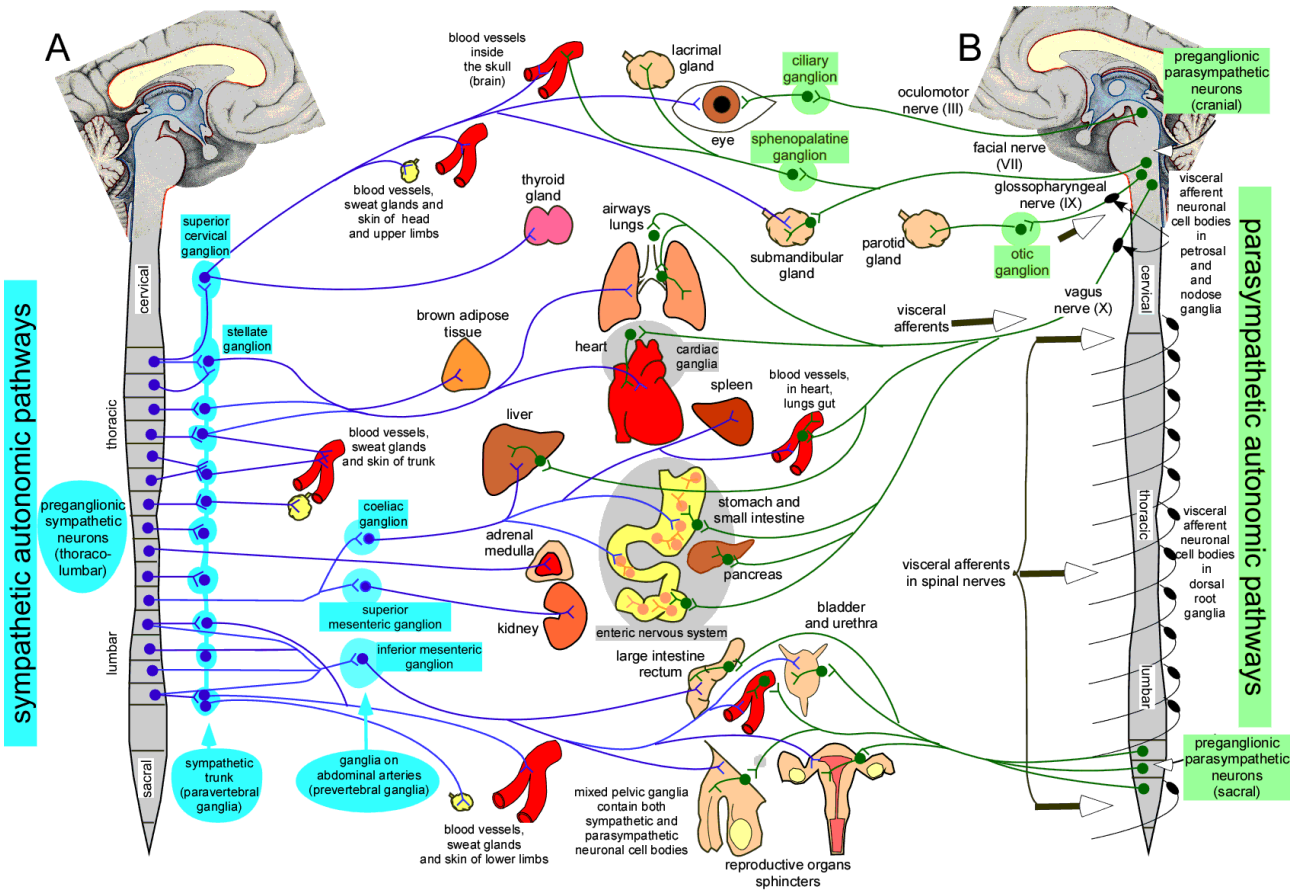


Figure 15.2 The Autonomic Nervous System. Sympathetic (left) and parasymathetic (right) pathways. Credit: Scholarpedia, http://www.scholarpedia.org/article/File:Autonomic_nervous_system_main_figure_Blessing.gif, license CC-BY-NC-SA

Pre-Laboratory Questions

1. The sympathetic nervous system is referred to as the thoracolumbar system because its postganglionic neurons lie in the lateral horn of the spinal cord at thoracic and lumbar levels.
   a. True
   b. False
2. Preganglionic neurons of the parasympathetic nervous system.
   a. extend long axons to reach postganglionic neurons
   b. originate at sacral levels
   c. synapse close to the vertebral column at cervical levels
   d. originate from brainstem
   e. all are correct except answer c
3. Postganglionic neurons of the sympathetic nervous system receive input from all of the following sources except
   a. preganglionic neurons in the lateral horn of all levels of the spinal cord

b. preganglionic neurons that synapse in the sympathetic chain
c. preganglionic neurons that originate in the lumbar level of the spinal cord
d. preganglionic neurons that pass through the sympathetic chain without synapsing
e. all of the above are correct, no exceptions

4. A pre-ganglionic neuron of the sympathetic nervous system will synapse in the dorsal root ganglion chain.
   a. true
   b. false
5. Postganglionic neurons are arranged as a chain along side the spinal vertebral column
   a. sympathetic nervous system
   b. parasympathetic nervous system
   c. both
   d. neither

Exercises

- Exercise 1 Identification of the autonomic divisions
- Exercise 2 Problem solving: Acetylcholine's autonomic effects

Exercise 1: Identification of the autonomic divisions

Place an "**X**" to show which division is involved for each of the following:

CONDITION	SYMPATHETIC	PARASYMPATHETIC
Adrenergic fibers		
Postganglionic fibers cholinergic		
Long preganglionic/short postganglionic axons		
Short preganglionic/long postganglionic axons		
Derived from cranial and sacral nerves		
Derived from spinal nerves T1 to L3		
Repose-and-repair division		
Fight-or-flight division		
Control more specific		
Dry mouth and bronchiolar dilatation		
Constricts eye pupils and decreases HR		

MATCH the following to sympathetic (**S**) division, parasympathetic (**P**) division, (**B**) both, or (**N**) neither:

1. _____ Terminal ganglia
2. _____ Craniosacral outflow
3. _____ Two-neuron efferent chain
4. _____ Adrenergic fibers
5. _____ Cervical ganglia
6. _____ Otic and ciliary ganglia
7. _____ Increases HR, respiratory rate, and BP
8. _____ Increases gastric motility and lacrimal secretion
9. _____ Active when you are relaxing in a hammock
10. _____ Innervation of skeletal muscles
11. _____ Active when you are competing in the Boston Marathon
12. _____ Nerve cell bodies in ganglia

Exercise 2: Problem solving: Acetylcholine's autonomic effects

We have a problem solving activity using a patient's case and this is presented in multiple-choice format.

Consider each choice individually and write an argument for accepting or rejecting it. Since the problem has one best answer, you will write one argument for acceptance and four for rejection.

For each response, first state whether you are accepting or rejecting that statement. Then, write a detailed explanation of why you accept or reject each of the choices.

PROBLEM:

Mr. A. Prentice has been suffering from functional urinary retention and a hypoactive urinary bladder.

Bethanechol, a drug that mimics acetylcholine's autonomic effects, is prescribed to manage his problem. Which of the following **adverse effects** might Mr. Coral experience while taking this drug?

A. Dry eyes due to deficient tear formation.

B. Deficient salivation.

C. Constipation.

D. Decreased sexual arousal.

E. Diarrhea

Post-laboratory Questions

1. A presynaptic parasympathetic neuron may reach its target organ by which mechanism?
   a. Passing through a sympathetic ganglion without synapsing and accompanying sympathetic fibers to reach its target.
   b. Synapsing in a sympathetic ganglion and joining the course of the postsynaptic sympathetic nerve to reach its target.
   c. Joining the course of an unrelated nerve to reach its target.
   d. Traveling directly to its target with its original nerve.
2. Sympathetic signals to smooth muscles of blood vessels of arms and legs will be sent via which neurotransmitters?
   a. ACh, then norepinephrine
   b ACh, then ACh
   c. Epinephrine, then norepinephrine
   d. Norepinephrine, then ACh
3. The effects of the sympathetic nervous system are often more generalized and widespread than the effects of the parasympathetic nervous system (which tend to be more specific and localized). How does the anatomy of the sympathetic nervous system provide for more widespread effects?

4. Why do we feel cold when facing a “fight or flight” situation?

5. Describe major parasympathetic and sympathetic physiological effects on target organs.

16.

CHAPTER 16 THE NEUROLOGICAL EXAM

By Krishnan Prabhakaran

Motivation.

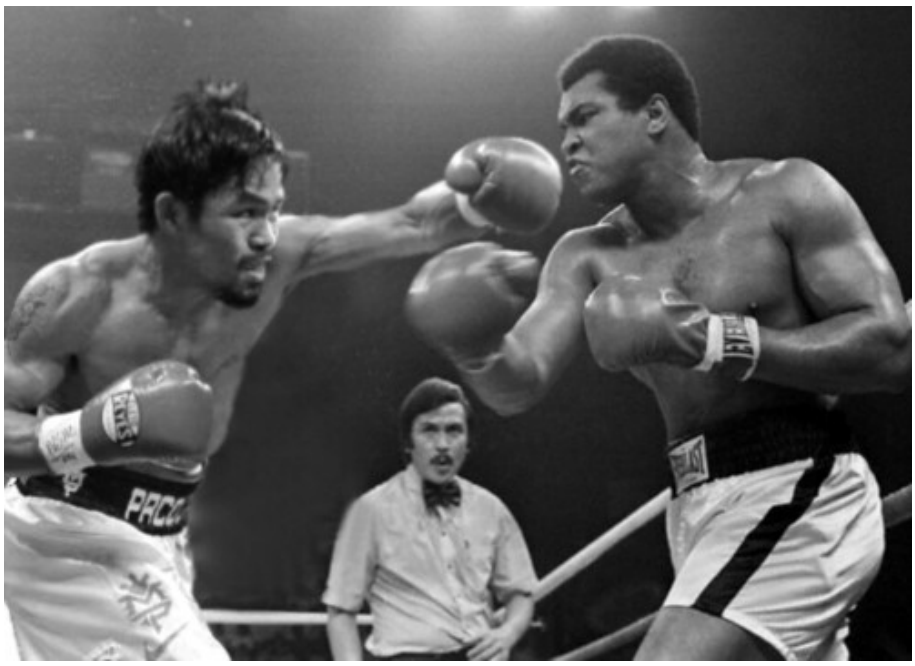


Figure 16.1 Head trauma, concussion, or traumatic brain injury can be experienced upon forceful impact to the head. Picture: Manny Pacquiao vs. Mohammad Ali boxing legend. Credit: mario on flickr, license CC BY-NC

Head trauma and concussions can happen to adults and children alike. There are countless different ways in which traumatic brain injuries can occur: a direct physical blow to the head, falling on the ground, or a car accident – among many other possibilities.

However, concussions can also happen even when there is no direct blow to the head. In some cases, a concussion can even happen with simple sudden movements or jolts, and these "minor" concussions often go undetected and undiagnosed. Even when caused by a

direct blow to the head, most concussions don't lead to a loss of consciousness and are left untreated.

Each concussion is different, and not everyone exhibits the same symptoms. The best way to recognize and assess the extent of a concussion is to get a neurological exam by a clinical neuroscience practitioner. Here is what you can expect.

There are many types of neurological assessments that licensed practitioners will do with their patients. Neurological assessments are the most effective way of recognizing and analyzing concussions. In most cases, doctors will use a special brain imaging techniques like CT or MRI scans to look for brain abnormalities.

Unfortunately, CT & MRI scans are often ineffective in recognizing concussions because most lesions in the brain caused by a head trauma are too small to be identified by these types of scans. This is why neurological assessments are a fundamental tool in understanding the effects of a head trauma as a whole and can evaluate just how extensive the damage is.

Common neurological assessments include:

- Assessing mental capacity & status
- Pupil size assessment
- Sensory exams
- Pupil reactivity assessment
- Blood pressure measurement
- Handgrip strength assessment
- Motor function & balance exercises
- Pulse measurements
- Respiration assessment

In most cases, these neurological assessments last around an hour. They are non-invasive and don't involve any brain stimulants. Sometimes people might not feel any initial symptoms after a traumatic brain injury. This is why it's generally a good idea to visit a practitioner and go through the examination to make sure everything is in good order.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Describe the mental status exam and perform simple tests to determine brain function
- Perform sensory and motor exams (e.g. sight, eye movement) to determine cranial nerve function
- Utilize sensory and motor exams to determine the health of spinal cord functions
- Perform coordination and gait exams as indicators of cerebellar integration of neuronal function

Background.

A. Overview of the Neurological Exam

The **neurological exam** is a clinical assessment tool used to rapidly determine which specific parts of the CNS are affected by damage or disease. The exam can be broken down into the following subsets:

- **Mental Status Exam** = assesses the higher cognitive functions such as memory, orientation, and language.
- **Cranial Nerve Exam** = tests the function of the 12 cranial nerves and, therefore, the central and peripheral structures associated with them.
- **The Sensory Exam** = tests the sensory functions associated with the spinal nerves.
- **The Motor Exam** = tests the motor functions associated with the spinal nerves
- **The Coordination Exam** = tests the ability to perform complex and coordinated movements. **The Gait Exam** = specifically assesses the motor function of walking and can be considered part of the coordination exam because walking is a coordinated movement.

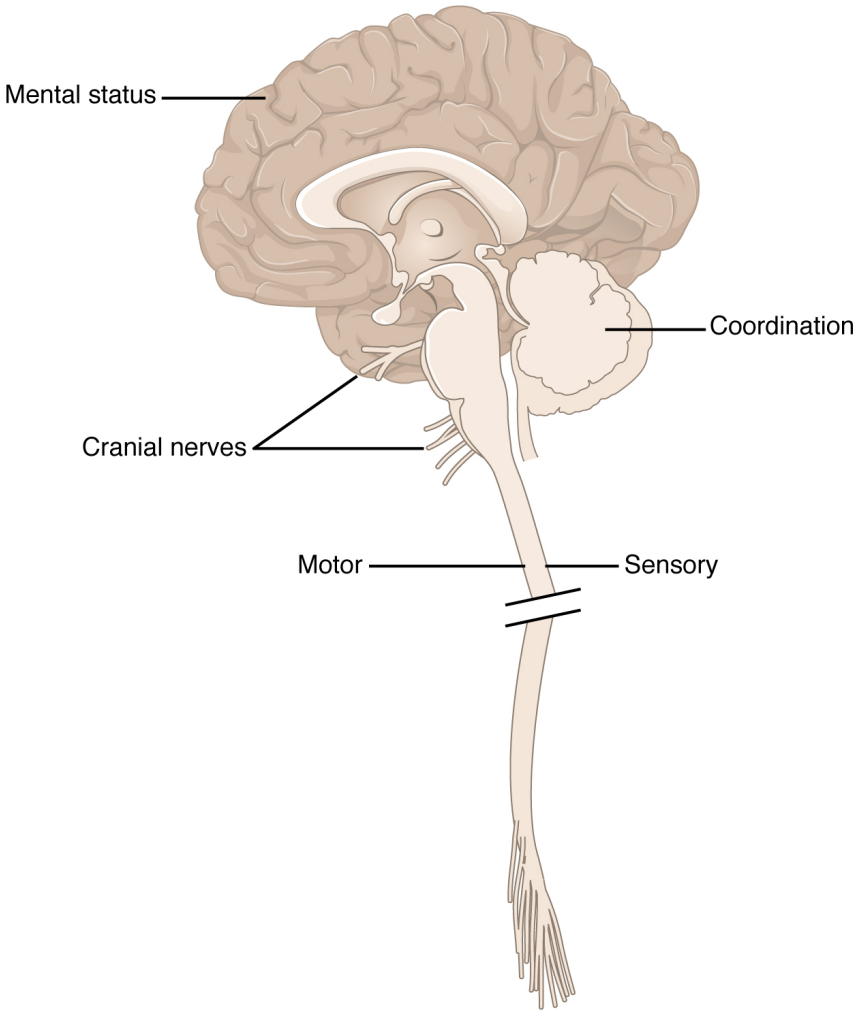


Figure 16.2 Anatomical Underpinnings of the Neurological Exam. The different regions of the CNS relate to the major sections of the neurological exam: the mental status exam, cranial nerve exam, sensory exam, motor exam, and coordination exam (including the gait exam).

B. Causes of Neurological Deficits

1. **Stroke** also called **CVA** cerebrovascular accident= the loss of blood flow to a part of the brain. There are different types of stroke as indicated below.

- **Ischemic stroke** = the loss of blood flow to an area because vessels are blocked or narrowed. This is often caused by an embolus (blood clot or fat deposit), thickening of the vessel wall or drop in blood volume = **hypovolemia**. **Transient ischemic attack (TIA)** is similar to an ischemic stroke, but symptoms are resolved within 24 hours.
- **Hemorrhagic stroke** = bleeding into the brain because of a damaged blood vessel. Accumulated blood fills in a region of the cranial vault and presses against the tissue in the brain. This pooling blood causes secondary symptoms such as loss of function, pressure on neighboring arteries resulting in a larger damage area, potentially compromising the blood-brain barrier resulting in additional

fluid on brain = **edema**.

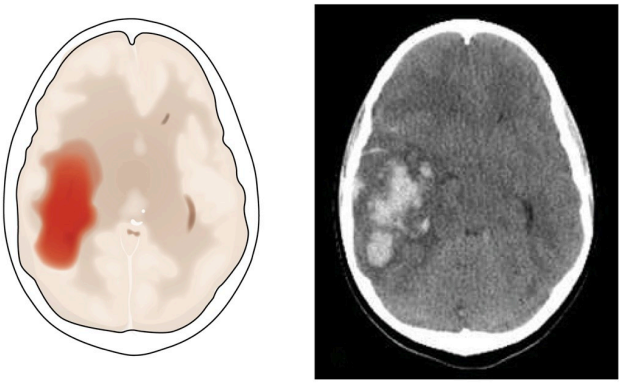


Figure 16.3 Hemorrhagic Stroke (a) A hemorrhage into the tissue of the cerebrum results in a large accumulation of blood with an additional edema in the adjacent tissue. The hemorrhagic area causes the entire brain to be disfigured as suggested here by the lateral ventricles being squeezed into the opposite hemisphere. (b) A CT scan shows an intraparenchymal hemorrhage within the parietal lobe. (credit b: James Heilman)

2. **Blunt force trauma** can cause neurological deficits (Figure 16.1).
3. **Neurodegenerative diseases, developmental, and other disorders**

- **Alzheimer's disease** = a progressive disorder characterized by the loss of higher cerebral functions and is the most common cause of senile dementia or senility. Symptoms may appear at 50 – 60 years or age. Associated with ACh shortages, shrinkage of the gyri, and formation of neural tangles among the CNS neurons and Alzheimer plaques within the cerebrum.
- **Parkinson's disease** = neurodegenerative disorder of the substantia nigra resulting in decreased production of dopamine. The basal nuclei become more active, which raises skeletal muscle tone and produces rigidity and stiffness. Individuals, with Parkinson disease have difficulty starting voluntary movements, because opposing muscle groups do not relax; they must be overpowered. Once a movement is underway, every aspect must be voluntarily controlled through intense effort and concentration.
- **Huntington's disease** = genetic disorder of the basal nuclei result in too much movements. occurs 1 in 20,000 births and is the result of a dominant gene located on chromosome 4. Causes a progressive neurological degeneration leading to death within 20 years from onset of symptoms. Symptoms show in 20s or 30-40 years of age.
- **Amyotrophic Lateral Sclerosis (ALS)** = progressive, degenerative disorder that affects the motor neurons in the spinal cord, brain stem, and cerebral hemispheres. The degeneration affects both upper and lower motor neurons. Because a motor neuron and its dependent muscle fibers are so

intimately related, the destruction of the CNS neurons causes atrophy of the associated skeletal muscles.

- **Rabies** – A bite from a rabid animal injects the rabies virus into the peripheral tissues, where virus particles quickly enter the synaptic knobs. Retrograde flow then carries the virus into the CNS, with potential fatal consequences. Many toxins (including heavy metals), some pathogenic bacteria, and other viruses also bypass CNS defenses by exploiting axoplasmic transport.
- **Multiple Sclerosis (MS)** = autoimmune disease causing deterioration of the myeline that affects axons in the optic nerve, brain, and spinal cord. MS results in paralysis and potentially death. The disorder is progressive and functional impairment increases following each new incident. Women are 1.5 times more likely to have MS than men.
- **Cerebral Palsy** – refers to a number of disorders that affect voluntary motor performance; they appear during infancy or childhood and persist throughout the life of affected individuals. The cause may be trauma associated with premature or unusually stressful birth, maternal exposure to drugs, or a genetic defect that causes the improper development of motor pathways.
- **Referred Pain** – the sensation of pain in a part of the body other than its actual source.

Pre-Laboratory Questions

1.The neurological exam is an assessment tool used to rapidly determine which parts of the CNS are affected using 5 different exams _____, _____, _____, _____, and _____.

2. Bleeding into the brain due to a damaged blood vessel is called a _____ _____.

3. _____ disease is a progressive degenerative disease caused by degeneration of the substantia nigra resulting in stooping, rigidity, stiffness and tremors.

4. The three cranial nerves that transmit gustatory impulses are the _____, _____, and _____.

5. All three nerves transmitting gustatory impulses travel through the _____ and is why gag and vomiting reflexes are triggered when we experience something distasteful.

6. The primary gustatory area is located in which part of the brain? _____

7. The loss of taste sensation is called _____.

8. Olfactory sensation reaches the brain via which cranial nerve? _____

9. Brain disorders can distort the sense of smell so that olfactory hallucinations occur. Transient _____ _____ occur in some epileptics just before they have a seizure.

10. The _____ test uses a tuning fork placed on the top of the skull to determine sensorineural hearing.

Exercises

- Exercise 1 The Mental Status Exam
- Exercise 2 The Cranial Nerve Exam
- Exercise 3 The Sensory and Motor Exams
- Exercise 4 Coordination and Gait Exams

Exercise 1 The Mental Status Exam

This exam probes the functions of the cerebral cortex.

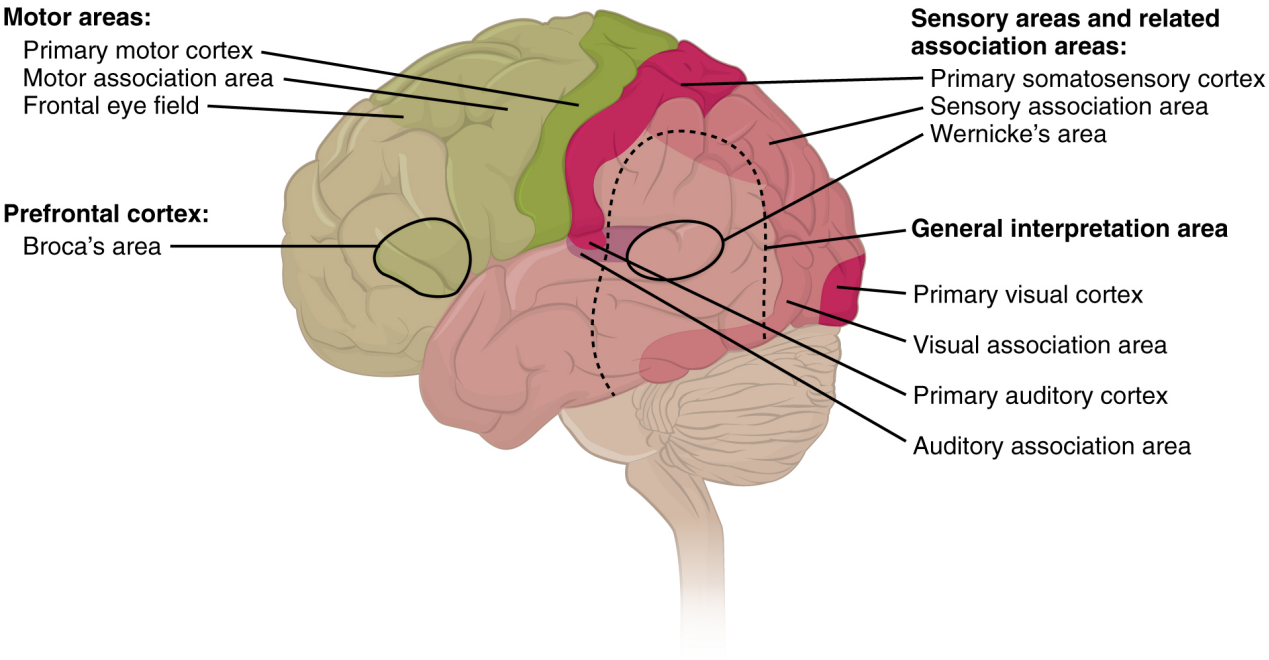


Figure 16.4 Types of cortical areas. The cerebral cortex can be described as containing three types of processing regions: primary, association, and integration areas. The primary cortical areas are where sensory information is initially processed, or where motor commands emerge to go to the brain stem or spinal cord. Association areas are adjacent to primary areas and further process the modality-specific input. Multimodal integration areas are found where the modality-specific regions meet; they can process multiple modalities together or different modalities on the basis of similar functions, such as spatial processing in vision or somatosensation

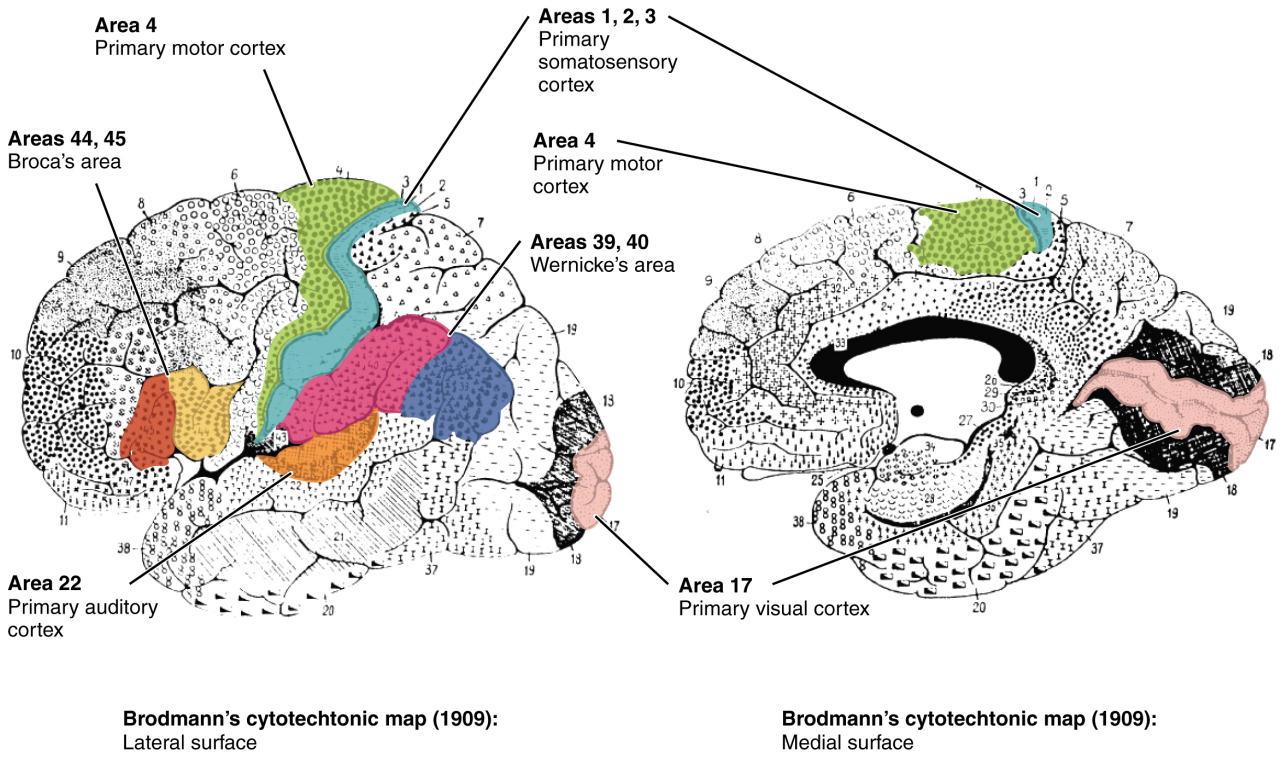


Figure 16.5 Brodmann's Areas of the Cerebral Cortex On the basis of cytoarchitecture, the anatomist Korbinian Brodmann described the extensive array of cortical regions, as illustrated in his figure. Subsequent investigations found that these areas corresponded very well to functional differences in the cerebral cortex. (credit: modification of work by "Looie496"/Wikimedia Commons, based on original work by Korvinian Brodmann

The cerebrum is the seat of many of the higher mental functions, such as memory and learning, language, and conscious perception, which are the subjects of subtests of the mental status exam. As discussed in Ch. 13 the cerebrum is a thin layer of gray material about 1 mm thick that is highly folded. Brodmann first described about 50 different regions of the cerebrum that correspond to their various functions. There are three types of processing regions:

- **Primary** = The primary cortical areas are where sensory information is initially processed, or where motor commands emerge to go to the brain stem or spinal cord.
- **Association** = Association areas are adjacent to primary areas and further process the modality-specific input.
- **Integration** areas = Multimodal integration areas are found where the modality-specific regions meet; they can process multiple modalities together or different modalities on the basis of similar functions, such as spatial processing in vision or somatosensation. Example of picking up a glass and based on what is in it determines what body movements we make.

Required Materials

- Your classmates
- Dull pointer such as a pen cap
- Any object for recognizing by touch

Procedure

1. **Cognitive Abilities:** In this exercise, you will use some of the commonly used practices to test for cognitive abilities. You can practice asking these questions and noting the answers using one of your group mates as a "patient". Use pen and paper (or iPad notebook etc.) to record your questions and answers.

- Orientation and Memory
  - **Orientation** = the patient's awareness of his or her immediate circumstances.
    - **Awareness of time** = date. "Do you know what day it is?"
    - **Awareness of place** = location of where they are and why as well as who they are. "Do you know where you are?," "What is your name?," "Who is the current president?"
  - **Memory** = the patient's ability to recall information. Memory is largely a function of the temporal lobe, along with structures beneath the cerebral cortex such as the hippocampus and the amygdala. Amnesia can be defined as losing memories of events of the past **retrograde amnesia** or inability to make future memories **anterograde amnesia.** Short term memory can be assessed using the three-word test. Patients are given three words (ex. Book, clock, train) and after a brief time period are asked to recall the three words.
- Language and Speech
  - **Language** is at the core of what it means to be self-aware. Asking the patient to perform a set of actions can assess the ability to understand language. "Use you right pointer finger to touch the tip of your nose and then your left elbow." Often, language deficits can be determined without specific subtests; if a person cannot reply to a question properly, there may be a problem with the reception of language. **Aphasia** is the loss or speech or language.
  - **Speech**
    - **Broca's area** = responsible for speech production. **Expressive aphasia** = speech production is compromised leading to broken or haulted speech with incorrect grammar usage.
    - **Wernicke's area** = responsible for processing or understanding speech. **Receptive aphasia** = patients do not understand what is said to them or what they are saying even when they are talking.
    - **Conduction aphasia** = patient's inability to connect understanding of speech to production of speech. Symptoms include inability to faithfully repeat spoken language.
    - **Sensorium** = the parts of the brain involved in reception and interpretation of sensory stimuli. From the primary cortical areas of the somatosensory, visual, auditory, and gustatory senses to the association areas that process information in these modalities, the

cerebral cortex is the seat of conscious sensory perception. Two subtests assess specific functions of these cortical areas.

- **Praxis** = a practical exercise in which the patient performs a task completely on the basis of verbal description without any demonstration from the examiner. For example, the patient can be told to take their left hand and place it palm down on their left thigh, then flip it over so the palm is facing up, and then repeat this four times.
- **Gnosis** – sensory perception involving two processes.
  - **Stereognosis** = involves the naming of objects strictly on the basis of the somatosensory information that comes from manipulating them with their eyes closed, e.g. by touch
  - **Graphesthesia** = recognize numbers or letters written on the palm of the hand with a dull pointer, such as a pen cap.

- **Judgment and Abstract reasoning** = Making judgments and reasoning in the abstract are necessary to produce movements as part of larger responses. "When your alarm goes off, do you hit the snooze button or jump out of bed?" Is 10 extra minutes in bed worth the extra rush to get ready for your day? Will hitting the snooze button multiple times lead to feeling more rested or result in a panic as you run late? The prefrontal cortex is related to personality.

Exercise 2 The Cranial Nerve Exam

Required Materials

- Your classmates
- Eye Exam or Snellen Chart
- Tuning forks
- Cotton tipped applicator
- Pen or pencil

Procedure

The Cranial Nerve Exam allows directed tests of forebrain and brain stem structures. Follow the instructions for testing or try to come up with ways in which you could given the definitions of nerve function. Record what you tested and the results.

- *The olfactory nerve (CN I)* receives sense of smell. How can you test this?
- *Optic nerve (CNII)* receives sense of vision. Testing vision relies on the tests that are common in an optometry office such as the **Snellen chart.** Testing the extent of the visual field means that the examiner can establish the boundaries of peripheral vision as simply as holding their hands out to either side and asking the patient when the fingers are no longer visible without moving the eyes to

track them. Physical inspection of the optic disk, or where the optic nerve emerges from the eye, can be accomplished by looking through the pupil with an ophthalmoscope.

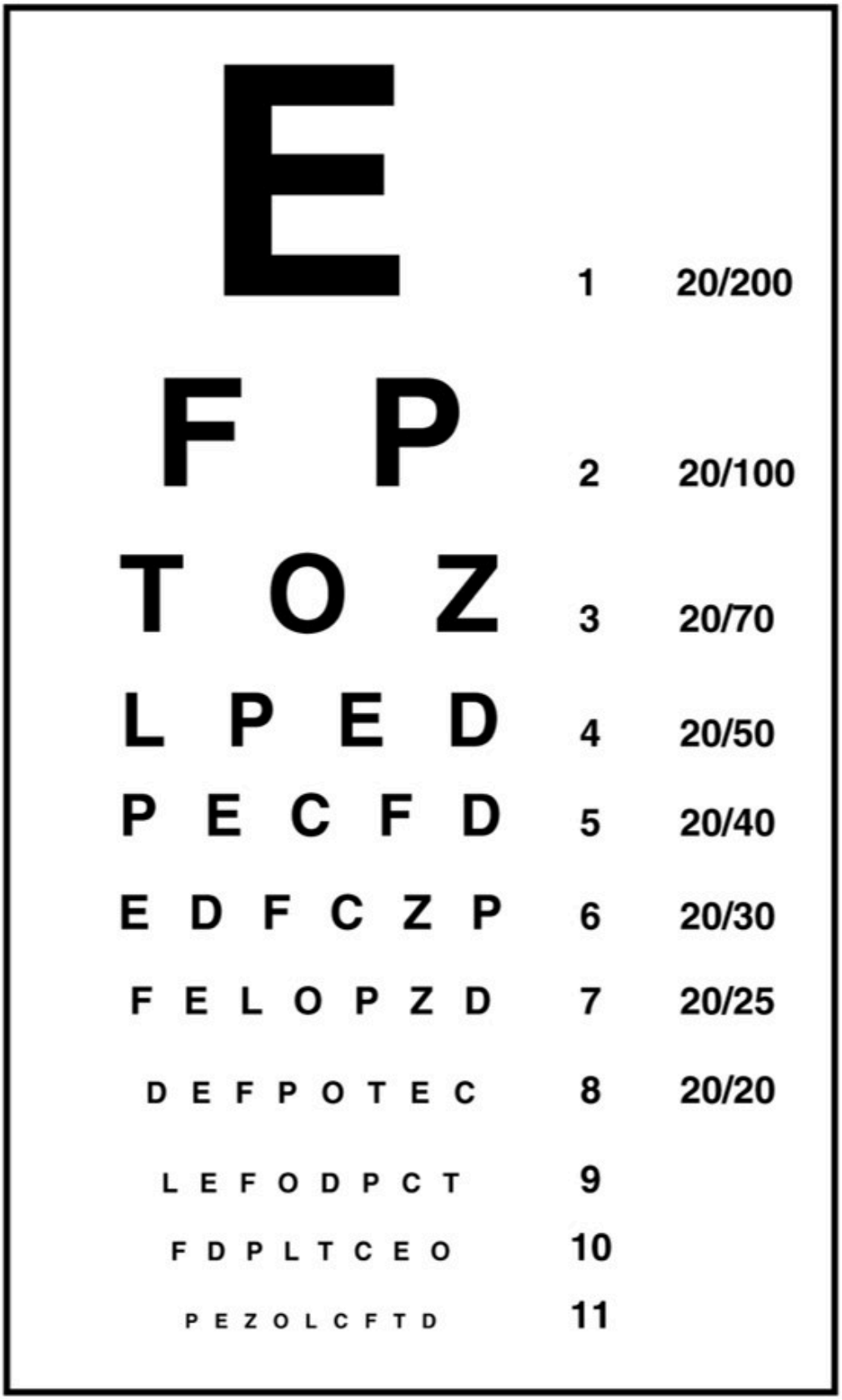


Figure 16.6 The Snellen Chart The Snellen chart for visual acuity presents a limited number of Roman letters in lines of decreasing size. The line with letters that subtend 5 minutes of an arc from 20 feet represents the smallest letters that a person with normal acuity should be able to read at that distance. The different sizes of letters in the other lines represent rough approximations of what a person of normal acuity can read at different distances. For example, the line that represents 20/200 vision would have larger letters so that they are legible to the person with normal acuity at 200 feet

- *Vestibulocochlear nerves (CN VIII)* receives sense of equilibrium and hearing. Problems with balance, such as vertigo, and deficits in hearing may both point to problems with the inner ear. Problems with hearing can be assessed using a tuning fork to determine types of hearing loss:
    - **Conductive hearing**= relies on vibrations being conducted through the ossicles of the middle ear.
        - The **Rinne test** uses a vibrating tuning fork is placed on the mastoid process and the patient indicates when the sound produced from this is no longer present. Then the fork is immediately moved to just next to the ear canal so the sound travels through the air. If the sound is not heard through the ear, meaning the sound is conducted better through the temporal bone than through the ossicles, a conductive hearing deficit is present.
    - **Sensorineural hearing** = relies on the transmission of sound stimuli through the neural components of the inner ear and cranial nerve.
        - The **Webber test** also uses a tuning fork to differentiate between conductive versus sensorineural hearing loss. In this test, the tuning fork is placed at the top of the skull, and the sound of the tuning fork reaches both inner ears by travelling through bone. In a healthy patient, the sound would appear equally loud in both ears. With unilateral conductive hearing loss, however, the tuning fork sounds louder in the ear with hearing loss. This is because the sound of the tuning fork has to compete with background noise coming from the outer ear, but in conductive hearing loss, the background noise is blocked in the damaged ear, allowing the tuning fork to sound relatively louder in that ear. With unilateral sensorineural hearing loss, however, damage to the cochlea or associated nervous tissue means that the tuning fork sounds quieter in that ear.

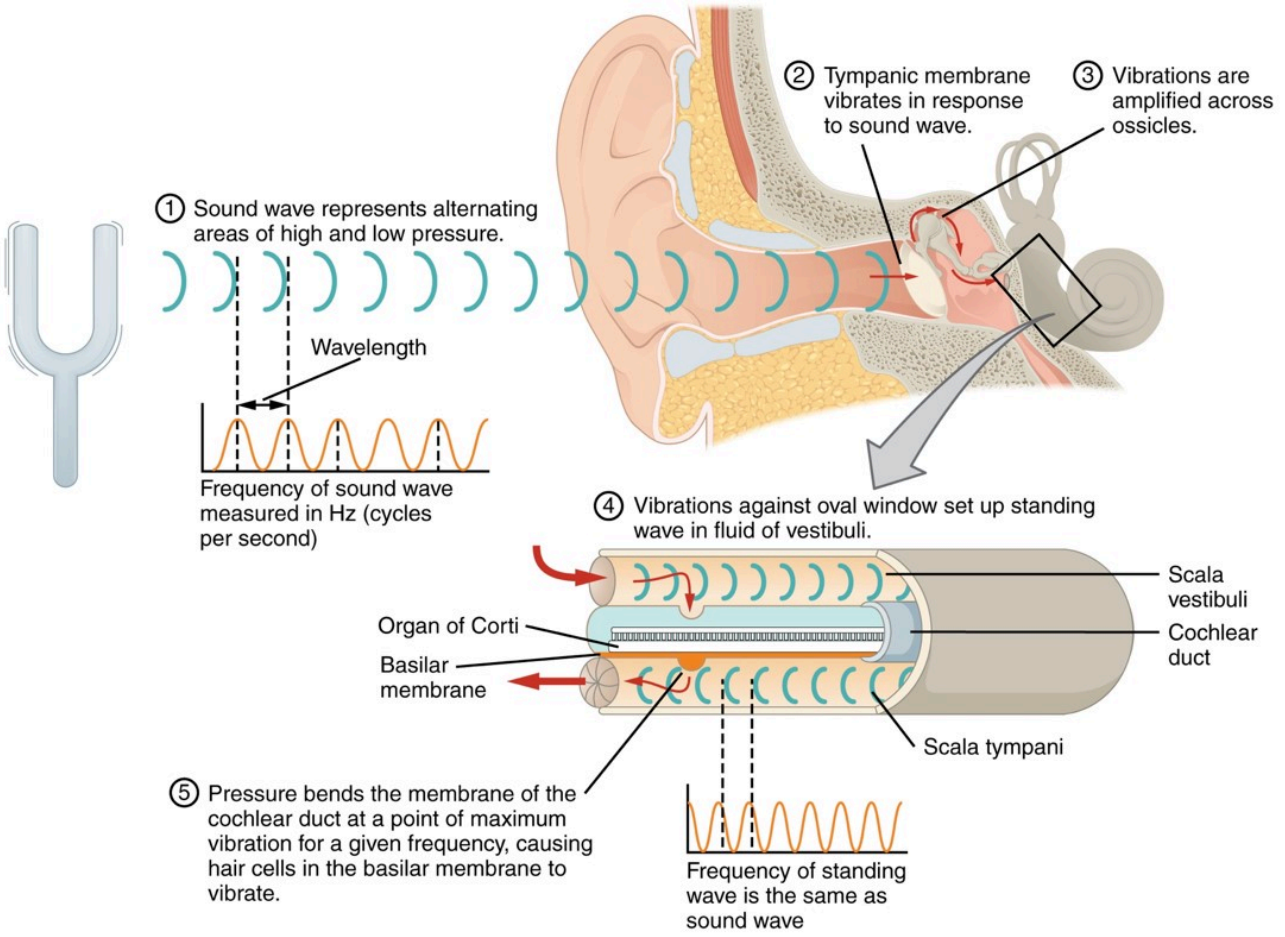


Figure 16.7 Transmission of Sound Waves to Cochlea (Rinnes and Webber test) A sound wave causes the tympanic membrane to vibrate. This vibration is amplified as it moves across the malleus, incus, and stapes. The amplified vibration is picked up by the oval window causing pressure waves in the fluid of the scala vestibuli and scala tympani. The complexity of the pressure waves is determined by the changes in amplitude and frequency of the sound waves entering the ear.

- Taste sensation is relayed to the brain stem through fibers of the *facial (CN VII)* and *glossopharyngeal nerves (CN IX)* and the *vagus nerve (X)*. How would you test this function?
- *The trigeminal nerve (CN V)* is a mixed nerve that carries the general somatic senses from the head, similar to those coming through spinal nerves from the rest of the body. The primary sensory subtest for the trigeminal system is sensory discrimination. A cotton-tiped applicator, which is cotton attached to the end of a thin wooden stick, can be used easily for this. The wood of the applicator can be snapped so that a pointed end is opposite the soft cotton-tipped end. The cotton end provides a touch stimulus, while the pointed end provides a painful, or sharp, stimulus. While the patient's eyes are closed, the examiner touches the two ends of the applicator to the patient's face, alternating randomly between them. The patient must identify whether the stimulus is sharp or dull.
- Gaze Control. The three nerves that control the extraocular muscles are the:
  - *Oculomotor (CN III)* – Movement of eyelid and eyeball (via superior rectus, inferior rectus, medial rectus, and inferior oblique), shape of lens, contracts pupil size
  - *Trochlear (CN IV)* – Movement of eye by the superior oblique

    - *Abducens (CN VI)* – Movement of the eyeball by the lateral rectus
- Gaze Control. The types of movements that are tested are:
    - **Saccades** = rapid, conjugate movements of the eyes to survey a complicated visual stimulus, or to follow a moving visual stimulus. Testing eye movement is simply a matter of having the patient track the tip of a pen as it is passed through the visual field.
    - **Diplopia**, or double vision, as the two eyes are temporarily pointed at different stimuli.
    - **Convergence** = when the two eyes move to look at something closer to the face, they both adduct. To keep the stimulus in focus, the eye also needs to change the shape of the lens, which is controlled through the parasympathetic fibers of the oculomotor nerve. The change in focal power of the eye is referred to as **accommodation**. Accommodation ability changes with age; focusing on nearer objects, such as the written text of a book or on a computer screen, may require corrective lenses later in life. Coordination of the skeletal muscles for convergence and coordination of the smooth muscles of the ciliary body for accommodation are referred to as the **accommodation–convergence reflex**.
- A crucial function of the cranial nerves is to keep visual stimuli centered on the fovea of the retina. The **vestibulo-ocular reflex (VOR)** coordinates all of the components, both sensory and motor, that make this possible
- Nerves of the Face and Oral Cavity. The *facial (CN VII)* and *glossopharyngeal (CN IX)* nerves convey gustatory stimulation to the brain. The *hypoglossal nerve* is the motor nerve that controls the muscles of the tongue, except for the palatoglossus muscle, which is controlled by the *vagus nerve*. There are two sets of muscles of the tongue. The **extrinsic muscles of the tongue** are connected to other structures, whereas the **intrinsic muscles of the tongue** are completely contained within the lingual tissues.
    - Facial nerve = controls muscles controlling facial expressions, secretion of saliva by the submandibular and sublingual glands and tears by the lacrimal gland, and sensory function for taste from the anterior 2/3 of the tongue
    - Glossopharyngeal = controls secretion of saliva by the parotid glands, elevation of pharynx during swallowing, and taste.
        - **Aguesia** = loss of taste
        - **Bells Palsy** = characterized by muscle weakness that causes one half of the face to droop. Bell's palsy may be a reaction to a viral infection and usually resolves on its own within six months.
    - These nerves can be tested by sticking out the tongue and saying "ah"
- Motor Nerves of the Neck. The *accessory nerve (CN XI)* innervates the sternocleidomastoid (flex head forward and side to side) and trapezius muscles (extension and hyperextension of head as well as shrugging of shoulders).

Exercise 3 The Sensory and Motor Exams

Required Materials

- Your classmates
- Cotton tipped applicator
- Reflex hammer

Procedure

Where indicated, follow the instructions to test the sensory and motor functions mentioned.

Sensory Modalities and Location

1. Somatic senses are incorporated mostly into the skin, muscles, or tendons, whereas the visceral senses come from nervous tissue incorporated into the majority of organs such as the heart or stomach.
2. The somatic senses are those that usually make up the conscious perception of the how the body interacts with the environment.
3. The visceral senses are most often below the limit of conscious perception because they are involved in homeostatic regulation through the autonomic nervous system.
4. Testing of the senses begins with examining the regions known as dermatomes that connect to the cortical region where somatosensation is perceived in the postcentral gyrus.
5. To test the sensory fields, a simple stimulus of the light touch of the soft end of a cotton-tipped applicator is applied at various locations on the skin.
6. The **Romberg test:** The patient is asked to stand straight with feet together then after achieving balance the patient closes their eyes and has to maintain the balance.

Muscle Strength and Voluntary Movement

1. The skeletomotor system is largely based on the simple, two-cell projection from the precentral gyrus of the frontal lobe to the skeletal muscles. Outputs from the frontal lobe synapse at the ventral horn motor neurons (Upper Motor Neuron UMN and Lower Motor Neuron LMN) before projecting to the skeletal muscle.
2. The lack of muscle tone, known as **hypotonicity** or **flaccidity**, may indicate that the LMN is not conducting action potentials that will keep a basal level of acetylcholine in the neuromuscular junction.
3. If muscle tone is present, muscle strength is tested by having the patient contract muscles against resistance. The examiner will ask the patient to lift the arm, for example, while the examiner is pushing down on it.
4. Diseases that result in UMN lesions include cerebral palsy or MS, or it may be the result of a stroke. A sign of UMN lesion is a negative result in the subtest for **pronator drift**. The patient is asked to extend both arms in front of the body with the palms facing up. While keeping the eyes closed, if the patient unconsciously allows one or the other arm to slowly relax, toward the pronated position, this could indicate a failure of the motor system to maintain the supinated position.

Reflexes

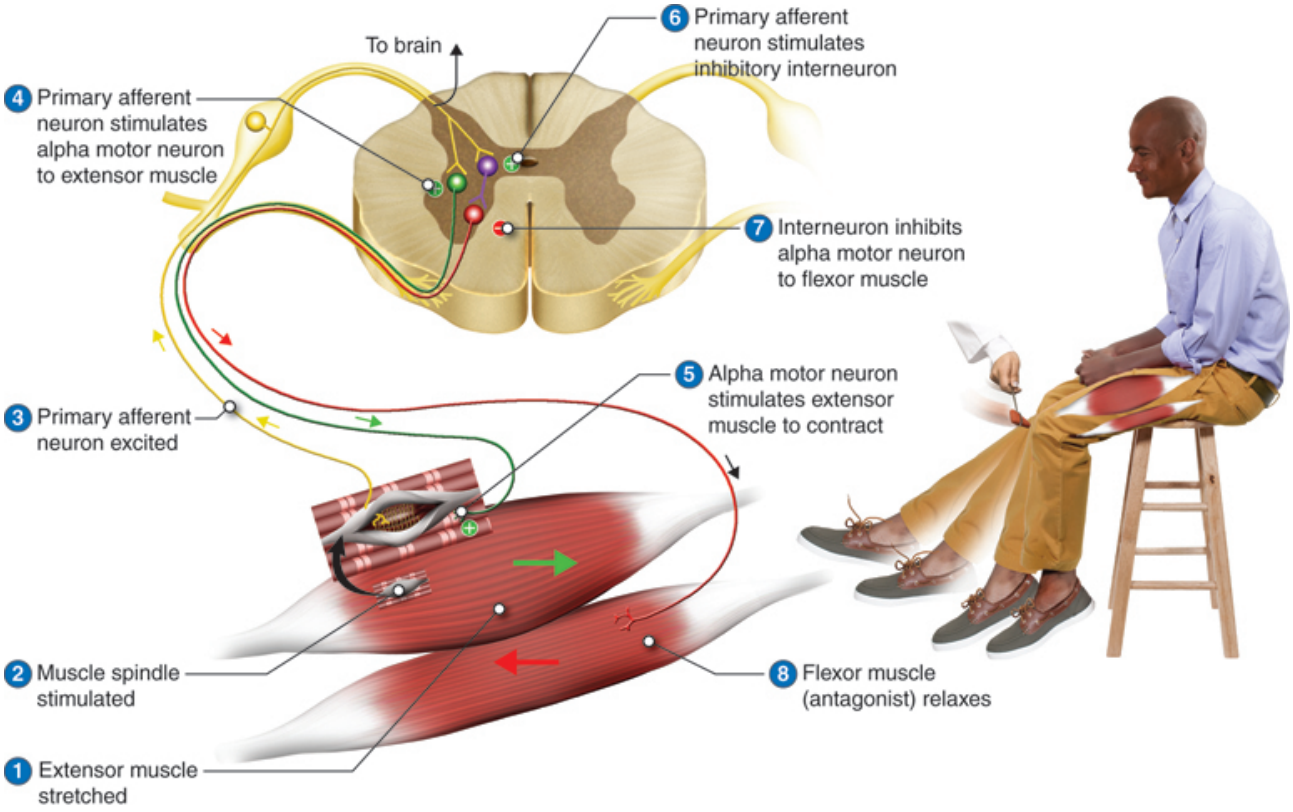


Figure 16.8 Knee jerk reflex. Using a Reflex Hammer, firmly tap the tendon as shown in the figure. You expect a knee jerk response that is a reflex in response to the overextension of the patellar tendon when hit by the hammer while the leg dangles as shown. Credit: Cenveo, license CC-BY

1. For the arm, the common reflexes to test are of the biceps, brachioradialis, triceps, and flexors for the digits. For the leg, the **knee-jerk reflex** of the quadriceps is common, as is the **ankle reflex** for the gastrocnemius and soleus.
2. **Plantar reflex** that tests for the **Babinski sign** on the basis of the extension or flexion of the toes at the plantar surface of the foot. The plantar reflex is commonly tested in newborn infants to establish the presence of neuromuscular function. To elicit this reflex, an examiner brushes a stimulus, usually the examiner's fingertip, along the plantar surface of the infant's foot. An infant would present a positive Babinski sign, meaning the foot dorsiflexes and the toes extend and splay out. As a person learns to walk, the plantar reflex changes to cause curling of the toes and a moderate plantar flexion.

Comparison of Upper and Lower Motor Neuron Damage

1. Many of the tests of motor function can indicate differences that will address whether damage to the motor system is in the upper or lower motor neurons. Signs that suggest a UMN lesion include muscle weakness, strong deep tendon reflexes, decreased control of movement or slowness, pronator drift, a positive Babinski sign, **spasticity**, and the **clasp-knife response**. Spasticity is an excess contraction in resistance to stretch. It can result in **hyperflexia**, which is when joints are overly

flexed. The clasp-knife response occurs when the patient initially resists movement, but then releases, and the joint will quickly flex like a pocket knife closing.

2. A lesion on the LMN would result in paralysis, or at least partial loss of voluntary muscle control, which is known as **paresis**. The paralysis observed in LMN diseases is referred to as **flaccid paralysis**, referring to a complete or partial loss of muscle tone, in contrast to the loss of control in UMN lesions in which tone is retained and spasticity is exhibited. Other signs of an LMN lesion are **fibrillation**, **fasciculation**, and compromised or lost reflexes resulting from the denervation of the muscle fibers

Exercise 4 Coordination and Gait Exams

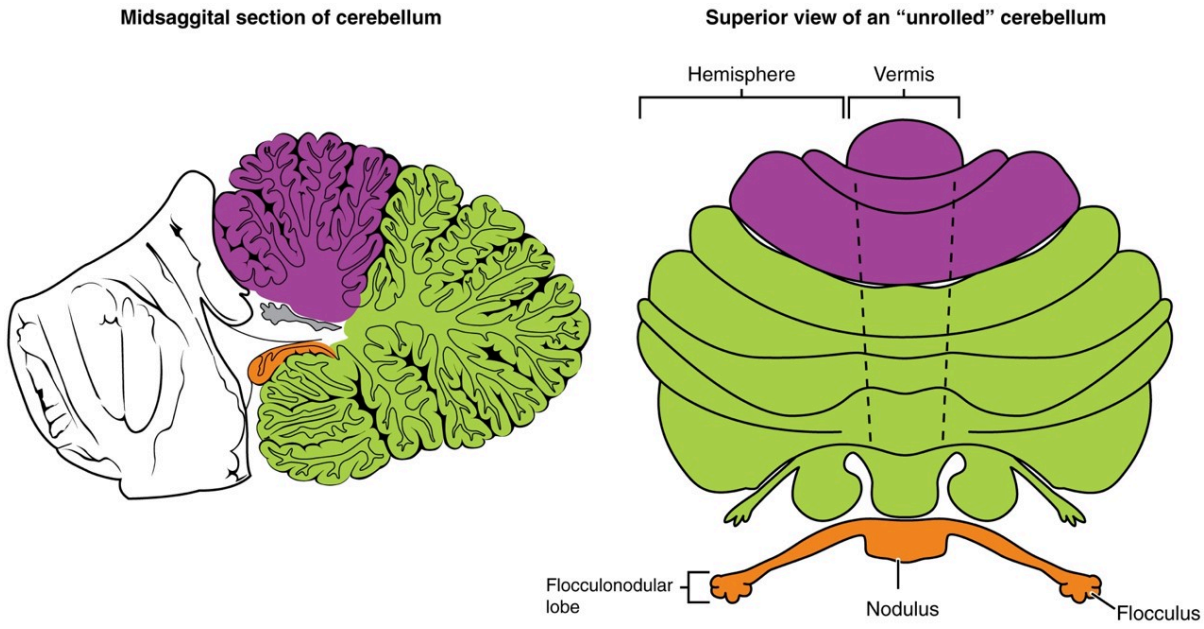


Figure 16.9 Major Regions of the Cerebellum The cerebellum can be divided into two basic regions: the midline and the hemispheres. The midline is composed of the vermis and the flocculonodular lobe, and the hemispheres are the lateral regions.

Locations and Connections of the Cerebellum

1. **Cerebellum** = accounts for 11% of the brain's mass.
2. The cerebellum functions in the coordination and modulation of motor command from the cerebral cortex and maintaining balance and equilibrium.
3. The cerebellum is partially hidden by the cerebral hemispheres and is the second largest structure in the brain.
4. The cerebellum is separated from the cerebrum by the **transverse fissure**.
5. The cerebellum also possesses fold-like wrinkles called **folia**, is divided into two hemispheres, and further subdivided into lobes: the **anterior lobe and posterior lobe**.

6. The two cerebellar hemispheres are separated by the **vermis** while the anterior and posterior lobes are separated by **the primary fissure**.
7. The white matter of the cerebellum is called the **arbor vitae** and is surrounded by gray matter called the **cerebellar cortex**.

Coordination and Alternating Movement

1. Testing for cerebellar function is the basis of the coordination exam. The subtests target appendicular musculature, controlling the limbs, and axial musculature for posture and gait. The assessment of cerebellar function will depend on the normal functioning of other systems addressed in previous sections of the neurological exam. Motor control from the cerebrum, as well as sensory input from somatic, visual, and vestibular senses, are important to cerebellar function.
2. The subtests that address appendicular musculature, and therefore the lateral regions of the cerebellum, begin with a check for tremor. The patient extends their arms in front of them and holds the position while the examiner watches for tremors.
3. The **check reflex** depends on cerebellar input to keep increased contraction from continuing after the removal of resistance. The patient flexes the elbow against resistance from the examiner to extend the elbow.

Required Materials

- Your classmates

Procedure

Where you see instructions, ask your "patient" or classmate to follow these. Record what you did and what you observed.

Posture and Gait

1. Gait can either be considered a separate part of the neurological exam or a subtest of the coordination exam that addresses walking and balance.
2. A subtest called station begins with the patient standing in a normal position to check for the placement of the feet and balance. The patient is asked to hop on one foot to assess the ability to maintain balance and posture during movement.
3. Subtests of walking begin with having the patient walk normally for a distance away from the examiner, and then turn and return to the starting position. The examiner watches for abnormal placement of the feet and the movement of the arms relative to the movement. The patient is then asked to walk with a few different variations. Tandem gait is when the patient places the heel of one foot against the toe of the other foot and walks in a straight line in that manner. Walking only on the heels or only on the toes will test additional aspects of balance.

4. **Ataxia** = presents as a loss of coordination in voluntary movements. Ataxia can also refer to sensory deficits that cause balance problems, primarily in proprioception and equilibrium. Ataxia is often the result of exposure to exogenous substances (alcohol, ketamine or mercury), focal lesions (stroke, trauma, MS, or tumor), or a genetic disorder.

Post-laboratory Questions

1.The corner of the eye next to the nose is called the _____ and it possesses a fleshy elevation called the _____.

2. Name the three nerves that innervate the extrinsic eye muscles. _____, _____, and _____.

3. The X-shaped structure at the base of the brain where visual images cross over to the opposite side of the brain is called the _____.

4. Which cranial nerve transmits sensory information from the eye? _____

5. Losing memories of events of the past is called _____ _____.

6. Loss of the ability to produce speech is _____ _____ and can be caused by damage to _____ area of the brain.

7. Recognizing numbers or letters written on the palm of the hand with a dull pointer is called _____.

8. Registering pain in a part of the body other than the actual source is called _____ _____.

9. Assessing balance by asking the patient to stand up with feet together and close their eyes is the _____ test.

10. A positive sign of _____ is displayed by extension or the toes at the plantar surface of the foot.

17.

CHAPTER 17 THE ENDOCRINE SYSTEM

By Rajeev Chandra

Motivation.

Figure 17.1 Endocrine System and Balance. The endocrine system is responsible for regulating many of the variables controlling the body's internal environment. Hormones of the endocrine system coordinate and control growth, metabolism, temperature regulation, the stress response, reproduction, and many other functions. Image Credit: photographer Sumit Bose, Wikimedia Commons, photo title Yoga, license CC-BY

You may never have thought of it this way, but when you send a text message to two friends to meet you at the dining hall at six, you're sending digital signals that (you hope) will affect their behavior—even though they are some distance away. Similarly, certain cells send chemical signals to other cells in the body that influence their behavior. This long-

distance intercellular communication, coordination, and control is critical for homeostasis, and it is the fundamental function of the endocrine system.

The laboratory exercises in this module will identify several of the "classical" endocrine glands, describe the location and structure of these glands (both gross and histological), and outline the functions of the hormones that are secreted from these glands. Regulation of the glands by factors in the internal environment will also be explored in a simulated experiment.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Identify the classical endocrine glands on a model or diagram
- List the hormones produced by each endocrine gland identified, and discuss the actions of each hormone identified
- Differentiate among the histology of the endocrine glands when viewed on a microscope slide
- Identify the zona glomerulosa, zona fasciculata, zona reticularis, and adrenal medulla, and list the hormones that are released from each region
- Identify pancreatic islets
- Describe the nature of the feedback loops that regulate the activity of the hypothalamus, pituitary gland, the target glands, and target tissues

Background.

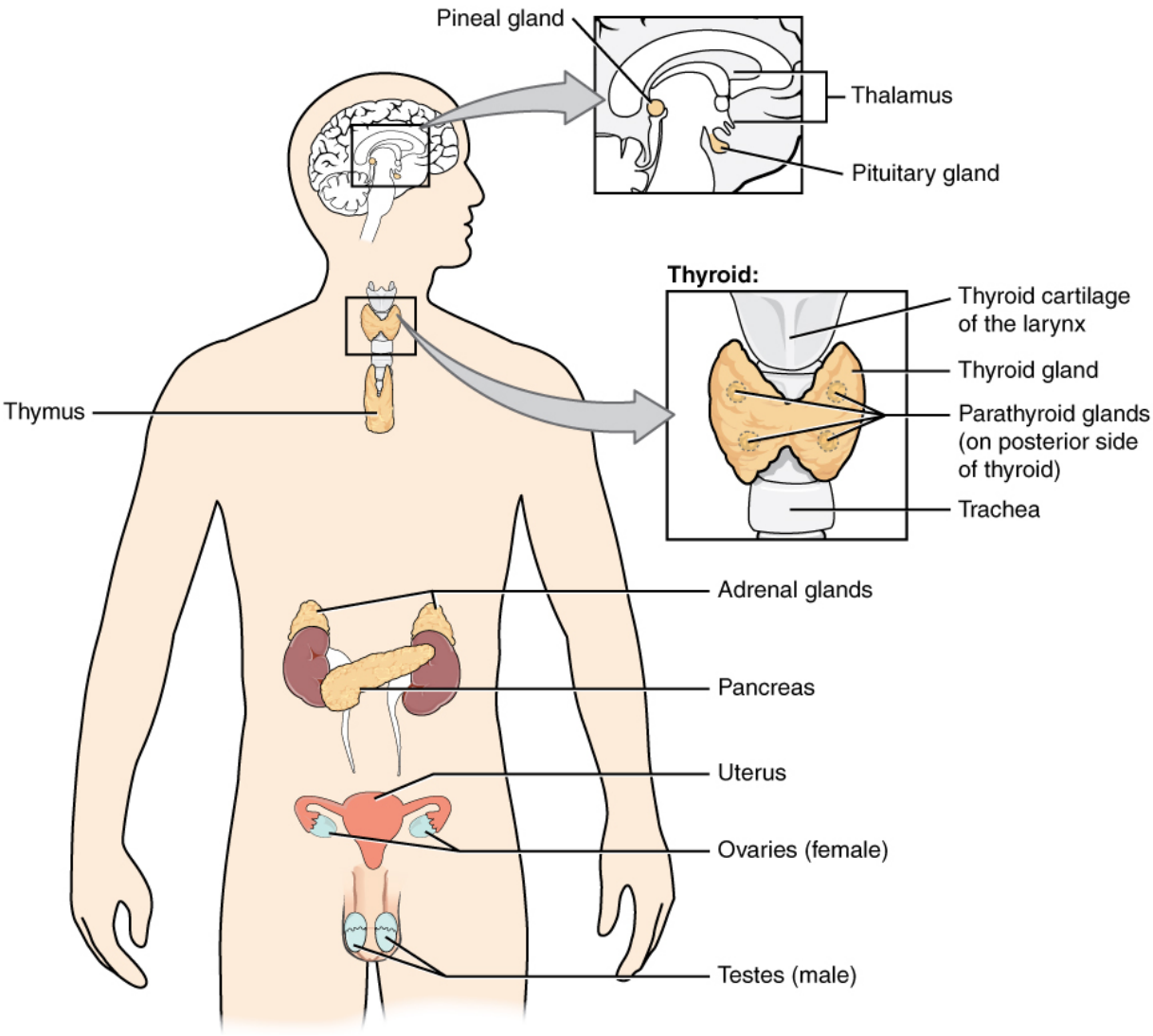


Figure 17.2 Major endocrine organs.

Overview

Hormones are chemical messengers produced by cells and released into the bloodstream, where they travel throughout the body. This allows these messengers to act on cells and organs that may be distant from the cells that synthesized them. Although many cells release chemicals that communicate with other cells, we typically describe some organs or glands as being part of the "endocrine system." Glands that are typically included in discussions of the anatomy and physiology of the endocrine system are shown at right.

Each endocrine gland secretes particular hormones, which in turn has particular effects on the target cells and organs. We'll be looking at these glands and hormones individually as part of this exercise.

SPECIFIC ENDOCRINE GLANDS

Adrenal glands

The adrenal glands (as their name implies) are located near the kidneys (ad-RENAL). They are paired, pyramidal glands that sit on the superior aspect of each kidney.

The adrenal glands are composed of two distinct regions: the outer adrenal cortex, and the inner adrenal medulla. These regions can be seen when the glands are sectioned, but the real differences are clear when the tissue is viewed under a microscope.

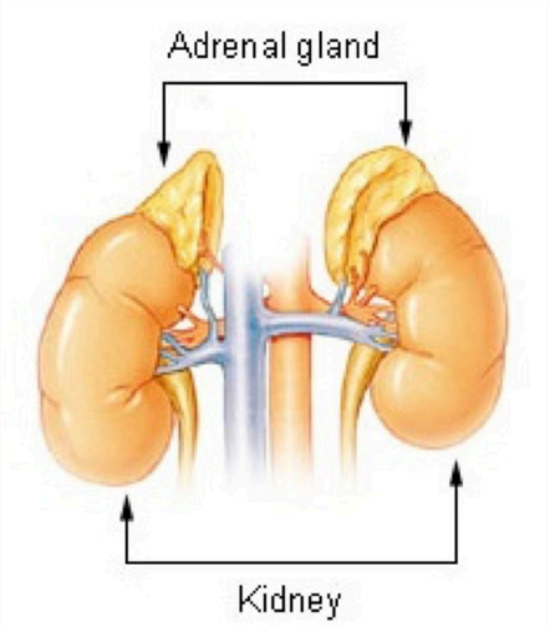


Figure 17.3 Adrenal Glands. Credit: Wikipedia, license Public Doman.

Adrenal Cortex

The adrenal cortex can be further divided into 3 sub-regions or layers:

The **zona glomerulosa**, the outermost or most superficial layer, which synthesizes and secretes aldosterone in response to stimuli like decreased blood pressure. Aldosterone

(a steroid) regulates Na+ and K+ balance, and plays an important role in fluid homeostasis.

The **zone fasciculata**, the middle layer, synthesizes and secretes cortisol and other glucocorticoids in response to ACTH from the anterior pituitary.

The **zona reticularis**, the deepest layer of the cortex, secretes androgens, or sex hormones (that are also steroids). These hormones act throughout the body and have similar effects as sex steroids produced by the ovaries and testes.

Adrenal Medulla

The adrenal medulla is the innermost (deepest) region of the adrenal gland, and consists mostly of modified sympathetic nerves. As a result, the adrenal medulla synthesizes and secretes catecholamines epinephrine and norepinephrine into the bloodstream.

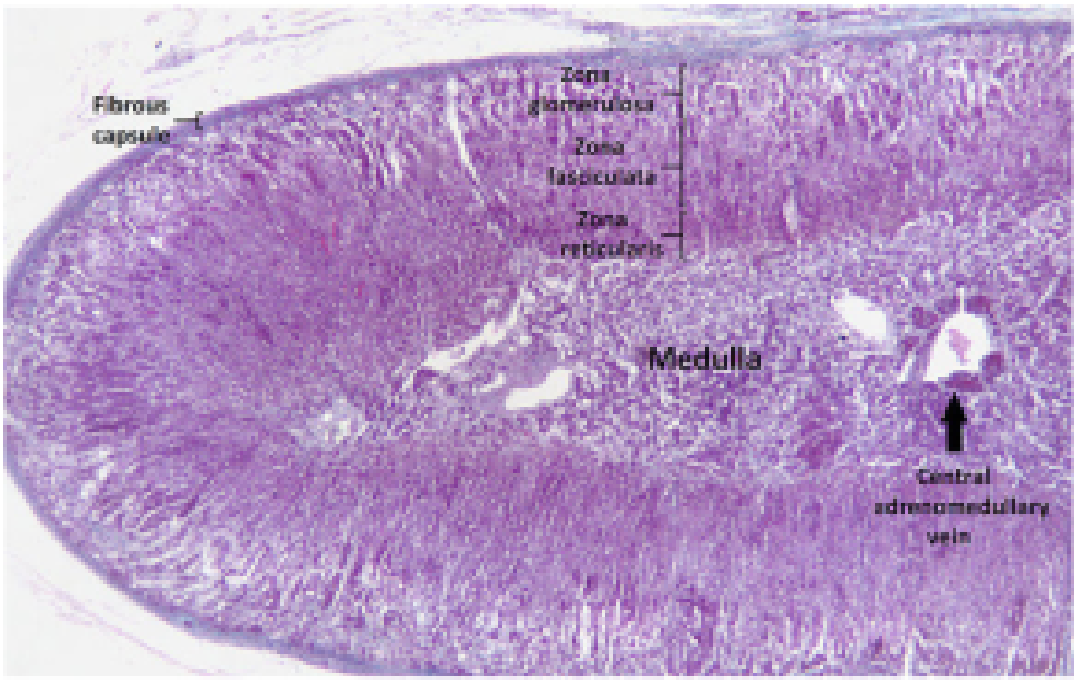


Figure 17.4 Adrenal gland histology. A histological image that clearly shows the cortex and medulla, and the layers of the cortex. Credit: photo by Jpogi, Wikimedia Commons, license CC0

Thyroid gland

The thyroid gland is a butterfly-shaped gland located on the anterior aspect of the larynx (voicebox). The right and left lobes on either side (analogous to the butterfly's wings) are connected by a thin band of glandular tissue called the isthmus (Figure 17.5).

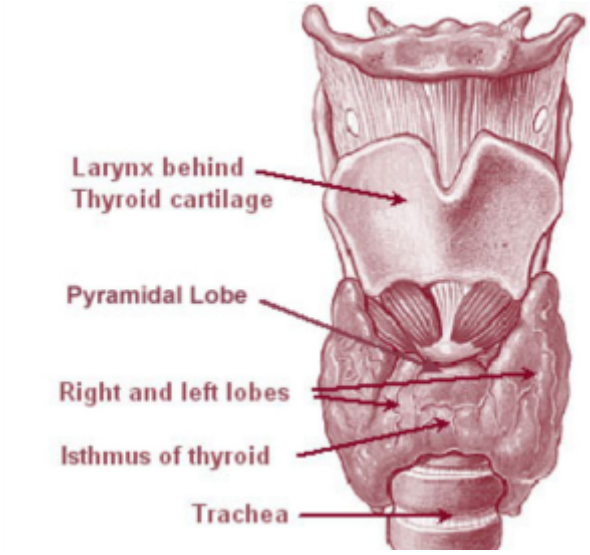


Figure 17.5 Thyroid gland anatomical location. Credit: Wikimedia Commons, license Public Domain.

Histologically, the thyroid gland is composed of follicles, round structures where thyroid hormones are

synthesized and released. Several follicles can be seen in the photomicrograph below. The substance in the follicles is called colloid, which is an iodine-rich precursor to thyroid hormones. The follicular cells use these precursor molecules to synthesize and release the finished thyroid hormones (triiodothyronine, or T3, and thyroxine, or T4). Thyroid hormones act on many other cells in the body and have many effects, including increasing heart rate, increasing protein synthesis, and increasing overall metabolic rate. Parafollicular cells are found in-between the follicles. These cells synthesize another hormone called calcitonin, which plays a role in calcium balance in the body.

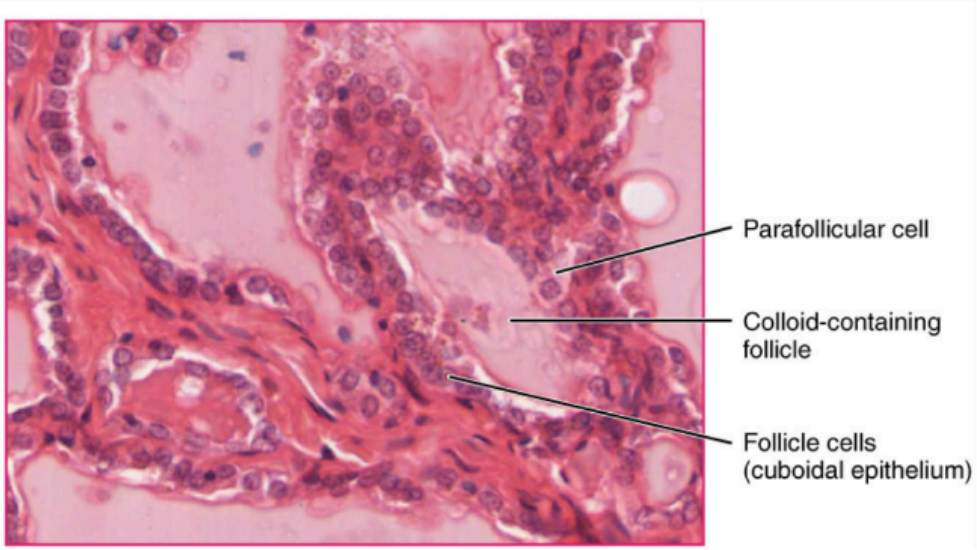


Figure 17.6 Thyroid gland histology.

Parathyroid glands

The parathyroid glands are 4 – 6 small, round glands found on the posterior aspect of the thyroid gland (Figure 17.7). These glands secrete parathyroid hormone (PTH) in response to low levels of calcium in the plasma. PTH acts to activate osteoclasts to dissolve existing bone tissue, liberating the calcium that is stored there. PTH also acts to increase calcium absorption from the intestines and increases the reabsorption of calcium in the kidney tubules. The net result of PTH on the body is to increase calcium ion levels in the plasma.

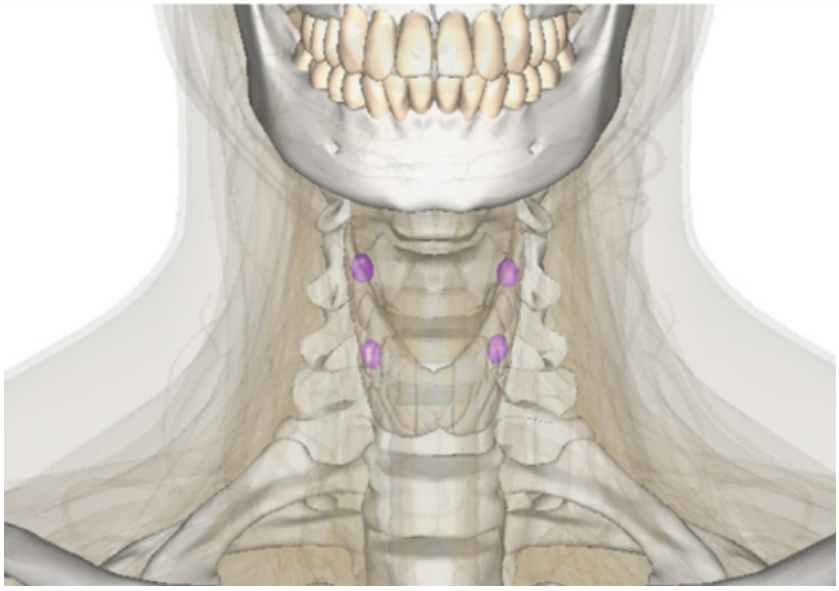


Figure 17.7 Parathyroid glands anatomical location. Purple spots indicate the glands. Image credit: By BodyParts3D, Wikimedia Commons, license CC-BY-SA

A photomicrograph of the parathyroid gland (Figure 17.8) shows the cells that are responsible for the synthesis and release of PTH called chief cells, or parathyroid cells. Other cells that are present in the parathyroid glands are called oxyphil cells, but their function is not clear.

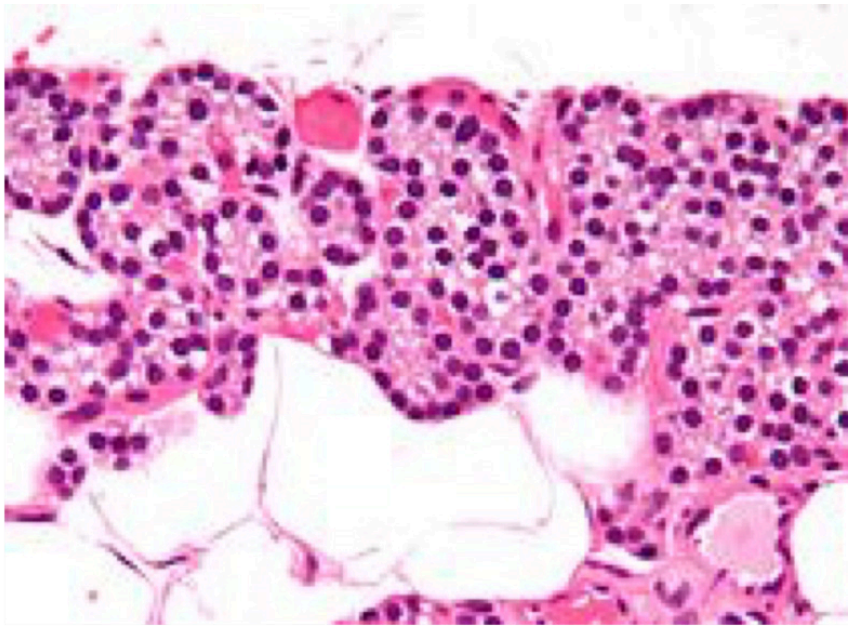


Figure 17.8 Parathyroid gland histology. Credit: Image by Nephron, Wikimedia Commons, license CC-BY-SA

Pancreas

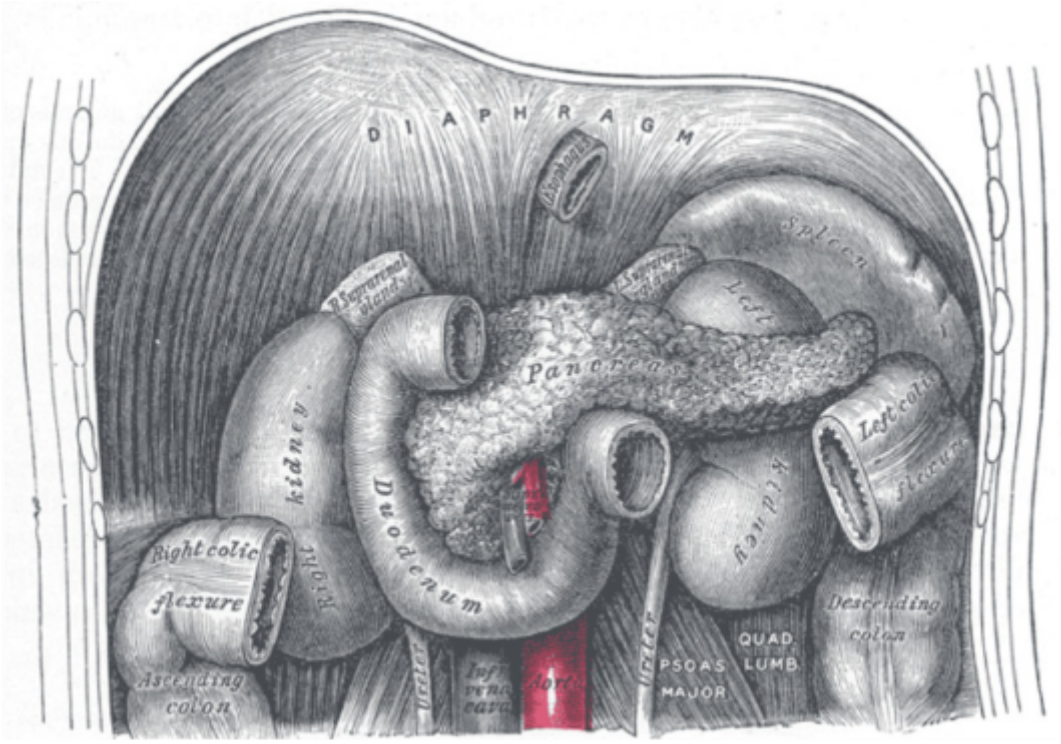


Figure 17.9 Pancreas anatomic location. Credit: Gray's Anatomy (1918) on Wikimedia Commons, Public Domain.

The pancreas is a large, comma-shaped organ (Figure 17.9) that has both exocrine functions (synthesizing digestive juices that are secreted into the small intestine) and endocrine functions. It is located in the abdominal cavity, posterior to the stomach and tucked into the curve of the duodenum.

Several hormones are synthesized and secreted from the pancreas, including insulin, glucagon, and somatostatin. (Somatostatin is known by another name – **growth hormone inhibiting hormone**, the same hormone that is released from the hypothalamus to regulate the activity of the pituitary gland.)

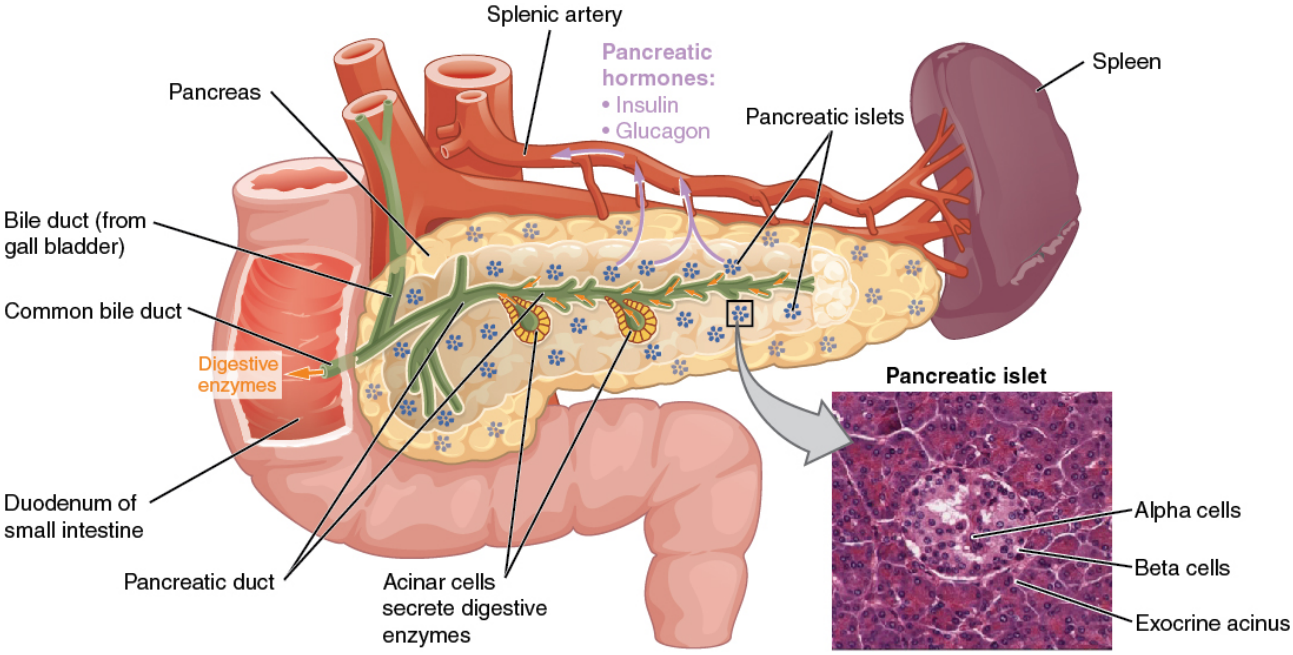


Figure 17.10 Pancreas. The diagram shows the location of the pancreas relative to the duodenum. This diagram also shows the relationship between the exocrine cells (those that produce the digestive juices) and the clusters of endocrine cells – the pancreatic islets or Islets of Langerhans- that are scattered throughout the tissue.

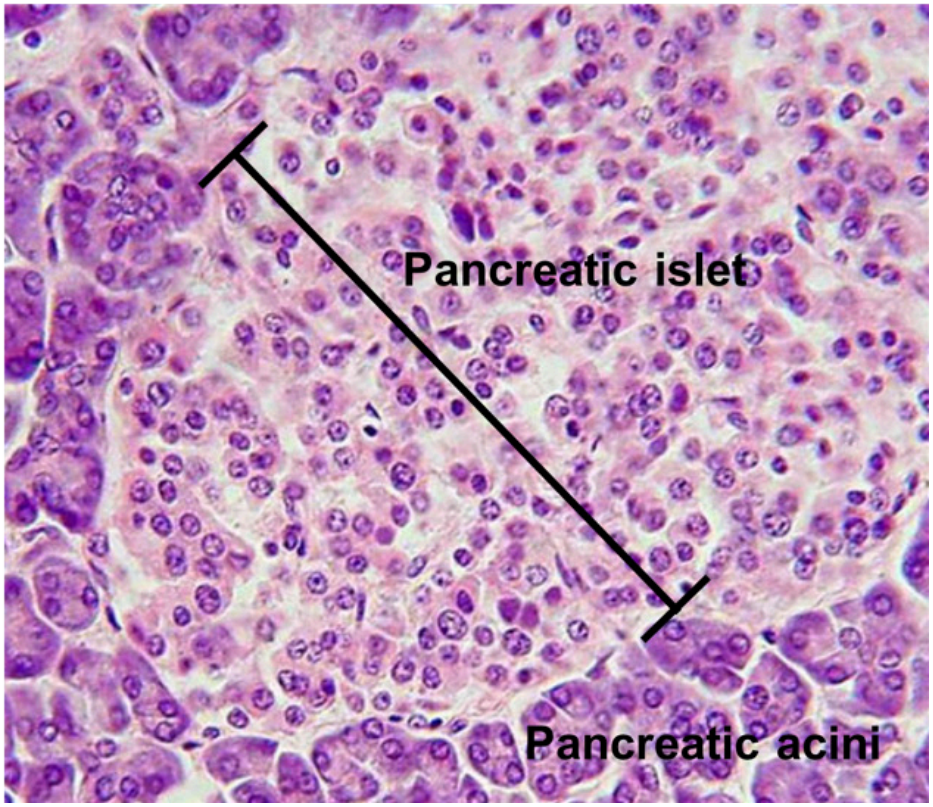


Figure 17.11. Pancreas histology. A magnified photomicrograph of the pancreatic islets. The pancreatic islets can be clearly distinguished from the exocrine tissue that surrounds them. Credit: Photo by Polarlys on Wikimedia Commons, license CC-BY

The two main hormones released from the pancreatic islet cells are insulin and glucagon. Insulin is released from beta cells in the pancreatic islets, and has the actions to increase the uptake of glucose from the blood into tissues. This results in decreased glucose in the blood plasma. Glucagon is released from alpha cells, and has the effect to release glucose from body cells into the plasma, resulting in increased blood glucose levels. Somatostatin is released from delta cells in the islets. The action of somatostatin is generally inhibitory. In the digestive system, somatostatin acts to inhibit the release of both insulin and glucagon. In the anterior pituitary (discussed above), somatostatin inhibits the release of growth hormone (GH) from the anterior pituitary.

Reproductive Glands: *Ovaries and Testes*

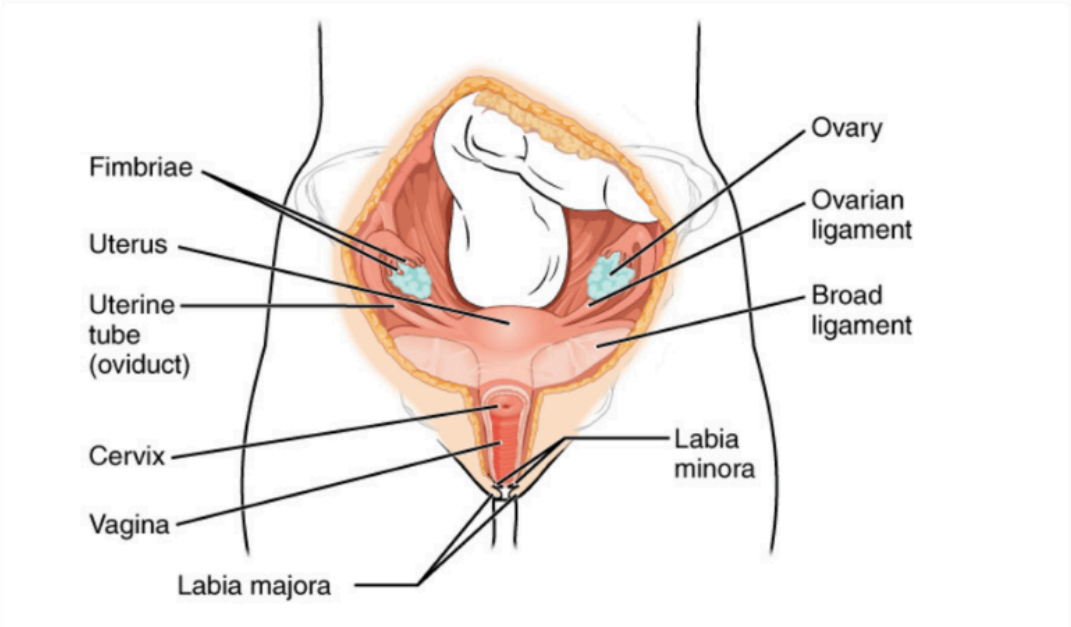


Figure 17.12 Ovaries. Anterior view, shown in blue.

The ovaries (Figure 17.12) are the female gonads that produce both gametes (cells that play a role in reproduction) and hormones. They are small, paired glands located deep in the pelvic cavity, and the gametes they produce are called **oocytes**. The production of oocytes is dependent on the hormonal activity of the anterior pituitary. The oocytes are released from the ovary and travel through the uterine tube to the uterus.

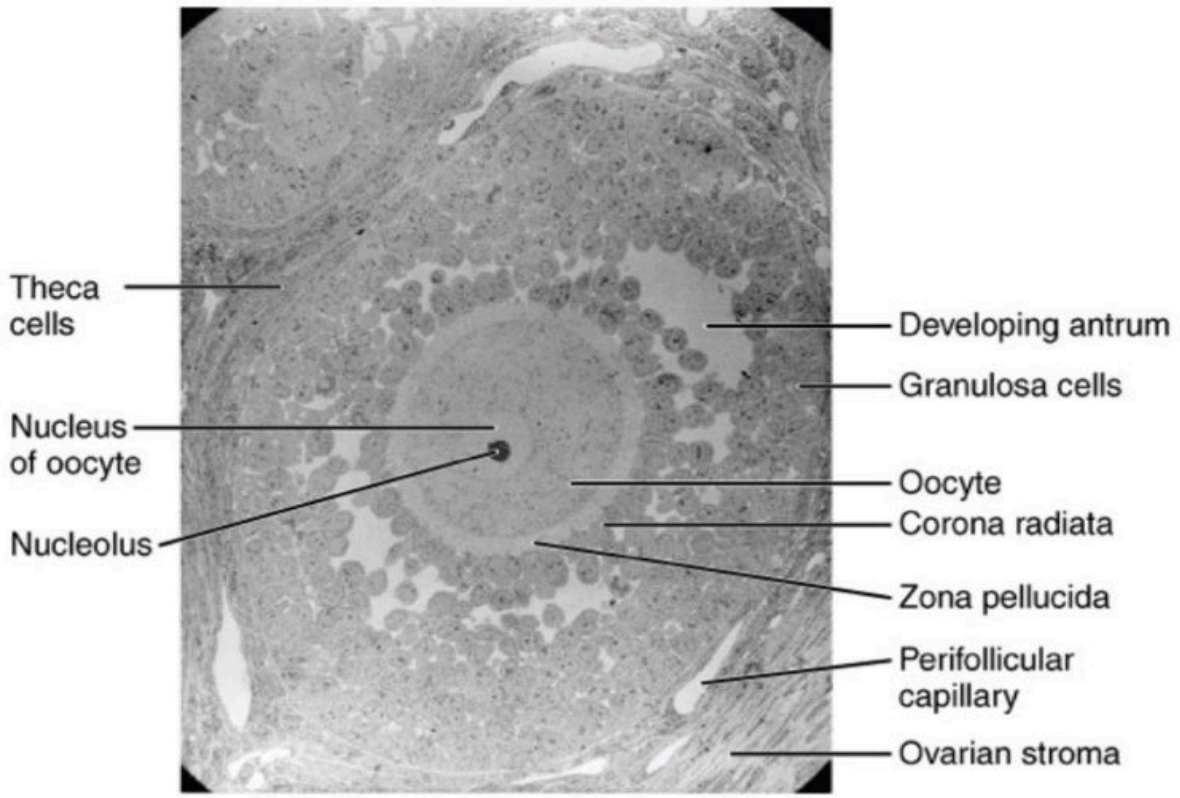


Figure 17.13 Folliculogenesis. Secondary follicle developing in the cortex of ovary. Electron micrograph of a secondary follicle, the oocyte, theca cells (thecae folliculi), and developing antrum are clearly visible. EM × 1100. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Ooctyes develop within follicles in the cortex of the ovary (Figure 17.13). The process where oocytes are released from the ovary is called **ovulation.**

The ovary also produces female sex hormones called **estrogens**. There are three estrogens produced by the ovary: **estrone, estradiol and estriol**. All the estrogens are classified as steroids due to their chemical structure. Estrogens regulate the ovarian and menstrual cycles, influencing the maturation of the oocyte in the ovary, the release of the oocyte during ovulation, and the changes seen in the uterus as it prepares to receive a potential zygote. Estrogens are also important in the development of secondary sex characteristics like breast development and fat redistribution. Another hormone produced by the ovary is **progesterone**, a hormone that plays important roles in preparing the body for pregnancy in the event that an oocyte is fertilized by a sperm cell.

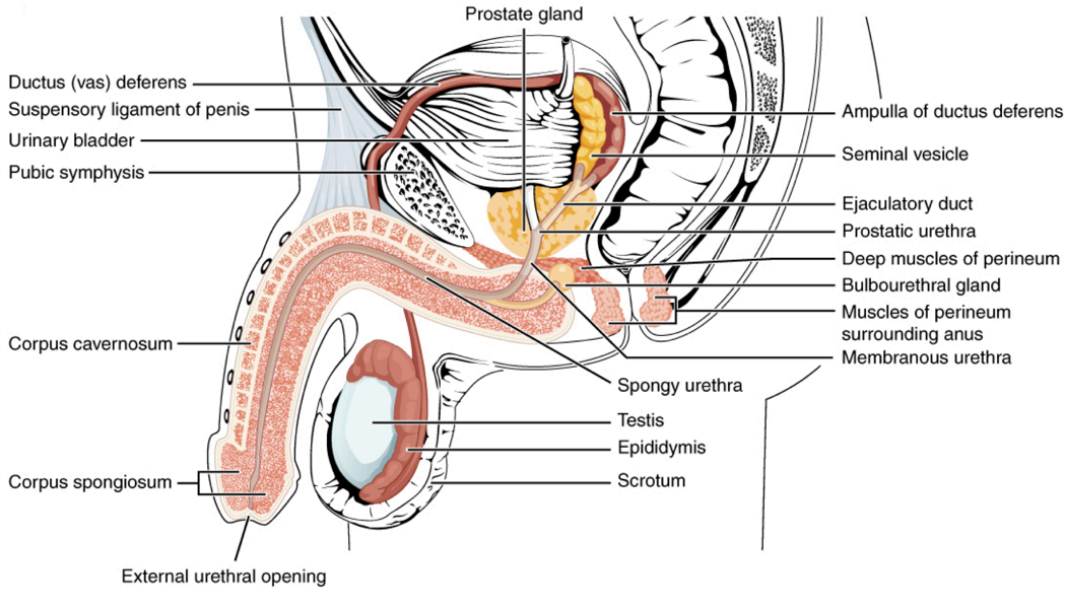


Figure 17.14. Testes. Lateral view, shown in blue.

The testes are male gonads (Figure 17.14) , and like the ovaries in females they produce both gametes (sperm) and hormones. The testes are also small paired structures, however they are located outside the pelvic cavity in males. Sperm that are produced in the testes must travel back into the pelvic cavity through a long duct system before being released from the body via the penis as part of the semen. The production of sperm in the male is regulated similarly to the oocyte production in females, via hormones that are released from the anterior pituitary.

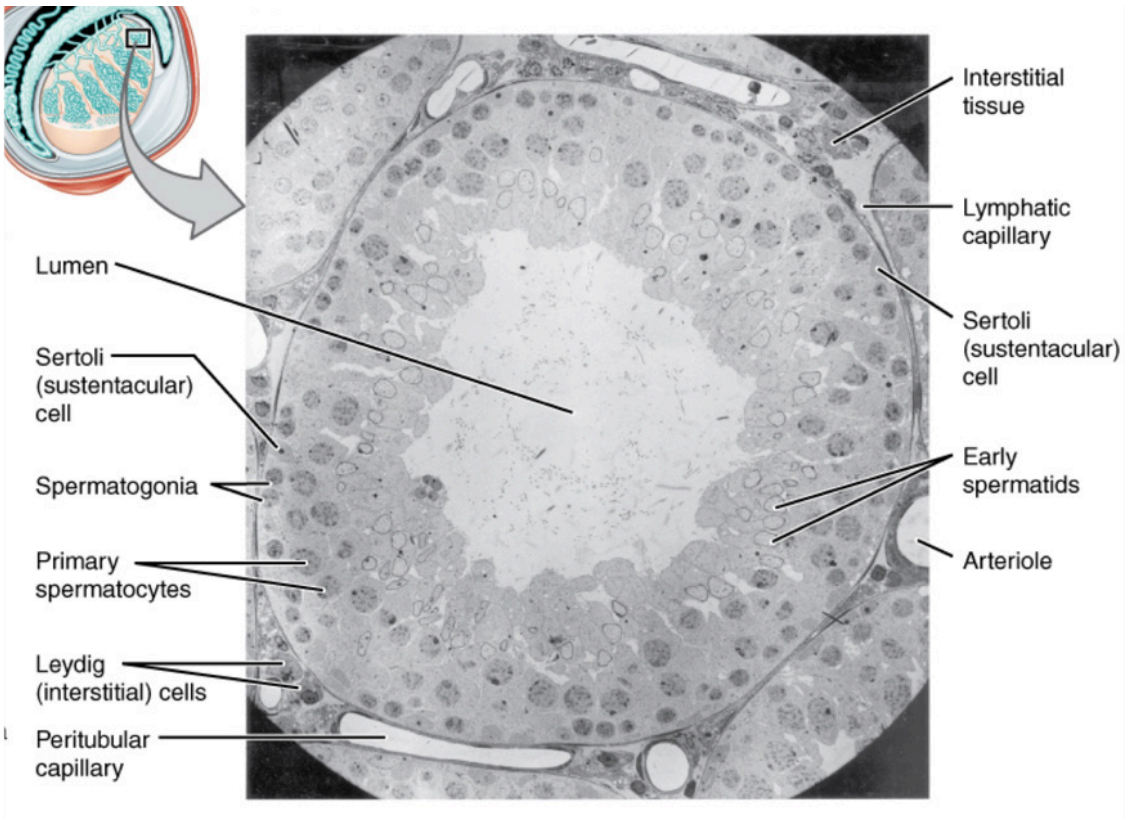


Figure 17.15 Cross section of a seminiferous tubule within testis. In this electron micrograph of a cross-section of a seminiferous tubule from a rat, the lumen is the light-shaded area in the center of the image. The location of the primary spermatocytes is near the basement membrane, and the early spermatids are approaching the lumen (tissue source: rat). EM × 900. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Sperm is produced within the seminiferous tubule (Figure 17.15). Maturing sperm move through an extensive duct system both in the testis and to / through the pelvic cavity.

The main male sex hormone produced by the testes is **testosterone**. Like the estrogens from the ovary, testosterone is a steroid hormone that plays important roles in the development of secondary sex characteristics in males (increased bone and muscle mass, deepening voice, facial hair). Testosterone also influences the development of the sperm. A second hormone produced by the testes is inhibin, which plays a role in regulating the development and maturation of sperm.

Pituitary Gland and Hypothalamus

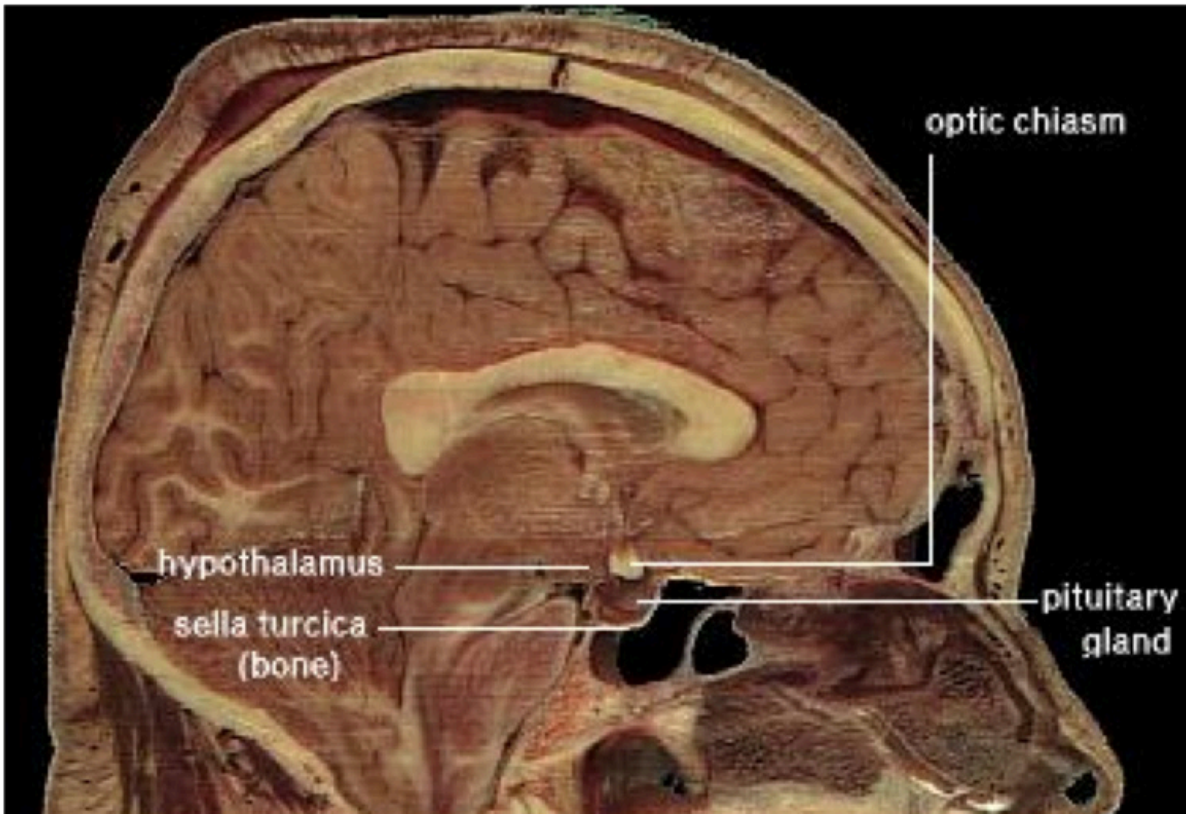


Figure 17.16 Pituitary gland and hypothalamus. The photo of the brain shows the location of the pituitary gland relative to the brain. Lateral view.. Credit: Wikimedia Commons, license Public Domain

The pituitary gland extends below the inferior aspect of the brain, inferior to the hypothalamus (Figure 17.16). We describe the pituitary gland as the "master gland" because it secretes hormones that regulate the activity of other endocrine glands, in addition to hormones that act on other cells and tissues in the body.

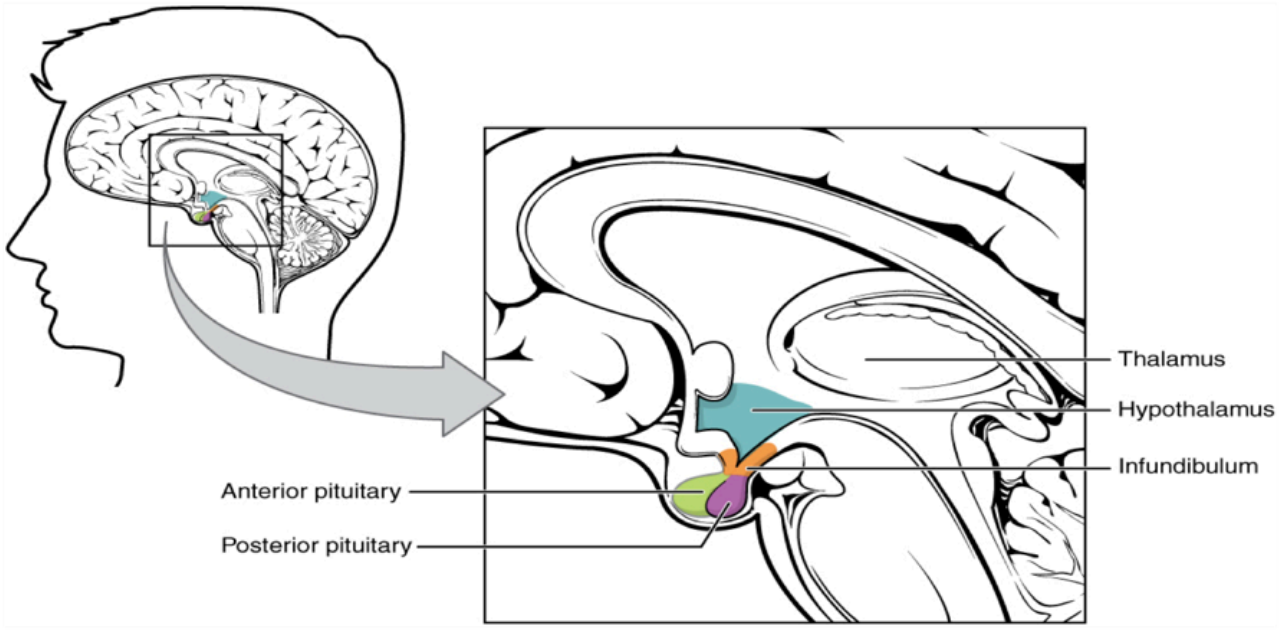


Figure 17.17 The pituitary complex. The diagram shows the relationship between the pituitary lobes and the hypothalamus by color-coding the individual components.

Pituitary Complex The hypothalamus region lies inferior and anterior to the thalamus (Figure 17.17). 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. The pituitary gland is composed of 2 distinct regions, or lobes: the **ANTERIOR lobe** (also called the **adenohypophysis**; sometimes called the *pars distalis*) and the **POSTERIOR lobe** (also called the **neurohypophysis**; sometimes called the *pars nervosa*).The differences between the two lobes can be seen easily when the tissue is examined under the microscope.

The posterior lobe is an extension of the brain tissue in the hypothalamus. This means that the posterior lobe is actually nervous tissue and not true glandular tissue. Hormones are synthesized in cell bodies in the hypothalamus, then transported to the axon terminals in the posterior lobe. These hormones are released from the axon terminals into the bloodstream. The anterior lobe is true glandular tissue: hormones are synthesized, stored and released from the cells here.

Hormones Secreted from the Pituitary Gland

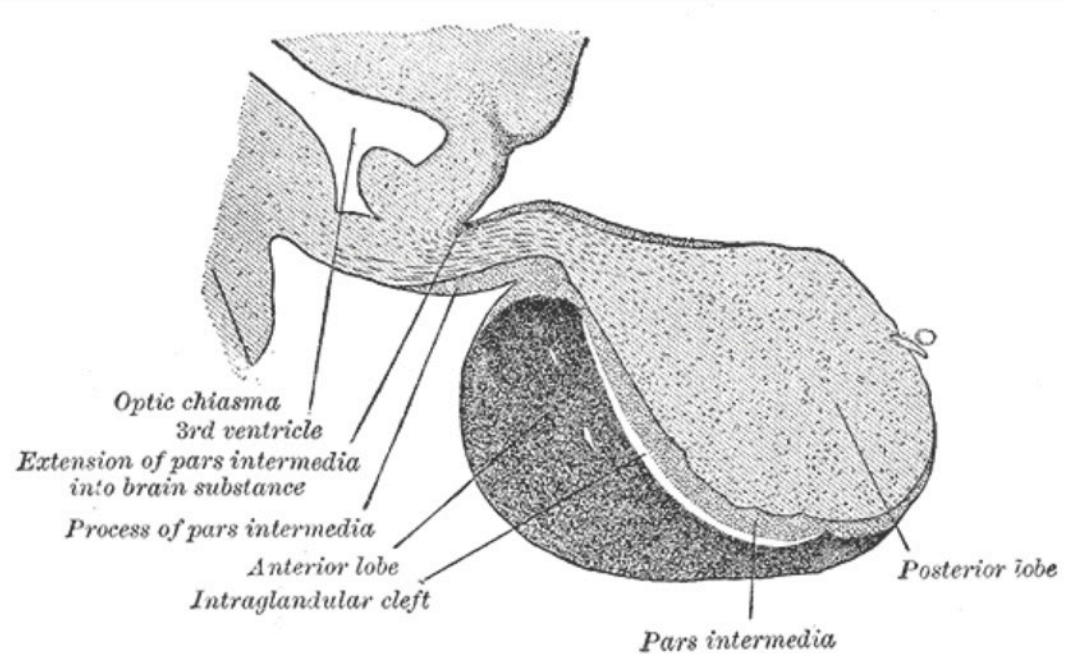


Figure 17.18 The pituitary gland or hypophysis. Anterior and posterior lobes are shown. The lobes are distinguishable microscopically due to color differences as drawn in this figure. Credit: Gray's Anatomy (1918) on Wikimedia Commons, license Public Domain.

Two hormones are secreted from the posterior pituitary:

- Antidiuretic hormone (ADH)
- Oxytocin

Neurosecretory cells in the hypothalamus release oxytocin (OT) or ADH into the posterior lobe of the pituitary gland. These hormones are stored or released into the blood via the capillary plexus (Figure 17.19).

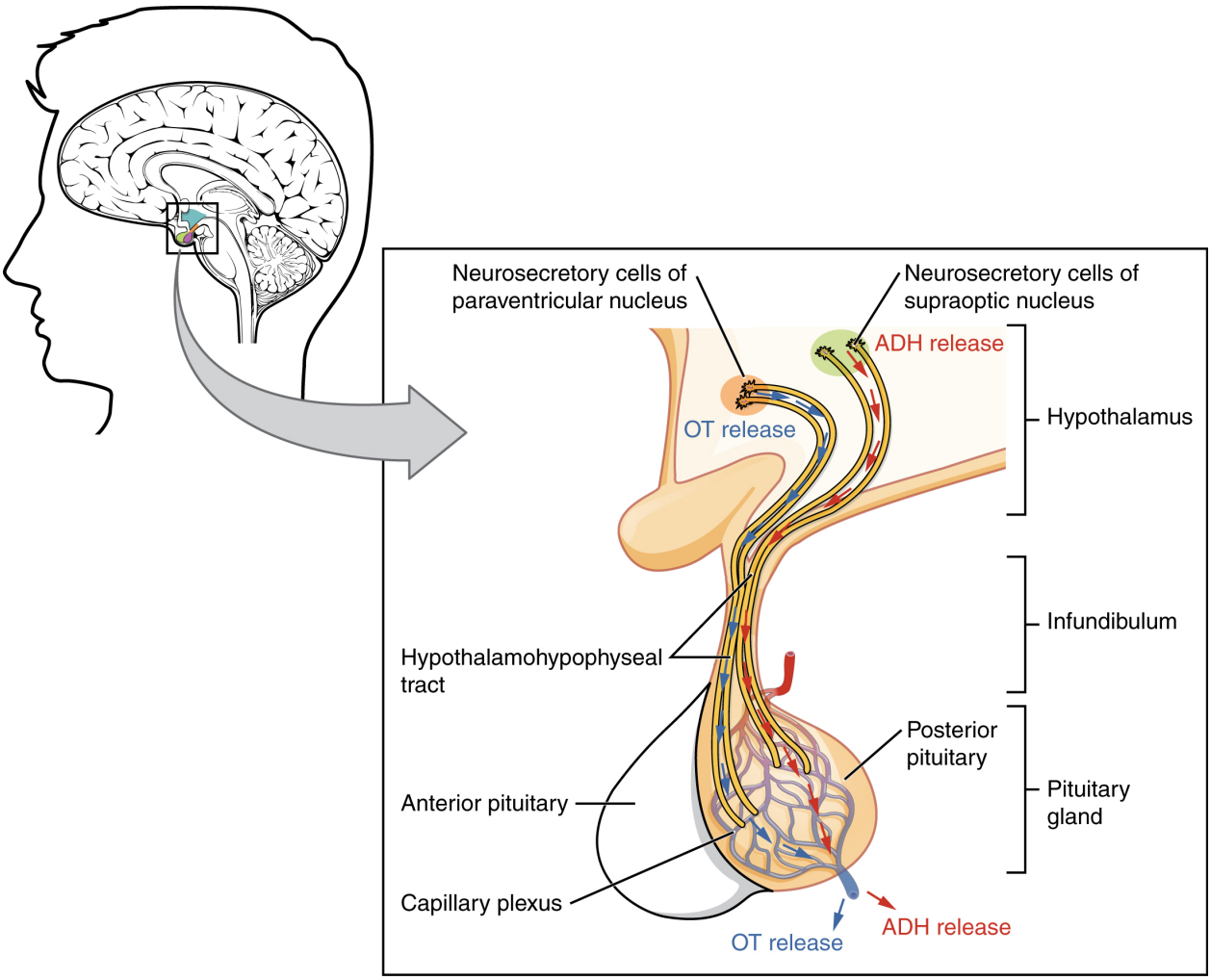


Figure 17.19 ADH and oxytocin (OT). Synthesized in the hypothalamus and then transported to the posterior pituitary for release to the blood.

Six hormones are released from the anterior pituitary:

- Growth hormone (GH)
- Prolactin
- Follicle-stimulating hormone (FSH)
- Luteinizing hormone (LH)
- Adrenocorticotropic hormone (ACTH)
- Thyroid-stimulating hormone (TSH)

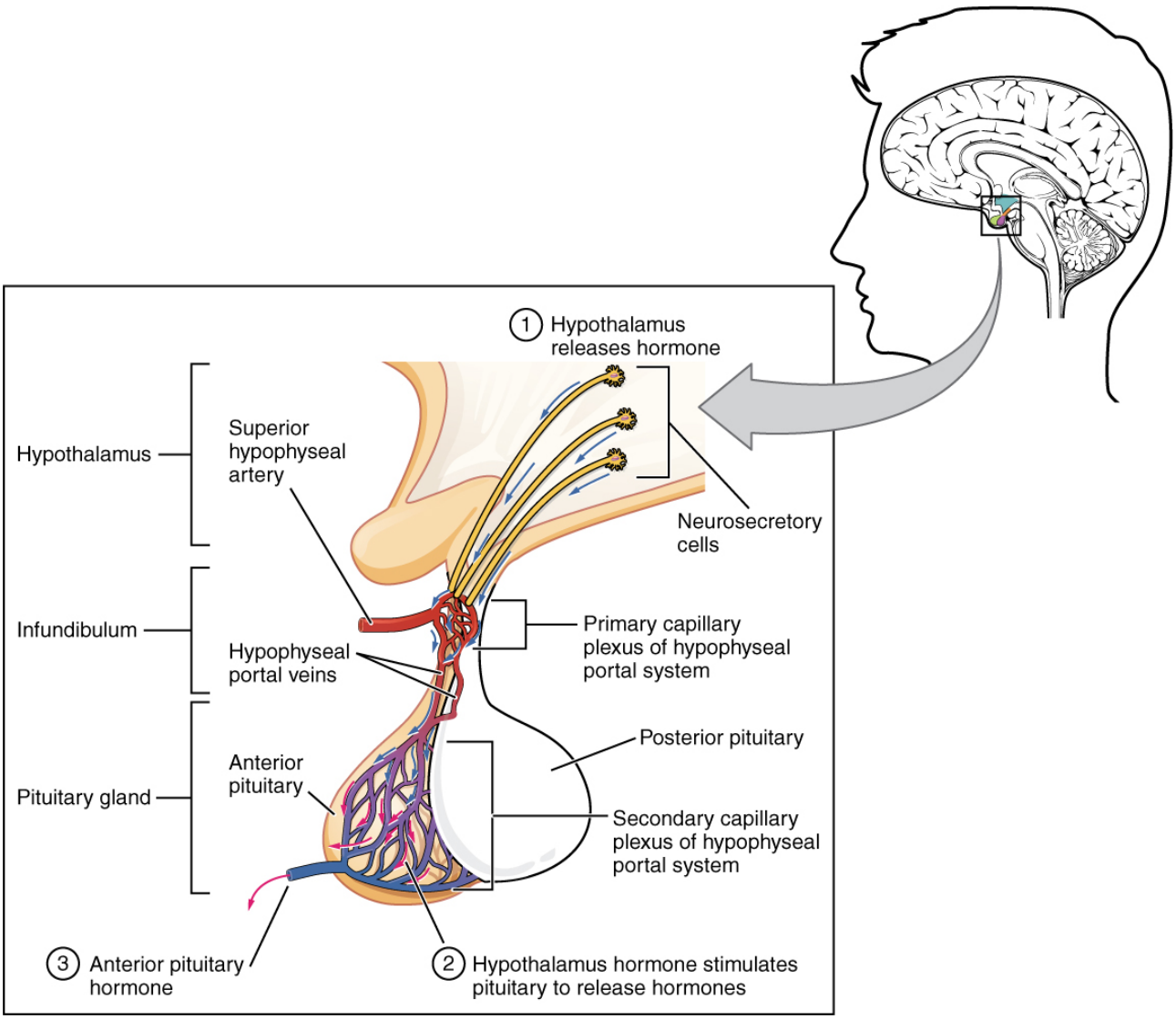


Figure 17.20 Anterior pituitary hormones. The image shows hormones from the hypothalamus being sent directly to the anterior pituitary via the hypophyseal portal system, where they act on the cells of the that gland to stimulate or inhibit their release.

The anterior pituitary is composed of three distinct cell types that can be seen more easily when they are stained with acidic or basic dyes. ACIDOPHILS are cells that appear red when stained with acidic dyes. BASOPHILS are cells that appear blue when stained with basic dyes. CHROMOPHOBES are cells that remain uncolored in the presence of either type of dye. The hormones that are released from the anterior pituitary are associated with either acidophils or basophils. The table below (Post-Laboratory Questions, #4) shows you which hormones are released from each type of cell.

REGULATION OF THE PITUITARY AND TARGET ORGANS / GLANDS

Feedback Loops

The release of hormones in the endocrine system are regulated through feedback mechanisms. Negative feedback is used to inhibit further hormone secretion: when a sufficient amount of hormone is released, it "feeds back" to decrease or prevent further release. In other words, the gland has released sufficient hormone to produce the desired effect, so further hormone release is inhibited. Because the hypothalamus

and pituitary glands are regulating the activity of endocrine glands, they are also subject to feedback mechanisms and their activity will be altered in response to levels of other hormones.

The regulation of the anterior pituitary involves the release of hormones from the hypothalamus; regulation of the endocrine glands involves the release of hormones from the anterior pituitary. Further, hormones released from the endocrine glands interact with both the hypothalamus and the pituitary to regulate their activity, in a classic arrangement known as a feedback loop.

The pathways of three hormones are examined in this activity: thyroid hormone, cortisol and testosterone. The hormonal pathways are similar in all three cases. In each case: the hypothalamus secretes a releasing hormone to regulate the activity of the anterior pituitary gland the anterior pituitary then secretes hormones that regulate the activity of a target gland (the thyroid gland, the adrenal gland or the testis) the hormones released from the target glands "feed back" to the anterior pituitary and the hypothalamus to inhibit the further release of those hormones. The hypothalamus is like a command center: if it is not stimulated, it will not secrete releasing hormones to stimulate the anterior pituitary, which in turn will not stimulate the target glands.

Pre-Laboratory Questions

After reviewing the Background information please answer the following questions.

1. Endocrine glands _____.

1. secrete hormones that travel through a duct to the target organs
2. release neurotransmitters into the synaptic cleft
3. secrete chemical messengers that travel in the bloodstream
4. include sebaceous glands and sweat glands

2. Chemical signaling that affects neighboring cells is called _____.

1. autocrine
2. paracrine
3. endocrine
4. neuron

3. A student is in a car accident, and although not hurt, immediately experiences pupil dilation, increased heart rate, and rapid breathing. What type of endocrine system stimulus did the student receive?

1. humoral
2. hormonal
3. neural
4. positive feedback

4. Which of the following is an anterior pituitary hormone?

1. ADH
2. oxytocin
3. TSH
4. Cortisol

5. How many hormones are produced by the posterior pituitary?

1. 0
2. 1
3. 2
4. 6

6. The adrenal glands are attached superiorly to which organ?

1. thyroid
2. liver
3. kidneys
4. hypothalamus

7. The gonads produce what class of hormones?

1. amine hormones
2. peptide hormones
3. steroid hormones
4. catecholamines

8. If an autoimmune disorder targets the alpha cells, production of which hormone would be directly affected?

1. somatostatin
2. pancreatic polypeptide
3. insulin
4. glucagon

Exercises

- Exercise 1 Identify major endocrine glands and their locations
- Exercise 2 Name the main hormones secreted by each major endocrine gland
- Exercise 3 Describe the function of the main hormones
- Exercise 4 Identify microscopic structures of endocrine glands

Exercise 1 Identify major endocrine glands and their locations

Required Materials

- Torso Model
- Organs of the Endocrine System board model
- The Endocrine System poster
- Post-it notes
- Labeling tape

Procedure

1. This activity requires students identifying the locations of various Endocrine Glands using Torso Models. Students will also be able to explore respective structures of the Endocrine Glands using board model depicting various endocrine glands.
2. Use the board model to identify and become familiar with the anatomy of the following endocrine glands: pituitary gland, thyroid gland, parathyroid glands, pancreas, adrenal gland, testis, ovary, pancreas. Place a label on each (using post-it notes) and take a picture. Insert the labeled picture in the space below. Alternatively, you can sketch and label.

3. Now that you know what these glands look like, find them on the torso model. Use the post-it notes to label them. Take a picture of the labeled glands on the torso model and insert in the space below. Alternatively, you can sketch and label.

Exercise 2 Name the main hormones secreted by each major endocrine gland

Required Materials

- Endocrine system poster

Procedure

Students will be utilizing this lab manual and OpenStax Human Anatomy and Physiology Text resources as well as the Endocrine System Posterto learn and identify hormones secreted by various endocrine glands. For each gland listed in the table below, find and list the hormones it produces.

Gland	**Hormones produced**
Pituitary (posterior)	
Pituitary (anterior)	
Thyroid	
Parathyroid	
Pancreas	
Adrenal	
Ovary	
Testis	

Exercise 3 Describe the function of the main hormones

Required Materials

- None

Procedure

Students will be utilizing this lab manual and OpenStax Human Anatomy and Physiology Text resources to learn and identify functions of some important hormones in the table below.

Hormones	**Hormone name and function**
Pituitary (posterior) hormones	1. 2.
Pituitary (anterior) hormones	1. 2. 3. 4. 5. 6.
Thyroid	1. 2.
Parathyroid	1.
Pancreas	1. 2. 3.
Adrenal	1. 2. 3.
Ovary	1. 2.
Testis	1.

Exercise 4 Identify microscopic structures of endocrine glands

Required Materials

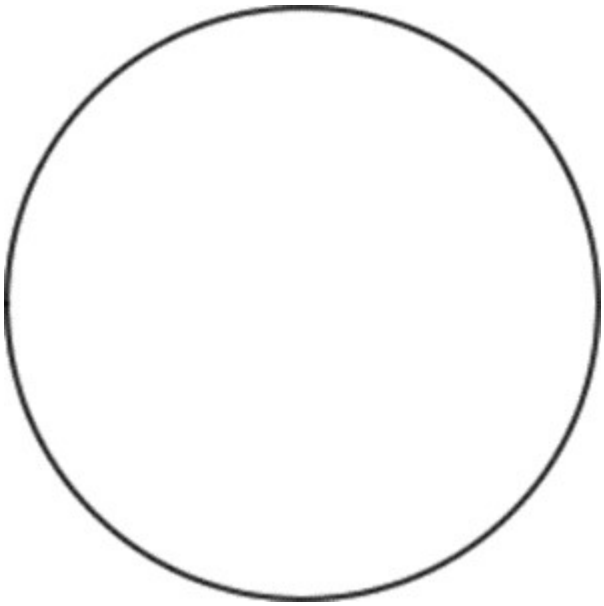
- Compound microscope
- Microscope lens paper
- Microscope lens solution
- Microscope immersion oil
- Slide of Adrenal Section (human) (Figure 17.4)
- Mammal Thyroid and Parathyroid Glands slide (Figure 17.6 thyroid, 17.8 parathyroid)
- Human Pancreas slide (Figure 17.11)
- Slide of Mammal Ovarian Follicles (Figure 17.13)
- Human Testis slide (Figure 17.15)
- Hypophysis (pituitary gland) slide (Figure 17.18)

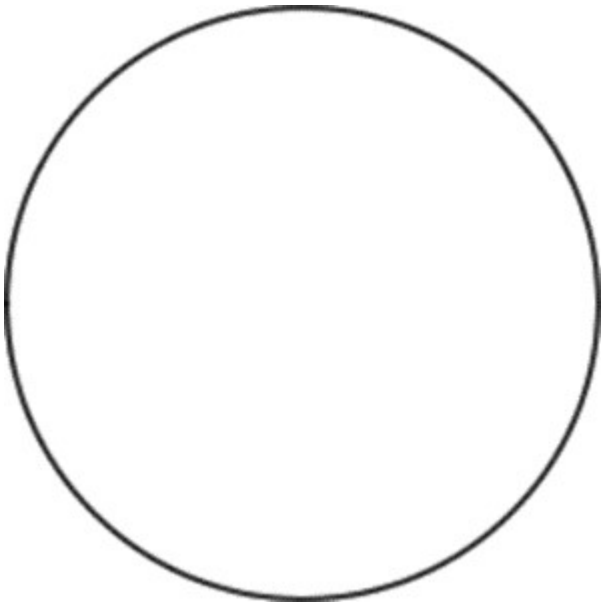
Procedure

For each of the 6 endocrine gland slides listed above, follow these instructions:

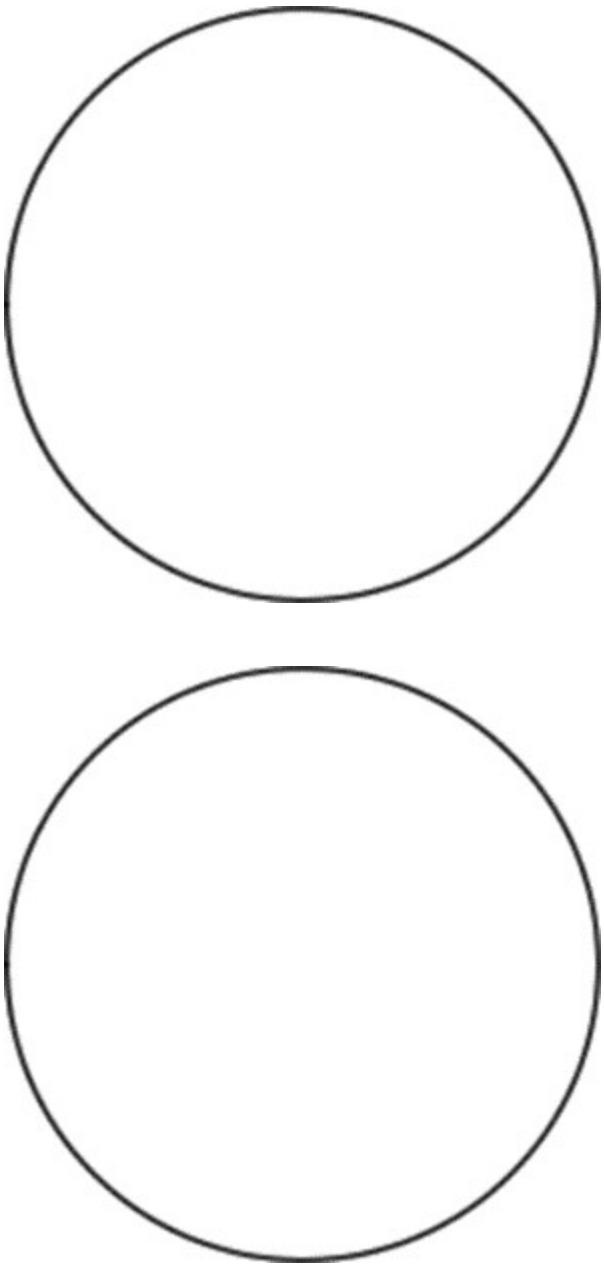
1. Ask your instructor for a prepared slide. Refer to the Figures indicated above for each slide to see what you expect to observe.
2. Place it on the stage of microscope and bring it into focus using low power (4 x 10 magnification).
3. Study tissue on slide. Move slide vertically and horizontally.
4. Change the magnification to high power (10 x 10).
5. Draw the tissues at low and high magnification to show the cell and tissue structure as best as you can. Label.

Adrenal

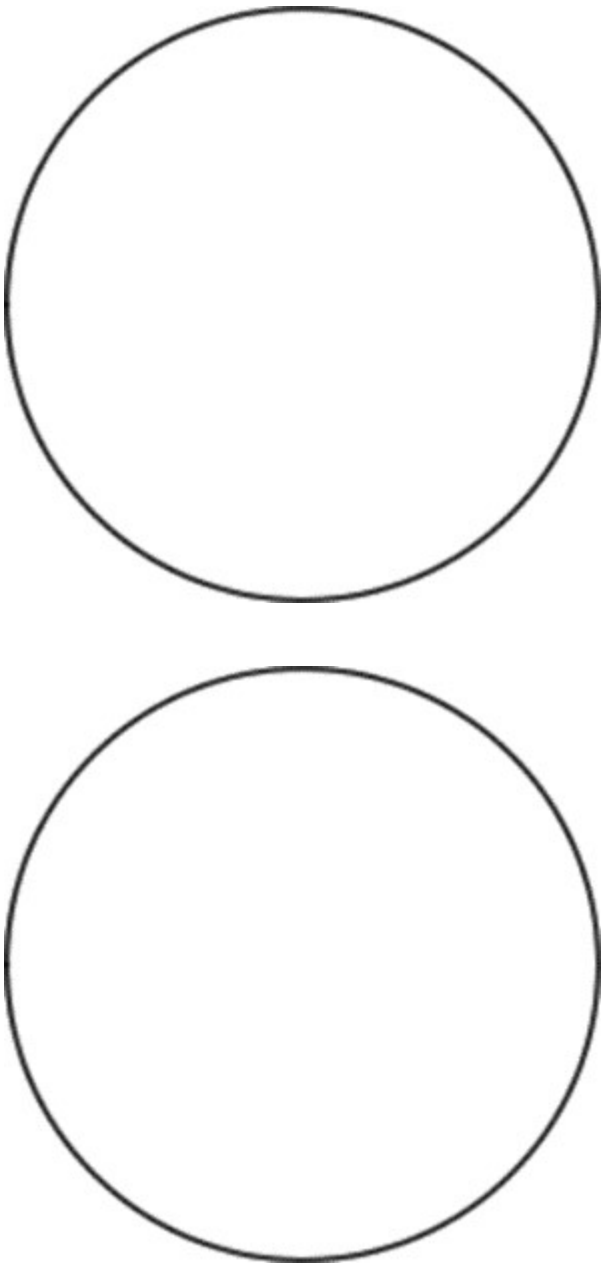




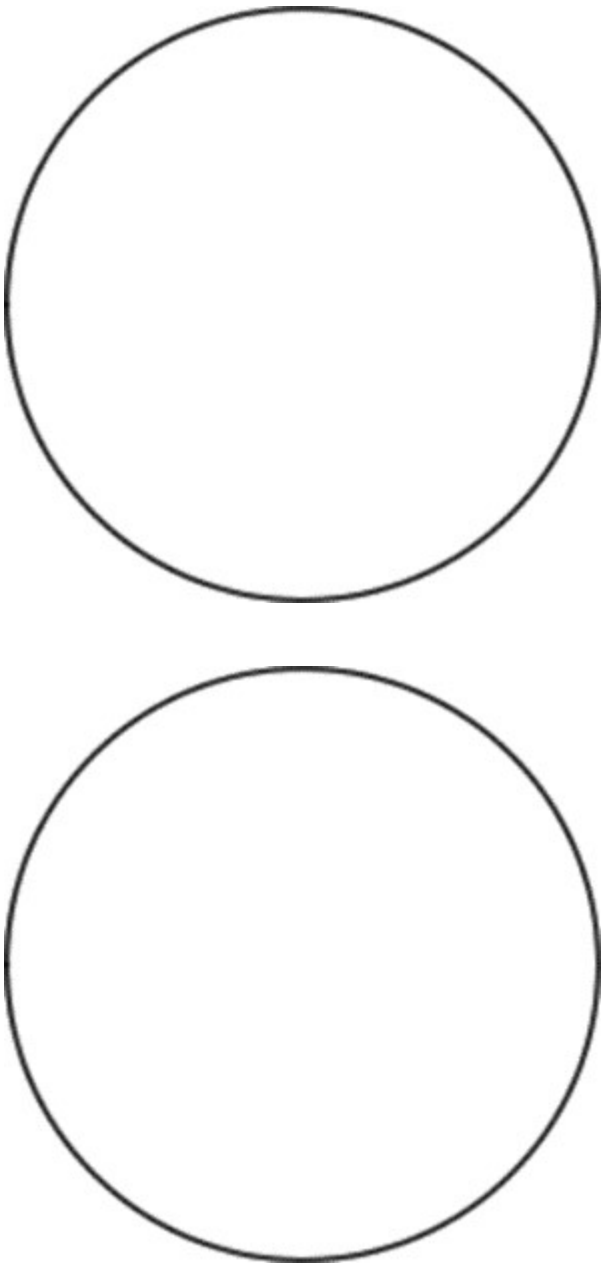
Thyroid



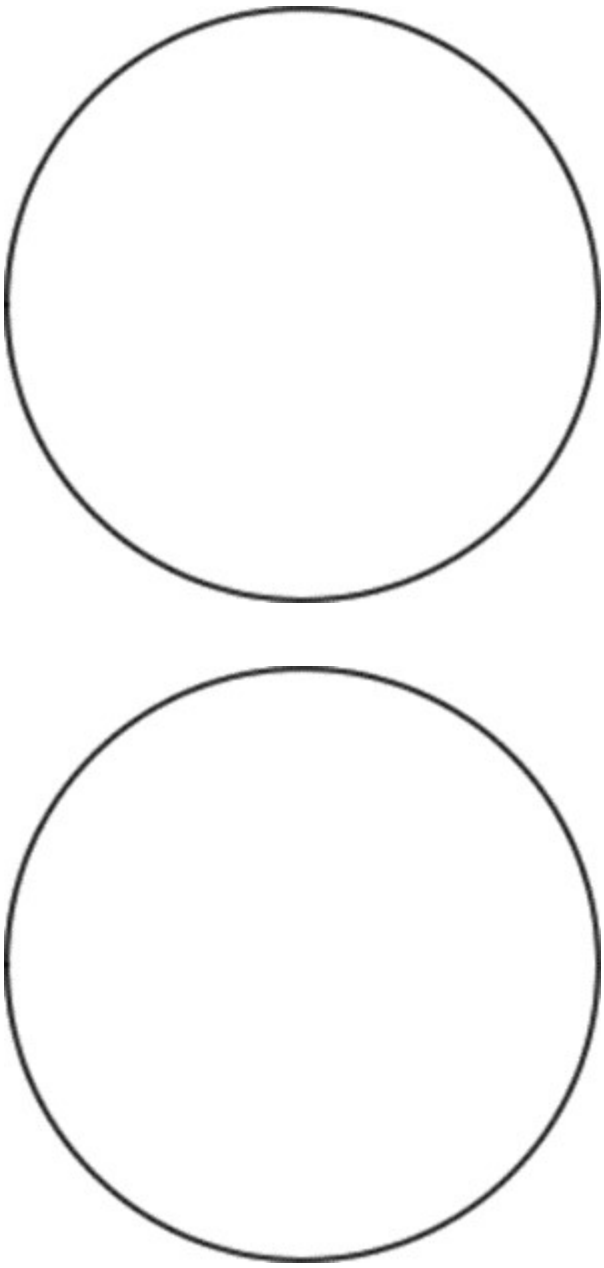
Parathyroid



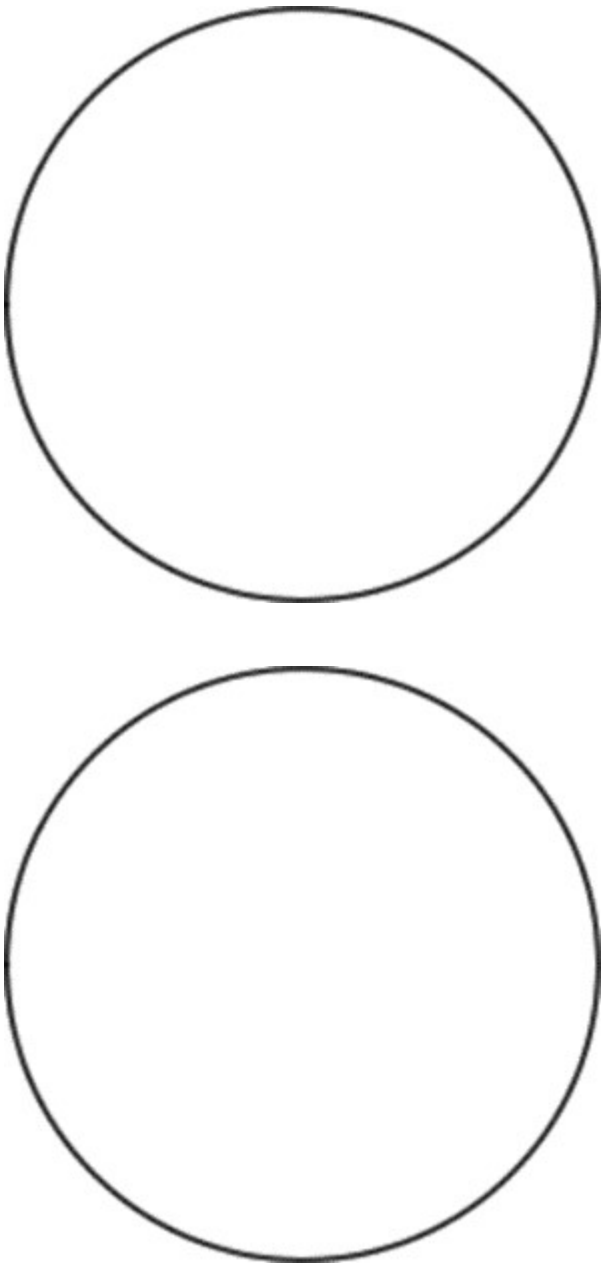
Pancreas



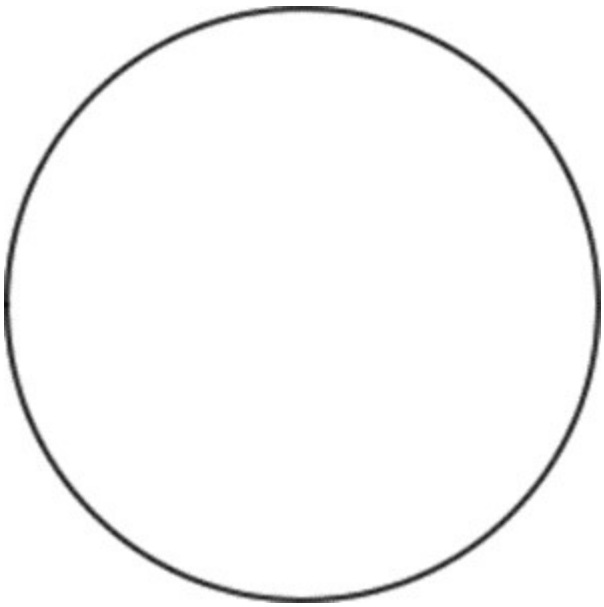
Ovarian follicle

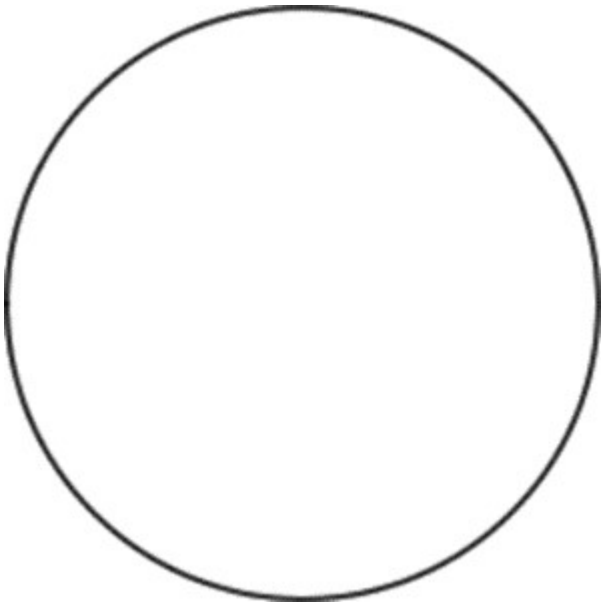


Testis



Hypophysis (pituitary gland)





Post-laboratory Questions

1. **Hormones of the Pancreas.** Fill in the below table with the hormone that is released from each cell type found in the pancreatic islets. In the last column, briefly describe the actions of each hormone.

Cell type	Hormone released	Actions
Alpha cells		
Beta cells		
Delta cells		

2. **Sex Hormones.** Fill in the below table with the hormone that is released from each gonad. Note that there is more than one hormone released from each gonad. In the last column, briefly describe the actions of each hormone.

Gonad	Hormone released	Actions – on gametes and on other cells in the body
Testes		
Ovary		

3. **Summary of Hormone Action.** For each hormone in the left-hand column, fill in the table with the target cells or tissues on which each hormone acts; the effects of the hormones on those target cells or organs; and the stimulus for the release of each hormone.

Thyroid and Parathyroid Hormones			
Hormone	Stimulus for Release	Target Cells / Tissues	Effects
Thyroid Hormones (T3 and T4)			
Calcitonin			
Parathyroid Hormone			

4. **Source, Actions, and Hypothalamic Regulation of the Anterior Pituitary.** Fill in the table with the actions of each hormone, and the name of the hypothalamic hormone(s) that regulate their release.

Pituitary Gland	Cells	Hormones Produced	Action of Hormones	Hypothalamic releasing or inhibiting hormone
Anterior (adenohypophysis)	Acidophils	GH Prolactin		
	Basophils	FSH LH ACTH TSH		
	Chromophobes	NA	NA	NA
Posterior (neurohypophysis)	Axon terminals	ADH		NA
	Axon terminals	Oxytocin		NA

18.

CHAPTER 18 THE CARDIOVASCULAR SYSTEM: BLOOD

By Rajeev Chandra

Motivation.

Sickle cell disease is a group of inherited red blood cell disorders most common in the United States. Approximately 100,000 Americans have the disease. In the United States, sickle cell disease is most prevalent among African Americans. About one in 12 African Americans carry the sickle cell trait, which means they are carriers of the disease.

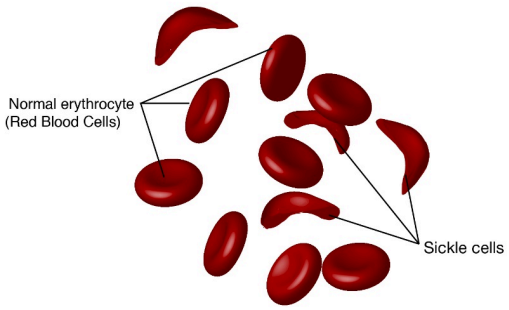


Figure 18.1 Sickle shaped red blood cells found in patients with sickle cell disease. (Credit: National Human Genome Research Institute.https://www.genome.gov/genetics-glossary/Sickle-Cell-Disease, Public Domain license)

Sickle cell disease is caused by a mutation in the hemoglobin-beta gene found on chromosome 11. Hemoglobin transports oxygen from the lungs to other parts of the body. Red blood cells with normal hemoglobin (hemoglobin-A) are smooth and round and glide through blood vessels. In people with sickle cell disease, abnormal hemoglobin molecules – hemoglobin S – stick to one another and form long, rod-like structures. These structures cause red blood cells to become stiff, assuming a sickle shape. Their shape causes these red blood cells to pile up, causing blockages and damaging vital organs and tissue.

Sickle cells are destroyed rapidly in the bodies of people with the disease, causing anemia. This anemia is what gives the disease its commonly known name – sickle cell anemia. The sickle cells also block the flow of blood through vessels, resulting in lung tissue damage that causes acute chest syndrome, pain episodes, stroke and priapism (painful, prolonged erection). It also causes damage to the spleen, kidneys and liver. The damage to the spleen makes patients – especially young children – easily overwhelmed by bacterial infections.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Name the major components of blood and identify the percentage of each present in whole blood.
- Compare and contrast red blood cells, leukocytes, and platelets microscopically
- Classify the white blood cells (leukocytes) based on microscopic structure and function
- Conduct ABO and Rh blood typing on simulated blood samples, and state the importance of this test

Background.

Recall that blood is a connective tissue. Like all connective tissues, it is made up of cellular elements and an extracellular matrix. The cellular elements—referred to as the formed elements—include red blood cells (RBCs), white blood cells (WBCs), and cell fragments called platelets. The extracellular matrix, called plasma, makes blood unique among connective tissues because it is fluid. This fluid, which is mostly water, perpetually suspends the formed elements and enables them to circulate throughout the body within the cardiovascular system.

Functions of Blood

The primary function of blood is to deliver oxygen and nutrients to and remove wastes from body cells, but that is only the beginning of the story. The specific functions of blood also include defense, distribution of heat, and maintenance of homeostasis.

Transportation

Nutrients from the foods you eat are absorbed in the digestive tract. Most of these travel in the bloodstream directly to the liver, where they are processed and released back into the bloodstream for delivery to body cells. Oxygen from the air you breathe diffuses into the blood, which moves from the lungs to the heart, which then pumps it out to the rest of the body. Moreover, endocrine glands scattered throughout the body release their products, called hormones, into the bloodstream, which carries them to distant target cells. Blood also picks up cellular wastes and byproducts, and transports them to various organs for removal. For instance, blood moves carbon dioxide to the lungs for exhalation from the body, and various waste products are transported to the kidneys and liver for excretion from the body in the form of urine or bile.

Defense

Many types of WBCs protect the body from external threats, such as disease-causing bacteria that have entered the bloodstream in a wound. Other WBCs seek out and destroy internal threats, such as cells with mutated DNA that could multiply to become cancerous, or body cells infected with viruses.

When damage to the vessels results in bleeding, blood platelets and certain proteins dissolved in the plasma, the fluid portion of the blood, interact to block the ruptured areas of the blood vessels involved. This protects the body from further blood loss.

Maintenance of Homeostasis

Recall that body temperature is regulated via a classic negative-feedback loop. If you were exercising on a warm day, your rising core body temperature would trigger several homeostatic mechanisms, including increased transport of blood from your core to your body periphery, which is typically cooler. As blood passes through the vessels of the skin, heat would be dissipated to the environment, and the blood returning to your body core would be cooler. In contrast, on a cold day, blood is diverted away from the skin to maintain a warmer body core. In extreme cases, this may result in frostbite.

Blood also helps to maintain the chemical balance of the body. Proteins and other compounds in blood act as buffers, which thereby help to regulate the pH of body tissues. Blood also helps to regulate the water content of body cells.

Composition of Blood

You have probably had blood drawn from a superficial vein in your arm, which was then sent to a lab for analysis. Some of the most common blood tests—for instance, those measuring lipid or glucose levels in plasma—determine which substances are present within blood and in what quantities. Other blood tests check for the composition of the blood itself, including the quantities and types of formed elements.

One such test, called a hematocrit, measures the percentage of RBCs, clinically known as erythrocytes, in a blood sample. It is performed by spinning the blood sample in a specialized centrifuge, a process that causes the heavier elements suspended within the blood sample to separate from the lightweight, liquid plasma (Figure 18.2). Because the heaviest elements in blood are the erythrocytes, these settle at the very bottom of the hematocrit tube. Located above the erythrocytes is a pale, thin layer composed of the remaining formed elements of blood. These are the WBCs, clinically known as leukocytes, and the platelets, cell fragments also called thrombocytes. This layer is referred to as the buffy coat because of its color; it normally constitutes less than 1 percent of a blood sample. Above the buffy coat is the blood plasma, normally a pale, straw-colored fluid, which constitutes the remainder of the sample.

The volume of erythrocytes after centrifugation is also commonly referred to as packed cell volume (PCV). In normal blood, about 45 percent of a sample is erythrocytes. The hematocrit of any one sample can vary significantly, however, about 36–50 percent, according to gender and other factors. Normal hematocrit values for females range from 37 to 47, with a mean value of 41; for males, hematocrit ranges from 42 to 52, with a mean of 47. The percentage of other formed elements, the WBCs and platelets, is extremely small so it is not normally considered with the hematocrit. So the mean plasma percentage is the percent of blood that is not erythrocytes: for females, it is approximately 59 (or 100 minus 41), and for males, it is approximately 53 (or 100 minus 47).

Composition of Blood

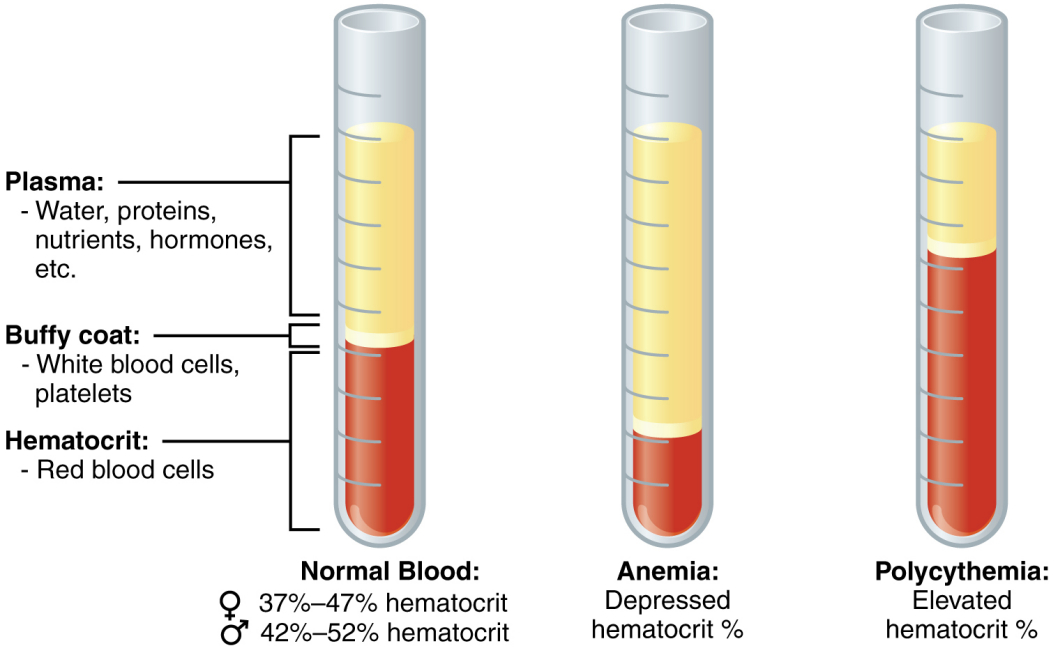


Figure 18.2 The cellular elements of blood include a vast number of erythrocytes and comparatively fewer leukocytes and platelets. Plasma is the fluid in which the formed elements are suspended. A sample of blood spun in a centrifuge reveals that plasma is the lightest component. It floats at the top of the tube separated from the heaviest elements, the erythrocytes, by a buffy coat of leukocytes and platelets. Hematocrit is the percentage of the total sample that is comprised of erythrocytes. Depressed and elevated hematocrit levels are shown for comparison.

Characteristics of Blood

When you think about blood, the first characteristic that probably comes to mind is its color. Blood that has just taken up oxygen in the lungs is bright red, and blood that has released oxygen in the tissues is a more dusky red. This is because hemoglobin is a pigment that changes color, depending upon the degree of oxygen saturation.

Blood is viscous and somewhat sticky to the touch. It has a viscosity approximately five times greater than water. Viscosity is a measure of a fluid's thickness or resistance to flow, and is influenced by the presence of the plasma proteins and formed elements within the blood. The viscosity of blood has a dramatic impact on blood pressure and flow. Consider the difference in flow between water and honey. The more viscous honey would demonstrate a greater resistance to flow than the less viscous water. The same principle applies to blood.

The normal temperature of blood is slightly higher than normal body temperature—about 38 °C (or 100.4 °F), compared to 37 °C (or 98.6 °F) for an internal body temperature reading, although daily variations of 0.5 °C are normal. Although the surface of blood vessels is relatively smooth, as blood flows through them, it experiences some friction and resistance, especially as vessels age and lose their elasticity, thereby producing heat. This accounts for its slightly higher temperature.

The pH of blood averages about 7.4; however, it can range from 7.35 to 7.45 in a healthy person. Blood

is therefore somewhat more basic (alkaline) on a chemical scale than pure water, which has a pH of 7.0. Blood contains numerous buffers that actually help to regulate pH.

Blood constitutes approximately 8 percent of adult body weight. Adult males typically average about 5 to 6 liters of blood. Females average 4–5 liters.

Blood Plasma

Like other fluids in the body, plasma is composed primarily of water: In fact, it is about 92 percent water. Dissolved or suspended within this water is a mixture of substances, most of which are proteins. There are literally hundreds of substances dissolved or suspended in the plasma, although many of them are found only in very small quantities.

Visit this site for a list of normal levels established for many of the substances found in a sample of blood. Serum, one of the specimen types included, refers to a sample of plasma after clotting factors have been removed. What types of measurements are given for levels of glucose in the blood?

Plasma Proteins

About 7 percent of the volume of plasma—nearly all that is not water—is made of proteins. These include several plasma proteins (proteins that are unique to the plasma), plus a much smaller number of regulatory proteins, including enzymes and some hormones.

The three major groups of plasma proteins are as follows:

- Albumin is the most abundant of the plasma proteins. Manufactured by the liver, albumin molecules serve as binding proteins—transport vehicles for fatty acids and steroid hormones. Recall that lipids are hydrophobic; however, their binding to albumin enables their transport in the watery plasma. Albumin is also the most significant contributor to the osmotic pressure of blood; that is, its presence holds water inside the blood vessels and draws water from the tissues, across blood vessel walls, and into the bloodstream. This in turn helps to maintain both blood volume and blood pressure. Albumin normally accounts for approximately 54 percent of the total plasma protein content, in clinical levels of 3.5–5.0 g/dL blood.
- The second most common plasma proteins are the globulins. A heterogeneous group, there are three main subgroups known as alpha, beta, and gamma globulins. The alpha and beta globulins transport iron, lipids, and the fat-soluble vitamins A, D, E, and K to the cells; like albumin, they also contribute to osmotic pressure. The gamma globulins are proteins involved in immunity and are better known as an antibodies or immunoglobulins. Although other plasma proteins are produced by the liver, immunoglobulins are produced by specialized leukocytes known as plasma cells. (Seek additional content for more information about immunoglobulins.) Globulins make up approximately 38 percent of the total plasma protein volume, in clinical levels of 1.0–1.5 g/dL blood.
- The least abundant plasma protein is fibrinogen. Like albumin and the alpha and beta globulins, fibrinogen is produced by the liver. It is essential for blood clotting, a process described later in this chapter. Fibrinogen accounts for about 7 percent of the total plasma protein volume, in clinical levels of 0.2–0.45 g/dL blood.

Other Plasma Solutes. In addition to proteins, plasma contains a wide variety of other substances. These include various electrolytes, such as sodium, potassium, and calcium ions; dissolved gases, such as oxygen, carbon dioxide, and nitrogen; various organic nutrients, such as vitamins, lipids, glucose, and amino acids; and metabolic wastes. All of these nonprotein solutes combined contribute approximately 1 percent to the total volume of plasma.

The components of whole blood are **plasma** (the liquid matrix), accounting for 55% of the volume, and the **formed elements** (red blood cells, white blood cells and platelets), which account for the remaining 45% of volume. Plasma is a straw-colored liquid consisting of 90% water, salts and proteins that are important for maintaining osmotic balance, buffering against pH changes, maintaining blood viscosity, transporting certain materials, and for blood clotting when a blood vessel is injured. There are three major formed elements – **red blood cells (erythrocytes)**, **white blood cells (leukocytes),** and **platelets (which are cell fragments)**.

Red blood cells, the most numerous cells in the blood, carry oxygen from the lungs to all parts of the body. A red blood cells is a biconcave disk with a thin center, a shape that provides a large surface area for efficient diffusion of oxygen, and the flexibility to pass through even the smallest blood vessels. Red blood cells contain the protein **hemoglobin** which has an iron ion incorporated into its structure. When blood travels through the lungs, the oxygen in the lungs combines with the iron in the hemoglobin. When the blood moves through the body's capillary system, the oxygen carried in the red blood cells is released from the iron to the other cells of the body.

White blood cells make up only about 1% pf the blood volume. They are an important part of the immune system. Their primary function is to provide defense against invaders in the body, which may include bacterial, parasites, fungi, and viruses. White blood cells may attack a foreign body directly, produce antibodies that identify, attach to and neutralize a foreign body, or they may trigger other cells to act in destroying the foreign body.

Platelets perform a vital function in the process of coagulation, or blood clotting, which occurs when a blood vessel is injured.

FORMED ELEMENTS

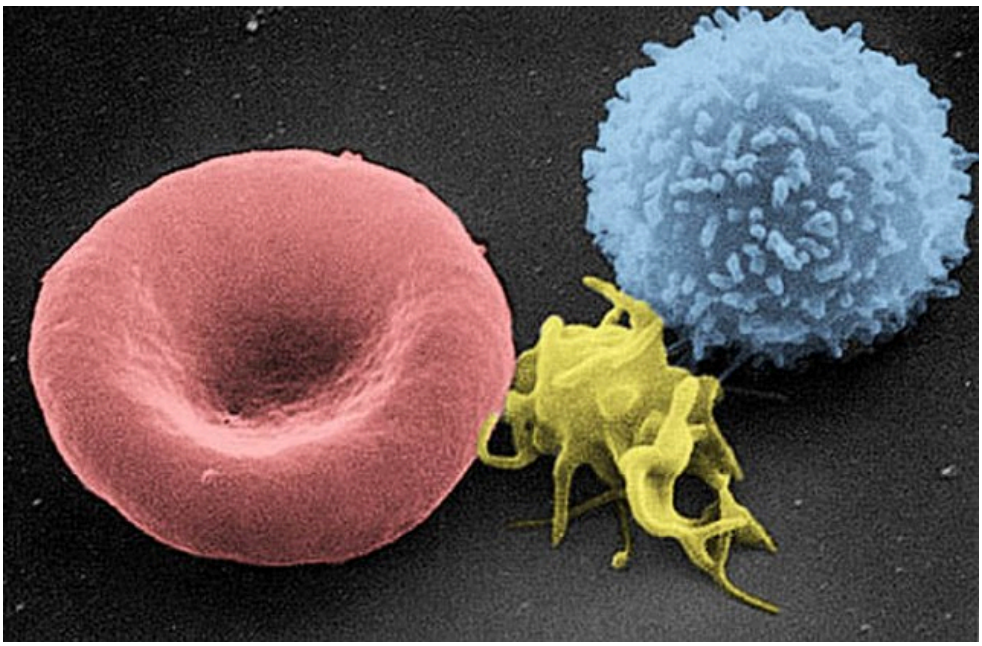


Figure 18.3 Formed elements of blood. Electron micrograph; red: erythrocyte (red blood cell), blue: leukocyte (white blood cell), yellow: thrombocyte (platelet). Credit: Electron Microscopy Facility at National Cancer Institute at Frederick (NCI-Frederick), license Public Domain.

Erythrocytes (Red Blood Cells)

Erythrocytes are the cells that carry oxygen to tissues and waste products (like CO2) back to the lungs. They have a unique, biconcave-disk shape that is reminiscent of an old-timey cough drop: thin in the center, but thicker at the periphery. Erythrocytes have no nuclei and almost no organelles, but do contain large amounts of the oxygen-binding protein **hemoglobin**. Some estimates indicate there are as many as 300 million hemoglobin molecules per red blood cell. Erythrocytes are the most numerous formed elements.

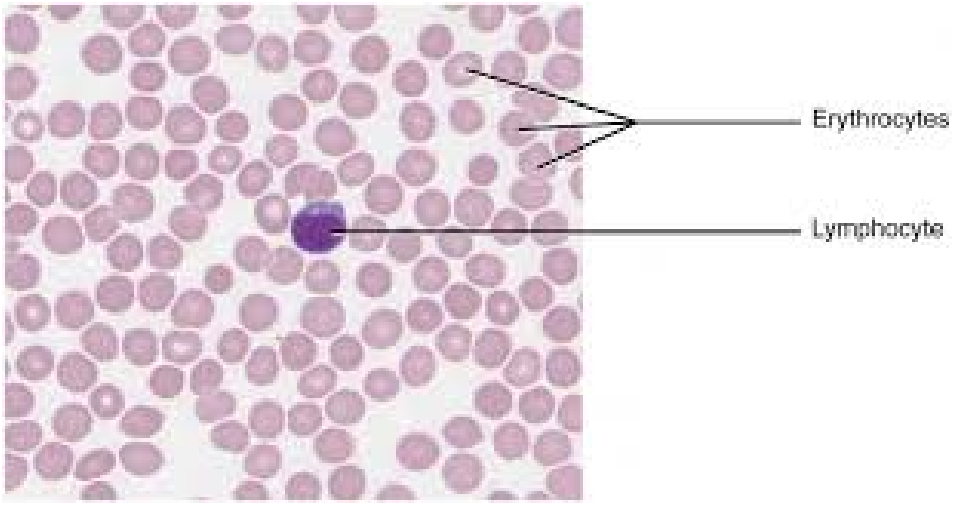


Figure 18.4. Blood smear showing red blood cells (erythrocytes) and one type of leukocyte called lymphocyte. Wrights' stain.

Leukocytes (White Blood Cells)

Leukocytes are usually divided into two groups, based on the presence of granules that appear in the cytoplasm when stained: **granular leukocytes** (which contain granules), and **agranular leukocytes** (without granules). Leukocytes have immune functions.

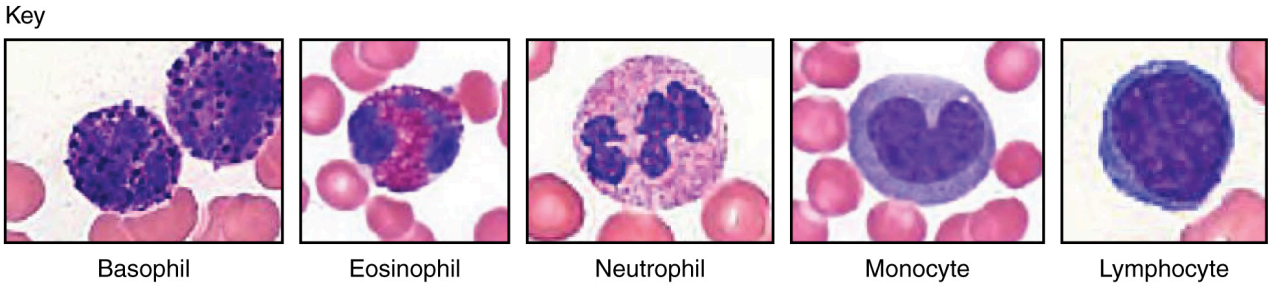


Figure 18.5 Different types of leukocytes. Granulocytes: basophil, eosinophil, neutrophil; agranulocytes: monocyte, lymphocyte.

Agranular leukocytes: Lymphocytes

Lymphocytes are small cells that are notable for the large, darkly staining nucleus surrounded by a thin crescent of cytoplasm. These are the second-most numerous leukocytes.

Agranular leukocytes: Monocytes

Monocytes are large cells that have a large, horseshoe shaped or U-shaped nucleus. The surrounding cytoplasm tends to be light blue when stained.

Granular leukocytes: Neutrophils.

Neutrophils are so named because they do not interact strongly with a dye (hence, NEUTR-ophils). The cytoplasm may have a pink-ish or purplish tint and the granules may be pink or purple. They are notable for their multi-lobed nuclei in mature cells (although less-mature cells may have a horseshoe or U-shaped nuclei, making them difficult to distinguish from monocytes).Neutrophils are the most common leukocyte.

Granular leukocytes: Eosinophils

Eosinophils interact strongly with the acidic dye eosin, which stains the granules an orange color (and give them their name, EOSIN-ophils). The nuclei of eosinophils are lobed, like neutrophils, but the bright red-orange granules make these cells distinctive.

Granular leukocytes: Basophils

Basophils are small cells that interact strongly with basic dye (and so are named BAS-ophils), which stains the granules in the cytoplasm a dark blue color. The nuclei are often not visible through the dark granules. Basophils are the lease numerous leukocytes.

Platelets

Platelets are not cells, but rather cell fragments and thus are quite small. They have no organelles or nuclei, and they cytoplasm often stains purple or blue. They contain granules which may also stain dark blue or purple. Platelets play important roles in blood clotting.

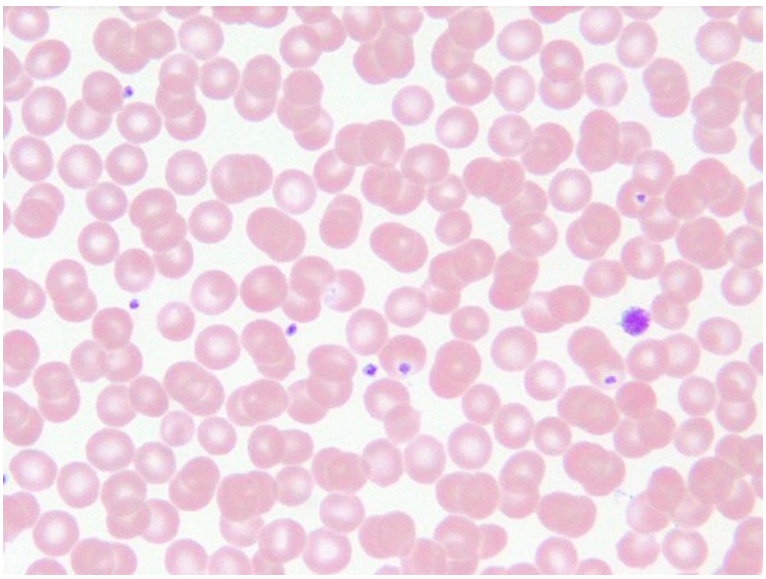


Figure 18.6 Thrombocytes (platelets) and erythrocytes (red blood cells). Platelets are very small and purple. Credit: Wikimedia Commons, license CC-BY-SA

Summary: Below is a table of the appearance and functions of the formed elements in the blood (Figure 18.7).

Formed element	Major subtypes	Numbers present per microliter (μL) and mean (range)	Appearance in a standard blood smear	Summary of functions	Comments
Erythrocytes (red blood cells)		5.2 million (4.4–6.0 million)	Flattened biconcave disk; no nucleus; pale red color	Transport oxygen and some carbon dioxide between tissues and lungs	Lifespan of approximately 120 days
Leukocytes (white blood cells)		7000 (5000–10,000)	Obvious dark-staining nucleus	All function in body defenses	Exit capillaries and move into tissues; lifespan of usually a few hours or days
	Granulocytes including neutrophils, eosinophils, and basophils	4360 (1800–9950)	Abundant granules in cytoplasm; nucleus normally lobed	Nonspecific (innate) resistance to disease	Classified according to membrane-bound granules in cytoplasm
	Neutrophils	4150 (1800–7300)	Nuclear lobes increase with age; pale lilac granules	Phagocytic; particularly effective against bacteria. Release cytotoxic chemicals from granules	Most common leukocyte; lifespan of minutes to days
	Eosinophils	165 (0–700)	Nucleus generally two-lobed; bright red-orange granules	Phagocytic cells; particularly effective with antigen- antibody complexes. Release antihistamines. Increase in allergies and parasitic infections	Lifespan of minutes to days
	Basophils	44 (0–150)	Nucleus generally two-lobed but difficult to see due to presence of heavy, dense, dark purple granules	Promotes inflammation	Least common leukocyte; lifespan unknown
	Agranulocytes including lymphocytes and monocytes	2640 (1700–4950)	Lack abundant granules in cytoplasm; have a simple-shaped nucleus that may be indented	Body defenses	Group consists of two major cell types from different lineages
	Lymphocytes	2185 (1500–4000)	Spherical cells with a single often large nucleus occupying much of the cell's volume; stains purple; seen in large (natural killer cells) and small (B and T cells) variants	Primarily specific (adaptive) immunity: T cells directly attack other cells (cellular immunity); B cells release antibodies (humoral immunity); natural killer cells are similar to T cells but nonspecific	Initial cells originate in bone marrow, but secondary production occurs in lymphatic tissue; several distinct subtypes; memory cells form after exposure to a pathogen and rapidly increase responses to subsequent exposure; lifespan of many years
	Monocytes	455 (200–950)	Largest leukocyte with an indented or horseshoe-shaped nucleus	Very effective phagocytic cells engulfing pathogens or worn out cells; also serve as antigen-presenting cells (APCs) for other components of the immune system	Produced in red bone marrow; referred to as macrophages after leaving circulation
Platelets		350,000 (150,000–500,000)	Cellular fragments surrounded by a plasma membrane and containing granules; purple stain	Hemostasis plus release growth factors for repair and healing of tissue	Formed from megakaryocytes that remain in the red bone marrow and shed platelets into circulation

Figure 18.7 Characteristics of the formed elements of blood.

Blood Types and Blood Typing

In this exercise, you will determine the blood type of four different synthetic blood samples using antisera to the A, B, and Rh (D) antigens that exist on human red blood cells. The procedure for the blood test is the same that would be used for a real blood test, but for convenience and safety, the blood and antisera are synthetic and contain no biological materials.

Blood Types

Although the basic composition and function of blood in each of us is the same, there are different human blood types. The cell membrane of red blood cells, like that of other cells, has molecules that project from its surface. Some of the molecules function as identification badges, allowing the immune system to recognize the cell as normal component of an individual's body. If blood from a person whose red cells have different surface molecules is injected into someone, those molecules are recognized as foreign to the body, or antigenic. The immune system attacks the antigens and attempts to destroy them and the cells that carry them. This is why transfusion with an incompatible blood type is harmful. The recipient's body recognizes the antigens on the transfused red blood cells as foreign and attacks and destroys the cells. For that reason, donated blood is thoroughly tested for A, B, O and Rh antigens, and is transfused only into compatible recipients.

The ABO Blood Groups

The ABO blood groups (types) result from the presence or absence of two antigens, A and B, on the surface of the red blood cells. If antigens are present very early in life, the immune system recognizes those antigens as "self" and will not generate an immune response to them. As a result, the body does not generate antibodies to any A and B antigens present on its own blood cells. However, the immune system does produce antibodies to any A and B blood antigens not present on the organism's own cells. Type A blood has the A antigen on its red blood cells and anti-B antibodies in the plasma. Type B blood has the B antigen on its red blood cells and A antibodies in the plasma. Type AB blood has both A and B antigens on the red blood cells and no antibodies in the plasma. Finally, type O blood has neither A nor B antigens on the red blood cells and both A and B antibodies in the plasma. These antibodies are present even if the person has not had any foreign blood introduced into their body. It is hypothesized that the antibodies are present because of similarity between the A and B blood antigens and other antigens present in the environment. If two antigens are similar enough, the antibodies generated to one antigen will also recognize the other.

The relationships of the ABO blood types to the presence of antigens and antibodies in the blood are summarized in the table that follows.

Blood Group	Antigen Present on RBCs	Antibody Present in Plasma
A	A	Anti-B
B	B	Anti-A
AB	A and B	Neither anti-A nor anti-B
O	Neither A nor B	Both anti-A and anti-B

The Rh Blood Groups

Another important antigen found on the surface of blood cells is the Rh factor. The Rh antigen is actually a whole group of closely related antigens. Blood containing an Rh antigen is said to be Rh positive (Rh+); blood lacking the antigen is said to be Rh negative (Rh-). Unlike the case for the ABO antigens, the production of Rh antibody requires prior exposure to the antigen, such as would occur in an Rh- pregnant woman carrying a fetus that was Rh+.

Pre-Laboratory Questions

After reviewing the background information, please answer the following questions.

1.Which of the following statements about blood is true?

Blood is about 92 percent water.
Blood is slightly more acidic than water.
Blood is slightly more viscous than water.
Blood is slightly more salty than seawater.

2.Which of the following statements about albumin is true?

It draws water out of the blood vessels and into the body's tissues.
It is the most abundant plasma protein.
It is produced by specialized leukocytes called plasma cells.
All of the above are true.

3.Which of the following plasma proteins is *not* produced by the liver?

fibrinogen
alpha globulin
beta globulin
immunoglobulin

4. Why would it be incorrect to refer to the formed elements as cells?

5. True or False: The buffy coat is the portion of a blood sample that is made up of its proteins.

Exercises

- Exercise 1 Microscopy of formed elements on a prepared blood smear
- Exercise 2 Identifying the properties of formed elements
- Exercise 3 ABO-Rh blood typing with synthetic blood
- Exercise 4 Predicting the reactions of individual blood types with various anti-sera

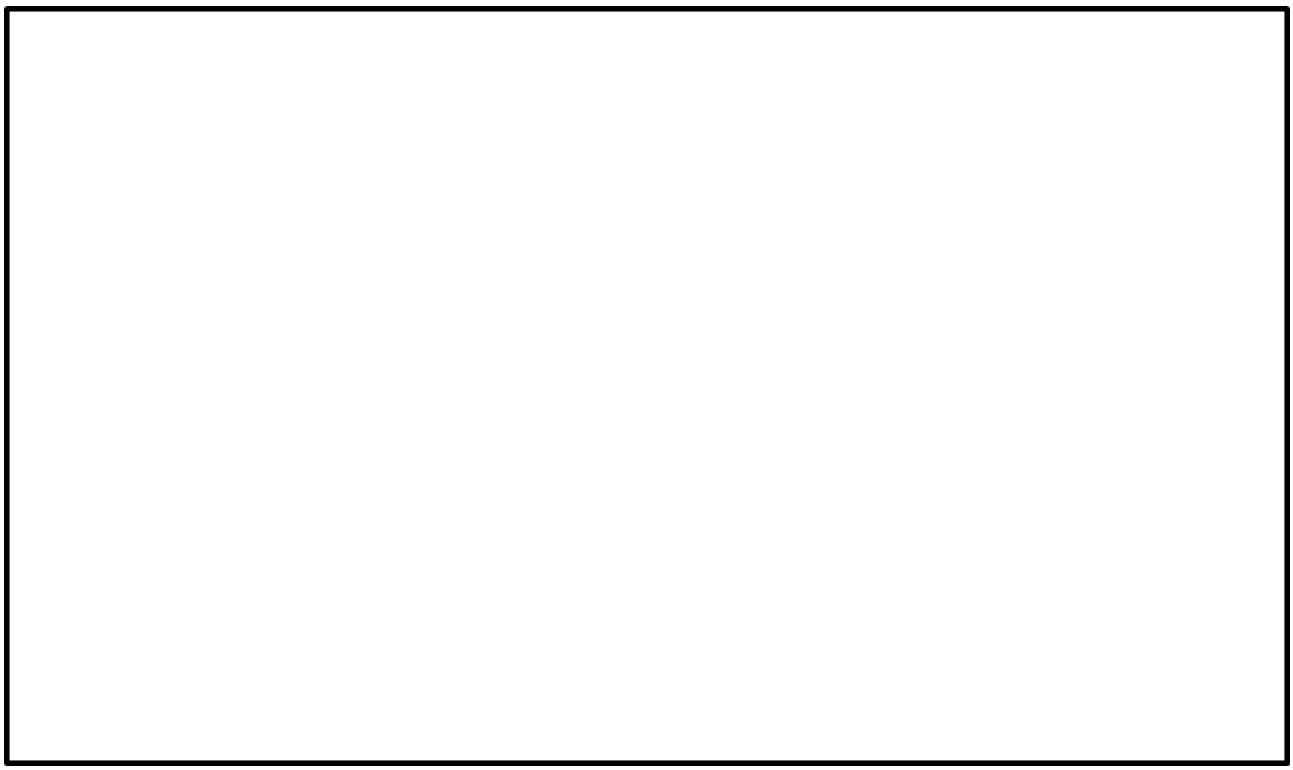
Exercise 1 Microscopy of formed elements on a prepared blood smear

Required Materials

- Compound microscope
- Microscope lens paper
- Microscope lens solution
- Microscope immersion oil
- Human Blood Wright's smear
- Blood Cell Model

Procedure

1. Ask your instructor for a prepared blood smear slide with Wright's stain.
2. Refer to the Figures 18.4, 18.5, 18.6 for what you expect to see.
3. Place the on the stage of microscope and bring it into focus using low power (4 x 10 magnification).
4. Change the magnification to high power (10 x 10), followed by 40 x 10. Focus. Flip objective so that the slide is between the 40x and 100x objective.
5. Add a drop of immersion oil onto the coverslip.
6. Click the 100x objective onto the drop of oil. Use the fine focus adjustment to focus.
7. Draw the formed elements at this 100 x 10 magnification.
8. Identify the following formed elements based on the illustrations provided in the table. Note that some elements will be much easier to locate than others due to their relative abundance in whole blood: **Basophils, Eosinophils, Erythrocytes, Lymphocytes, Monocytes, Neutrophils and Platelets.**
9. Sketch and label each formed element you observe in the space below.



Exercise 2 Identifying the properties of formed elements

Using the data collected from the microscopic observation of prepared human blood smear slide and included tabulated information on formed elements, complete the following table of information on formed elements of blood.

Formed Element	Nucleus Shape or Appearance	Other Features of the Cytoplasm / Granules	Functions
Erythrocyte			
Basophil			
Eosinophil			
Lymphocyte			
Monocyte			
Neutrophil			

Exercise 3 ABO-Rh blood typing with synthetic blood

Required Materials

- Understanding Blood Type Interactions Kit (Aldon IS3103)
  - Simulated blood samples (4), in dropper vials
  - Simulated anti-A, anti-B, and anti-Rh serum, in dropper vials
  - Plastic well plates for blood typing
  - Plastic toothpicks for stirring

Procedure

Video of procedure

1. Using the dropper vial, place a drop of Sample 1 in each well of the blood typing well plate.
2. To prevent contamination, always close the cap on one vial before opening the next vial.

   - Add a drop of anti-A serum to well A. Close the cap.
   - Add a drop of anti-B serum to well B. Close the cap.
   - Add a drop of anti-Rh serum (anti-D) to well Rh. Close the cap.

3. Using a different mixing stick for each well, gently stir the synthetic blood and antiserum drops for 30 seconds. Remember to use a new mixing stick for each sample to avoid contamination of our samples. Carefully examine the resulting thin films of liquid in each well. If a film is uniform in appearance there is no agglutination. If the sample appears granular, agglutination has occurred.
4. Enter your results in the following data table. Enter YES if agglutination has occurred, NO if there is no agglutination. Get a clean slide and repeat the above steps for samples 2 – 4.

Data Table – Results of mixing synthetic blood samples with various anti-serums.

	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**
Anti-A serum				
Anti-B serum				
Anti-Rh serum				
Blood type?				

Exercise 4 Predicting the reactions of individual blood types with various anti-sera

Fill in the table with predictions. Indicate whether you expect to see **agglutination** ("clumping") or **no agglutination** when each of the following blood types is mixed with each anti-serum. (Anti-serum contains antibodies, so anti-A antiserum contains anti-A antibodies, anti-B antiserum contains anti-B antibodies, and anti-Rh serum contains anti-Rh antibodies)

Data Table – Predicted reactions when different blood types are mixed with various anti-sera.

Blood type	When mixed with anti-A serum....	When mixed with anti-B serum...	When mixed with anti-Rh serum...
A+			
A –			
B+			
B-			
AB+			
AB-			
O+			
O-			

Post-laboratory Questions

1. Which of the following statements about mature, circulating erythrocytes is true?
    a. They have no nucleus.
    b. They are packed with mitochondria.
    c. They survive for an average of 4 days.
    d. All of the above
2. The production of healthy erythrocytes depends upon the availability of _____.
    a. copper
    b. zinc
    c. vitamin B12
    d. copper, zinc, and vitamin B12
3. Which of the following describes a neutrophil?
    a. abundant, agranular, especially effective against cancer cells

b. abundant, granular, especially effective against bacteria

c. rare, agranular, releases antimicrobial defensins

d. rare, granular, contains multiple granules packed with histamine

4. A patient has been experiencing severe, persistent allergy symptoms that are reduced when she takes an antihistamine. Before the treatment, this patient was likely to have had increased activity of which leukocyte?

a. basophils

b. neutrophils

c. monocytes

d. natural killer cells

5. Thrombocytes are more accurately called _____.

a. clotting factors

b. megakaryoblasts

c. megakaryocytes

d. platelets

6. The process by which leukocytes squeeze through adjacent cells in a blood vessel wall is called _____.

a. leukocytosis

b. positive chemotaxis

c. emigration

d. cytoplasmic extending

7. The process in which antibodies attach to antigens, causing the formation of masses of linked cells, is called _____.

a. sensitization

b. coagulation

c. agglutination

d. hemolysis

8. People with ABO blood type O _____.

a. have both antigens A and B on their erythrocytes

b. lack both antigens A and B on their erythrocytes

c. have neither anti-A nor anti-B antibodies circulating in their blood plasma

d. are considered universal recipients

9. Hemolytic disease of the newborn is a risk during a subsequent pregnancy in which _____.

a. a type AB mother is carrying a type O fetus

b. a type O mother is carrying a type AB fetus

c. an Rh+ mother is carrying an Rh– fetus

d. an Rh– mother is carrying a second Rh+ fetus

10. Hemophilia is characterized by _____.

a. inadequate production of heparin

b. inadequate production of clotting factors

c. excessive production of fibrinogen
d. excessive production of platelets

19.

CHAPTER 19 THE CARDIOVASCULAR SYSTEM: THE HEART

By Aylin Marz

Motivation.

Heart disease is the number one cause of death in the U.S.racial and ethnic disparities observed in heart disease deaths also shows a disproportionately higher number of deaths due to heart disease are in Black, non-Hispanic persons. Some risk factors such as obesity, hypertension, diabetes, and high cholesterol that contribute to heart disease deaths are disproportionately higher in African American communities. Both biological factors and non-biological societal issues contribute to these disparities. As health practitioners in your communities, it is very important to be aware of the risks facing your patients and advise them for heart-healthy lifestyles. Caring and good choices can lower risk.

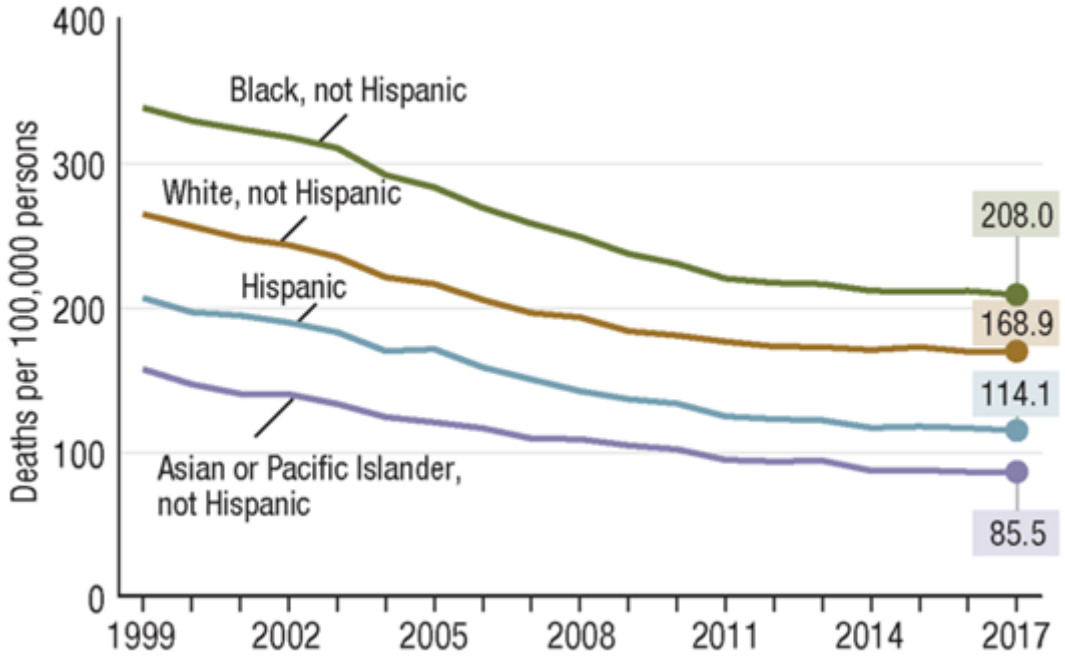


Figure 19.1 Death Rates for Heart Disease by Race. (Credit: Centers for Disease Control, Health, United States Spotlight, Racial and Ethnic Disparities in Heart Disease. April 2019. Public Domain License)

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Dissect a pig's or sheep's heart and label the main chambers, valves, vessels, and other structures.
- Identify and trace the path of blood flow through the heart using the dissected heart
- Relate electrocardiogram (ECG) peaks to the electrical activity, systole/diastole of the heart chambers, and the "lub" and "dub" sounds of the heart beat
- Compare the ECG of a normal heart to a diseased heart's ECG

Background.

Heart Anatomy. The heart resides within the pericardial sac and is located in the mediastinal space within the thoracic cavity (Figure 19.2).

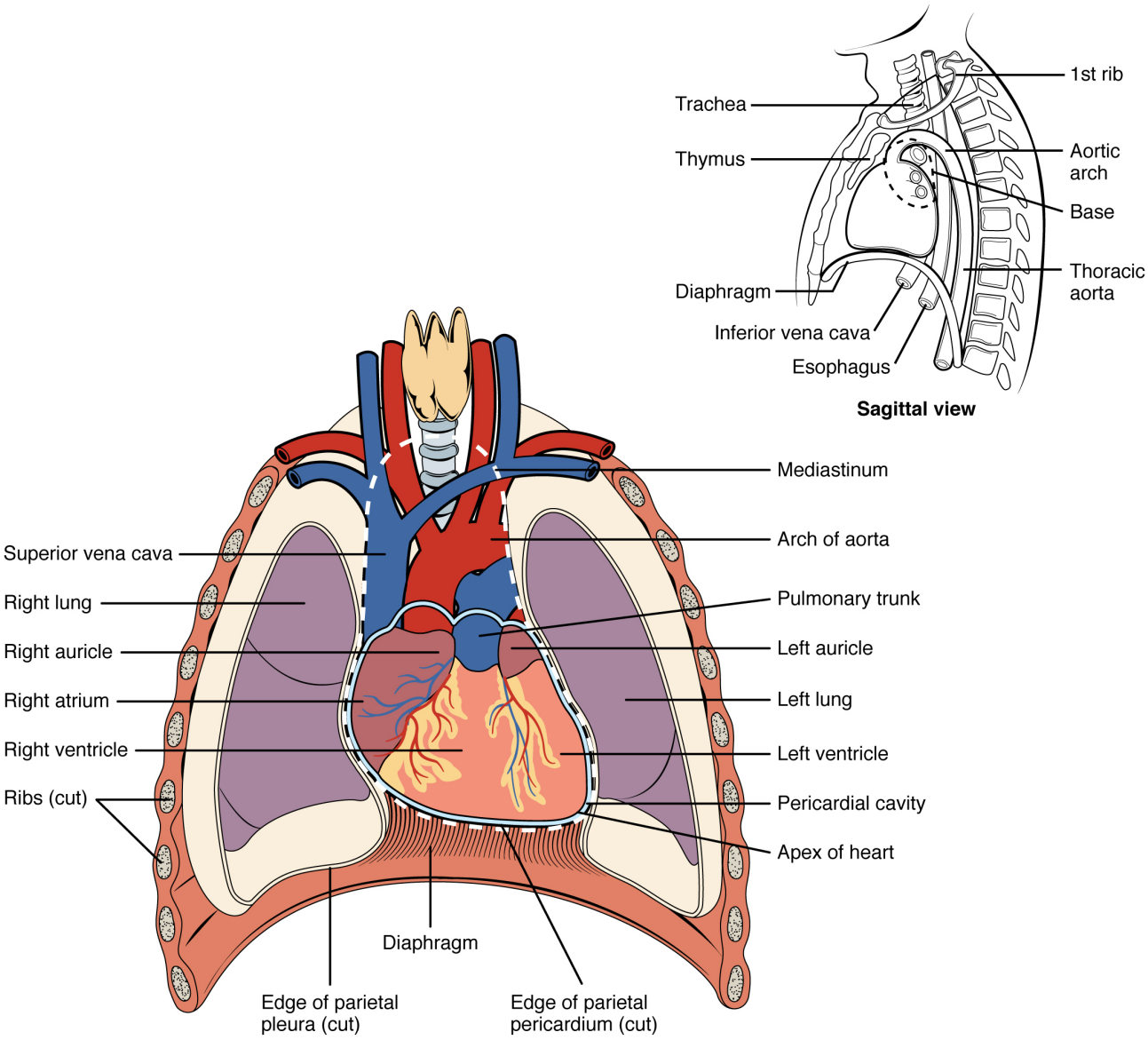


Figure 19.2 Position of the Heart. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

The pericardial sac consists of two fused layers: an outer fibrous capsule and an inner parietal pericardium lined with a serous membrane. Between the pericardial sac and the heart is the pericardial cavity, which is filled with lubricating serous fluid. The walls of the heart are composed of an outer epicardium, a thick myocardium (cardiac muscle layer), and an inner lining layer of endocardium (Figure 19.3).

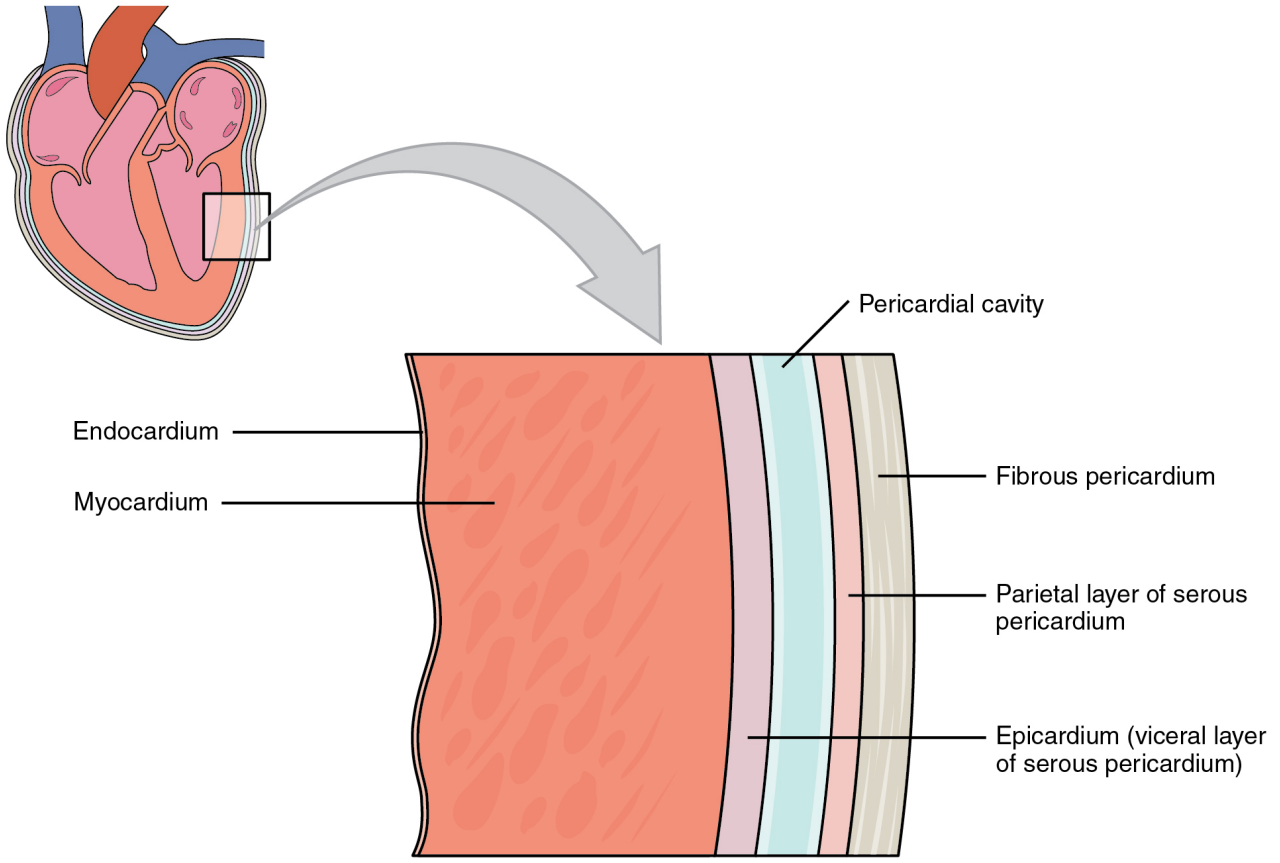


Figure 19.3 Membranes and Layers of the Heart.(Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

The human heart consists of a pair of atria, which receive blood and pump it into a pair of ventricles, which pump blood into the vessels. The right atrium receives systemic blood relatively low in oxygen and pumps it into the right ventricle, which pumps it into the pulmonary circuit. Exchange of oxygen and carbon dioxide occurs in the lungs, and blood high in oxygen returns to the left atrium, which pumps blood into the left ventricle, which in turn pumps blood into the aorta and the remainder of the systemic circuit. The septa are the partitions that separate the chambers of the heart. They include the interatrial septum, the interventricular septum, and the atrioventricular septum. Two of these openings are guarded by the atrioventricular valves, the right tricuspid valve and the left mitral valve, which prevent the backflow of blood. Each is attached to chordae tendineae that extend to the papillary muscles, which are extensions of the myocardium, to prevent the valves from being blown back into the atria. The pulmonary valve is located at the base of the pulmonary trunk, and the left semilunar valve is located at the base of the aorta (Figure 19.4).

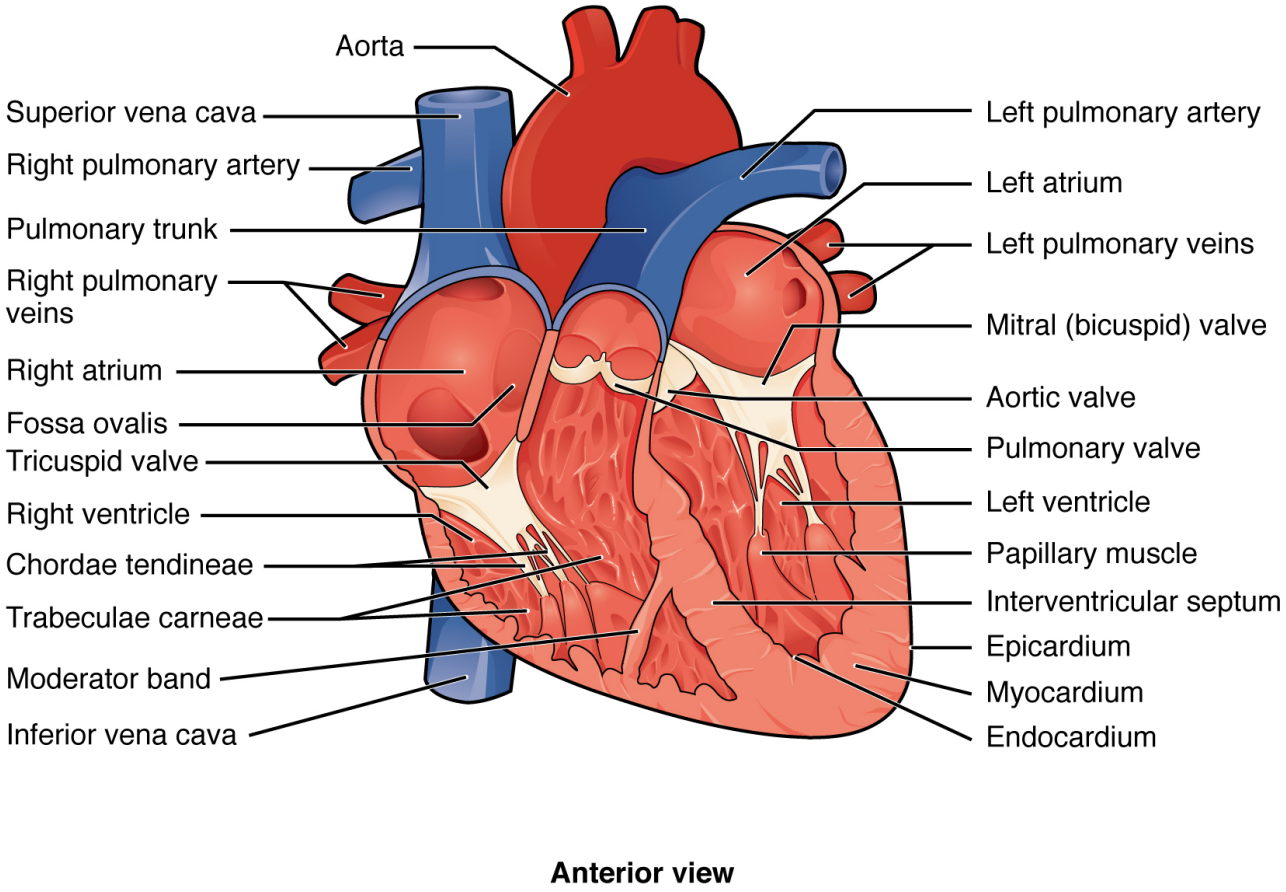


Figure 19.4 Internal Structures of the Heart. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

The right and left coronary arteries are the first to branch off the aorta and arise from two of the three sinuses located near the base of the aorta and are generally located in the sulci. Cardiac veins parallel the small cardiac arteries and generally drain into the coronary sinus (Figure 19.5).

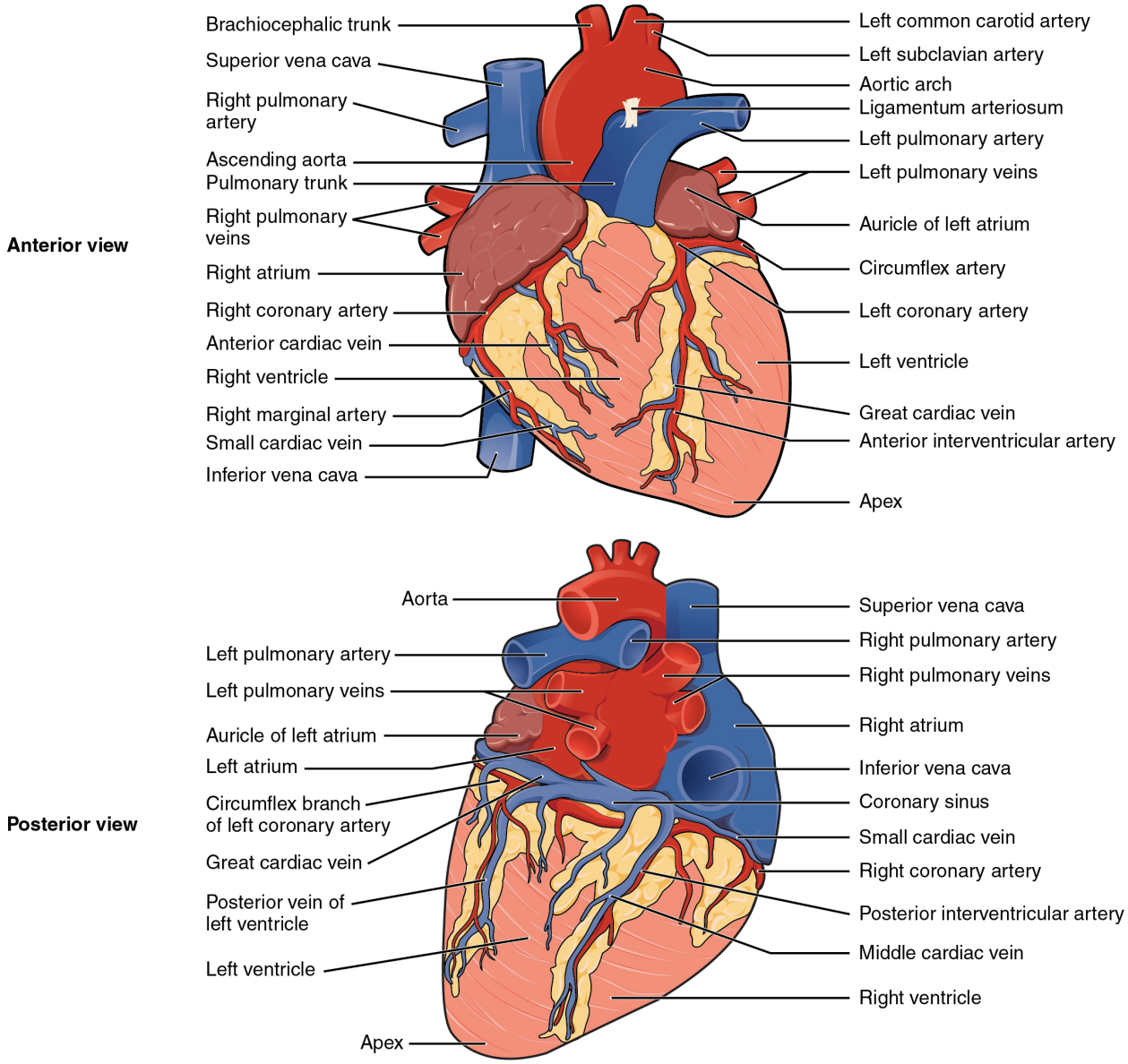


Figure 19.5 External Structures of the Heart. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Cardiac Muscle and Electrical Activity. The heart is regulated by both neural and endocrine control, yet it is capable of initiating its own action potential followed by muscular contraction. The conductive cells within the heart establish the heart rate and transmit it through the myocardium (cardiac muscle). The contractile cells (cardiac muscle cells) contract and propel the blood. The normal path of transmission for the conductive cells is the sinoatrial (SA) node, internodal pathways, atrioventricular (AV) node, atrioventricular (AV) bundle of His, bundle branches, and Purkinje fibers (Figure 19.6).

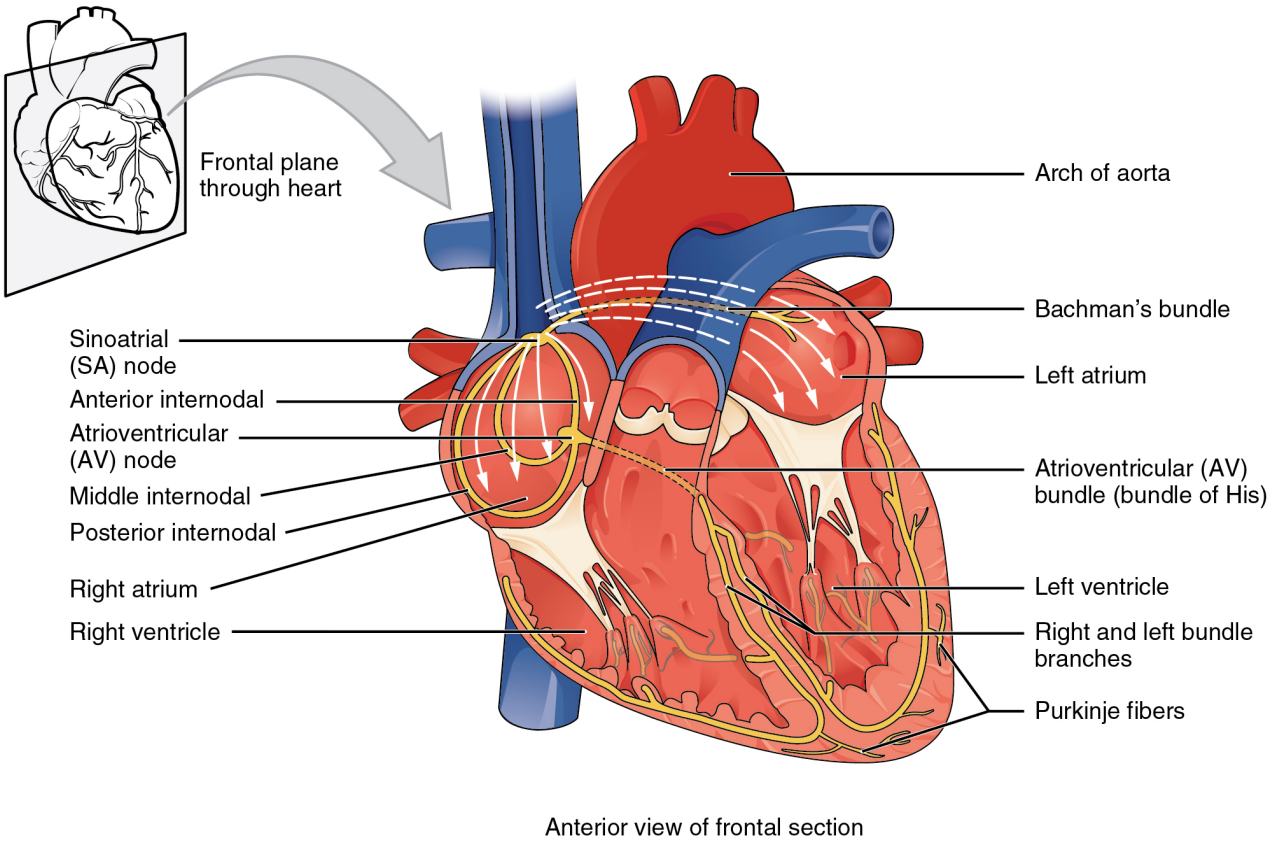


Figure 19.6 The Conduction System of the Heart. The SA node (pacemaker) to the AV node, to the bundle of His (AV bundle) and Purkinje fibers, the heart generates and conducts electrical signals to control the order in which cardiac muscle areas contract. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license).

Cardiac conduction occurs in a cycle starting with the SA node that initiates atrial contraction. The electrical signal then is passed to the AV node and AV bundle and Purkinje fibers to initiate ventricular contraction. As the ventricular contraction is initiated, the atria relax (Figure 19.7).

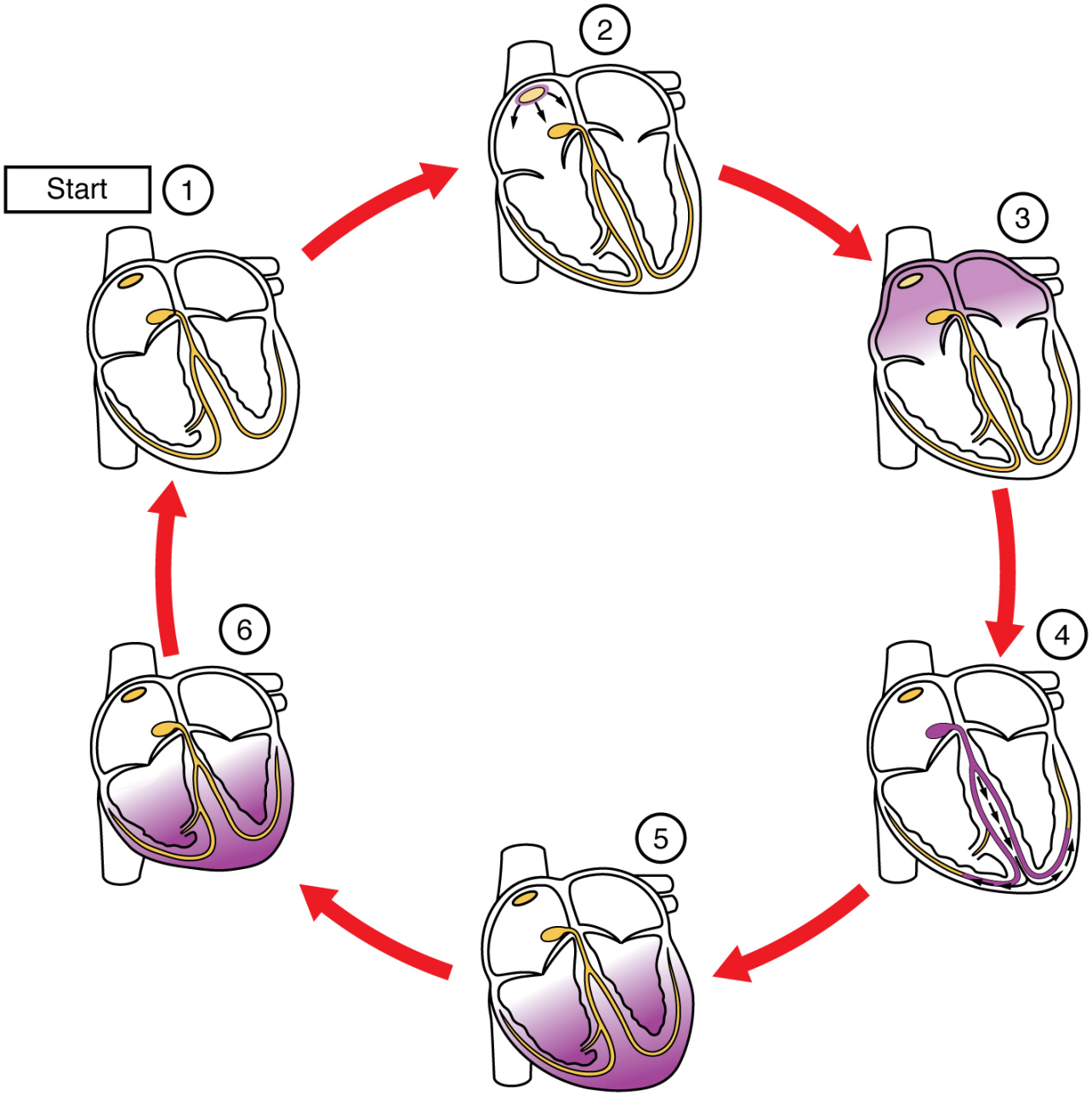


Figure 19.7 Cardiac Conduction Cycle. (1) The sinoatrial (SA) node and the remainder of the conduction system are at rest. (2) The SA node initiates the action potential, which sweeps across the atria. (3) After reaching the atrioventricular node, there is a delay of approximately 100 ms that allows 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 Electrocardiogram (ECG) is used to record the electrical signals generated by the heart's conducting cells (SA node, AV node, AV bundle, Purkinje cells) and contracting cells (myocardium or cardiac muscle cells). Electrodes are placed as shown in Figure 19.8 and the recorded traces are used to distinguish normal and abnormal heart function.

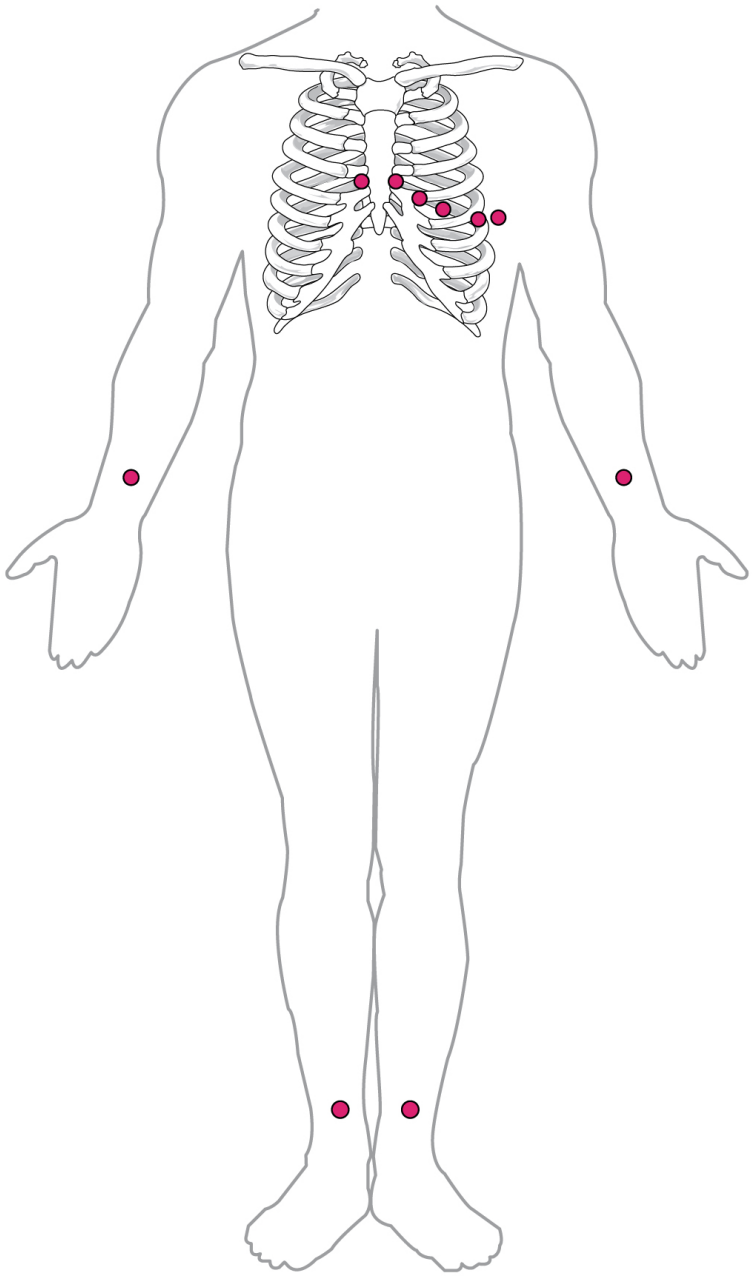


Figure 19.8 Placement of ECG Leads for a 12-point ECG Recording. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Recognizable points on the ECG include the P wave that corresponds to atrial depolarization, the QRS complex that corresponds to ventricular depolarization, and the T wave that corresponds to ventricular repolarization (Figures 19.9 and 19.10).

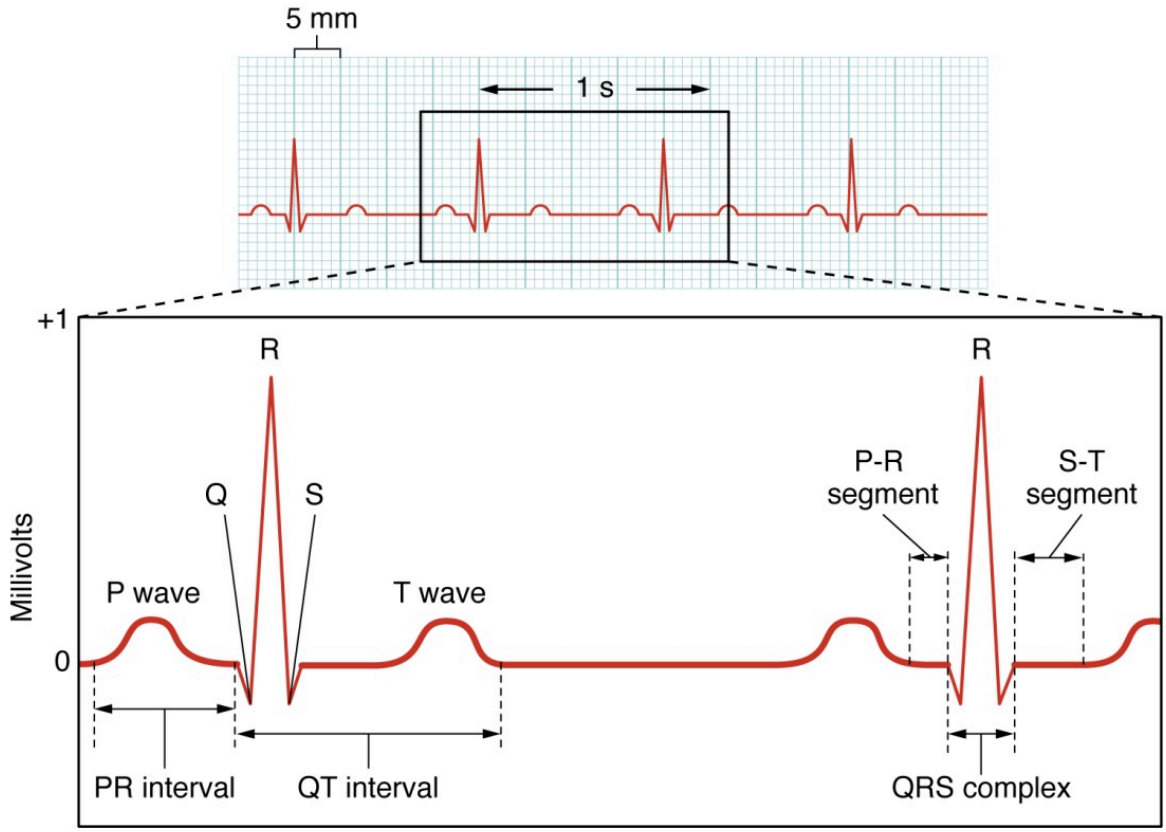


Figure 19.9 ECG Trace. A normal tracing shows the P wave, QRS complex, and T wave. Also indicated are the PR, QT, QRS, and ST intervals, plus the P-R and S-T segments. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

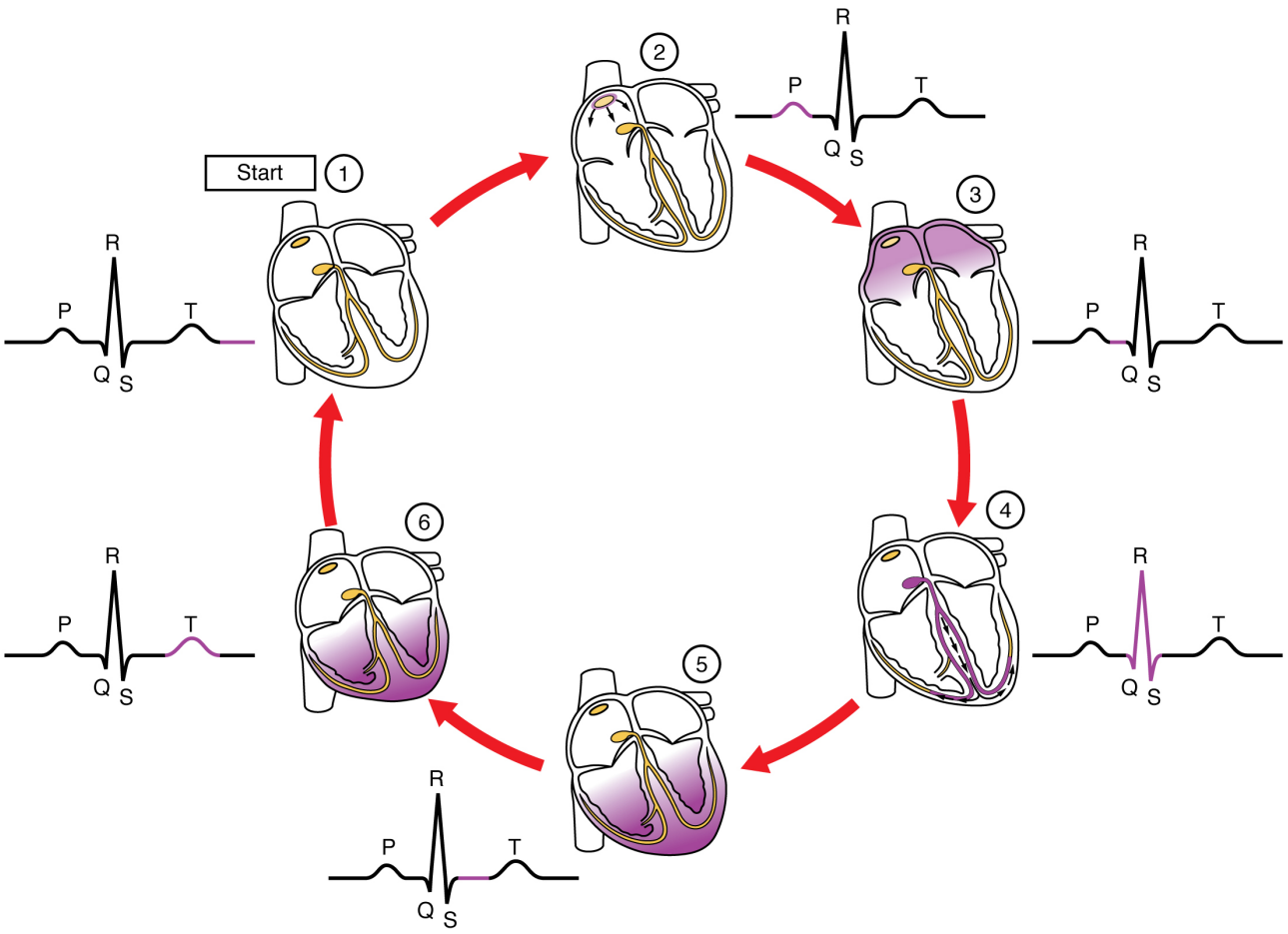


Figure 19.10 ECG Tracing Correlated to the Cardiac Cycle. This diagram correlates an ECG tracing with the electrical and mechanical events of a heart contraction. Each segment of an ECG tracing corresponds to one event in the cardiac cycle. P wave corresponds to atrial depolarization and contraction, the QRS complex corresponds to ventricular depolarization and contraction, and the T wave corresponds to ventricular repolarization and relaxation.

Cardiac Cycle. The cardiac cycle comprises a complete relaxation and contraction of both the atria and ventricles, and lasts approximately 0.8 seconds. Beginning with all chambers in diastole (relaxation), blood flows passively from the veins into the atria and past the atrioventricular valves into the ventricles. The atria begin to contract (atrial systole), following depolarization of the atria, and pump blood into the ventricles. The ventricles begin to contract (ventricular systole), raising pressure within the ventricles. When ventricular pressure rises above the pressure in the atria, blood flows toward the atria, producing the first heart sound, S1 or **lub**. As pressure in the ventricles rises above two major arteries, blood pushes open the two semilunar valves and moves into the pulmonary trunk and aorta in the ventricular ejection phase. Following ventricular repolarization, the ventricles begin to relax (ventricular diastole), and pressure within the ventricles drops. As ventricular pressure drops, there is a tendency for blood to flow back into the atria from the major arteries, producing the dicrotic notch in the ECG and closing the two semilunar valves. The second heart sound, S2 or **dub**, occurs when the semilunar valves close. When the ventricular pressure falls below that of the atria, blood moves from the atria into the ventricles, opening the atrioventricular valves and marking one complete heart cycle (Figure 19.11).

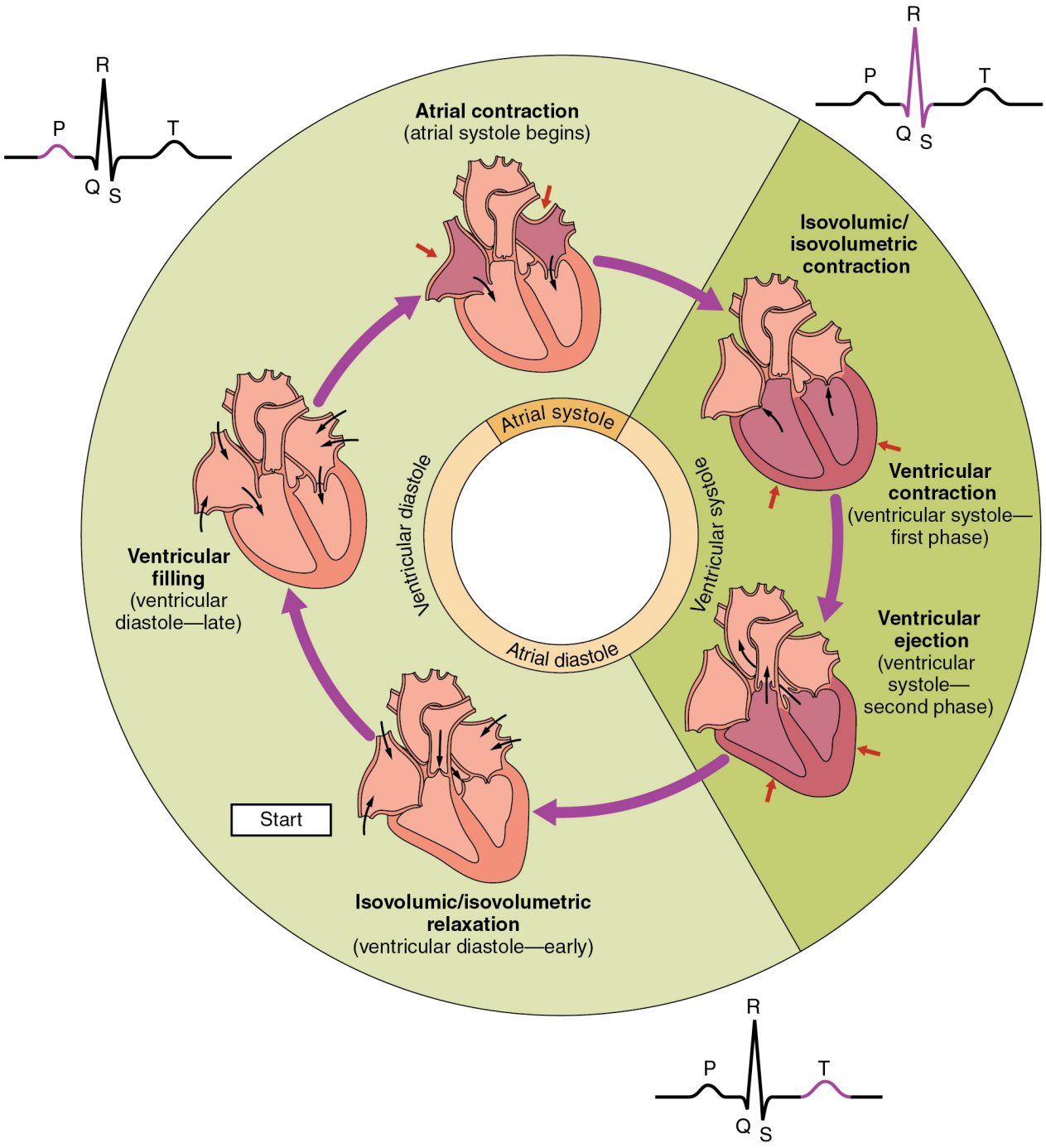


Figure 19.11 Overview of the Cardiac Cycle and Correlation to the ECG Trace. The cardiac cycle begins with atrial systole and progresses to ventricular systole, atrial diastole, and ventricular diastole, when the cycle begins again. Correlations to the ECG are highlighted. (Credit: OpenStax Anatomy and Physiology, CC-BY license)

The valves prevent backflow of blood. Failure of the valves to operate properly produces turbulent blood flow within the heart; the resulting heart murmur can often be heard with a stethoscope. Normal and abnormal heart sounds can be heard using a stethoscope and a method called auscultation (Figure 19.12 and 19.13).

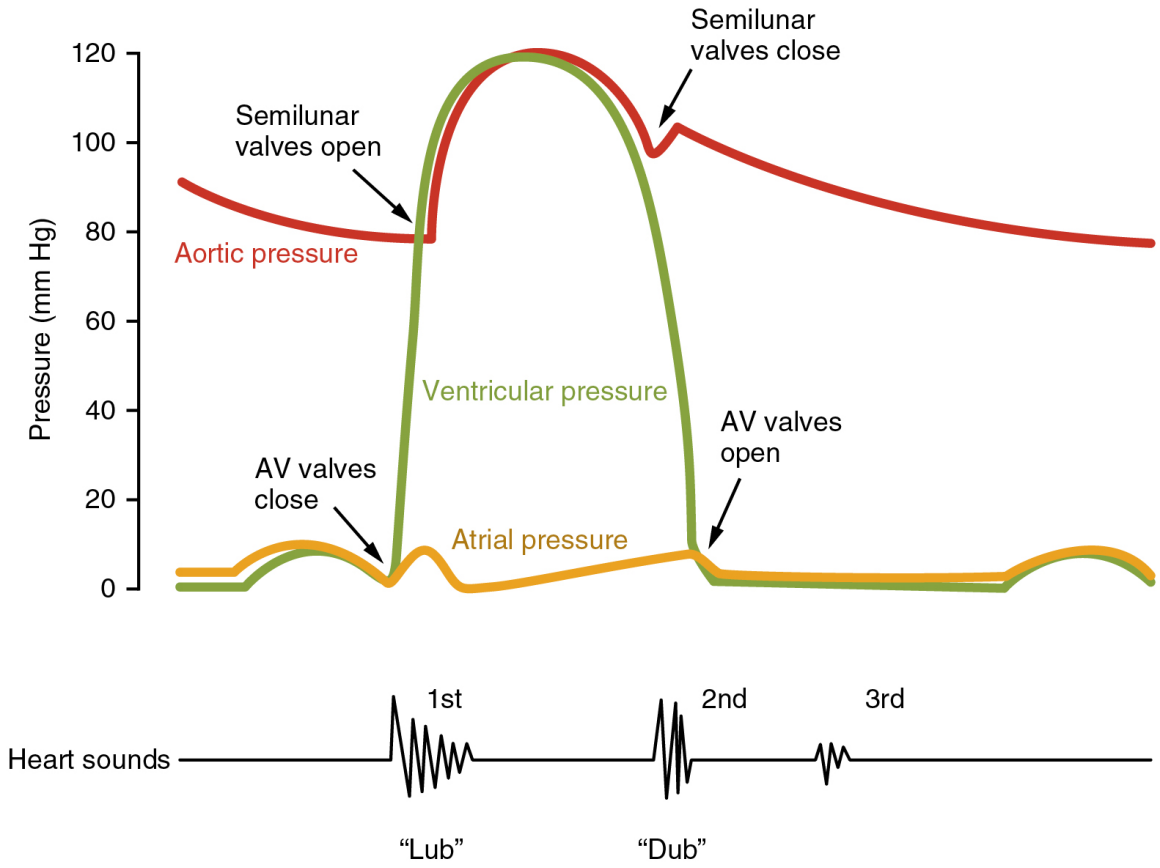


Figure 19.12 Heart Sounds and the Cardiac Cycle. The "lub" sound of the closing of the AV valves and the "dub" sound of the closing of the semilunar valves correspond to the shown pressure changes within the atria, ventricles and arteries. (Credit: OpenStax Anatomy and Physiology, CC-BY license)

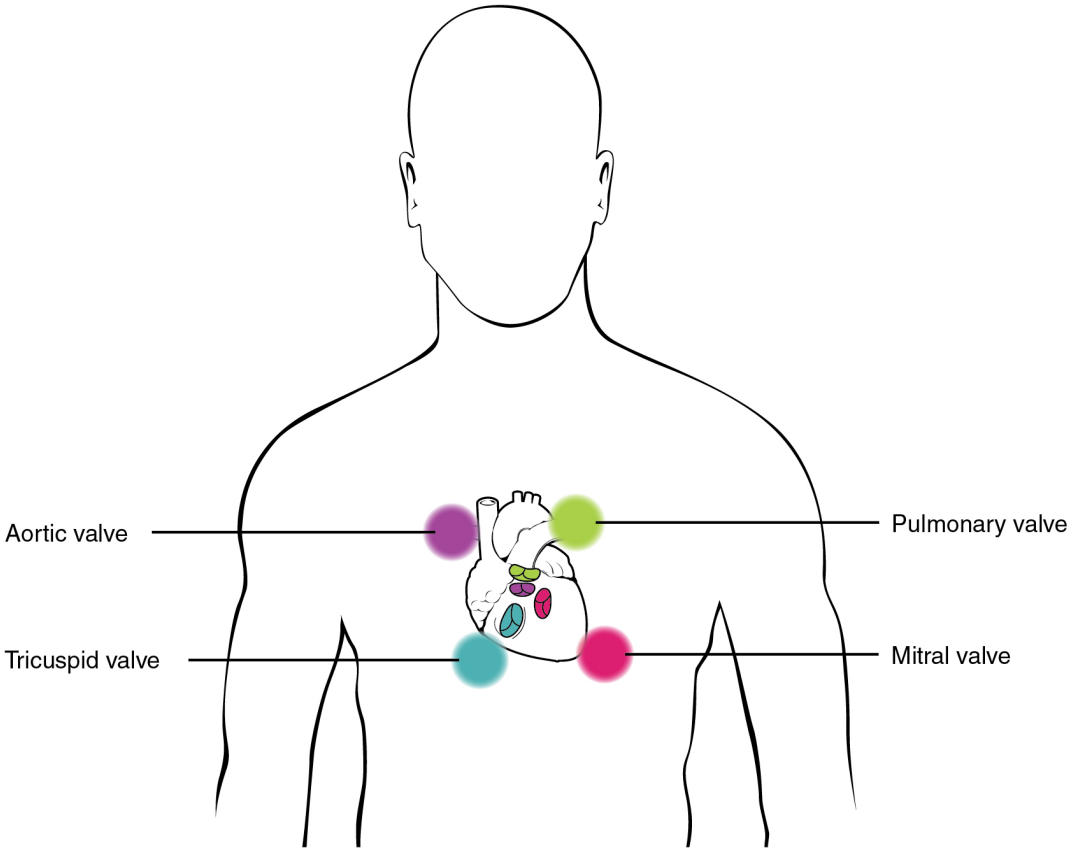


Figure 19.13. Stethoscope Placement for Auscultation. Proper placement of the bell of the stethoscope facilitates auscultation. At each of the four locations on the chest, a different valve can be heard. (Credit: OpenStax Anatomy and Physiology, CC-BY license)

Cardiac Physiology. Cardiac output (CO) is determined by multiplying the Heart Rate (HR) by Stroke Volume (SV). HR is beats per minute and can be determined by counting the number of "lub" and "dub" sounds per minute by auscultation or by taking the pulse from the wrist (brachial artery) or neck (carotid artery). Heart rate can also be determined by using the ECG and counting the number of QRS peaks per minute. SV is the volume of blood pumped by the ventricles. SV is the difference between End Diastolic Volume (EDV) and End Systolic Volume (ESV).

Many factors affect HR and SV and together, they contribute to cardiac function. HR is largely determined and regulated by autonomic stimulation and hormones. There are several feedback loops that contribute to maintaining homeostasis dependent upon activity levels. SV is regulated by autonomic innervation and hormones, but also by venous return. Venous return is the volume of blood that returns to the atria of the heart and is determined by activity of the skeletal muscles, blood volume, and changes in peripheral circulation. Figure 19.14 summarized the main influencers of cardiac output.

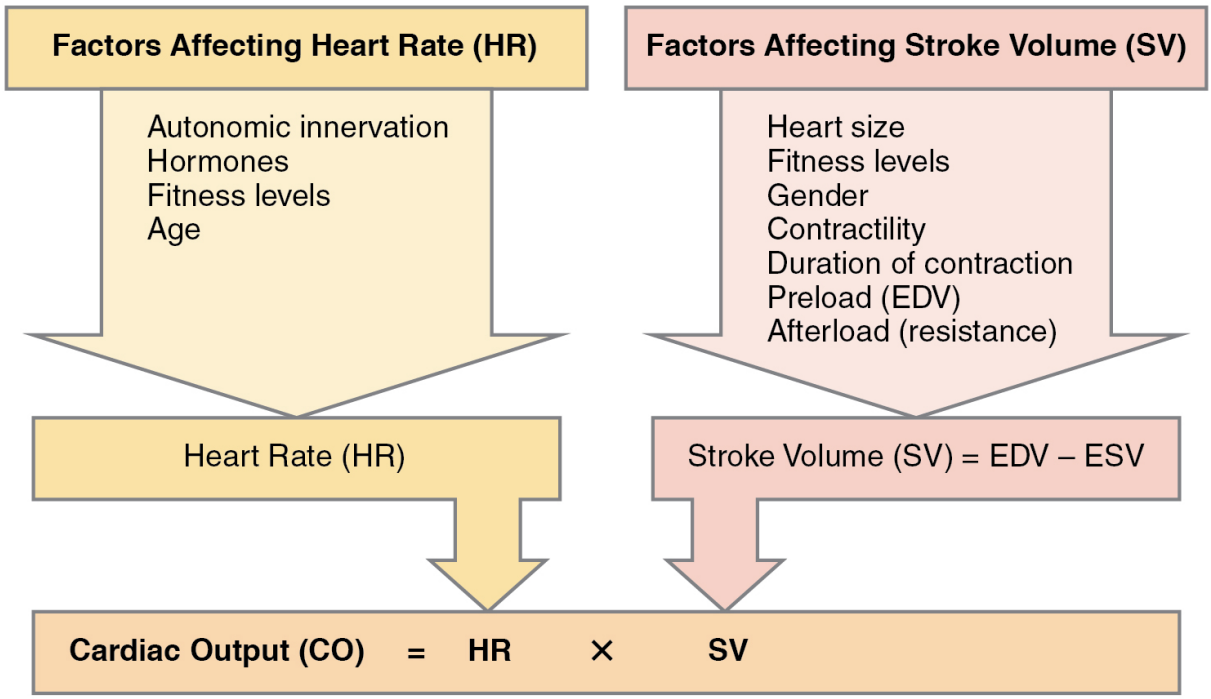


Figure 19.14 Major Factors Affecting Cardiac Output. (Credit: OpenStax Anatomy and Physiology, CC-BY license)

Pre-Laboratory Questions

After you review the Background information above, answer the following questions before attempting the Exercises in the laboratory.

1. What are the main chambers of the heart? Sketch and label each.
2. What are the main blood vessels that bring blood into and pump it out of the heart? Sketch and label each. Indicate which one brings blood "into" and which one takes blood "out of" the heart.
3. What is the function of the coronary arteries and veins? Where are these located?
4. List the nodes and fibers involved in cardiac conduction starting with the pacemaker and listing these structures in the order of activation.
5. List the steps in the cardiac cycle starting with a heart that has all chambers relaxed.
6. What do the P, QRS and T designation on an ECG correlate to in atrial and ventricular depolarization/repolarization and contraction/relaxation?
7. Which event produces the "lub" and "dub" sounds of the heart beat?
8. What is auscultation and the name of the instrument used for it?
9. What is the formula for cardiac output?
10. List one way in which you can determine heart rate.

Exercises

- Exercise 1 Pig or Sheep Heart Dissection – Heart Anatomy
- Exercise 2 Blood Flow Through the Heart
- Exercise 3 Electrocardiogram (ECG) Analysis in Normal and Diseased Hearts

Exercise 1 Pig or Sheep Heart Dissection – Heart Anatomy

Dissection guide: https://www.biologycorner.com/anatomy/circulatory/heart/heart_dissection.html

Required Materials

- dissection tray,
- dissection tools (knife or scalpel; forceps; scissors; dissection pins for labeling)
- gloves
- preserved pig or sheep heart
- T-pins
- labeling tape
- Heart Model on a Stand
- Giant Heart Model
- Heart Bismount

Procedure

1. Orient yourself to the superficial aspect of the heart first. Many preserved specimens have fat associated with them, making the features difficult to see (unlike models). If the fibrous pericardium is intact, slit it open with a scalpel or cut it with scissors, then cut it from the attachments. Note how the visceral pericardium differs from the parietal pericardium.

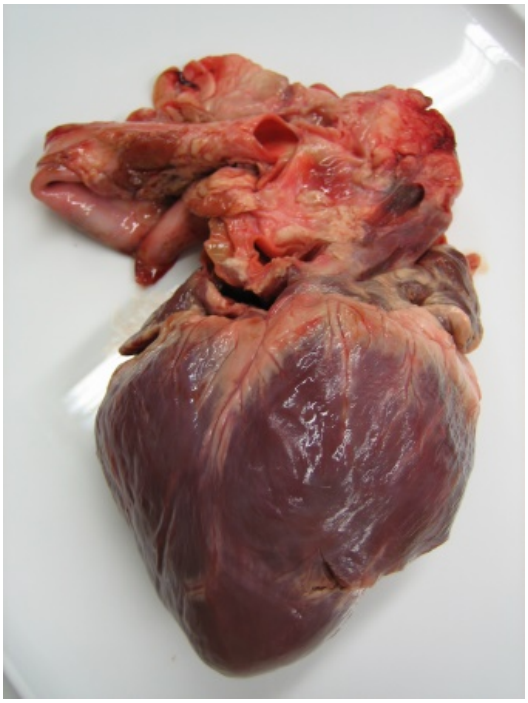
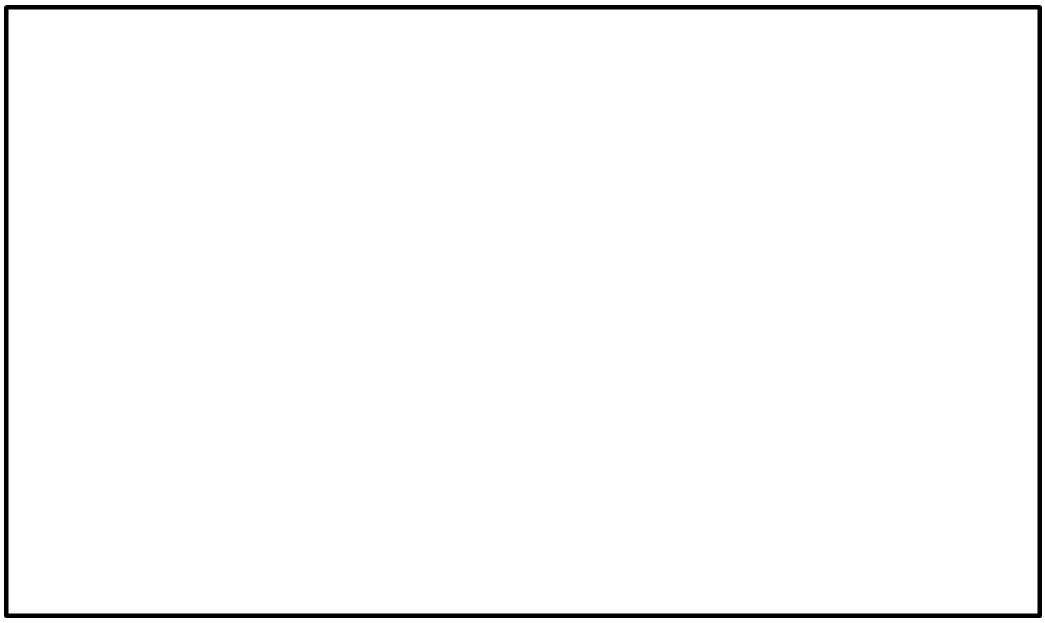


Figure 19.15 Pig's Heart. Superficial view of the extracted pig's heart prior to dissection (Credit: Wikimedia Commons, Creative Commons CC-BY-SA license)

2. Examine the external surface of the heart. Determine which side is superior (broad, with large blood vessels issuing from it) and which side is inferior (the apex is pointed). Next, determine which side is anterior. Locate the **pulmonary trunk**. This large vessel delivers blood to the lungs from the right side of the heart. It can be found in the middle of the anterior side of the heart. Place a pin on the pulmonary trunk and label it using tape. Take a picture and insert it below.

3. Once you've distinguished anterior from posterior aspects of the heart, you should locate the **auricles**, the puppy-ear-shaped external extensions of the atria. The rest of the heart will be the **ventricles**. With your gloved hands you may be able to distinguish between the right and left ventricles – the right ventricle is smaller and thinner-walled, and will feel flabby when you squeeze it. You should also be able to feel with fingers the **interventricular sulcus** (but it may be filled with fat). The **atrioventricular sulci** can also be felt just underneath the auricles on each side. Use the pins to label the atria and ventricles. Take a picture and insert it below.



4. Using a scalpel, make a single cut through the ventricle up to the atria / base of the heart, so that the heart is divided into anterior and posterior halves. Open the two halves (or, if you've cut completely through the heart, separate the two halves) so that you can observe the internal features of the heart. Identify the **AV valves** (**bicuspid and tricuspid**) and their features, including the **chordae tendineae** and their attachment to the **papillary muscles**. Within the walls of the ventricles, you should be able to see and feel the **trabeculae carneae**, or muscular ridges that are distinct from the papillary muscle. The thick **interventricular septum** between the **right and left ventricles** should be very evident. Note that the walls of the left ventricle are much thicker than those of the right ventricle. In the atria, you may be able to see and feel the ridges of the **pectinate muscles**. Use pins to label these structures. Take a picture and insert it below.

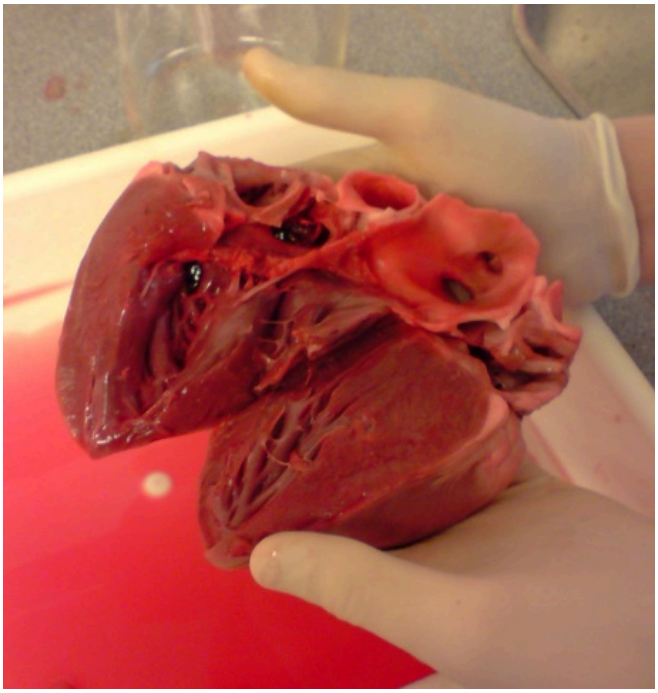


Figure 19.16 Dissected Pig's Heart. Section through the pig's heart showing the chambers and blood vessels. (Credit: Wikimedia Commons, Creative Commons CC-BY-SA license)

5. Using the pictures you took as guide, create a drawing to show the anatomical features of the heart in the space provided below On your drawing, label the right and left ventricles, the right and left atria, the bicuspid and tricuspid valves, the papillary muscles, the chordae tendineae, the interventricular septum, the pulmonary trunk and the aorta.

Exercise 2 Blood Flow Through the Heart

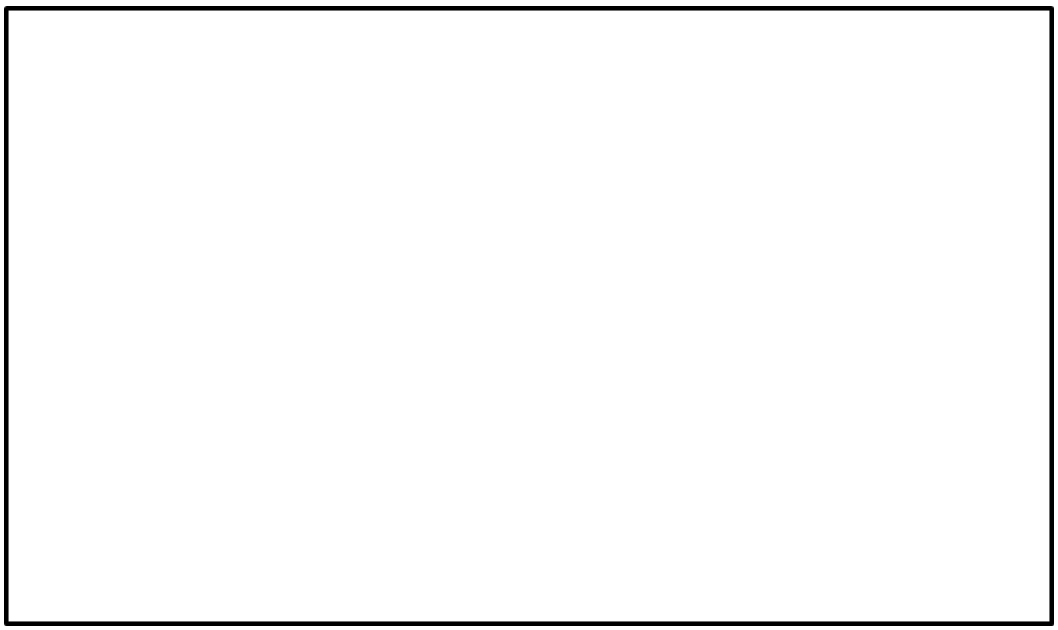
Required Materials

- dissected pig or sheep heart
- gloves
- T-pins
- labeling tape

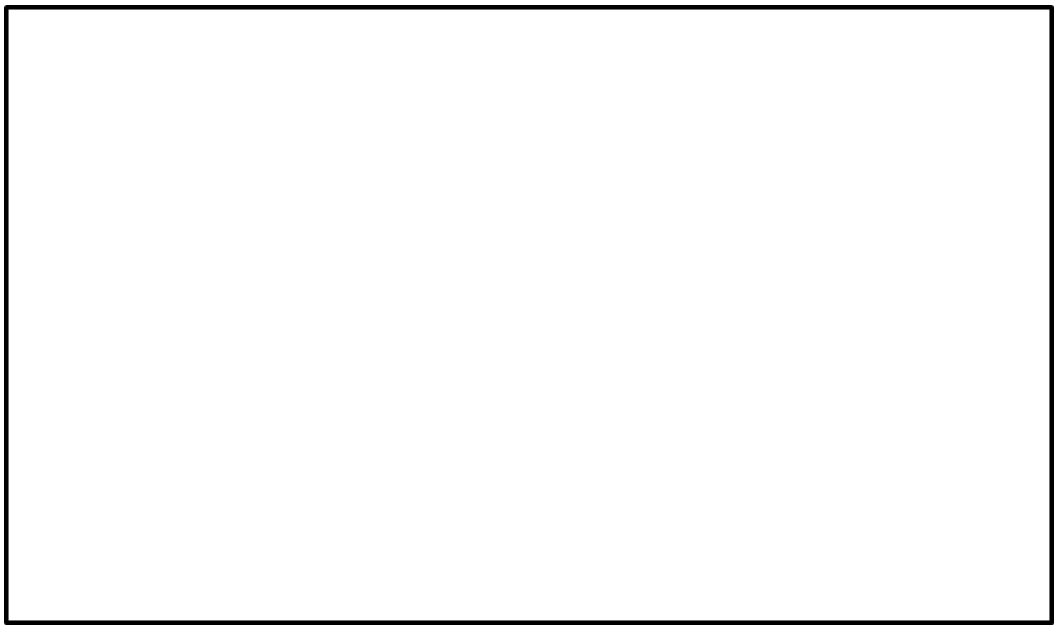
Procedure

Use the dissected heart to label the path of the heart from the entry of blood into the heart chambers to the exit of blood from these chambers and out of the heart. Use the dissecting pins and tape to label the following.

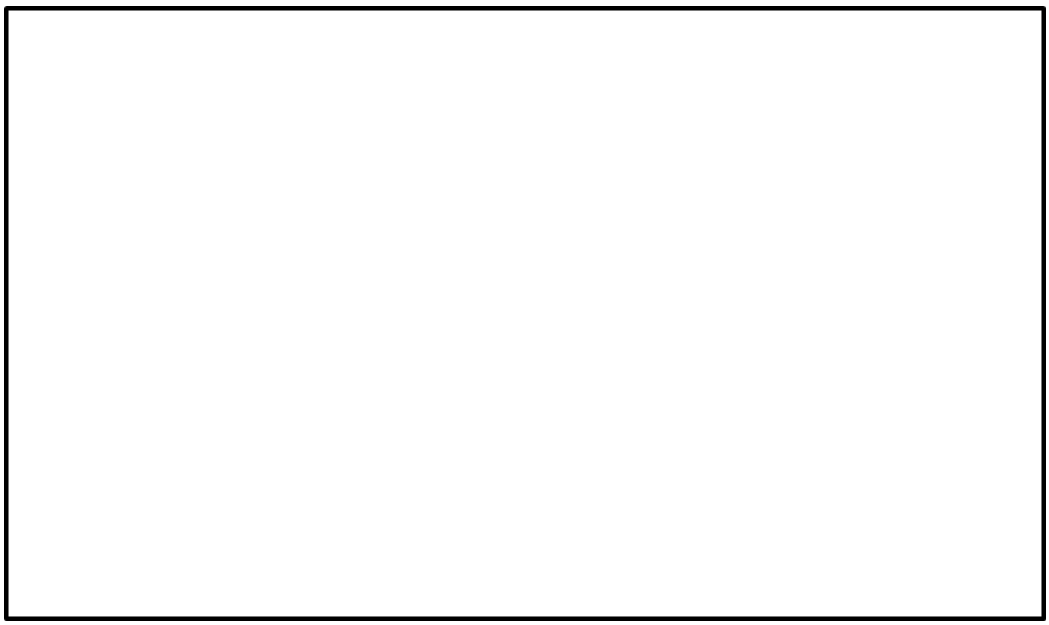
1.Find and label the veins that bring blood to the heart. Take a picture and paste it below.



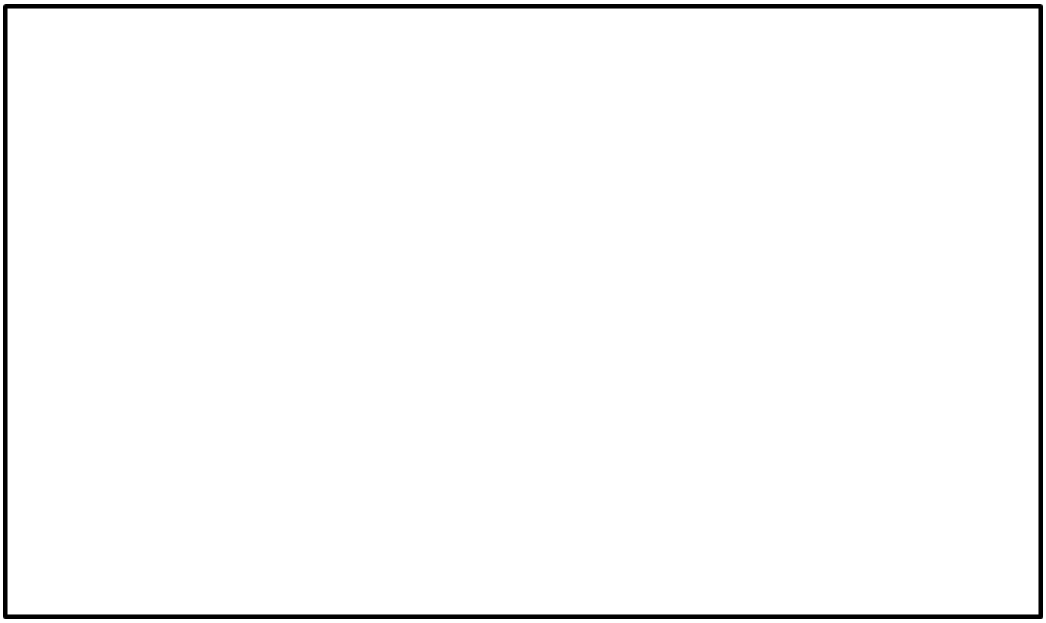
2. Label the heart chambers into which blood flows. Take a picture and paste it below.



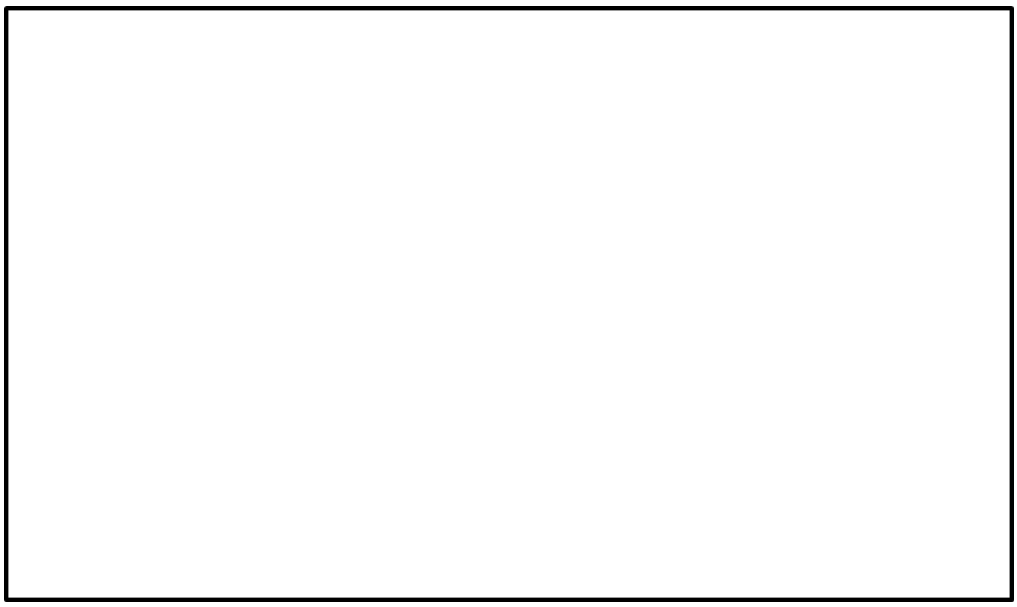
3. Label the two heart valves through which blood flows from the entry chambers to the exit chambers. Take a picture and insert it below.



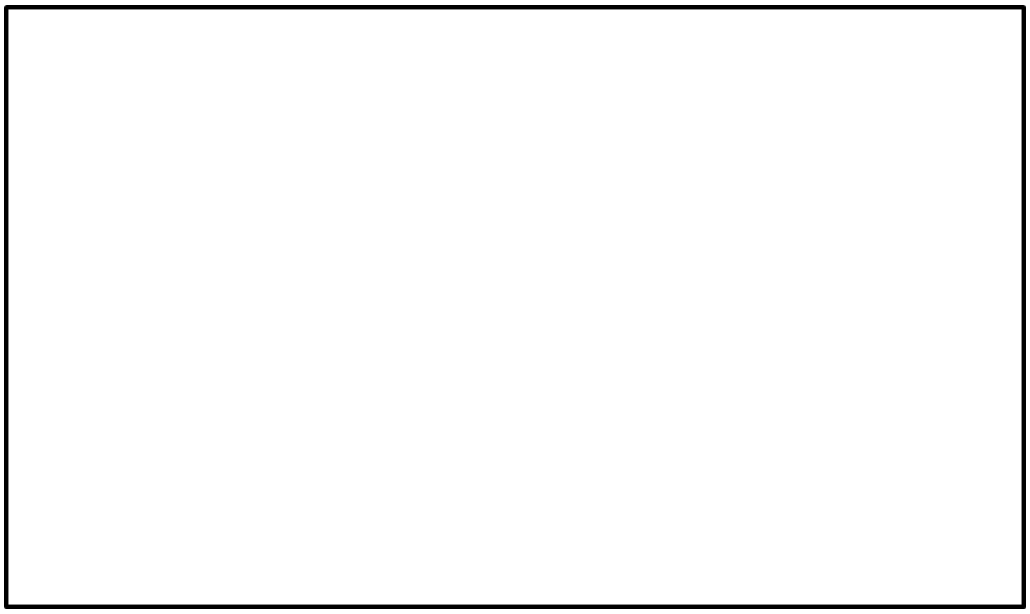
4. Label the two chambers from which blood gets pumped out. Take a picture and insert it below.



5. Identify the arteries that carry blood out of the heart from the two chambers you labeled above. Label each artery. Take a picture and insert it below.



6. Using the pictures you took as a guide, create a drawing to trace the path of blood flow from entry into to exit from the heart. Label the veins, the heart chambers, the heart valves, and the arteries. Use red color to show oxygenated blood and blue color to show deoxygenated blood.



Exercise 3 Electrocardiogram (ECG) Analysis in Normal and Diseased Hearts

Required Materials

- stethoscope
- timer

Procedure

1.Use the stethoscope as shown in Figure 19.17 to listen to the heart sounds of a classmate. Count the number of beats per 10 seconds. **Record this value here: _____**

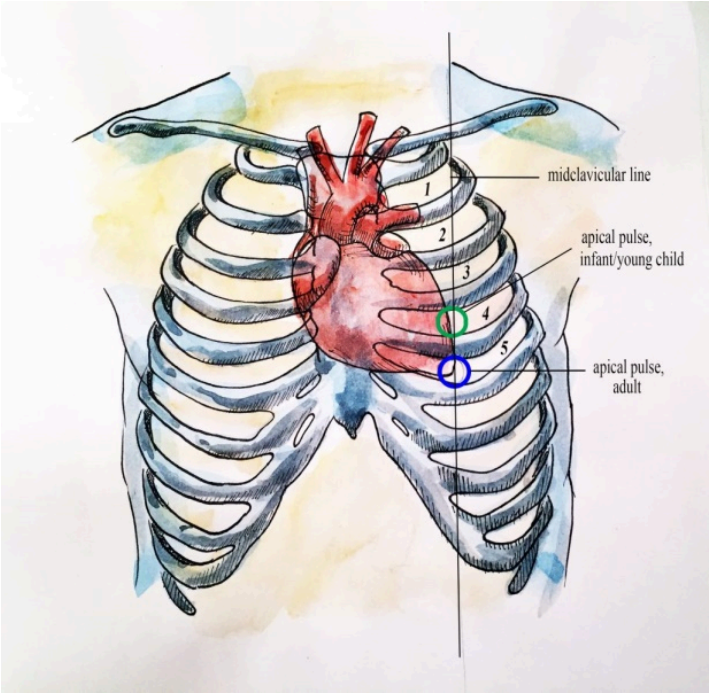


Figure 19.17 Apical Pulse Location. The location where the heart's mitral valve is best heard when using auscultation with a stethoscope. (Credit: Health Assessment Guide for Nurses by Feng, Bertiz, Agostini. Creative Commons license CC-BY-4.0)

2. Calculate how many seconds it takes from the start of one heart beat to the next. **Record: _____**

3.Calculate how many beats the heart beats per minute (60 seconds) in BPM (beats per minute). **Record: _____**

4. Examine the following EKG (also known as ECG):

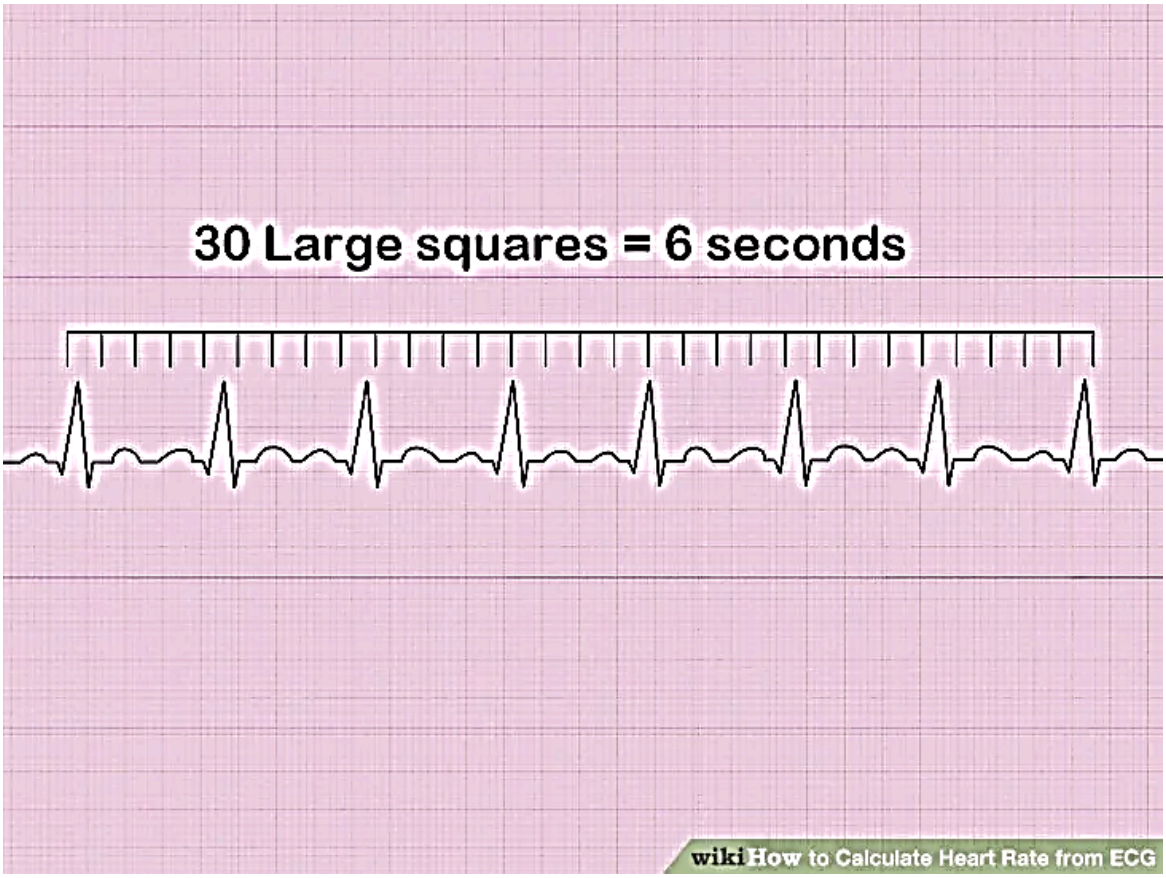


Figure 19.18. How to calculate heart rate from ECG. (Credit: WikiHow, Creative Commons CC-BY-NC-SA license)

5. How many QRS complexes do you count within the 6 seconds indicated by the 30 large squares of the EKG paper in Figure 19.18? **Record:**_____

6. What is the heart rate corresponding to this EKG trace? Calculate it in BPM. **Record:** _____

7. If this EKG were taken from the friend whose heart rate you determined above, how many QRS complexes would you expect to see within the 6 second window of the EKG? **Record:**_____

8. How many squares from the left edge would you expect to hear the first "lub" sound? Last "lub" sound (in Figure 19.18)? **Record:**_____

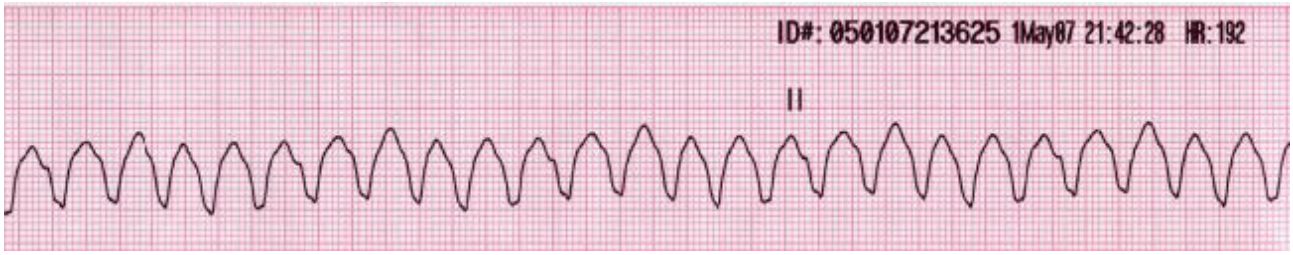


Figure 19.19 ECG of Patient with Ventricular Tachycardia. (Credit: Wikimedia Commons, Creative Commons CCO license)

9. In Figure 19.19, you have the ECG recording of a patient with a condition called tachycardia. Count the

number of peaks per 30 squares to **determine the 6 second and then the 1 minute heart rate in BPM. Record: _____, _____**

10. How does the heart rate in tachycardia compare to the heart rate in the normal ECG shown in Figure 19.18?

11. If you were to guess, what do you think the word Tachycardia refers to based on your findings above?

Post-laboratory Questions

1. **Scenario 1: You dissect a pig's heart and see that there is a hole between the right atrium and left atrium.**

    - What would be the effect of this hole on the oxygenation level of the blood pumped out of the heart into the systemic circulation?
    - Explain the reasoning behind your answer. Use a sketch of the heart to help.

2. **Scenario 2: You dissect a pig's heart and see that the tricuspic atrioventricular valve is instead bicuspid. You read some medical literature on this subject and learn that this condition may result in the valve not closing properly.**

    - What effect will this have on the ability of the heart to pump blood out of the heart?
    - Will this affect pulmonary circulation or systemic circulation?
    - Explain the reasoning behind your answers to (a) and (b). Use a sketch of the heart to help.

3. **In lab, you use a stethoscope to auscultate with a stethoscope and listen to the apical pulse of a classmate.**

    - If you hear 20 "lub" and "dub" sounds in 15 seconds, what is the heart rate of your friend in BPM?
    - In the cardiac cycle, what does the "lub" sound you hear correspond to? How about the "dub" sound?
    - If you obtain an EKG of the same classmate, how many QRS complexes do you expect to see in the 30 large squares of the EKG paper that correspond to 6 seconds?

20.

CHAPTER 20 THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS AND CIRCULATION

By Aylin Marz

Motivation.

Sars-Cov-2 virus causing the COVID-19 pandemic affects many systems of the body including those related to circulation. Blood clots, injured blood vessels, and bleeding found in lungs and effects on the heart as well as other body parts have been found in autopsies of patients who died from COVID-19. Since all organs use blood vessels the clots that block blood flow or injuries to blood vessels may explain how this unusual virus causes multi-organ damage, unlike many other viruses that have specific targets.

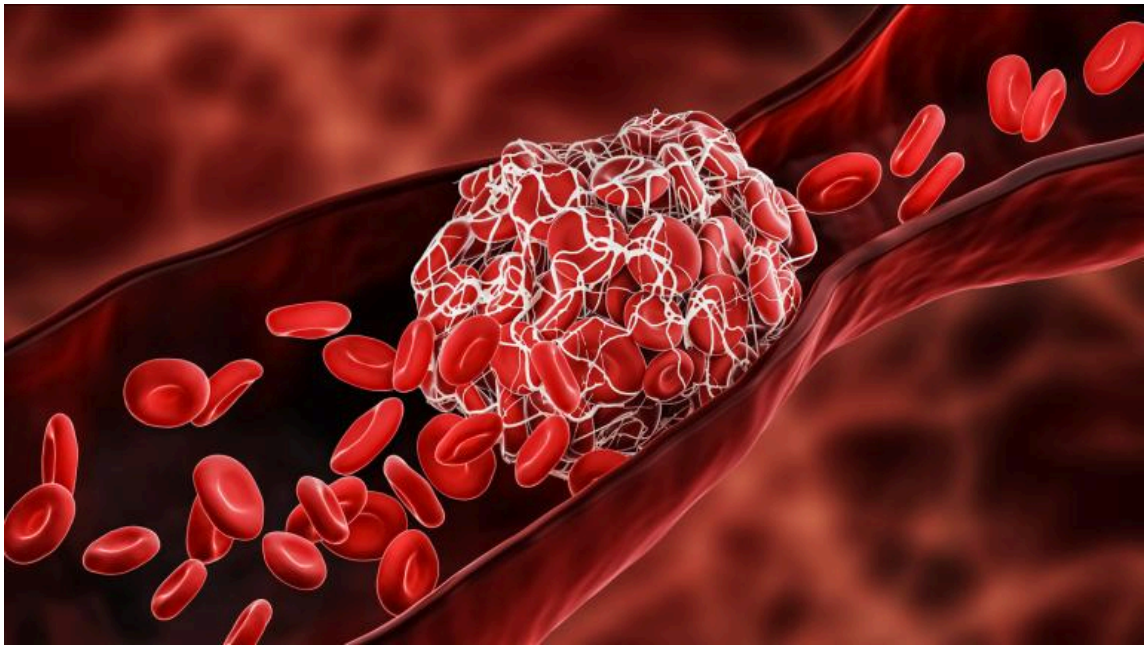


Figure 20.1 Clump of blood cells forming a clot and blocking/reducing the flow of blood in a blood vessel, similar to what is observed in COVID-19. (Credit: National Heart, Lung, and Blood Institute; National Institutes of Health; U.S. Department of Health and Human Services; public domain)

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Identify the major arteries and veins of the body using a torso model
- Perform arterial blood pressure measurement utilizing a pressure cuff and stethoscope
- Analyze factors that affect blood flow and blood pressure.

Background.

Structure and Function of Blood Vessels

Blood pumped by the heart flows through a series of vessels known as arteries, arterioles, capillaries, venules, and veins before returning to the heart (Figure 20.2). Arteries transport blood away from the heart and branch into smaller vessels, forming arterioles. Arterioles distribute blood to capillary beds, the sites of exchange with the body tissues. Capillaries lead back to small vessels known as venules that flow into the larger veins and eventually back to the heart.

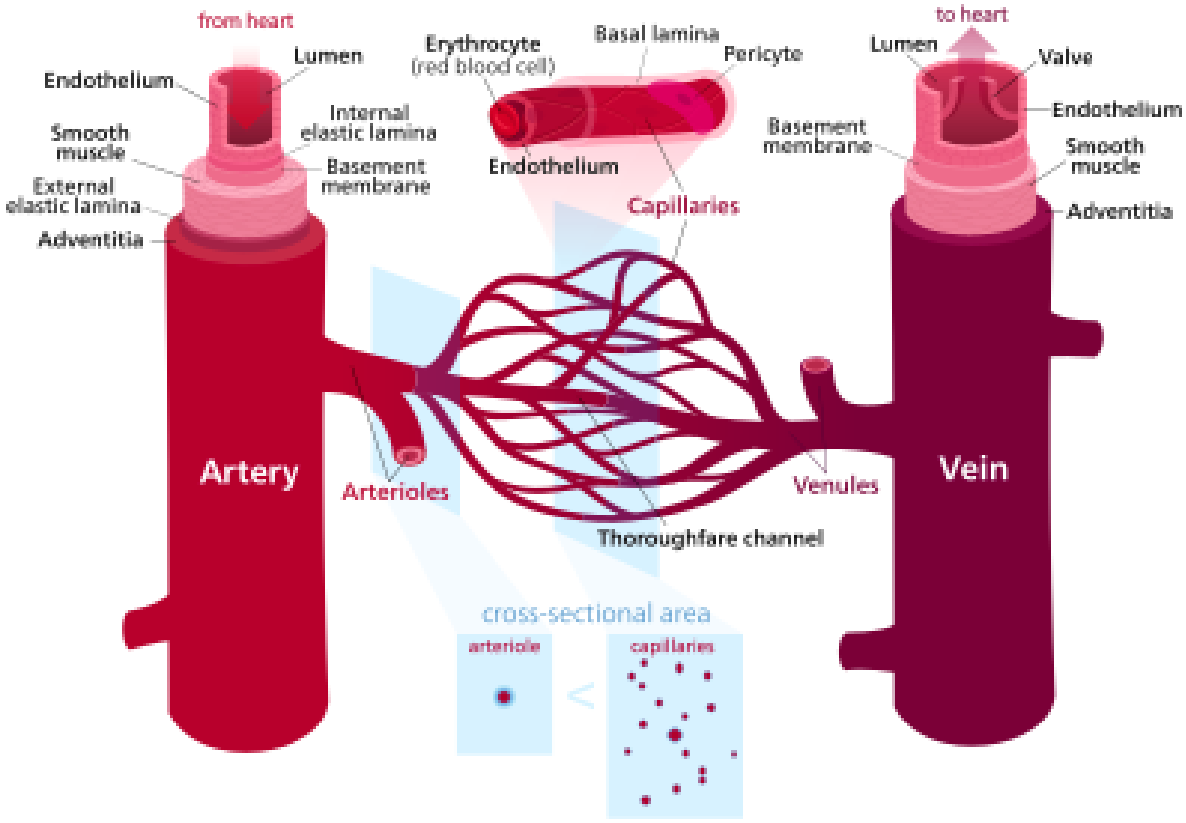


Figure 20.2 Comparison of Artery, Vein and Capillary Structures and Organization.
(Credit: Wikimedia commons, CC-BY-SA license)

The arterial system is a relatively high-pressure system, so arteries have thick walls that appear round in cross section (Figure 20.3). The venous system is a lower-pressure system, containing veins that have larger lumens and thinner walls. They often appear flattened. Arteries, arterioles, venules, and veins are composed of three tunics known as the tunica intima, tunica media, and tunica externa. Capillaries have only a tunica intima layer. The tunica intima is a thin layer composed of a simple squamous epithelium known as endothelium and a small amount of connective tissue. The tunica media is a thicker area composed of variable amounts of smooth muscle and connective tissue. It is the thickest layer in all but the largest arteries. The tunica externa is primarily a layer of connective tissue, although in veins, it also contains some smooth muscle. Blood flow through vessels can be dramatically influenced by vasoconstriction and vasodilation in their walls.

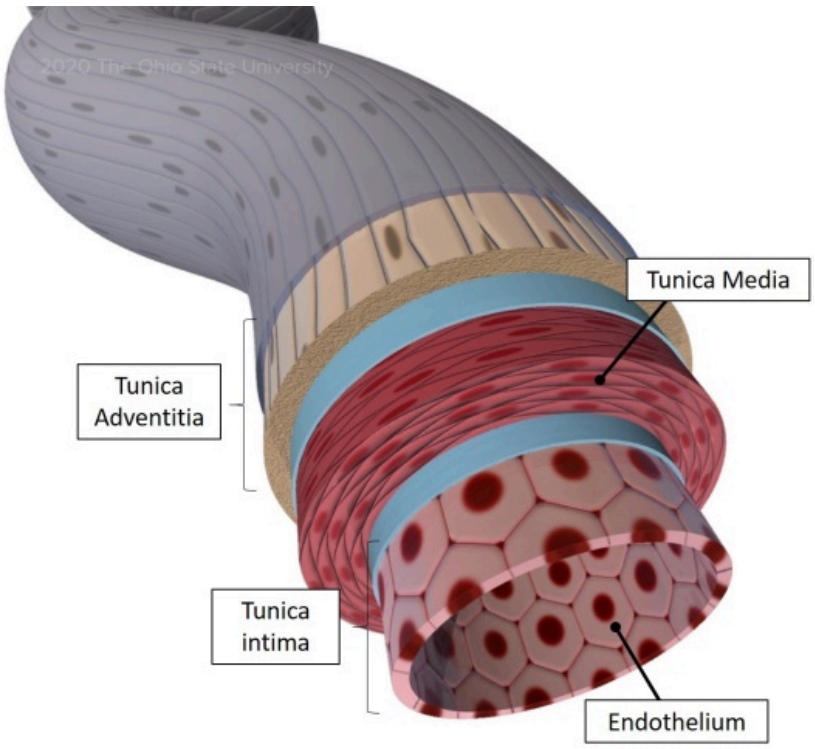


Figure 20.3 Artery wall structures or tunics. (Credit: Veterinary Medicine, Ohio State Pressbooks; CC-BY-NC 3.0 licenese)

Blood Flow, Blood Pressure and Resistance

Blood flow is the movement of blood through a vessel, tissue, or organ. The slowing or blocking of blood flow is called resistance. Blood pressure is the force that blood exerts upon the walls of the blood vessels or chambers of the heart. The components of blood pressure include systolic pressure, which results from ventricular contraction (of the heart), and diastolic pressure, which results from ventricular relaxation. Pulse pressure is the difference between systolic and diastolic measures, and mean arterial pressure is the "average" pressure of blood in the arterial system, driving blood into the tissues. Pulse, the expansion and recoiling of an artery, reflects the heartbeat. The variables affecting blood flow and blood pressure in the systemic circulation are cardiac output (amount of blood pumped by heart per minute), compliance, blood volume, blood viscosity, and the length and diameter of the blood vessels.

In the arterial system, vasodilation and vasoconstriction of the arterioles is a significant factor in systemic blood pressure: Slight vasodilation greatly decreases resistance and increases flow, whereas slight vasoconstriction greatly increases resistance and decreases flow. In the arterial system, as resistance increases, blood pressure increases and flow decreases. In the venous system, constriction increases blood pressure as it does in arteries; the increasing pressure helps to return blood to the heart. In addition, constriction causes the vessel lumen to become more rounded, decreasing resistance and increasing blood flow. Venoconstriction, while less important than arterial vasoconstriction, works with the skeletal muscle pump, the respiratory pump, and their valves to promote venous return to the heart (Figure 20.4).

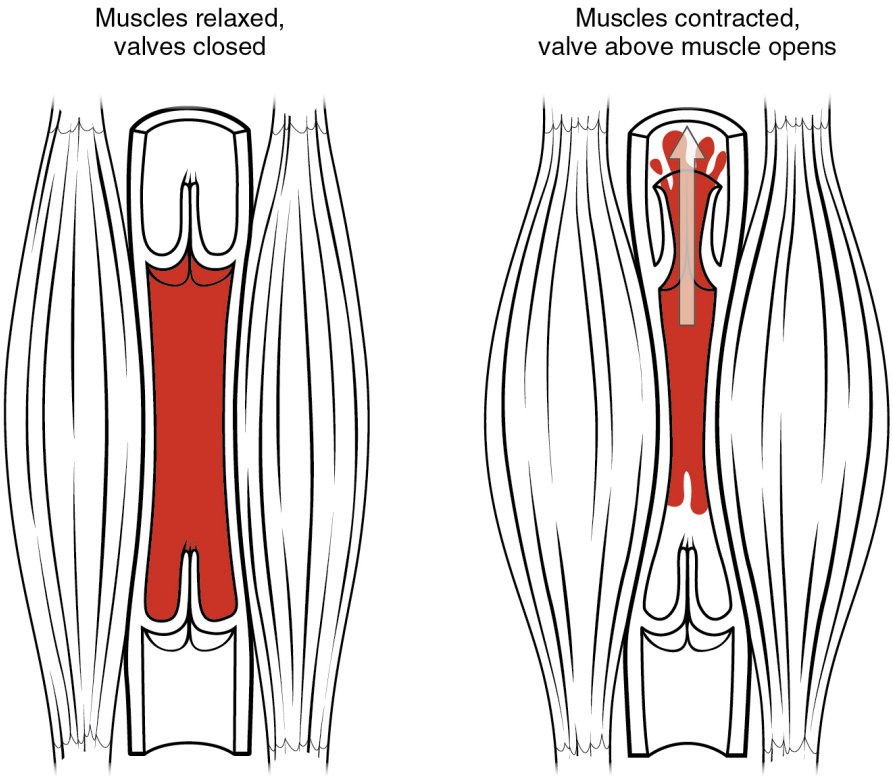


Figure 20.4 Skeletal Muscle Pump. Contraction and relaxation of the skeletal muscles in the leg act as a pump to help increase the blood pressure in the veins and help return blood to the heart. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Capillary Exchange

Small molecules can cross into and out of capillaries via simple or facilitated diffusion. Some large molecules can cross in vesicles or through clefts, fenestrations, or gaps between cells in capillary walls. However, the bulk flow of capillary and tissue fluid occurs via filtration and reabsorption. Filtration, the movement of fluid out of the capillaries, is driven by the capillary hydrostatic pressure or CHP. Reabsorption, the influx of tissue fluid into the capillaries, is driven by the blood colloid osmotic pressure or BCOP. Filtration predominates in the arterial end of the capillary; in the middle section, the opposing pressures are virtually identical so there is no net exchange, whereas reabsorption predominates at the venule end of the capillary. The hydrostatic and colloid osmotic pressures in the interstitial fluid are negligible in healthy circumstances (Figure 20.5).

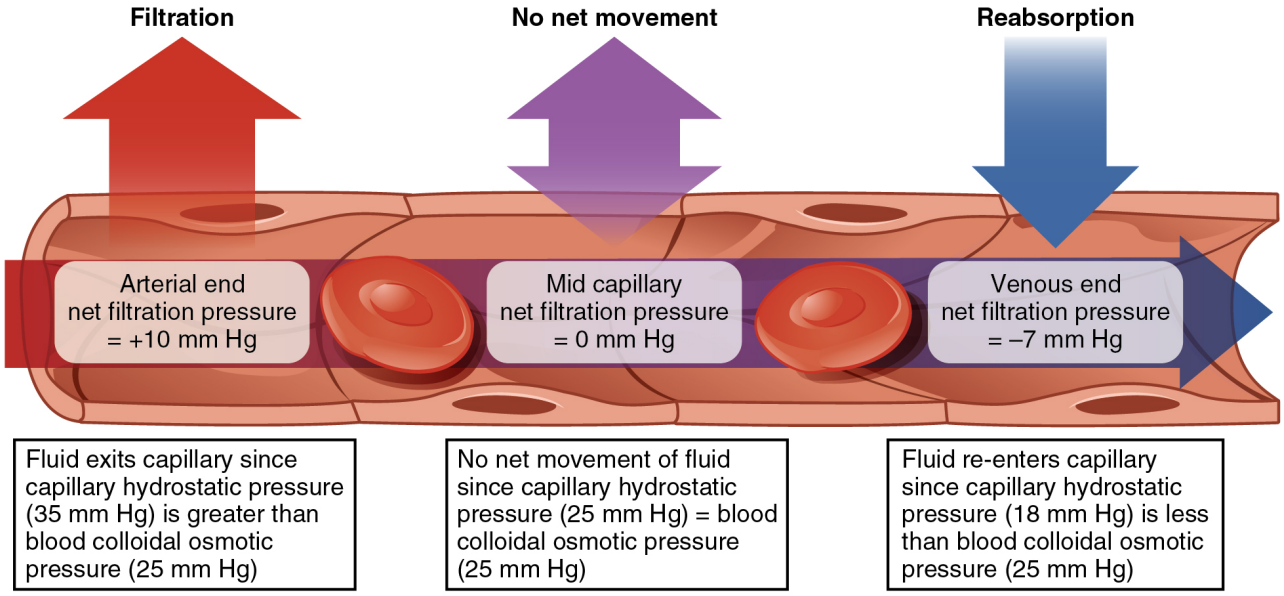


Figure 20.5 Capillary Exchange. (Credit: OpenStax Anatomy and Physiology; CC-BY 4.0 license)

Homeostatic Regulation of the Vascular System

Neural, endocrine, and autoregulatory mechanisms affect blood flow, blood pressure, and eventually perfusion of blood to body tissues (Figure 20.6). Neural mechanisms include the cardiovascular centers in the medulla oblongata, baroreceptors in the aorta and carotid arteries and right atrium, and associated chemoreceptors that monitor blood levels of oxygen, carbon dioxide, and hydrogen ions. Endocrine controls include epinephrine and norepinephrine, as well as antidiuretic hormone ADH, the renin-angiotensin-aldosterone mechanism, atrial natriuretic hormone ANH, and erythropoietin EPO. Autoregulation is the local control of vasodilation and constriction by chemical signals and the myogenic response (response of smooth muscles of the blood vessels). Exercise greatly improves cardiovascular function and reduces the risk of cardiovascular diseases, including hypertension, a leading cause of heart attacks and strokes. Significant hemorrhage can lead to a form of circulatory shock known as hypovolemic shock. Sepsis, obstruction, and widespread inflammation can also cause circulatory shock.

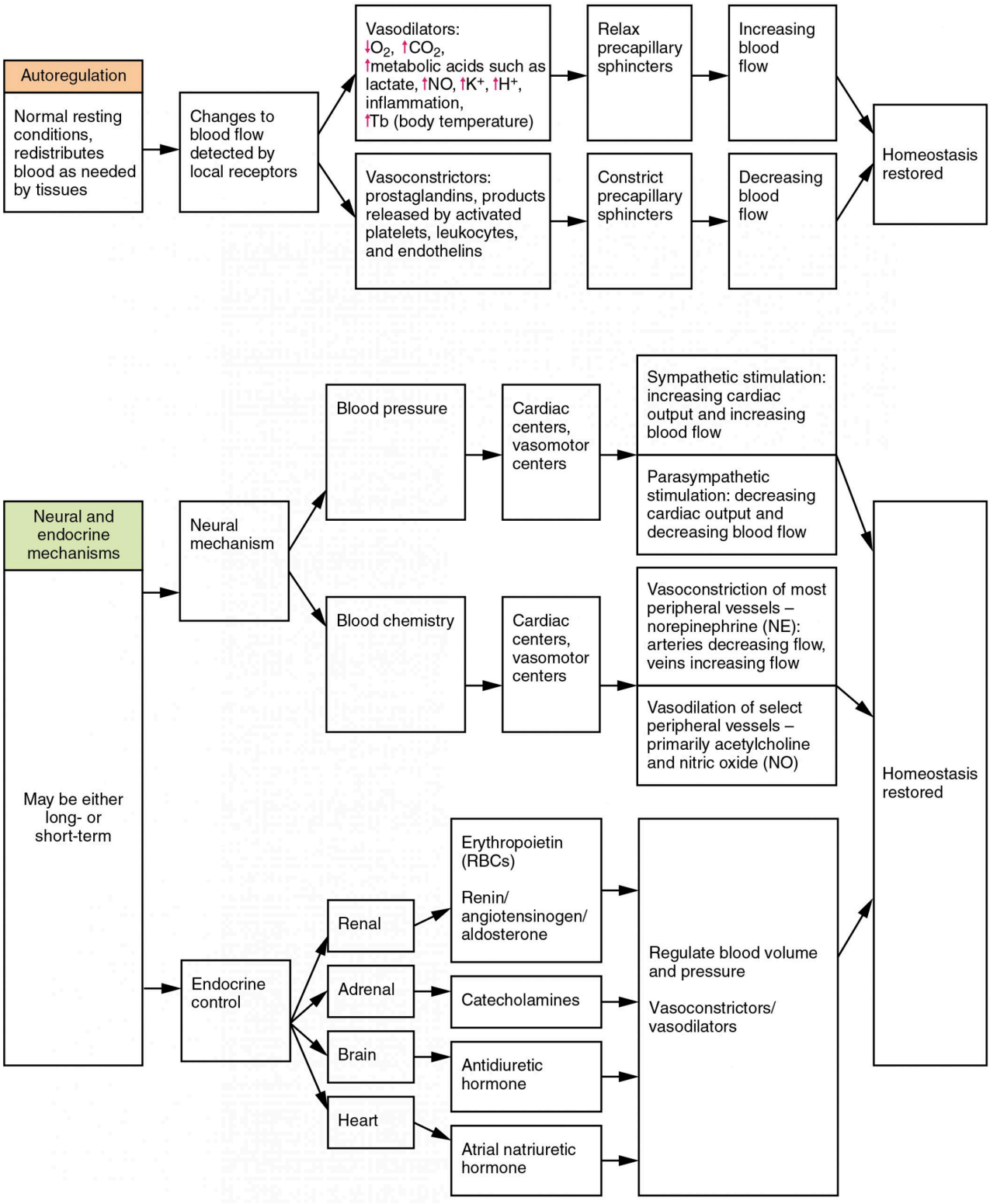


Figure 20.6 Summary of Factors Maintaining Vascular Homeostasis. Sufficient blood flow, appropriate blood pressure, correct distribution, and adequate perfusion are regulated by autoregulatory, neural and endocrine mechanisms. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Circulatory Pathways

The right ventricle pumps oxygen-depleted blood into the pulmonary trunk and right and left pulmonary arteries, which carry it to the right and left lungs for gas exchange. Oxygen-rich blood is

transported by pulmonary veins to the left atrium. The left ventricle pumps this blood into the aorta (Figure 20.7).

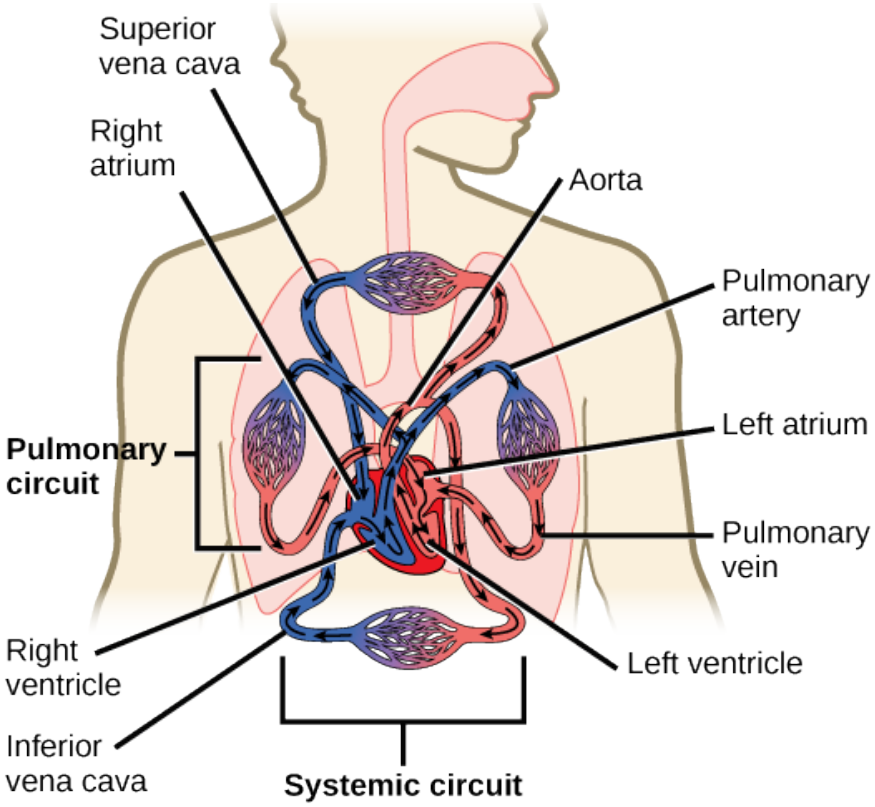


Figure 20.7 Systemic and Pulmonary Circulation. Flow of oxygenated and deoxygenated blood through the circulatory system. (Credit: OpenStax Anatomy and Physiology, license CC-BY 4.0)

The main regions of the aorta are the ascending aorta, aortic arch, and descending aorta, which is further divided into the thoracic and abdominal aorta. The coronary arteries that oxygenate the heart itself branch from the ascending aorta. After oxygenating tissues in the capillaries, systemic blood is returned to the right atrium from the venous system via the superior vena cava, which drains most of the veins superior to the diaphragm, the inferior vena cava, which drains most of the veins inferior to the diaphragm, and the coronary veins via the coronary sinus. The hepatic portal system carries blood to the liver for processing before it enters circulation.

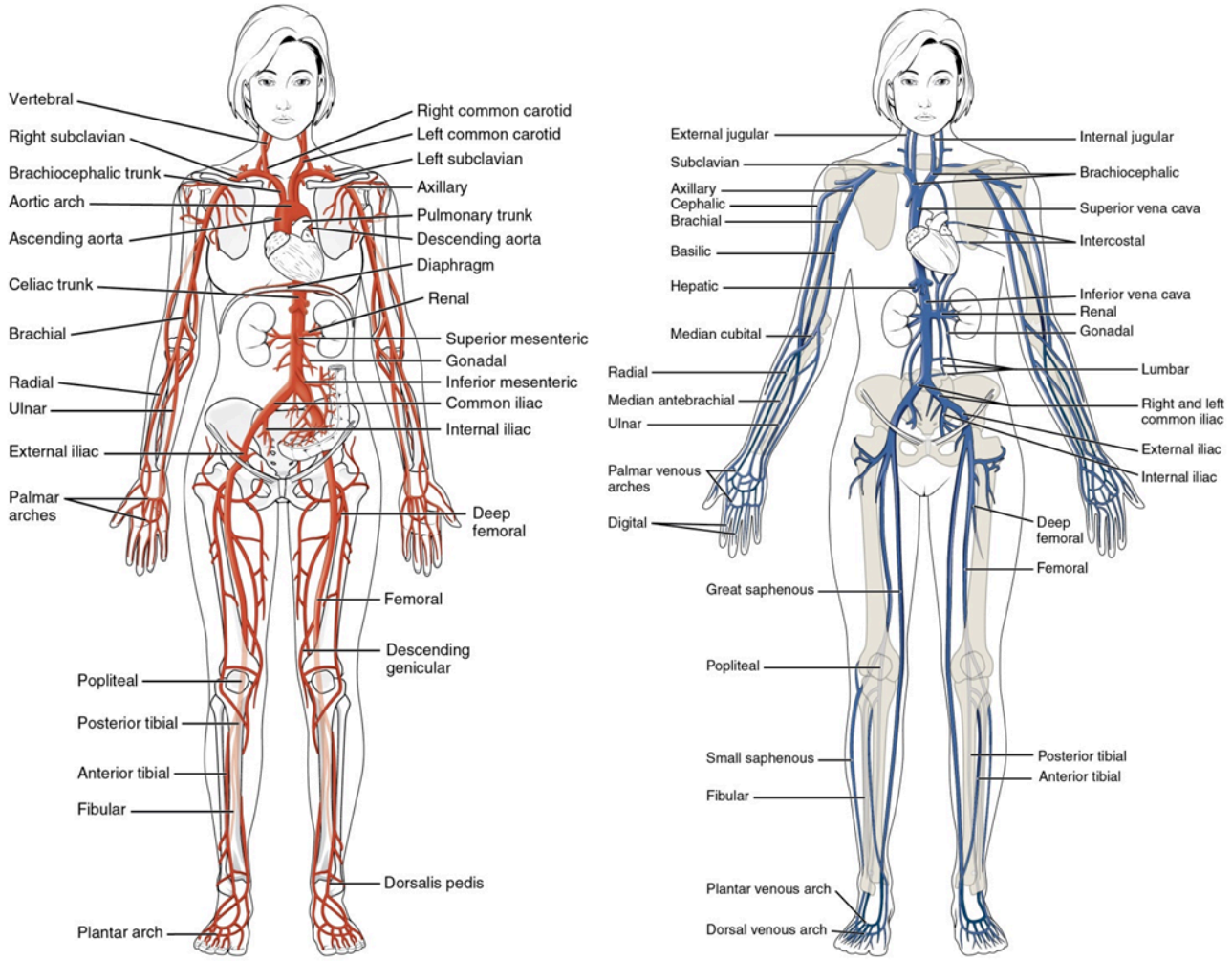


Figure 20.8 Major Arteries and Veins of Circulation. Arteries are shown on the left in red and veins are shown on the right in blue. (Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license)

Pre-Laboratory Questions

After you review the Background information above, answer the following questions before attempting the Exercises in the laboratory.

1. Name one structural feature of arteries that help their function.
2. What is the function of valves in veins?
3. How does having just a tunica interna and no other layers help the function of capillaries?
4. Define the terms vasoconstriction and vasodilation.
5. List the main arteries and veins blood follows as it is pumped from the heart to the lungs and back in the pulmonary circuit.
6. List the main arteries and veins blood follows as it travels from the heart to the rest of the body and back to the heart again.

Exercises

- Exercise 1 Examine the microanatomy of blood vessels
- Exercise 2 Identify the main arteries and veins of the body on a torso model
- Exercise 3 Measure blood pressure using a blood pressure cuff and stethoscope
- Exercise 4 Analyze factors affecting blood pressure

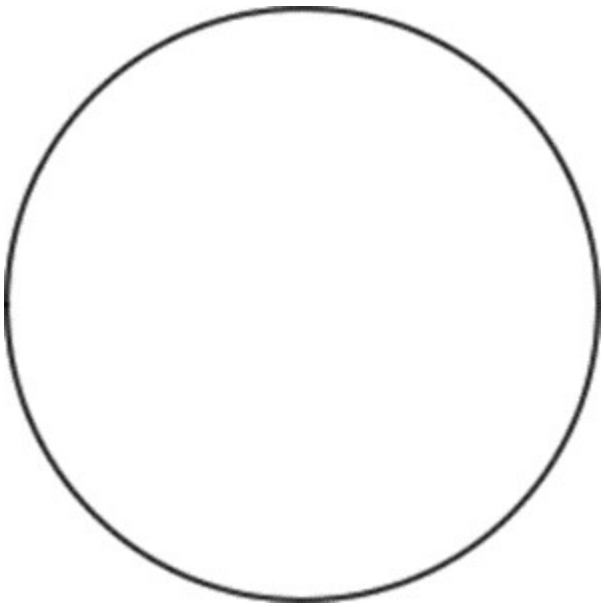
Exercise 1 Examine the microanatomy of blood vessels

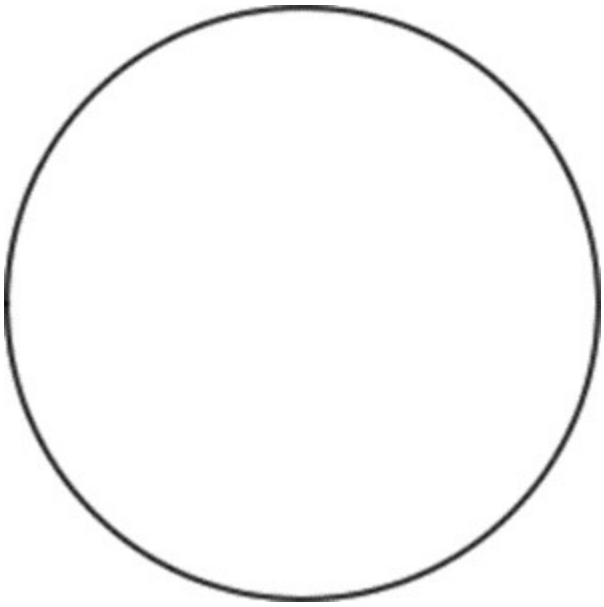
Required Materials

- Compound microscope
- Microscope lens paper
- Microscope lens solution
- Microscope immersion oil
- Human Artery and Vein prepared microscope slide

Procedures

1. Obtain a microscope and plug it in on your bench. Make sure the objective and ocular lenses are clean. If not, use the lens paper and lens cleaning solution to wipe these.
2. Turn on the microscope and adjust the ocular lens distance until you see only one lit circle when you look through the eyepiece.
3. Obtain a human artery and vein slide and first observe it using the 4x objective to focus, 10x and 40x to see higher magnification. Compare your observations with the blood vessel structure drawings in figures 20.2 and 20.3 to better understand what you are seeing.
4. Sketch and label what you observe using low magnification and high magnification in the space below. Your sketch should allow you to label the following structures: artery, vein, capillary, endothelium, tunica interna, tunica media (on vein and artery only), tunica externa (on vein and artery only), and valve (if present, on vein only).





Exercise 2 Identify the main arteries and veins of the body on a torso model

Required Materials

- Torso model
- Circulatory system model
- Post-it notes
- Labeling tape

Procedures

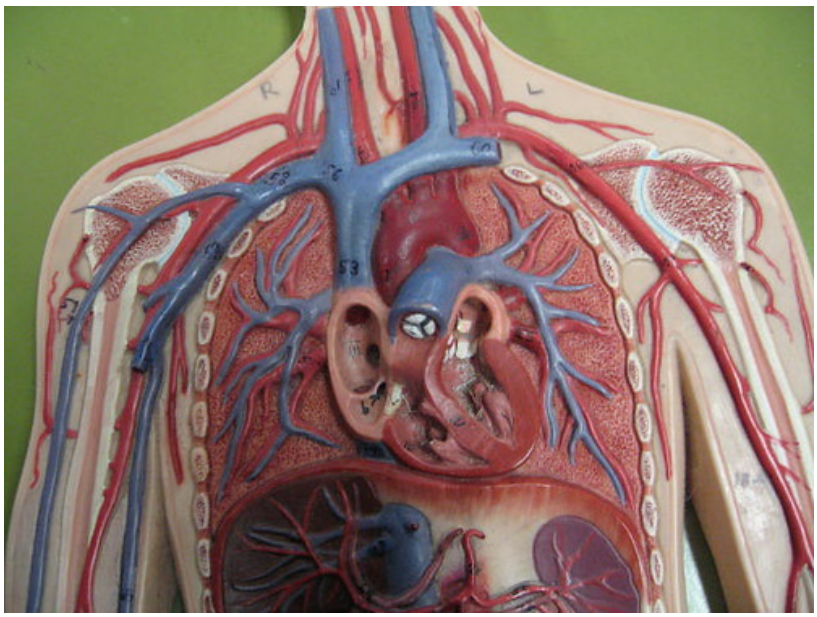


Figure 20.9 Torso Model Example Showing Blood Vessels. (Credit: Creative Commons Images; WordPress Openverse; "Blood Vessel Model 3" by GreenFlames09 is marked with CC BY 2.0.)

1. You will find multiple torso models that also contain arteries and veins as part of them, similar to the image shown in Figure 20.9. Select a torso model and remove the plastic organs to expose the blood vessels.
2. Use the post-its or the labeling tape to name the main arteries and veins. Refer to Figure 20.8 showing the main arteries and veins of the human body to check your work and for guidance.
3. Take a picture with your labeled blood vessels on the model and paste in the space below. Alternatively, you can sketch the model with blood vessels and label it in the space below.

Exercise 3 Measure blood pressure using a blood pressure cuff and stethoscope

Required Materials

- Syphygmomanometer (blood pressure cuff)
- Stethoscope

Procedure

In this exercise you will learn to measure blood pressure and test the effects of exercise on blood pressure.

Follow the steps below to measure the resting systolic and diastolic blood pressure. Record the values here:

- Resting Systolic Pressure:_____
- Resting Diastolic Pressure: _____

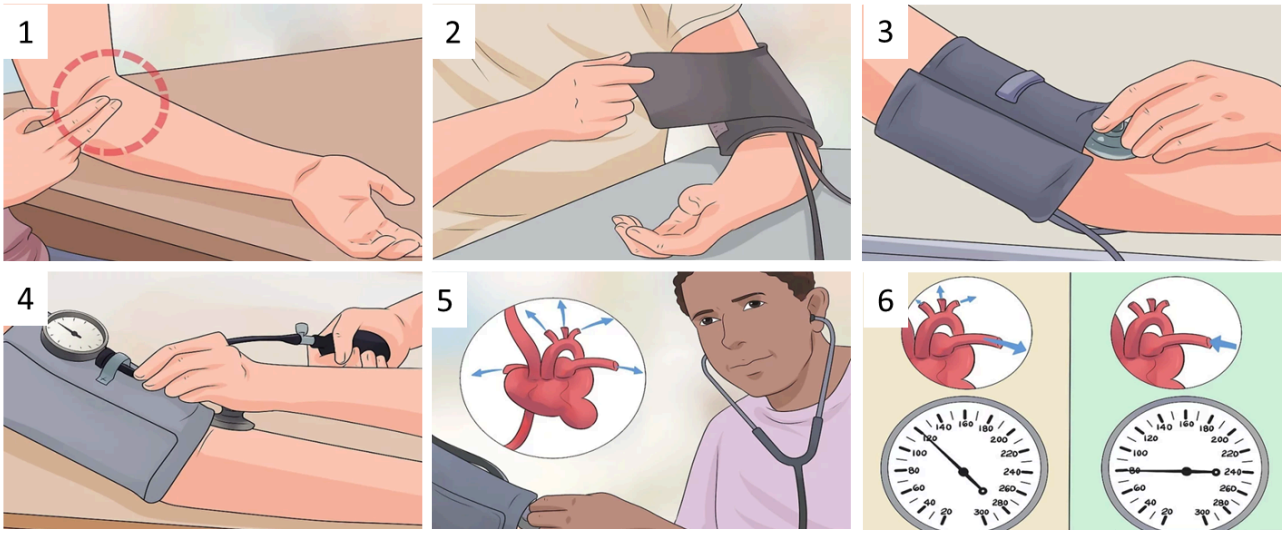


Figure 20.10. Steps involved in measuring blood pressure using a syphgmomanometer and stethoscope. (Credit: wikiHow, CC BY-NC-SA 3.0 license, https://www.wikihow.com/Take-Blood-Pressure-Manually)

1.Locate the pulse. Place your index and middle fingers over the inside center of the inner elbow. When you press lightly you should be able to feel the pulse of the brachial artery from this position. If you have difficultly locating your pulse, place the head of the stethoscope (the round piece at the end of the tube) in the same general area and listen until you can hear the heartbeat.

2.Wrap the cuff around the arm and tighten. Tuck the cuff end through the metal loop and slide it onto your upper arm. The cuff should be roughly 1 inch (2.5 cm) above the bend of your elbow and should be evenly tight around your arm. Make sure that the skin is not pinched by the cuff as you wrap it securely. The cuff should have heavy duty velcro on it, which will hold the cuff closed.

3.Place the stethoscope under the cuff. The head should be face down, with the wide part of the chest piece in contact with the skin. It should be positioned directly over the pulse of your brachial artery that you found earlier. Also place the stethoscope earpieces in your ears. The earpieces should face forward and point toward the tip of your nose.

4.Inflate the cuff until no blood flow sounds are heard with stethoscope. The gauge needs to be positioned where you can see it. You should hold the pump in your right hand.Turn the screw on the pump bulb clockwise to close the airflow valve, if necessary. Rapidly squeeze the pump bulb until you no longer hear the sound of the pulse through the stethoscope. Stop once the gauge reads 30 to 40 mmHg above normal blood pressure, usually between 160 to 180 mmHg.

5.Deflate the cuff slowly and listen for systolic reading. Open the airflow valve by twisting the screw counterclockwise. Let the cuff deflate gradually.The gauge should fall 2 mm, or two lines on the gauge, per second. Note the measurement on your gauge at the precise moment you hear ythe heartbeat again. This measurement is your **systolic reading**. Systolic blood pressure refers to the force your blood exerts against the artery walls as your heart pumps. This is the blood pressure created when your heart contracts.

6.Continue deflating the cuff and listen for diastolic reading. Note the measurement on your gauge at the precise moment the sound of the heartbeat disappears. This measurement is your **diastolic reading**. Diastolic blood pressure refers to your blood pressure in between heartbeats.

For an adult, the systolic blood pressure should be less than 120 mmHg and the diastolic blood pressure should be less than 80 mmHg. This range is considered "normal."

Exercise 4 Analyze factors affecting blood pressure

In this exercise we will determine the effect of hot and cold water immersion on blood pressure and blood flow.

Remember that sufficient blood flow is necessary for organ function. However, too much blood abnormally diverted to an area can challenge the integrity of the blood vessels increasing risk of rupture. As our nervous, endocrine and local control mechanisms respond to changes like exercise and cold, the radius/diameter of some blood vessels is changed; vasoconstricting to reduce blood flow and vasodilating to increase blood flow. Vasoconstriction and vasodilation in turn affect blood pressure (Figure 20.11).

Poiseuille's equation:

$$\text{Blood flow} = \frac{\pi \Delta P \, r^4}{8\eta\lambda}$$

π is the Greek letter pi, used to represent the mathematical constant that is the ratio of a circle's circumference to its diameter. It may commonly be represented as 3.14, although the actual number extends to infinity.
ΔP represents the difference in pressure.
r^4 is the radius (one-half of the diameter) of the vessel to the fourth power.
η is the Greek letter eta and represents the viscosity of the blood.
λ is the Greek letter lambda and represents the length of a blood vessel.

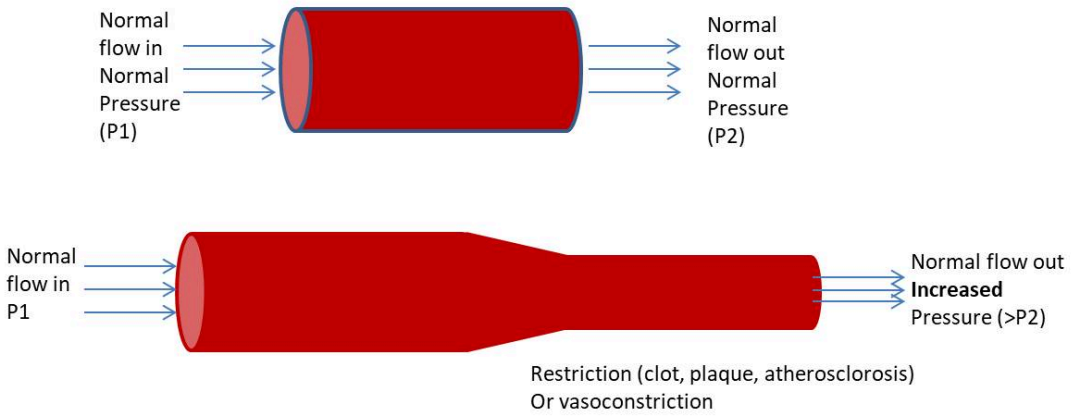


Figure 20.11 Blood flow formula and example of effect on blood pressure. (Credit: OpenStax Anatomy and Physiology)

Required Materials

- Syphygmomanometer (blood pressure cuff)
- Stethoscope

- Ice bath (ice, in large beaker or bucket)
- Warm water bath (hot plate, large beaker or bucket)
- Thermometer

Procedures

1.Follow the steps described in Exercise 3 (Figure 20.10) above to measure blood pressure of a classmate (subject) who is resting, and record it:

  - Resting Systolic Pressure:_____
  - Resting Diastolic Pressure: _____

2.Prepare an ice bath in a large beaker (or other container) placing sufficient ice to bring down the water temperature to 0-10^{o}C.

3.Ask your classmate (subject) to immerse their left hand in the ice bath for 5 minutes.

4.While the hand is still in the ice bath, measure blood pressure and record it:

  - Cold Systolic Pressure:_____
  - Cold Diastolic Pressure: _____

5.Remove your classmate's hand from ice water and let them rest while you prepare a warm water bath. Warm up the water on a hotplate but make sure you do not exceed 40oC. You can mix warm and tapwater to obtain the temperature needed.

6.Have your classmate immerse their hand in the warm water container for 5 minutes.

7.While the hand is still in the ice bath, measure blood pressure and record it.

  - Warm Systolic Pressure:_____
  - Warm Diastolic Pressure: _____

Post-laboratory Questions

1.In Exercise 1, you observed normal capillary, artery and vein structure. Below you have a diseased artery in the kidney (Figure 20.12).

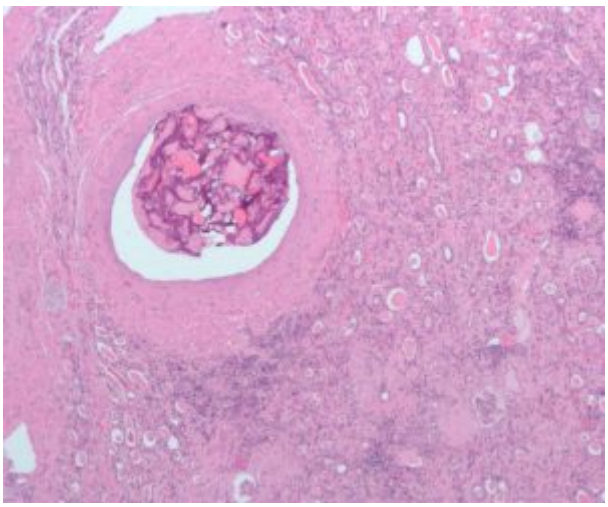


Figure 20.12 Cross section of a diseased artery in the kidney. (Credit: Wikipedia, Nephron. CC-BY-SA3 license)

Compare and contrast the structure of this artery with the normal artery you observed.

- List the similarities between this diseased artery and the normal artery features you observed.
- List what is different in this artery compared to the normal artery you observed.
- What effect would you expect this artery problem to have on blood flow? Blood pressure? Explain.

2.In Exercise 3, did blood pressure increase or decrease after cold treatment? Why do you think this change occurred? Explain.

3.In Exercise 3, did blood pressure increase or decrease after warm treatment? Why do you thin this change occurred? Explain.

21.

CHAPTER 21 THE LYMPHATIC AND IMMUNE SYSTEM

By Joseph D'Silva

Motivation.

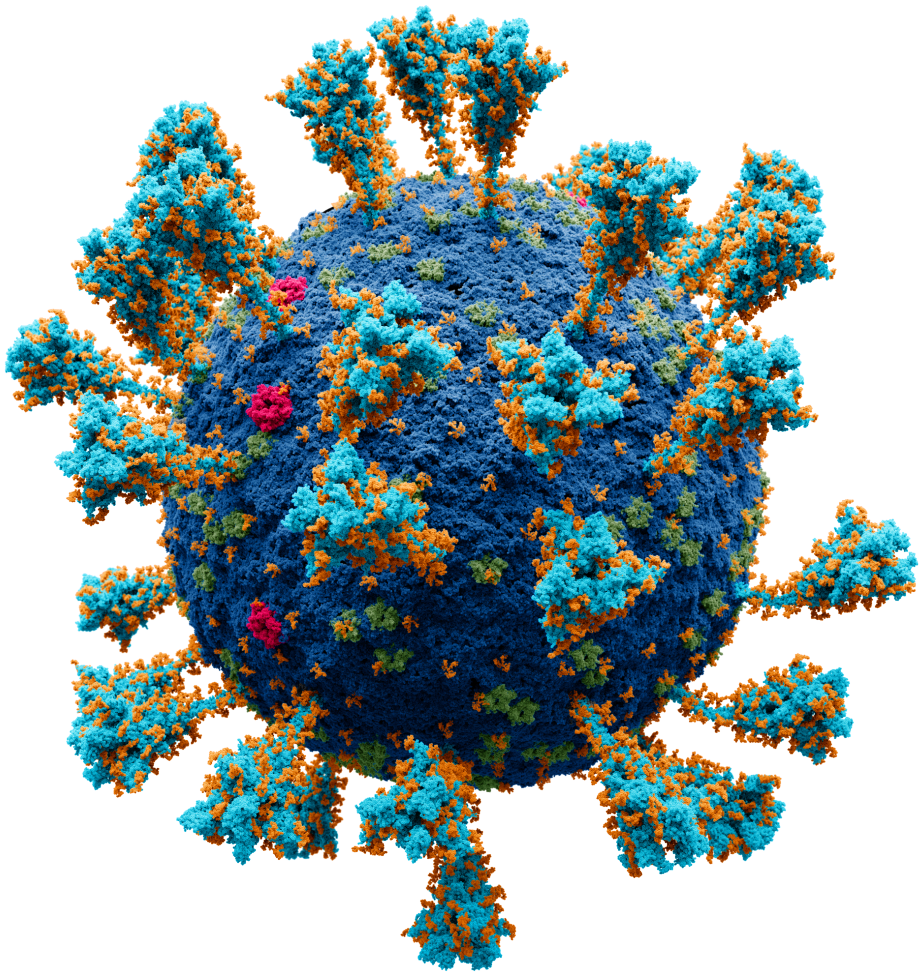


Figure 21.1 Sars-CoV2 Coronavirus. Depiction of the virus causing the 2019 pandemic of COVID-19 disease. Scientifically accurate atomic model of the external structure of SARS-CoV-2. Each "ball" is an atom. Credit Alexey Solodovnikov (Idea, Producer, CG, Editor), Valeria Arkhipova (Scientific Consultant), Wikimedia Commons, license CC-BY-SA

Vaccination has been very much in the news since the novel coronavirus SARS-CoV-2 messed up our lives beginning in December 2019. There was a race to create and manufacture a vaccine against the virus quickly because thousands of lives were being lost daily worldwide. Finally, in 2020, vaccines were developed and have been a savior for people. In 2022, people above 55 years of age are able to get their fourth vaccine shot for the Corona virus.

Vaccination is related to immunity. It provides protection to the body so that an infectious agent does not attack it. Every year, people get vaccinated against the flu (influenza) virus. Vaccinations protect us also against polio, mumps, smallpox and other diseases. Immunity is

a part of the lymphatic system in our body. To understand the lymphatic system, we will have to know its structure and how it functions physiologically.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Identify and describe the structure and distribution of major lymphatic vessels and organs
- Describe the histology of a lymph node, spleen, tonsils, Peyer's patches
- Compare and contrast the structure and function of different lymphoid organs

Background.

The lymphatic system is made up of lymph fluid, cells, tissues and organs. Lymph is a colorless fluid that contains cells. The cells are lymphocytes. They are found in lymph nodules and nodes and in spleen, bone marrow and thymus (Figure 21.2 and 21.3). Lymphocytes proliferate in the tissues and mature there. Lymphatic vessels (capillaries) are structures through which cells travel and can be found under the skin. These capillaries have closed or blinded ends. Vessels are organized into larger trunks. The trunks are (1) right and left jugular; (2) right and left subclavian; (3) right and left bronchomediastinal; (4) intestinal; (5) right and left lumbar trunks. Each trunk drains a particular area in the body. The trunks lead to two ducts: (1) right lymphatic and (2) thoracic (Figure 21.4).

White blood cells travel through the lymphatic ducts going to tissues and organs where they are needed to neutralize harmful pathogens (antigens). These cells are macrophages, B-lymphocytes and T-lymphocytes. When an antigen is detected, B-lymphocytes react to it and produce antibodies. The antibodies provide us with immunity and are produced by the T-lymphocytes and B-lymphocytes after a person receives vaccinations. Vaccines used in vaccination are prepared from dead infectious agents, for example, COVID virus. Lymphatic tissue is found in these organs: thymus, spleen and ileum.

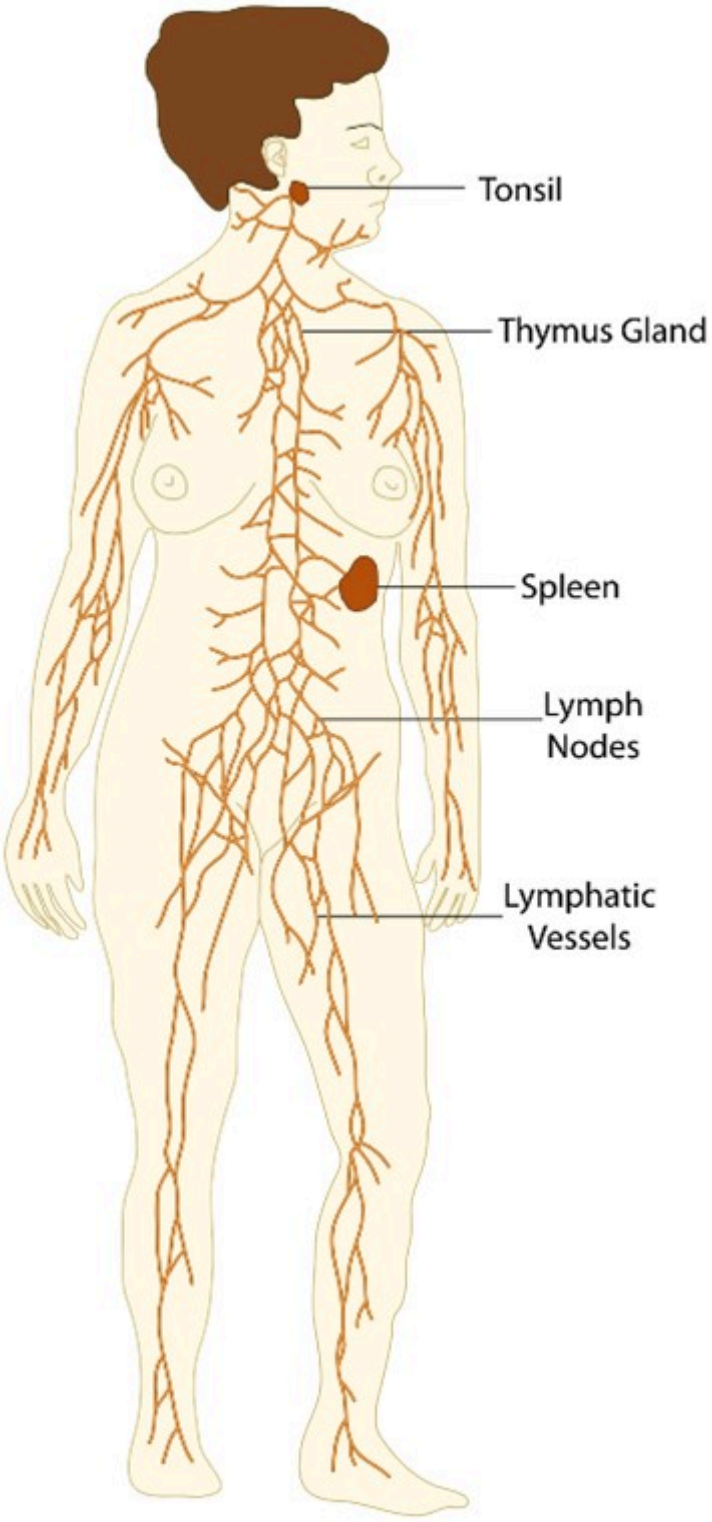


Figure 21. 2. Location lymphatic tissues and organs of the lymphatic system. Shown in relation to the lymphatic vessels. Credit: Wikimedia Commons, license CC-BY 3.0.

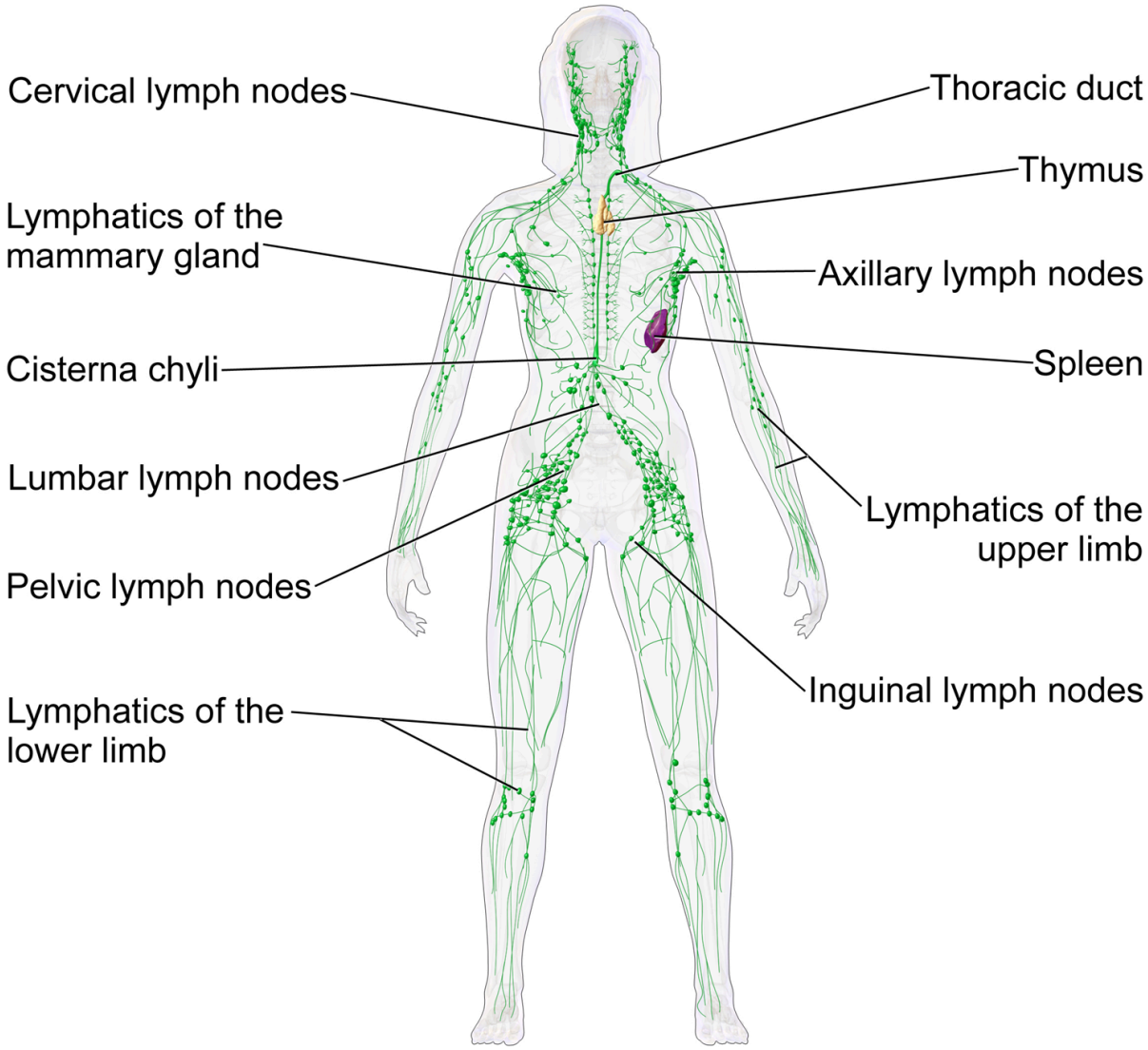


Figure 21. 3 Distribution of lymph nodes in the lymphatic system. In relation to the lymphatic vessels and some lymphatic organs. Credit: BruceBlaus, Blausen.com staff (2014). "Medical gallery of Blausen Medical 2014". WikiJournal of Medicine 1 (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436. – Own work; Wikimedia Commons, license CC-BY 3.0

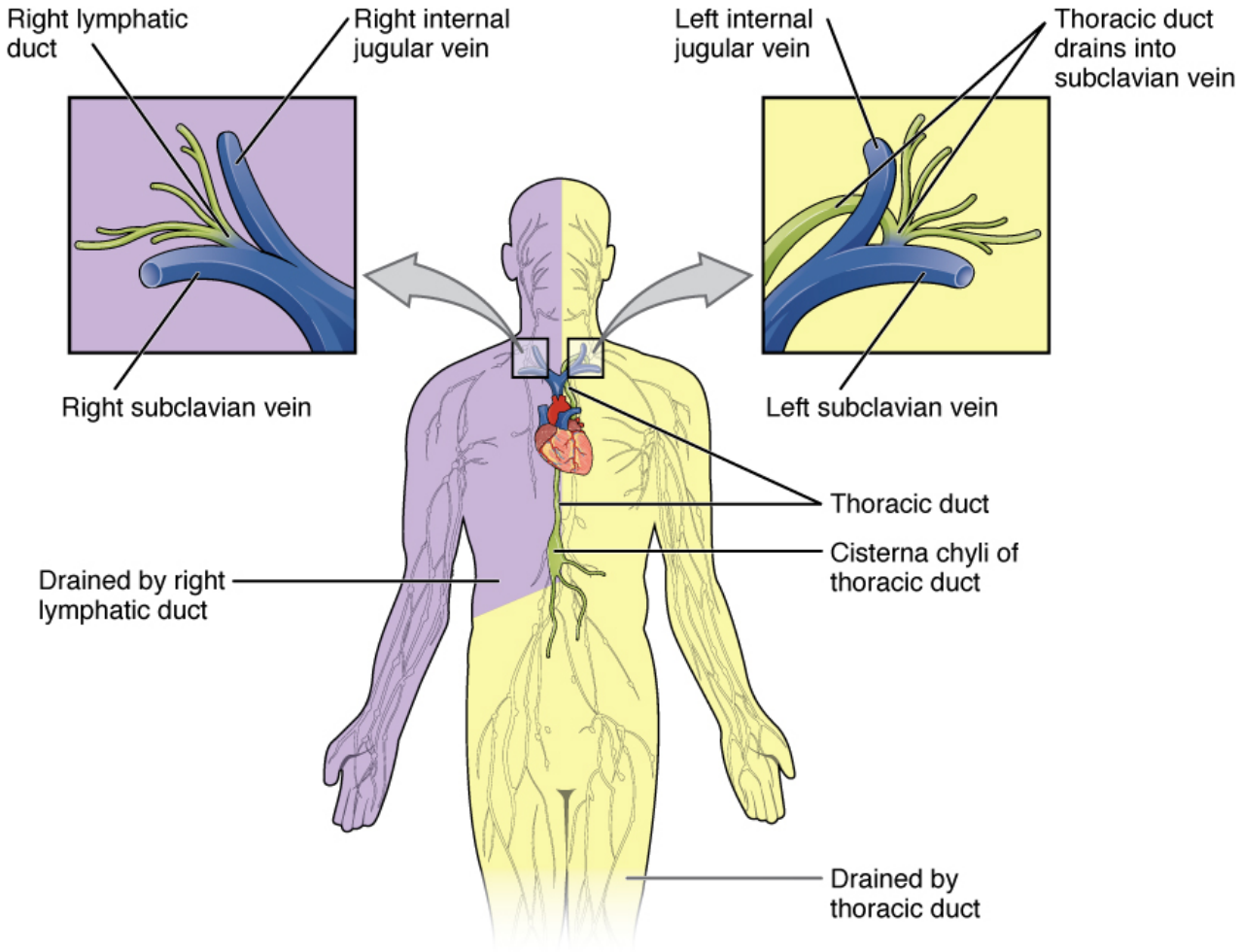


Figure 21.4 Lymphatic trunks and ducts system. Credit: OpenStax Anatomy and Physiology, license CC-BY 3.0

Histology of Lymphatic Organs

Thymus (Figure 21.5). The thymus consists of two lobes, merged in the middle, surrounded by a capsule. The lobes consist of an outer cortex rich with cells and an inner less dense medulla. The lobes are divided into smaller lobules between which trabeculae radiate out from the capsule along the division lines of the lobes.

The cortex is mainly made up of thymocytes and epithelial cells. The thymocytes, immature T cells, are supported by a network of the finely-branched epithelial reticular cells, which is continuous with a similar network in the medulla. This network forms an adventitia to the blood vessels, which enter the cortex via divisions (septa) near the junction with the medulla. Other cells are also present in the thymus, including macrophages, dendritic cells, and a small amount of B cells, neutrophils and eosinophils.

In the medulla, the network of epithelial cells is coarser than in the cortex, and the lymphoid cells are relatively fewer in number. Concentric, nest-like bodies called Hassall's corpuscles (also called thymic corpuscles) are formed by aggregations of the medullary epithelial cells. These are concentric, layered whorls of epithelial cells that increase in number throughout life.

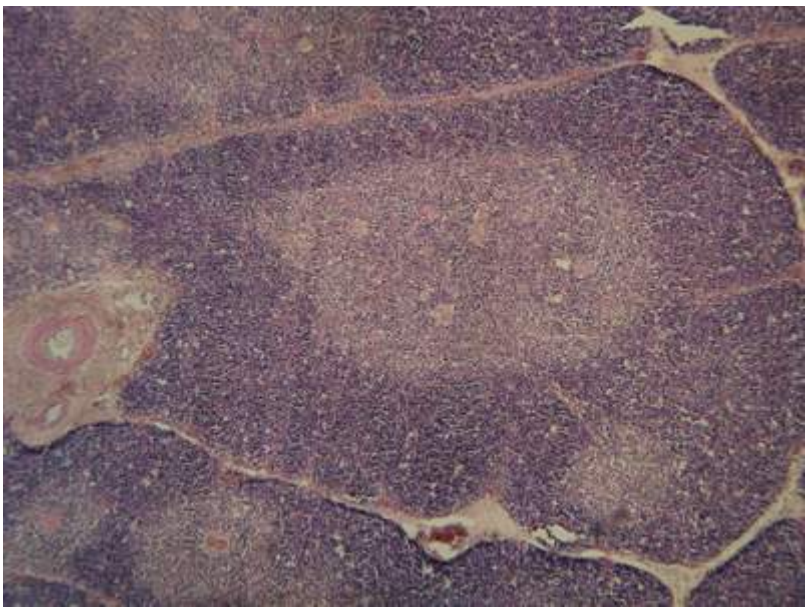


Figure 21. 5 Histology of the thymus. micrograph showing a lobule of the thymus. The cortex (deeper purple area) surrounds a less dense and lighter medulla. Trabeculae are connective tissue that separate the lobules. Credit: Wikipedia, license CC-BY-SA 3.0

Spleen (Figure 21.6) The spleen contains two different tissues, white pulp and red pulp. The white pulp functions in producing and growing immune and blood cells. The red pulp functions in filtering blood of antigens, microorganisms, and defective or worn-out red blood cells. The white pulp contains many lymphocytes which are small cells with dark purple nuclei in H&E stained slides. Most of the rest of the mesenchyme of the spleen is red pulp. You can also observe the dividing connective tissue or trabeculae that extend in from the capsule covering of the spleen.

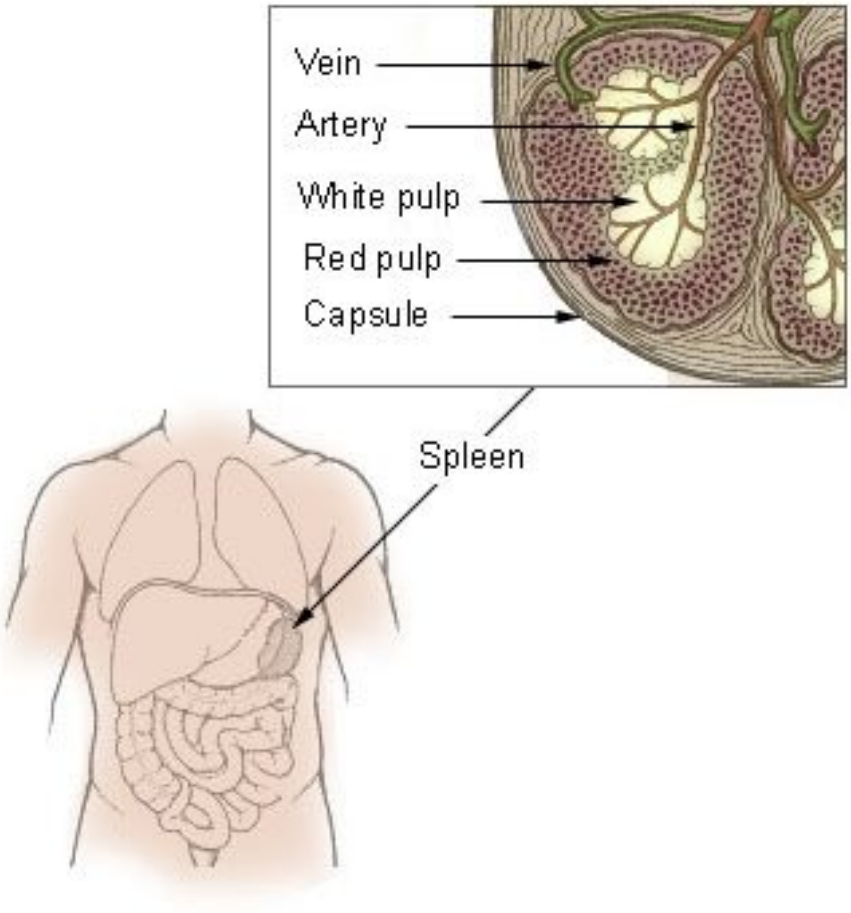


Figure 21.6 Anatomic location and microanatomy of spleen. Diagram Credit: Wikipedia, license Public Domain.

Tonsils (Figure 21.7) Tonsils are large non-encapsulated (or partially encapsulated) masses of lymphoid tissue. They can be found in the pharynx or nasopharynx and at the base of the tongue. The superficial part of the tonsils are covered with a stratified squamous epithelium. Tonsils have many invaginations which form blind crypts. Below the epithelium, there are many lymphoid follicles beneath which have germinal centers.

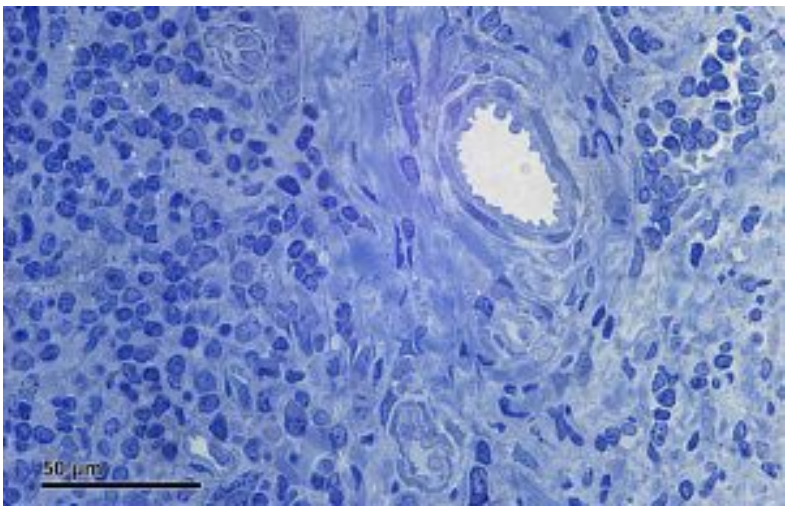


Figure 21.7 Human tonsil microanatomy. Credit: Dr. Josef Reischig, Wikimedia Commons, license CC-BY-SA 3.0

Peyer's patches (Figure 21.8) Peyer's patches, which are organized lymphoid nodules, are commonly found in the small intestines. Peyer's patches appear as oval or round lymphoid follicles extending from the mucosa layer of the ileum into the submucosa layer. B lymphocytes found in the follicles' germinal centers and these lymphocytes are the majority in adults. T lymphocytes are found in the zones between follicles. Follicle-associated epithelium covers all lymphoid follicles which differ from the intestinal epithelium of the villi due to having fewer goblet cells. This layer contains M cells or microfold cells which uptake and transport of antigens from lumen.

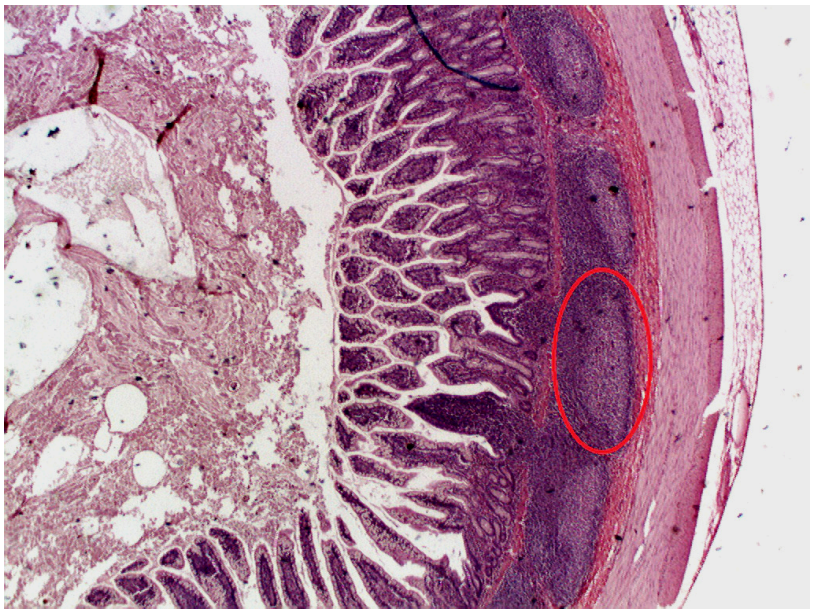


Figure 21. 8. Cross section of ileum with a Peyer's patch (circled in red). Credit: Wikimedia Commons, Author: Plainpaper; license CC-BY-SA 3.0

Pre-Laboratory Questions

After studying the Background information above answer the following questions prior to doing the lab exercises.

1. Define lymphocytes, lymph and lymphatic capillaries.
2. Sketch a figure to show the lymphatic trunks and ducts.
3. List the areas of the body that are drained by each individual trunk.
4. Describe the structures in a spleen section that you would find under the microscope.
5. Compare and contrast the histological structure of the thymus and a tonsil.

Exercises

- Exercise 1 Identify the main organs and glands of the lymphatic system
- Exercise 2 Histology of the thymus
- Exercise 3 Microanatomy of the spleen
- Exercise 4 Examination of tonsil histology
- Exercise 5 Vermiform appendix / ileum Peyer's patches

Exercise 1 Identify the main organs and glands of the lymphatic system

Required Materials

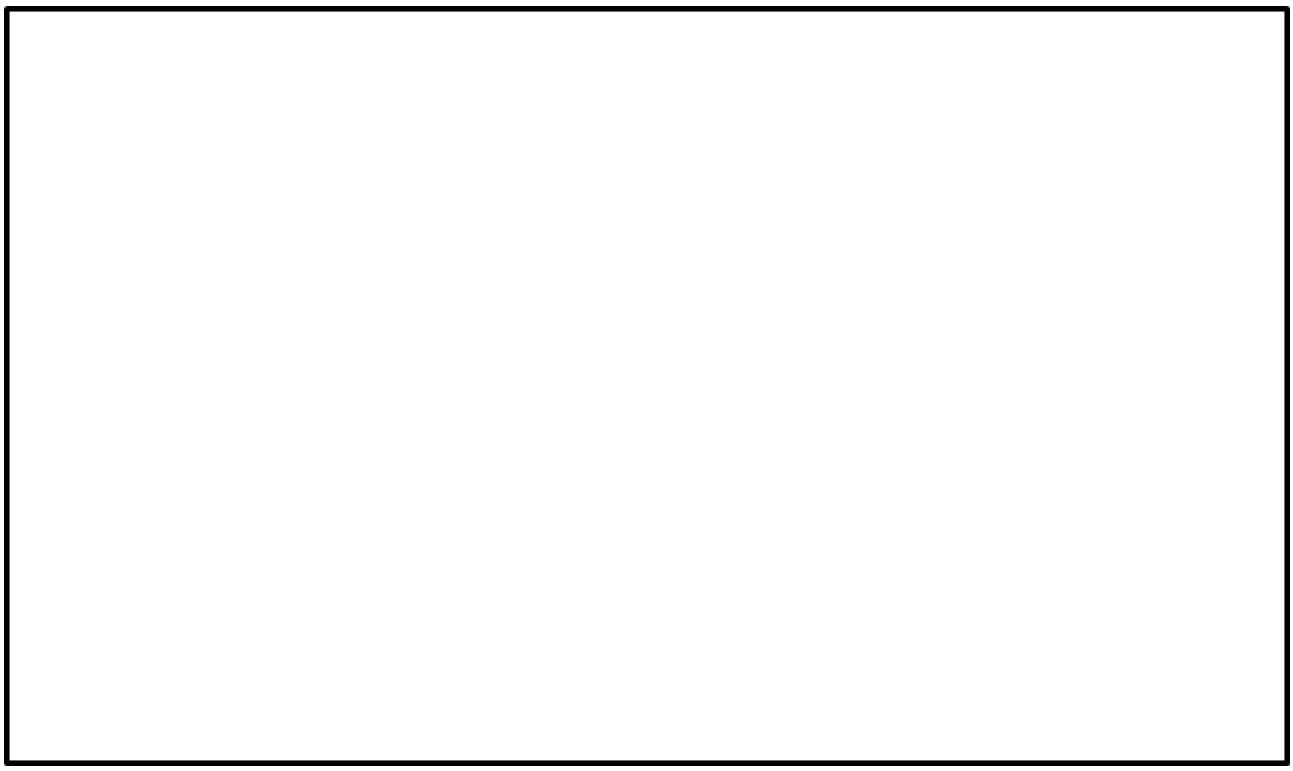
- Torso models
- Lymphatic System Anatomy poster
- The Body's Defenses poster
- Post-it notes
- Labeling tape

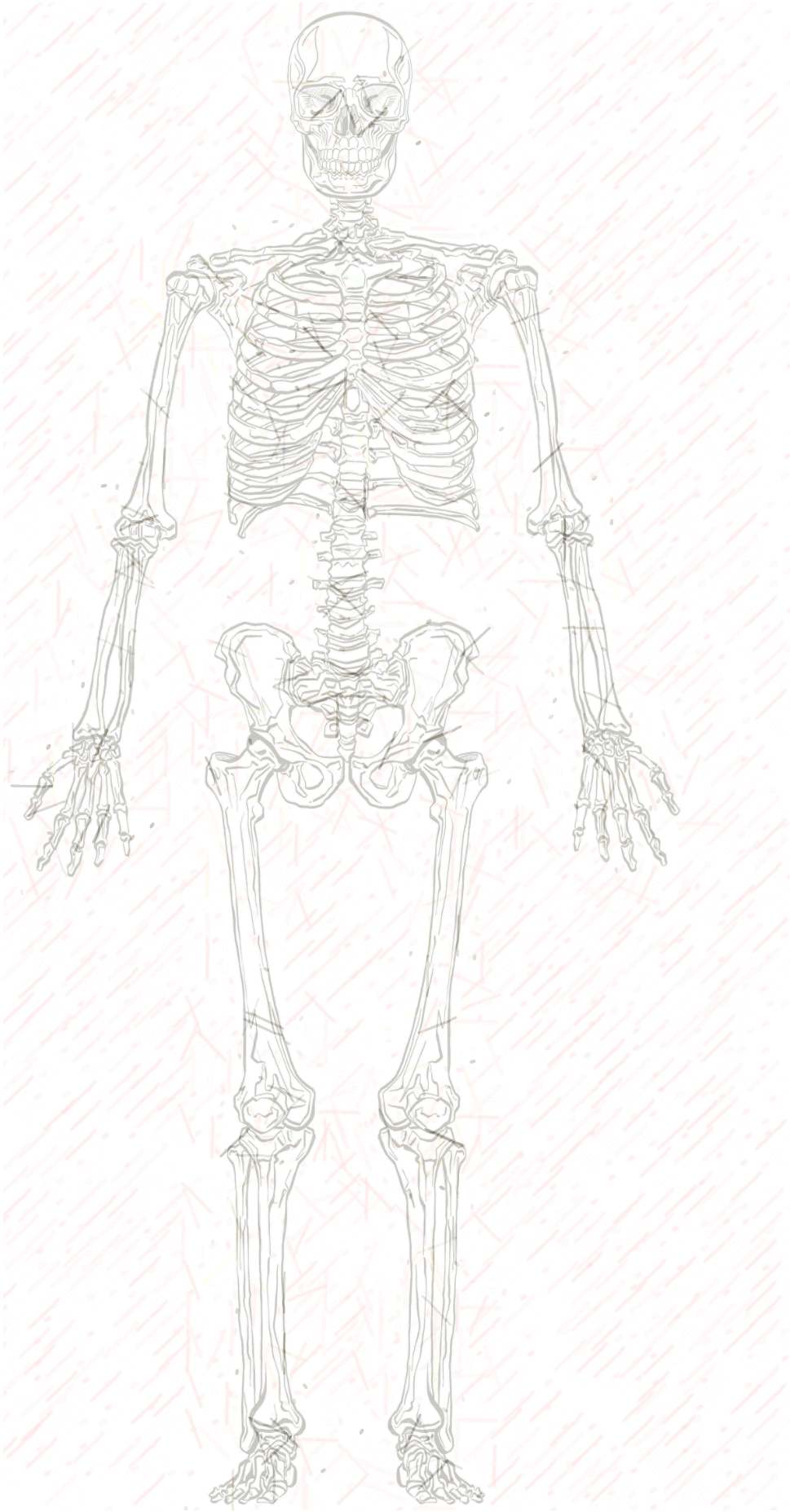
Procedure

1. Use your textbook, torso models, lymphatic system anatomy poster, and the body's defenses poster to identify the structures of the immune system shown in Figure 21. 2, 21.3 and 21.4.
2. Locate the thymus gland and spleen. The thymus gland can be found in the mediastinum. The

spleen is located in the ULC (upper left quadrant) in the pelvic cavity. The vermiform appendix is in the RLQ (right lower quadrant). All these organs contain lymphatic tissue.

3. Use post-it notes or labeling tape to label as many of these lymphoid tissues, organs, and vessels as you can find on the torso models.
4. Take a picture of the torso model with the post-it notes/labels. Insert your picture in the space below. Alternatively, you can sketch the body (use the skeletal outline given as a guide), and label these lymphoid structures.





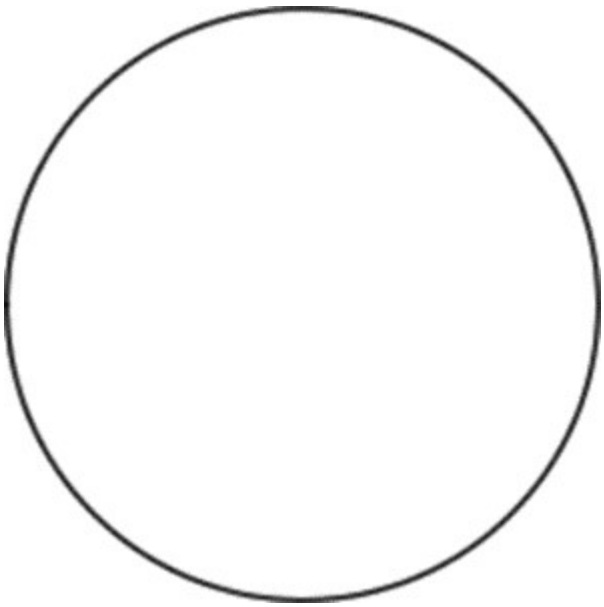
Exercise 2 Histology of the thymus

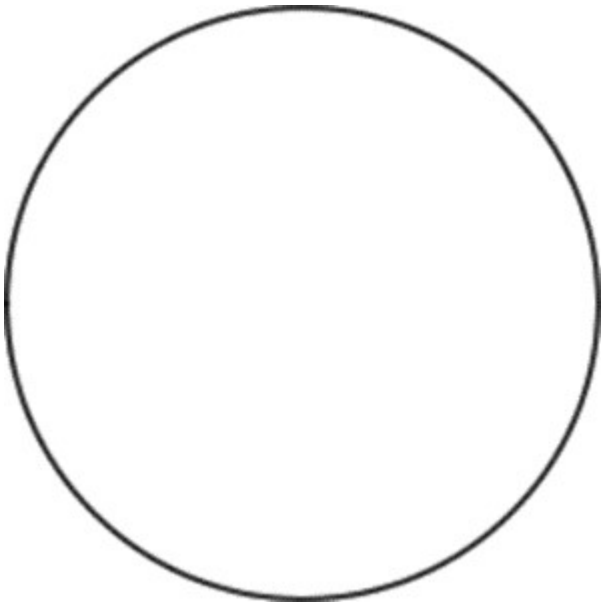
Required Materials

- Compound microscope
- Microscope lens paper
- Microscope lens cleaning solution
- Microscope immersion oil
- Slide of the Human Thymus

Procedure

1. Ask your instructor for a slide showing the thymus (Figure 21.5).
2. Scan under low power.
3. The tissue in the thymus is divided into lobules. The lobules are separated from one another by trabeculae. Identify trabeculae which appear as thin white connective tissue. Each lobule consists of a light central medulla and a cortex that surrounds it. The cortex consists of a dense population of T-lymphocytes in stages of development and appears blue in color.
4. Select different regions of the thymus and observe under high power.
5. Take a picture of your observations at low power and high power, paste the picture below and label the main structures and cell types observed.





Exercise 3 Microanatomy of the spleen

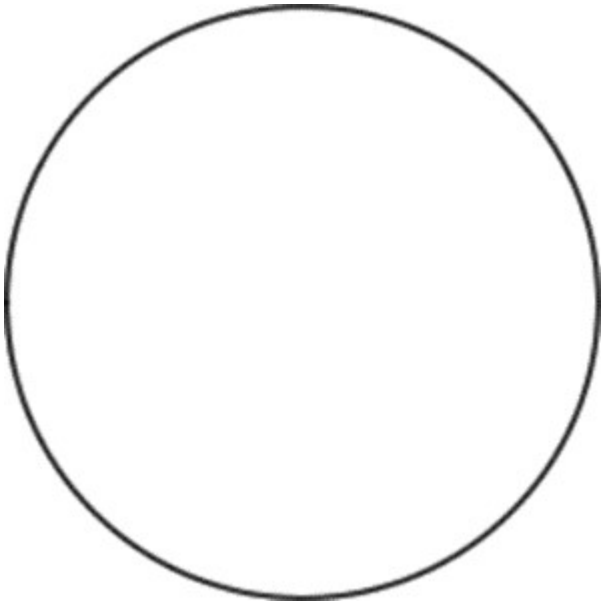
Required Materials

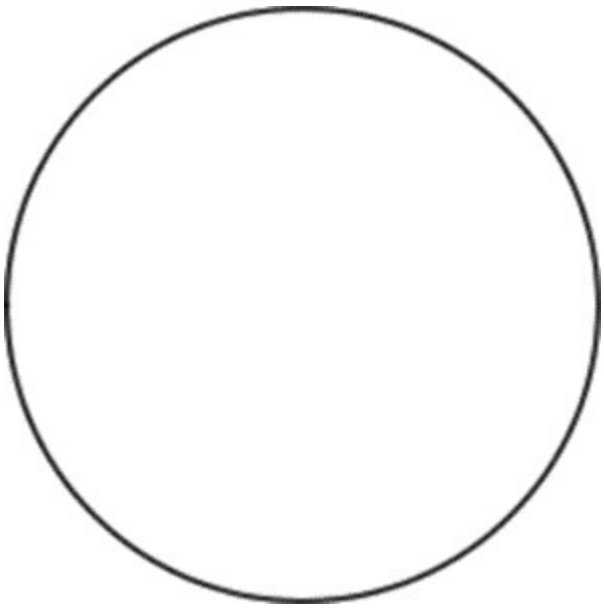
- Compound microscope
- Microscope lens paper
- Microscope lens cleaning solution
- Microscope immersion oil
- Slide of the Human Spleen

Procedure

1. Ask your instructor for a slide showing the spleen (Figure 21.6).

2. Scan under low power.
3. The tissue in the spleen can be identified by its white and red pulp. The white pulp surrounds an artery and consists of B-lymphocytes and T-lymphocytes mostly. The red pulp is made up of red blood cells. Trabeculae can be observed in the the splenic tissue.
4. Select different regions of the spleen and observe under high power.
5. Take a picture of your observations at low power and high power, paste the picture below and label the main structures and cell types observed.





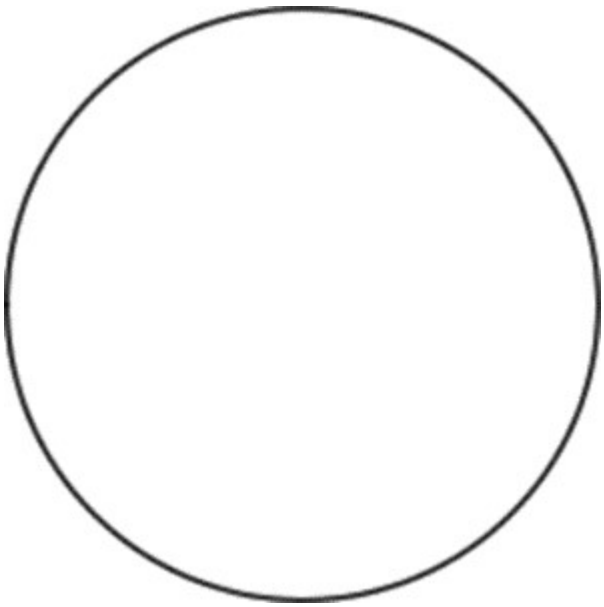
Exercise 4 Examination of tonsil histology

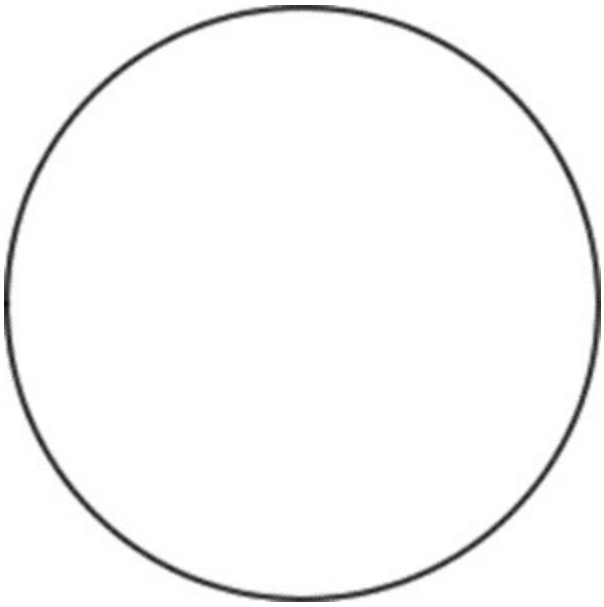
Required Materials

- Compound microscope
- Microscope lens paper
- Microscope lens cleaning solution
- Microscope immersion oil
- Slide of the Human Palatine Tonsil

Procedure

1. Ask your instructor for a slide showing a tonsil (Figure 21.7).
2. Scan under low power.
3. Tonsils are lymphatic nodules. They are located in the oral cavity and pharynx. The tissue is broken up by a number of crypts. These are deep infolding tissue. Tonsilar nodules are made up of large number of lymphocytes. Germinal centers are light in color and surrounded by lymphocytes that are deep blue.
4. Select different regions of the tonsil and observe under high power.
5. Take a picture of your observations at low power and high power, paste the picture below and label the main structures and cell types observed.





Exercise 5 Vermiform appendix / ileum Peyer's patches

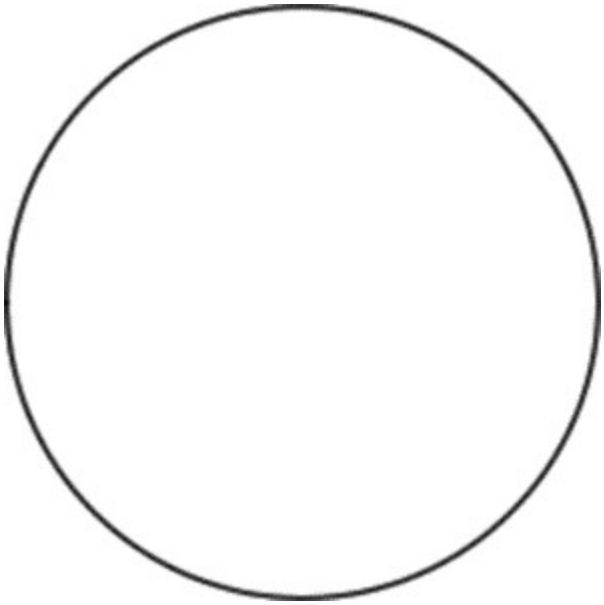
Required Materials

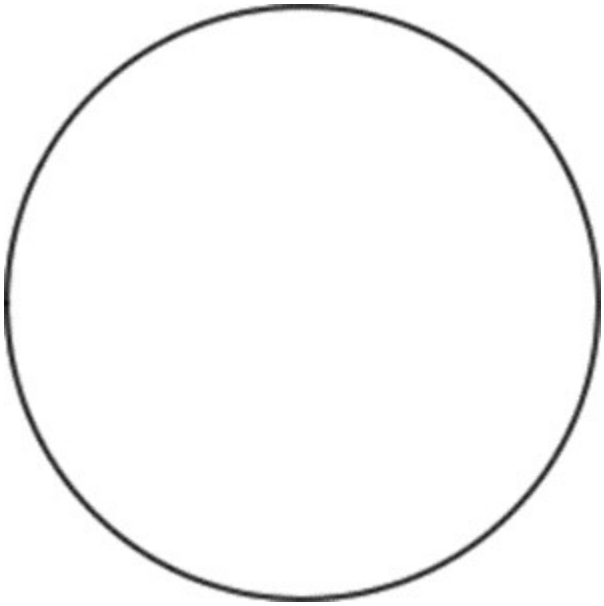
- Compound microscope
- Microscope lens paper
- Microscope lens cleaning solution
- Microscope immersion oil
- Slide of the Human Ileum with Peyer's Patches

1. Ask your instructor for a slide showing the vermiform appendix/ileum (Figure 21.8).
2. Scan under low power.
3. Located in the submucosa are a number of lymphatic nodules. Each nodule consists of a light

germinal center surrounded by darker staining capsule. Peyer's patches are nodules in the walls of the ileum. They are made up of lymphocytes.

4. Select different regions of the Peyer's patches and observe under high power.
5. Take a picture of your observations at low power and high power, paste the picture below and label the main structures and cell types observed.





Post-laboratory Questions

1. The areas of the body that are drained by the right and left subclavian trunks are the _____limbs.
2. Two lymphatic ducts are the _____ and _____.
3. Sketch the structure of spleen and describe it.
4. Study the structure of a tonsil and describe it.

5. What are Peyer's patches and where are they found?

22.

CHAPTER 22 THE RESPIRATORY SYSTEM

By Krishnan Prabhakaran

Motivation.

COPD, or chronic obstructive pulmonary disease, is a progressive disease, which means it gets worse over time. With COPD, less air flows in and out of the airways, making it hard to breathe. In the United States, COPD affects more than 15 million adults, and many more do not know they have it. More than half of those diagnosed are women. COPD is a major cause of disability, and it is the fourth leading cause of death in the United States according to the Centers for Disease Control and Prevention (CDC).

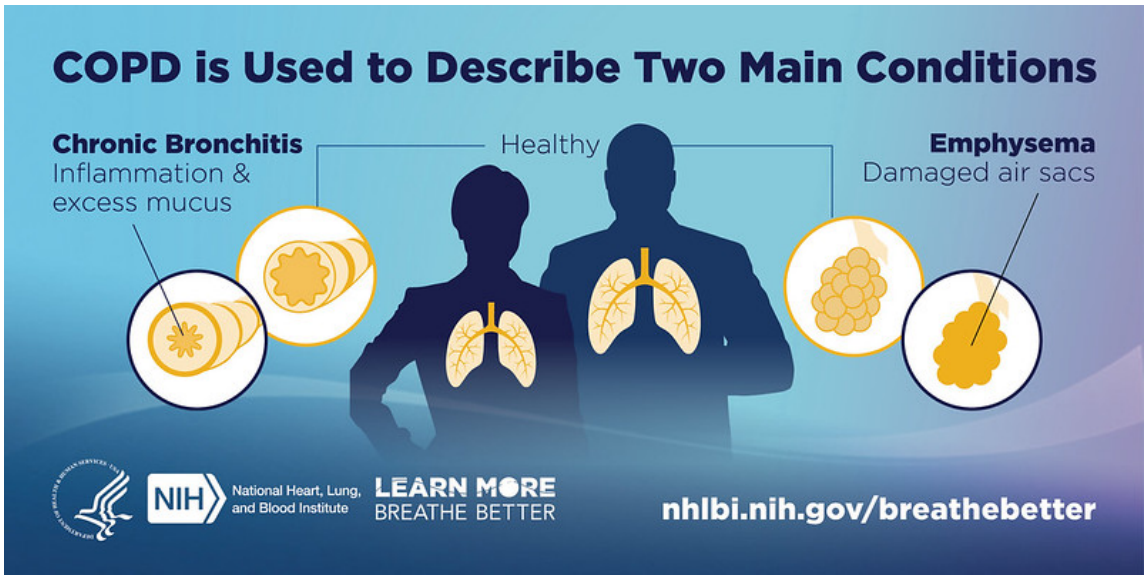


Figure 22.1 COPD includes two main conditions. Credit: National Institutes of Health, National Heart, Lung, and Blood Institute NHLBI.

- **Chronic (long-term) bronchitis** (Figure 20.1, left) is caused by repeated or constant irritation and inflammation in the lining of the airways. Lots of thick mucus forms in the airways, making it hard to breathe.
- **Emphysema** (Figure 20.1, right) develops when there's damage to the walls between many of the air sacs in the lungs. Normally, these sacs are elastic or stretchy. When

you breathe in, each air sac fills up with air, like a small balloon. When you breathe out, the air sacs deflate, and the air goes out. In emphysema, it is harder for your lungs to move air out of your body.

COPD can cause coughing that produces large amounts of a slimy substance called mucus. It can also cause problems breathing, shortness of breath, chest tightness, and other symptoms. Symptoms of COPD often develop slowly but worsen over time, and they can limit your ability to do routine activities. Serious COPD may prevent you from doing even basic activities like walking, cooking, or taking care of yourself.

The good news is that COPD can often be prevented, mainly by not smoking. Cigarette smoking is the leading cause of COPD. Most people who have COPD smoke or used to smoke. However, up to 30% of people with COPD never smoked. A rare genetic condition called alpha-1 antitrypsin (AAT) deficiency can also cause the disease.

Other risk factors for COPD are:

- Exposure to certain gases or fumes in the workplace
- Exposure to heavy amounts of secondhand smoke and pollution
- Frequent use of a cooking fire without proper ventilation

Although there is no cure, treatments and lifestyle changes such as quitting smoking can help you feel better, stay more active, and slow the progress of the disease. You may also need oxygen therapy, pulmonary rehabilitation, or medicines to treat complications.

(Source: https://www.nhlbi.nih.gov/health/copd)

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Identify the major respiratory system structures on a cadaver specimen, model, or diagram, and state their function
- Identify tracheal or lung tissue features on a microscope slide relating structure to

function

- Describe the role of muscle contraction and volume changes in the thorax in the mechanics of breathing.
- Describe the sounds heard with a stethoscope when breathing.
- Identify and explain the importance of various chemical and mechanical factors on modulating breathing rate

Background.

Anatomy of the Respiratory System

The major organs of the respiratory system function primarily to provide oxygen to body tissues for cellular respiration, to remove the waste product carbon dioxide, and to help 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

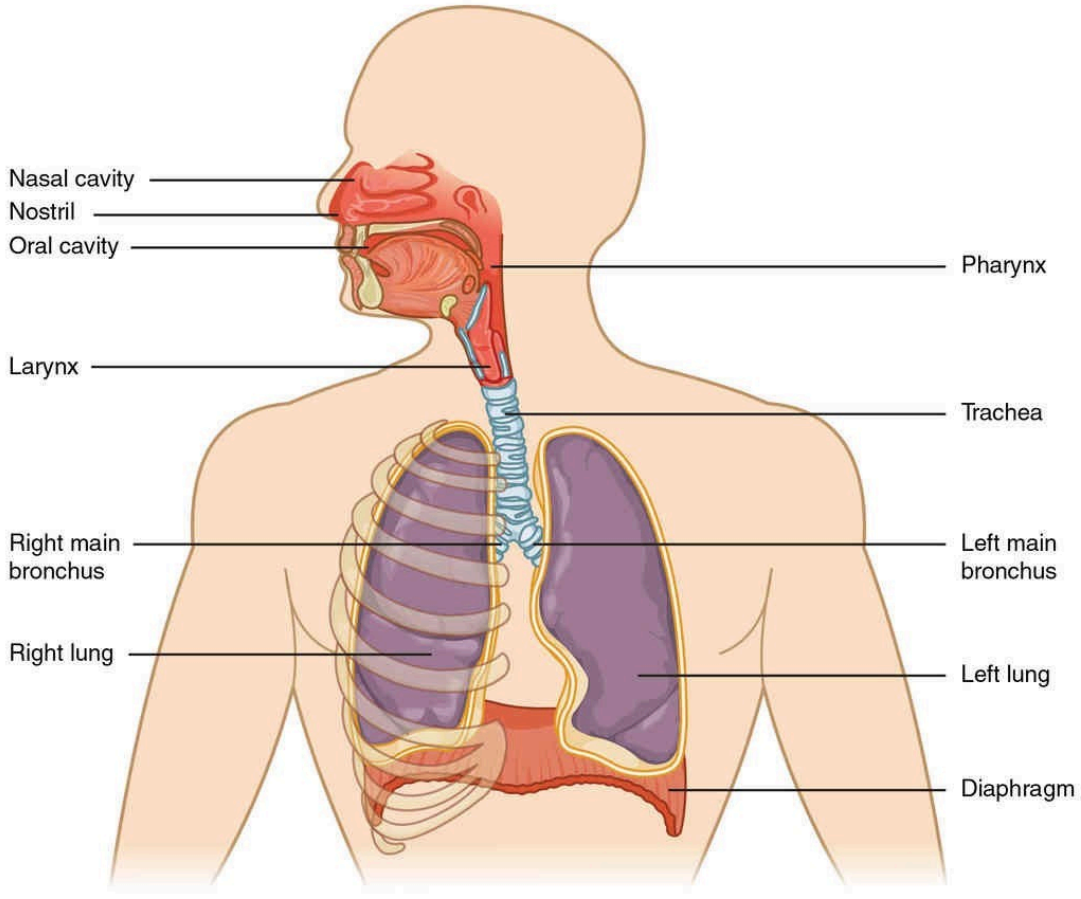


Figure 22.2 Major respiratory structures. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The major respiratory structures (Figure 22.2) extend from the nasal cavity to the diaphragm. Functionally, the respiratory system can be divided into a conducting zone and a respiratory zone. The **conducting zone** includes the organs and structures not directly involved in gas exchange, while gas exchange occurs solely in the **respiratory 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 to warm and humidify the incoming air. Several structures within the conducting zone perform other functions as well.

Nose and Nasal Cartilages

The major entrance and exit for the respiratory system is through the nose. When discussing the nose, it is helpful to divide it into two major sections: the **external nose**, and the **nasal cavity** or **internal nose**.

The **external nose** consists of the surface and skeletal structures that result in the outward appearance of the nose and contribute to its numerous functions (Figure 22.3). The **root** is the region of the nose located between the eyebrows, while the **bridge** is the part of the nose that connects the root to the rest of the nose. The **dorsum nasi** is the length of the nose, while the **apex** is the tip of the nose. On either side of the apex, the nostrils are formed by the **alae**

(singular = **ala**), which are cartilaginous structures that form the lateral sides of each **naris** (plural = **nares**), or nostril opening. Each external naris is protected by guard hairs.

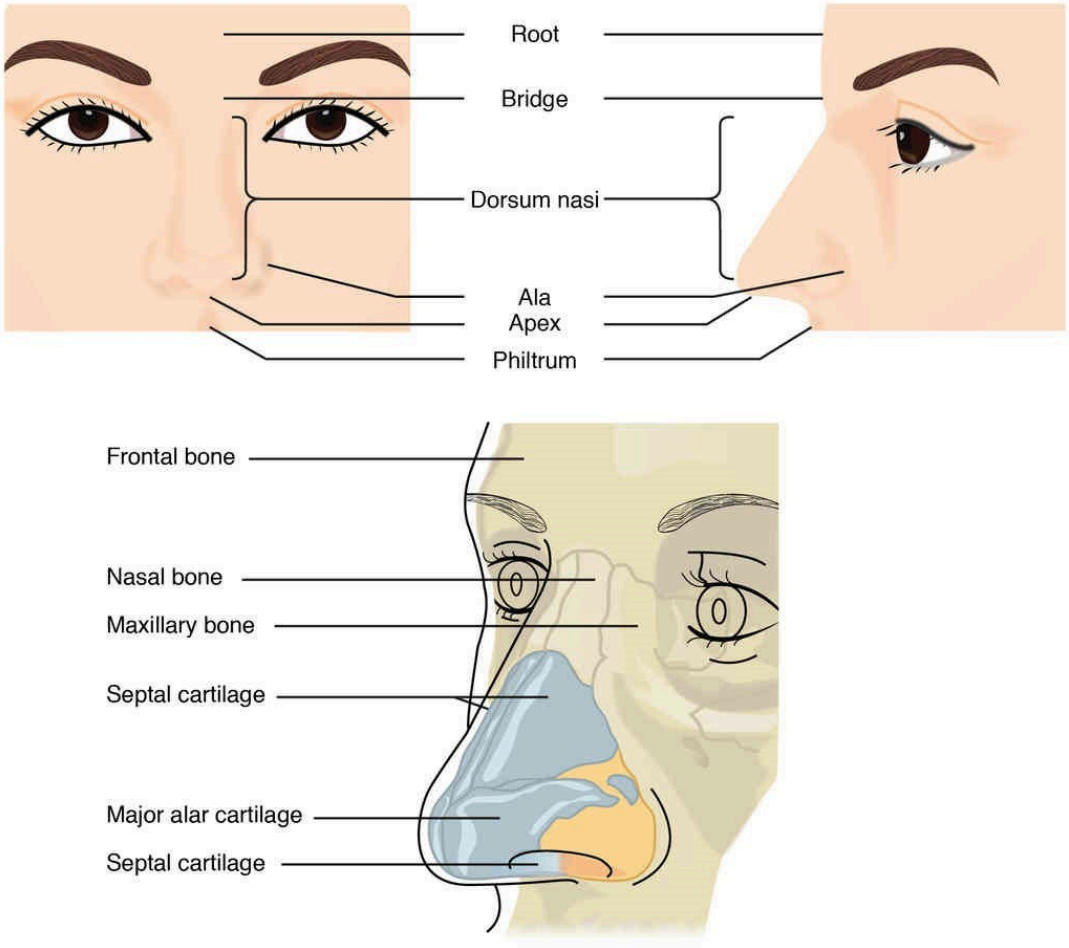


Figure 22.3 Nose This illustration shows features of the external (top) and skeletal features of the nose (bottom). Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Underneath the thin skin of the nose are its skeletal features (see Figure 22.3, lower illustration). While the root and bridge of the nose consist of bone, the protruding portion of the nose is composed of cartilage. As a result, when looking at a skull, the nose is missing. The **nasal bone** is one of a pair of bones that lies under the root and bridge of the nose. The nasal bone articulates superiorly with the **frontal bone** and laterally with the **maxillary bones**. **Septal cartilage** is flexible hyaline cartilage connected to the nasal bone, forming the dorsum nasi. The **alar cartilage** makes up the apex of the nose and extends to surround each naris.

Internally, the **nares** open into the **nasal vestibule**, which is lined with stratified squamous epithelium. Behind the vestibule is the **nasal cavity**, which is separated into left and right sections by the nasal septum (**Figure 3**).The **nasal septum** is formed anteriorly by a portion of the septal cartilage (the flexible portion you can touch with your fingers) and posteriorly by the perpendicular plate of the ethmoid bone (a cranial bone located just posterior to the nasal bones) and the thin vomer bones (whose name refers to its plough shape). Each lateral wall of the nasal cavity has three bony projections, called the **superior**, **middle**, and **inferior nasal conchae** (singular = **concha**). Conchae serve to increase the surface area of the nasal cavity and to disrupt the flow of air as it enters into the nose, causing air to bounce along the epithelium, where it is cleaned and warmed. Each concha overlies a corresponding (superior, middle, inferior) **meatus**, or passageway that leads posteriorly away from the nasal cavity. The conchae and **meatuses** also conserve water and prevent dehydration of the nasal epithelium by trapping water during exhalation. The floor of the nasal cavity is composed of the **palate**. The **hard palate** at the anterior region of the nasal cavity is composed of bone, while the **soft palate**, at the posterior portion of the nasal cavity, consists of muscle tissue. Air exits the nasal cavities via the **internal nares** and moves into the **pharynx** (Figure 22.4).

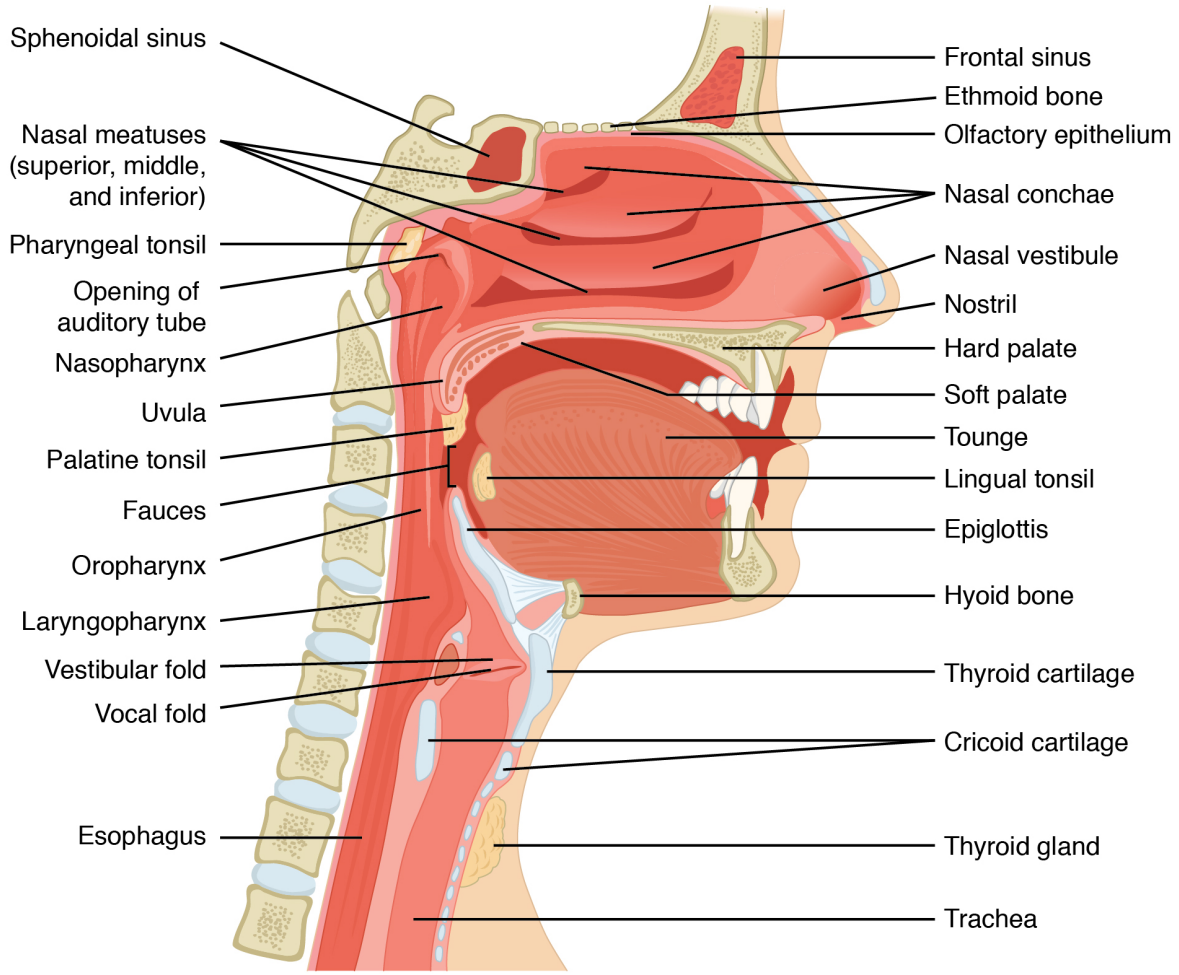


Figure 22.4 The upper airway. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Behind the vestibule, the conchae, meatuses, and sinuses are lined by **respiratory epithelium** composed of **pseudostratified ciliated columnar epithelium** (Figure 22.5). 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 so that it may be swallowed. This moist epithelium also functions to warm and humidify incoming air.

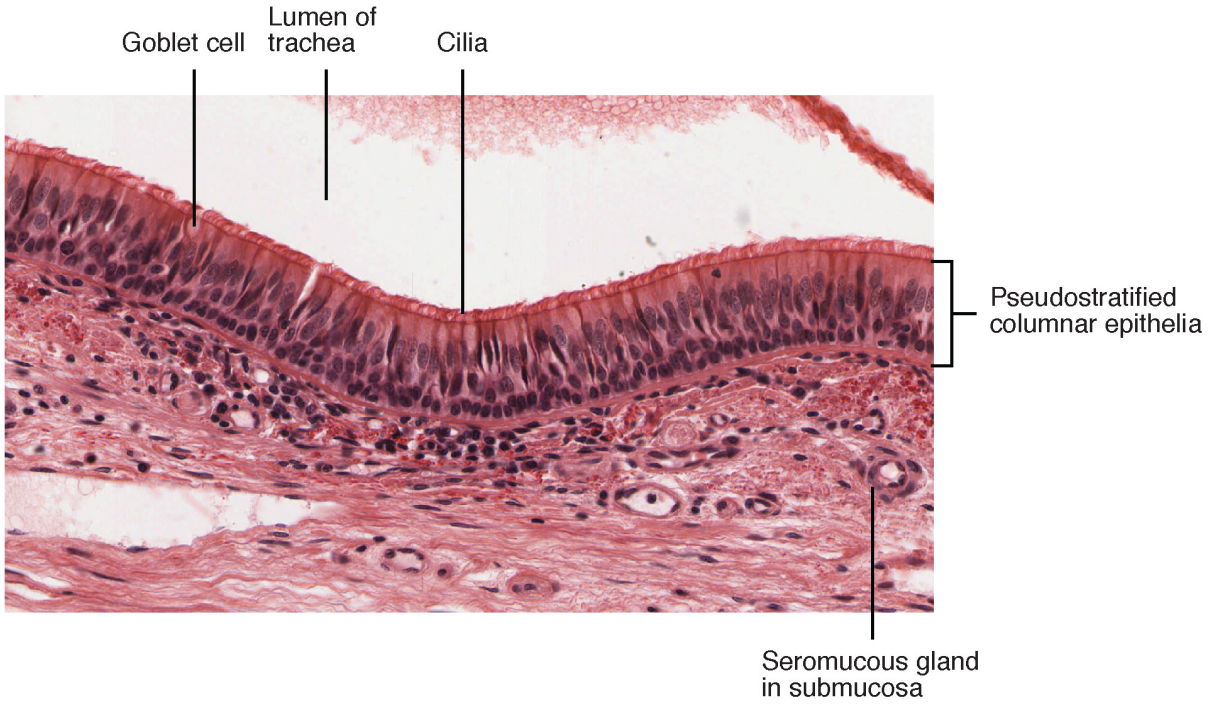


Figure 22.5 Pseudostratified columnar epithelium. Respiratory epithelium is pseudostratified ciliated columnar epithelium. Seromucous glands provide lubricating mucus. LM × 680. (Micrograph provided by the Regents of University of Michigan Medical School © 2012) Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Pharynx

The **pharynx** is a tube that is formed by skeletal muscle and lined by a mucous membrane that is continuous with that of the nasal cavities (see Figure 22.4). The pharynx is divided into three major regions: the nasopharynx, the oropharynx, and the laryngopharynx (Figure 22.6).

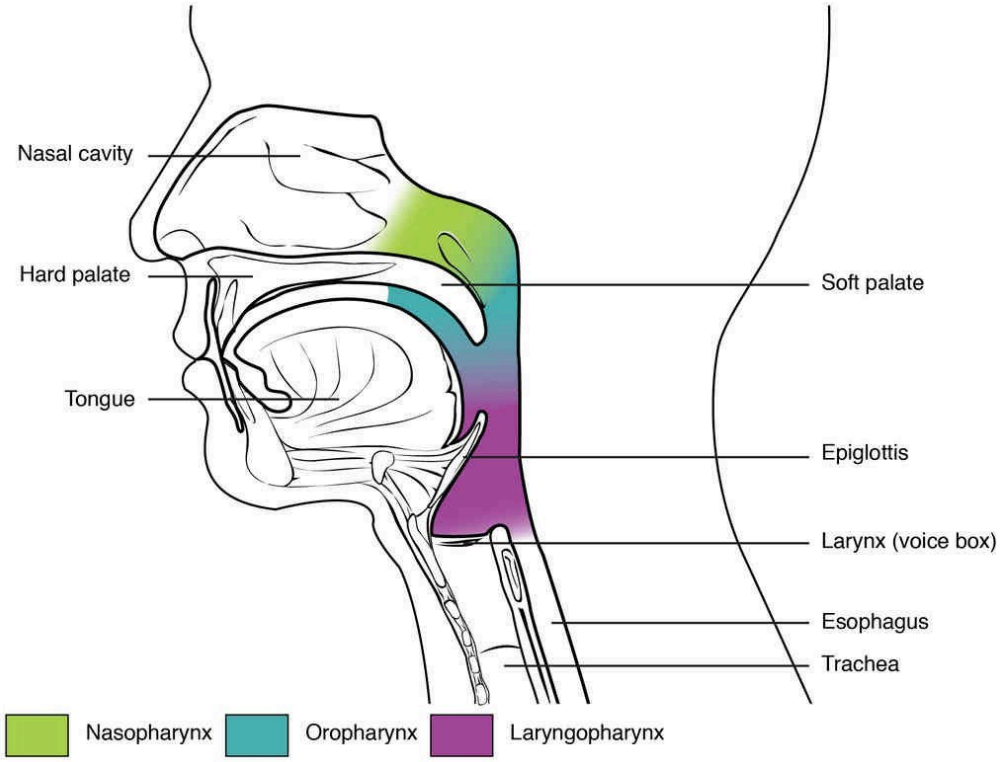


Figure 22.6 Divisions of the pharynx. The pharynx is divided into three regions: the nasopharynx, the oropharynx, and the laryngopharynx. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The uppermost **nasopharynx** sits directly posterior to the nasal cavity, and it serves only as an airway. The nasopharynx has two openings on the lateral walls though. These openings are the **auditory (eustachian** or **pharyngotympanic) tubes**, which connect the nasopharynx to each middle ear cavity. These connections are why colds often lead to ear infections. As the pharynx descends behind the oral cavity it becomes the **oropharynx**, which serves as a passageway for both air and food. The **uvula** is a small bulbous, teardrop-shaped structure located at the apex of the soft palate that partially separates the oral cavity from this region. 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 in to the nasal cavity. The most inferior portion of the pharynx is the **laryngopharynx**, which is located 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** (Figure 22.6).

Larynx

The **larynx** is commonly known as the "voice box" because it is an important organ for sound production in humans. It is a cartilaginous structure oriented inferior to the laryngopharynx that connects the pharynx to the **trachea** and helps regulate the volume of air that enters and leaves the lungs (Figure 22.7). The larynx occurs about the level of the fourth through sixth cervical vertebrae and consists of a number of cartilages. 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. It is a shield-shaped structure made of hyaline cartilage. The thyroid cartilage contains the **laryngeal prominence**, or "Adam's apple", which tends to be more prominent in males due to the presence of increased testosterone levels. Inferior to the thyroid cartilage is the **cricoid cartilage**, which forms a ring. The cricoid cartilage also consists of hyaline cartilage and it appears relatively narrow when observed from the anterior, but increases in size at its posterior surface.

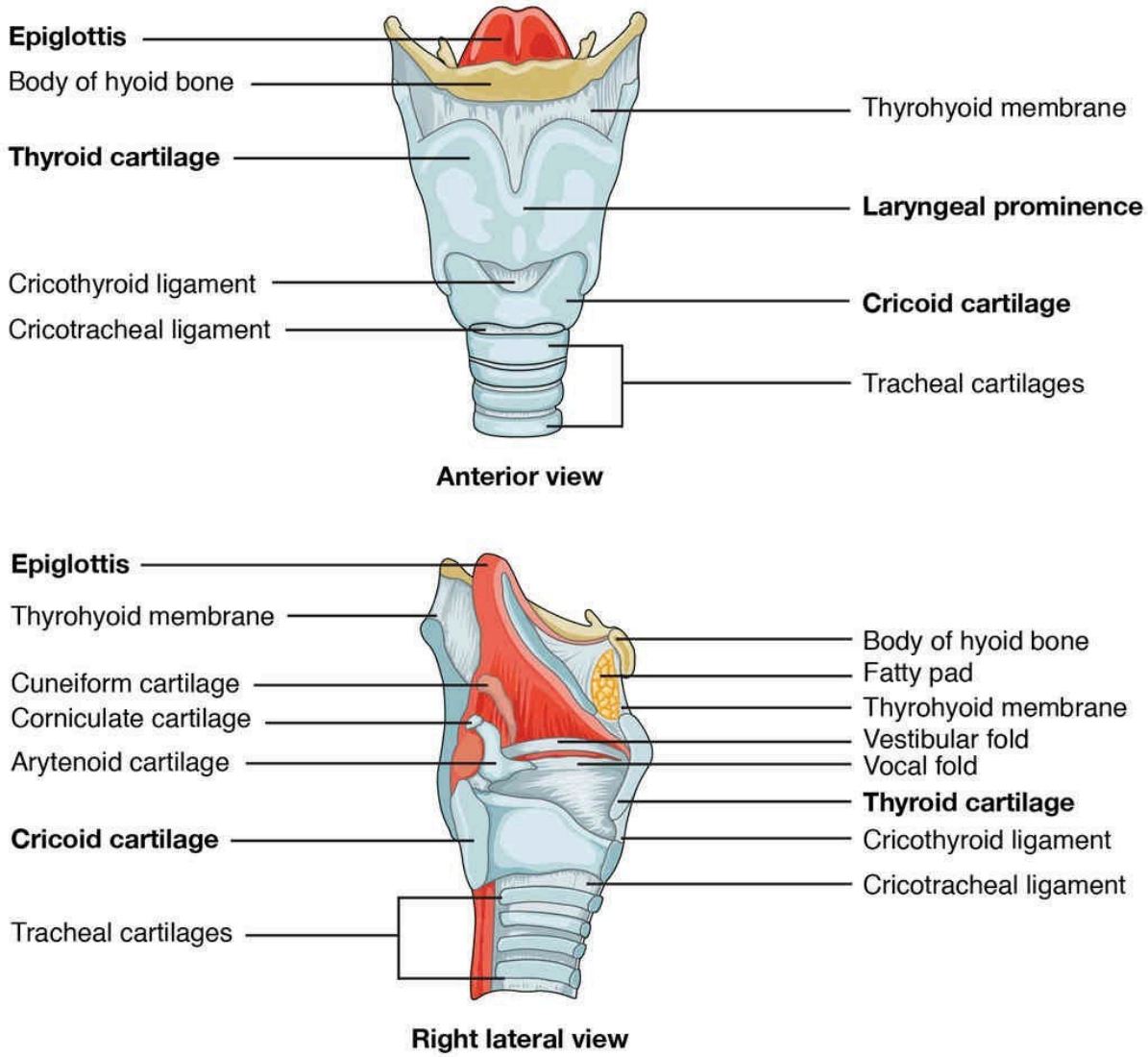


Figure 22.7 The larynx. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Three smaller, paired cartilages—the **arytenoids**, **corniculates**, and **cuneiforms**—attach to the **epiglottis** and the vocal cords and muscles that help move the vocal cords to produce speech (**Figure 6**). Superior to the cricoid cartilage in the posterior wall of the pharynx are the paired **arytenoid cartilages**. These cartilages attach to the posterior end of the **vocal cords** (**vocal folds**). Movement of the arytenoids pulls on the vocal cords, causing them to stretch and increase the pitch of the voice. This requires the contraction of intrinsic muscles attached to the arytenoid cartilages, while the vocal cords are held stationary by the thyroid cartilage anteriorly. Superior to the vocal cords are a folded pair of mucous membranes, known as the **vestibular folds** (**false vocal cords**) (Figure 22.8). At the posterior, superior edge of the larynx is the **corniculate** and **cuneiform cartilages** (Figure 22.7). Each of this is made from hyaline cartilage.

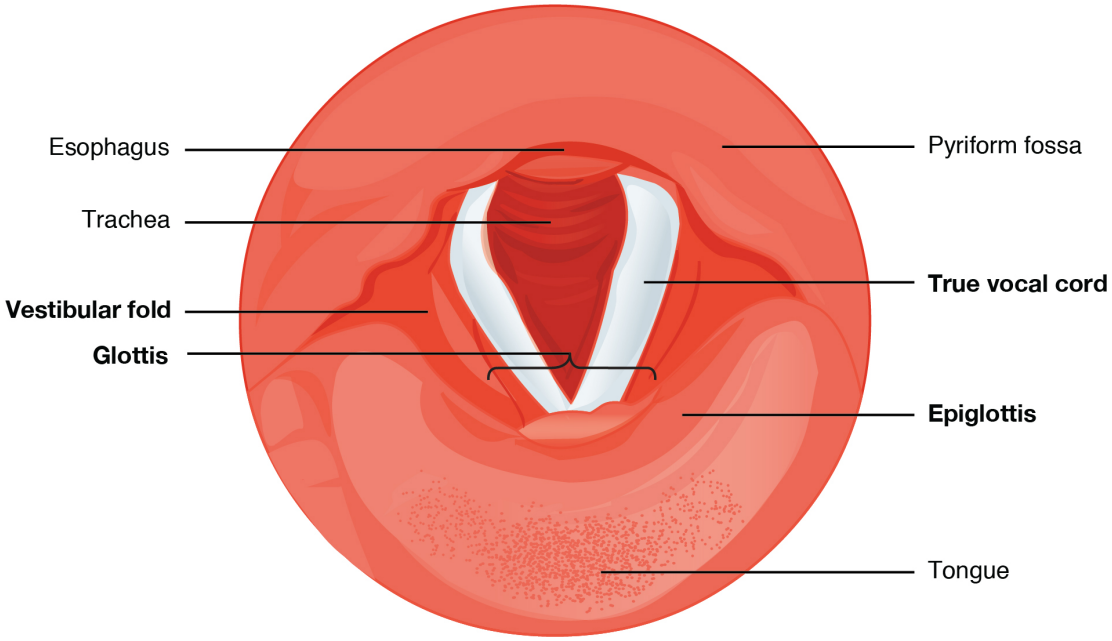


Figure 22.8 The vocal cords. The true vocal cords and vestibular folds of the larynx are viewed inferiorly from the laryngopharynx. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The most posterior cartilage of the larynx is the **epiglottis**, which is composed of elastic cartilage and mucous membrane. This cartilage is a very flexible piece of cartilage that covers the opening of the trachea (**Figure 3**). During swallowing, the epiglottis is pulled down and in to the "closed" position where the unattached end rests on the **glottis**. The glottis is composed of the vestibular folds, the true vocal cords, and the space between these folds (**Figure 7**).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.

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Trachea and Bronchi

The trachea is commonly known as the "windpipe" because it extends and carries air from the larynx toward the lungs (Figure 22.9a). The trachea is a straight tube whose lumen is kept open by 16 to 20 stacked, C-shaped **tracheal cartilages**. These cartilages are composed of hyaline cartilage and they are connected to one another by dense connective tissue. The trachea is also lined with respiratory epithelium, which is continuous with the larynx (Figure 22.9b). The esophagus borders the trachea posteriorly.

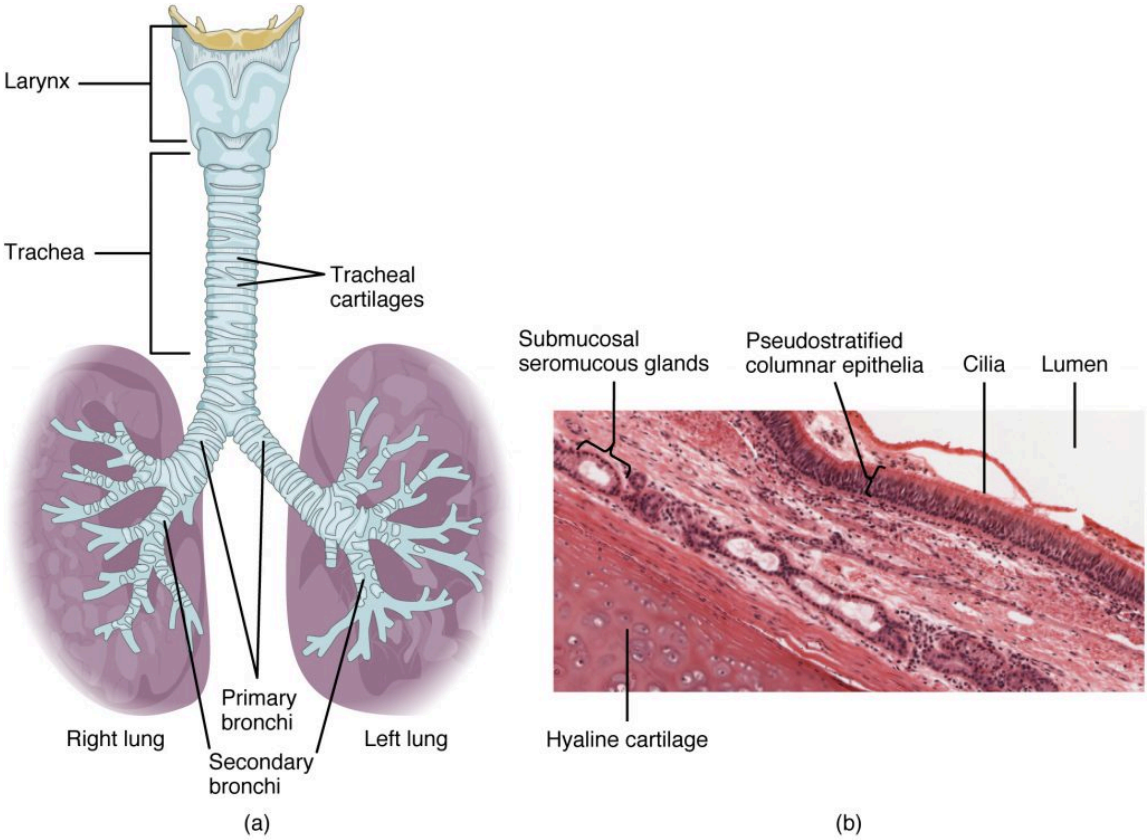


Figure 22.9 The trachea. (a) The tracheal tube is formed by stacked, C-shaped pieces of hyaline cartilage. (b) The layer visible in this cross section of tracheal wall tissue between the hyaline cartilage and the lumen of the trachea is the mucosa, which is composed of pseudostratified ciliated columnar epithelium that contains goblet cells. LM × 1220. (Micrograph provided by the Regents of University of Michigan Medical School © 2012). Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Bronchial Tree

At its most inferior end, the trachea branches into two tubes, which enter the lungs. These tubes are the right and left **primary** (**main**) **bronchi**. These bronchi are also lined by pseudostratified ciliated columnar epithelium containing mucus-producing goblet cells (Figure 22.9b). Rings of cartilage, similar to those of the trachea, support the structure of these bronchi and prevent their collapse. The primary bronchi enter the lungs at the **hilum** (Figure 22.10), a concave region where blood vessels, lymphatic vessels, and nerves also enter the lungs. Once inside the lungs, the main bronchi first divide into **lobar** (**secondary**) **bronchi**, which further divide to form the **segmental bronchi** (Figure 22.10). This extensive branching of the bronchi produces a structure called a **bronchial tree** (**respiratory tree**). 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 of these structures helps to trap debris and pathogens.

The bronchi continue to divide until they become the **bronchioles**, small respiratory tubes with smooth muscle in their walls, no cartilage, and an inner lining of respiratory epithelium (Figures 22.10 and 22.12). There are more than 1000 **terminal bronchioles** in each lung and the muscular wall can change the size of the tubing to increase or decrease airflow through the tube.

Lungs and Histology

From a gross perspective, the lungs are pyramid-shaped, paired organs that are connected to the trachea by the right and left bronchi. On the inferior surface, the lungs are bordered by the diaphragm (**Figure 10**). The right lung is shorter and wider than the left lung, and the left lung occupies a smaller volume than the right. The **cardiac notch** is an indentation on the surface of the left lung that allows space for the heart (**Figure 9**). The apex of the lung is the superior region, whereas the base is the opposite region near the diaphragm.

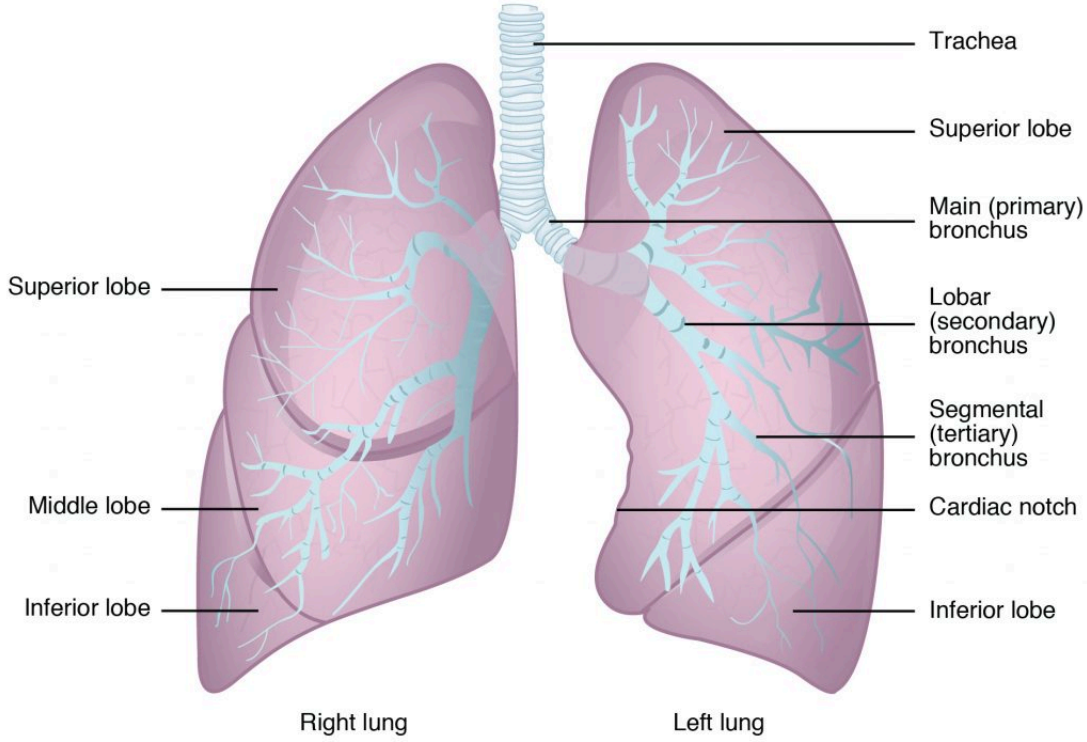


Figure 22.10. Gross anatomy of the lungs. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Each lung is composed of smaller units called **lobes**. The right lung consists of three lobes: the **superior**, **middle**, and **inferior lobes**. The left lung consists of two lobes: the **superior** and **inferior lobes** (Figure 22.10). **Fissures** separate these lobes from each other. In the right lung, the upper, **horizontal fissure**, separates the upper from the middle lobes while the lower, **oblique fissure** separates the inferior and middle lobes. Since the left lung only has a superior and inferior lobe, one **oblique fissure** is present, separating these two regions.

The lungs are enclosed by membranous sacs known as the **pleurae**, which are attached to the mediastinum. The pleurae consist of two layers. The **visceral pleura** is the layer that is superficial to the lungs, and extends into and lines the lung fissures (Figure 22.11). In contrast, the **parietal pleura** is the outer layer that connects to the thoracic wall, the mediastinum, and the diaphragm. The visceral and parietal pleurae connect to each other at the **hilum** and the **pleural cavity** is the space that sits between these layers.

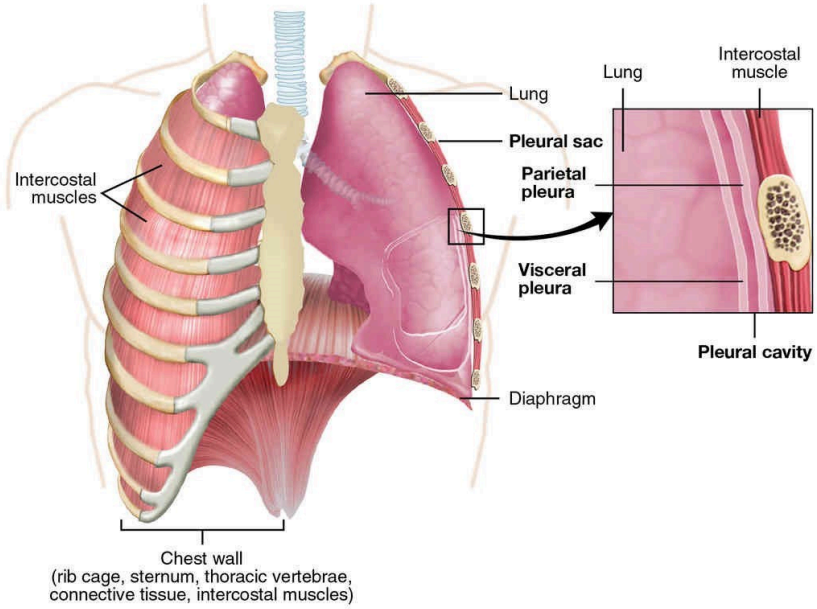


Figure 22.11. The Parietal and visceral pleurae of the lungs.
Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The pleurae perform two major functions: They produce pleural fluid and create cavities that separate the major organs. **Pleural fluid** is secreted by mesothelial cells from both pleural layers and it helps to reduce friction between the two layers to prevent trauma during breathing. It also creates surface tension that helps maintain the position of the lungs against the thoracic wall.

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 22.12), which then leads to an **alveolar duct**. This passageway ultimately opens into a cluster of **alveoli**. An **alveolus** is one of the many small, grape-like sacs that are attached to each of the alveolar ducts. An **alveolar sac** is a cluster of many individual alveoli that are responsible for gas exchange.

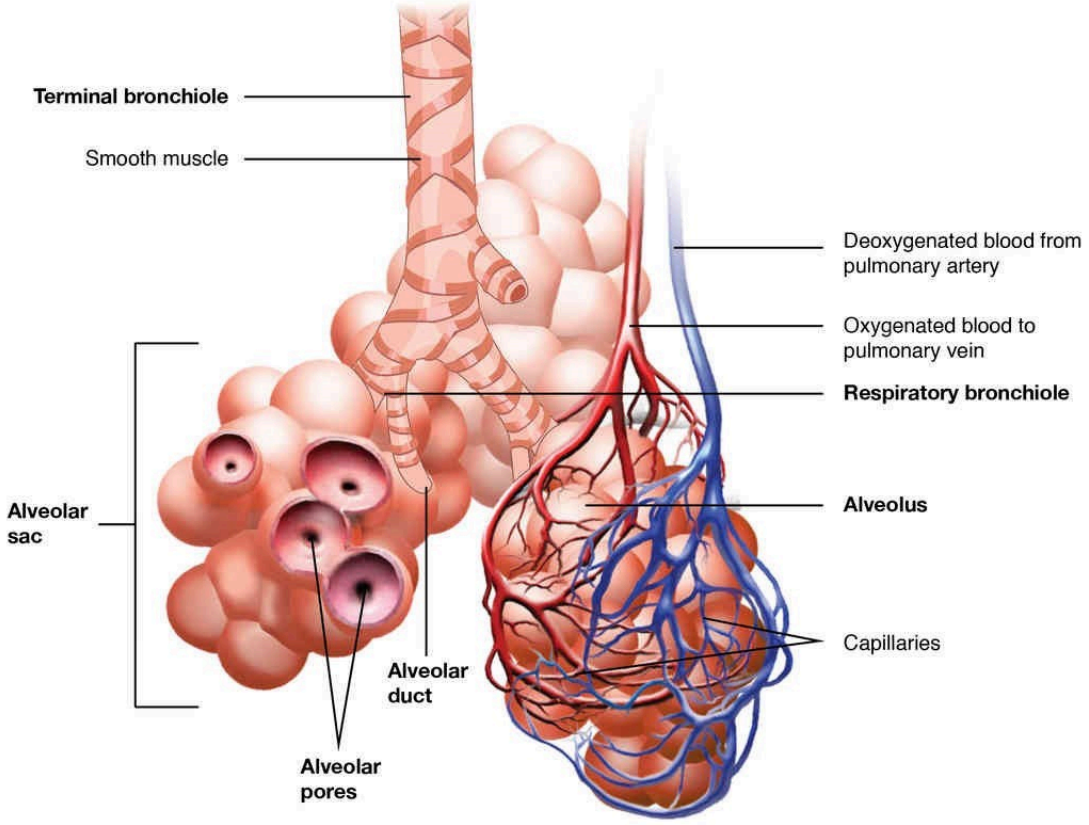


Figure 22.12 The respiratory zone. Bronchioles lead to alveolar sacs in the respiratory zone, where gas exchange occurs. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Each alveolus has elastic walls that allow it 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 22.13).

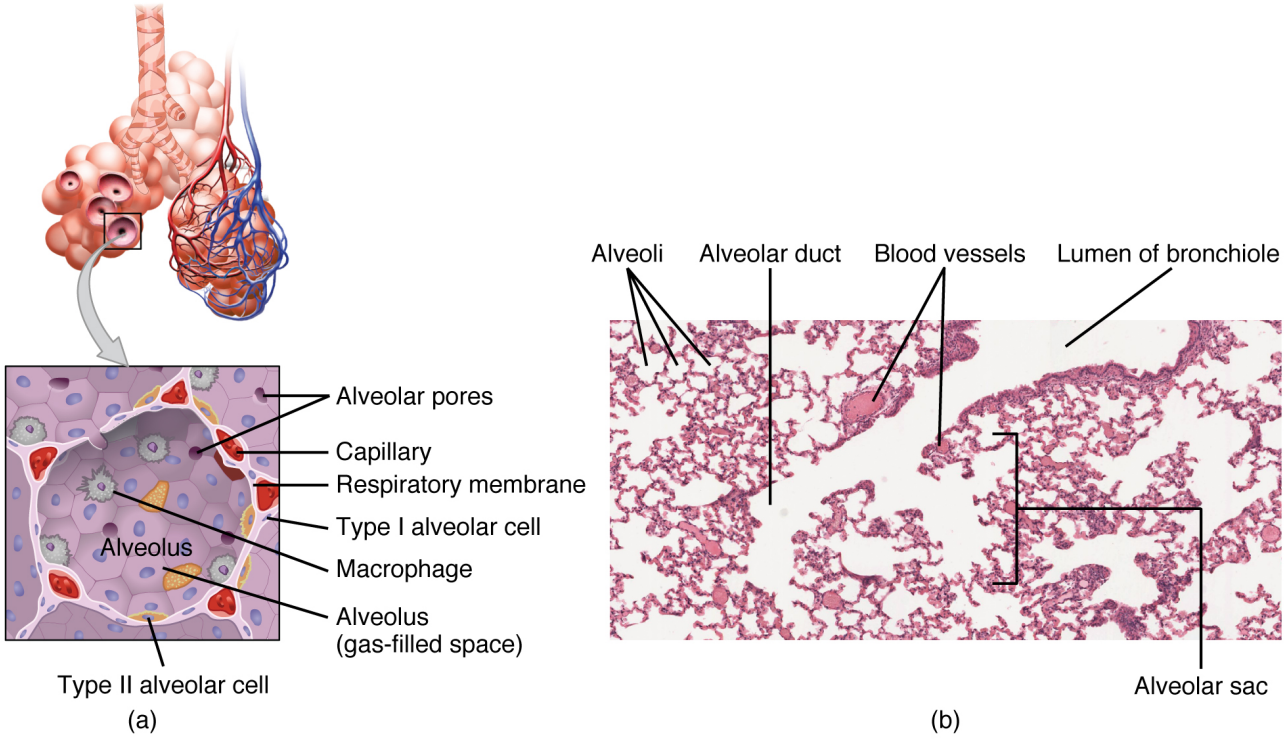


Figure 22.13 Structures of the respiratory zone. (a) The alveolus is responsible for gas exchange. (b) A micrograph shows the alveolar structures within lung tissue. LM × 178. (Micrograph provided by the Regents of University of Michigan Medical School © 2012). Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

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. Type II alveolar cells are interspersed among the type I cells and secrete pulmonary surfactant. This substance is composed of phospholipids and proteins that help to reduce the surface tension of the alveoli. Roaming around the alveolar wall are the alveolar macrophages, phagocytic cells of the immune system that removes debris and pathogens that have reached the alveoli.

Physiology of the Respiratory System

Mechanics of Breathing

Pulmonary ventilation is the act of breathing, which can be described as the movement of air into and out of the lungs. The major mechanisms that drive pulmonary ventilation are **atmospheric pressure**, the air pressure within the lungs, called **intrapulmonary pressure**, and the pressure within the pleural cavity, called **intrapleural pressure**. **Atmospheric pressure** is the amount of force that is exerted by gases in the air surrounding any given surface, such as the body. Atmospheric pressure can be expressed in terms of the unit atmosphere, abbreviated atm, or in millimeters of mercury (mm Hg). One atm is equal to 760 mm Hg,

which is the atmospheric pressure at sea level. **Intrapulmonary pressure** is the pressure of the air within the lungs, which changes during the different phases of breathing. **Intrapleural pressure** is the pressure of the air within the pleural cavity, between the visceral and parietal pleurae. The difference in these pressures drives pulmonary ventilation because air flows down a pressure gradient, that is, air flows from an area of higher pressure to an area of lower pressure. Air flows into the lungs largely due to a difference in pressure; atmospheric pressure is greater than intrapulmonary pressure, and intrapulmonary pressure is greater than intrapleural pressure. Air flows out of the lungs based on the same principle; pressure within the lungs becomes greater than the atmospheric pressure.

Pulmonary ventilation comprises two major steps: **inspiration** and **expiration**, both of which are dependent upon the differences in pressure between the atmosphere and the lungs.

Inspiration is the process that causes air to enter the lungs while **expiration** is the process that causes air to leave the lungs (Figure 22.14). A **respiratory cycle** is one sequence of inspiration and expiration. In general, two muscle groups are used during normal inspiration: the diaphragm and the external intercostal muscles. Additional muscles can be used if a bigger breath is required though. When the diaphragm contracts, it moves inferiorly toward the abdominal cavity, creating a larger thoracic cavity and more space for the lungs. At the same time, contraction of the external intercostal muscles moves the ribs upward and outward, causing the rib cage to expand, which increases the volume of the thoracic cavity. Due to the adhesive force of the pleural fluid, the expansion of the thoracic cavity forces the lungs to stretch and expand as well. This increase in volume leads to a decrease in alveolar pressure, creating a pressure lower than atmospheric pressure. As a result, a pressure gradient is created that drives air into the lungs. Inspiration and expiration occur due to the expansion and contraction of the thoracic cavity, respectively.

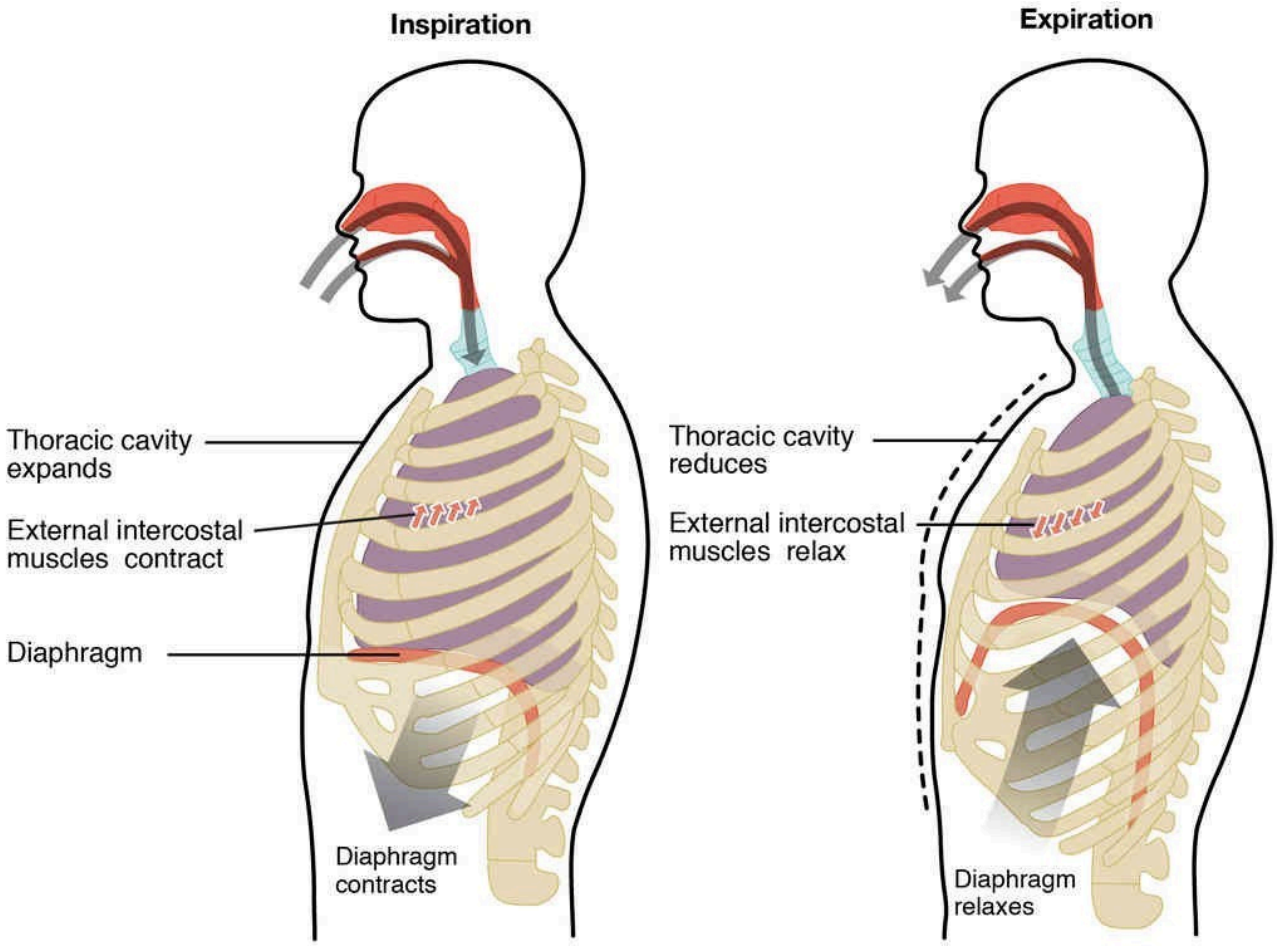


Figure 22.14 Inspiration and expiration. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The process of normal expiration is **passive**, meaning that energy is not required to push air out of the lungs. Instead, the elasticity of the lung tissue causes the lungs to recoil, as the diaphragm and intercostal muscles relax following inspiration (Figure 22.2). In turn, the thoracic cavity and lungs decrease in volume, causing an increase in interpulmonary pressure. The interpulmonary pressure rises above atmospheric pressure, creating a pressure gradient that causes air to leave the lungs.

There are different types, or modes, of breathing that require a slightly different process to allow inspiration and expiration. **Quiet breathing**, also known as **eupnea**, is a mode of breathing that occurs at rest and does not require the cognitive thought of the individual. During quiet breathing, the diaphragm and external intercostals must contract. In contrast, **forced breathing**, also known as **hyperpnea**, is a mode of breathing that can occur during exercise or actions that require the active manipulation of breathing, such as singing. During forced breathing, inspiration and expiration both occur due to muscle contractions. In addition to the contraction of the diaphragm and intercostal muscles, other accessory muscles must also contract. During forced inspiration, muscles of the neck, including the scalenes, contract and lift the thoracic wall, increasing lung volume. During forced expiration, accessory muscles of the abdomen, including the obliques, contract, forcing abdominal organs upward against the diaphragm. This helps to push the diaphragm further into the thorax, pushing more air out. In addition, accessory muscles

(primarily the internal intercostals) help to compress the rib cage, which also reduces the volume of the thoracic cavity.

Measurement of Respiratory Parameters

Gas exchange between air and blood occurs within the alveolar air sacs (Figure 22.15). The efficiency of gas exchange is dependent on ventilation. Cyclical breathing movement. Cyclical breathing movement alternately inflate and deflate the alveolar air sacs. Inspiration provides the alveoli with some fresh atmospheric air, and expiration removes some of the stale air, which has reduced oxygen and increased carbon dioxide concentrations.

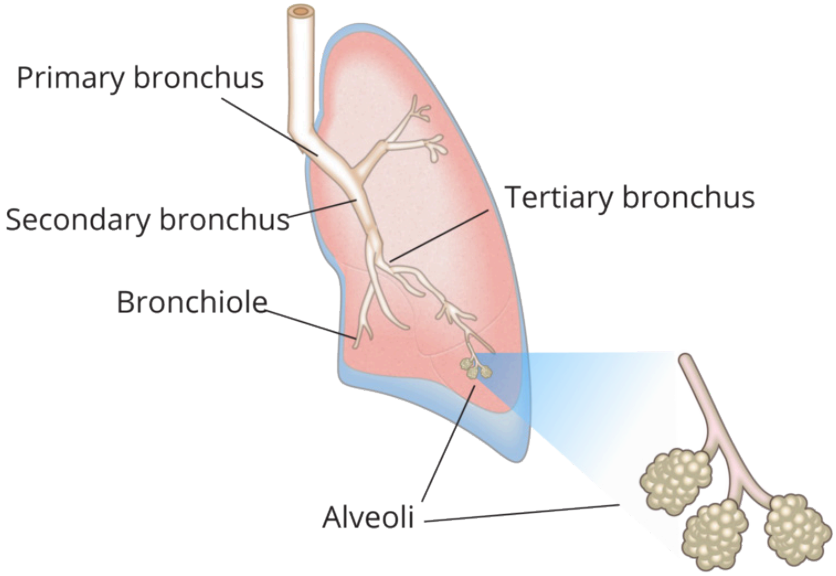


Figure 22.15 Schematic diagram of bronchial tree. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Pulmonary Volumes and Capacities

Spirometry allows many components of pulmonary function to be visualized, measured, and calculated. Respiration consists of repeated cycles of inspiration followed by expiration. During the respiratory cycle, a specific volume of air is drawn into and then expired from the lungs – the **Tidal Volume** (VT). In normal ventilation, the rate of breathing (breaths/minute) is approximately 15 respiratory cycles per minute. This value varies with the level of activity. The product of breaths/minute and VT is the **Expired Minute Volume** – the amount of air exhaled in one minute of breathing, which also changes according to the level of activity.

Note that the volume of air remaining in the lungs after a full expiration, **residual volume** (RV), cannot be measured by spirometry as it is impossible to exhale all the gas in the lungs. [There are specialized techniques to measure RV, but normally this volume is estimated from tables that predict RV based on age, sex, height and weight.]

The common lung volumes and capacities are shown in Figure 22.16 and Table 22.1, below. Note that

the lung capacities are always the *sum* of at least two lung volumes, e.g., **vital capacity** (VC) is the sum of **tidal volume** (VT), **expiratory reserve volume** (ERV) and **inspiratory reserve volume** (IRV).

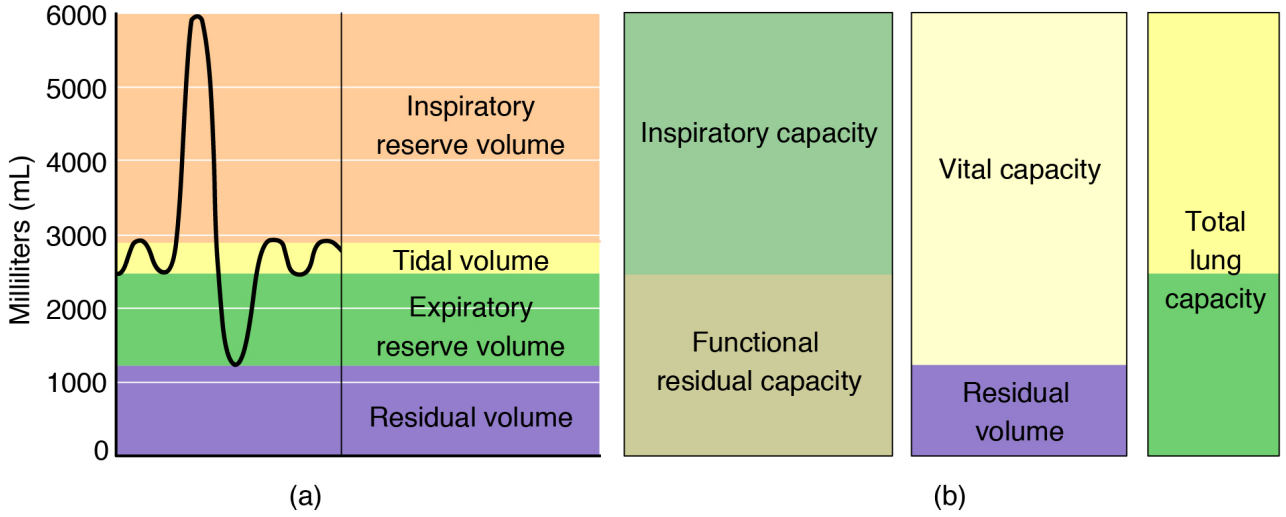


Figure 22.16 . Spirometry measures for respiratory volumes and capacities. These two graphs show (a) respiratory volumes and (b) the combination of volumes that results in respiratory capacity. Volumes are representative of a healthy young male adult.

Lung volume measures:

- **Tidal volume or VT:** the volume breathed in and out in each breath.
- **Inspiratory reserve volume or IRV:** the maximum volume above the tidal volume that we can inhale into our lungs.
- **Expiratory reserve volume or ERV:** the maximum volume we can exhale from our lungs at the end of a normal breath.
- **Residual volume or RV:** the volume of air remaining in the lungs which is impossible for use to expire.

Lung capacity measures:

- **Expiratory capacity** (**EC**): the volume of air that we can expire after a normal inspiration and = V T + ERV.
- **Functional residual capacity** (**FRC**): the volume of air remaining in the lungs at the end of a normal expiration and = ERV + RV.
- **Total lung capacity** (**TLC**): all the air that it is possible for the lungs to contain and = RV + ERV + V T + IRV.
- **Vital capacity** (**VC**): all the air that can be expired following a maximal inhalation and = ERV + V T + IRV.
- **Inspiratory capacity** (**IC**): all the air breathed in during a maximal inhalation and = V T + IRV.

Respiratory Rate and Control of Respiration

Breathing usually occurs without thought, although at times you can consciously control it, such as when you swim under water, sing a song, or blow bubbles. The respiratory rate is the total number of breaths, or respiratory cycles, that occur each minute. Respiratory rate can be an important indicator of disease, as the rate may increase or decrease during an illness or in a disease condition. The respiratory rate is controlled by the respiratory center located within the medulla oblongata in the brain, which responds primarily to changes in carbon dioxide, oxygen, and pH levels in the blood.

The normal respiratory rate of a child decreases from birth to adolescence. A child under 1 year of age has a normal respiratory rate between 30 and 60 breaths per minute, but by the time a child is about 10 years old, the normal rate is closer to 18 to 30. By adolescence, the normal respiratory rate is similar to that of adults, 12 to 18 breaths per minute.

Dyspnea

Dyspnea refers to difficulty in breathing. What is difficult for one person is not necessarily so for another, so dyspnea has a psychological dimension. Perhaps the simplest view is to regard dyspnea as being a consequence of a mismatch between the afferent inputs that stimulate breathing (such as decreased P_{O2}, increased P_{CO2}, decreased pH, and activation of lung and chest wall receptors) and the efferent output to the muscles of respiration. That is, for whatever reason, breathing can not increase sufficiently to match the perceived central nervous system requirements, leading to feelings of distress and breathlessness.

Dyspnea may be acute or chronic. When people tell you that they are "breathless", it is necessary to try to understand what they mean by this. Everyone gets breathless if they exercise vigorously. This is physiological and reversed rapidly when exercise finishes and should not be regarded as dyspnea. Illnesses that can be associated with the acute onset of dyspnea include pneumothorax, acute asthmatic attacks, pneumonia, myocardial infarction and rapidly developing heart failure. The major respiratory diseases associated with chronic dyspnea are COPD and restrictive lung disease. (*Dyspnea section source material: ADInstruments NZ Limited 2019, license CC BY-SA*)

Acid-Base Effects of the Respiratory Gases

The respiratory rate and the depth of inspiration are regulated by the medulla oblongata and pons; however, these regions of the brain do so in response to systemic stimuli. It is a dose response, positive-feedback relationship in which the greater the stimulus, the greater the response. Thus, increasing stimuli results in forced breathing. Multiple systemic factors are involved in stimulating the brain to produce pulmonary ventilation.

The major factor that stimulates the medulla and pons to produce changes in respiration is surprisingly not oxygen concentration, but rather the concentration of carbon dioxide in the blood. As you may recall, carbon dioxide is a waste product of cellular respiration and can be toxic. Concentrations of chemicals are sensed by **chemoreceptors**. A **central chemoreceptor** is one of the specialized receptors that are located in the brain and brainstem, whereas a **peripheral chemoreceptor** is one of these receptors located in the carotid arteries and aortic arch. Concentration changes in certain substances, such as carbon dioxide or hydrogen ions, stimulate these receptors, which in turn signal the respiration centers of the brain. In

the case of carbon dioxide, as the concentration of CO_2 in the blood increases, it readily diffuses across the blood-brain barrier, where it collects in the extracellular fluid. Increased carbon dioxide levels lead to increased levels of hydrogen ions, ultimately decreasing the pH of the blood. This increase in hydrogen ions in the brain triggers the central chemoreceptors to stimulate the respiratory centers to initiate contraction of the diaphragm and intercostal muscles. As a result, the rate and depth of respiration increase, allowing more carbon dioxide to be expelled, which brings more air into and out of the lungs. These actions promote a reduction in the blood levels of carbon dioxide, and therefore hydrogen ions. In contrast, low levels of carbon dioxide in the blood cause low levels of hydrogen ions in the brain and an increase in blood pH. These changes lead to a decrease in the rate and depth of pulmonary ventilation, producing shallow, slow breathing.

Another factor involved in influencing the respiratory activity of the brain is systemic arterial concentrations of hydrogen ions. Increasing carbon dioxide levels can lead to increased H^+ levels, as mentioned above, as well as other metabolic activities, such as lactic acid accumulation after strenuous exercise. Peripheral chemoreceptors of the aortic arch and carotid arteries sense arterial levels of hydrogen ions. Removal of carbon dioxide from the blood helps to reduce hydrogen ions, thus increasing systemic pH. The peripheral chemoreceptors are also responsible for sensing large changes in blood oxygen levels. If blood oxygen levels become quite low—about 60 mm Hg or less—then peripheral chemoreceptors stimulate an increase in respiratory activity.

Pre-Laboratory Questions

1. What is the role of the respiratory system, in terms of the overall function of the body?
2. Which of the following statements regarding tidal volume (VT) is true?
    1. It is the volume breathed during forced breathing.
    2. It is the volume breathed in each breath.
    3. It is the volume breathed in each minute.
    4. It is unaffected by the frequency of breathing.
3. Which of the following statements regarding the Expiratory Reserve Volume (ERV) is true?
    1. ERV is kept at a low volume so that the vast bulk of the alveolar gas can be replaced with fresh air during the next inspiration.
    2. ERV is the maximal amount of air that can be exhaled from the lungs after a normal expiration.
    3. ERV is very small and unimportant in normal respiration.
4. Which of the following does Vital Capacity (VC) measure?
    1. The amount of gas that it is vital to retain in the respiratory system at the end of expiration.
    2. The maximum volume of gas in the respiratory system that can be exchanged with each breath.
    3. The volume of gas exchanged during normal breathing.
5. Which of the following statements regarding Total Lung Capacity (TLC) is true?
    1. It increases as the frequency of breathing increases.
    2. It is a measure of the volume of gas in the respiratory system at the end of a maximal

inspiration.

3. It is constant in amount from person to person.

6. In the respiratory system, what is the major difference between a volume and a capacity?
    1. A capacity is the sum of at least two volumes.
    2. A volume is the sum of at least two capacities.

Exercises

- Exercise 1 Study the anatomy and organization of the respiratory system
- Exercise 2 Pulmonary function measurements

Exercise 1 Study the anatomy and organization of the respiratory system

Required Materials

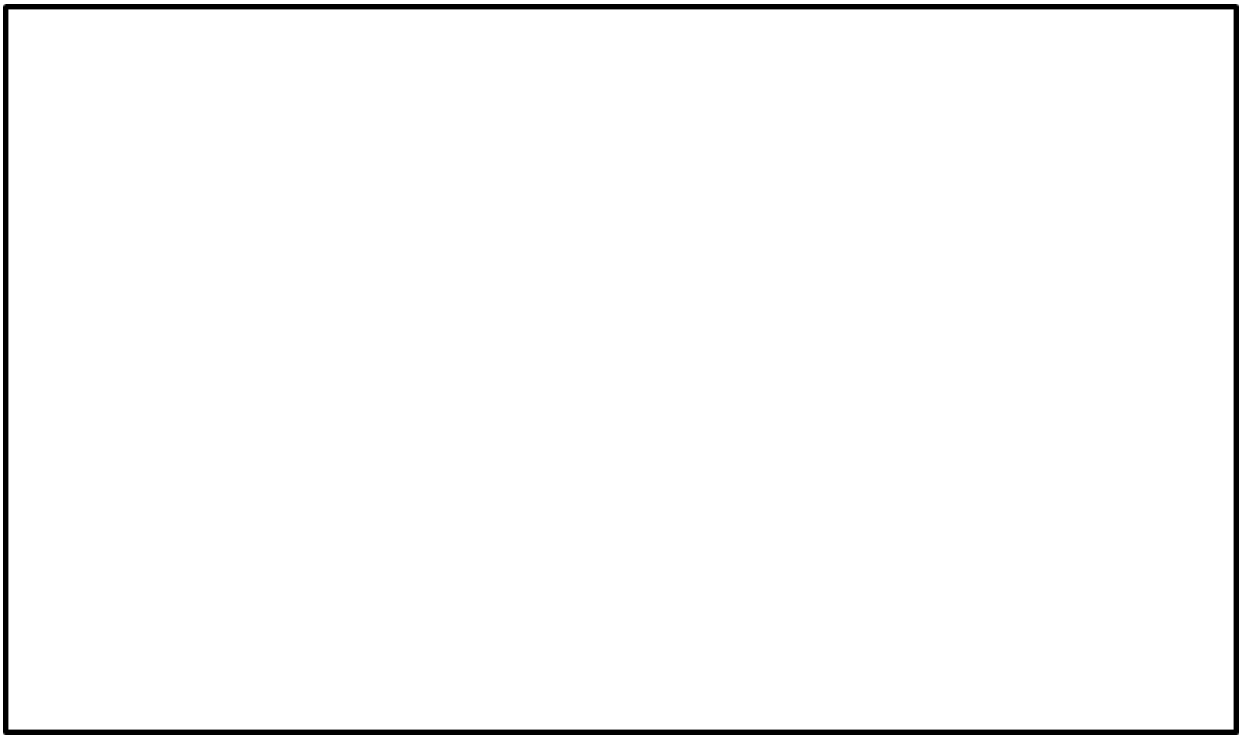
- Torso Model
- The Respiratory System Poster
- Respiratory System with Magnified Alveolus Model
- Half of the Human Head Model
- Median Section of the Head Model
- Human Larynx Model
- Smoker's Lung Model
- Post-it notes
- Labeling tape
- Compound microscope
- Microscope lens cleaner
- Microscope lens solution
- Microscope immersion oil
- Slide of Mammal Trachea

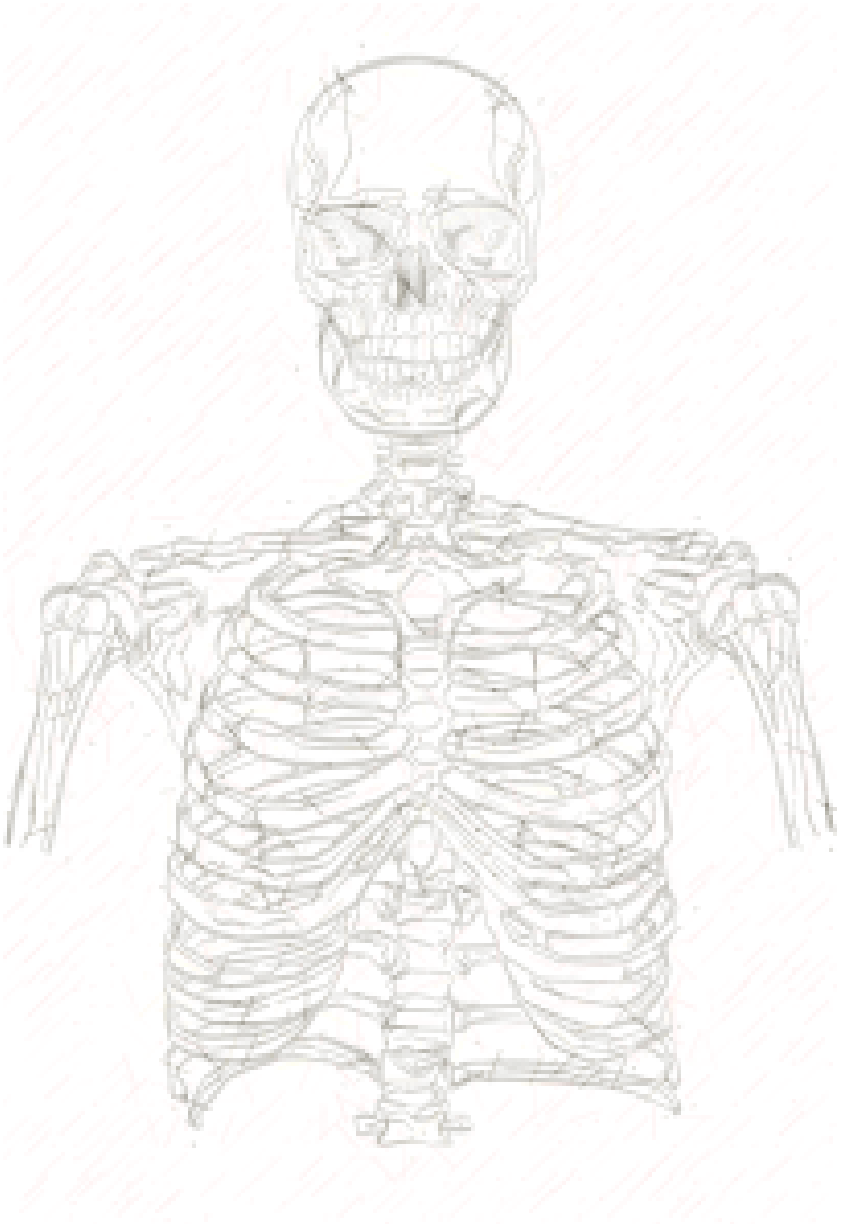
Exercise 1A: Overview of the respiratory system

Procedure

1. Look at the charts and models of the respiratory system for a general orientation and compare them to figure 22.1. Locate the following structures. Label these on the torso model or other models using post-it notes or labeling tape. Take a picture of your labeled model and insert the image below. Alternatively, you can sketch and label using the skeletal drawing to guide you or free drawing from models.

    - Bronchus
    - Nasal cavity
    - Right lung
    - Left lung
    - Larynx
    - Nose
    - Trachea
    - Pharynx





Exercise 1B: Nose and nasal cartilages

Procedure

1. Examine a median section on a model or chart of the head and look for the **nose, nasal cartilages, external nares** (nostrils), and **nasal septum**.
2. Examine the features identified in step 1 and compare them to what you see in Figures 22.3 and 22.4.
3. Using the models and charts, locate the **superior, middle,** and **inferior conchae** in the nasal cavity.
4. Identify where the nasal cavity ends, giving rise to two openings, the **posterior nasal apertures,** or **choanae**, which lead to the **pharynx**. Label all these nasal features using post-its or labeling tape, take a picture and insert your image below. Alternatively, you can sketch and label.

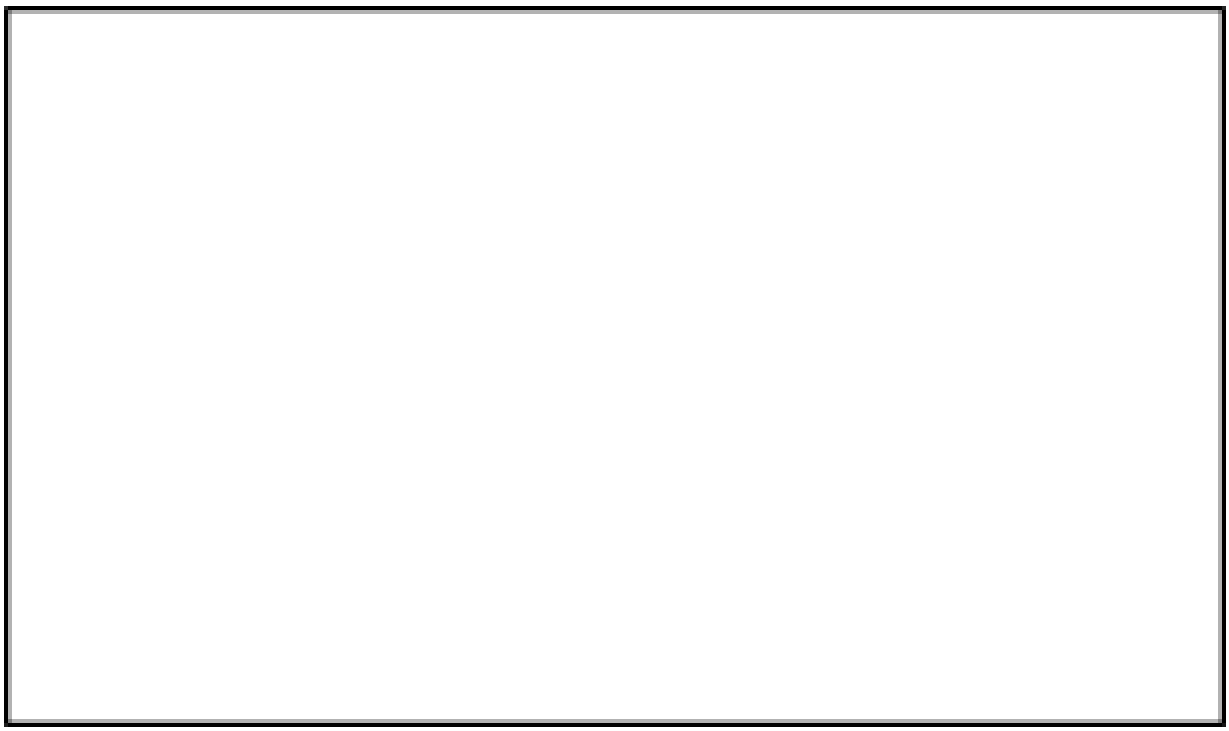
5. The **pharynx** can be divided in to three regions based on location. Use the models and charts to find these regions.
6. Examine the features from step 5 in Figures 22.4 and 22.6. Label the regions of pharynx using the post-it notes or labeling tape, take a picture and insert it below. Alternatively, you can sketch and label.
7. The **larynx** is commonly known as the "voice box" because it is an important organ for sound production in humans. Using the models and charts, locate the prominent cartilages of the larynx; these include the **thyroid cartilage, cricoid cartilage,** and **arytenoid cartilage**. Locate the **vocal cords** (**vocal folds**), which attach to the anterior end of these cartilages.

8. Examine the features from step 7 in Figures 22.7 and 22.8. Also use this figure to locate the **vestibular folds**, which are oriented superior to the vocal cords.
9. Using the models and charts, locate the posterior structures of the larynx. These include the **corniculate** and **cuneiform cartilages,** the **epiglottis**, and the **glottis**.
10. Examine the features from step 9 in Figure 22.7. Label these features of the larynx using post-it notes or labeling tape, take a picture and insert it below. Alternatively, you can sketch and label.

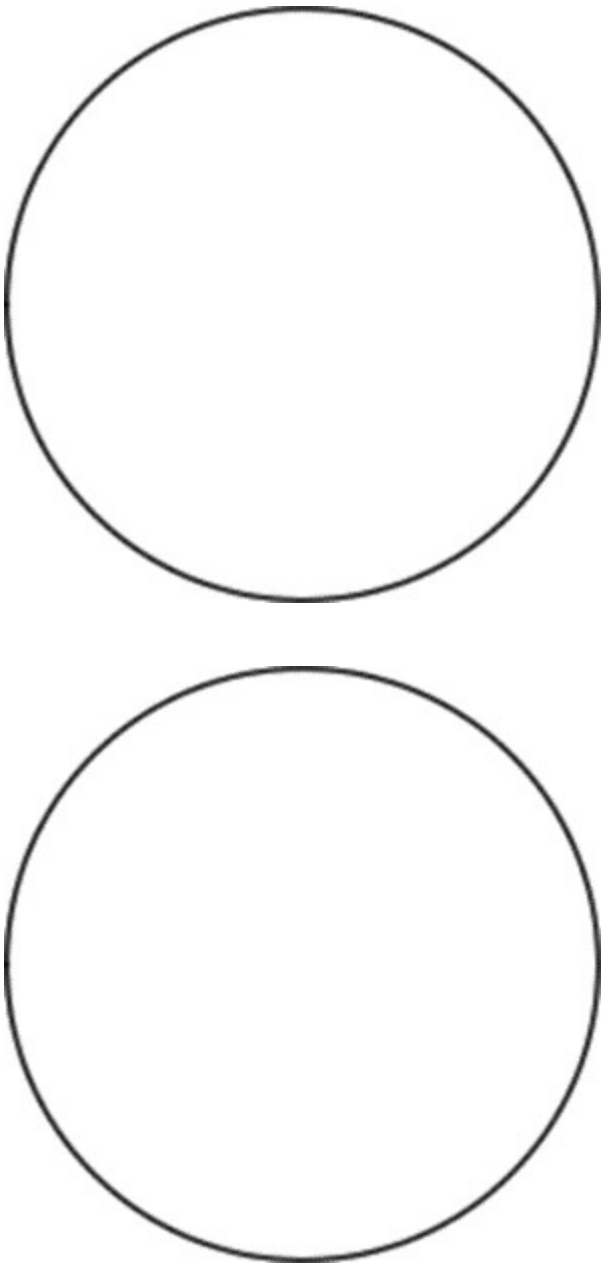
Exercise 1C: Trachea and bronchi

Procedure

1. The **trachea** is a straight tube whose lumen is kept open by c-shaped **tracheal cartilages**. Examine these cartilages by running your fingers gently down the outside of your throat. Palpate the cartilage rings below the larynx.
2. Locate the tracheal cartilages and the inferior **carina** in Figures 22.9 and 22.10. Label the trachea and tracheal features using post-it notes or labeling tape, take a picture of the labeled model and insert the image below. Alternatively, you can sketch and label.



3. Obtain a prepared slide or a histological section of the trachea and find the tracheal **cartilage**, **respiratory epithelium,** and **posterior tracheal membrane** (absent in some slide preparations).
4. Examine the features from step 3 in Figure 22.9.
5. In the space provided below sketch what you observed at low and high magnification of the tracheal slide. Label the tracheal features listed in step 3.



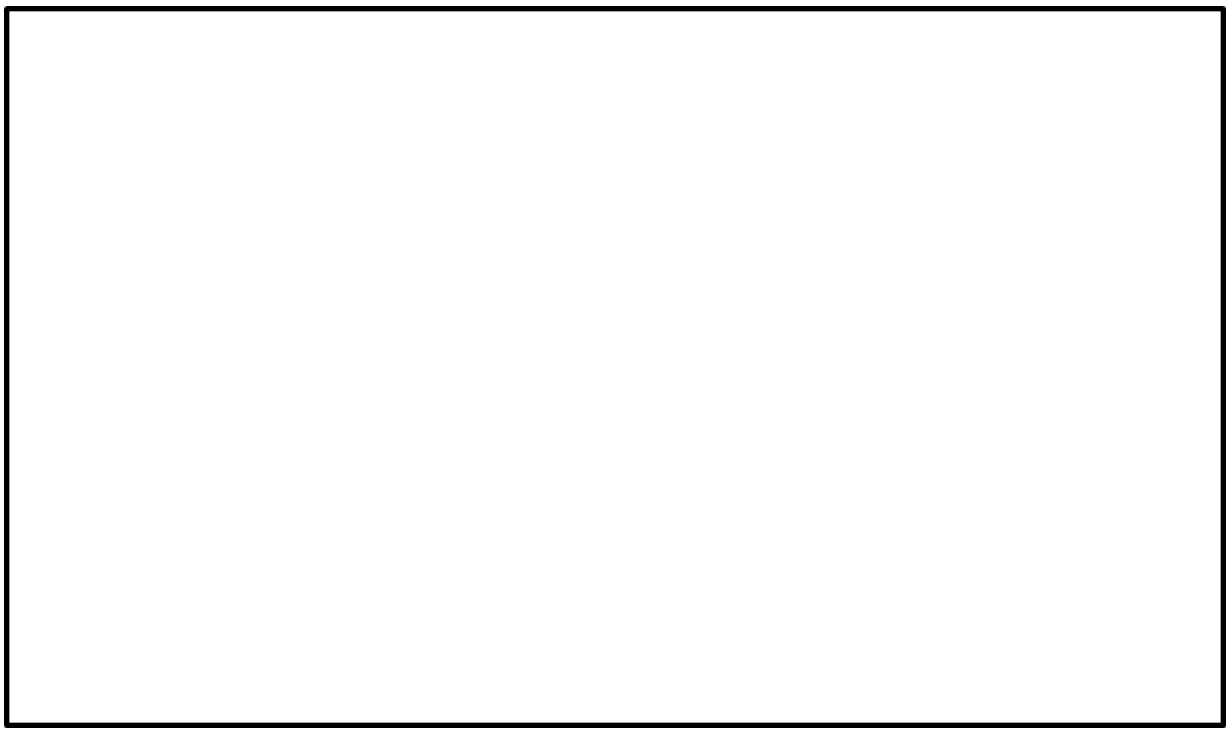
6. Using the provided models and charts, observe the extensive branching of the bronchi, which produce a structure called the **bronchial tree**.
7. Examine the bronchial tree in Figures 22.9, 22.10 and 22.12. You should be able to identify the **main bronchi, lobar bronchi,** and **segmental bronchi**. Label these features on a model using post-it notes or labeling tape, take a picture and insert the image below. Alternatively, you can sketch and label.

Exercise 1D: Lungs

Procedure

1. Look at the models or charts in the lab and identify the major features of the lungs. These include the **superior lobe, middle lobe,** and **inferior lobe** of the right lung and the **superior lobe** and **inferior lobe** of the left lung. Also identify the indentation of the left lung, the **cardiac impression** where the apex of the heart rests.
2. Examine these lung features in Figure 22.10.
3. Use Figure 22.11 to locate and identify the **visceral** and **parietal pleura** that surround the lungs. You should be able to identify the **pleural cavity**, which is the space that separates these two membranes. Label the lung structures mentioned in steps 1-3 on the models using post-it notes or labeling tape, take a picture and insert it in the space below. Alternatively, you can sketch and label these features below.

4. On a model or chart identify the **main bronchi**. You should be able to see that the main **bronchi** continue to divide until they become **bronchioles**.
5. The **bronchioles** continue to divide, leading to passageways known as the **alveolar ducts**, which branch into **alveoli**. Using the provided slide or image, locate the **terminal bronchioles, respiratory bronchioles, alveolar ducts,** and **alveoli**. Also examine these alveolar features in Figure 22.13.
6. Using the models and charts, observe the **alveolar sac**, the cluster of alveoli located around the terminal end of the alveolar duct. Label the bronchiolar and alveolar structures mentioned in steps 4-6 using post-it notes or labeling tape, take a picture and insert it below. Alternatively, you can sketch and label these features in the space below.



7. Observe the differences between a smoker's lung and a normal lung using the Smoker's Lung Model in the lab. Note the similarities and differences you observe in the anatomy of the healthy and diseased lungs shown. Write these down here:

Exercise 2 Pulmonary function measurements

Exercise 2A: Respiratory sounds

Required Materials

- Stethoscope
- Alcohol wipes
- Lab Partner

Procedure

1. In this exercise you will listen to the breathing sound of an individual using a stethoscope.
2. Find a partner to complete this activity with.
3. Obtain a stethoscope.
4. Clean the earpieces of the stethoscope with an alcohol wipe and let them dry.
5. Make sure that the earpieces of the stethoscope point toward the anterior as you would insert them

into your ear.

6. Locate the larynx of your partner and place the diaphragm of the stethoscope just inferior to it.
7. Listen for the sounds as your lab partner inhales and exhales. These are tracheal and bronchial sounds.
8. Locate the triangle of auscultation, an area just medial to the inferior angle of the scapula. This is an ideal area for listening to sounds because fewer muscles cover this region of the thoracic cavity.
9. Have your lab partner inhale and exhale deeply several times.
10. Listen for a smooth flow of air into and out of the lungs. Wheezing or other rattling-like noises are indictors of congestion in the lungs.
11. Record the observations of what you hear in the space below. Indicate the breathing condition of your lab partner:

Exercise 2B: Factors Influencing Rate and Depth of Respiration

In this exercise, you will first determine the breathing rate of an individual when they are at rest. Then, the volunteer will perform a series of activities to see how each one effects the rate of respiration over time.

Required Materials

- Stop watch (App on phone or iPad)
- Paper bag
- Lab partner

Part 1: Determining Resting (Quiet) Respiration Rate

Here, you will be determining the resting respiration rate of the subject. This will serve as a control to compare respiration rates to when you observe different activities.

Procedure

1. Decide which partner will be the subject and which will bet the recorder. You may switch spots later, if time allows.
2. The volunteer should sit comfortably and quietly in a chair for a minimum of one minute before recording begins.
3. Using the stop watch, the recorder should then count the number of breaths taken by the subject over a 1-minute time period.
4. Record this value in respirations/minute in the data Table 1 below.

Part 2: Factors Influencing Rate and Depth of Respiration

Procedure

1. Again, have the test subject sit quietly in a chair to perform the first part of this activity. The same

volunteer who you determined resting respiration rate for should also complete part 2.
2. Have the volunteer preform each of the following activities listed in Table 1, below. The volunteer should perform each activity for a period of 1 minute.
3. During each activity, record the subject's breathing rate. Record this information in Table 1 as breaths/minute.
4. Record any other observations that you think are pertinent in the Table 1.

Part 3: Determining Respiration Rate During Various Activities

Procedure

1. You may choose a different volunteer to complete Part 3 of the activity. To begin part 3, have the test subject sit quietly in a chair to perform the first part of this activity.
2. Have the volunteer preform each of the following activities.

Quiet Respiration

1. Allow the subject to breathe normally for one minute.
2. After this initial period, record the subject's respiration rate (respirations/min.) during quiet inspiration. Enter the data in Table 2, below.

Deep Inhale

1. Allow the subject to breathe normally for two minutes.
2. After this initial period, have the subject deeply inhale and then hold their breath for as long as possible. Record (in seconds) how long the subject was able to hold their breath for. Enter this data in Table 2, below.
3. As soon as the subject exhales, record the respiratory rate for several minutes (this time may vary) until a normal, resting breathing pattern returns. Also record how long it took (recovery time) for the subject's breathing pattern to return to normal (in seconds).
4. Enter this data in Table 2, below.

Forced Exhale

1. Repeat the procedure for "Deep Inhale" above, but first the subject will inhale deeply, then exhale forcefully and completely, then hold their breath WITHOUT INHALING.
2. Record the length of time (in seconds) that their breath was held and the respiratory rate until the subject has recovered.
3. Enter this data in Table 2, below.

Hyperventilation

1. Have the subject to hyperventilate (breath rapidly, about 1 breath/4 seconds) for approximately 30 seconds, then hold their breath for as long as possible.
2. Record the length of time (in seconds) that their breath was held and the respiratory rate until the subject has recovered.
3. Enter this data in Table 2, below.

Re-Breathing

1. Have the subject breath into a paper bag for 3 minutes. WATCH CAREFULLY for unusual or unwanted reactions or behaviors.
2. After this initial period, have the subject inhale as deeply as possible and then hold their breath for as long as possible. Record the length of time (in seconds) that their breath was held and the respiratory rate until the subject has recovered. Also record how long it took (recovery time) for the subject's breathing pattern to return to normal (in seconds).
3. Enter this data in Table 2, below.

Jogging In Place

1. Have the subject jog in place (or run up and down the stairs) for 2 minutes.
2. After this initial period, have the subject inhale as deeply as possible and then hold their breath for as long as possible. Record the length of time (in seconds) that their breath was held and the respiratory rate until the subject has recovered. Also record how long it took (recovery time) for the subject's breathing pattern to return to normal (in seconds).
3. Enter this data in Table 2, below.

Analysis

Table 1. Respiratory Rates During Various Activities

Tasks Performed	Observations and Rate of Breathing
Quiet respiration	
Talking	
Yawning	
Laughing	
Standing	
Concentrating	
Swallowing water	
Coughing	
Lying down	
Running in place	

Table 2. The Effect of Various Activities on Breath-Holding and Normal Recovery

Activity	Time Breath was held after activity (sec.)	Recovery time (sec.)	Respiratory rate du (respirations/min)
Quiet respiration			
Deep inhale and breath holding			
Deep inhale – forceful exhale and breath holding			
Hyperventilation			
Re-breathing (breathing into paper bag)			
Jogging in place			

Analysis Questions

1. After inhaling and holding your breath, was your urge to inspire or exhale?
2. After exhaling and holding your breath, was your urge to inspire or exhale?
3. Explain your answers from questions 1 and 2.
4. Explain the effect that hyperventilation has on respiratory rate and recovery. (HINT: Think about the gases that are found in the plasma during hyperventilation.)

Post-laboratory Questions

1. Some of the nasal cartilages are made of hyaline cartilage. What functional adaptation does cartilage have over bone in making up the framework of the nose?
2. The trachea branches into two tubes that go to the lungs. What are these tubes called?
3. What small structure in the lung is the site of exchange of oxygen with the blood capillaries?
4. Considering the differences that you observed between the normal lung and the smoker's lung, how would these differences lead to functional differences in a nonsmoker versus a smoker?

23.

CHAPTER 23 THE DIGESTIVE SYSTEM

By Joseph D'Silva

Motivation.

Figure 23.1 The blue circle is the global sign for diabetes. Credit: Wikimedia Commons by IntDiabetesFed, license CC-BY-SA-3.0

Diabetes is a disorder of pancreas which is an accessory organ of the digestive system. In diabetes the pancreas is unable to regulate the level of sugar in our blood. Diabetes prevalence is disparately high in African-American populations in the U.S. compared to other racial groups.

The pancreas is an associated part of the digestive system that consists of the mouth, pharynx, esophagus, stomach, small and large intestine. Other associated components of the digestive system are the liver and gall bladder. The digestive system functions to process food that is eaten and to convert it into useable energy by metabolism and therefore the digestive system is important in our lives for survival. Diabetes is a disorder that can be managed with a proper diet and exercise. In this chapter, you will learn the parts of the digestive system and its associated organs and their functions.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Identify the structures of the digestive system and associated parts.
- Describe the histology of the esophagus, stomach, small and large intestine.
- Explain the function of the stomach, small and large intestine.
- Describe the function of the liver, gall bladder and pancreas.
- Explain carbohydrate metabolism.

Background.

The digestive system consists of the mouth, pharynx, esophagus, stomach, small intestine and large intestine. The organs associated with the digestive system are the liver, gall bladder and pancreas and several glands (Figure 23.2). Each organ of the digestive system is made up of specialized tissues with specific functions (Figure 23.3).

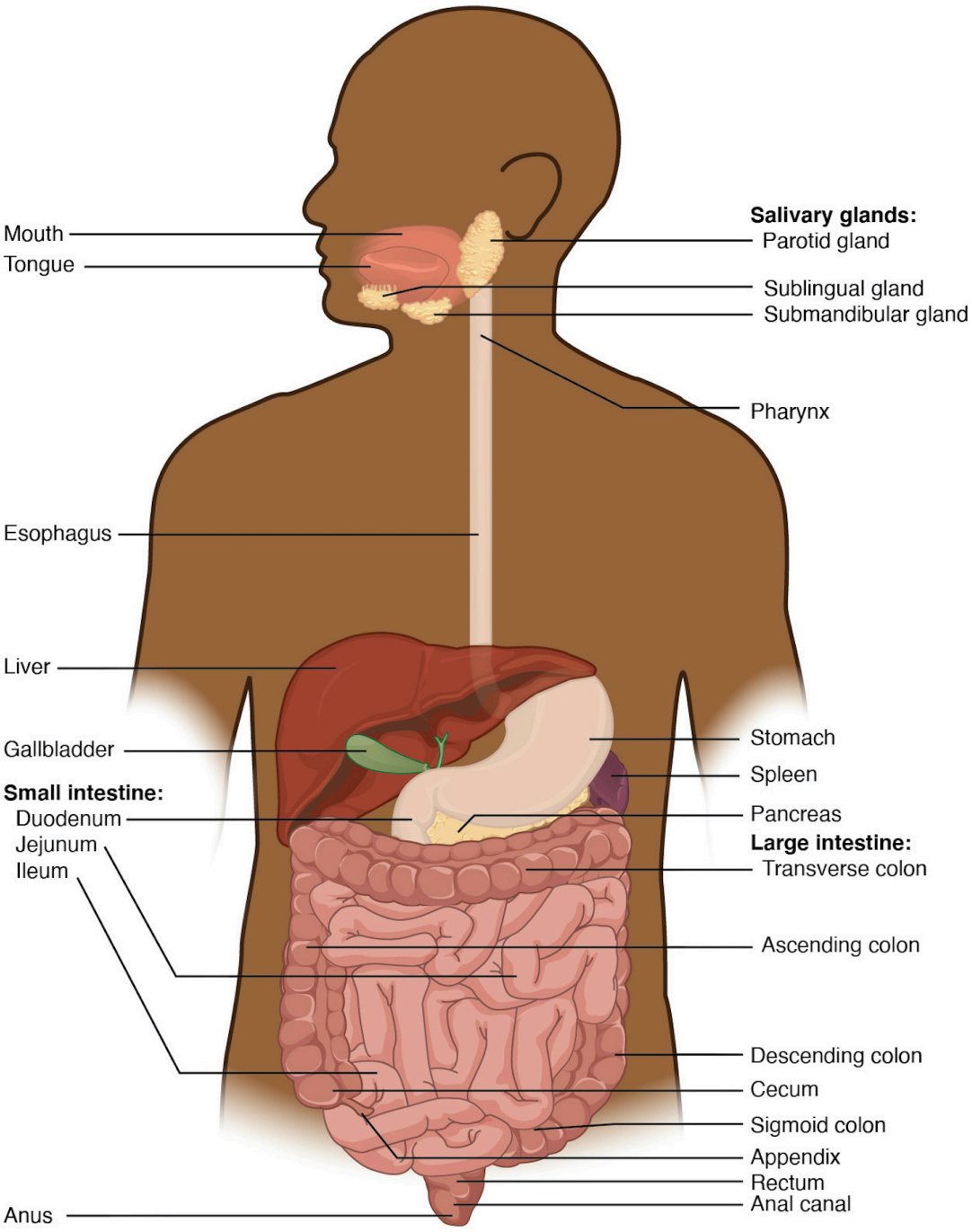


Figure 23.2 Components of the digestive system. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The digestive system is mostly suspended in the abdominal cavity. Food goes through the digestive canal or alimentary canal (Figure 23.2) and is processed as it moves down the lumens of a set of digestive organs starting with the mouth.

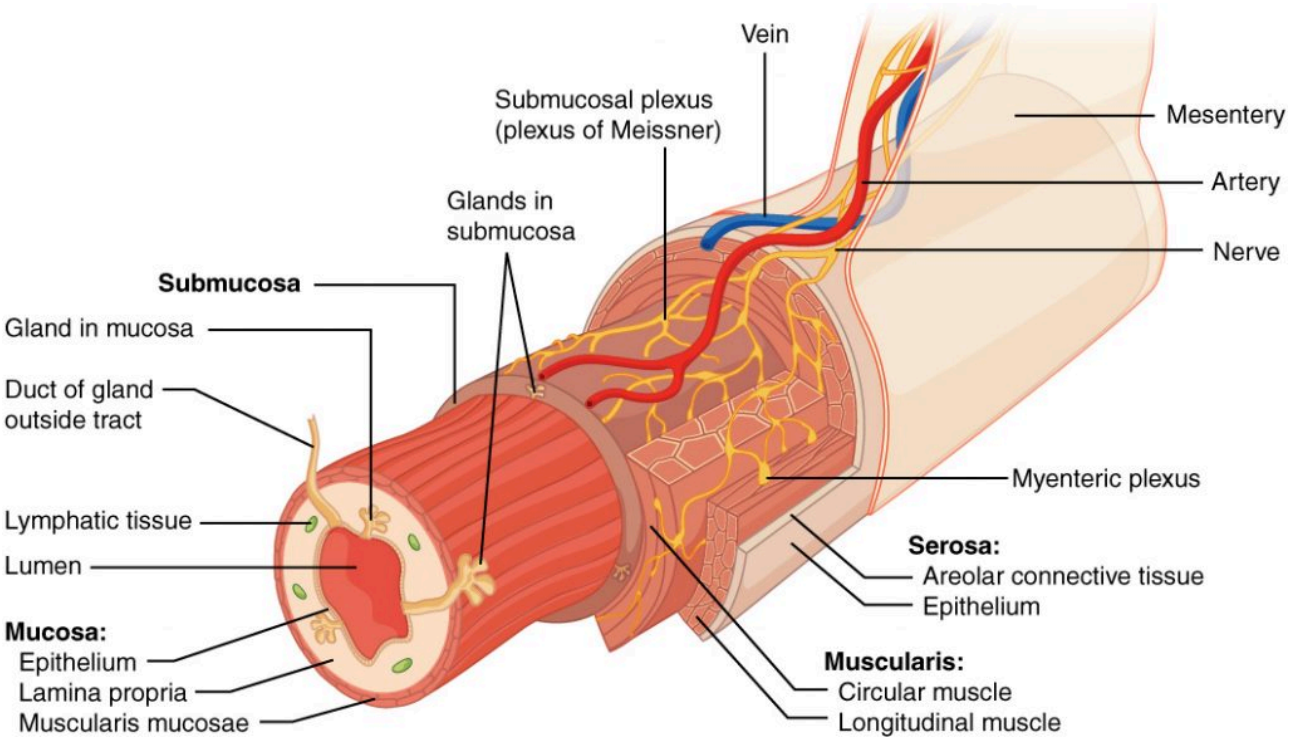


Figure 23.3 Layers of the alimentary canal. Credit: OpenStax Anatomy and Physiology, license CC-BY 4.0

The **mouth** is a cavity with teeth, tongue and salivary glands. The **pharynx** is a hollow tube that connects with the **esophagus** (Figure 23.4). (The pharynx is also connected with the respiratory system.)

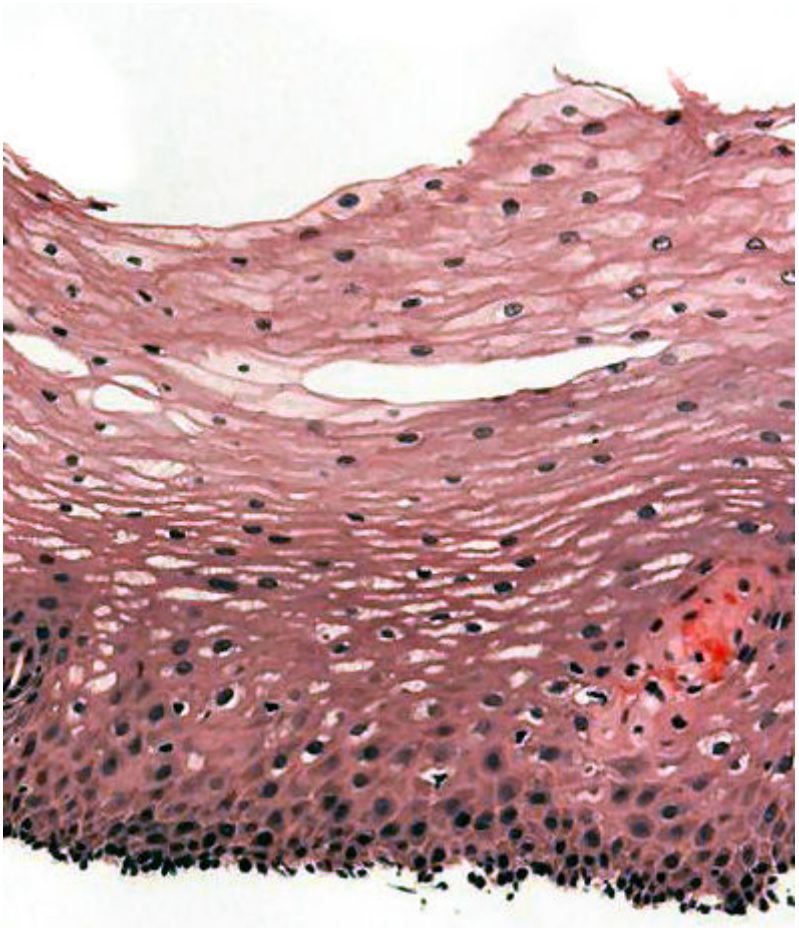


Figure 23.4 Histology of the esophagus. Stratified squamous epithelium faces the lumen. Credit: Wikipedia by user Samir, license CC-BY-SA

The tubular esophagus passes through an opening in the diaphragm (muscular organ that divides the thoracic and abdominal cavity.) It leads to a curved **stomach** which is essentially a holding bag that is a muscular organ (Figures 23.4 and 23.5).

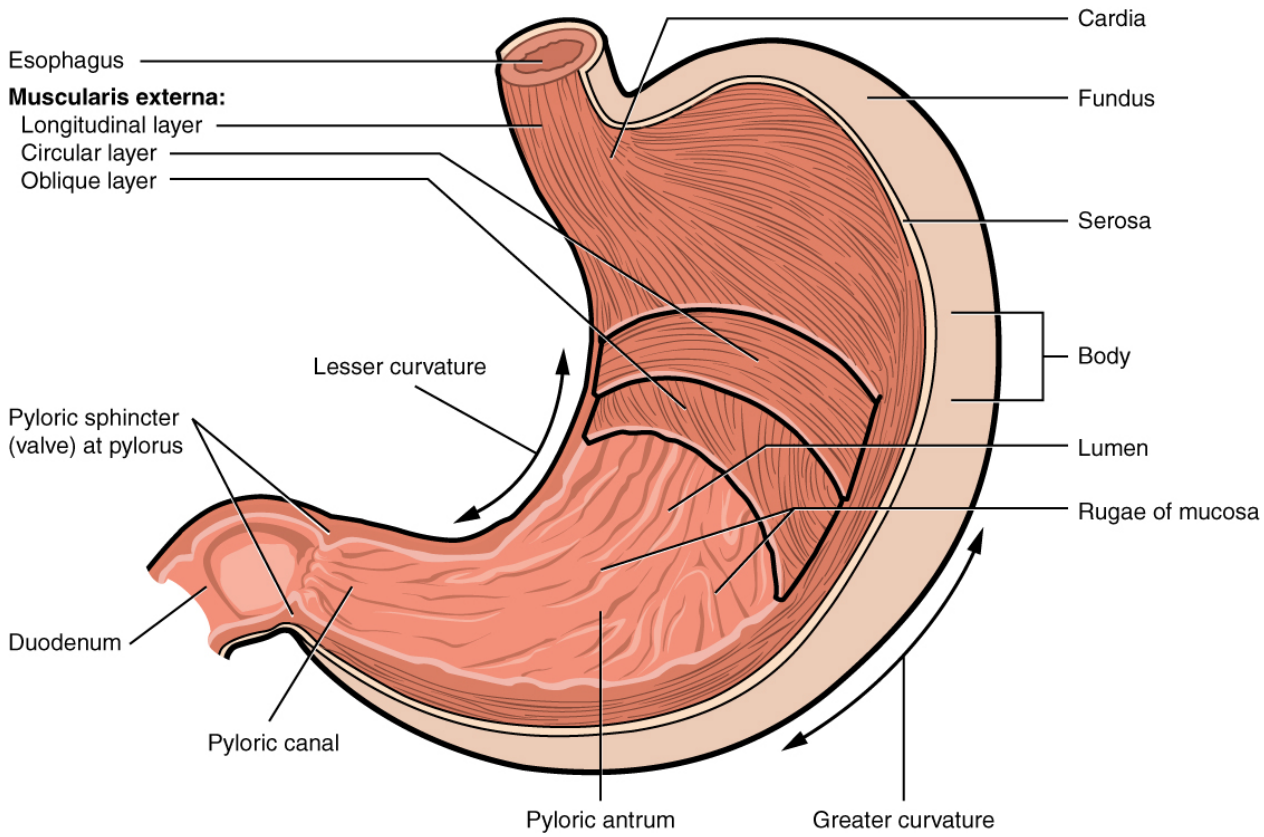


Figure 23.5 The stomach. Structure of the stomach are shown. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

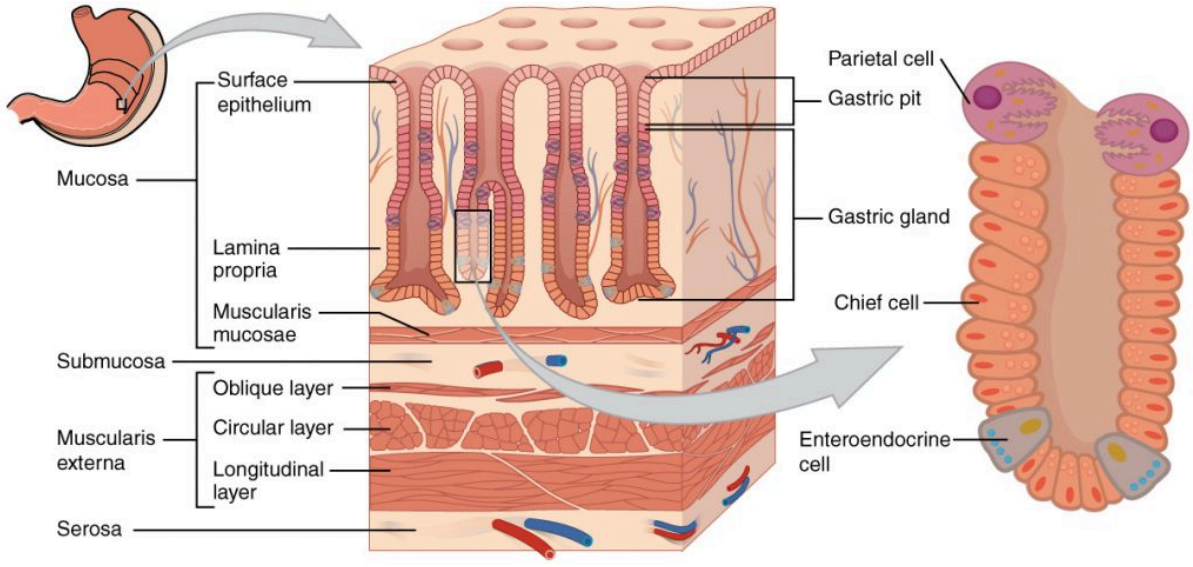


Figure 23.5 Histology of the stomach. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The stomach is connected to the **small intestine** which is approximately 671 cm., long. Most of digestion and absorption occur in the small intestine. Between the stomach and the small intestine is a pyloric

sphincter. It is a valve that prevents the backflow of food once it passes from the stomach into the small intestine (Figure 23.6).

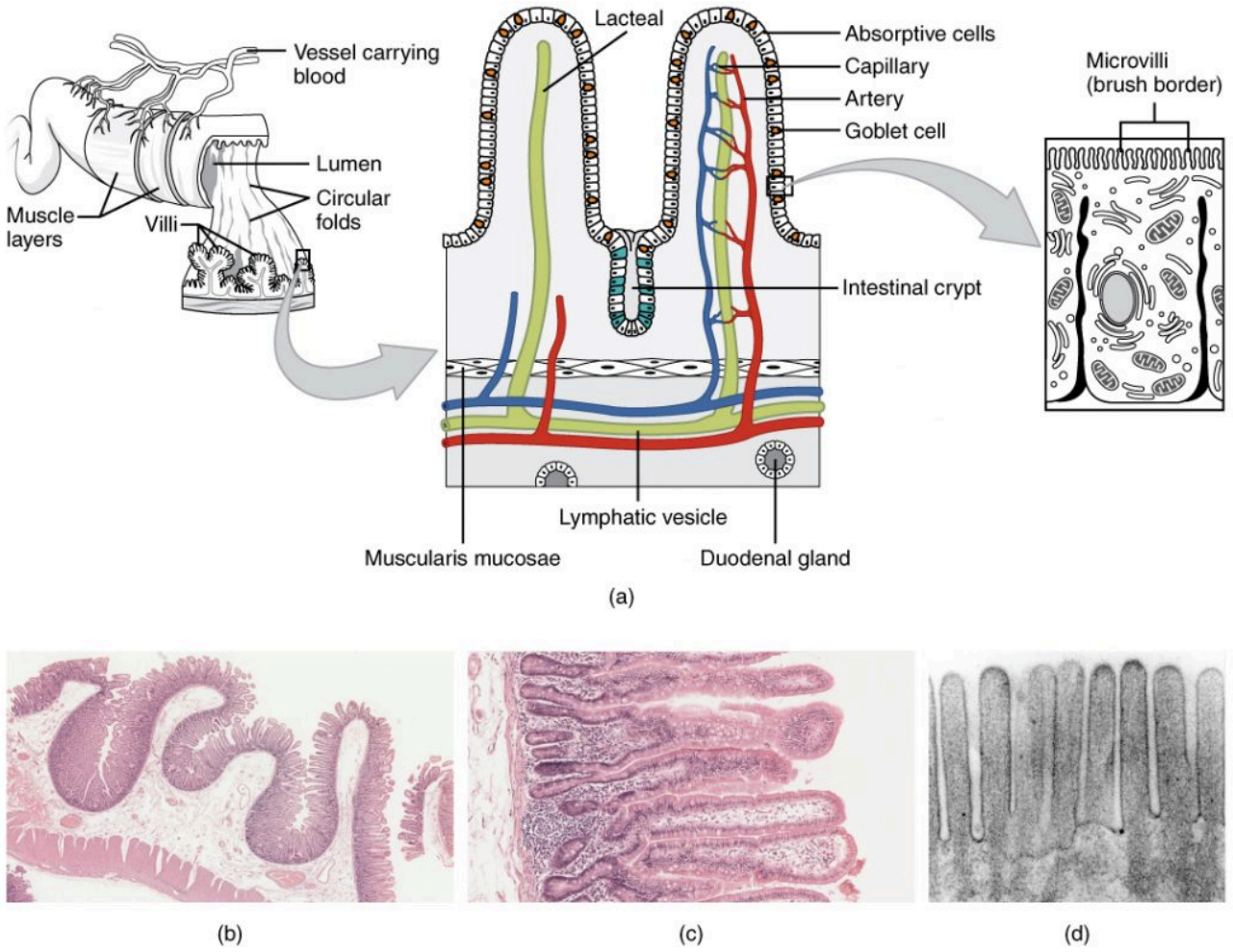


Figure 23.6 Histology of the Small Intestine (a) The absorptive surface of the small intestine is vastly enlarged by the presence of circular folds, villi, and microvilli. (b) Micrograph of the circular folds. (c) Micrograph of the villi. (d) Electron micrograph of the microvilli. From left to right, 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) Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Undigested food passes from the small intestine into the **large intestine**. The large intestine is 213 cm long (Figure 23.7). The large intestine stores waste such as feces and water.

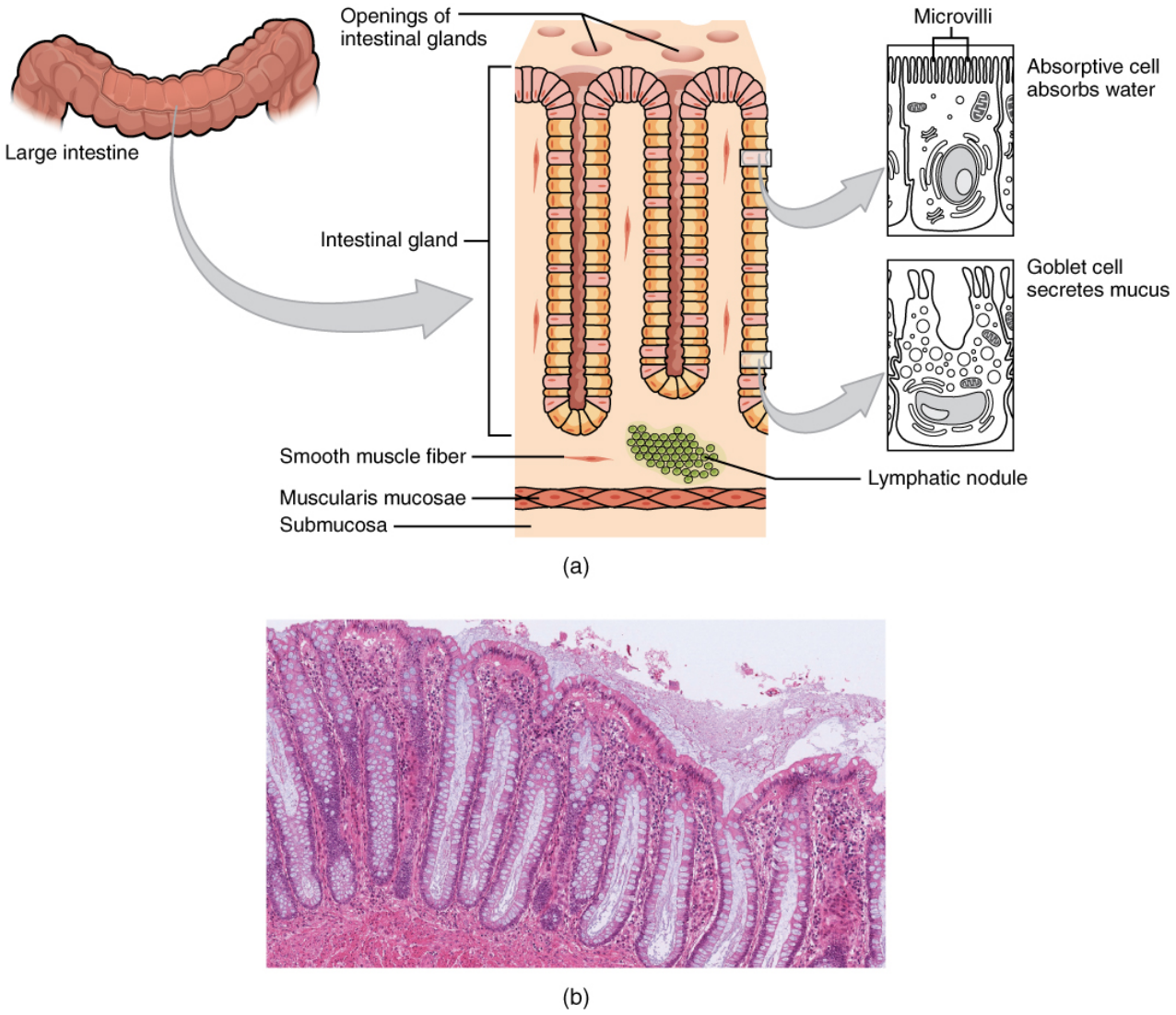


Figure 23.7 Histology of the large Intestine (a) The histologies of the large intestine and small intestine (not shown) are adapted for the digestive functions of each organ. (b) This micrograph shows the colon's simple columnar epithelium and goblet cells. LM x 464. (credit b: Micrograph provided by the Regents of University of Michigan Medical School © 2012). Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The **pancreas** is an organ located in the bend between the stomach and small intestine (Figure 23.8). It secretes a number of enzymes that mediates to break down carbohydrates, proteins and fats.

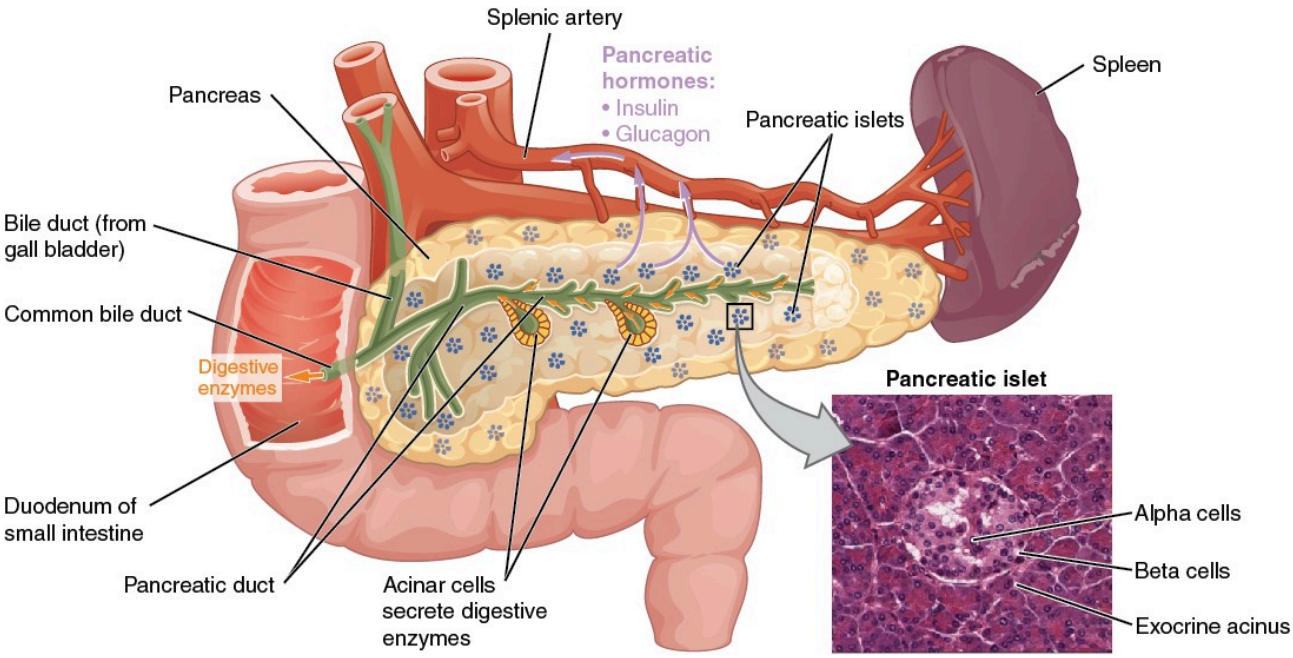


Figure 23.8 Anatomy and histology of the pancreas. The pancreas has a head, a body, and a tail. The exocrine part of pancreas produces pancreatic juice containing digestive enzymes that get delivered to the duodenum through the pancreatic duct. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0.

The liver functions to remove toxins and store sugar, as well as producing bile that is stored in the gallbladder and helps with digestion of fats (Figure 23.9). The gall bladder stores this bile that emulsifies fats.

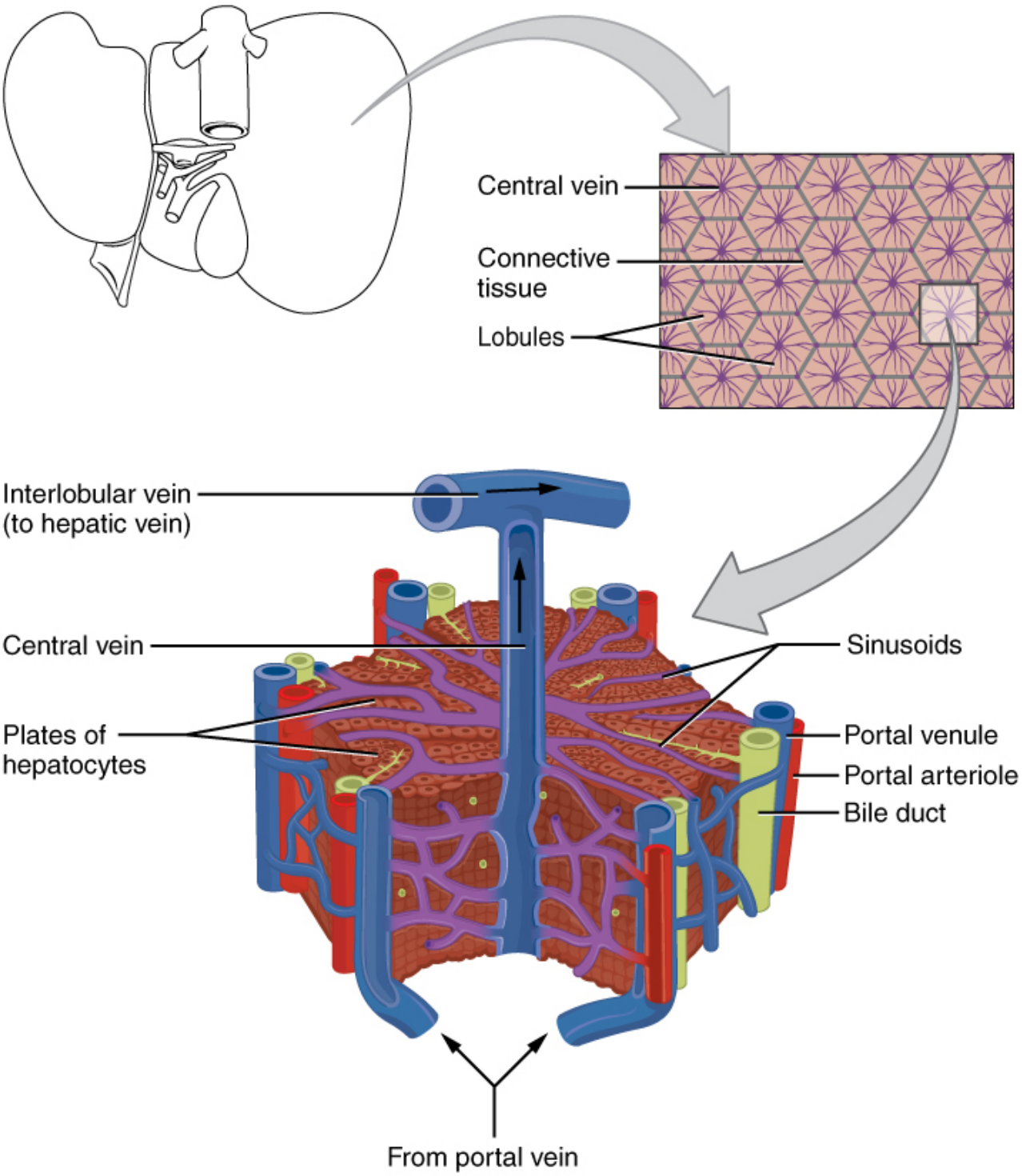


Figure 23.9 The microanatomy of the liver. The hepatocytes produce bile that get carried to the gallbladder via the bile duct. Credit: OpenStax Anatomy and Phyiology, license CC-BY-4.0

The main functions of the digestive system are movement food (propulsion), digestion of food by secreted chemicals or mechanically, and absorption of the digested food (Figure 23.10, Table 1).

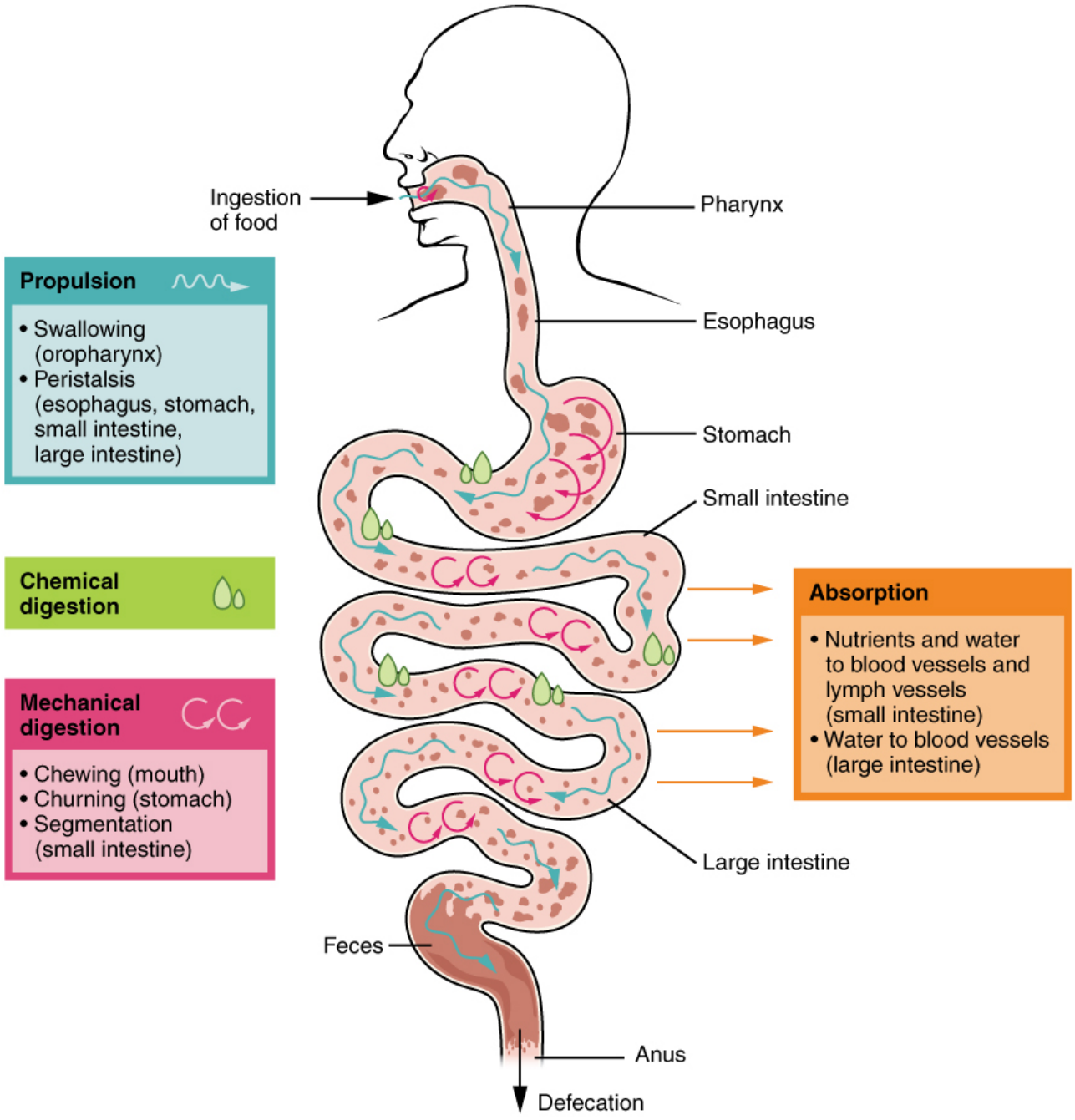


Figure 23.10 The main functions of the digestive system. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Table 1 Functions of the Digestive System

Organ	Major functions	Other functions
Mouth	• Ingests food • Chews and mixes food • Begins chemical breakdown of carbohydrates via salivary amylase • Moves food into the pharynx • Begins breakdown of lipids via lingual lipase	• Moistens and dissolves food, allowing you to taste it • Cleans and lubricates the teeth and oral cavity • Has some antimicrobial activity
Pharynx	• Propels food from the oral cavity to the esophagus	• Lubricates food and passageways
Esophagus	• Propels food to the stomach	• Lubricates food and passageways
Stomach	• Mixes and churns food with gastric juices to form chyme • Begins chemical breakdown of proteins • Releases food into the duodenum as chyme • Absorbs some fat-soluble substances (for example, alcohol, aspirin) • Possesses antimicrobial functions	• Stimulates protein-digesting enzymes • Secretes intrinsic factor required for vitamin B12 absorption in small intestine
Small intestine	• Mixes chyme with digestive juices • Propels food at a rate slow enough for digestion and absorption • Absorbs breakdown products of carbohydrates, proteins, lipids, and nucleic acids, along with vitamins, minerals, and water • Performs physical digestion via segmentation	• Provides optimal medium for enzymatic activity
Accessory organs	• Liver: produces bile salts, which emulsify lipids, aiding their digestion and absorption • Gallbladder: stores, concentrates, and releases bile • Pancreas: produces digestive enzymes and bicarbonate	• Bicarbonate-rich pancreatic juices help neutralize acidic chyme and provide optimal environment for enzymatic activity
Large intestine	• Further breaks down food residues • Absorbs most residual water, electrolytes, and vitamins produced by enteric bacteria • Propels feces toward rectum • Eliminates feces	• Food residue is concentrated and temporarily stored prior to defecation • Mucus eases passage of feces through colon

Pre-Laboratory Questions

1. Relate the parts of the digestive to your own body. Name the structures in the mouth that are associated with the digestive system.
2. Draw and name the parts of the stomach.
3. The stomach functions to _____.
4. Look up the histology of the stomach, small and large intestines. What four structures do these organs have in common?
5. In the abdominal cavity, the liver is located in the _____ _____ quadrant. Name two functions of the liver.

Exercises

- Exercise 1 Main organs of the digestive system
- Exercise 2 Accessory organs of the digestive system
- Exercise 3 Histology of esophagus, stomach, small intestine and large intestine
- Exercise 4 Microanatomy of the pancreas and liver
- Exercise 5 Digestion of starch by salivary enzymes

Exercise 1 Main organs of the digestive system

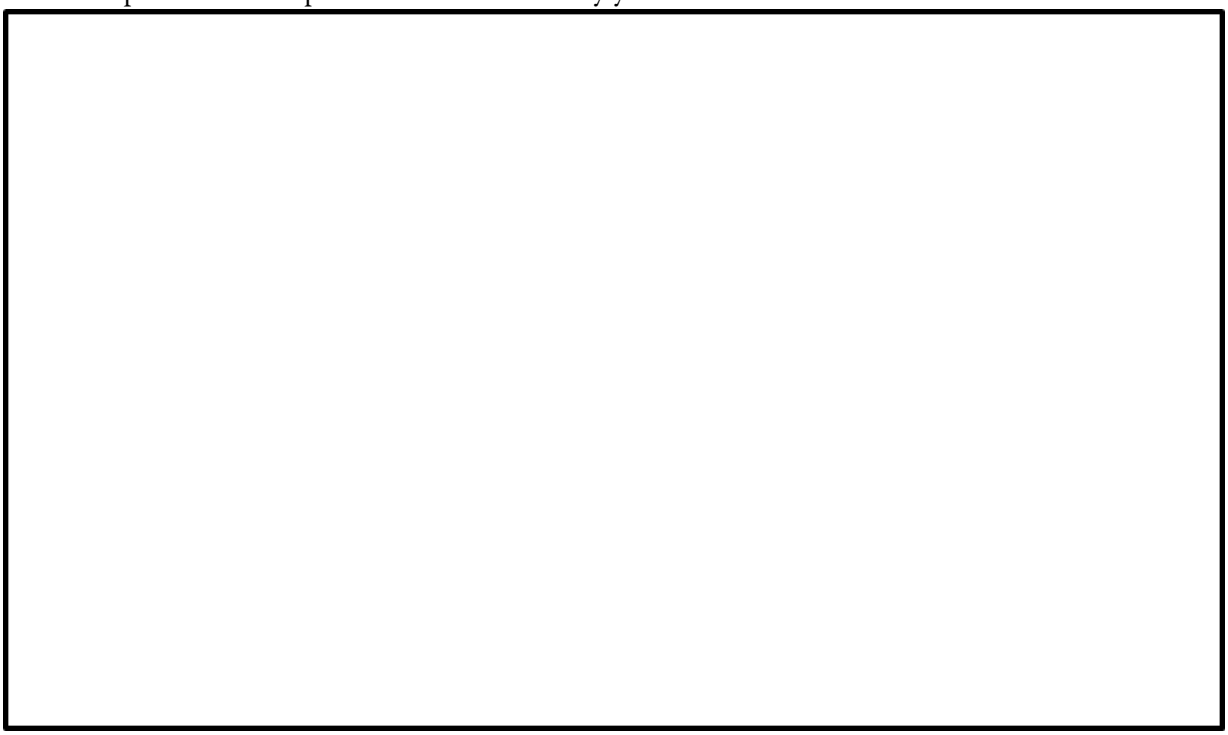
Required Materials

- The Digestive System Poster
- Human Digestive System Model
- Torso Models
- Post-it notes
- Labeling tape

Procedure

1. Study a poster and models of the digestive system and identify the mouth, pharynx, esophagus, stomach, small and large intestine.

2. Using post-it notes or labeling tape label these structures on the torso model. Take a picture and insert the picture in the space below. Alternatively you can sketch and label these structures.



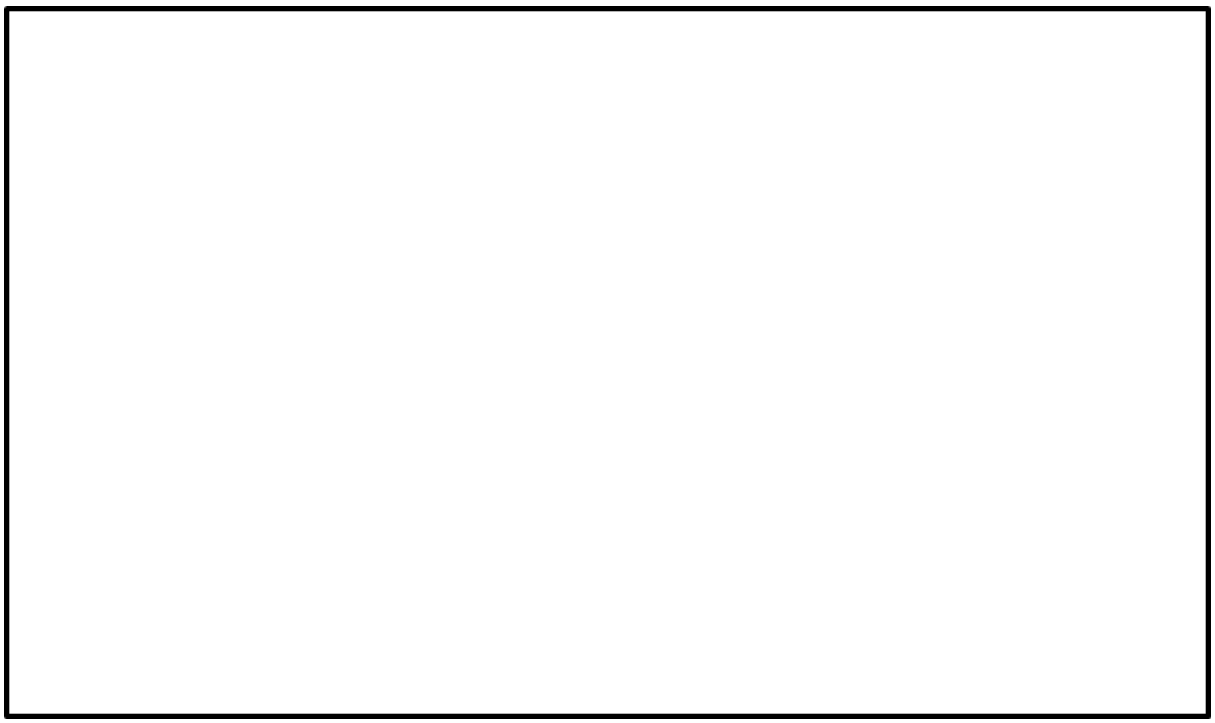
Exercise 2 Accessory organs of the digestive system

Required Materials

- The Digestive System Poster
- Human Digestive System Model
- Torso Models
- Construction paper
- Tape
- Markers

Procedure

1. On your torso model, locate the precise position of the organs associated with the digestive system: pancreas, liver, gall bladder.
2. The abdominal cavity can be divided into four quadrants or nine regions. Use these quadrants/regions to locate the organs. Use colorful construction paper, tape and markers to delineate the four quadrants of the abdominal cavity on the model.
3. Write in the pancreas, liver, and gallbladder into the quadrants you find them in. Take a picture of your labeled model. Insert the picture below. Alternatively, you can sketch and label to show the abdominal locations of these accessory organs.



4. Fill in the chart below indicating the location of the digestive organs and the accessory organs of the digestive system that reside in the abdominal cavity: stomach, small intestine, large intestine, liver, gall bladder, pancreas.

Right Upper Quadrant (RUQ)	**Left Upper Quadrant (RUQ)**
Right Lower Quadrant (LLQ)	**Left Lower Quadrant (LLQ)**

Exercise 3 Histology of esophagus, stomach, small intestine and large intestine

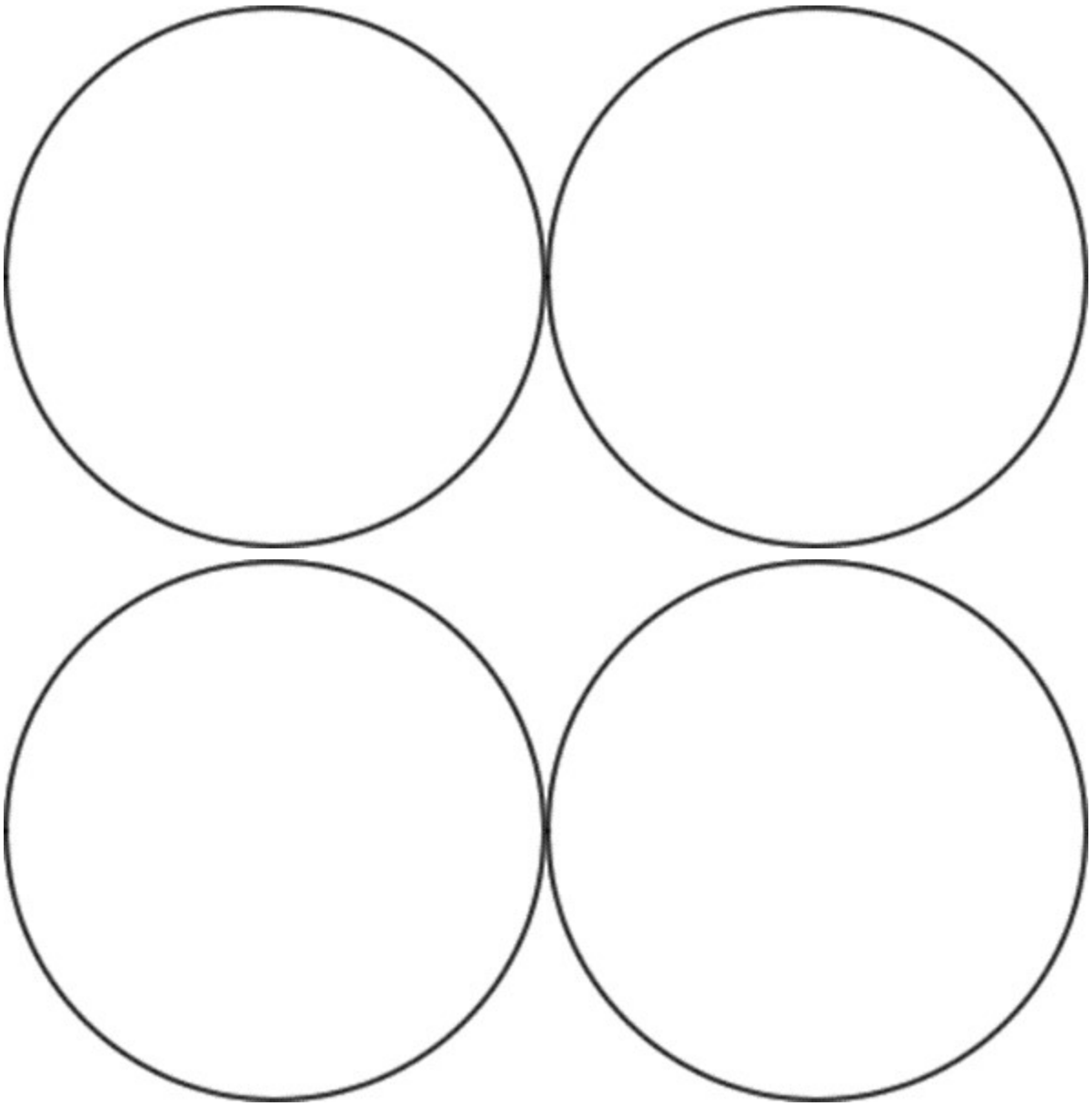
Required Materials

- Compound microscope

- Microscope lens paper
- Microscope lens cleaning solution
- Microscope immersion oil
- Slide of Mammal Esophagus
- Mammal Stomach Composite slide
- Mammal Intestine Composite slide
- Large Intestine (Human) slide

Procedure

1. Obtain histological slides and study the structure of the esophagus, stomach, small and large intestine.
2. There are four structures that you should be able to identify by looking through a microscope: mucosa, submucosa, muscularis and serosa.
3. Study the tissues and record how they are different. Provide labeled sketches below to show these layers in the four slides:



Exercise 4 Microanatomy of the pancreas and liver

Required Materials

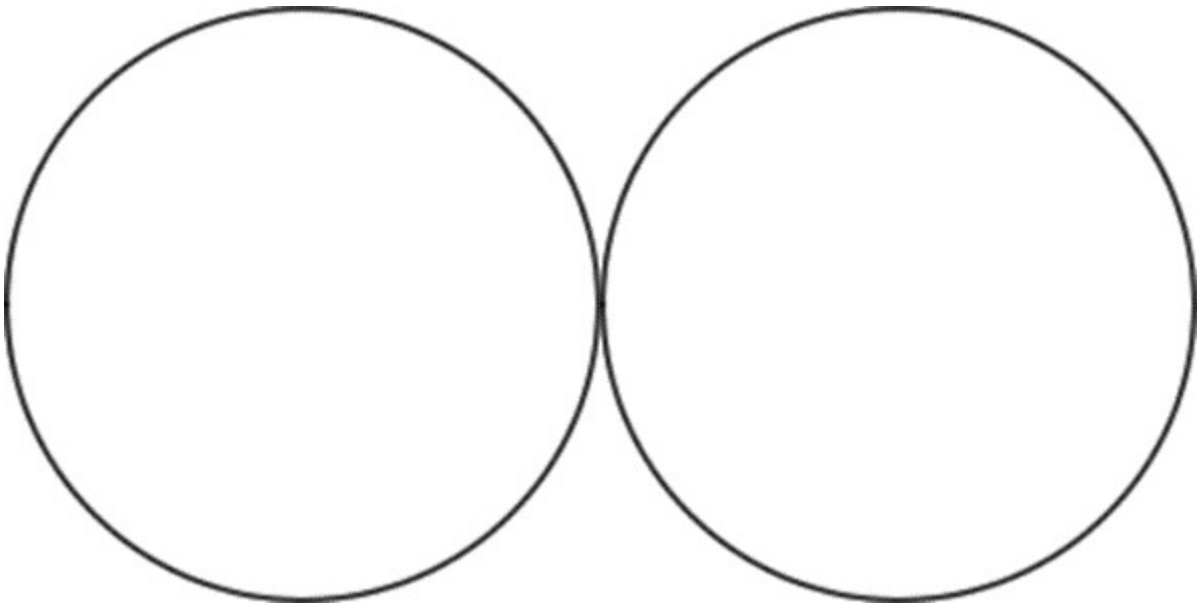
- Compound microscope
- Microscope lens paper
- Microscope lens cleaning solution
- Microscope immersion oil
- Human Pancreas slide
- Human Liver slide

Procedure

1. Obtain slides to show the tissues and cells that make up the pancreas and liver. These are accessory

organs of the digestive system.

2. Locate the islets of Langerhans that play a critical role in controlling blood sugar levels. What is the hormone that is secreted by the islets of Langerhans? _____
3. The liver is divided into lobules. What are the cells that make up the liver primarily? State their function. _____
4. Sketch what you observed under the microscope in the pancreas and liver slides. Label the hepatocytes of liver, and the islets and exocrine acini of pancreas.



Exercise 5 Digestion of starch by salivary enzymes

Required Materials

- Test tubes
- Test tube rack
- Tube labeling pen
- 1% starch solution
- Water
- Iodine (KI) solution in dropper bottle
- Graduated cylinder
- ruler

Procedure

1. Carry out an experiment to show the presence of carbohydrates. Ask your instructor for three test tubes.
2. Label test tubes A, B & C. The test tubes A & B will be your experimental sample. Test tube C will

be control.

- Test Tube A: Saliva + Starch
- Test Tube B: Water + Starch
- Test Tube C: Water + Water

3. Collect saliva in test Test Tube A.
4. Use a ruler to measure the amount of saliva in Test Tube A.
5. Mark Test Tube B and C to the same level. Add water to this level.
6. Put 2 ml of starch into Test Tube A and into Test Tube B.
7. Put 2 ml of deionized water into Test Tube C.
8. Put a drop of iodine (KI) solution into each tube. Remember that iodine solution itself is yellow/brown and it turns purple in the presence of starch.
9. Write down the results in the table below. Put a check mark if you see a reaction (purple) and an X if there is none.

	Test Tube A	Test Tube B	Test Tube C
Reaction			

10. Did your saliva digest starch? Use your results to explain your answer.

_____

Post-laboratory Questions

1. Name the sphincter muscles that allow foods to enter and leave the stomach.
2. One role of hydrochloric acid HCl in the stomach is to convert a precursor enzyme _____ to _____.
3. The four layers of the small and large intestine are _____, _____, _____, and _____.
4. The islets of Langerhans secretes a hormone called_____ that regulates blood sugar levels.

24.

CHAPTER 24 METABOLISM AND NUTRITION

By Joseph D'Silva

Motivation.

Metabolism concerns a number of reactions in the cell to provide energy for the body to function. The energy comes from food. Diabetes and obesity are two disorders of the digestive system that are closely linked to metabolic reactions. In diabetes, the level of sugar in the blood cannot be maintained at a homeostatic level. Obesity is defined as an excessive accumulation of fat. The occurrence of both diabetes and obesity in the United States and among African Americans is higher compared to other racial groups.

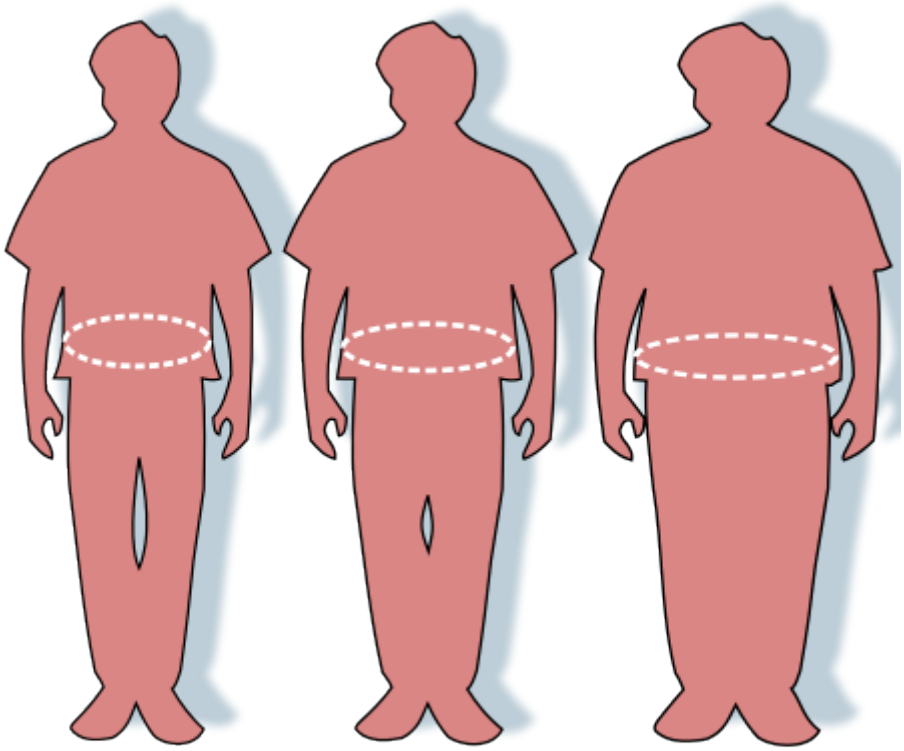


Figure 24.1 Optimal, overweight and obese conditions are illustrated here. Illustration of obesity and waist circumference. From left to right, as labeled in the original image, the "healthy" man has a 33 inch (84 cm) waist, the "overweight" man a 45 inch (114 cm) waist, and the "obese" man a 60 inch (152cm) waist. The graphic is based on information from Report of the Dietary Guidelines Advisory Committee on the Dietary Guidelines for Americans (2000). Renée Gordon (FDA), Victovoi Original image by FDA Credit: Wikipedia, license Public Domain

Diabetes is prevalent particularly among ethnic minority populations. Native Americans, Mexican Americans, and African Americans show a higher rate of diabetes than other populations according to several studies. It is well established that several ethnic minority populations, such as Native Americans, Mexican Americans, and African Americans, are particularly prone to obesity. More interestingly, Afro-American women have a higher rate (37.4%) than their counterpart white women (22.4%). That is, a Body Mass Index in (kg/m2) >30. There are a number of reasons for being obese: genetics, culture, lack of physical exercise....to name a few. But diabetes is a disorder that can be managed by putting strict disciplines into our daily lives. Healthy eating habits, regular exercise and motivation can reduce the risks of diabetes.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Define carbohydrate metabolism and observe in yeast
- Define diabetes and causes and measure blood sugar levels
- Define obesity and BMI and measure BMI.
- Make a meal plan using MyPlate nutritional recommendations

Background.

In physiological terms, metabolism is the sum total of all the chemical reactions that occur in the human body to produce energy and eliminate waste. Nutrition is linked to metabolism. We derive energy that we generate in our body is provided by carbohydrates, proteins and fats. Carbohydrates are made up of glucose molecules. For example, a molecule of glucose is $C_6H_{12}O_6$.. When carbohydrates are eaten and absorbed in the small intestine by cells, the glucose molecule is converted to ATP which is energy. The reaction that occurs is:

$$\mathbf{C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6\,H_2O + 36\ ATP\ (energy)}$$

A complex set of reactions take place by which a molecule of glucose combines with six molecules of oxygen to produce six molecules of carbon dioxide and six molecules of water. In metabolism, two concepts need to be studied: catabolism and anabolism. In catabolism, complex molecules are broken down to simpler ones. Anabolism is where simple molecules are combined to form complex ones. Breaking down a molecule of glucose ($\mathbf{C_6H_{12}O_6}$) is a catabolic reaction.

Glucose concentration in our body can be measured and the normal level is 4.4 to 6.1 mmol/L (79 to 110 mg/dL). The blood sugar level can by measured using simple at-home test kits. In diabetics, the amount is above this level and can reach up to 200 mg/dL.

Table 1. The levels of blood sugar before and after a meal.

Fasting	<100 mg/dL
Before meal	70-130 mg/dL
After meal	<189 mg/dL

Excessive intake of carbohydrates in diabetics can lead to increase in blood sugar level. Obesity takes

place when excessive amounts of calories produced by the body through food intake are not burned or spent The weight of a person can define his/her obesity and can be measured by the BMI (Body Mass Index) where the mass is the weight divided by the height^2 (kg/m 2). The table below compares the ranges of weight to indicate obesity.

Table 2 BMI vs. weight category

Category[25]	**BMI (kg/m^2)**
Underweight	< 18.5
Normal weight	18.5 – 24.9
Overweight	25.0 – 29.9
Obese (Class I)	30.0 – 34.9
Obese (Class II)	35.0 – 39.9
Obese (Class III)	≥ 40.0

Behavioral, genetic and metabolic causes also play a role in obesity. Diabetes and obesity are linked to nutrition. Uncontrolled dietary habits or intake of too many calories of food can cause blood sugar levels to increase and/or lead to obesity. Practical steps can be taken to reduce carbohydrate and obesity. People who are diabetic or obese face high risk factors. (Include) Fortunately, both of them are manageable with rigorous exercise and diet control.

Pre-Laboratory Questions

1. Define metabolism.
2. Explain the role of glucose in metabolism
3. Define diabetes and the role of sugar consumption in diabetes.
4. Define obesity and BMI.
5. Describe how food consumption (nutrition) is related to metabolism.

Exercises

- Exercise 1 Determine blood sugar levels
- Exercise 2 Effect of sugar intake on blood sugar levels

- Exercise 3 Determination of BMI
- Exercise 4 Effect of sucrose levels on yeast metabolism
- Exercise 5 Application of USDA dietary guidelines

Exercise 1 Determine blood glucose levels

Required Materials

- Lancets
- Glucose test strips
- Glucose meter (instruction manual)
- Alcohol wipes
- Biohazardous waste container
- Bloodborne Pathogens Safety Training

Procedure

1. Take an unused glucose test strip and place it in the glucose meter (orient as indicated in insruction manual)
2. Use an alcohol wipe to thoroughly clean a fingertip (your own only!) and let try thoroughly
3. Take a new lancet, gently and quickly press on fingertip and release.
4. Place the used lancet in the provided biohazardous waste container.
5. Touch the tip of the glucose strip in the glucose meter to the drop of blood on your fingertip.
6. Read the value shown on the meter screen. **Record here:**_____
7. Remove the glucose strip from meter and discard in biohazardous waste container.
8. Use an alcohol wipe to clean the fingertip.

Exercise 2 Effect of sugar intake on blood sugar levels

Required Materials

- 8 oz. bottles of water (unopened)*
- Teaspoon measures*
- Sugar*
- Lancets
- Glucose test strips
- Glucose meter (instruction manual)

- Alcohol wipes
- Biohazardous waste container

*These are kept and used in designated area outside the lab that is safe for food and drink consumption only.

Procedure

1.Prepare the following 5 bottles of water:

- Water: nothing added to bottle
- 1% sugar solution: 1/2 teaspoonful of sugar added to bottle
- 2% sugar solution: 1 teaspoonful of sugar added to bottle
- 3% sugar solutionL 1 1/2 teaspoonful of sugar added to bottle
- 5% sugar solution: 2 1/2 teaspoonful of sugar added to bottl.

2. One person from the group: Drink the water. Measure your blood glucose level as done in Exercise 1. Enter the data in Table 3 below.

3. Drink the 1% sugar solution. Wait for 10 minutes. Measure your blood glucose level as done in Exercise 1. Enter the data in Table 3 below.

4. Drink the 2% sugar solution. Wait for 10 minutes. Measure your blood glucose level as done in Exercise 1. Enter the data in Table 3 below.

5. Drink the 3% sugar solution. Wait for 10 minutes. Measure your blood glucose level as done in Exercise 1. Enter the data in Table 3 below.

6. Drink the 5% sugar solution. Wait for 10 minutes. Measure your blood glucose level as done in Exercise 1. Enter the data in Table 3 below.

Table 3 Blood glucose levels

Concentration of Sugar (%)	Amount of Sugar in Blood(mg/dL)
1%	
2%	
3%	
5%	
Water	

Analysis Questions:

1. Does the blood sugar level rise with concentration of sugar?
2. Why did you use water only to test blood sugar level for this experiment?

3. What other factor might make your blood sugar level vary?
4. In real life, what might this tell you about the consumption of carbohydrates in large quantities?

Exercise 3 Determination of BMI

Required Materials

- Tape measure or meter ruler
- Scale

Procedure

1. Use a tape measure or meter ruler to determine your height (one person from your group) and four of your peers (one person from each other group).
2. Measure your weights using the scale. Insert the data in the table below. Then, use the formula BMI = Weight/height^2 (kg/m^2) to calculate BMI (Body Mass Index). Enter weight, height, and BMI into Table 4 below.
3. What does the data indicate about your category of obesity? Refer to Table 2 above. Enter Category into Table 4 below.

Table 4 Class data for BMI.

Height (m)	Weight (kg)	BMI (kg/m^2)	Category
1.			
2.			
3.			
4.			
5.			

Exercise 4 Effect of sucrose levels on yeast metabolism

Required Materials

- 5 yeast cells plates on solid agar medium containing 1% (wt/vol) yeast powder* (grown for 2-3 days, differing sucrose concentrations as shown in Table 5)
- Ruler

Procedure

1. The goal in this exercise is to observe the role of sugar on colonies of yeast cells. The yeast cells were cultured in a growth medium that has been supplemented with varying concentrations of sucrose (a carbohydrate) which is found in everyday food. See Table 5 below.

Table 5 Role of carbohydrates in nutrition

Growth medium	**Concentration of added sucrose**
(A). Cells were plated on solid medium containing 1% (wt/vol) yeast powder *	0.0% (wt/vol).
(B) Cells were plated on solid medium containing 1% (wt/vol) yeast powder *	0.25% (wt/vol).
(C) Cells were plated on solid medium containing 1% (wt/vol) yeast powder *	0.5% (wt/vol)
(D) Cells were plated on solid medium containing 1% (wt/vol) yeast powder *	1% (wt/vol)
(E) Cells were plated on solid medium containing 1% (wt/vol) yeast powder *	2% (wt/vol).

*Adapted with permission from Manuel Alonso, Carlos A. Stella. 2012. Teaching nutritional biochemistry: an experimental approach using yeast. *Adv. Physiol. Edn., 36: 313-318.*

2. Your instructor will supply you with Petri dishes containing a growth medium that has been inoculated with yeast cell for two to three days.

3. When yeast cells grow, they form colonies. The size of the colonies will indicate the effect of different concentrations of sucrose which is a carbohydrate.

4. Use a ruler to measure the diameter of the colony. Small colony growth will be limited while medium growth will be larger in diameter. Full growth will be largest in diameter. Record your data in the table below. Photograph the colonies. Use Table 6 below to insert your photos as well.

Table 6. Results of yeast growth on agar plates

Sucrose Concentration (wt/vol)	Growth (small or medium or full)	Photograph
A. 0.0%		
B. 0.25%		
C. 0.5%		
D. 1%		
E. 2%		

Analysis Questions

1. Which concentration of sucrose yielded the most number of colonies? What does this tell us about the role of sucrose (a carbohydrate) in our diet?

Exercise 5 Application of USDA dietary guidelines

Required Materials

- Choose My Plate Poster
- Nutrition and Metabolism Poster
- USDA MyPlate Web Site: https://www.myplate.gov/

Procedure

1. Open https://www.myplate.gov/
2. Explore the MyPlate Food Groups: Fruits, vegetables, grains, protein foods, and dairy.
3. The ***Dietary Guidelines for Americans, 2020-2025*** are available. Learn more
4. Now study Table 1-1 *Healthy U.S. Style Dietary Pattern at the 2,000-Calorie Level, With Daily or Weekly Amounts From Food Groups, Subgroups, and Components*.
5. Table 1-1 shows what you need to consume to maintain a 2,000 calorie level of food intake. Write down the recommendations here:

Post-laboratory Questions

1. Metabolism can be defined as reactions that take place in our body. Carbohydrate metabolism refers to the breakdown of _____(glucose) to produce _____ .

2. The level of glucose at any time in our body can be determined by a glucose test. Fasting blood sugar refers to blood sugar level sampled after ____ since the last meal was eaten.

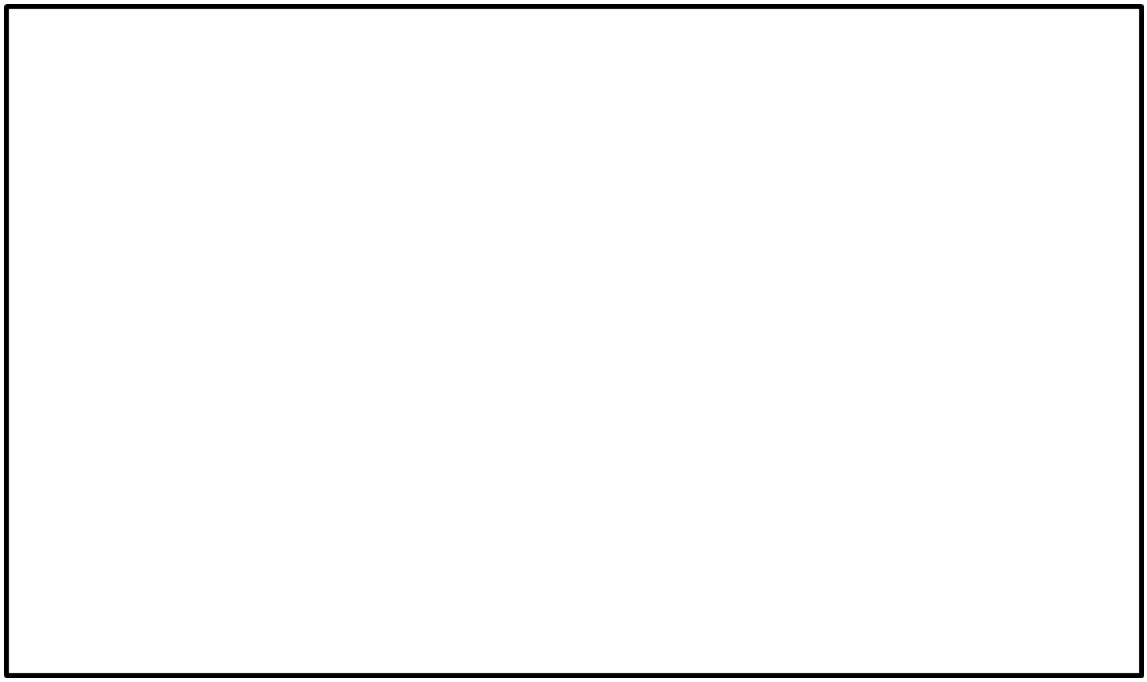
3. Based on the BMI recorded in your class, _____ persons were not obese. The criterion for obesity is a BMI between _____ and _____ $kg/m^{2.}$

4. How much of each category of the food groups of the fruit, protein, vegetables, dairy, and grain is needed to maintain a 2000 calorie level of nutrition for a female person who is 19 years old, is 5'5″ tall and weights 150 lbs? Go here to find out.

- fruits: _____cups
- protein: _____ounces
- vegetables: _____cups
- dairy: _____cups
- grain: _____ounces

5. Are you making every bite count? Take the MyPlate Quiz to find out! Levels have been added to the MyPlate Quiz. Take the quiz today to find out your level and get personalized resources to *Start Simple with MyPlate*.

- Start Quiz
- Insert a screenshot of your quiz results below.



25.

CHAPTER 25 THE URINARY SYSTEM

By Ganesan Kamatchi

Motivation.

Figure 25.1 Patient undergoing dialysis by a hemodialyzer machine. The hemodialyzer machine shown here is 33.5 inches tall, 19 inches deep and 17.5 inches wide. The kidney is much smaller than this machine and is the size of our fist. Credit: Wikimedia Commons by Shanel, license CC-BY-SA 3.0

Hemodialysis, also spelled haemodialysis, or simply dialysis, is a process of purifying the blood of a person whose kidneys are not working normally. This type of dialysis achieves the extracorporeal removal of waste products such as creatinine and urea and free water from the blood when the kidneys are in a state of failure. Hemodialysis is one of three renal replacement therapies (the other two being kidney transplant and peritoneal dialysis). An alternative method for extracorporeal separation of blood components such as plasma or cells is apheresis. Hemodialysis can be an outpatient or inpatient therapy. Routine hemodialysis is conducted in a dialysis outpatient facility, either a purpose built room in a

hospital or a dedicated, stand-alone clinic. Less frequently hemodialysis is done at home. Dialysis treatments in a clinic are initiated and managed by specialized staff made up of nurses and technicians; dialysis treatments at home can be self-initiated and managed or done jointly with the assistance of a trained helper who is usually a family member.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Describe the external structure of the kidney, including its location, support structures, and covering
- Identify the major internal divisions and structures of the kidney
- Identify the major blood vessels associated with the kidney and trace the path of blood through the kidney
- Provide specific examples to demonstrate how the urinary system responds to maintain homeostasis in the body in relation with other systems

Background.

The urinary system consists of two kidneys, two ureters, a single urinary bladder, and a single urethra (Figure 25.2). This system has roles that you may already be aware of, such as cleansing the blood and ridding the body of wastes. However, there are additional, equally important functions played by the system. Take for example, regulation of pH, a function shared with the lungs and the buffers within the blood. Additionally, the regulation of blood pressure is a role shared with the heart and blood vessels. What about regulating the concentration of solutes in the blood? Did you know that the kidney is important in determining the concentration of red blood cells?

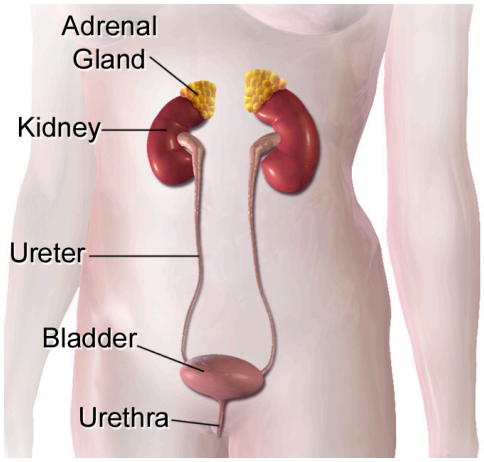


Figure 25.2 The urinary system. Kidney, ureters, urinary bladder, and urethra form the main components of the urinary system. Credit: Creative Commons by BruceBlaus, license CC-BY-SA 4.0

Most importantly, the urinary system works to remove the dissolved materials from the blood through the process of filtration. Filtration occurs when one or more substances pass through a selectively permeable membrane, while others are retained. Within the kidneys, filtration involves both metabolic waste products, such as urea or toxins, as well as materials that are beneficial to the body. Any filtered material that is not desirable though will be excreted from the body. If the kidneys fail, these functions are compromised or lost altogether, with devastating effects on the homeostasis. Affected individuals may experience weakness, lethargy, shortness of breath, anemia, widespread edema (swelling), metabolic acidosis, rising potassium levels, heart arrhythmias, and more. Each of these functions is vital to your well-being and survival.

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 (Figure 25.3). They are roughly the size of your fist, and the male kidney is typically a bit larger than the female kidney.

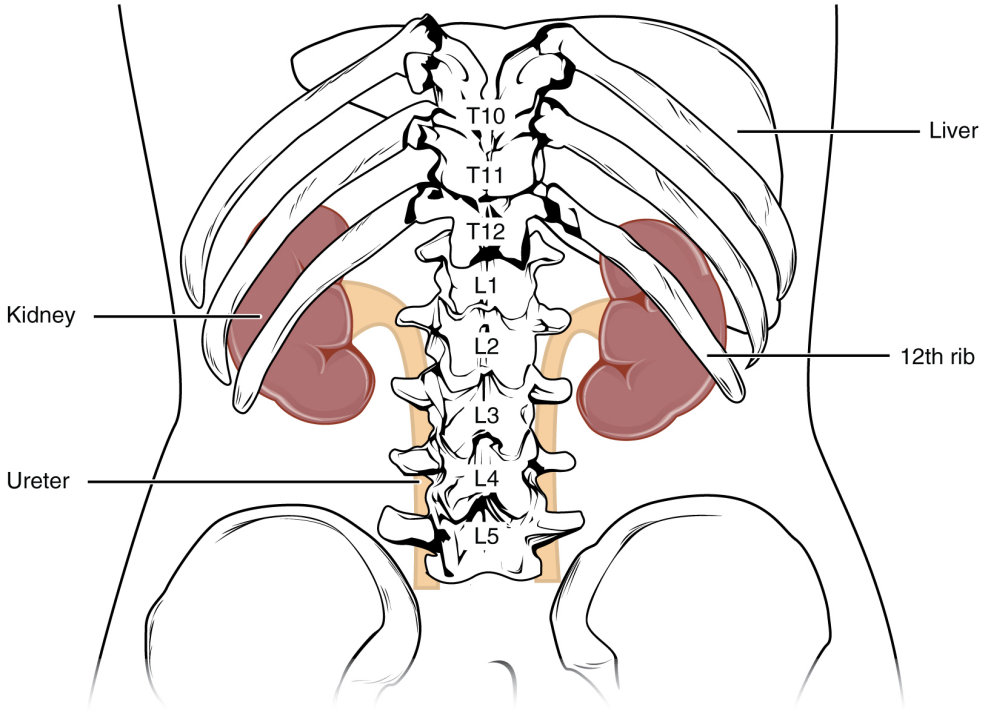


Figure 25.3 The kidneys. Posterior view. This image shows a human torso and shows the location of the kidneys within the torso. The kidneys are slightly protected by the ribs and are surrounded by fat for protection (not shown).

In this laboratory, you will use models, diagrams and histological samples to study the anatomy of the urinary system. Specifically, you will examine the gross and microscopic anatomy of the system as it is represented in humans. As you study the anatomy, keep in mind that the urinary system functions to remove the dissolved materials from the blood, regulate electrolytes and fluid volume, concentrate and release waste products, and reabsorb metabolically important substances.

Blood Supply to the Kidney

The kidneys are well vascularized, receiving about 25 percent of the cardiac output at rest. The kidney filters metabolic products from the blood and returns important components such as water, glucose, and ions back into the blood. To ensure this, blood flow into and out of the kidneys is essential (Figure 25.4).

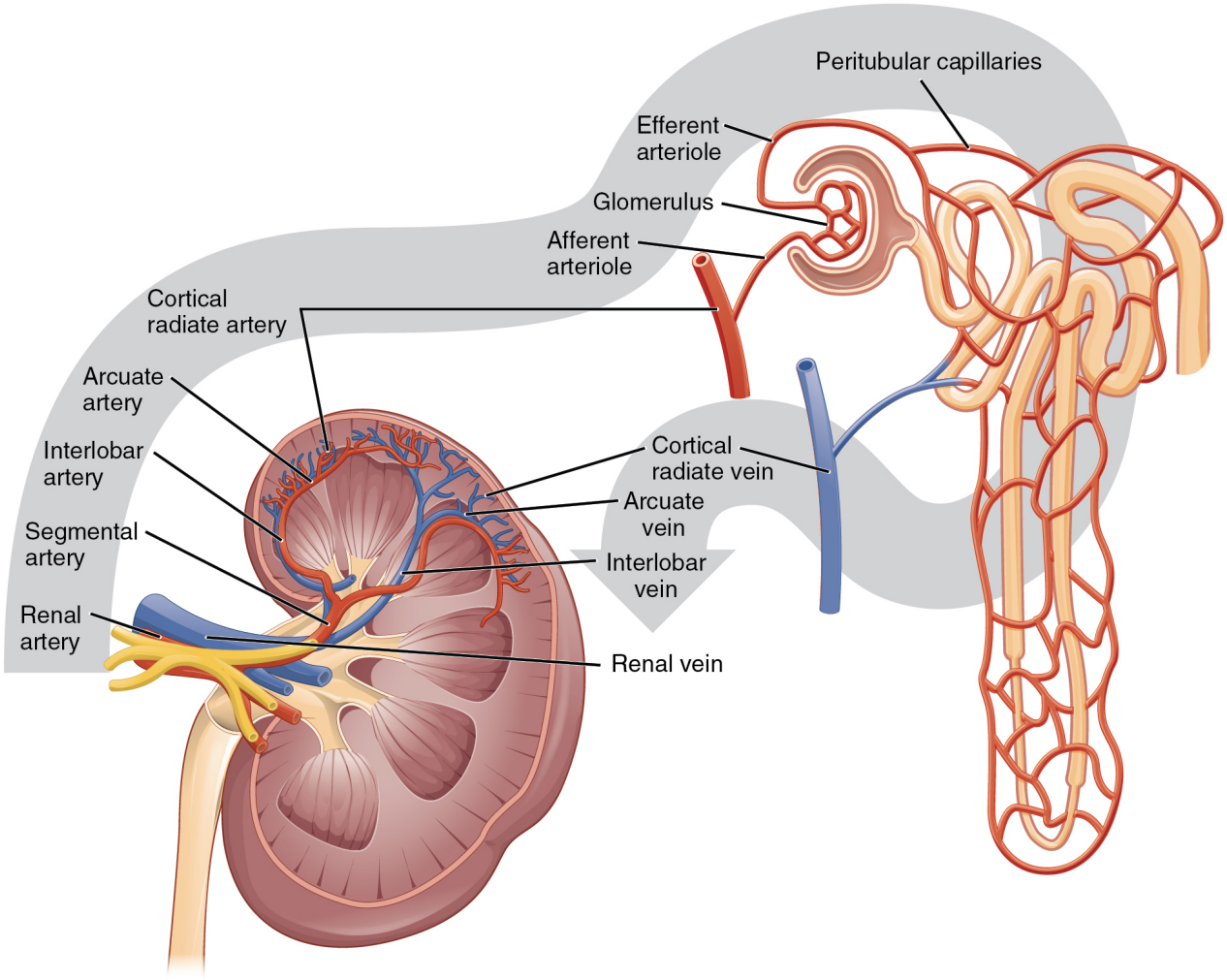


Figure 25.4 Blood flow in the kidney. Gross anatomy (left) and microscopic anatomy (nephron, right). Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The first vessel to enter the kidney comes from the abdominal aorta, and this vessel is the renal artery. Once in the kidney, the renal artery first divides into segmental arteries, which are located within the renal sinus. As the segmental arteries continue to branch, blood flows into the interlobar arteries, which pass through the renal columns and extend to the cortex. Once the interlobar arteries reach the cortex, they bend abruptly and branch to form the arcuate arteries. These vessels are named so because they form an arc located between the medulla and cortex of the kidney. From here, the arteries become the cortical radiate (interlobular) arteries, which enter into the cortex.

The cortical radiate arteries then branch to form the afferent arterioles. The afferent arterioles will take blood to the glomerulus, a cluster of capillaries where filtration occurs. Blood then travels through the efferent arterioles and into the peritubular capillaries. It is within the peritubular capillaries that reabsorption and secretion will take place. In some regions of the cortex, the efferent arterioles may also branch to give rise to the vasa recta. These vessels only represent a small number of capillaries within the kidney, but they are important for producing concentrated urine.

Whereas the renal arteries form directly from the descending aorta, the renal veins return cleansed blood directly to the inferior vena cava. Blood from the peritubular capillaries or vasa recta will first be directed

to the cortical radiate (interlobular) veins. From here, the blood will be sent to the arcuate veins, to the interlobar veins, and then to the renal vein, which leads to the vena cava.

Histology of the Kidney

The renal structures that conduct the essential work of the kidney cannot be seen by the naked eye. Only a light or electron microscope can reveal these structures. Even then, serial sections and computer reconstruction are necessary to give us a comprehensive view of the functional anatomy of the nephron and its associated blood vessels.

Nephrons are the "functional units" of the kidney and located in the renal cortex (Figure 25.5).

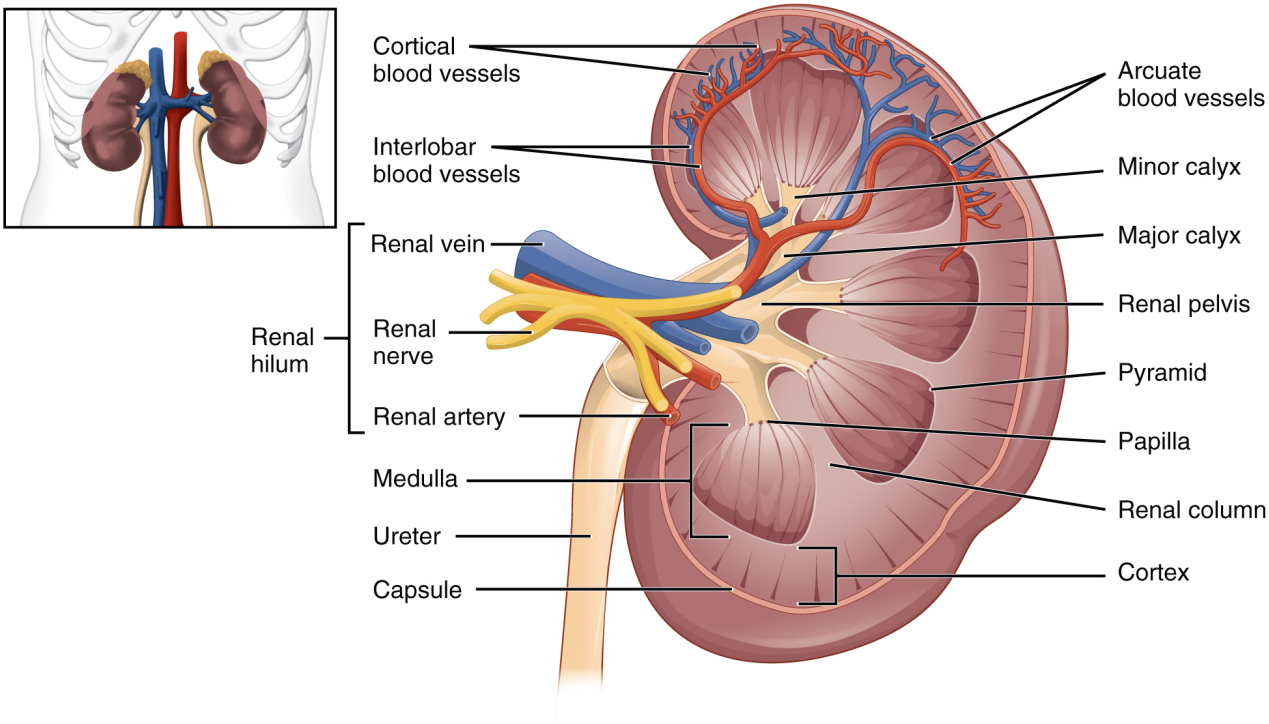


Figure 25.5 Left kidney. Major regions of the kidney: cortex, medulla, pyramids, papilla, minor calyx, major calyx, renal pelvis (drains into the ureter). Most nephrons are located in the blood vessel rich cortical region of the kidney.

Nephrons cleanse the blood and balance the constituents of circulation. These structures take a simple filtrate of the blood and modify it into urine. The system's ability to filter the blood resides in about 2 to 3 million glomeruli, which are distributed more or less equally between the two kidneys. Because glomeruli filter the blood based mostly on particle size, large elements like blood cells, platelets, antibodies, and albumen are excluded. All other solutes, such as ions, amino acids, vitamins, and wastes, are filtered to create a filtrate composition that is very similar to blood plasma. Overall, the principle task of the nephron population is to balance the plasma to homeostatic set points and excrete potential toxins in the urine. They do this by accomplishing three principle functions— filtration, reabsorption, and secretion. The functional regions that make up a single nephron include the renal corpuscle, proximal convoluted tubule, nephron loop, and distal convoluted tubule. While the renal corpuscle, proximal convoluted tubule and distal convoluted tubule are located in the cortex, the nephron loop is located in the medulla region of the kidney (Figure 25.6).

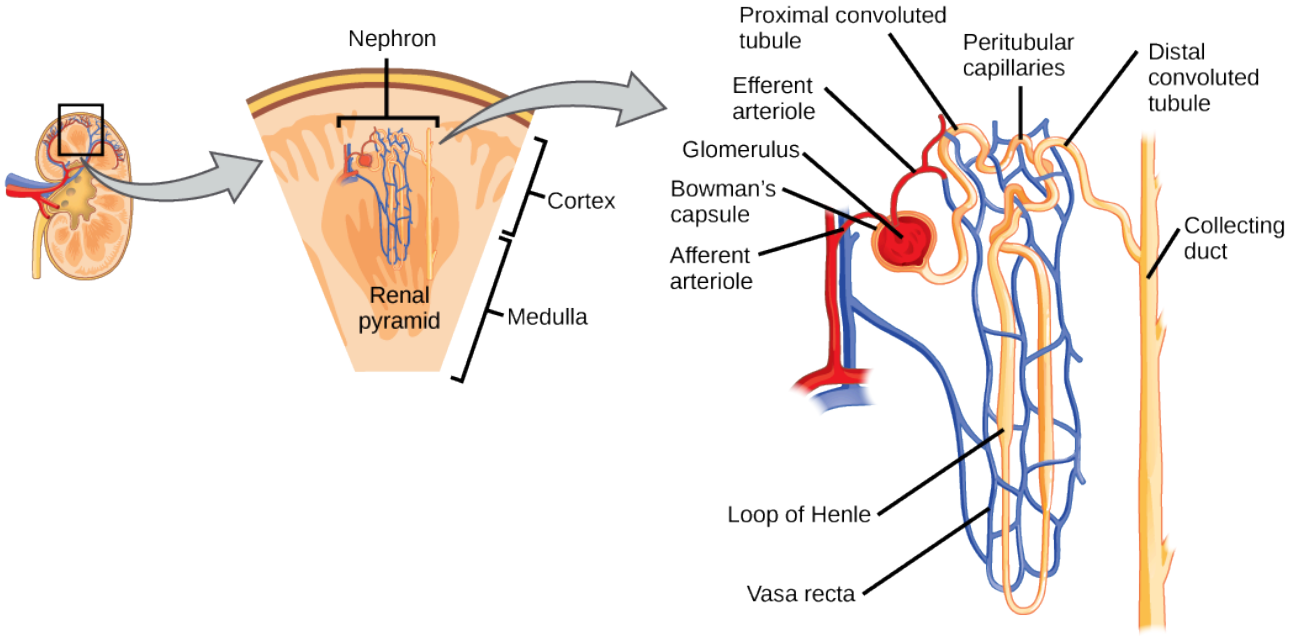


Figure 25.6 Nephron location and structures. Credit: OpenStax Biology, license CC-BY-4.0

As the afferent arterioles enter into the nephron, they will form a tuft of high-pressure capillaries known as the glomerulus. Surrounding the glomerulus is a thin, double-walled capsule, known as the glomerular capsule (Bowman's capsule) and the space between each is known as the capsular space. Together, the glomerulus and capsule are known as the renal corpuscle, making up the proximal end of each nephron (Figure 25.6). This region is where filtration takes place. Through this process, water and some solutes in the blood plasma will pass from the capillaries of the glomerulus and into the capsular space of the nephron to begin filtrate production.

The remaining portion of the nephron consists of a continuous and sophisticated tubule system (Figures 25.7 and 25.8). As blood passes through the glomerulus, 10 to 20 percent of the plasma filters through small spaces between the cells of the glomerulus. This filtered fluid is then captured by the Bowman's capsule and funneled to the proximal convoluted tubule (PCT). Simple cuboidal cells form this tubule with prominent microvilli on the luminal surface, forming a brush border. These microvilli create a large surface area to maximize the reabsorption of some solutes (Na^+, Cl^-, glucose, etc.) from the blood and secretion of these back into the tubule for disposal. This is one of the most essential functions of this region of the nephron. Once filtrate leaves the PCT, it is directed into the nephron loop (Loop of Henle), which consists of two portions. The descending and ascending portions of the loop are simply continuations of the same tubule. They run adjacent and parallel to each other after having made a hairpin turn at the deepest point of their descent. The descending loop of Henle consists of an initial short, thick portion and long, thin portion, whereas the ascending loop consists of an initial short, thin portion followed by a long, thick portion. Fluid will then be directed to the last portion of the nephron, known as the distal convoluted tubule (DCT). These cells are not as active as those in the PCT; thus, there are fewer microvilli on their apical surface.

As fluid flows through this tubule system, water, glucose, and many electrolytes are returned to the

blood. Any urea or other wastes that are collected are concentrated as they pass through the nephron and into the collecting duct, a tube that receives fluid from the nephrons. The collecting ducts are continuous with each nephron, but not technically part of it. In fact, each duct collects filtrate from several nephrons for final modification. Collecting ducts merge as they descend deeper in the medulla to form about 30 terminal ducts, which empty at a papilla.

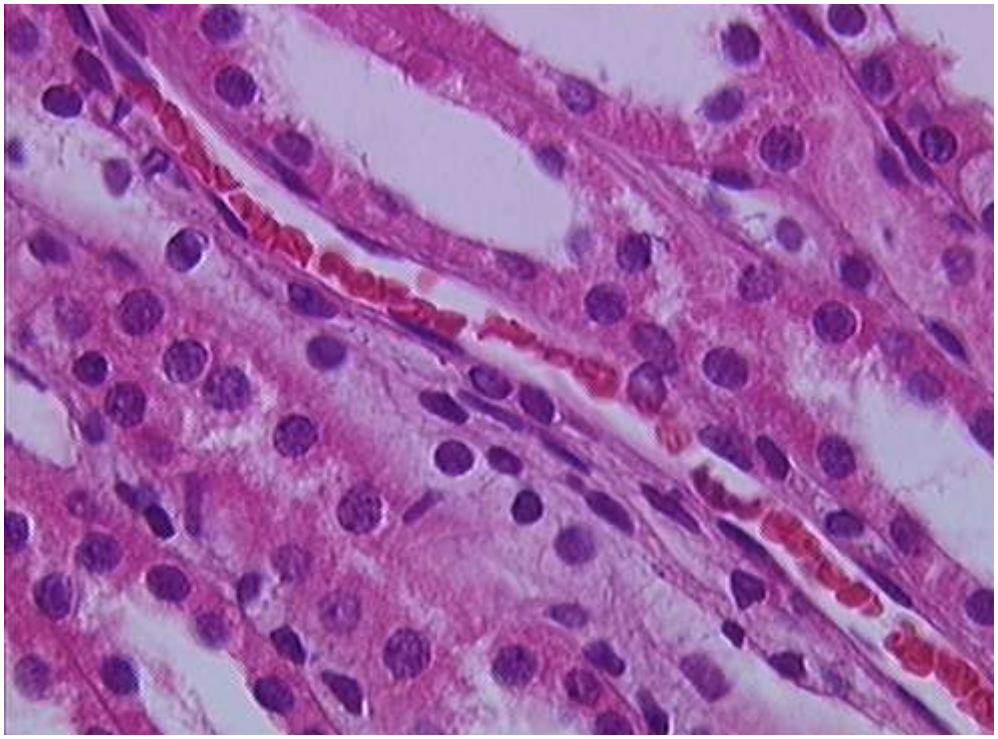


Figure 25.7 Renal medulla. Present here in the kidney medulla are sections of nephron straight distal tubules (low cuboidal walls), straight proximal tubules (tall cuboidal walls), and vasa recta (lined by endothelium). Credit: UCLA Histology Collection by Roger A. Gorski, Ph.D.,licence CC-BY-NC-SA-1.0

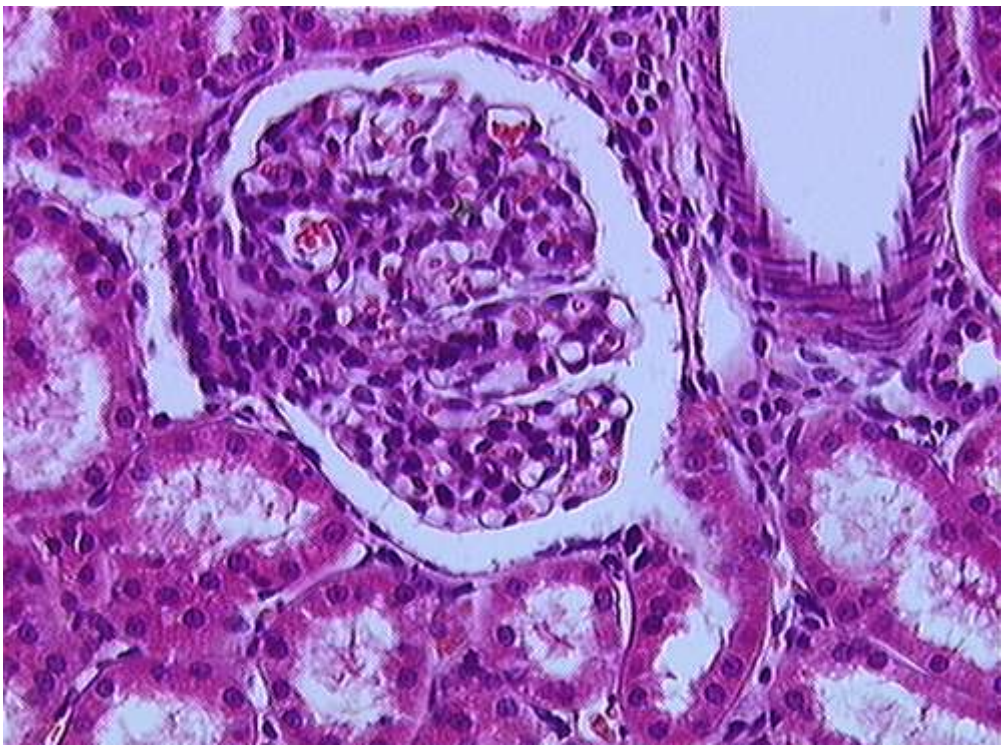


Figure 25.9 Renal cortex. A number of features of the renal corpuscle can be seen here. The parietal and visceral layers of Bowman's capsule, which consist of two types of simple squamous epithelium, line the capsular space. The filtrate leaves the glomerulus via the urinary pole, which leads to a proximal convoluted tubule (PCT). At the vascular pole are found the afferent and efferent arterioles (not visible here) and the macula densa, a specialized portion of the distal tubule as it returns to its glomerulus of origin. UCLA Histology Collection, by Roger Gorski, Ph.D., license CC-BY-NC-SA-1.0

The Ureter

As urine is formed, it drains into the calyces of the kidney, which merge to form the funnel shaped renal pelvis within each hilum. As the renal pelvis extends out of the hilum, it narrows to become the ureter of each kidney. The ureters go downwards, turn medially and pierce the bladder wall obliquely. This is important because it creates a one-way valve (a physiological sphincter rather than an anatomical sphincter) that allows urine into the bladder, but prevents the reflux of urine from the bladder back into the ureter.

The ureters are approximately 30 cm long and consist of three tissue layers (Figure 25.9). The inner mucosa is lined with transitional epithelium and scattered goblet cells that secrete protective mucus. The thick muscular layer of the ureter consists of both 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, outer adventitial layer composed of collagen and fat anchors the ureters between the parietal peritoneum and the posterior abdominal wall.

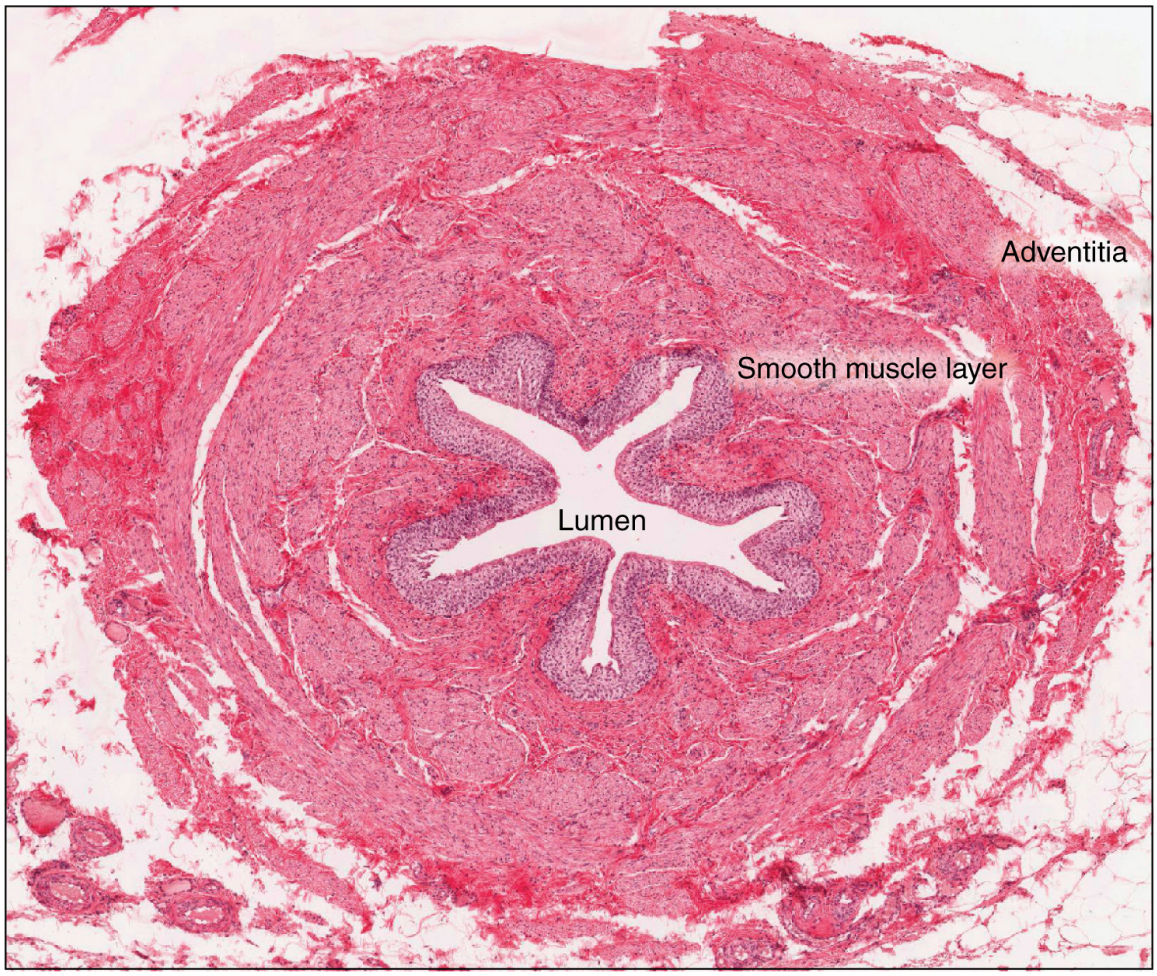


Figure 25.9 Histology of the ureter. Cross section. Credit: OpenStax Anatomy and Physiology, license C-BY-4.0

The Urinary Bladder

The urinary bladder is the primary organ that collects urine from both ureters (Figure 25.10). In females, the bladder lies anterior to the uterus, posterior to the pubic bone and anterior to the rectum. During late pregnancy, its capacity is reduced due to compression by the enlarging uterus, resulting in increased frequency of urination. 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.

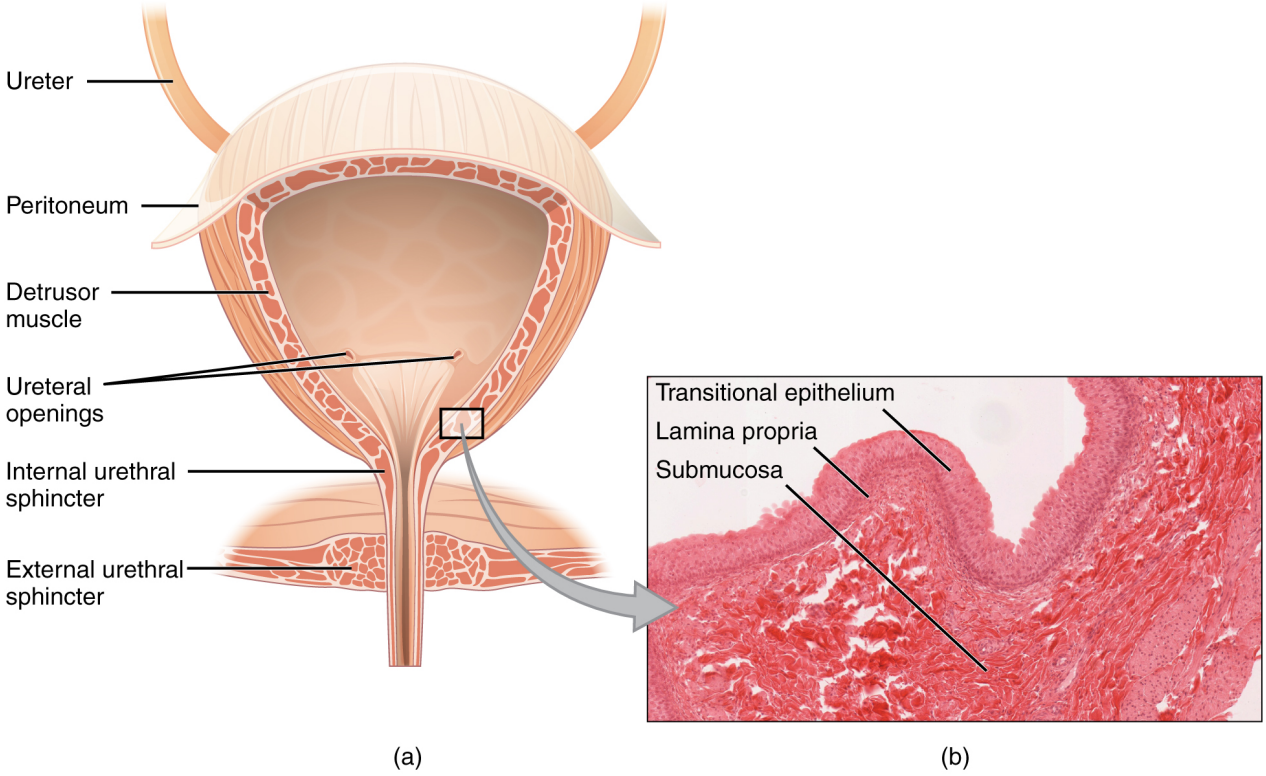


Figure 25.10 The urinary bladder. Gross anatomy (left) and histology (right). Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The bladder is unique in the fact that it is a highly distensible organ composed of irregular crisscrossing bands of smooth muscle, collectively called the detrusor muscle. The interior surface is made of transitional epithelium that is structurally suited for the large volume fluctuations of the bladder. When empty, its cells resemble columnar epithelia, but when stretched, it "transitions" (hence the name) to a squamous appearance. The volume of urine that the adult bladder can collect and hold can range from nearly zero to 600 mL, so the makeup of this tissue must allow it to be adaptable.

In addition to its elasticity, the detrusor muscle can contract with significant force in the young. Though the bladder's strength can significantly diminish with age, voluntary contractions of abdominal skeletal muscles can increase intra-abdominal pressure to promote more forceful bladder emptying.

The Urethra

The terminal organ of the urinary system is the urethra, which 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.

The urethra in both males and females begins inferior and central to the two ureteric openings in the bladder. Together, these structures form the three points of a triangular-shaped area at the base of the bladder, known as the trigone. 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, which consists of smooth muscle, and a second voluntary external urinary sphincter that is made of skeletal muscle.

Female Urethra

The female urethra (Figure 25.11a) is approximately 3 to 4 cm long and it passes from the urinary bladder to the external urethral orifice. The external urethral orifice is embedded in the anterior vaginal wall, inferior to the clitoris, superior to the vaginal opening, and medial to the labia minora. Its short length is less of a barrier to fecal bacteria than the longer male urethra and is the best explanation for the greater incidence of urinary tract infections (UTIs) 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.

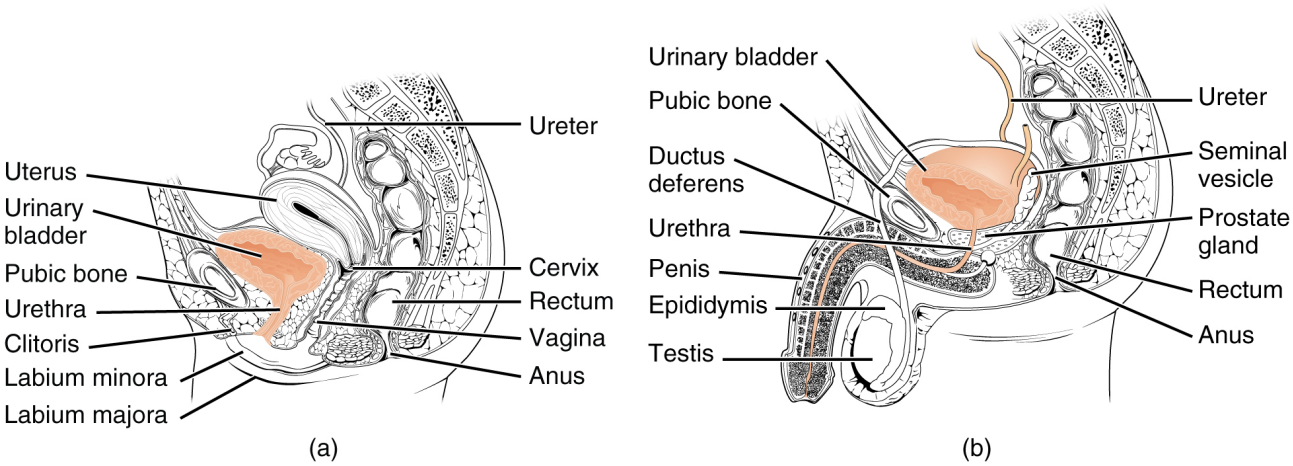


Figure 25.11 The urethra. Lateral view. The female (left) and male (right) urethra, as well as the neighboring pelvic structures are shown. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Male Urethra

The male urethra (Figure 25.11b) is much longer than the female urethra, averaging 20 cm in length. After leaving the urinary bladder, the urethra passes through the prostate gland, which is positioned inferior to the bladder, before passing below the pubic symphysis. It is divided into three regions: the prostatic urethra, the membranous urethra, and the spongy (penile) urethra. The first region of the urethra is the prostatic urethra and it passes through the prostate gland. During sexual intercourse, it receives sperm via the ejaculatory ducts and secretions from the seminal vesicles. Paired bulbourethral glands produce and secrete mucus into the urethra to buffer urethral pH during sexual stimulation. The mucus neutralizes the usually acidic environment and lubricates the urethra, decreasing the resistance to ejaculation. The prostatic urethra continues as the membranous urethra, which passes through the deep muscles of the perineum, where it is invested by the overlying urethral sphincters. Finally, the spongy urethra exits at the tip (external urethral orifice) of the penis, after passing through the erectile tissue (corpus spongiosum) of the penis. Mucous glands are found along much of the length of the urethra, ultimately helping to protect the urethra from the extreme pH of urine. Innervation is the same in both males and females.

PHYSIOLOGY

Introduction

Urine is formed through the purification of plasma by glomerular filtration, tubular absorption, and secretion. The characteristics of the urine change, depending on influences such as water intake, exercise, environmental temperature, nutrient intake, and other factors. Some of the characteristics such as color and odor are rough descriptors of your state of hydration. For example, if you exercise or work outside, and sweat a great deal, your urine will turn darker and produce a slight odor, even if you drink plenty of water (Figure 25.12). Athletes are often advised to consume water until their urine is clear. This is good advice; however, it takes time for the kidneys to process body fluids and store it in the bladder. Another way of looking at this is that the quality of the urine produced is an average over the time it takes to make that urine. Producing clear urine may take only a few minutes if you are drinking a lot of water or several hours if you are working outside and not drinking much. In a normal, healthy individual, about 0.6 – 2.5 L of urine may be produced daily.

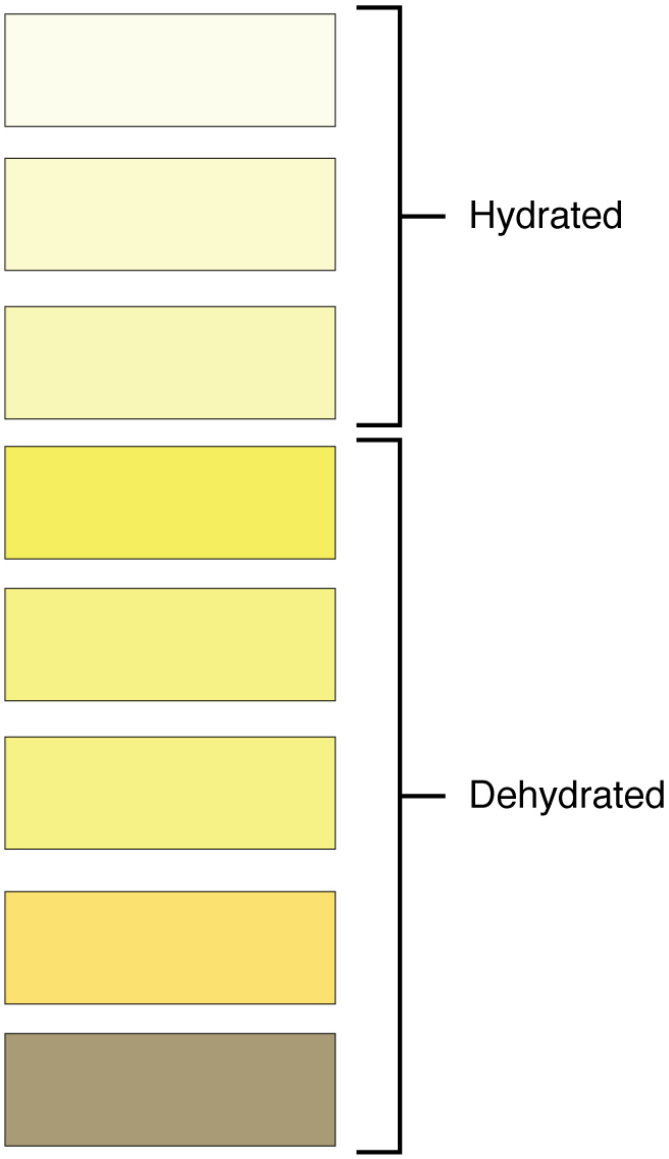


Figure 25.12 Urine color. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The color, clarity, and components of urine provide clues to the health and function of the kidneys and the body in general. The color of urine is determined mostly by the breakdown products of red blood cell destruction. The "heme" of hemoglobin is converted by the liver into water-soluble forms that can be excreted into the bile and indirectly into the urine. This yellow pigment is urochrome. Some foods (ex. beets, berries, or rhubarb), as well as some vitamins and drug therapies may alter the color of one's urine. Dehydration may produce darker, more concentrated urine that may also possess the slight odor of ammonia. Most of the ammonia produced from protein breakdown is converted into urea by the liver, so ammonia is rarely detected in fresh urine. The strong ammonia odor you may detect in bathrooms or alleys is due to the breakdown of urea into ammonia by bacteria in the environment. About one in five people detect a distinctive odor in their urine after consuming asparagus; other foods such as onions, garlic, and fish can impart their own aromas! These food-caused odors are harmless though. While freshly voided urine is usually clear, it will become cloudy upon standing due to bacterial growth. Persistently cloudy (turbid) urine may indicate an infection. The waste products of metabolism (CO_2, urea, uric acid, creatinine, NaCl, ammonia) are all normal constituents of urine. However, the presence of substances like albumin, glucose, or ketones, or changes in pH or urine output are key factors in identifying renal diseases or other metabolic disorders.

Various tests (both physical and chemical) have been developed for routine urinalysis. Some of these tests and their procedures are described below (tests for pH, specific gravity, glucose, protein, and ketones). Recently, the dipstick method has been developed to replace many of these individual tests, and is commonly used in most doctors' offices. These test strips can not only detect many substances (ex. blood, bilirubin, protein, ketones, pH, glucose, and nitrites), but also their relative amounts.

pH

Freshly voided urine usually has a pH around 6.0, but the pH of normal urine samples can range from 4.7 – 7.5. Urine pH is highly influenced by a person's diet. A high-protein diet often results in acidic urine, while a vegetable-rich diet results in more alkaline urine. The pH is also subject to diurnal fluctuations. Urine samples that are 24 hours old or older gradually become more alkaline due to the bacterial breakdown of urea. Urine that is consistently acidic is indicative of metabolic or respiratory acidosis, methanol poisoning, or metabolic disorders such as phenylketonuria. At the other end of the spectrum, production of consistently alkaline urine is a sign of metabolic or respiratory alkalosis or a urinary tract infection. It can also result from urine retention in the bladder, anemia, alkaline therapy, or obstructing gastric ulcers.

Ketones

Ketones are intermediary products of fat metabolism and are not usually present in urine in any detectable amount. Finding ketones in the urine suggests that the body is using fat as an energy source in preference to glucose. Conditions leading to insufficient carbohydrate reserves will cause elevated levels of acetoacetic acid, acetone, and beta hydroxybutyric acid in the blood and urine, also known as ketonuria. Ketonuria can be brought on by hypothermia, dietary imbalances (starvation or inadequate carbohydrate intake), diabetes mellitus, or genetically or chemically-induced metabolic disorders. Diabetes mellitus is the

most common disorder associated with urine ketones. Progressive ketosis, a state of raised ketone levels, can lead to coma and death.

Proteins

Due to their large size, protein molecules are usually restricted to the glomerular capillaries during the filtration process in the nephron. This means that only trace amounts of protein should be found in a normal urine, approximately 10 mg / 100 mL (dL) in a random sample. However, under certain physiological and pathological conditions, increased levels of proteins can be detected in the urine. Pathologic albuminuria is found in cases of glomerular damage, febrile diseases, anemia, hypertension, and toxemia of pregnancy. Excessive protein ingestion, excessive muscular exertion, prolonged exposure to cold and acute abdominal diseases may lead to a condition known as physiologic albuminuria.

Glucose

Under normal conditions, urine will also contain only trace amounts of glucose (≤ 30 mg per 100 mL of urine). When glucose levels exceed this, the condition is known as glucosuria. This is found in cases of diabetes mellitus, pregnancy, excess stress, renal tubule damage, or brain damage. The renal threshold for glucose is about 160 mg/100 mL. In cases of glucosuria, blood glucose levels will exceed this amount and as a result, the excess glucose cannot be absorbed by the kidneys and it will "spill" into the urine. Incidentally, excess Vitamin C (ascorbic acid) contamination of the urine (> 400 mg/L) can give a false positive result for this test.

Specific Gravity

Specific gravity is a measure of the quantity of solutes per unit volume of a solution and is traditionally easier to measure than osmolarity. Urine will always have a specific gravity greater than pure water (water = 1.00) due to the presence of solutes. Distilled water is generally used as a reference for calibrating a urine hydrometer and determining the specific gravity of urine samples. Normally, the specific gravity of a urine sample is between 1.015 and 1.025, however, normal samples can vary anywhere from 1.002 – 1.030. As the amount of dissolved solid in a urine solution increases, so does the specific gravity. The production of consistently dilute urine (specific gravity < 1.015) results in a condition called hyposthenuria. This state is usually indicative of conditions such as chronic nephritis, diabetes insipidus, or cardiovascular problems. Urine which is consistently concentrated (specific gravity > 1.030) results in hypersthenuria. This condition is indicative of such disorders as acute nephritis and diabetes mellitus.

Pre-Laboratory Questions

1. Where are the kidneys located within the body?

    a. abdomen
    b. anterior abdominal wall
    c. anterior to parietal peritoneum

d. posterior to parietal peritoneum

2. Urine comes out of the body through this

a. ureter
b. urethra

3. Where does filtration take place within the nephron?

a. renal corpuscle
b. proximal convoluted tubule
c. distal convoluted tubule
d. collecting duct

4. Trace the pathway that urine would take once it is produced in the renal tubules to when it is released through the process of urination (micturition).

a. papillary duct → minor calyx → major calyx → renal pelvis → ureter → urinary bladder → urethra
b. papillary duct → major calyx → minor calyx → renal pelvis → ureter → urinary bladder → urethra
c. papillary duct → renal pelvis → minor calyx → major calyx → ureter → urinary bladder → urethra
d. papillary duct → ureter → minor calyx → major calyx → renal pelvis → urinary bladder → urethra

5. What is the correct composition of the urine?

a. 90% water/10% solutes
b. 95% water/5% solutes
c. 80% water/20% solutes
d. 85% water/15% solutes

Exercises

- Exercise 1 The kidney
- Exercise 2 Blood supply to the kidney
- Exercise 3 Pig or sheep kidney dissection
- Exercise 4 Histology of the kidney
- Exercise 5 The ureter
- Exercise 6 The urinary bladder
- Exercise 7 The urethra
- Exercise 8 Urinalysis

Exercise 1 The Kidney

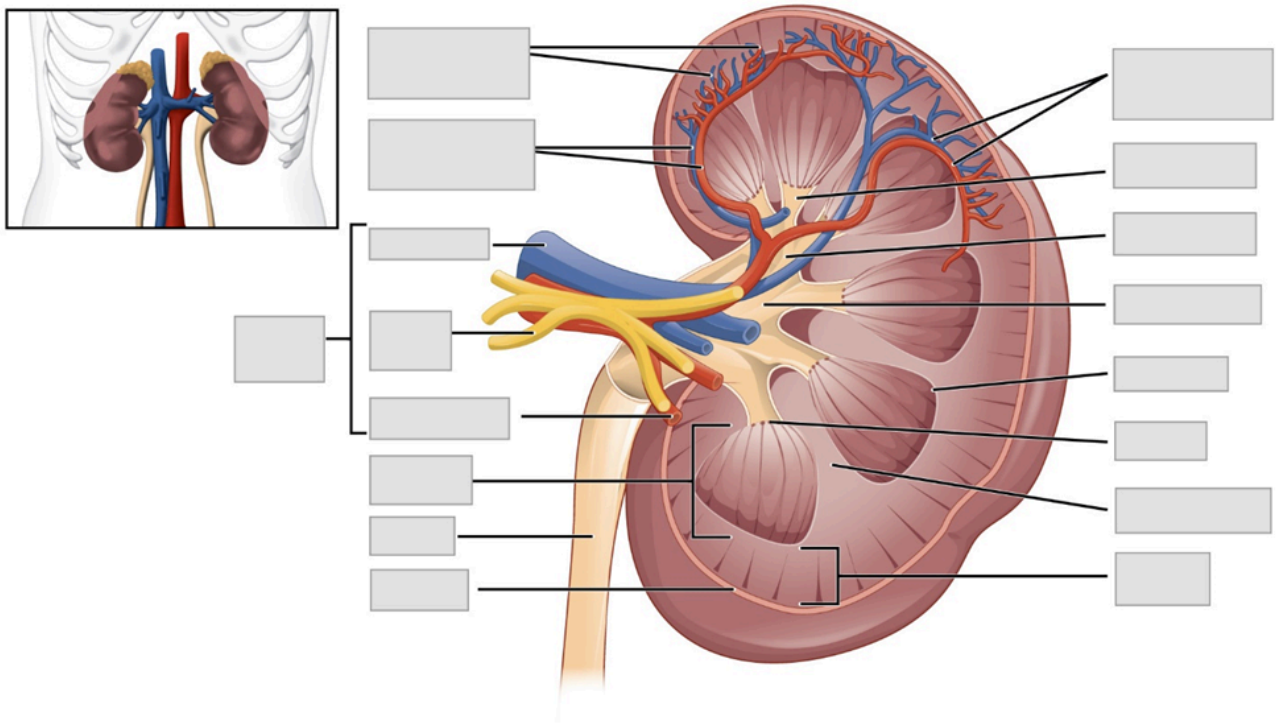
Required Materials

- The Urinary Tract poster
- Kidney, Nephron, Glomerulus model
- Torso model

Procedure

1. Use the models and posters to observe the following features of the kidney and urinary system. Label these features on the image given below.

Arcuate Blood Vessels	Pyramid
Capsule	Renal Artery
Cortex	Renal column
Cortical Blood Vessels	Renal Hilum
Interlobar Blood Vessels	Renal Nerve
Major calyx	Renal pelvis
Medulla	Renal Vein
Minor calyx	Ureter
Papilla	



Exercise 2 Blood supply to the kidney

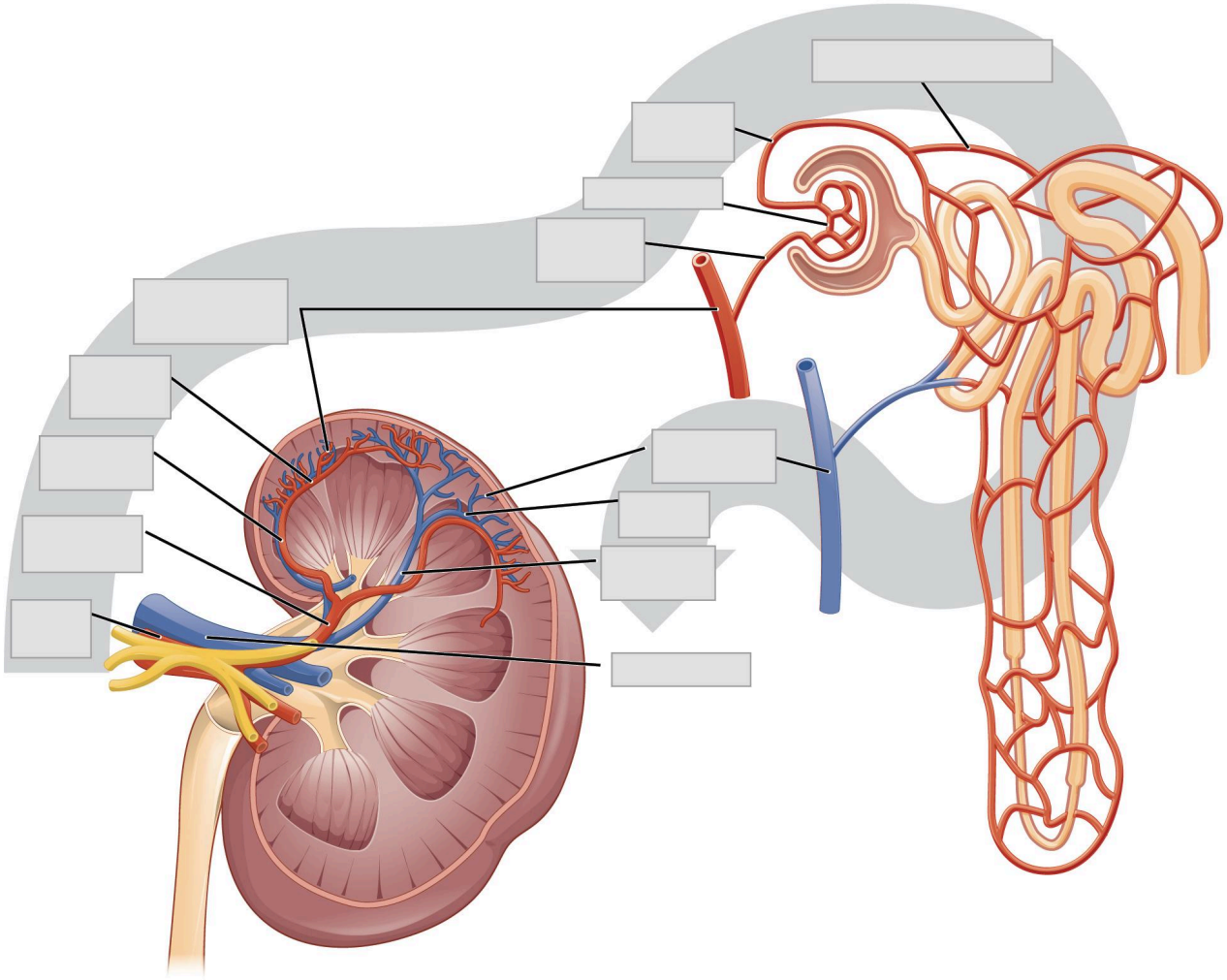
Required Materials

- The Urinary Tract poster
- Kidney, Nephron, Glomerulus model
- Torso model

Procedure

1. Use the models and posters to observe the following features of the blood vessels of the kidney and urinary system. Label these features on the image given below.

Afferent Arteriole	Interlobular Artery
Arcuate Artery	Interlobular Vein
Arcuate Vein	Peritubular Capillaries
Efferent Arterioles	Renal Artery
Glomerulus	Renal Vein
Interlobar Artery	Segmental Artery
Interlobar Vein	



Exercise 3 Pig or sheep kidney dissection

Required Materials

- Preserved pig or sheep kidney dissection specimen
- Dissection tray
- Dissection instruments
- Gloves
- T-pins for labeling
- Labeling tape
- Marker pens

Procedure

1.Obtain one dissection specimen per group. Place in tray.

2. Observe and label the superficial structures indicated below. To label, use the T-pins and place tape on them you can write on. Label as many of the features shown in the figure below on your specimen. Take a picture of the labeled specimen and paste it below.

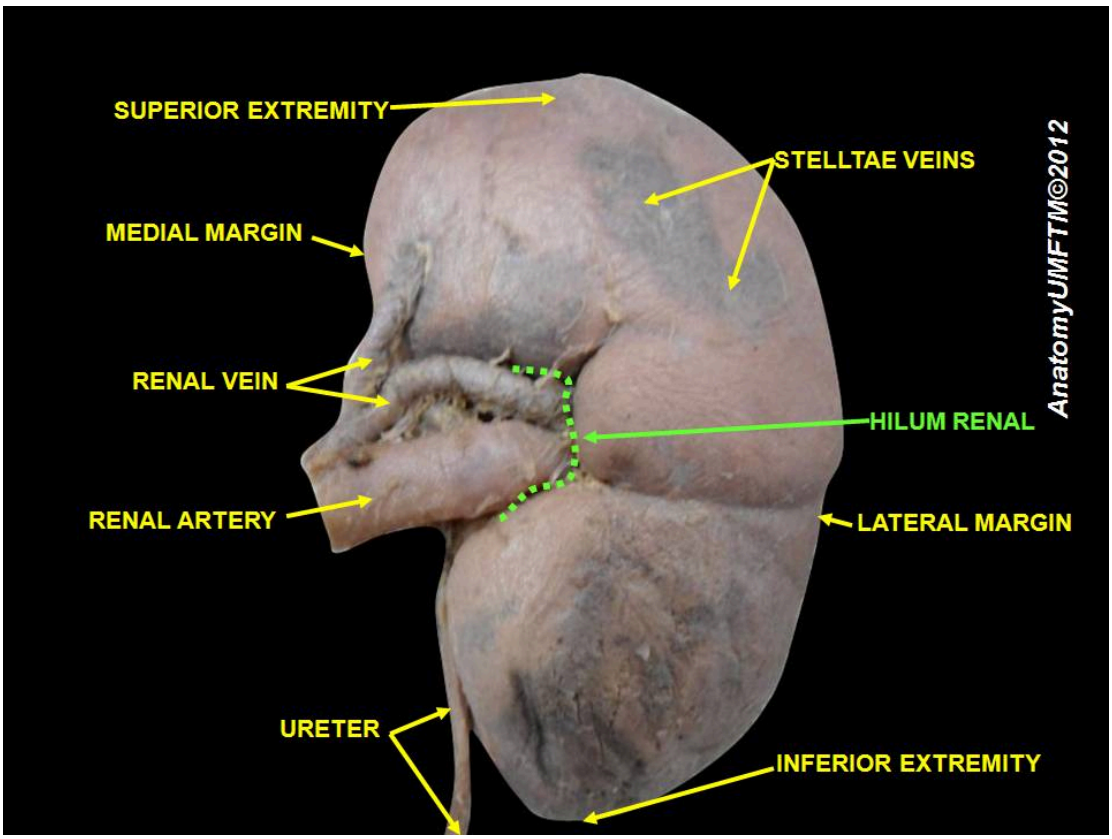


Image Credit: Anatomist90, Wikimedia Commons, license CC-BY-SA 3.0

3. Using the image below as a guide and a sharp instrument (scalpel, knife) dissect the pig or sheep kidney. Observe and label the internal structures indicated on the dissected section below. To label, use the T-pins

and place tape on them you can write on. Label as many of the features shown in the figure below on your specimen. Take a picture of the labeled specimen and paste it below.

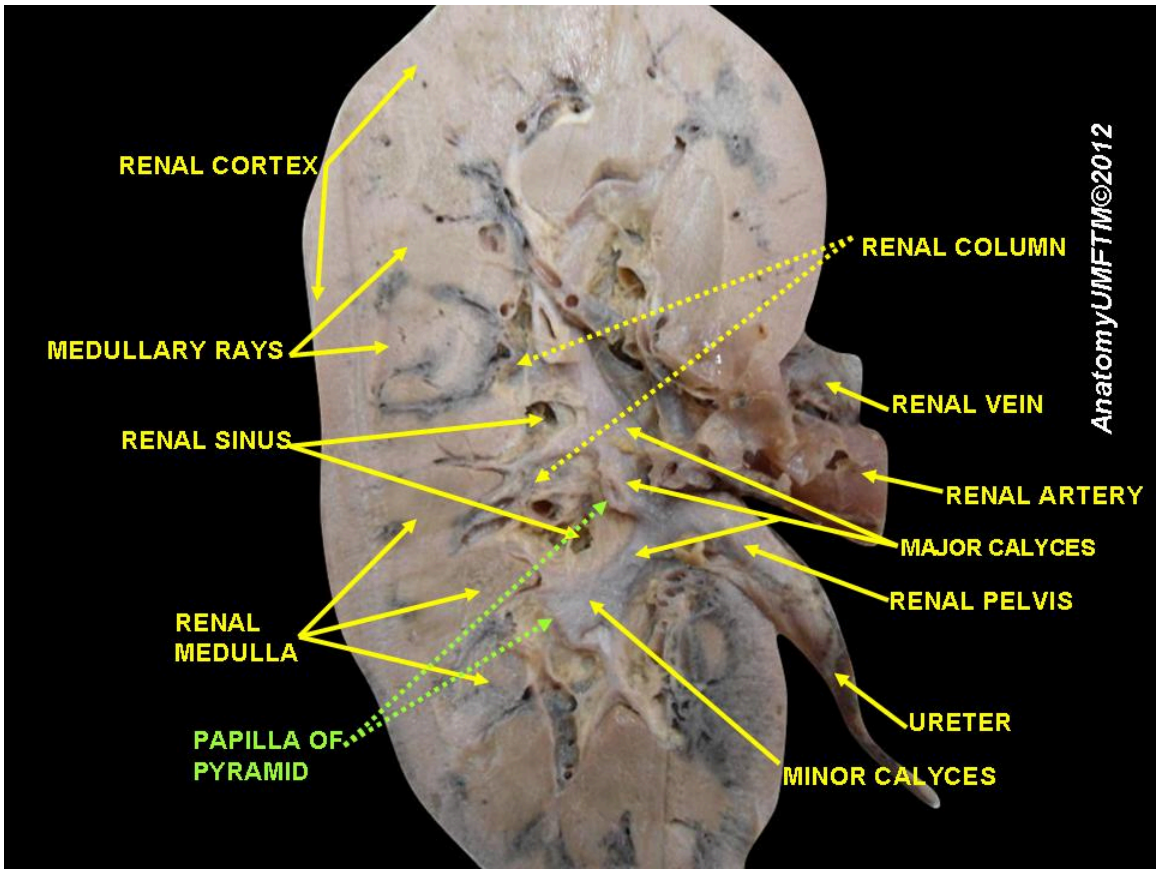


Image Credit: Anatomist90, Wikimedia Commons, license CC-BY-SA-3.0

Exercise 4 Histology of the kidney

Required Materials

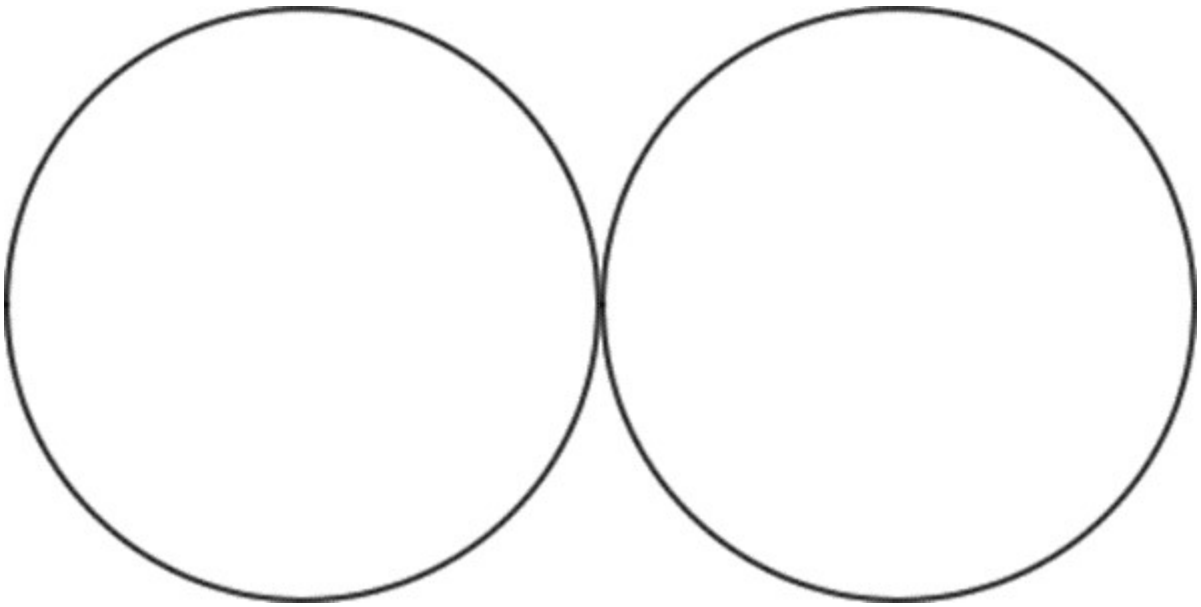
- Compound microscope
- Microscope lens paper
- Microscope lens cleaning solution
- Microscope immersion oil
- Slide of Mammal Kidney Median

Procedure

1. Obtain a slide of the kidney and place it on the microscope stage
2. Bring the structures into focus at low power and scan the regions for the cortex and medulla.
3. Next, change to high power and examine the glomerulus and other structures.
4. Identify

    - Basement membrane
    - Brush border
    - Distal convoluted tubule
    - Glomerulus
    - Macula densa
    - Proximal convoluted tubule
    - Collecting duct
    - Nephron loop

4. Sketch the histological structures as seen through the microscope in the space provided below and label the parts shown above. Provide one low magnification and one high magnification sketch in the space below.



Exercise 5 The ureter

Required Materials

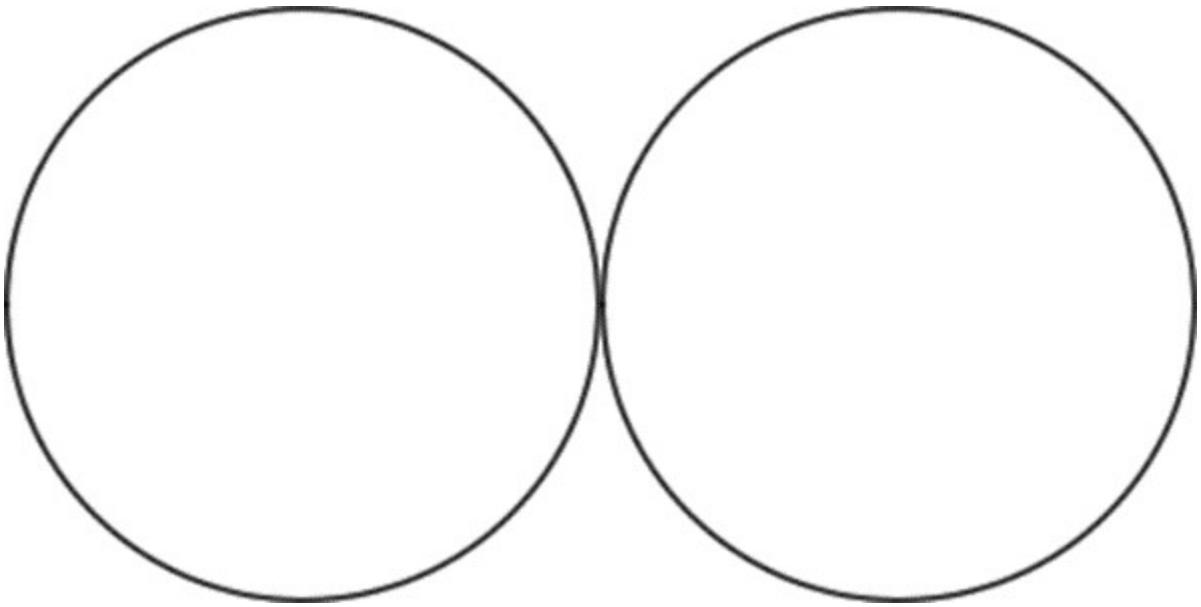
- Compound microscope
- Microscope lens paper
- Microscope lens cleaning solution
- Microscope immersion oil
- Slide of Human Ureter

Procedure

1. Obtain a slide of the ureter and place it on the microscope stage
2. Bring the structures into focus at low power and scan the regions for the various parts of the ureter. Next, change to high power and examine the structures
3. Identify

    - Adventitia
    - Lumen
    - Smooth muscle layer

4. Sketch the histological structures of the ureter as seen through the microscope in the space provided below and label the parts shown above. Provide a low magnification and a high magnification sketch.



Exercise 6 The urinary bladder

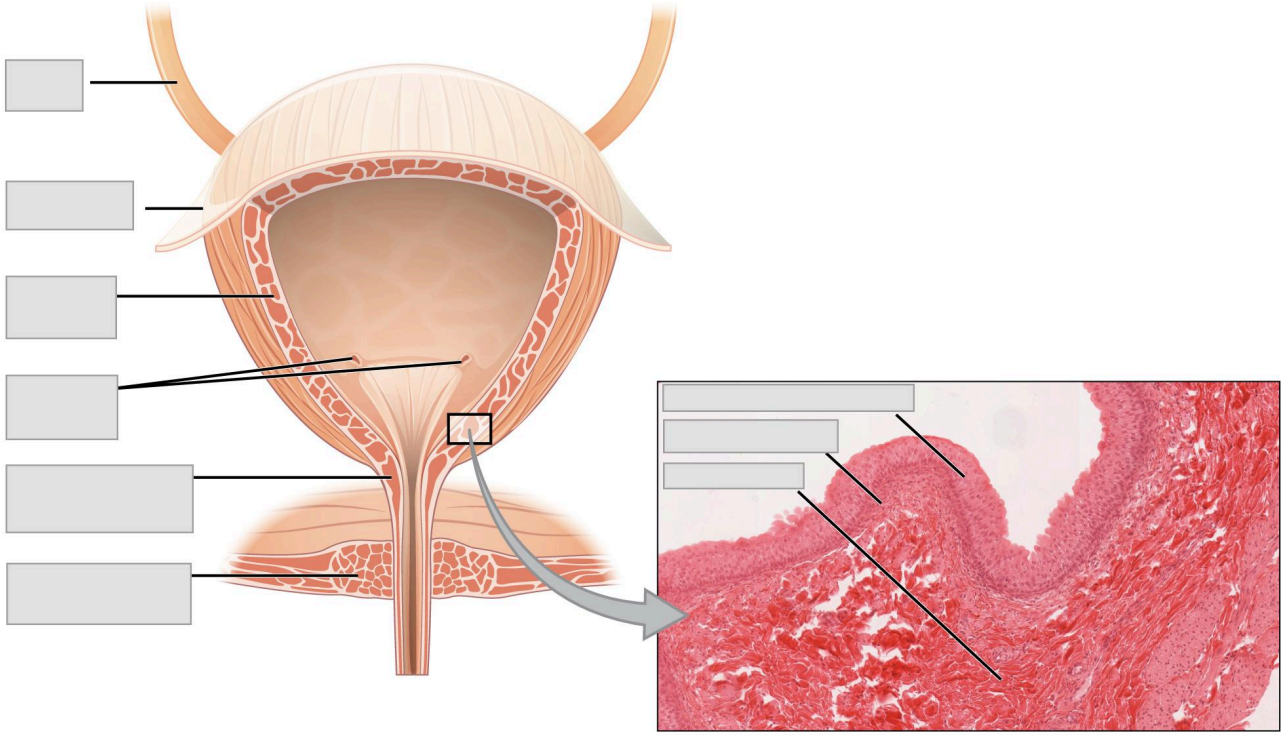
Required Materials

- The Urinary Tract poster
- Kidney, Nephron, Glomerulus model
- Torso model

Procedure

1. Use the models, posters and Figure 25.10 in Background to observe the following features of the urinary bladder. Label these features on the image given below.

Detrusor muscle	Submucosa
External urethral sphincter	Transitional epithelium
Internal urethral sphincter	Ureteral openings
Lamina propria	Ureter
Peritoneum	



(a) (b)

Exercise 7 The urethra

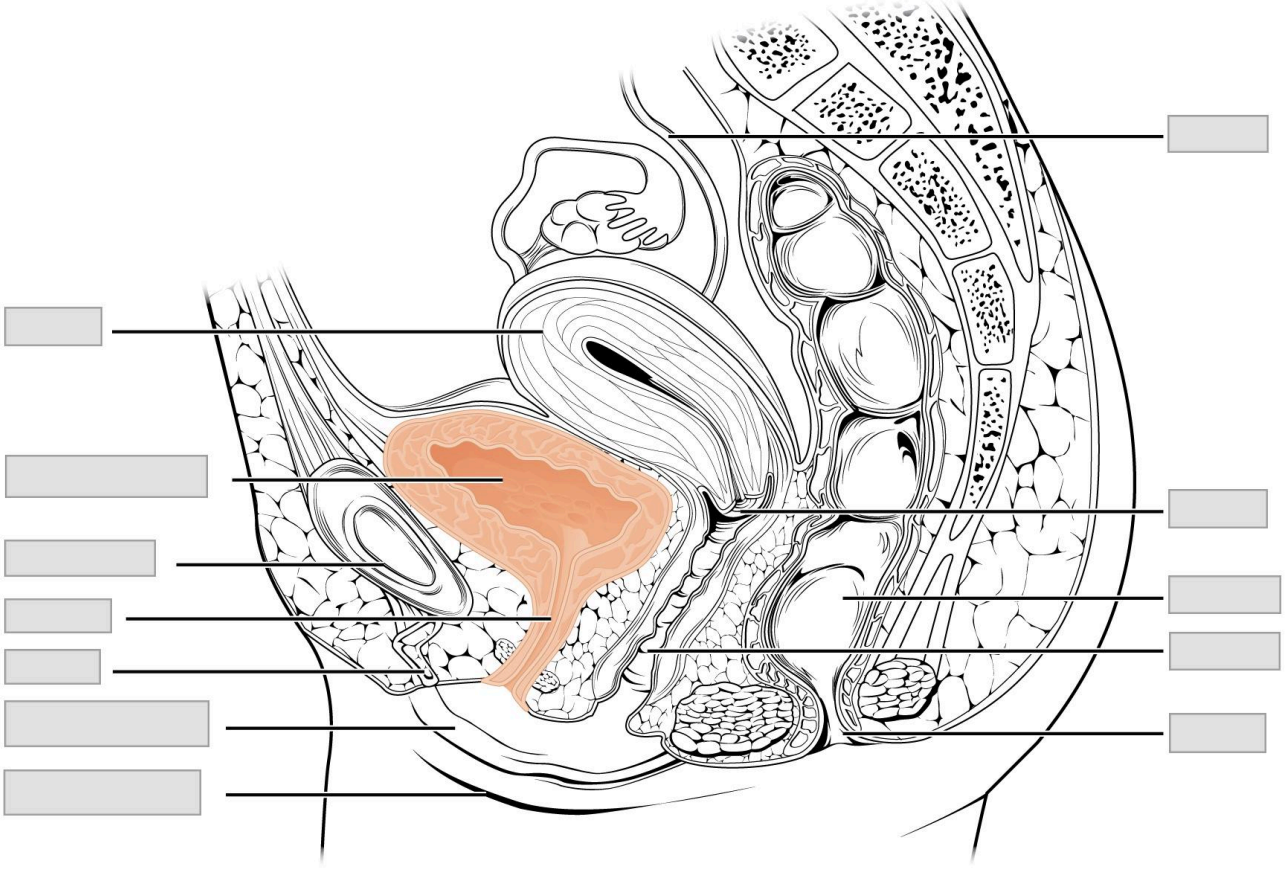
Required Materials

- The Urinary Tract poster
- Kidney, Nephron, Glomerulus model
- Male Pelvis Model
- Female Pelvis Model
- Torso model

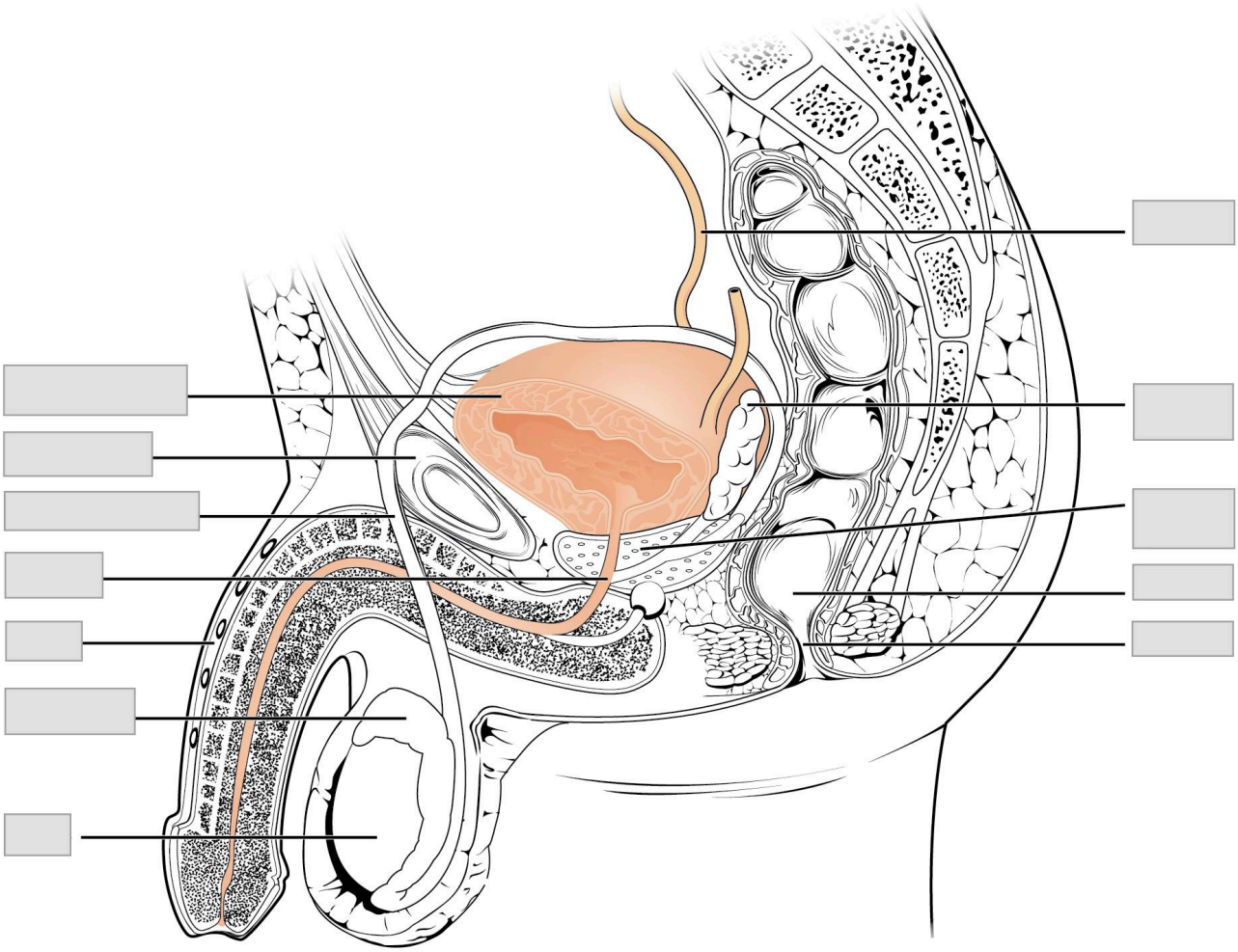
Procedure

1. Use the models, posters and Figure 25.11 in Background to observe the following features of the female and male pelvis. Label these features on the images given below.

Anus	Pubic bone
Cervix	Rectum
Clitoris	Seminal vesicle
Ductus deferens	Testis
Epididymis	Ureter
Labium majora	Urethra
Labium minora	Urinary bladder
Penis	Uterus
Prostate gland	Vagina



(a)



(b)

Exercise 8 Urinalysis

Required Materials

- Sterile urine collection containers
- Marker or wax pencil
- 4-factor urinary test strips (glucose, ketone, protein, pH)
- Four disposable pipets
- Test tube rack
- Artificial urine samples from each of four "patients" and one normal
- Beakers
- Graduated cylinder
- Gloves

Procedure

1. You should work in groups of 2-4 to complete this activity. Make sure that you thoroughly clean

your workspace before and after the activity to ensure that you do not contaminate your samples or leave a mess behind.

2. In this exercise, you will use artificial urine samples to analyze the dissolved and suspended components. You also have the option of using your own urine, collected with the sterile cups with lid and handled carefully.
3. Obtain five clean cups. Using the marker or wax pencil, label each tube with the name or number of each artificial urine sample. If you are using your own urine, you can leave it in the sterile cup with lid until use.
4. Measure 10 mL of each "simulated" or fake urine sample.
5. Record your observations of the physical characteristics of each sample (color, clarity and smell) in Table 1, below.
    1. For color: urine is normally a pale yellow. This is due to a pigment called urochrome, which is a metabolic product of hemoglobin breakdown. High levels of vitamin B may cause urine to artificially be bright yellow, while low fluid intake may cause urine to be a deep yellow color.
    2. For clarity: fresh urine is typically clear or slightly cloudy. Urine turbidity (clarity) is often affected when red blood cells, white blood cells, epithelial cells, bacteria, mucus, lipids, or crystals. Crystals generally make urine cloudy or opaque.
    3. For smell: urine should have a faint, but characteristic odor. Consumption of certain food, such as asparagus, may produce compounds, leading to stronger odors.
6. Once all of your observations are recorded, keep your samples and continue below.
7. To determine the chemical composition of the urine samples (fake or real) dip an unused 4-factor urinary test strip into each urine sample. Use a new strip for each sample.
8. Using the comparison chart provided on the bottle of strips, identify and record the pH, ketones, protein, and glucose amount in Table 2 below.

Analysis

Table 1. Physical Characteristics of Urine

Sample	**Color**	**Clarity**	**Smell**
Sample #1			
Sample #2			
Sample #3			
Sample #4			
Sample #5			
Your sample			

Table 2. Chemical Composition of Urine

Sample	pH	Glucose	Protein	Ketones
Sample #1				
Sample #2				
Sample #3				
Sample #4				
Sample #5				
Your sample				

Analysis Questions

- Based on your observations, which of the 5 samples is normal?
- What are some abnormalities you observed in each of the other 4 "patient" samples?

Post-laboratory Questions

Post-laboratory questions

1. The smallest functional unit of the kidney is known as what?

   a. glomerular capsule
   b. nephron
   c. Bowman's capsule
   d. renal calyx

2. The renal corpuscle is comprised of what two components?

   a. glomerulus
   b. nephron
   c. Bowman's capsule
   d. renal calyx

3. Name the four regions of the renal tubule:

   a. proximal convoluted tubule
   b. loop of Henle

c. distal convoluted tubule
d. collecting duct
e. glomerular capsule

4. What are the components of the juxtaglomerular apparatus?

a. juxtaglomerular cells
b. nephron
c. Bowman's capsule
d. macula densa

5. Body's "water-treatment plant" is composed of the following

a. kidneys
b. ureter
c. urinary bladder
d. urethra
e. adrenal glands

6. Urine leaves the body through the _____ (urethra/ureter)

7. The _____ (right/left) kidney is positioned at a slightly higher level than the other

8. The following enzyme is released by the kidney

a. angiotensin
b. angiotensinogen
c. renin
d. erythropoietin

9. The thick structure that covers the kidney

a. connective tissue

b. capsule
c. Bowman's capsule
d. renal corpuscle

10. The following hormone is released by the kidney

a. angiotensin
b. angiotensinogen
c. renin
d. erythropoietin

11. _____ gland is located on the superior aspect of the kidney

a. pineal
b. thymus
c. adrenal
d. thyroid

12. The _____ (renal column/renal papilla) is the extension of the renal cortex projecting into the renal medulla

13. The correct number of major renal calyx is

a. 10-20
b. 1
c. 100
d. 2-3

14. The minor calyx extends into the

a. renal pyramid
b. renal cortex
c. renal column
d. renal pelvis

15. The ureter extends into the kidney as

    a. renal pelvis
    b. major calyx
    c. minor calyx
    d. renal pyramid
    e. renal capsule

16. The components of nephron is

    a. afferent arteriole
    b. renal corpuscle
    c. efferent arteriole
    d. renal tubule

17. The urinary bladder is located in the _____ (abdominal/pelvic) cavity

18. Trigone is a part of

    a. nephron
    b. urinary bladder
    c. ureter
    d. urethra

19. Components of male urethra include

    a. prostatic urethra
    b. membranous urethra
    c. trigone
    d. spongy urethra

20. Components of net glomerular filtration pressure are

a. blood pressure
b. glomerular hydrostatic pressure
c. plasma colloid osmotic pressure
d. capsular hydrostatic pressure

21. Filtrate from the glomerulus goes into the

a. ureter
b. renal pelvis
c. renal tubule
d. juxtaglomerular apparatus

22. Each kidney receives about _____ % of the cardiac output

a. 12.5
b. 1.5
c. 5
d. 25

23. The liquid that comes out of renal corpuscle is the _____ (filtrate/urine)

24. _____% of the filtrate from the glomerulus will be reabsorbed in the renal tubules

a. 25
b. 55
c. 99
d. 72

25. Trace the correct order of urinary tubule from the renal corpuscle to the renal papilla.

a. proximal convoluted tubule → distal convoluted tubule → nephron loop → collecting duct → renal papilla
b. proximal convoluted tubule → collecting duct → nephron loop → distal convoluted tubule → renal papilla

c. proximal convoluted tubule → renal papilla → distal convoluted tubule → collecting duct → nephron loop
d. proximal convoluted tubule → nephron loop → distal convoluted tubule → collecting duct → renal papilla

26.

CHAPTER 26 FLUID, ELECTROLYTE AND ACID-BASE BALANCE

By Aylin Marz

Motivation.

Figure 26.1 Fluid balance in nursing care.

Ensuring that patients are sufficiently hydrated is an important part of nursing care. Intake of fluids as well as ability to pump fluids (blood) to the kidneys and away from tissue spaces are all equally important. Nurses can determine a patient is dehydrated severely if they have low blood pressure, high heart rate, cold hands and feet and low urine output. In the hospital setting dehydration can be treated. The figure shows how to do a skin turgor test for assessment of dehydration. To check skin turgor: use the thumb and index fingers to pinch an area of the skin and release it (Figure 26.1) . It should instantly return to place. Try this with your classmates!

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Critically evaluate the effects of altered blood pressure, volume, and osmolarity on maintaining fluid balance given patient medical history in a case study
- Determine the effects of abnormally high salt concentration on the health of red blood cells
- Model the effects of altered carbon dioxide and bicarbonate buffer on plasma

Background.

Fluid Balance. Your body is mostly water. Body fluids are aqueous solutions with differing concentrations of materials, called solutes. An appropriate balance of water and solute concentrations must be maintained to ensure cellular functions. If the cytosol (intracellular fluid or ICF, Figure 26.2) becomes too concentrated due to water loss, cell functions deteriorate. If the cytosol becomes too dilute due to water intake by cells, cell membranes can be damaged, and the cell can burst. Fluid balance is maintained by the exchange of water and solutes between the intracellular fluid and extracellular fluid (interstitial fluid IF and plasms, Figure 26.2)

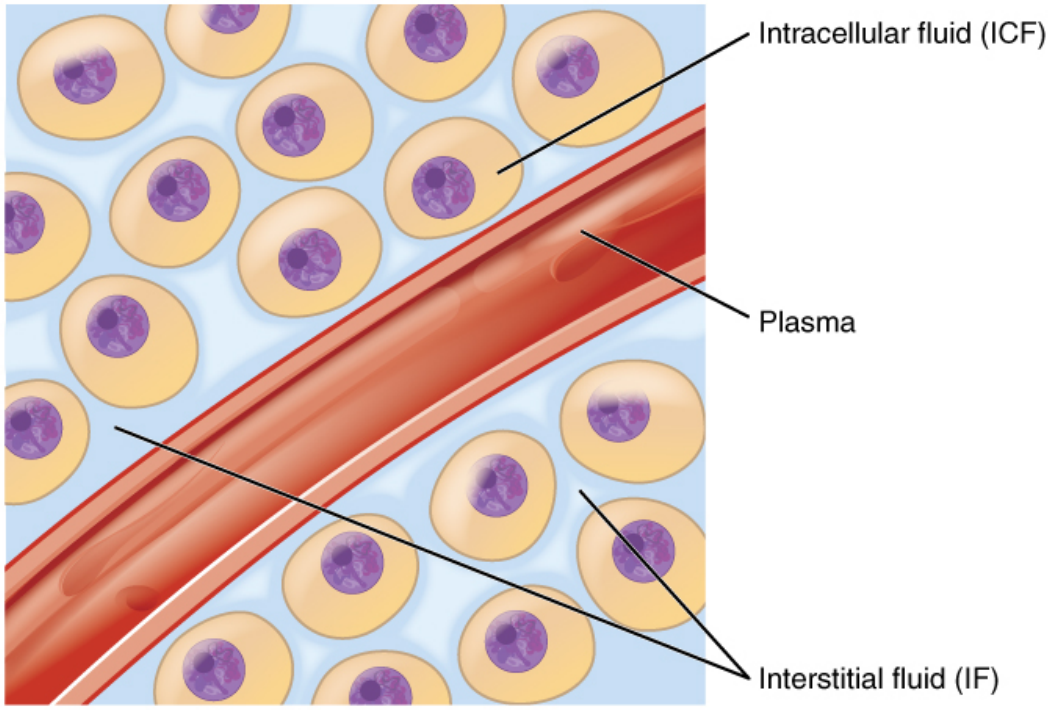


Figure 26.2 Intracellular and extracellular fluid compartments within the tissues of the body. The cytosol of cells are the intracellular compartments that exchange water and solutes with the extracellular compartment: IF and plasma. Capillaries are the sites of fluid exchange. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Hydrostatic pressure is the force exerted by a fluid against a wall and causes movement of fluid between

compartments. In the body, blood pressure within the blood vessels correlates with hydrostatic pressure within the capillaries that are the sites of fluid exchange. Fluid can also move between compartments along an osmotic gradient (from low solute to high solute concentration) (Figure 26.3). Active transport processes require ATP to move some solutes against their concentration gradients between compartments. Passive transport of a molecule or ion depends on its ability to pass easily through the membrane, as well as the existence of a high to low concentration gradient. Passive or active processes can be used to maintain the proper solute concentrations in the extracellular and intracellular compartments.

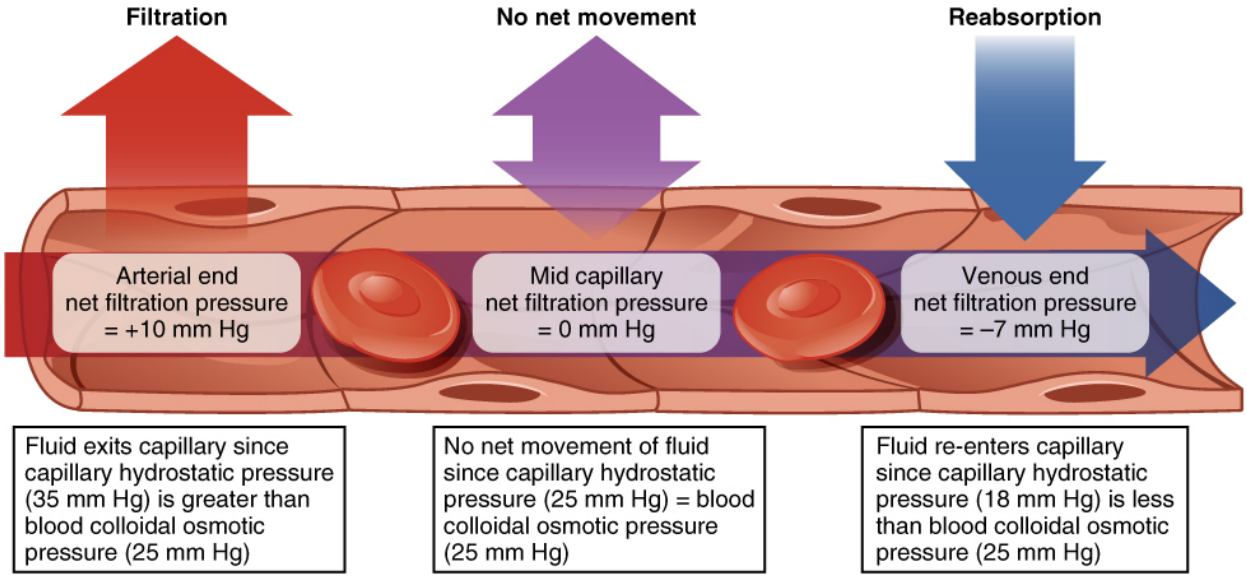


Figure 26.3 Fluid exchange at the arterial and venous ends of the capillary. Filtration of water out of the capillary is caused by the higher arterial pressure compared to the colloidal osmotic pressure (solute concentration). On the venous end, water is reabsorbed into the capillary from the interstitial fluid due to low venous pressure compared to the osmotic pressure within the capillary. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Homeostasis requires that water intake and output be balanced. Most water intake comes through the digestive tract via liquids and food, but roughly 10 percent of water available to the body is generated at the end of aerobic respiration during cellular metabolism. Urine produced by the kidneys accounts for the largest amount of water leaving the body. The kidneys can adjust the concentration of the urine to reflect the body's water needs, conserving water if the body is dehydrated or making urine more dilute to expel excess water when necessary. Antidiuretic Hormone ADH is a hormone that helps the body to retain water by increasing water reabsorption by the kidneys, as well as enhancing thirst to increase water intake. Other hormones that regulate electrolyte balance (see below) and neural regulation also play a role in maintaining water balance.

Electrolyte Balance. Electrolytes serve various purposes, such as helping to conduct electrical impulses along cell membranes in neurons and muscles, stabilizing enzyme structures, and releasing hormones from endocrine glands. The ions in plasma also contribute to the osmotic balance that controls the movement of water between cells and their environment. Imbalances of these ions can result in various problems in the body, and their concentrations are tightly regulated. Aldosterone and angiotensin II are two hormones that

control the exchange of sodium and potassium between the renal filtrate and the renal collecting tubule. Calcium and phosphate are regulated by parathyroid hormone PTH, calcitriol, and calcitonin hormones.

Acid-Base Balance. A variety of buffering systems exist in the body that helps maintain the pH of the blood and other fluids within a narrow range—between pH 7.35 and 7.45. A buffer is a substance that prevents a radical change in fluid pH by absorbing excess hydrogen or hydroxyl ions. Most commonly, the substance that absorbs the ion is either a weak acid, which takes up a hydroxyl ion (OH^-), or a weak base, which takes up a hydrogen ion (H^+). Several substances serve as buffers in the body, including cell and plasma proteins, hemoglobin, phosphates, bicarbonate ions, and carbonic acid. The bicarbonate buffer is the primary buffering system of the IF surrounding the cells in tissues throughout the body. The respiratory and renal systems also play major roles in acid-base homeostasis by removing CO_2 and hydrogen ions, respectively, from the body.

Pre-Laboratory Questions

1. What does the term "fluid balance" refer to in the body?
2. What are electrolytes?
3. How does a "buffer" help maintain a particular pH?

Exercises

- Exercise 1 Fluid balance and edema: Factors affecting interstitial fluid accumulation
- Exercise 2 Electrolyte balance and red blood cells: Effects of hypernatremia and hyperchloremia
- Exercise 3 Acid-base balance and respiration: Effects of carbondioxide and buffering

Exercise 1 Fluid balance and edema: Factors affecting interstitial fluid accumulation

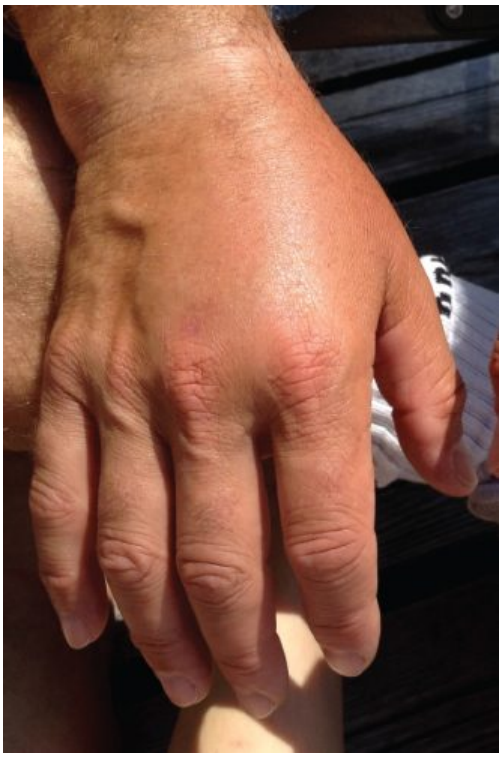


Image credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The image shows edema or swelling in the hand tissues of a patient. Edema refers to abnormal accumulation of interstitial fluid. As a nursing student you are trying to figure out what may have caused this issue.

The patient has the following history:

1. Heart valve disease
2. Hypertension
3. Hypercalcemia (abnormally high blood calcium levels)

Question 1. For each of the conditions above, discuss how it may or may not contribute to fluid retention in the interstitial spaces. Consider fluid exchange in capillaries. The factors to consider are capillary / blood vessel health (permeability), filtration / hydrostatic pressure (blood pressure) and colloid osmotic pressure (solutes in capillary)

1. Heart valve disease:
    1. Capillary health
    2. Filtration pressure

3. Colloid osmotic pressure

2. Hypertension:
    1. Capillary health
    2. Filtration pressure
    3. Colloid osmotic pressure
3. Hypercalcemia:
    1. Capillary health
    2. Filtration pressure
    3. Colloid osmotic pressure

Question 2: In the table below indicate the anticipated effect of the deficiencies listed on factors that cause edema and edema itself. Refer to Figure 26.3 above.

Condition	Arterial pressure (higher, lower, not changed?)	Venous pressure (higher, lower, not changed?)	Colloid osmotic pressure within capillary (higher, lower, not changed?)	Rate of water movement out of the capillary (increased, decreased, not changed?)	Probability of developing edema (increased, decreased, not changed?)
Leaky capillary					
Abnormally high blood volume					
Abnormally low blood pressure					
Hypocalcemia (calcium levels too low)					

Exercise 2 Electrolyte balance and red blood cells: Effects of hypernatremia and hyperchloremia

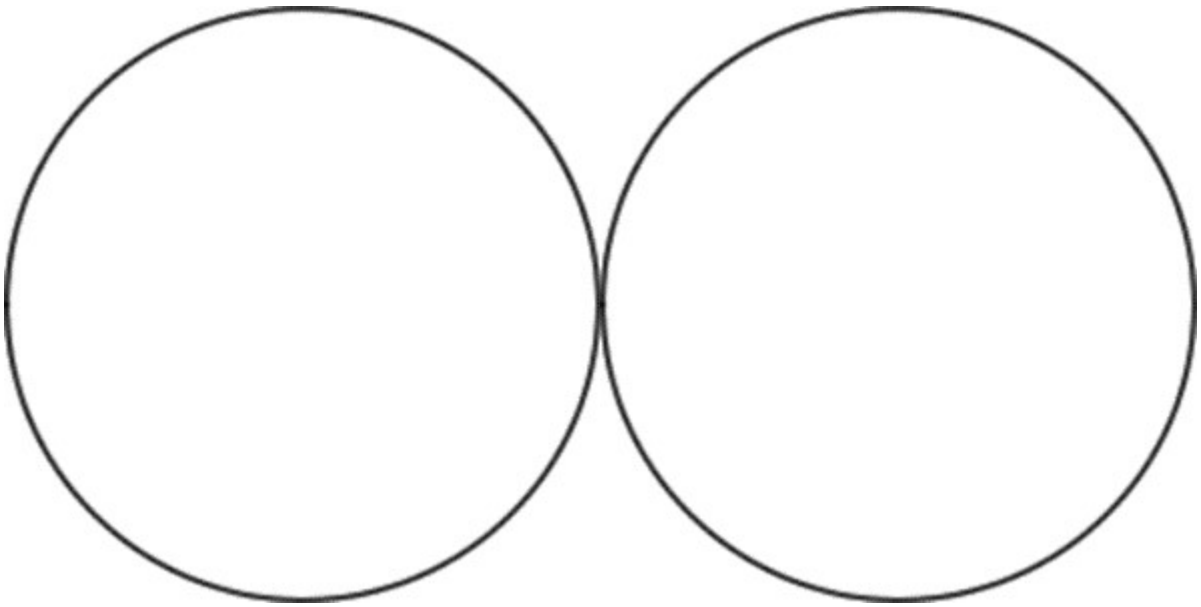
Hypernatremia refers to having blood sodium levels that are too high. *Hyperchloremia* refers to having blood chloride levels that are too high. In this exercise you will explore the effects of having abnormally high levels of both these ions in the environment on the health of red blood cells. Remember the process of osmosis? Consider that concept as you interpret your results.

Required Materials

- 0.9% Sodium Chloride NaCl solution
- 5% Sodium Chloride NaCl solution
- Sheep's blood (red blood cells)
- Dropper
- Microscope slides
- Coverslips
- Microscope oil
- Compound light microscope
- Absorbent paper
- Lens paper
- Wax pen for labeling
- Gloves

Procedure

1. Take two microscope slides and place them side by side on the bench. Label one of them 0.9% and the other one 5% NaCl.
2. Onto each slide place one drop of the corresponding NaCl solution.
3. Place one drop of Sheep's Blood onto each slide.
4. Gently place a coverslip on top of the blood solution.
5. Examine each slide under the microscope. First start at low magnification to find the cells and make your way stepwise to the highest magnification of 100x objective with oil.
6. Compare the shape of the red blood cells in 0.9% to those 5% NaCl solution. Describe the differences in shape.
7. Which of these solutions do you think is isotonic to the red blood cell cytoplasm? Explain
8. In the space below, draw the shape of the red blood cells observed at high magnification (100x) with 0.9% NaCl and with 5% NaCl.



Exercise 3 Acid-base balance and respiration: Effects of carbondioxide and buffering

Carbon dioxide CO_2 is produced in aerobic respiration of cells and is present in the air we breathe inhale and exhale. The amount of this gas in the bloodstream contributes to the pH of blood since it becomes carbonic acid (CH_2O_3) when dissolved in water.

$$\mathbf{CO_2 + H_20 \leftrightarrow\ CH_2O_3}$$

Sodium bicarbonate (same chemical that is baking soda) $Na^+HCO_3^-$ acts as one of the buffers in blood plasma to maintain the blood pH within the narrow limit of 7.35 and 7.45 that can support life

$$\mathbf{CO_2 + H_20 \leftrightarrow\ CH_2O_3 \leftrightarrow HCO_3^- \leftrightarrow H^+}$$

In this exercise you will explore the effects of carbon dioxide and the buffer sodium bicarbonate on pH.

Required Materials

- Distilled water
- Plastic cups or beakers (3 per group)
- Straws
- Carbonated water
- Baking soda (sodium bicarbonate)
- Stirrer
- pH strips

Procedure

1. Add distilled water into a cup and measure its pH using the pH strips. Dip the strip into the water and examine the color. Compare the color to the colors listed on the tube to determine pH. **Record the pH of water:_____**

2. Repeat 1 for a cup full of carbonated water. **Record the pH of carbonated water: _____**
3. Compare the pH of the distilled water to the carbonated water.
4. Stir in a small amount of baking soda (sodium bicarbonate) into both the cups. Measure the pH and record it.
    1. **pH or water+baking soda:_____**
    2. **pH of carbonated water+baking soda:_____**
5. Now add distilled water to a third cup and use a straw to blow air into the water to push your expiratory gases into the water.
6. Immediately measure the pH of the water with your expiratory gases in it. **Record the pH of water plus exhaled air: _____**

Post-laboratory Questions

1. **In Exercise 1** you determined some factors that can cause edema. The following are some treatment that are used to relieve/treat edema. For each of them explain how it works at the capillary level. Does it affect hydrostatic pressure, colloid osmotic pressure and how does that help relieve edema

    - Lowering the patient's blood pressure with medication:
    - Increasing the patient's protein intake:
    - Prescribing a diuretic to increase the kidneys' water output:

2. **In Exercise 2** you determined the effect of hypernatremia on red blood cells.

    - Based on your results above, articulate the effect of hypernatremia on red blood cells.
    - Consider osmosis. Did water move into or out of the red blood cells in the hypernatremia situation (5% NaCl)?
    - If someone has hypernatremia, which of the following intravenous sodium chloride solutions could help them? Hypotonic 0.45% sodium chloride, or hypertonic 3% sodium chloride? Explain.

3. **In Exercise 3** you examined the effects of carbon dioxide and bicarbonate buffer on pH. Based on your results, answer the following questions.

    - Why does carbonation change the pH? Does it make the pH more acidic or basic?
    - When you blow into the water you increased the level of carbon dioxide in the water. Did this make the water more or less acidic? Explain using this formula:

$$\mathbf{CO_2 + H_20 \leftrightarrow CH_2O_3 \leftrightarrow HCO_3^- \leftrightarrow H^+}$$

    - How did adding bicarbonate change the pH of the water (carbonated or distilled)? What do

you expect would happen if you added bicarbonate into the water with your expiratory gases? How does this buffering help maintain blood pH?

27.

CHAPTER 27 THE REPRODUCTIVE SYSTEM

By Rajeev Chandra

Motivation.

Washington, D.C. has among the highest rates of sexually transmitted diseases (STDs) and unintended pregnancy in the United States. Increasing everyone's reproductive health knowledge may help address these reproductive health issues. This analysis assessed whether high-risk pregnant African American women in Washington, D.C. who participated in an intervention to reduce behavioral and psychosocial risks had greater reproductive health knowledge than women receiving usual care.

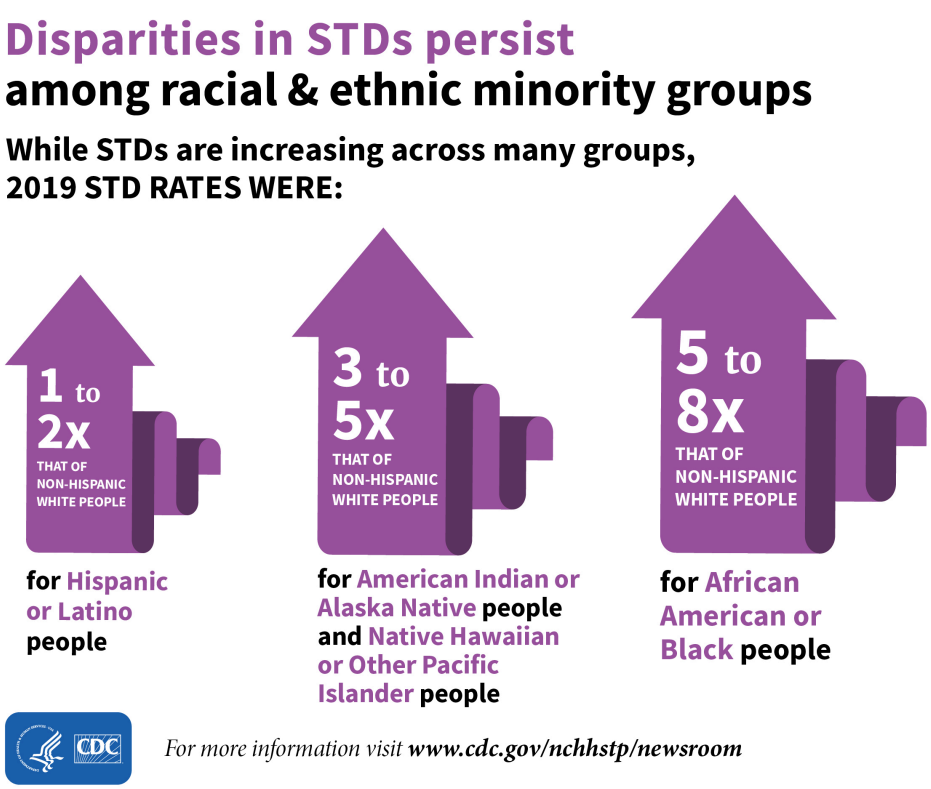


Figure 27.1 Centers for disease control broadcast on persistent disparities in STDs in minority groups. Credit: CDC

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Describe female reproductive organ histology and anatomy
- Describe the gross and microscopic anatomy of the male reproductive organs
- Relate the structure of sperm to its function

Background.

Overview of the Female Reproductive System

The female reproductive system functions to produce gametes and reproductive hormones, just like the male reproductive system; however, it also has the additional task of supporting a 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 27.2). Recall that the **ovaries** are the female **gonads** and the gamete that is produced is called an **oocyte**.

Ovaries

The **ovaries** are the female gonads (Figure 27.2 and Figure 27.3). 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, and are supported by the mesovarium, an extension of the peritoneum that connects the ovaries to the **broad ligament**. Extending from the mesovarium itself is the **suspensory ligament** that contains the ovarian blood and lymphatic vessels. Finally, the ovary itself is attached to the uterus via the **ovarian ligament**.

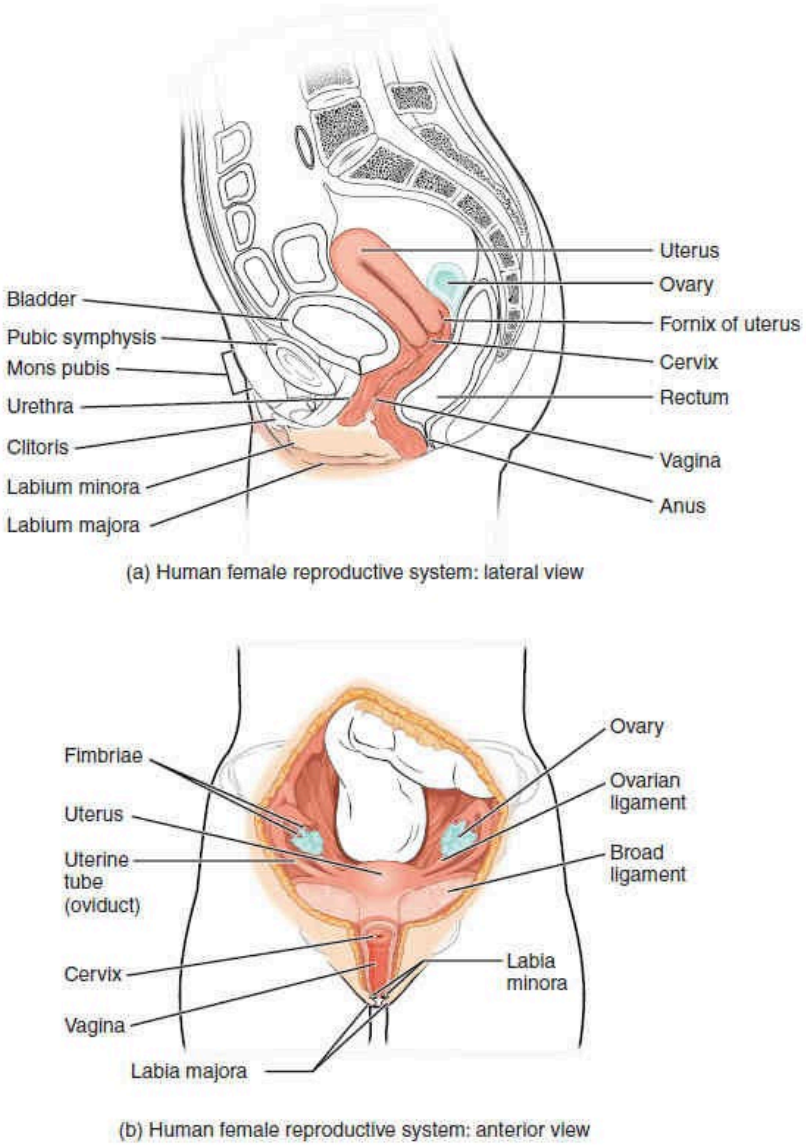


Figure 27.2. Female Reproductive System. The major organs of the female reproductive system are located inside the pelvic cavity. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The ovary consists of multiple layers of tissue. The outer-most covering of cuboidal epithelium called the ovarian surface epithelium sits just superficial to a dense connective tissue layer, known as the **tunica albuginea**. Beneath the tunica albuginea is the **cortex**, or outer portion, of the organ itself. 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** (Figure 27.3). The growth and development of ovarian follicles will be described shortly. Beneath the cortex lies the inner ovarian **medulla**, where the majority of blood vessels, lymphatic vessels, and the nerves of the ovary are localized to.

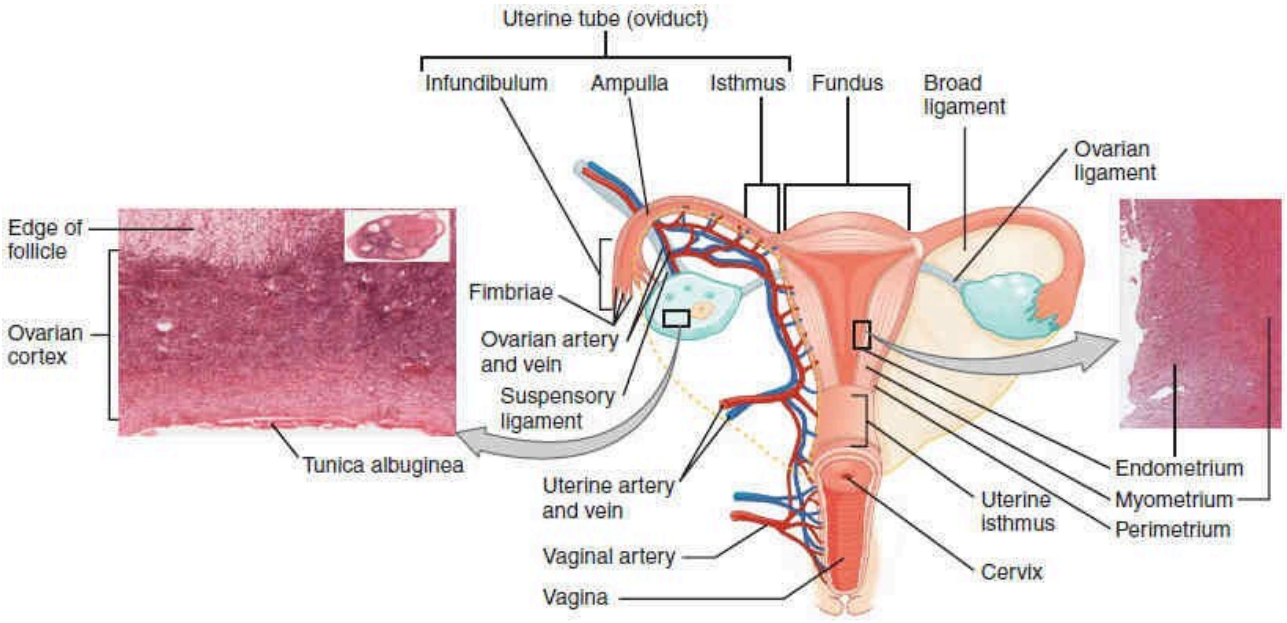


Figure 27.3 Ovaries, uterine tube, uterus. This anterior view shows the relationship of the ovaries, uterine tubes (oviducts), and uterus. Sperm enter through the vagina, and fertilization of an ovulated oocyte usually occurs in the distal uterine tube. From left to right, LM × 400, LM × 20. (Micrographs provided by the Regents of University of Michigan Medical School © 2012). Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The Ovarian Cycle and Oogenesis

The **ovarian cycle** is a set of predictable 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**. The cycle includes two interrelated processes: **oogenesis** (the production of female gametes) and **folliculogenesis** (the growth and development of ovarian follicles).

Oogenesis

Gametogenesis in females is called **oogenesis**. The process begins with ovarian stem cells, or **oogonia** (pleural: **oogonium**) (Figure 27.4). 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 prophase 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 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.

The initiation of **ovulation**, the release of an oocyte from the ovary, marks the transition from puberty into reproductive maturity for women. From the onset of ovulation and 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 27.4, 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.

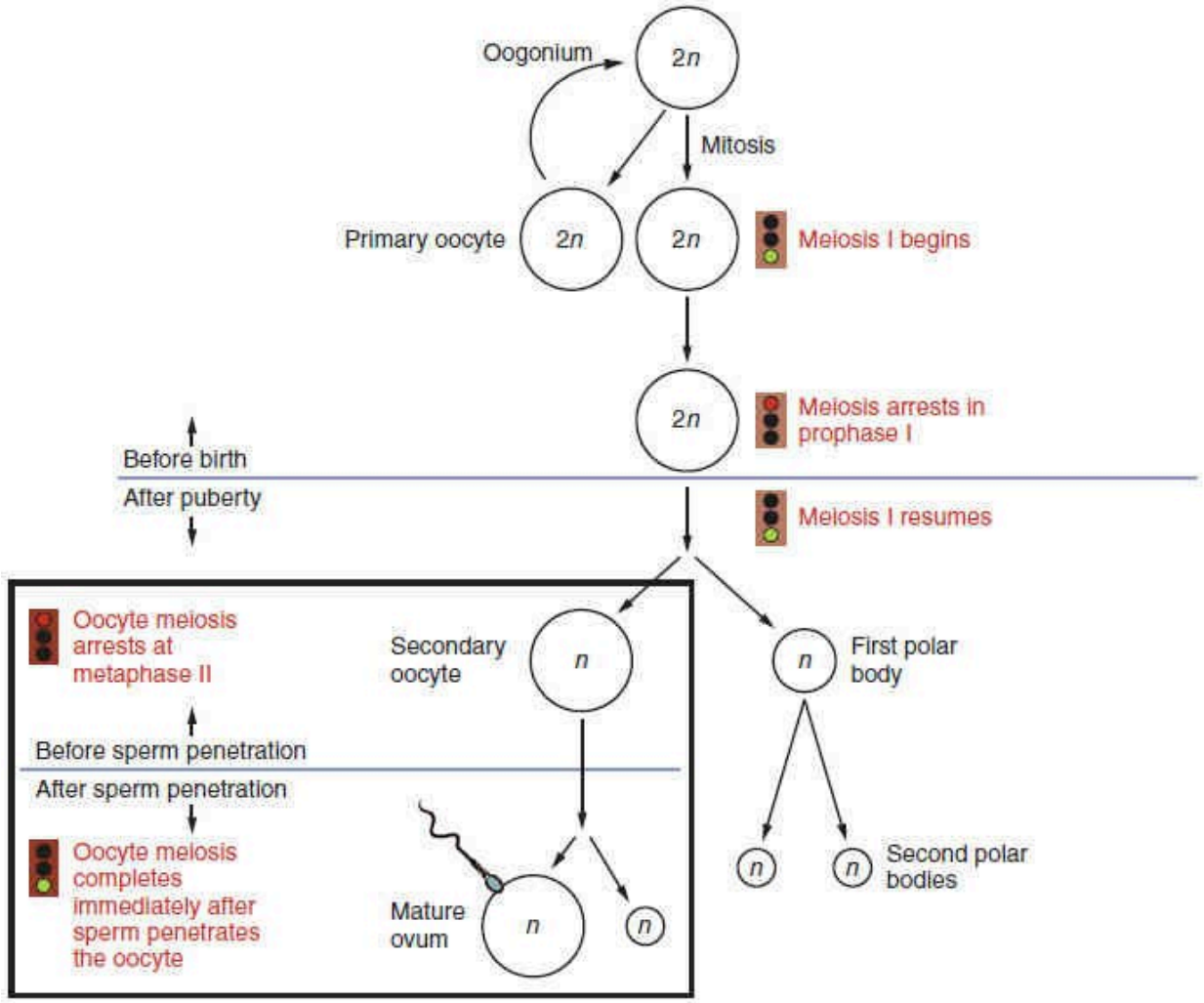


Figure 27.4 Oogenesis. The unequal cell division of oogenesis produces one to three polar bodies that later degrade, as well as a single haploid ovum, which is produced only if there is penetration of the secondary oocyte by a sperm cell. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

A question still remains though: How does the diploid secondary oocyte become an **ovum** —the haploid female gamete? Meiosis of a secondary oocyte is completed *only if a sperm succeeds in penetrating its barriers*. If union of a secondary oocyte and a sperm is successful, only then will meiosis II resume. This fusion will produce one haploid ovum that, at the moment of fertilization by a (haploid) sperm, becomes the first diploid cell of the new offspring (a **zygote**). Thus, the ovum can be thought of as a brief, transitional, haploid stage between the diploid oocyte and diploid zygote.

The larger amount of cytoplasm contained in the female gamete is used to supply the developing zygote

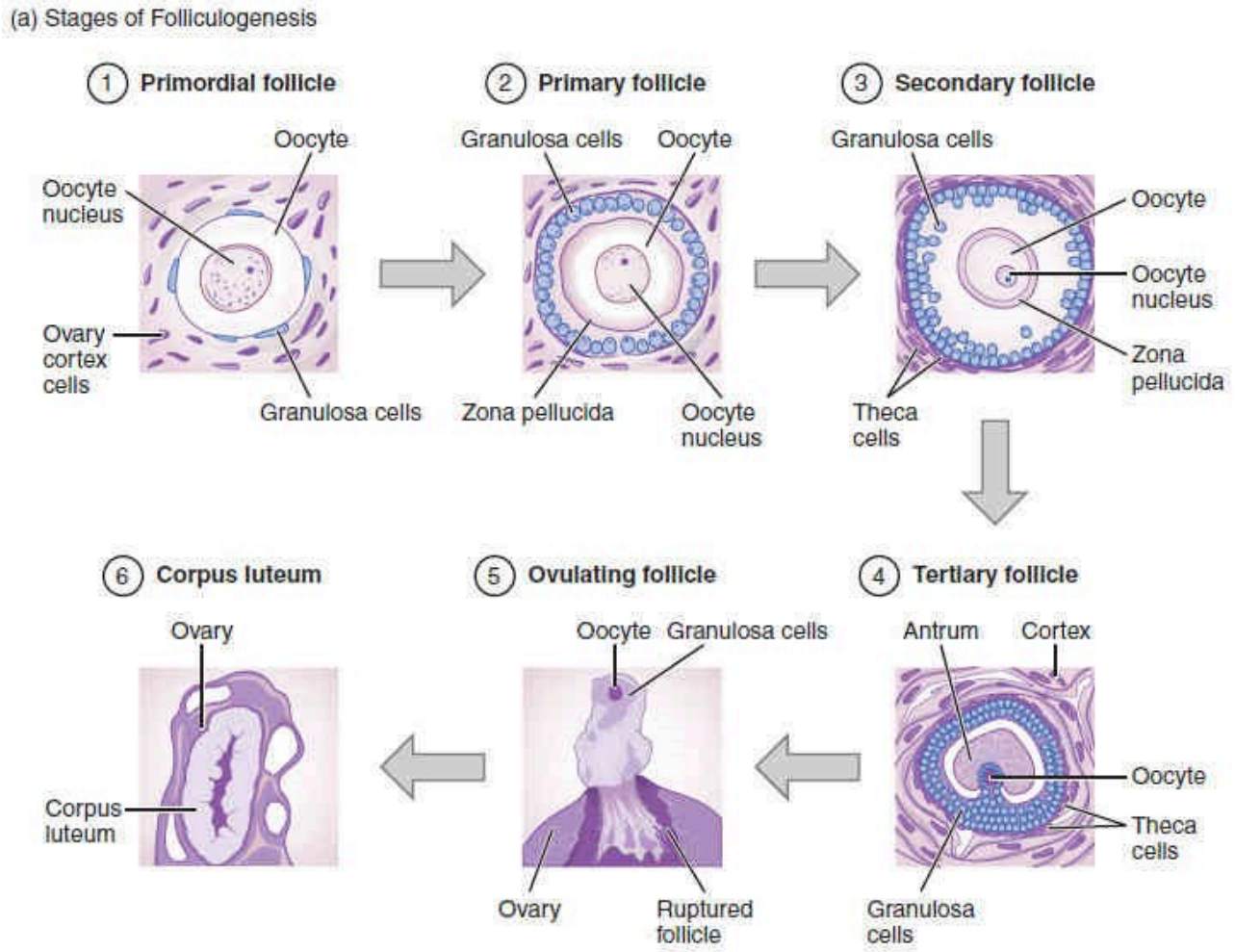
with nutrients during the period between fertilization and implantation into the uterus. Interestingly, sperm contribute only DNA at fertilization —not cytoplasm. Therefore, the cytoplasm and all of the cytoplasmic organelles in the developing embryo are of maternal origin.

Folliculogenesis

Remember, ovarian **follicles** are oocytes and their supporting cells. They grow and develop in a process called **folliculogenesis**, which typically leads to ovulation of one follicle approximately every 28 days, along with death to multiple other follicles. The death of ovarian follicles is called **atresia**, and can occur at any point during follicular development. Recall that, a female infant at birth will have one to two million oocytes within her ovarian follicles, and that this number declines throughout life until menopause, when no follicles remain. As you'll see next, follicles progress from **primordial**, to **primary**, to **secondary** and finally **tertiary** stages prior to ovulation—with the oocyte inside the follicle remaining as a primary oocyte until right before ovulation.

Folliculogenesis begins with follicles in a resting state. These small **primordial follicles** are present in newborn females and are the prevailing follicle type in the adult ovary (Figure 27.5). Primordial follicles have only a single flat layer of supporting cells, called **granulosa cells**, that surround the primary oocyte, and they can stay in this resting state for years—some until right before menopause.

After puberty, a few primordial follicles will respond to a recruitment signal each day, and will join a pool of immature growing follicles called **primary follicles**. Primary follicles start with a single layer of granulosa cells, but the granulosa cells then become active and transition from a flat or squamous shape to a rounded, cuboidal shape as they increase in size and proliferate. As the granulosa cells divide, the follicles—now called **secondary follicles** (Figure 27.5)—increase in diameter, adding a new outer layer of connective tissue, blood vessels, and **theca cells** —cells that work with the granulosa cells to produce estrogens. Within the growing secondary follicle, the primary oocyte now secretes a thin acellular membrane called the **zona pellucida** that will play a critical role in fertilization. A thick fluid, called follicular fluid, that has formed between the granulosa cells also begins to collect into one large pool, the **antrum**. Follicles in which the antrum has become large and fully formed are considered **tertiary follicles** (or **antral follicles**). Several follicles reach the tertiary stage at the same time, and most of these will undergo atresia. The one that does not die will continue to grow and develop until ovulation, when it will expel its secondary oocyte surrounded by several layers of granulosa cells from the ovary. Keep in mind that most follicles don't make it to this point. In fact, roughly 99 percent of the follicles in the ovary will undergo atresia, which can occur at any stage of folliculogenesis.



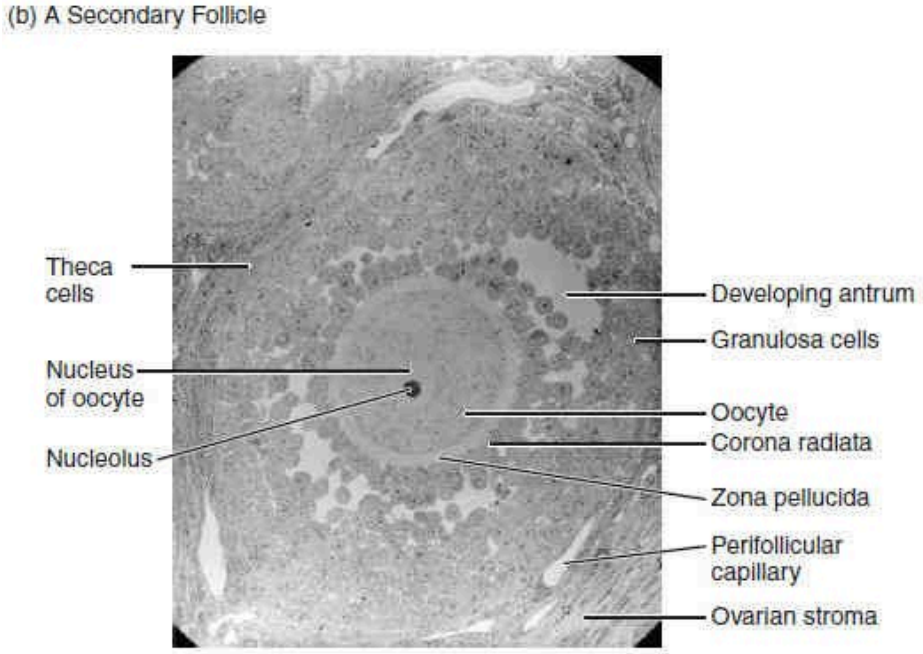


Figure 27.5 Folliculogenesis. (a) The maturation of a follicle is shown in a clockwise direction proceeding from the primordial follicles. FSH stimulates the growth of a tertiary follicle, and LH stimulates the production of estrogen by granulosa and theca cells. Once the follicle is mature, it ruptures and releases the oocyte. Cells remaining in the follicle then develop into the corpus luteum. (b) In this electron micrograph of a secondary follicle, the oocyte, theca cells (thecae folliculi), and developing antrum are clearly visible. EM × 1100. (Micrograph provided by the Regents of University of

Hormonal Control of the Ovarian Cycle

The process of development that we have just described, from primordial follicle to early tertiary follicle, takes approximately two months in humans. The final stages of development of a small cohort of tertiary follicles, ending with ovulation of a secondary oocyte, occur over a course of approximately 28 days. These changes are regulated by many of the same hormones that regulate the male reproductive system, including **GnRH**, **LH**, and **FSH**.

As in men, the hypothalamus produces GnRH, a hormone that signals the anterior pituitary gland to produce the gonadotropins FSH and LH (Figure 27.6). These gonadotropins leave the pituitary and travel through the bloodstream to the ovaries, where they bind to receptors on the granulosa and theca cells of the follicles. FSH stimulates the follicles to grow (hence its name of follicle-stimulating hormone), and the five or six tertiary follicles expand in diameter. The release of LH also stimulates the granulosa and theca cells of the follicles to produce the sex steroid hormone **estradiol**, a type of **estrogen**.

This phase of the ovarian cycle, when the tertiary follicles are growing and secreting estrogen, is known as the **follicular phase**. The more granulosa and theca cells a follicle has (that is, the larger and more developed it is), the more estrogen it will produce in response to LH stimulation. As a result of these large follicles producing large amounts of estrogen, systemic plasma estrogen concentrations increase. Following a classic negative feedback loop, the high concentrations of estrogen will stimulate the hypothalamus and pituitary to reduce the production of GnRH, LH, and FSH. Because the large tertiary follicles require FSH to grow and survive at this point, this decline in FSH caused by negative feedback leads most of them to die (atresia) (Figure 27.6, step 1). Typically, only one follicle, now called the **dominant follicle**, will survive this reduction in FSH, and this follicle will be the one that releases an oocyte. Scientists have studied many factors that lead to a particular follicle becoming dominant: size, the number of granulosa cells, and the number of FSH receptors on those granulosa cells all contribute to a follicle becoming the one surviving dominant follicle.

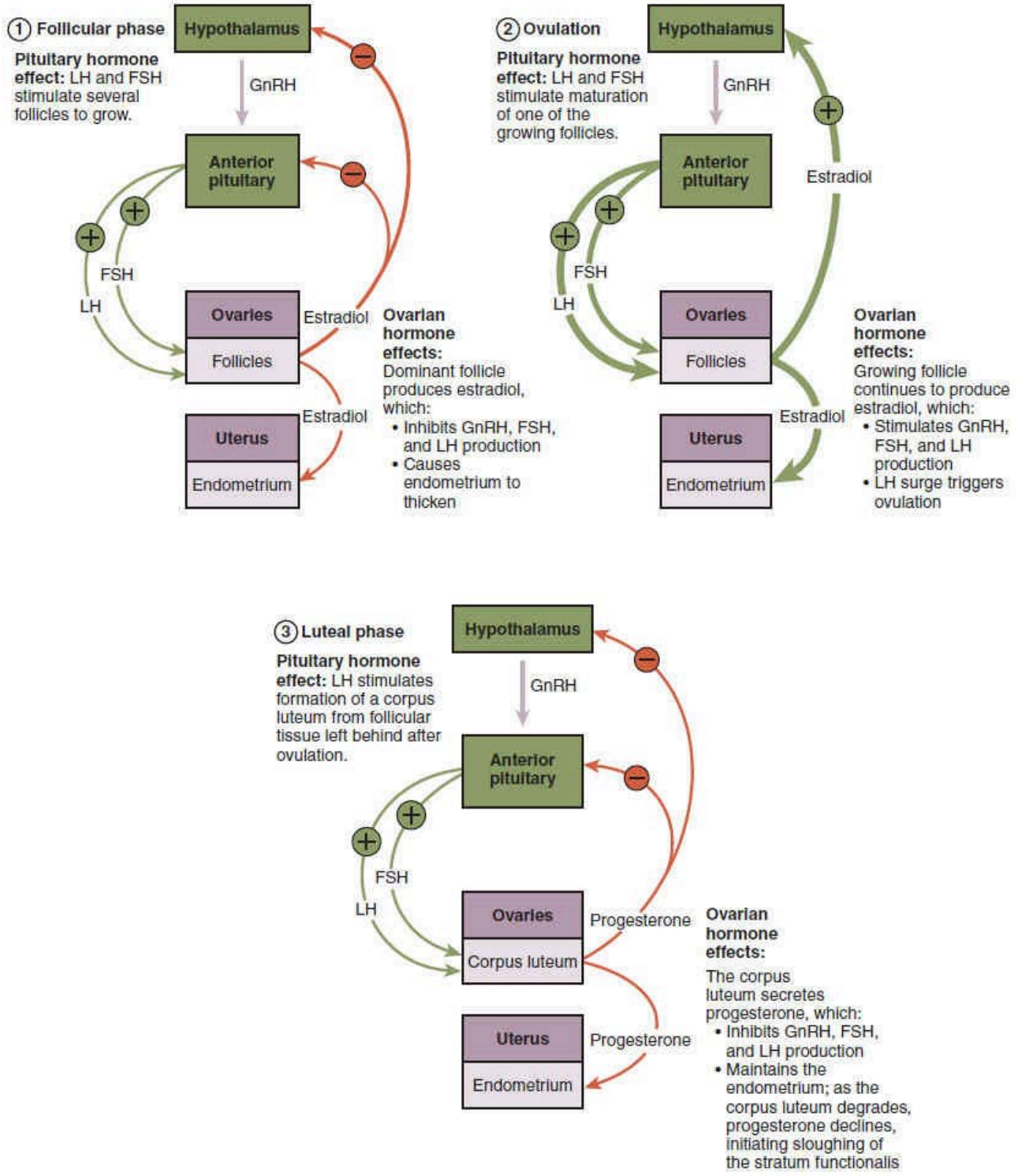


Figure 27.6 Hormonal regulation of ovulation. The hypothalamus and pituitary gland regulate the ovarian cycle and ovulation. GnRH activates the anterior pituitary to produce LH and FSH, which stimulate the production of estrogen and progesterone by the ovaries. Credit: OpenStax Anatomy and Physiology, CC-BY 4.0

When only the dominant follicle remains in the ovary, it again begins to secrete estrogen. It produces more estrogen than all of the developing follicles did together before the negative feedback occurred. It produces so much estrogen that the normal negative feedback doesn't occur. Instead, these extremely

high concentrations of systemic plasma estrogen trigger a regulatory switch in the anterior pituitary that responds by secreting large amounts of LH and FSH into the bloodstream (Figure 27.6, step 2).

The positive feedback loop by which more estrogen triggers release of more LH and FSH only occurs at this point in the cycle. It is this large burst of LH (called the LH surge) that leads to ovulation of the dominant follicle. The LH surge induces many changes in the dominant follicle, including stimulating the resumption of meiosis of the primary oocyte to a secondary oocyte. As noted earlier, the polar body that results from unequal cell division simply degrades. The LH surge also triggers proteases (enzymes that cleave proteins) to break down structural proteins in the ovary wall on the surface of the bulging dominant follicle. This degradation of the wall, combined with pressure from the large, fluid-filled antrum, results in the expulsion of the oocyte surrounded by granulosa cells into the peritoneal cavity. This release is **ovulation**.

There is one more important event that occurs in the ovarian cycle. The surge of LH also stimulates a change in the granulosa and theca cells that remain in the follicle after the oocyte has been ovulated. This change is called **luteinization** and it transforms the collapsed follicle into a new endocrine structure called the **corpus luteum**, a term meaning "yellowish body" (Figure 27.5). Instead of estrogen, the luteinized granulosa and theca cells of the corpus luteum begin to produce large amounts of the sex steroid hormone **progesterone**, a hormone that is critical for the establishment and maintenance of pregnancy. Progesterone triggers negative feedback at the hypothalamus and pituitary, which keeps GnRH, LH, and FSH secretions low, so no new dominant follicles develop at this time. This post-ovulatory phase of progesterone secretion is known as the **luteal phase** of the ovarian cycle (Figure 27.6, step 3). If pregnancy does not occur within 10 to 12 days, the corpus luteum will stop secreting progesterone and degrade into the **corpus albicans**, a nonfunctional "whitish body" that will degenerate in the ovary over a period of several months. During this time of reduced progesterone secretion, FSH and LH are once again stimulated, and the follicular phase begins again with a new cohort of early tertiary follicles beginning to grow and secrete estrogen.

Uterine (Fallopian) Tubes

The **uterine tubes** (also called **fallopian tubes** or **oviducts**) serve as the conduit of the oocyte from the ovary to the uterus (Figure 27.3). Each of the two uterine tubes is close to, but not directly connected to, the ovary and each is 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 of tissue: 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. 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.

Uterus

The **uterus** is the muscular organ that nourishes and supports the growing embryo (Figure 27.3). Its average size is approximately 5 cm wide by 7 cm long 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** or **corpus**, and the **cervix** is the narrow inferior portion of the uterus that projects into the vagina.

The wall of the uterus is made up of three layers (Figure 27.3 and Figure 27.7). 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**. Structurally, the endometrium consists of two layers: the **stratum basalis** (**basal layer**) and the **stratum functionalis** (**functional layer**). The stratum basalis layer lies adjacent to the myometrium; this layer does not shed during menses. In contrast, the thicker stratum functionalis layer contains the glandular endothelial tissues that line the uterine lumen. It is the stratum functionalis that grows and thickens in response to increased levels of estrogen and progesterone. In the luteal phase of the menstrual cycle, special branches off of the uterine artery called **spiral arteries** supply the thickened stratum functionalis (Figure 27.7). This inner functional layer provides the proper site of implantation for a fertilized egg, and—should fertilization not occur—it is only the functional layer of the endometrium that sheds during menstruation.

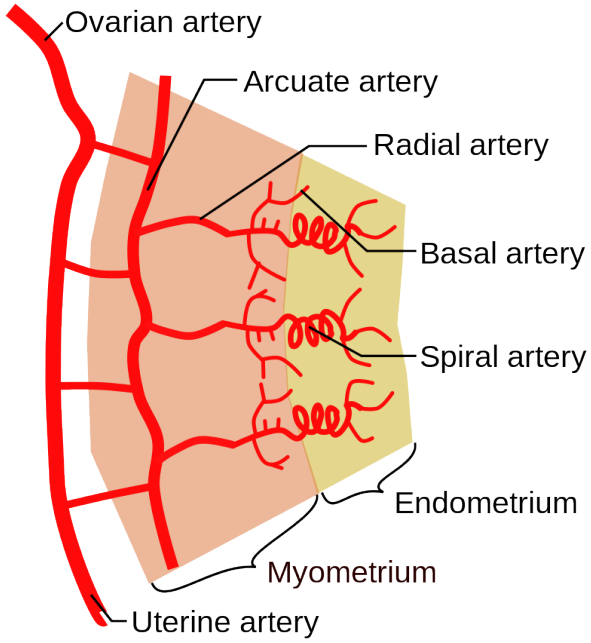


Figure 27.7 Layers and arterial vasculature of the uterus. The wall of the uterus consists of 3 layers:

the outer perimetrium (not shown), the myometrium, and the endometrium. Credit: Mikael Häggström, Wikimedia Commons, license Public Domain.

Ligaments

Several ligaments maintain the position of the uterus within the abdominopelvic cavity (Figure 27.3). The **broad ligament** is a fold of peritoneum that serves as a primary support for the uterus, extending laterally from both sides of the uterus and attaching it to the pelvic wall. The **round ligament** attaches to the uterus near the uterine tubes, and extends to the labia majora.

Vagina

The **vagina**, shown at the bottom of Figure 27.2 and in Figure 27.8, 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. A thin, perforated **hymen** can partially surround the opening to the **vaginal orifice** (**opening**).

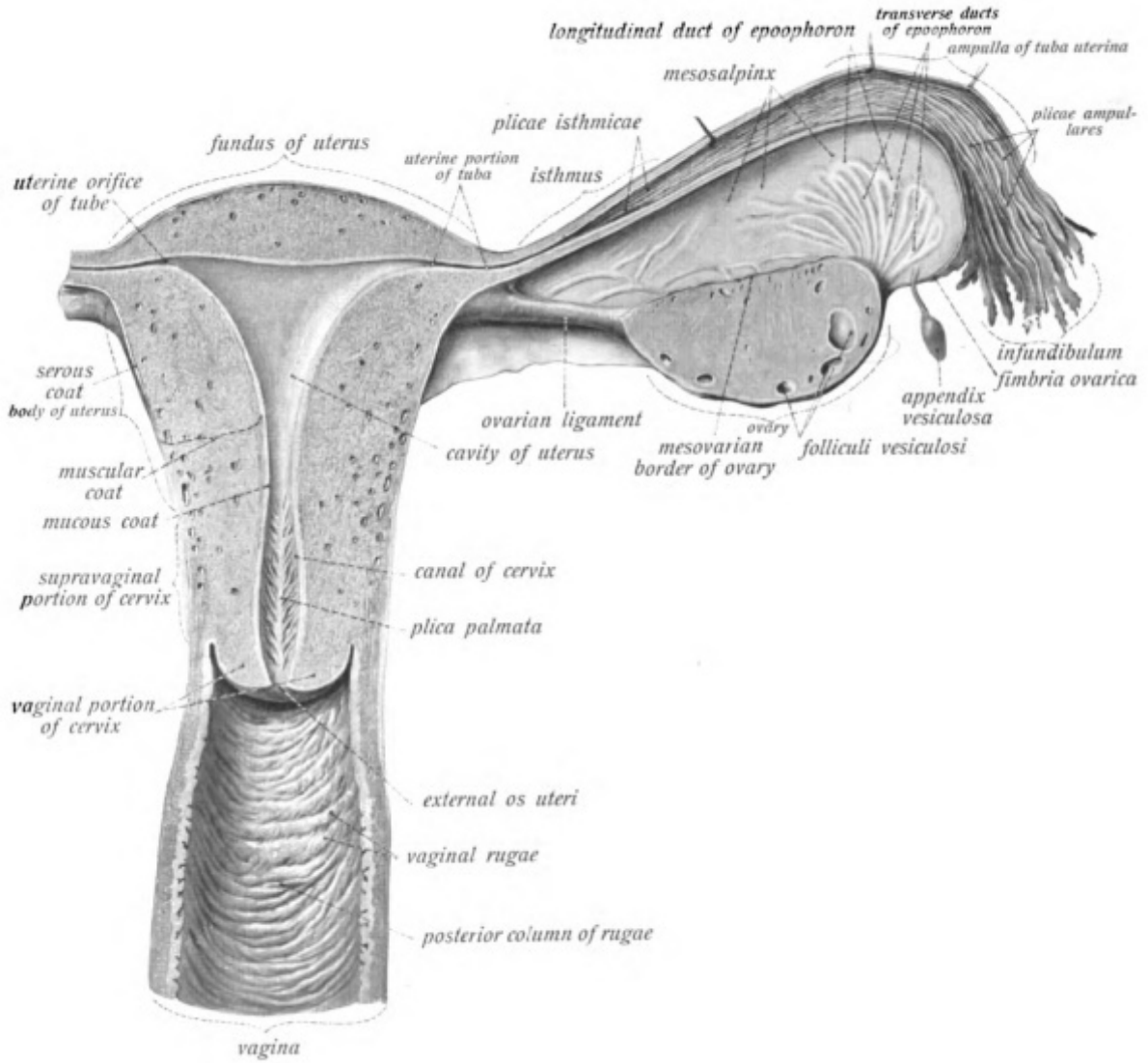


Figure 27.8 Cross section of the vagina. Credit: Dr. Johannes Sobotta – Sobotta's Atlas and Text-book of Human Anatomy 1906, Wikimedia Commons, Public Domain.

External Genitalia

The external female reproductive structures are referred to collectively as the **vulva** (Figures 27.2 and 27.9) and they include the structures that will be discussed next. The **mons pubis** is a pad of fat that is located anteriorly, 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 and the space between labia minora is known as the **vestibule**. 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. The vaginal opening, also known as the **vaginal orifice**, 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) .

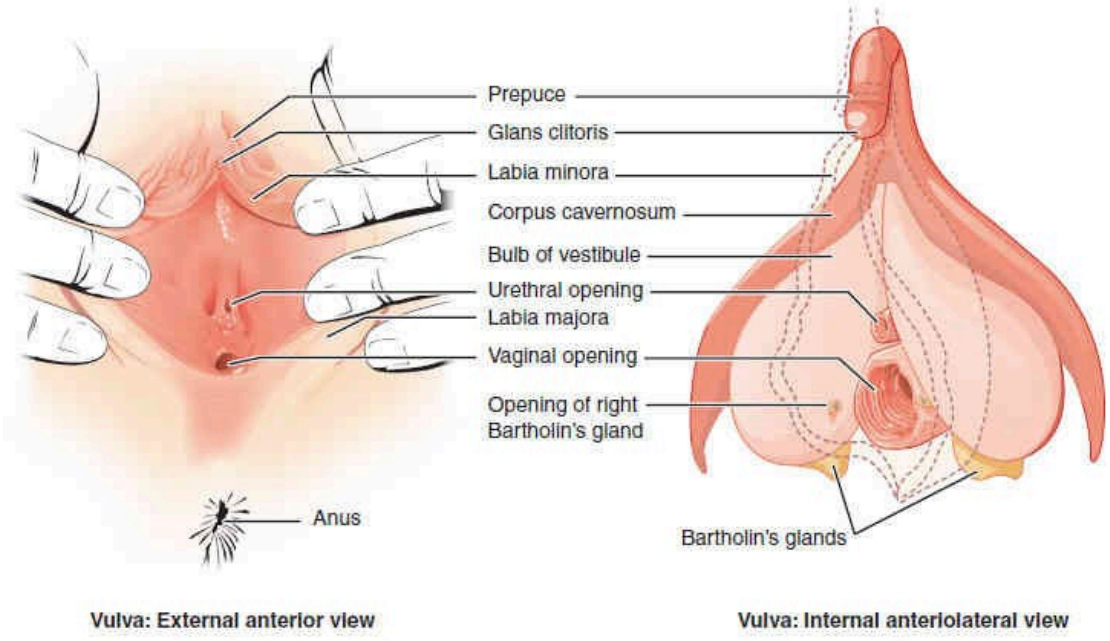


Figure 27.9 The external female genitalia The external female genitalia are referred to collectively as the vulva. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The Breast

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 27.10), whose coloration may deepen during pregnancy. The areolar region is characterized by small, raised areolar glands that secrete lubricating fluid during lactation to protect the nipple from chafing.

Internally, 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 (**lobule**) within the breast itself that contains groups of milksecreting cells in clusters called **alveoli** (Figure 27.10). 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, a baby can draw milk through the lactiferous ducts by suckling. The lobules 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.

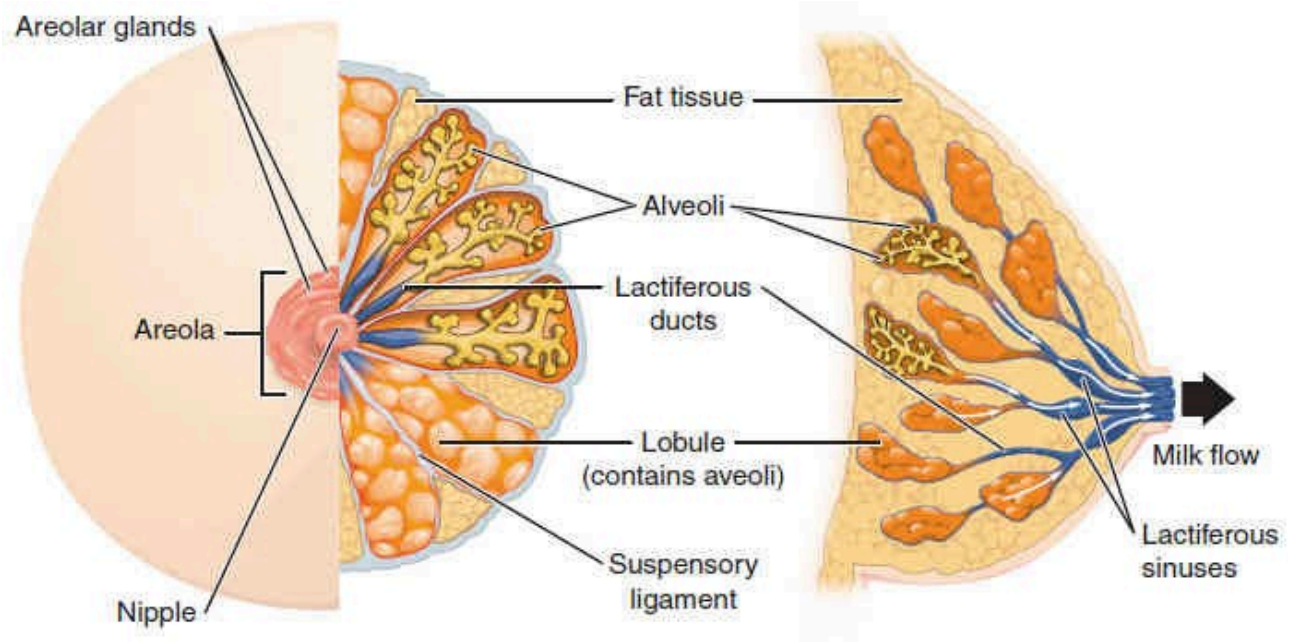


Figure 27.10 Anatomy of the breast. During lactation, milk moves from the alveoli through the lactiferous ducts to the nipple. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

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.

Overview of the Male Reproductive System

The function of the male reproductive system is to produce **male gametes**, known as **sperm**, to transfer these to the female reproductive tract, and to secrete the hormones that support male reproductive physiology. The paired **gonads**, or gamete-producing structures, are the **testes** (singular, *testis*) and they are a crucial component of the male's reproductive system. While the testes produce both sperm and **androgens**, several accessory organs and ducts aid in the process of sperm maturation and transport of the sperm and other seminal components to the **penis**, which delivers sperm to the female reproductive tract.

The structures of the male reproductive system include the **testes**, the **epididymis**, and the **penis**, as well as the ducts and glands that produce and carry semen (Figure 27.11).

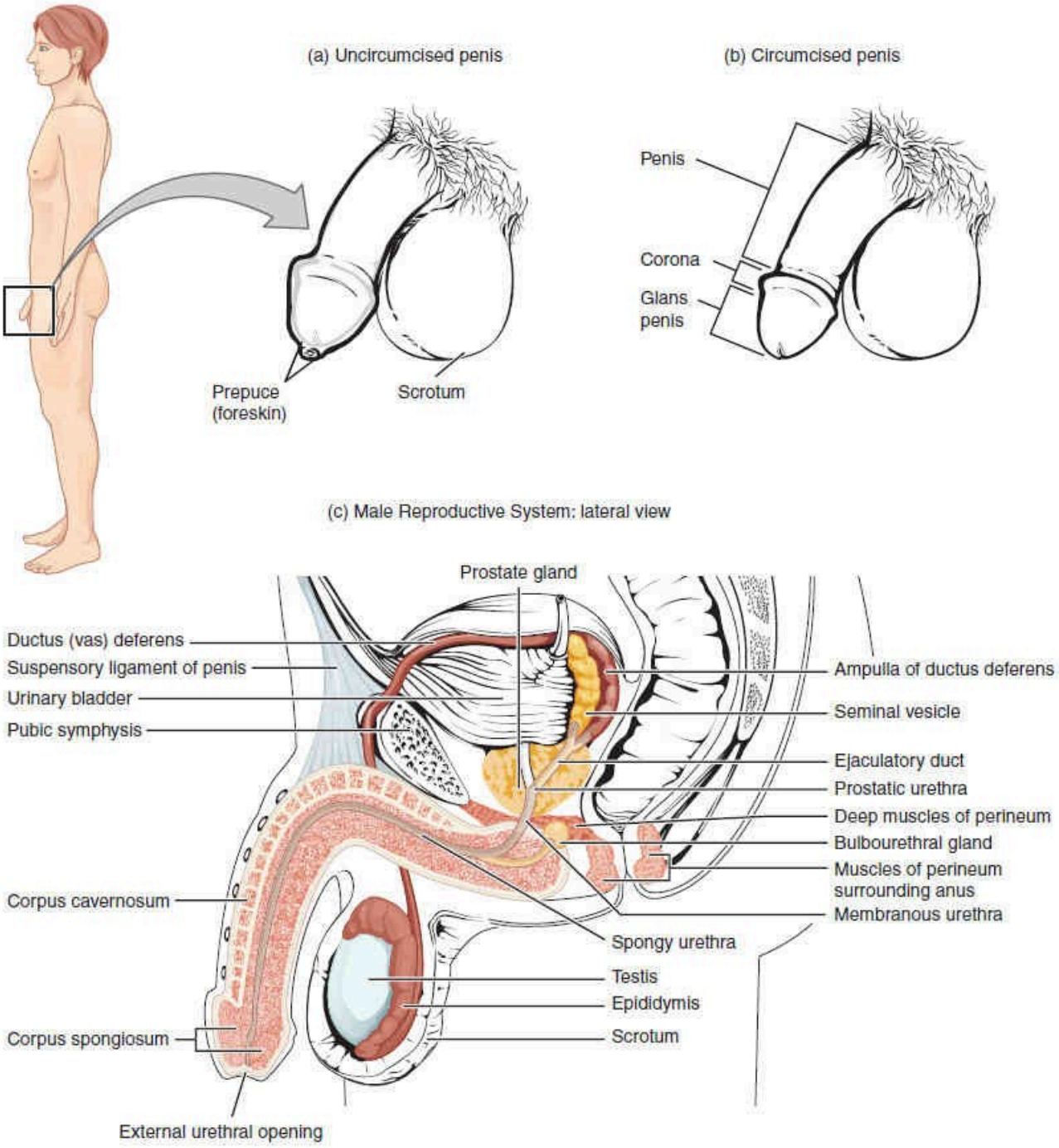


Figure 27.11 Structures and organization of the male reproductive system. The structures of the testicular reproductive system include the testes, the epididymides, the penis, and the ducts and glands that produce and carry semen. Sperm exit the scrotum through the ductus deferens, which is bundled in the spermatic cord. The seminal vesicles and prostate gland add fluids to the sperm to create semen. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Scrotum and Testes

The **testes** (singular, **testis**) are located in a skin-covered, highly pigmented, muscular sack called the **scrotum**. The scrotum extends from the body behind the penis (Figure 27.11). This location is important to sperm production, which occurs within the testes. The scrotum helps to regulate the temperature of the testes and maintains it around 35 degrees Celsius (95 degrees Fahrenheit). Temperature control is

accomplished by the smooth muscles of the scrotum moving the testes either closer to or further away from the abdomen, dependent upon the ambient temperature. This regulatory action is accomplished by the **cremaster muscle** in the abdomen and the **dartos fascia** (muscular tissue under the skin) within the scrotum.

The **dartos muscle** makes up the subcutaneous muscle layer of the scrotum (Figure 27.12). 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 raphe (Figure 27.12).

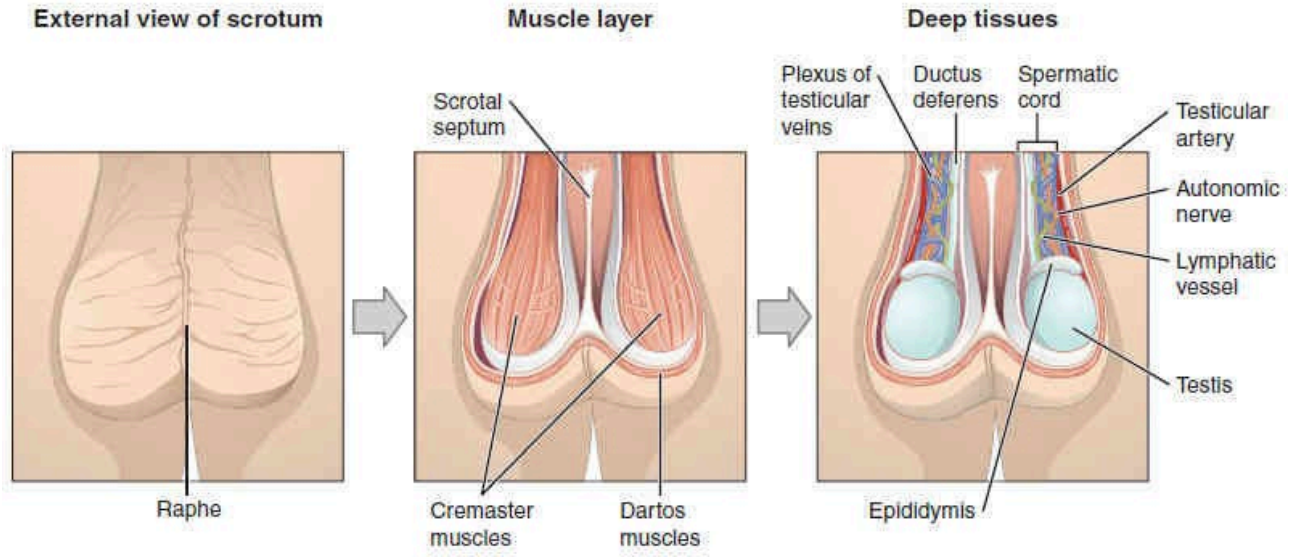


Figure 27.12 Scrotum and testes. This anterior view shows the structures of the scrotum and testes. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The **testes** 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 (Figures 27.11 and 27.12). They are surrounded by two distinct layers of protective connective tissue (Figure 27.13). The outer **tunica vaginalis** is a double-layered serous membrane. 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 **seminal vesicle lobules** (or just **lobules**). Within each lobule, sperm develop in tube-like structures known as the **seminiferous tubules**.

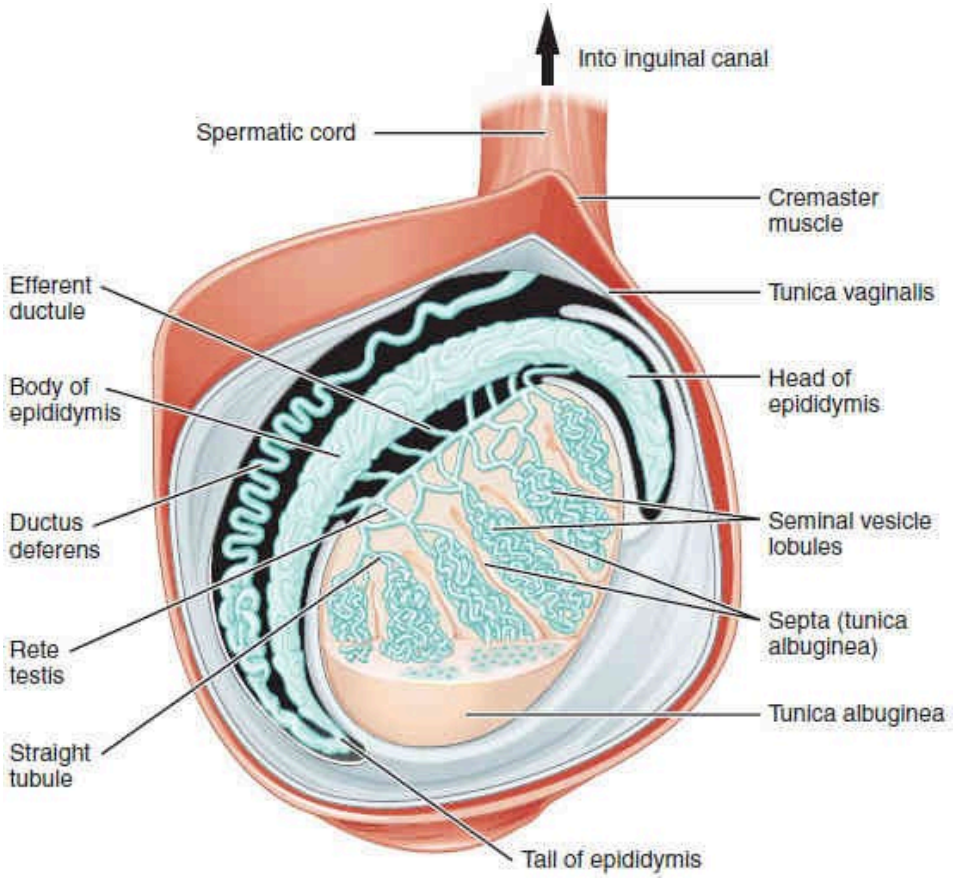


Figure 27.13 Anatomy of the testis. This sagittal view shows the seminiferous tubules, the site of sperm production. Formed sperm are transferred to the epididymis, where they mature. They leave the epididymis during an ejaculation via the ductus deferens. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

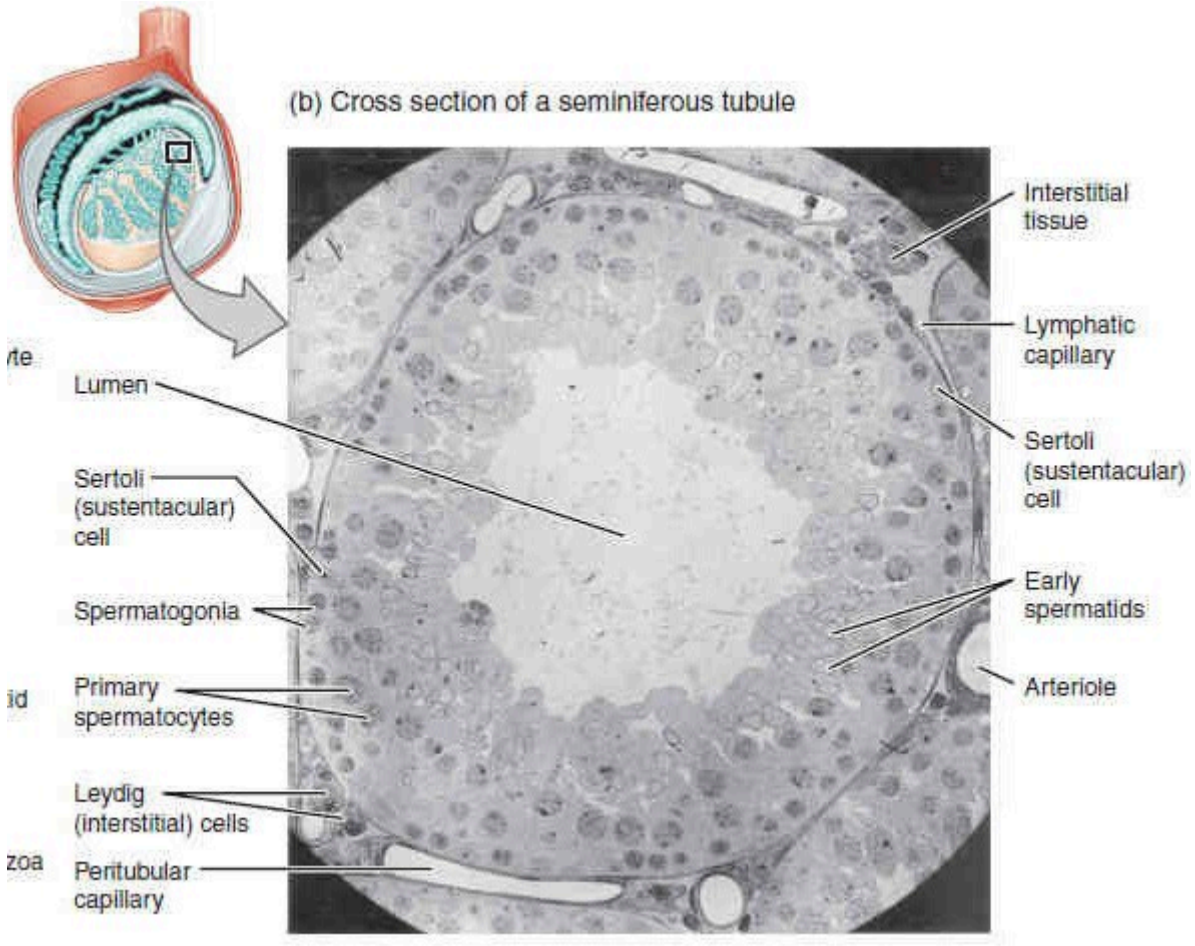


Figure 27.14 Histology of the testis – cross section of aseminiferous tubule. An electron micrograph of a cross-section of a seminiferous tubule from a rat. The lumen is the light-shaded area in the center of the image. The location of the primary spermatocytes is near the basement membrane, and the early spermatids are approaching the lumen (tissue source: rat). (Micrograph provided by the Regents of University of Michigan Medical School © 2012). Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Inside the seminiferous tubules are six different cell types. These include supporting cells called **sustentacular (Sertoli) cells**, hormone producing **interstitial (Leydig) 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.

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

Spermiogenesis and the Structure of a Mature 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 27.15).

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.

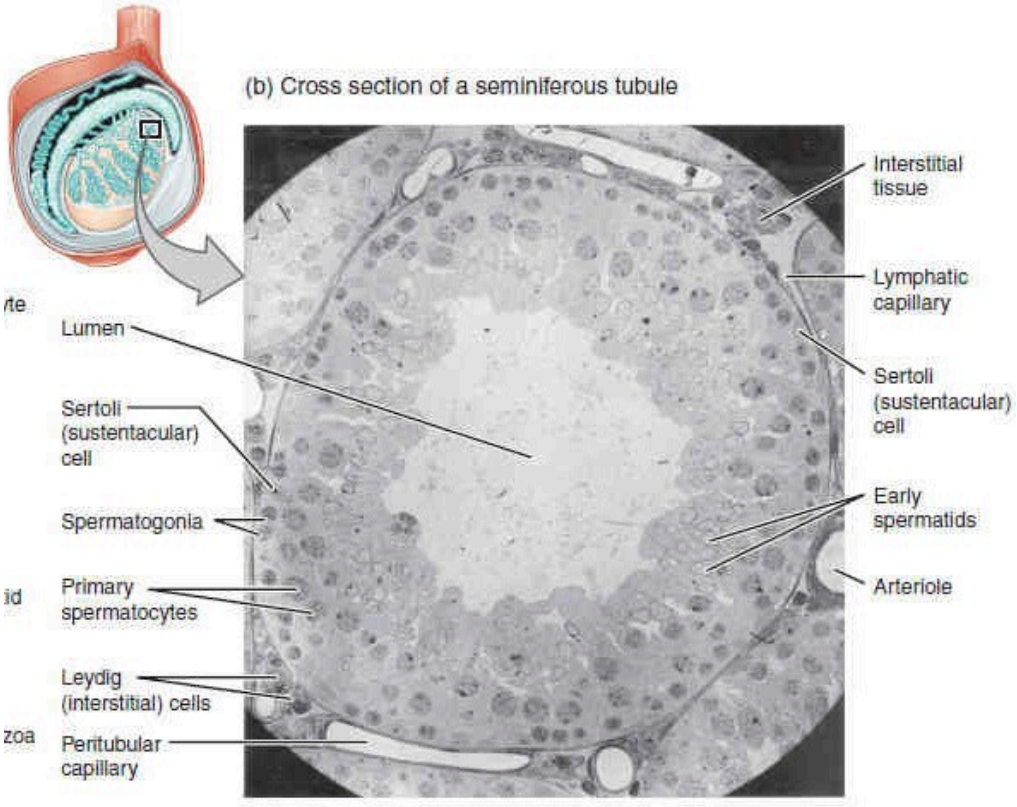


Figure 27.15 Structure of a mature sperm. Sperm cells are divided into a head, containing DNA; a mid-piece, containing mitochondria; and a tail, providing motility. The acrosome is oval and somewhat flattened. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Epididymis

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.

From the lumen of the seminiferous tubules, 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 (**Figure 4**). 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, a region known as the **body**, 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.

Spermatic cord

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 **vas deferens** is a thick, muscular tube that is bundled together inside the scrotum with connective tissue, blood vessels, and nerves, forming a structure known as the **spermatic cord** (see Figure 27.11 and Figure 27.12). Since 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.

As sperm pass through the **ampulla** (enlarged region) of the ductus deferens at ejaculation, they mix with fluid from the associated **seminal vesicles** (Figure 27.11 and Figure 27.16). The paired seminal vesicles are glands that contribute approximately 60% 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 27.16, 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 into the passing seminal fluid—now called **semen**.

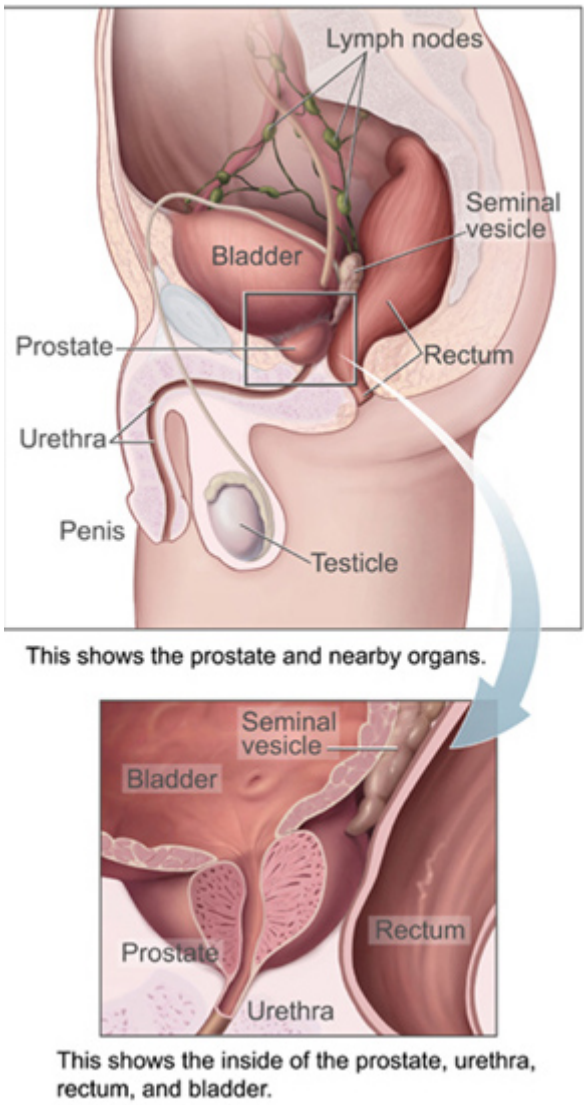


Figure 27.16 Organization of the spermatic cord and the prostate gland. a) Organization of the spermatic cord structures. An enlarged cross-section through some of these structures is found in the bottom portion of the image. b) Posterior view of the seminal vesicles and the prostate. The region of the urethra found here is known as the prostatic urethra. Credit: National Cancer Institute, Wikimedia Commons, Public Domain

The External Genitalia

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.

The **shaft** of the penis surrounds the urethra (**Figure 27.17**). Internally, 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 the **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**.

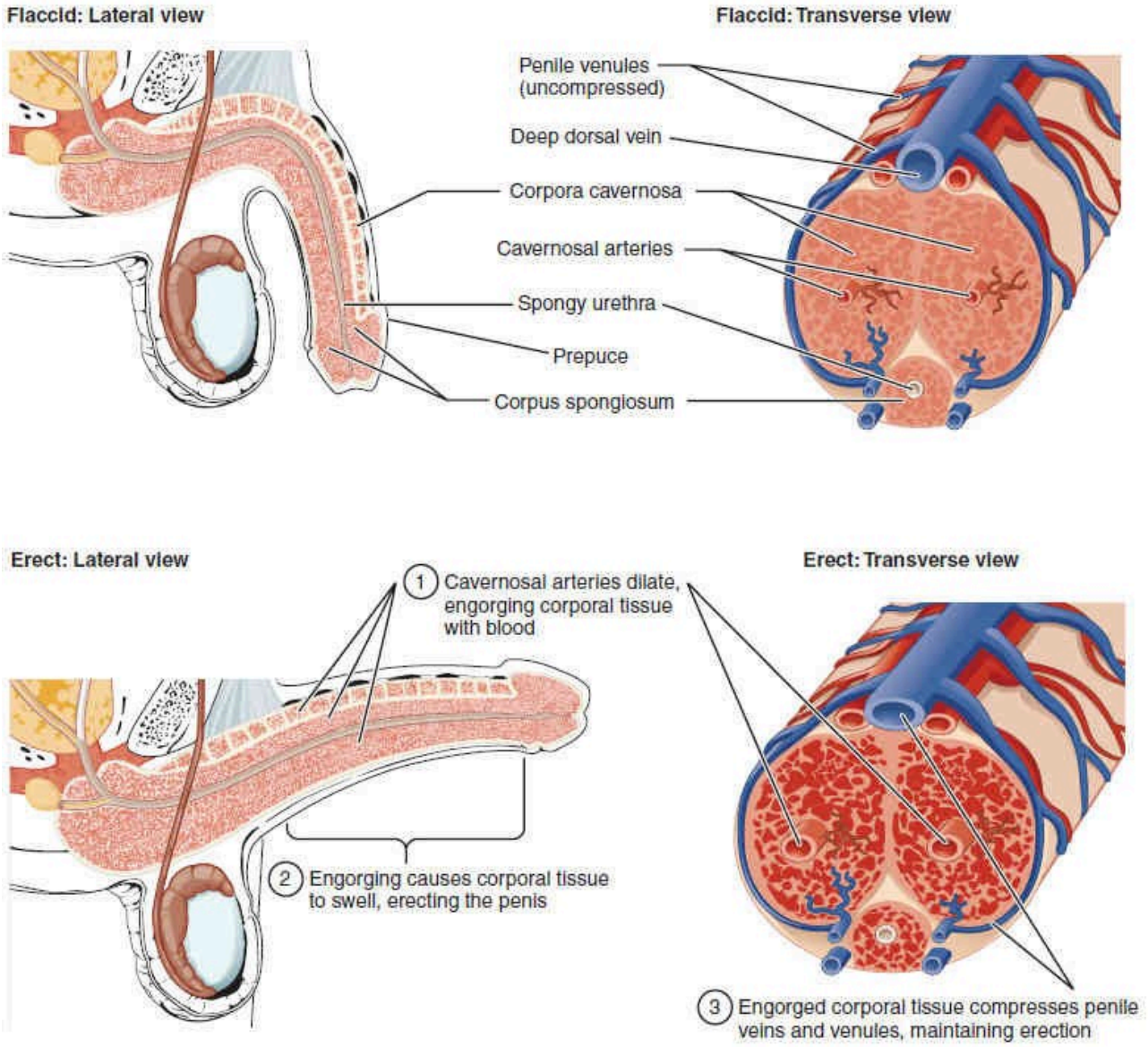


Figure 27.17. Cross-sectional anatomy of the penis. Three columns of erectile tissue make up most of the volume of the penis. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

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 (Figure 27.11). The skin from the shaft extends down over the glans and forms a collar called the **prepuce** or **foreskin** (Figure 27.11 and Figure 27.17). 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.

Both sexual arousal and REM sleep (during which dreaming occurs) can induce an erection. Penile erections are the result of engorgement of the tissues because more arterial blood flows into the penile tissues than is leaving through the veins. To initiate this process during sexual arousal, nitric oxide (NO) is

released from nerve endings near these blood vessels within the corpora cavernosa and spongiosum. Release of the NO activates a pathway that results in relaxation of the smooth muscles that surround the penile arteries, causing them to dilate. This dilation increases the amount of blood that can enter the penis and induces the endothelial cells in the penile arterial walls to also secrete NO and perpetuate the vasodilation. This rapid increase in blood volume fills the erectile chambers, and the increased pressure of the filled chambers compresses the thin-walled penile venules, preventing venous drainage of the penis. The result of this increased blood flow to the penis and reduced blood return from the penis is erection (Figure 27.17).

Hormones of the Male Reproductive System

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, though they increase during puberty, activating characteristic physical changes and initiating spermatogenesis.

The continued presence of testosterone is necessary to keep the male reproductive system working properly, and Leydig cells produce approximately 6-7 mg of testosterone per day. Maintaining these normal concentrations of testosterone promotes spermatogenesis, whereas low levels of testosterone can lead to infertility. The regulation of testosterone concentrations throughout the body is critical for male reproductive function, requiring an intricate interplay between the endocrine system and the reproductive system. The relationship between these two systems is shown in Figure 27.18.

Together, the hypothalamus and pituitary gland regulate the production of testosterone and the cells that assist in spermatogenesis. Initially, **gonadotropin-releasing hormone** (**GnRH**) from the hypothalamus activates the anterior pituitary to produce **luteinizing hormone** (**LH**) and **follicle stimulating hormone** (**FSH**), which in turn stimulate Leydig cells and Sertoli cells, respectively. The system also establishes a negative feedback loop because the end products of the pathway, testosterone and inhibin, interact with the activity of GnRH to inhibit their own production (Figure 27.18, steps 2 and 3).

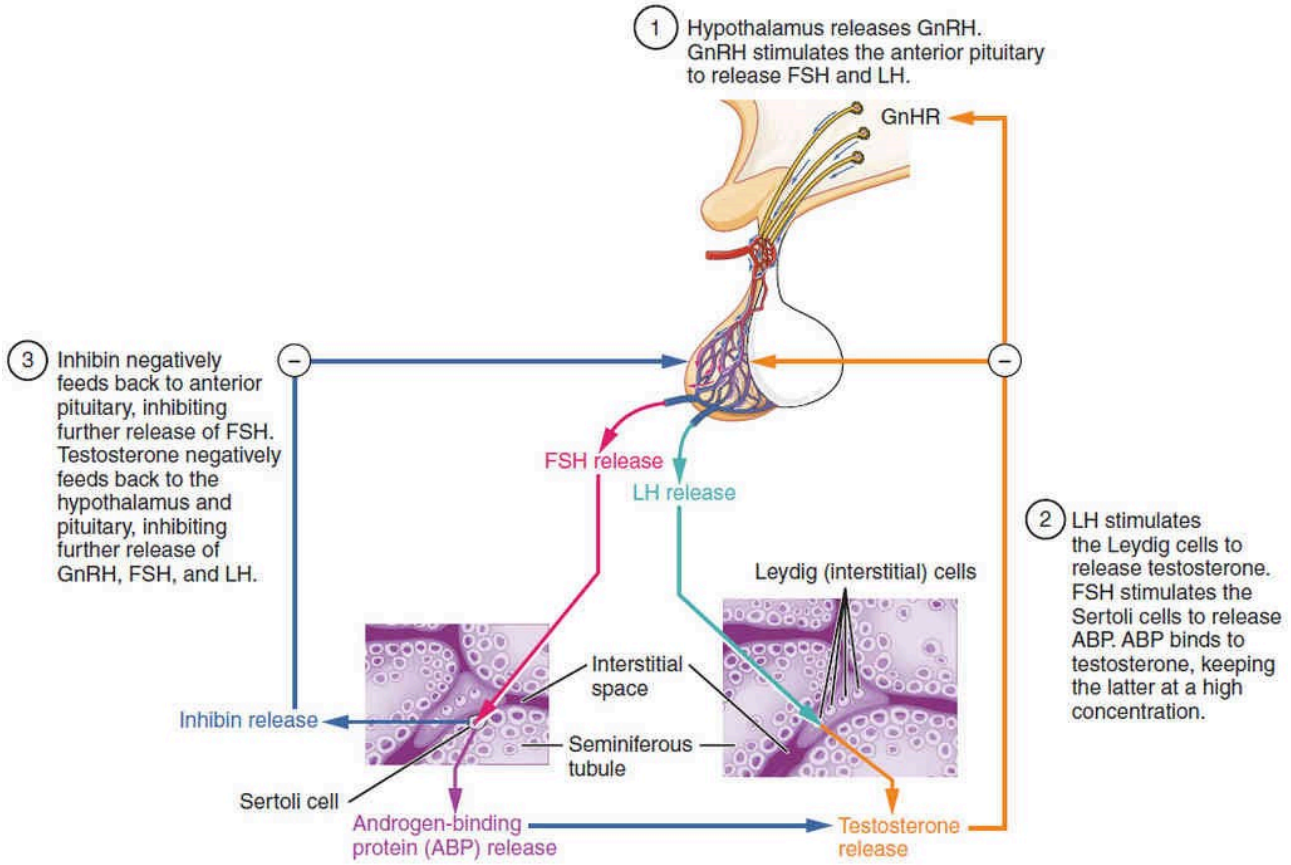


Figure 27.18 Regulation of testosterone production. The hypothalamus and pituitary gland regulate the production of testosterone and the cells that assist in spermatogenesis. GnRH activates the anterior pituitary to produce LH and FSH, which in turn stimulate Leydig cells and Sertoli cells, respectively. The system is a negative feedback loop because the end products of the pathway, testosterone and inhibin, interact with the activity of GnRH to inhibit their own production. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

The regulation of Leydig cell production of testosterone begins outside of the testes. The hypothalamus and the pituitary gland in the brain integrate external and internal signals to control testosterone synthesis and secretion. Pulsatile release of GnRH from the hypothalamus stimulates the endocrine release of hormones from the pituitary gland. Binding of GnRH to its receptors on the anterior pituitary gland stimulates release of the two gonadotropins: LH and FSH. These two hormones are critical for reproductive function in both men and women. In men, FSH binds predominantly to the Sertoli cells within the seminiferous tubules to promote spermatogenesis. FSH also stimulates the Sertoli cells to produce hormones called inhibins, which function to inhibit FSH release from the pituitary, thus reducing testosterone secretion. In men, LH binds to receptors on Leydig cells in the testes and upregulates the production of testosterone. As previously noted, a negative feedback loop predominantly controls the synthesis and secretion of both of these hormones and testosterone.

In addition to intra-testicular 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.

Pre-Laboratory Questions

1.What are the female gonads called?

- oocytes
- ova
- oviducts
- ovaries

2.Where does fertilization of the egg by the sperm typically occur?

- vagina
- uterus
- uterine tube
- ovary

3.The vulva includes the _____.

- lactiferous duct, rugae, and hymen
- lactiferous duct, endometrium, and bulbourethral glands
- mons pubis, endometrium, and hymen
- mons pubis, labia majora, and Bartholin's glands

4.From what structure does the corpus luteum originate?

- uterine corpus
- dominant follicle
- fallopian tube
- corpus albicans

5.What are male gametes called?

- ova
- sperm
- testes
- testosterone

6.Which hypothalamic hormone contributes to the regulation of the male reproductive system?

- luteinizing hormone
- gonadotropin-releasing hormone
- follicle-stimulating hormone
- androgens

7.Spermatogenesis takes place in the _____.

prostate gland
glans penis
seminiferous tubules
ejaculatory duct

8.What is the function of the epididymis?

sperm maturation and storage
produces the bulk of seminal fluid
provides nitric oxide needed for erections
spermatogenesis

Exercises

- Exercise 1 Overview of the female reproductive system
- Exercise 2 Microanatomy of the ovaries
- Exercise 3 Microanatomy of the uterus
- Exercise 4 Anatomy of the breast
- Exercise 5 Overview of the male reproductive system
- Exercise 6 Gross anatomy of the testes
- Exercise 7 Microanatomy of the testes
- Exercise 8 Histology of sperm
- Exercise 9 External genitalia

Exercise 1 Overview of the female reproductive system

Required Materials

- Torso models
- Female Reproductive System Poster
- Female Pelvis Models
- Human Uterus and Ovary Pathology Model
- Post-it notes
- Labeling tape

Procedure

1. Look at the charts and models of the female reproductive system for a general orientation. Locate the following structures. Use the post-it notes or labeling tape to label each structure on the models. Take pictures and insert these below. Alternatively, you can sketch and label.

    - Ovary
    - Uterine (fallopian) tube
    - Uterus
    - Vaginal canal
    - Clitoris
    - Labia minora (singular, *labium minus*)
    - Labia majora (singular, *labium majus*)

Exercise 2 Microanatomy of the ovaries

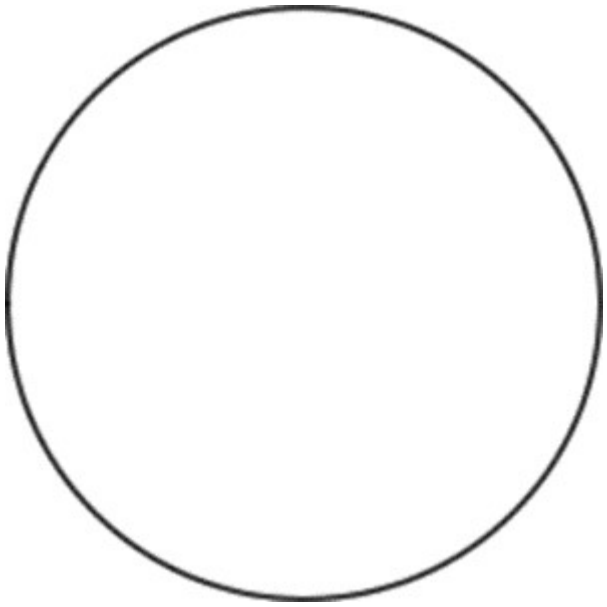
Required Materials

- Compound microscope
- Microscope lens paper
- Microscope lens cleaner
- Microscope immersion oil
- Slide of Human Ovary

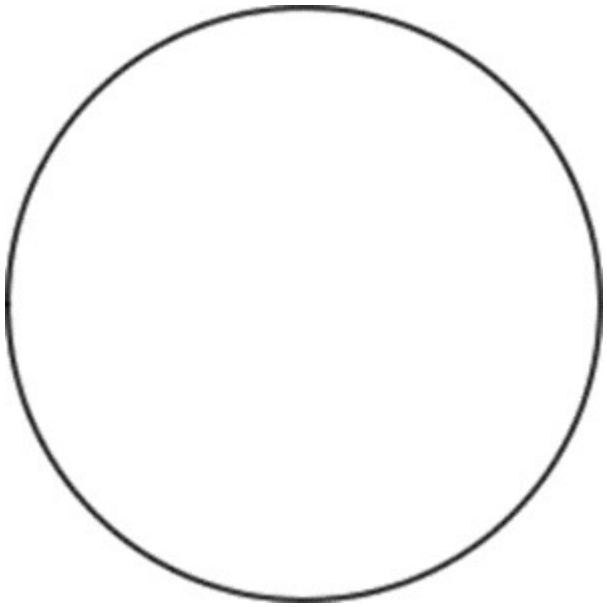
Procedure

1.Obtain a prepared slide or a histological section of the ovary. If using a microscope, observe the sample on low power.

2.Using the slide or provided image, locate the **medulla**, the highly vascularized tissue in the middle of each ovary. Once identified, look for circular structures within this region. These circles are **ovarian follicles**. Locate the **primordial follicles** in your preparation. These follicles contain **primary oocytes**, while more mature follicles will have **secondary oocytes**. Sketch and label these structures below:



3.Now observe your slide under high magnification. Using your prepared sample or image, locate the **primary**, **secondary**, and **tertiary follicles**. Some follicles may contain oocytes. Primary follicles will have a single layer of follicular cells surrounding an oocyte; secondary follicles will have multiple layers of follicular cells surrounding an oocyte; tertiary follicles contain significant amounts of fluid in the region known as the **antrum**. Using your sample and Figure 27.5, try to identify a **mature ovarian (Graafian) follicle**; these will be the largest follicles present. Sketch and label your observations below:



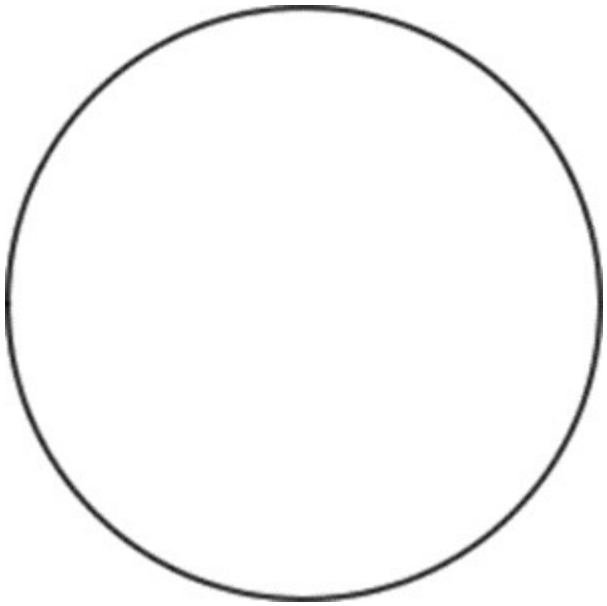
Exercise 3 Microanatomy of the uterus

Required Materials

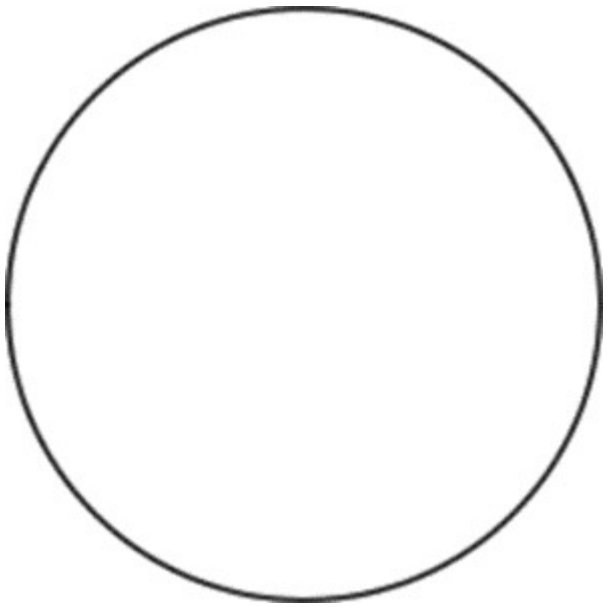
- Compound microscope
- Microscope lens paper
- Microscope lens cleaner
- Microscope immersion oil
- Slide of Human Uterus

Procedure

1.Obtain a prepared slide or a histological section of the uterus. If using a microscope, observe the sample on low power. Using the slide or provided image, locate the three layers of the uterus. Sketch and label these in the space below:



2.Now, examine the endometrium under higher power magnification. You should be able to identify two layers, including the **functional layer** and the **basal layer**. The functional layer will be the more superficial layer that is shed during **menstruation**, while the basal layer is deeper and will be retained. Using the same preparation or image, locate the myometrium. This layer will sit just deep to the endometrial tissue and it can be distinguished by the presence of smooth muscle. Draw an example of what you see below and label your drawing:



Exercise 4 Anatomy of the breast

Required Materials

- Female Reproductive System Poster
- Breast Cross Section Model (pathologies)
- Torso model
- Post-it notes
- Labeling tape

Procedure

1. Observe the external anatomy of the breast on the provided models. The major external features of the breast include the pigmented **areola**, the protruding **nipple**, the **body** of the breast, and the **axillary tail**. Identify each of these structures in the provided materials.
2. Use the provided models and charts to locate the internal structures of the breast. Much of the breast is composed of adipose tissue and embedded **mammary glands**. These glands are responsible for producing milk in lactating females. Identify the mammary gland and the following associated structures on the figure. Each gland consists of clusters of 15-20 **lobes**. Each lobe contains groups of milk-secreting cells in clusters called **alveoli**. These clusters can change in size depending on the amount of milk in the alveolar lumen. In nursing females, the mammary glands increase in size and lead to **lactiferous ducts**, which collect and direct milk to the **lactiferous sinuses**. Together, the ducts and sinuses collect and direct milk to exit the breast through the nipple.
3. Using post-it notes or labeling tape, label these structures on the models. Take pictures and insert

these in the space below. Alternatively you can sketch and label:

Exercise 5 Overview of the male reproductive system

Required Materials

- Male Reproductive System Poster
- Male Pelvis Models
- Male Pelvis with Testicular Pathology Model
- Torso models
- Post-it notes
- Labeling tape

Procedure

1. Look at the charts and models of the male reproductive system for a general orientation and locate the following structures. Use the post-it notes or labeling tape to label each structure on the models. Take pictures and insert these below. Alternatively, you can sketch and label.

    - Testis
    - Epididymis
    - Scrotal sac (scrotum)
    - Ductus (vas) deferens

- Seminal vesicle
- Prostate gland
- Bulbourethral gland
- Penis
- Urethra

Exercise 6 Gross anatomy of the testes

Required Materials

- Male Reproductive System Poster
- Male Pelvis Models
- Male Pelvis with Testicular Pathology Model
- Torso models
- Post-it notes
- Labeling tape

Procedure

1. Examine charts and a model of the testes. The **testes** are paired organs, sitting outside of the body.
2. Using the models identify the **tunica albuginea**, a tough connective sheath that surrounds the testes. Locate the invaginations of the membrane, where it invaginates to form many **lobules** within each testis. Located superficial to the tunica, is the **scrotal sac** (**scrotum**), this structure keeps the

testes on the exterior of the body, where temperature tends to be cooler and more supportive to **spermatozoa** (**sperm**) production. Locate the **dartos muscle**, a component of the scrotal sac. When the testes are cold, the muscle contracts, tightening the sac and bringing the testes closer to the body. The opposite actions occur when the environment is warm.

3. Use the post-it notes or labeling tape to label each structure on the models. Take pictures and insert these below. Alternatively, you can sketch and label.

Exercise 7 Microanatomy of the testes

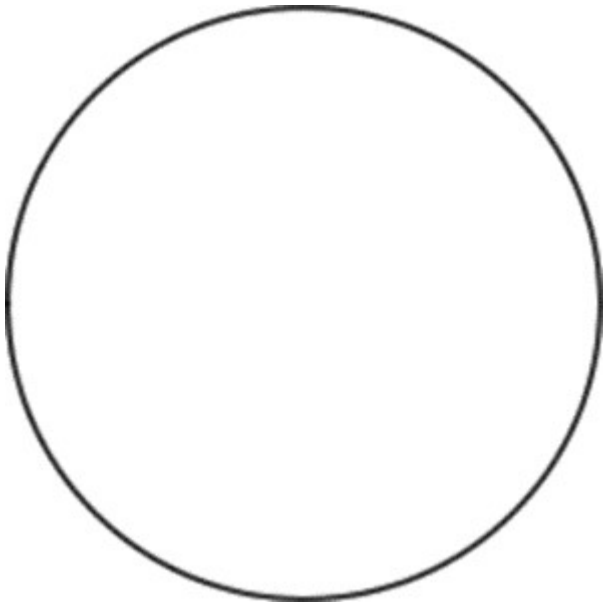
Required Materials

- Compound microscope
- Microscope lens paper
- Microscope lens cleaner
- Microscope immersion oil
- Slide of Human Testis
- Model of Meiosis

Procedure

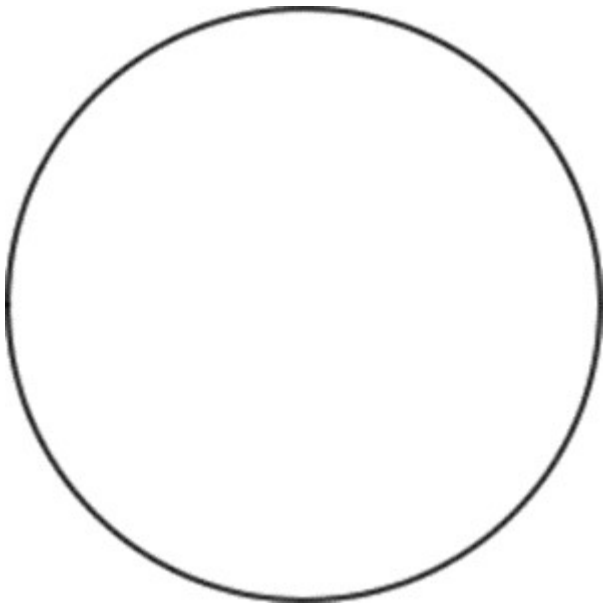
1. Obtain a prepared slide or a histological section of the testes. Identify the **seminiferous tubules** .

Multiple tubules may be identifiable in the preparation. It is within these structures where sperm are produced. Look for the triangular clusters of cells in between each tubule. These are the **interstitial (Leydig) cells**. They will produce the male sex hormone, **testosterone**. Sketch and label these tubules and interstitial structures in the space below:



2. Examine the seminiferous tubules under high magnification. You should be able to see an outer row of cells, known as the **spermatogonia**. These cells will divide by the process of mitosis, giving rise to **primary spermatocytes**. The primary spermatocytes will then undergo meiosis, or reduction division, to eventually produce **spermatozoa**. To do so, primary spermatocytes will initially divide to form **secondary spermatocytes**, which are found closer to the lumen of the seminiferous tubules. These cells will then become **spermatids**. Ultimately, the spermatids will lose their remaining cytoplasm and mature into functional **spermatozoa**. Locate the primary and secondary spermatocytes, spermatids, and spermatozoa. You may be able to see **sustentacular (Sertoli) cells**, which help nourish, support, and move the sperm during development.

3. Draw an example of what you see at high magnification of what is listed in step 2 in the space provided below:



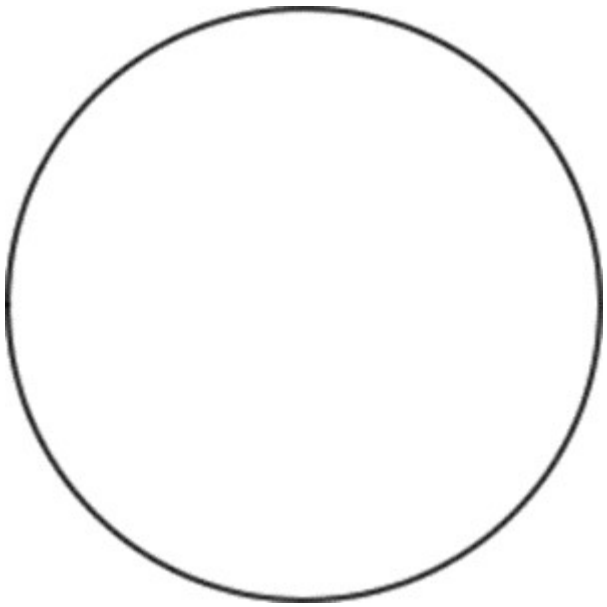
Exercise 8 Histology of sperm

Required Materials

- Compound microscope
- Microscope lens paper
- Microscope lens cleaner
- Microscope immersion oil
- Slide of Human Sperm

Procedure

1. Examine a prepared slide of sperm.
2. Identify the different components of the sperm cell. Each sperm consists of a **head**, **midpiece**, and **tail**. Sketch and label these structures below:



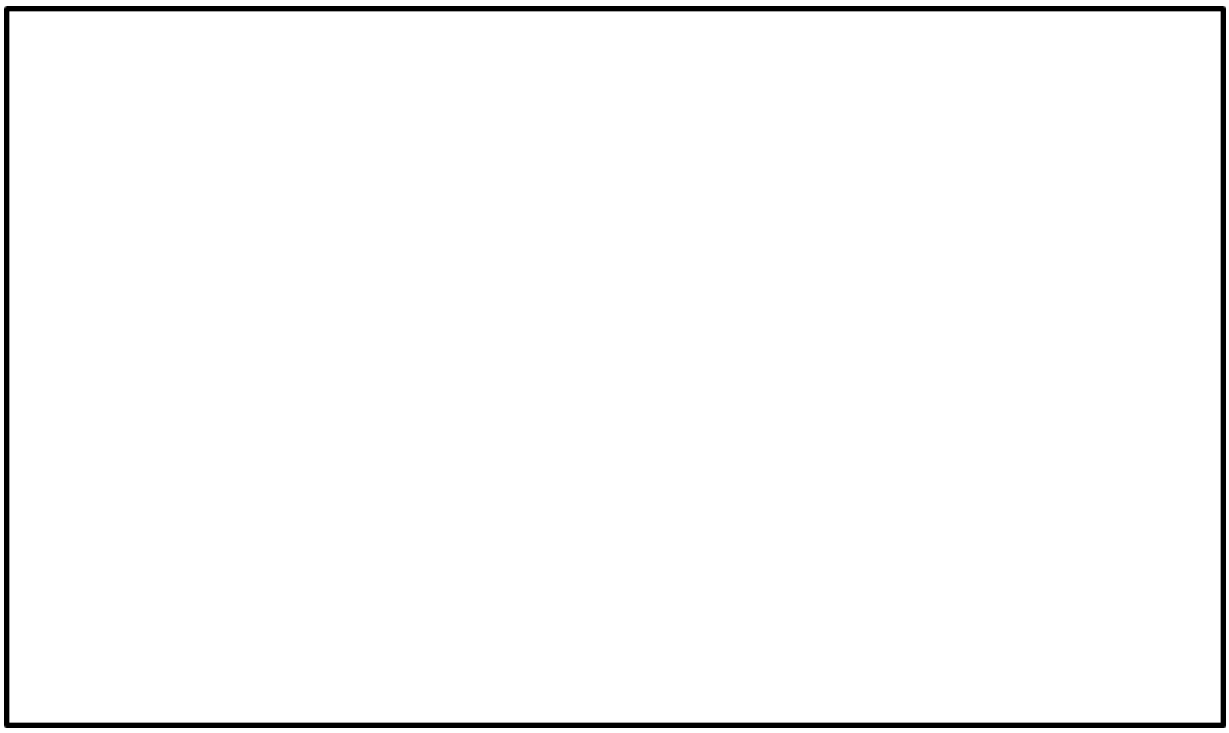
Exercise 9 External genitalia

Required Materials

- Male Reproductive System Poster
- Male Pelvis Models
- Male Pelvis with Testicular Pathology Model
- Torso Models.
- Post-it notes
- Labeling tape

Procedure

1. In addition to the testes, which are housed within the scrotum, the penis is considered to contribute to the external genitalia of a male's reproductive system. Use the provided models to locate and observe the external anatomy of the penis. The penis consists of the **root**, **bulb**, an elongated **shaft**, and a distally expanded region known as that **glans penis**. The glans is covered with the prepuce, or **foreskin**. Identify and label all of these structures using post-it notes or labeling tape. Take pictures and insert below. Alternatively, you can sketch and label.



2. Now, examine a model or chart of a cross section of the penis. Notice that the penis contains three distinct cylinders of erectile tissue that are anchored to the body proximally. Identify the **corpus spongiosum**, the cylinder of erectile tissue that contains the **spongy** (**penile**) **urethra**. Located dorsal to the spongiosum, two cylinders of **corpus cavernosa** are located. Follow the corpus spongiosum as it extends distally. At the most distal region of the penis, this tissue expands to form the glans penis. Note the **dorsal arteries** and **deep** (**cavernosal**) **arteries.** Together, these vessels take blood to the penis. When these vessels dilate, the erectile tissue of the penis engorge with blood, making the penis erect. Also locate the **dorsal vein** and **venules** of the penis. These vessels will remove blood from the penis, except for when the penis is erect. At this point, these vessels are compressed, preventing venous drainage of the penis.
3. Sketch and label all of the structure listed in step 2 in the space below:

Post-laboratory Questions

1. The _____ is the inner epithelial lining of the uterus.
2. A follicle is comprised of _____ cells, _____ cells, and the _____.
3. The finger-like structures on the fallopian tube that help sweep the ovum into the ampulla are called _____.
4. The layer of cells surrounding the ovulated ovum are called the _____.
5. The _____ holds the uterus and ovaries in place within the body.
6. The _____ is the layer of the endometrium that is shed every month.
7. The _____ is a tube that allows sperm cells to travel from the testes to the urethra.
8. Which cells are responsible for the production of testosterone in response to LH from the anterior pituitary?
9. The _____, _____, and _____, provide important fluids to the sperm before ejaculation.
10. True or False: warmer temperatures (above body temp) are essential for spermatogenesis.

28.

CHAPTER 28 DEVELOPMENT AND INHERITANCE

By Aylin Marz

Motivation.

Infant mortality is the death of an infant before his or her first birthday. The infant mortality rate is the number of infant deaths for every 1,000 live births. In addition to giving us key information about maternal and infant health, the infant mortality rate is an important marker of the overall health of a society. In 2020, the infant mortality rate in the United States was 5.4 deaths per 1,000 live births.

Almost 20,000 infants died in the United States in 2020. The five leading causes of infant death in 2020 were:

1. Birth defects.
2. Preterm birth and low birth weight.
3. Sudden infant death syndrome.
4. Injuries (e.g., suffocation).
5. Maternal pregnancy complications.

Racial and ethnic disparities are abundant and show that African American mothers lose their infants at an alarmingly higher rate than majority/white mothers (Figure 28.1). This is disturbing and we need to better understand how to improve maternal and infant health to fix this problem.

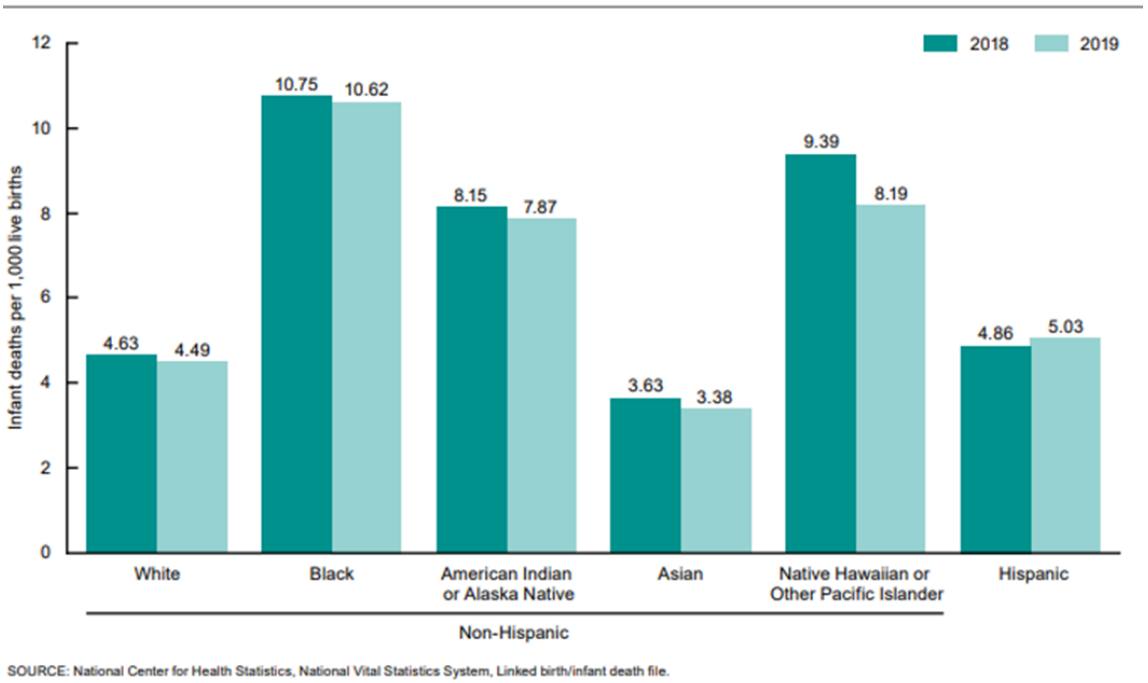


Figure 28.1 Infant mortality rates in the U.S. by race and ethnicity of the mother. Source: Centers for Disease Control, National Vital Statistics Reports, Infant Mortality in the United States, 2019. License, Public Domain.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Apply knowledge of fertilization and reproductive anatomy to a scenario on IVF success
- Describe the features of embryonic and fetal development using models
- Create models of Punnett squares to determine the outcome of crosses for different types of hereditary diseases

Background.

Fertilization

Hundreds of millions of sperm deposited in the vagina travel toward the oocyte, but only a few hundred actually reach it. The number of sperm that reach the oocyte is greatly reduced because of conditions within the female reproductive tract. Many sperm are overcome by the acidity of the vagina, others are blocked by mucus in the cervix, whereas others are attacked by phagocytic leukocytes in the uterus. Those sperm that do survive undergo a change in response to those conditions. They go through the process of capacitation, which improves their motility and alters the membrane surrounding the acrosome, the cap-like structure in the head of a sperm that contains the digestive enzymes needed for it to attach to and penetrate the oocyte.

The oocyte that is released by ovulation is protected by a thick outer layer of granulosa cells known as the corona radiata and by the zona pellucida, a thick glycoprotein membrane that lies just outside the oocyte's plasma membrane. When capacitated sperm make contact with the oocyte, they release the digestive enzymes in the acrosome (the acrosomal reaction) and are thus able to attach to the oocyte and burrow through to the oocyte's zona pellucida. One of the sperm will then break through to the oocyte's plasma membrane and release its haploid nucleus into the oocyte. The oocyte's membrane structure changes in response (cortical reaction), preventing any further penetration by another sperm and forming a fertilization membrane. Fertilization is complete upon unification of the haploid nuclei of the two gametes, producing a diploid zygote (Figure 28.2).

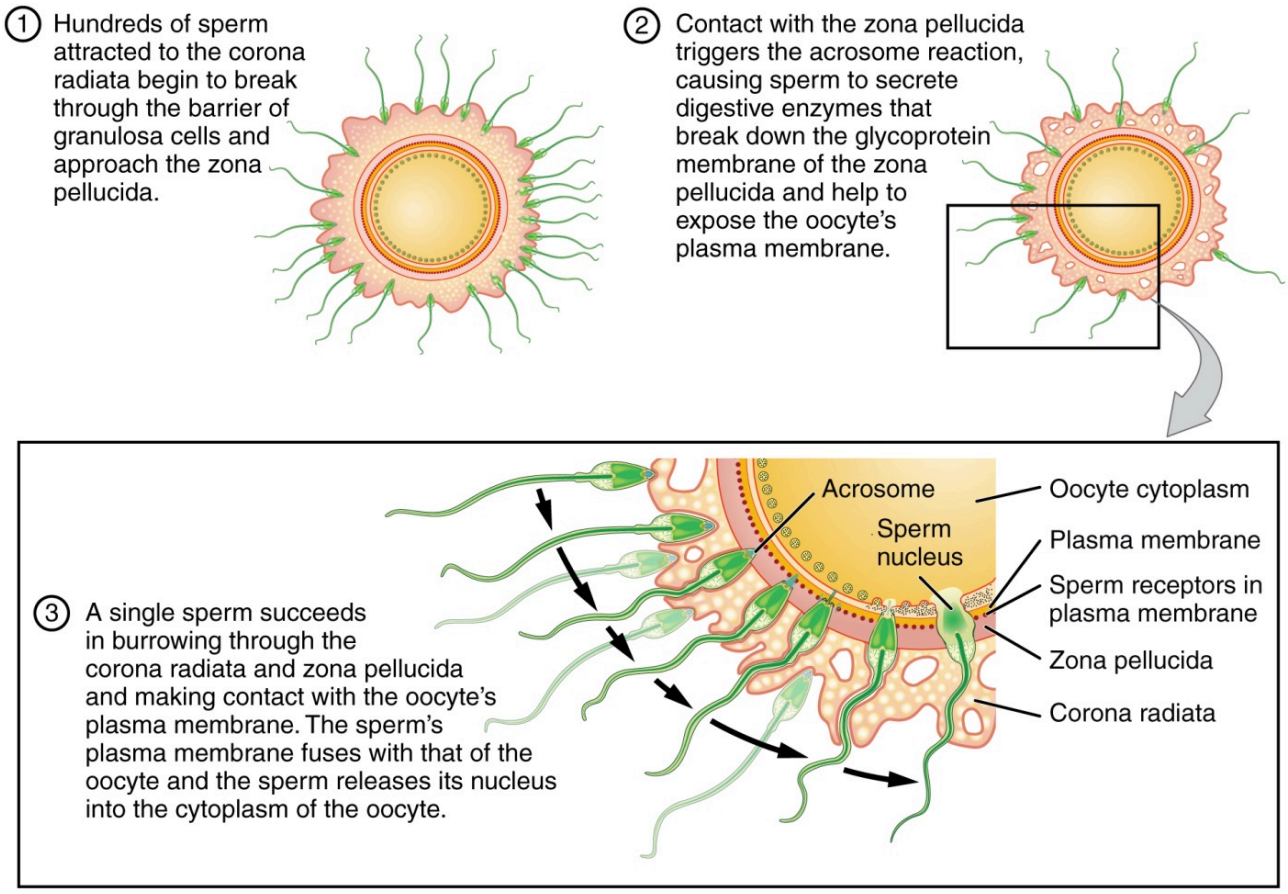


Figure 28.2. Sperm, ovulated oocyte, and fertilization. Credit: OpenStax Anatomy and Physiology, CC-BY 4.0 license

In vitro fertilization (IVF)

One form of fertility treatment for couples who have trouble conceiving is *in vitro* fertilization or IVF. In this treatment, the spem and ooctye are fertilized in a "test tube" outside the body. The zygote, after a few divisions, is transplanted into the uterus to allow for development in utero (Figure 28.3).

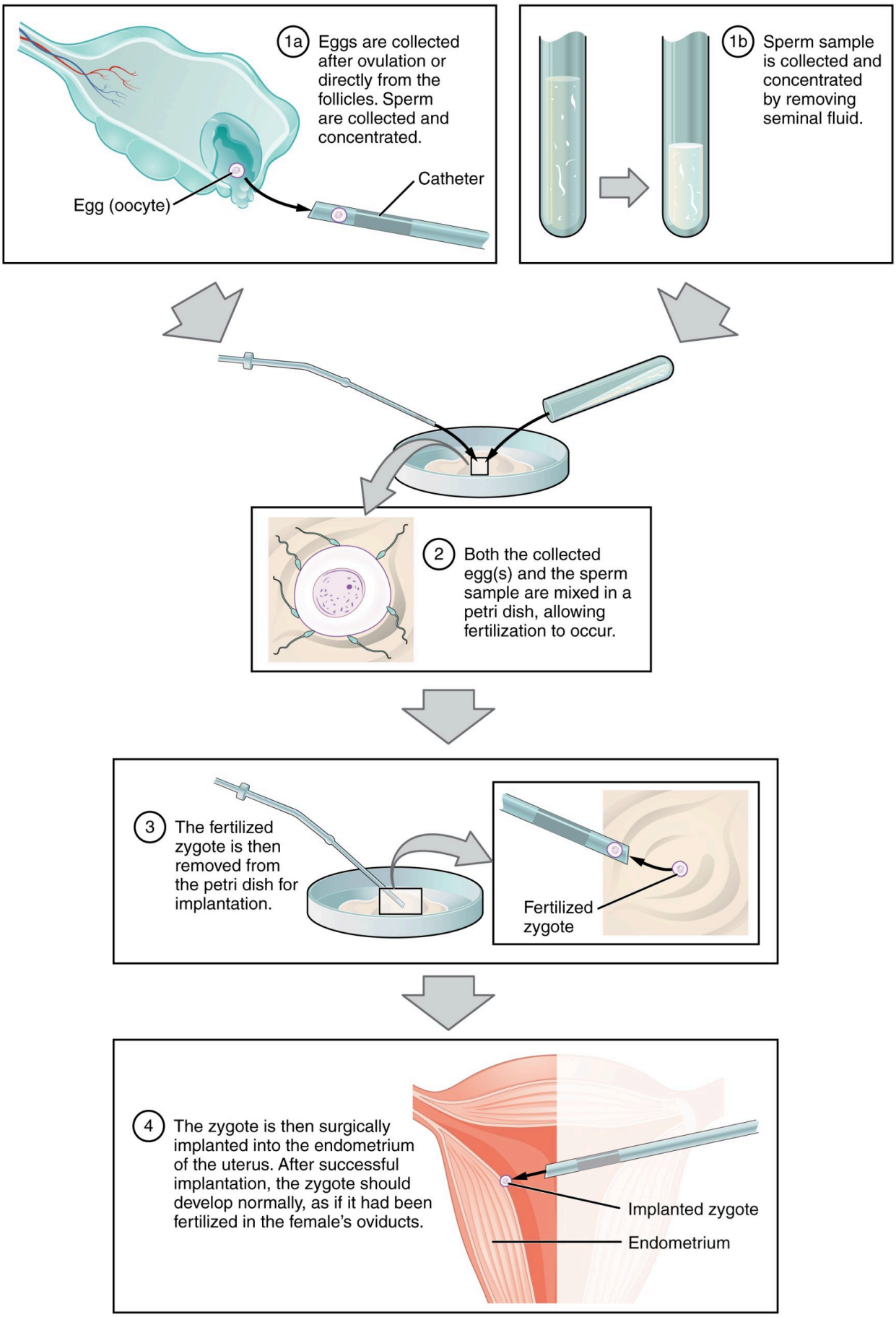


Figure 28.3 In vitro fertilization (IVF). This is a treatment used for infertility due to structural issues that interfere with sperm and oocyte finding each other in the oviduct. Credit: OpenStax

This treatment helps overcome conception issue due to low sperm count, structural difficulties getting sperm and oocyte to meet to fertilize, and structural issues that interfere with the fertilized oocyte to travel down the oviduct to implant into the uterine wall.

Embryonic and Fetal Development

As the zygote travels toward the uterus, it undergoes numerous cleavages in which the number of cells doubles going from one fertilized zygote cell to two-cell, four-cell, eight-cell etc. stages (*blastomeres*). Upon reaching the uterus, the conceptus has become a tightly packed sphere of cells called the *morula*, which then forms into a *blastocyst* consisting of an inner cell mass within a fluid-filled cavity surrounded by trophoblasts. The blastocyst implants in the uterine wall, the trophoblasts fuse to form a syncytiotrophoblast, and the conceptus is enveloped by the endometrium (Figure 28.4).

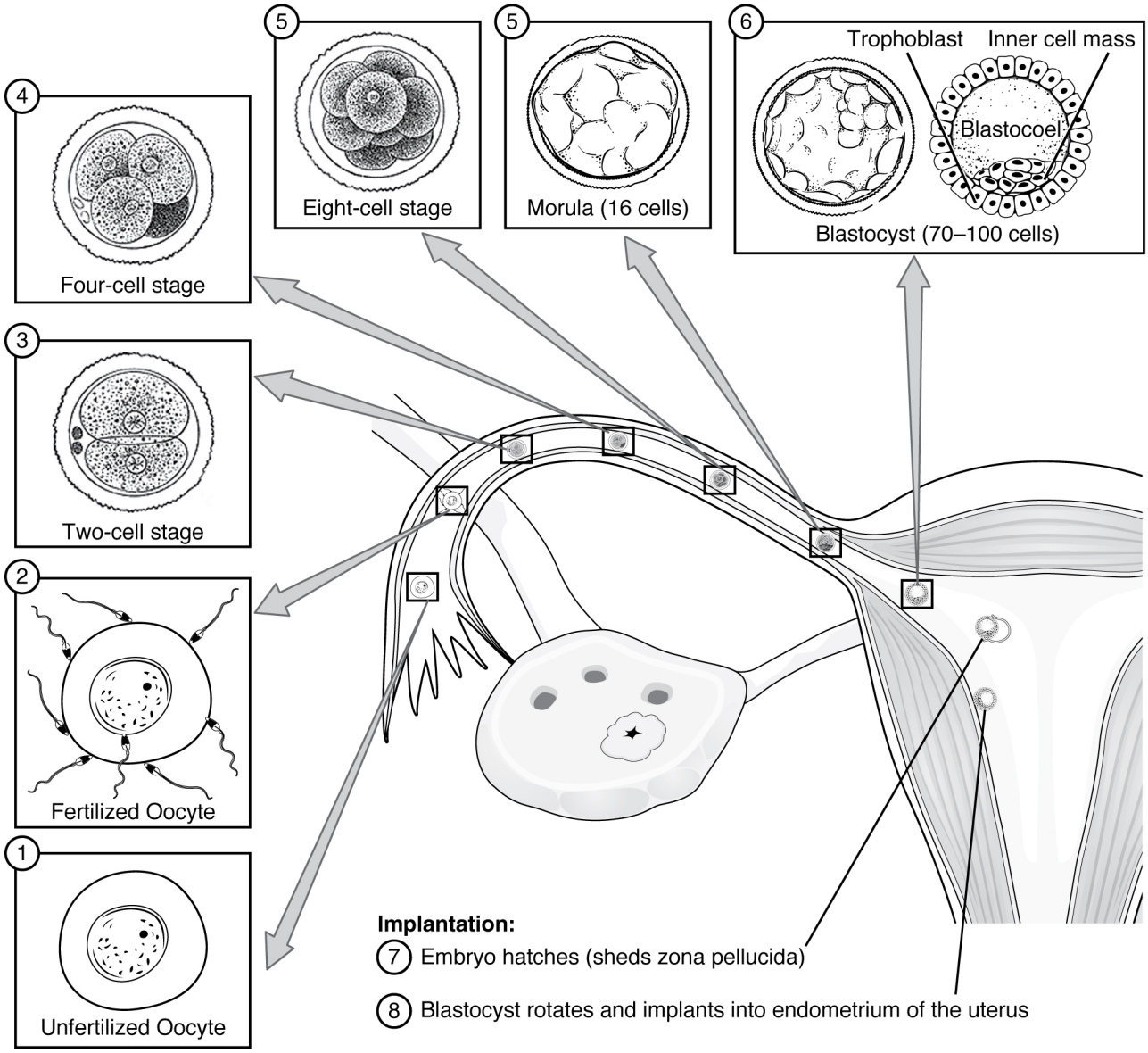


Figure 28.4 Pre-embryonic development. Ovulation, fertilization, pre-embryonic development, and implantation occur at specific locations within the female reproductive system in a time span of approximately 1 week. Credit: OpenStax Anatomy and Physiology, license CC-BY-4.0

Four embryonic membranes form to support the growing embryo: the amnion, the yolk sac, the allantois, and the chorion. The chorionic villi of the chorion extend into the endometrium to form the fetal portion of the *placenta*. The placenta supplies the growing embryo with oxygen and nutrients; it also removes carbon dioxide and other metabolic wastes.

Following implantation, embryonic cells undergo *gastrulation*, in which they differentiate and separate into an embryonic disc and establish three primary germ layers (the endoderm, mesoderm, and ectoderm). Through the process of embryonic folding, the fetus begins to take shape. Neurulation starts the process of the development of structures of the central nervous system and organogenesis establishes the basic plan for all organ systems. (Figure 28.5)

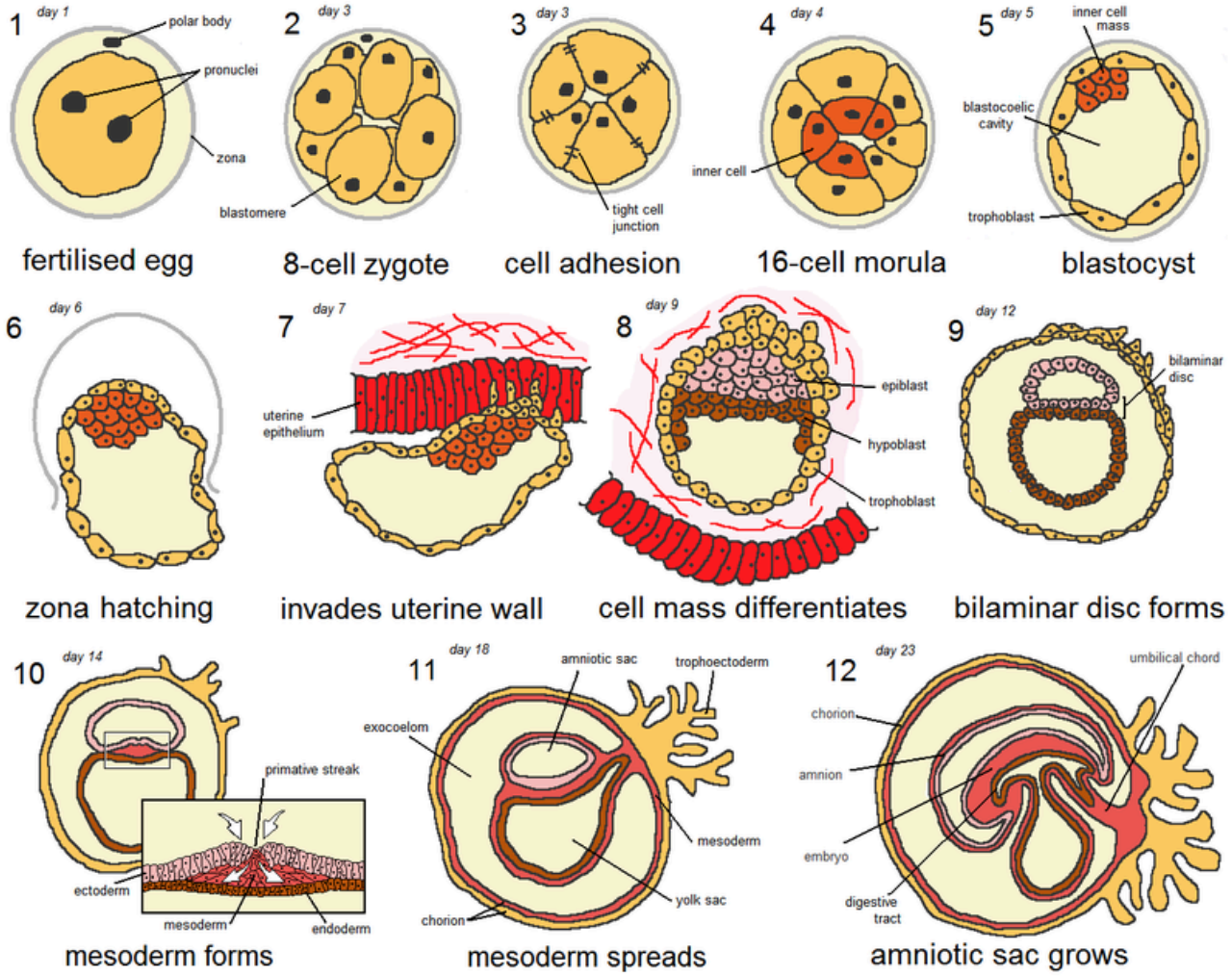


Figure 28.5 The first few weeks of embryogenesis in humans. Beginning at the fertilized egg, ending with the closing of the neural tube. Credit: Zephyrs on Wikimedia Commons, license CC-BY-SA-3.0.

The fetal period lasts from the ninth week of development until birth. During this period, male and female *gonads* differentiate. The fetal *circulatory system* becomes much more specialized and efficient than its embryonic counterpart. It includes three shunts—the ductus venosus, the foramen ovale, and the ductus arteriosus—that enable it to bypass the semifunctional liver and pulmonary circuit until after childbirth. The *brain* continues to grow and its structures differentiate. *Facial features* develop, the body elongates, and *the skeleton ossifies*. In the womb, the developing fetus moves, blinks, practices sucking, and circulates amniotic fluid. The fetus grows from an embryo measuring approximately 3.3 cm (1.3 in) and weighing 7 g (0.25 oz) to an infant measuring approximately 51 cm (20 in) and weighing an average of approximately 3.4 kg (7.5 lbs). Embryonic organ structures that were primitive and nonfunctional develop to the point that the newborn can survive in the outside world (Figure 28.6).

Figure 28.6 Fetal stages of development. From week 9 to birth. Credit: Diana Lang, Parenting and Family Diversity Issues, Pressbooks, Iowa State University Digital Press. License, CC-BY-4.0

Pregnancy, Labor, Birth and Later Stages. Hormones (especially estrogens, progesterone, and hCG) secreted by the corpus luteum and later by the placenta are responsible for most of the changes experienced during pregnancy. Estrogen maintains the pregnancy, promotes fetal viability, and stimulates tissue growth in the mother and developing fetus. Progesterone prevents new ovarian follicles from developing and suppresses uterine contractility.

Pregnancy weight gain primarily occurs in the breasts and abdominal region. Nausea, heartburn, and frequent urination are common during pregnancy. Maternal blood volume increases by 30 percent during

pregnancy and respiratory minute volume increases by 50 percent. The skin may develop stretch marks and melanin production may increase.

Toward the late stages of pregnancy, a drop in progesterone and stretching forces from the fetus lead to increasing uterine irritability and prompt labor. Contractions serve to dilate the cervix and expel the newborn. Delivery of the placenta and associated fetal membranes follows.

The first breath a newborn takes at birth inflates the lungs and dramatically alters the circulatory system, closing the three shunts that directed oxygenated blood away from the lungs and liver during fetal life. Clamping and cutting the umbilical cord collapses the three umbilical blood vessels. The proximal umbilical arteries remain a part of the circulatory system, whereas the distal umbilical arteries and the umbilical vein become fibrotic. The newborn keeps warm by breaking down brown adipose tissue in the process of nonshivering thermogenesis. The first consumption of breast milk or formula floods the newborn's sterile gastrointestinal tract with beneficial bacteria that eventually establish themselves as the bacterial flora, which aid in digestion.

The lactating mother supplies all the hydration and nutrients that a growing infant needs for the first 4–6 months of life. During pregnancy, the body prepares for lactation by stimulating the growth and development of branching lactiferous ducts and alveoli lined with milk-secreting lactocytes, and by creating colostrum. These functions are attributable to the actions of several hormones, including prolactin. Following childbirth, suckling triggers oxytocin release, which stimulates myoepithelial cells to squeeze milk from alveoli. Breast milk then drains toward the nipple pores to be consumed by the infant. Colostrum, the milk produced in the first postpartum days, provides immunoglobulins that increase the newborn's immune defenses. Colostrum, transitional milk, and mature breast milk are ideally suited to each stage of the newborn's development, and breastfeeding helps the newborn's digestive system expel meconium and clear bilirubin. Mature milk changes from the beginning to the end of a feeding. Foremilk quenches the infant's thirst, whereas hindmilk satisfies the infant's appetite.

Patterns of Inheritance. There are two aspects to a person's genetic makeup. Their genotype refers to the genetic makeup of the chromosomes found in all their cells and the alleles that are passed down from their parents. Their phenotype is the expression of that genotype, based on the interaction of the paired alleles, as well as how environmental conditions affect that expression.

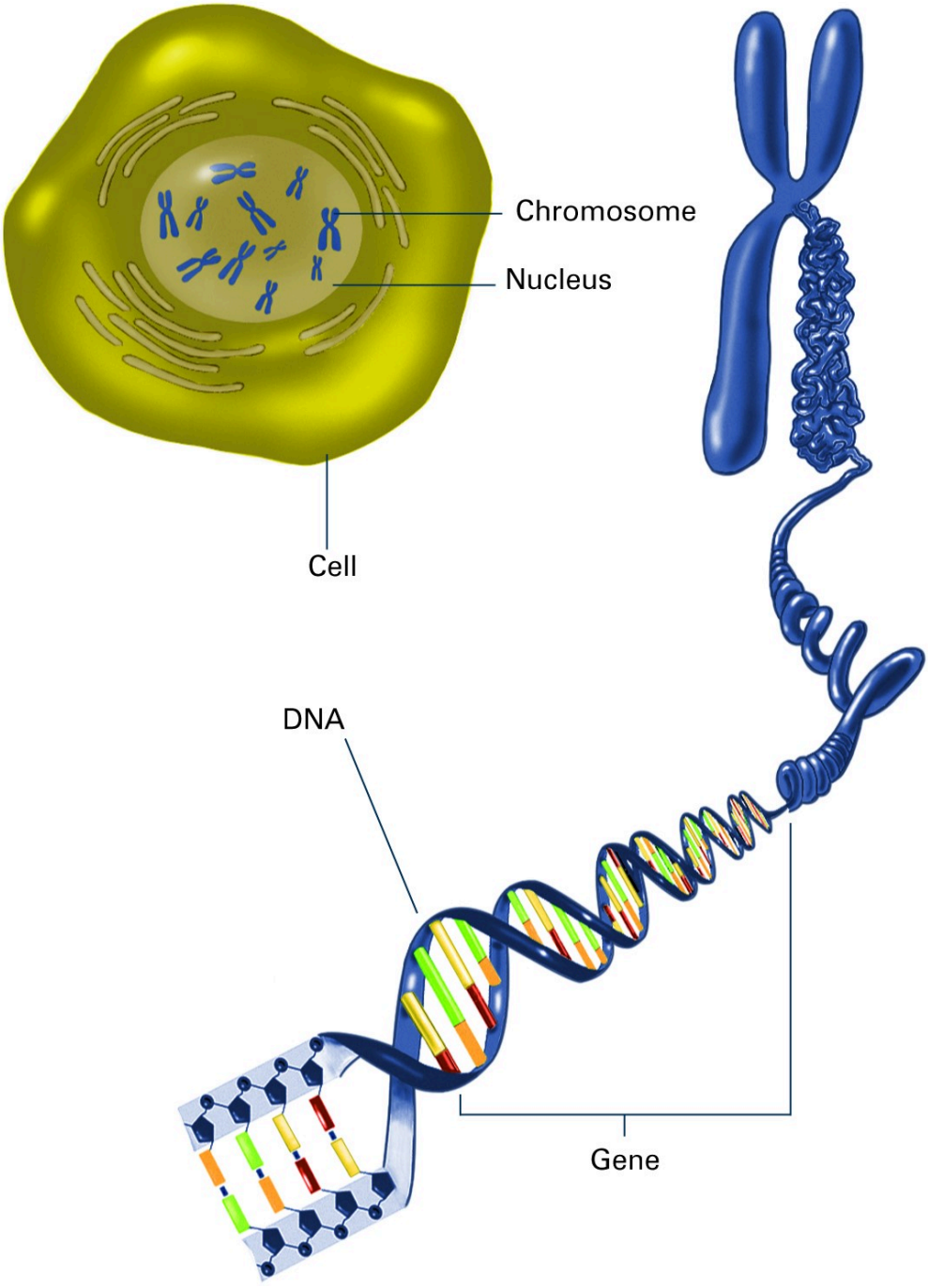


Figure 28.7 DNA makes up genes and is spooled within chromosomes inside the nucleus of a cell. Credit: National Institute of General Medical Sciences. License, Public Domain.

We inherit one copy of a gene from our mother and the other from our father; as genes come in pairs on diploid chromosomes. Each gamete, egg or sperm, has one copy of each gene type. Variants of genes are called **alleles**. We have a pair of alleles for each trait. Some alleles are dominant over others that are recessive. The dominant allele is expressed or observed if one **dominant** and one **recessive** allele are present. For example, for sickle cell anemia the allele HbS is recessive to the normal allele HbA. In order to have sickle cell disease we have to inherit an HbS allele from each parent (Figure 28.8)

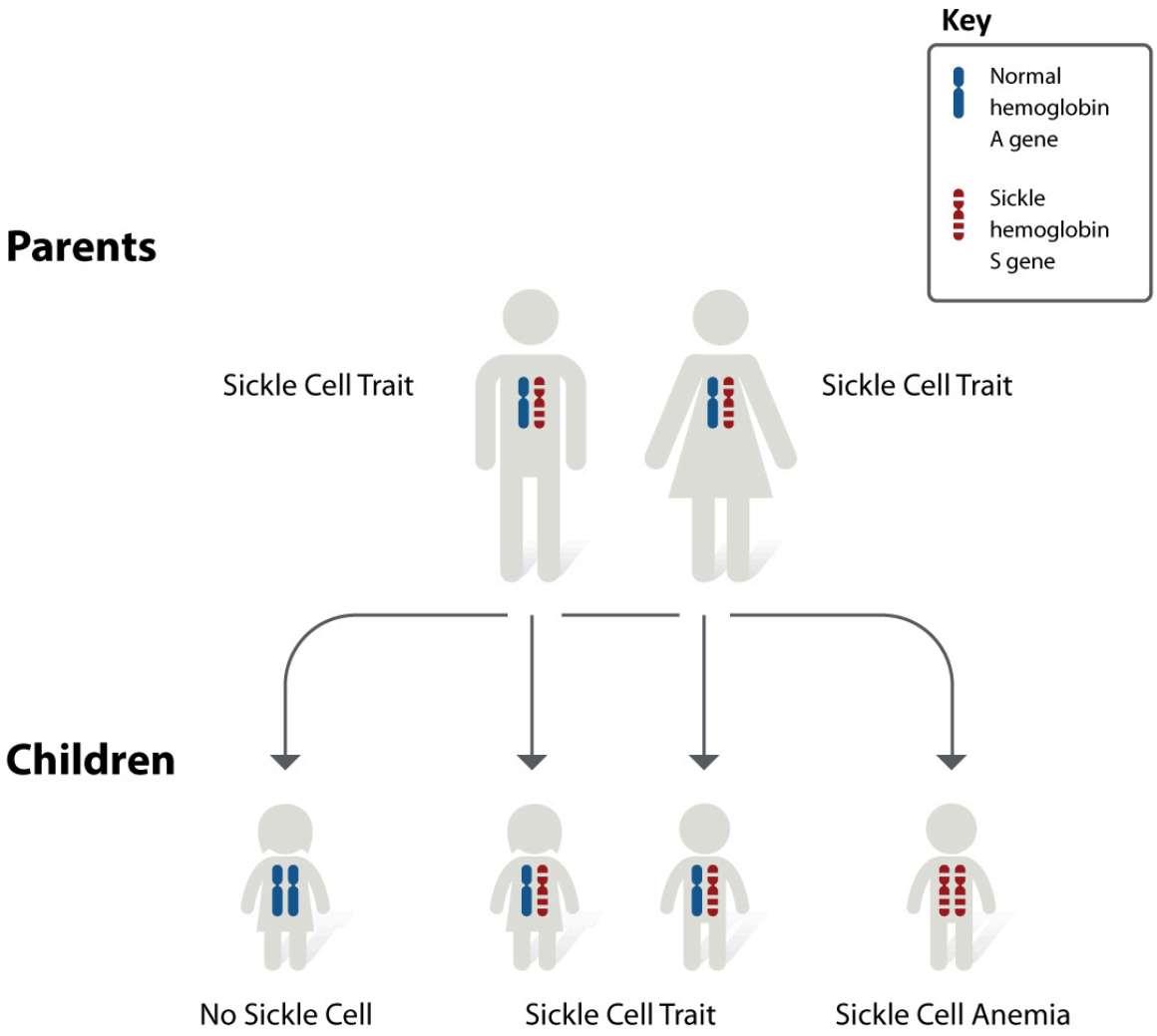


Figure 28.8 Inheritance pattern for sickle cell disease. Parents are carriers and have one copy of the sickle cell allele only. Each parent has an equal chance of passing on a normal or sickle cell disease allele to their children as shown. Credit: National Heart Lung and Blood Institute. License, Public Domain.

Human genetics focuses on identifying different alleles and understanding how they express themselves. Medical researchers are especially interested in the identification of inheritance patterns for genetic disorders, which provides the means to estimate the risk that a given couple's offspring will inherit a genetic disease or disorder. Patterns of inheritance in humans include autosomal dominance and recessiveness, X-linked dominance and recessiveness, incomplete dominance, codominance, and lethality. A change in the nucleotide sequence of DNA, which may or may not manifest in a phenotype (observed characteristic), is called a mutation.

Pre-Laboratory Questions

1. What is IVF?
2. At what week of pregnancy do we switch the terminology from embryo to fetus?
3. How many alleles of each gene do you have in a diploid cell? In a haploid sperm or egg cell?

Exercises

- Exercise 1 In vitro fertilization (IVF)
- Exercise 2 Embryonic and fetal development
- Exercise 3 Patterns of Inheritance

Exercise 1 In vitro fertilization (IVF)

Required Materials

- Human Uterus and Ovary Pathology Model
- Male Pelvis with Testicular Pathology Model
- Female Reproductive System Poster
- Male Reproductive System Poster

Procedure

1.Examine the **Human Uterus and Ovary Pathology Model**. List all the pathologies shown on this model that you think would interfere with fertility. For each, explain which part of the process the disorder would interfere with. In the third column, answer the questions "Would IVF help? Yes or No". In the fourth column, what IVF fixes to enable fertility.

Pathology	Interferes with (which process in conception)	Would IVF help?	How does IVF help?

2.Examine the **Male Pelvis with Testicular Pathology Model.** List all the pathologies shown on this model that you think would interfere with fertility. For each, explain which part of the process the disorder would interfere with. In the third column, answer the questions "Would IVF help? Yes or No". In the fourth column, what IVF fixes to enable fertility.

Pathology	Interferes with (which process in conception)	Would IVF help?	How does IVF help?

Exercise 2 Embryonic and fetal development

Required Materials

- Pregnancy Series Model (3B Scientific L10)
- Complete Anatomy 2022 App by 3D4Medical. Activated by the QR code on the pregnancy series model.

Procedure

1. Download the Complete Anatomy 2022 App by 3D4Medical. Activate the app by using the QR code on the Pregnancy Series Model (3B Scientific L10). https://www.youtube.com/watch?v=5sAtUWAn458
2. Using the app and other resources available to you examine the 8 models that show the following stages of development / conditions. For each stage / condition, list the main features:

    - 1st Month Embryo:
    - 2nd Month Embryo:
    - 3rd Month Embryo:
    - 4th Month Fetus (Transverse Lie):
    - 5th Month Fetus (Breech Position):
    - 5th Month Fetus (Transverse Lie):
    - 5th Month Twin Fetuses (Normal Position):
    - 7th Month Fetus:

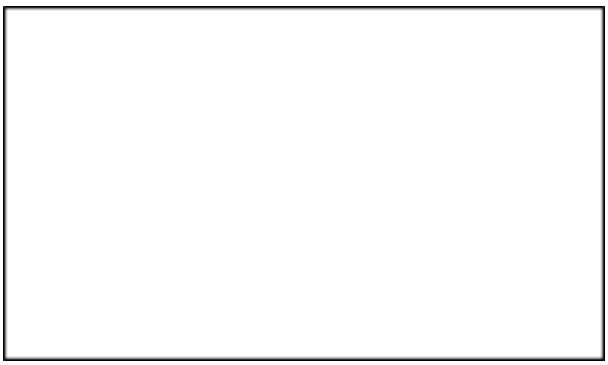
Exercise 3 Patterns of inheritance

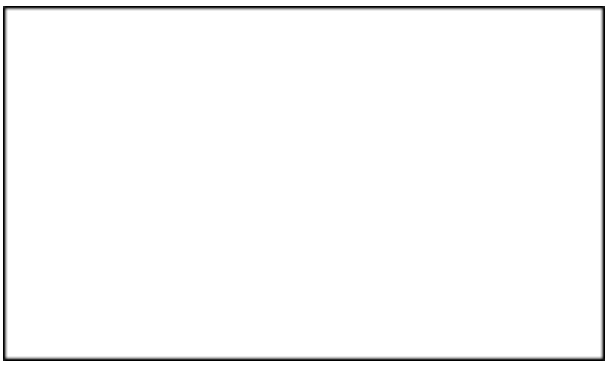
Required Materials

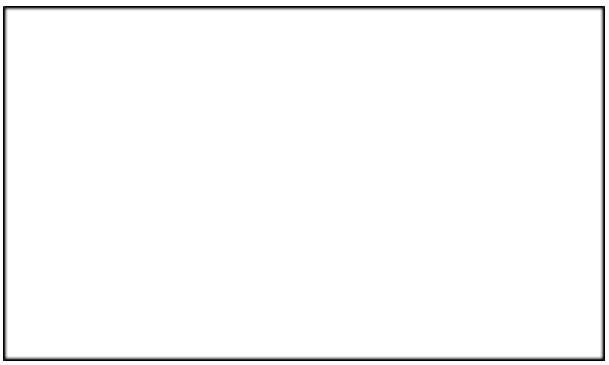
- Wooden sticks
- Marker pens
- Construction paper

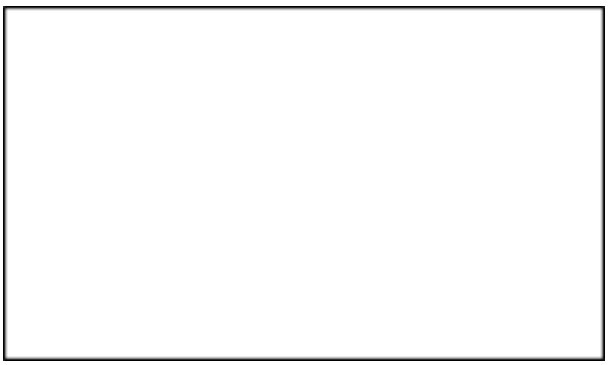
Procedure

1. In Figure 28.8 we saw an example of how a recessive disease is inherited. We see the potential outcome for children if both parents are carriers (have one copy of the disease allele). In recessive inheritance, you have to have both copies of the recessive allele to have the disease.
2. In this exercise, we are going to work with the inheritance of another gene called BRCA1. A mutation in this gene (or an allele of it) increases risk of developing breast cancer. The inheritance of this alelle is dominant.
3. Using the wooden sticks, set up the chromosomes of two parents both of whom have one copy of the BRCA1 mutant allele. Use red color for BRCA1 mutant and blue color for normal alleles.
4. Place four different construction paper pages onto your desk.
5. Work out all possible combinations of alleles that a child of these parents can inherit.
6. For each allele combination, indicate whether the child will be at higher risk of developing breast cancer or not. Write down this expected outcome on the paper together with the allele combinations shown with the colorful sticks.
7. Take a picture of each of the four scenarios and insert these photos below.









Post-laboratory Questions

1. **In Exercise 1**, would IVF help if a woman had uterine fibroid tumors that interfered with implantation? Explain.
2. **In Exercise 2,** you labeled the main features of embryonic and fetal stages of development. What are the most obvious differences between a 4 month fetus and 7 month fetus?
3. **In Exercise 3,** you worked with a dominant inheritance allele. How is this different than an allele that is inherited in recessive manner. Compare your data to the sickle cell example in Figure 28.8 to help answer this question.

29.

TUTORIAL ON DRAWING ANATOMICAL STRUCTURES

By Solomon R. Isekeije

Motivation.

Everyone has the innate ability to draw. Although drawing is a creative process, it involves the effective application of learned skills, for accurate depiction of objects or subjects. If we believe that drawing skills can be taught and learned then we can assume that everyone can learn to draw. Often, our inability to accurately depict objects or subjects is due to lack of trainings and familiarity with basic drawing skills. Enhanced visual acuity increase our ability for effective observation, interpretation, and ability to create drawings of three-dimensional images on two- dimensional surfaces. Economic and educational disparities against African Americans are some of the factors responsible for lower performance and limited engagement in art making processes among African American Youth. These setbacks may account for lower participation in creating and responding to visual arts among African American Youth compared to whites, Hispanic and other groups.

Learning Objectives

Upon completion of the work in this chapter students should be able to:

- Identify and compare basic organic and inorganic shape and forms to specific human organs and parts of the human anatomy.
- Apply a progressive drawing process in rendering selected human organs and parts of

the human anatomy.
- Understand how to accurately measure the proportion of the human skeletal system.
- Draw the complete human skeletal system.

Background.

The ability to **create and share** still and moving images such as drawing, graphic illustrations, photographic reproduction and videos is one of the most important technological advancements of this age. Today, our daily activities are inundated with scores of still and moving images in the form of drawings, emoji, short memes, photographs and videos of friends and family, observations from nature, interesting objects, and places, and pictures of the food we eat. With so much reference to images in our daily interaction, it makes sense to develop some basic drawing skills to fully participate and appreciate our current 21st century visual revolution. The development of basic drawing skills can be linked to a heighten sense of visual acuity. For professionals in the field of Nursing and Allied Health the ability to make quick, accurate observations and act upon those observations can make the difference between life and death for their patients.

One might argue that **good science** is based partly on **good observation**. If this argument holds merit, it makes sense for a Nursing and Allied Health practitioner to learn how to accurately perceive and document their observations. '*Observation is essential in science. Scientists use observation to collect and record data, which enables them to construct and test hypothesis and theories.*' https://www.sciencelearn.org.nz/resources/8-the-role-of-observation-in-science

To draw an object accurately, the observer must develop the ability to perceive the object down to the smallest detail and the skill to represent the same object on a two-dimensional surface or piece of paper. Depicting what we see in the natural world or three-dimensional images on a two-dimensional surface requires an understanding of specific image representational techniques. It is important to note that drawing is as much a representational process as it is an explorative process. Drawing can help us learn the shape and concurs of an organ by develop muscle memory of how to draw that organ. The process of repeating your drawing several times during practice, is how you develop muscle memory of that object. As the saying goes, 'Practice make perfect.'

Visual perception, balance, scale and proportion and drawing:

Visual perception: The weight of a line speaks to the thickness of the line. All drawing should start as very thin, barely visible lines which explore the shape of the object you wish to draw several times before *you finalize the outline or shape* of the object.

Balance: Symmetrical balance refers to equal placement and representation of objects on opposite sides of the same organ or *structure*, whole asymmetrical balance is the opposite. Applying this understanding will help you with placement in your drawing exercises. For example: the human head is symmetrically balanced. While a human kidney has an asymmetrical balance. This basic understanding provides visual

reference which guide the drawing process. To help establish some points of reference, always create a geometric shape like a square or rectangle and create your drawing within one of these shapes.

Shape and drawing:

A logical approach to creating a drawing of any object is to first associate that object to a basic organic or inorganic shape. Most animate and inanimate objects found in nature often retain organic shapes, while most man-made objects often have inorganic shapes like squares, triangles, rectangles etc. Most organs in the human anatomy are typically organic in shapes. Therefore, a helpful exercise on proper observation and drawing of any human organ is to first compare its shape to another common organic or inorganic shape. Like image comparison, associating words with object is one of the earliest and most effective learning methods during our elementary education. We even develop nursey rhyme to help our developing brains associate certain alphabets with specific images (A is for apple and B is for Ball).

The pressure of creating accurate drawings might create a sense of anxiety for some prospective Nursing and Allied Health practitioner. Since a steady hand is one of the requirements for a good drawing, anxiety associated with drawing might be responsible for poor drawings in Anatomy and Physiology courses. To help demystify the drawing process, you should not only compare the shapes of the organ to another familiar object, but you can also carve out its shape from a basic geometric block.

Examples: