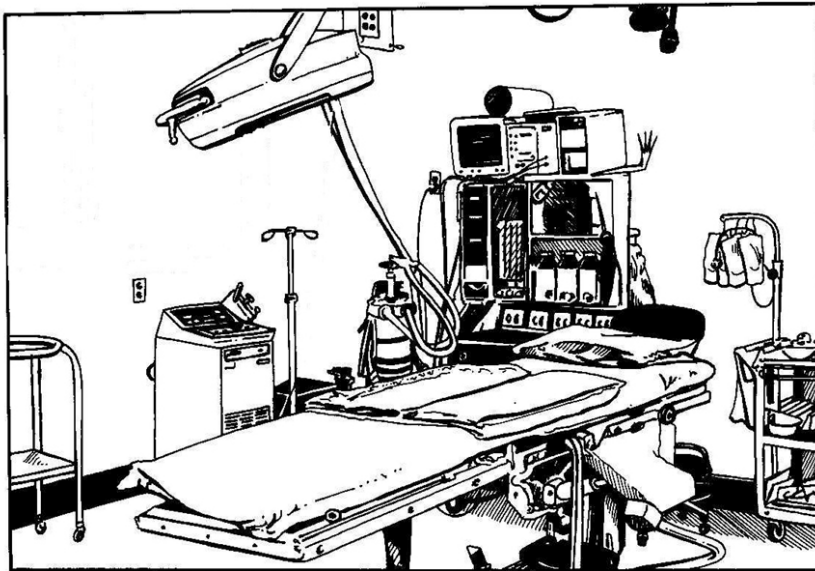


CDC B4N151

Surgical Service Journeyman, Part II

Volume 2. Anatomy and Physiology, Part II



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THIS VOLUME OF CDC B4N151, *Surgical Service Journeyman*, is basically a continuation of the first volume. It is part two of our discussion of the anatomy and physiology of the human body. Like volume 1, this volume is designed to provide you with background knowledge of the structures and functions of major organ systems so that you can function more effectively as a surgical technician.

In Unit 1 we discuss the highly specialized organs that provide us with our five "special senses." In addition, we talk about the variety of general sensory receptors in the body that feed information about our internal and external environments to the central nervous system.

In Unit 2 we get to the heart of anatomy and physiology (pun intended!) with an in-depth look at the structures and functions associated with the circulatory system. We begin by discussing the characteristics and composition of blood. Next, we look at the structure and function of the heart, followed by the vascular network, and finally, the lymphatic system. Because of its close association with the circulatory system, we also cover the anatomy and physiology of the respiratory system in this unit. In our discussion of the respiratory system, you will learn more about the process of respiration and the structures that make this life-sustaining activity possible.

Unit 3 talks about the body's food processing system and another system which helps regulate all bodily functions. In the first section, we talk about the different primary and accessory organs of digestion and their role in converting the food you eat into chemical compounds that your cells can use to survive and grow. The second section of Unit 3 is devoted to a discussion of the endocrine system, which along with the nervous system regulates the body's metabolic activities.

The final unit of this volume, Unit 4, covers two more closely related body systems, the urinary and reproductive systems. After studying the section on the urinary system, you should develop a fairly clear understanding of how blood is filtered by the kidneys to remove toxic substances. You'll also learn more about the urinary system's role in maintaining homeostasis, and how urine is produced, stored, and eliminated from the body. The last two sections of this unit explore the topic of human reproduction. We talk about the structures and functions of the male and female reproductive systems, and explain how these systems interact to create another human being.

We realize that this topic is complex. However, no matter how complicated or lengthy this material is, it is essential for you to know. If you are going to help people stay healthy (and sick people get better), you need some idea of what is where, what does what, and what works how. These volumes are designed not only to expand on what you learned in technical school, but also to challenge you to learn more about the amazing organism that is your body.

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NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

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Unit 1. Special Senses

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THE human sense organs provide us with an awareness of our internal and external environment, allowing us to react to a variety of stimuli. These sense organs contain numerous specialized structures called *receptors*. These receptors receive and interpret changes in the environment, then translate the changes into nervous impulses that can be analyzed by the brain. The signals initiated by the receptors in the various sense organs and interpreted by the brain are called sensations. It is these sensations that cause the brain to trigger reflex responses that are vital for maintaining or restoring the body’s homeostasis. Receptors are located throughout the body. Some are located internally and are responsible for monitoring changes in the viscera and musculoskeletal structures. Others are located on the outside of the body, in the skin, mucous membranes, and in so highly specialized organs. External receptors and sensory organs provide us with the five senses that most of us take for granted—sight, hearing, taste, smell, and touch. Beyond these classic senses, external receptors also allow us to sense changes in heat, cold, pain, pressure, and position. It is these special extensions of the nervous system that we discuss in this unit.

We start by discussing the structures of the eye and how these structures work together to produce the sensation of sight. Then, we look at the structures of the ear and the two senses it is responsible for—hearing and balance. The last section of this unit will familiarize you with the anatomical structures and specialized receptors that provide us with the senses of taste and smell, and various tactile (touch-related) sensations.

1–1. The Eye and the Sense of Sight

The eyes are our “windows to the world.” The visual receptors they contain react to the physical stimulus of variations in light radiation emanating from our external environment. Through a complex electrochemical process, this stimulus is converted into nervous impulses, which the vision center of the brain interprets as sight. Why is it important for you to learn more about the eyes and how they work? Besides furthering your knowledge of your own body’s complex processes, an increased understanding of the anatomy and physiology of the eyes allows you to become a more effective scrub and circulating specialist. This section has two lessons. The first provides you with a description of the different parts of the human eye and related accessory structures. The second lesson briefly outlines the chain of events and physiological processes that occur, which enable us to see.

201. Anatomy of the eye and its accessory structures

The eye is the organ of vision. It is a hollow, nearly spherical ball approximately 1 inch in diameter. Its front to back dimension is slightly greater due to the additional space taken up by the arc of the cornea on its anterior surface. The eye contains various specialized structures, most of which help to bend and focus light rays. It also contains specialized receptors that convert visible light into electrochemical nervous impulses.

The eye, or eyeball, lies in a cone-shaped, bony cavity called the *orbit*. The orbit is formed by the union of seven cranial bones and serves as a protective encasement for the majority of the eye. The bones that form the orbit are covered by a layer of fatty tissue, which helps cushion the eyeball. Approximately 80 percent of the eyeball is recessed in the orbit, leaving only the anterior surface (mainly the cornea) exposed. Accessory structures, such as the eyebrows, eyelids, eyelashes, and lacrimal apparatus, surround the eye and help protect it from injury. In addition, there are several muscles attached to the outer surface of the eye that enable it to move within the orbit. Figure 1–1 shows a cross-section view of the major parts of the human eye. Refer to this figure as we discuss the individual structures.

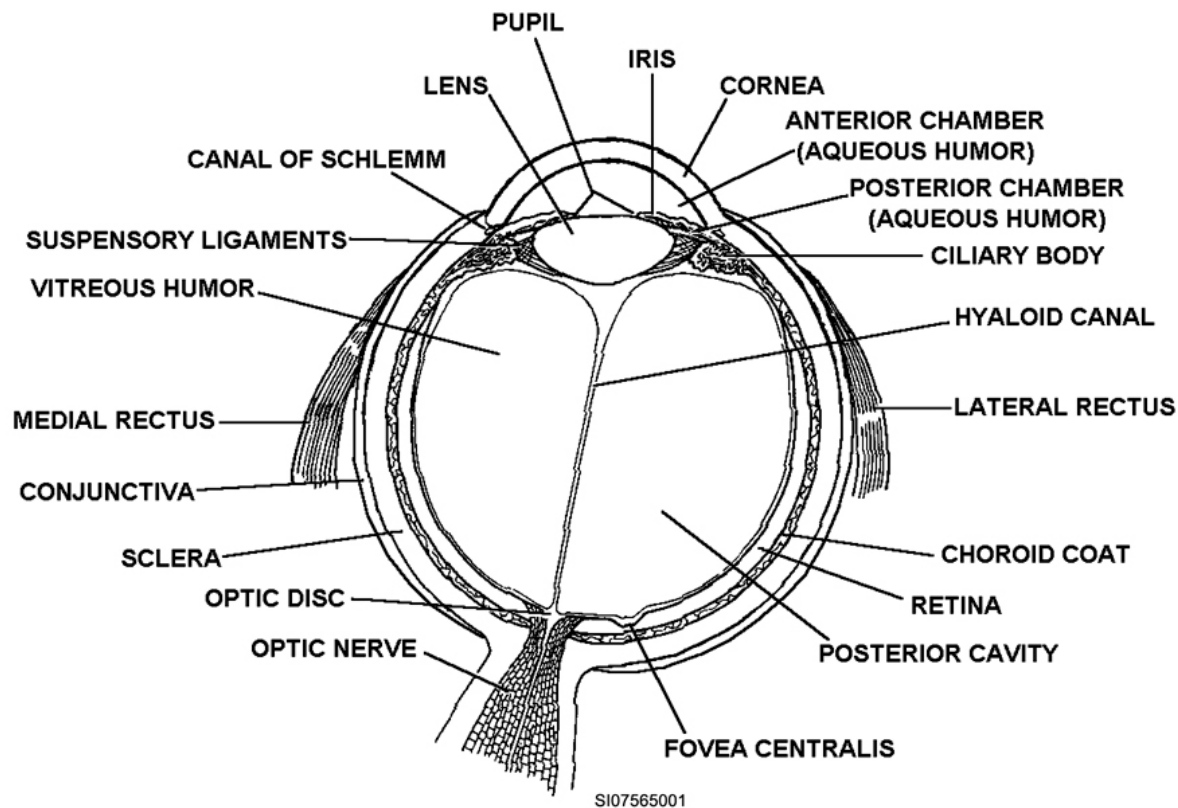


Figure 1–1. Cross-section of the human eye.

Layers of the eyeball

The wall of the eyeball is composed of three primary layers or tunics—outer layer, middle layer, and inner layer.

Layer	Description
<i>Outermost</i>	Is a tough, fibrous coat formed by the sclera and the cornea.
<i>Middle</i>	Is highly vascular and contains pigments. This layer contains the choroid, a muscular ciliary body, and the iris.
<i>Inner</i>	Is made-up of highly specialized receptors and nervous tissue, and is called the retina.

In addition to these three main structural layers, the eye contains tissues and substances that help bend and focus light rays. These structures and substances include the aqueous humor, crystalline lens, and vitreous body. They along with other structures are collectively known as *refractive media*.

Outer layer

As you look at the front portion of the human eye, you can see that the center portion is colored and the surrounding tissue (sclera) is white. If you look more closely at the area where the colored portion ends and the white portion begins, you'll notice a fine blue-gray line. This line is called the *limbus* and represents the transition area between the cornea and sclera.

Sclera

The sclera forms the white outer shell of the eyeball. It covers the eyeball except for the cornea and consists of a dense network of flexible, white fibrous connective tissue. The sclera is opaque (does not allow light to pass through). Its main functions are to help maintain the shape of the eyeball and protect the delicate internal structures from injury. It also serves as an attachment point for the six exterior (extrinsic) muscles that move the eye within the orbit.

There is a circular venous sinus deep within the sclera where it joins with the cornea. This sinus is called the *canal of Schlemm*, and it serves as a drainage outlet for aqueous humor (i.e., the watery fluid that fills the anterior chamber of the eye) into the venous system of the eye.

The sclera is thickest at its posterior portion and becomes thinner anteriorly until it joins with the cornea. The optic nerve and blood vessels penetrate the posterior sclera just above and nasal to the central or optical axis of the eye. Anteriorly the sclera joins with the transparent cornea.

Cornea

The cornea is continuous with the sclera and forms a slight bulge at the front of the eyeball. Think of the cornea as the portion of a sphere superimposed on the anterior surface of a larger sphere (the eyeball). If you have ever seen a contact lens, the cornea looks like an anatomical contact lens attached to the front of the eye. It covers about one-sixth of the total surface area of the eyeball. Since the cornea is transparent, it acts as the point where light enters the interior eye.

The cornea's main function is to bend (refract) the light rays as they enter the eye. In this respect, it acts much like the lens on a camera, enabling the eye to focus on distant objects. The cornea is the primary refractive medium of the eye, accounting for most of the eye's focusing capability. However, its focusing ability is fixed (similar to a hand magnifying glass lens), so fine focusing adjustments must be accomplished by changing the shape of the crystalline lens. We discuss this process later in this volume.

The cornea is composed of five layers of tissue and is avascular (contains no blood vessels). Since there are no blood vessels in the cornea, it receives nourishment from the aqueous humor and the tear fluid. The tear fluid bathes the outer corneal tissue layer and slowly diffuses through the deeper layers. Oxygen needed by the tissue is absorbed directly into the tissue from the air. The cornea is very delicate and, therefore, easily damaged. Superficial scratches and abrasions, and minor infections that affect only the outer layer usually heal without permanent scarring. However, if the damage extends into the deeper layers, permanent scarring may occur causing a severe distortion of vision. One way to correct vision problems associated with corneal scarring is to do a corneal transplant. This involves surgical removal of the damaged section of the cornea and replacing it with a graft from a human cadaver donor.

Middle (vascular) layer

The vascular layer or tunic is the middle layer of the eye. This layer contains three subdivisions—the choroid, the ciliary muscle or body, and the iris.

Choroid

The choroid lines the sclera and forms approximately two-thirds of the middle layer of the eye. It consists of a dark-brown layer of tissue, which contains numerous pigment cells and a network of blood vessels that supply most of the structures within the eye. The primary function of the choroid is to supply blood to the outermost layer of the retina. It also supplies blood to the sclera, ciliary muscle,

and iris. The dark color of the choroid, caused by the pigment cells and blood vessels, serves to absorb light rays, preventing their reflection inside the eye. The choroid is firmly attached to the sclera at the back of the eyeball, at the point where the optic nerve enters the eye, and at the anterior margin of the retina. The choroid membrane extends anteriorly to the ciliary muscle.

Ciliary muscle (body)

The ciliary muscle, or body, originates at the anterior border of the retina and attaches to the sclera. This triangular-shaped muscle is formed by a thickening of the choroid, and contains circular (sphincter) and longitudinal muscle fibers. The longitudinal fibers of the ciliary muscle (which resemble the meridian lines on a globe) are attached to suspensory ligaments (zonular fibers), which emanate from and suspend the lens. When the longitudinal fibers of the ciliary muscle contract, they pull forward on the body of the ciliary muscle, creating slack in the suspensory ligaments. This causes the lens to become more convex (curved outward) and enables the eyes to focus for close-up work such as reading. Conversely, when the ciliary muscle relaxes, the suspensory ligaments tighten and the curvature of the lens decreases. The eye can then focus on more distant objects. This shape changing and focusing is known as accommodation.

Iris

The iris is the most anterior segment of the vascular layer of the eye. It is continuous with the ciliary muscle and contains both longitudinal and circular muscle fibers arranged in a ring or doughnut configuration.

The hole in the middle of the iris is called the *pupil*. The pupil appears black because it opens into the dark interior of the eyeball. The iris lies anterior to the lens and posterior to the anterior chamber of the eye. The muscle fibers of the iris contract and relax, thereby altering the diameter of the pupil. This action regulates the amount of light entering the eye. When the iris relaxes, the pupil becomes dilated and more light enters the eye. This allows you to see in low-light situations. When the iris contracts, the pupil constricts and the amount of light entering the eye is decreased. This allows you to see more clearly when the light is extremely bright (when you are snow skiing or are out on the water on a bright, sunny day).

If you are a camera enthusiast, think of the iris as performing the same job as the aperture on a camera. The iris also contains pigments that are responsible for the color variations (e.g., blue, green, hazel, brown) you see in people's eyes. The iris consists of separate anterior and posterior layers. In people with blue eyes, the anterior layer contains no pigment cells and is, therefore, colorless. In this case, the blue color of the eye comes from the blue pigments present in the posterior layer. This blue layer is usually present in all eyes, but in individuals with dark eyes, the pigment *melanin* (the same pigment responsible for variations in skin coloration) is present in the anterior layer. This dark pigment gives the eyes a dark color because it obscures the blue color of the posterior layer.

Inner layer

The *retina* forms the innermost layer of the eyeball. Because it covers *only* the inside of the back part of the eye and has no anterior portion, it is an incomplete layer. It is a layer of specialized nervous tissue that is a direct extension of the brain and optic nerve. The retina is firmly attached to the globe of the eye posteriorly at the point where the optic nerve enters the eye. It terminates and attaches to the choroid just posterior to the ciliary muscle. The retina is composed of 10 layers of specialized neurons and light receptors. The primary function of the retina is to convert light to the nervous impulses, which are ultimately interpreted by the brain as visual images.

There are two types of light receptors (photoreceptors) found in the retina. These photoreceptors are called *rods and cones*. Rods and cones differ in several ways.

1. They are highly specialized neurons, which contain light-sensitive pigments that electrochemically convert light energy into a nervous impulse action potential.
2. They derive their names from the overall shape of their cell bodies. Rods have thin, elongated cell bodies and terminal projections. Cones have shorter, fatter cell bodies and terminal projections.
3. There are approximately 10 to 20 times more rods than cones, and the distribution of rods and cones in the retina varies considerably. Cones are most numerous in an area of the retina known as the *fovea centralis*. The fovea centralis is a small, bowl-shaped depression located in the middle of a yellowish area on the central portion of the posterior retina called the *macula lutea* (a Latin term meaning “yellow spot”). The distribution of cones decreases from the fovea centralis outward to the periphery of the retina. In contrast, rods are almost entirely absent from the fovea centralis and macula lutea and increase in numbers toward the outer (anterior-most) border of the retina.
4. Rods and cones differ in their respective functions. Rods are much more sensitive to light than cones, and as a result, enable us to see images in low-light conditions (night vision). In addition, the photosensitive pigment found in the rods provides only black and white vision, while the pigment in the cones enables us to see colors.
5. They differ in the sharpness of vision they produce. Rods allow us to see only the general outlines of images. Cones, on the other hand, provide us with sharp, detailed vision. To make it easier for you to differentiate between these two types of light receptors, just remember:

Rods	Black and white and night vision.
Cones	Color and daylight vision.

As we mentioned earlier, the fovea centralis contains the highest concentration of cones and almost no rods. Because of this and the fact that the cones provide more detailed vision than rods, the fovea centralis is the area of sharpest vision on the retina. In order to see the details of a particular area on an object in bright light conditions, you must move your eyes so the light rays reflecting off the object focus on the fovea centralis. This stimulates the greatest number of cones possible because they are concentrated in the fovea. Conversely, if you want to see objects more clearly in low light, look to one side of the object. This causes the available light rays to fall on a portion of the retina away from the fovea centralis, thereby stimulating a greater number of rods.

There is an area of the retina that is totally devoid of rods and cones—the *optic disk* or “blind spot.” The optic disk is located on the central portion of the posterior retina just medial to the fovea centralis. It is the area of the retina where nerve fibers converge to form the *optic nerve*, and the point where arteries and veins that supply the retina enter and exit the eyeball. The blind spot is created because the nerves and blood vessels that meet at this central area push the photoreceptors aside. Figure 1–2 is a view of the posterior portion of the right retina. It shows the areas and structures of the retina we just discussed, along with the surrounding layers of the eye as viewed from the front, through the lens.

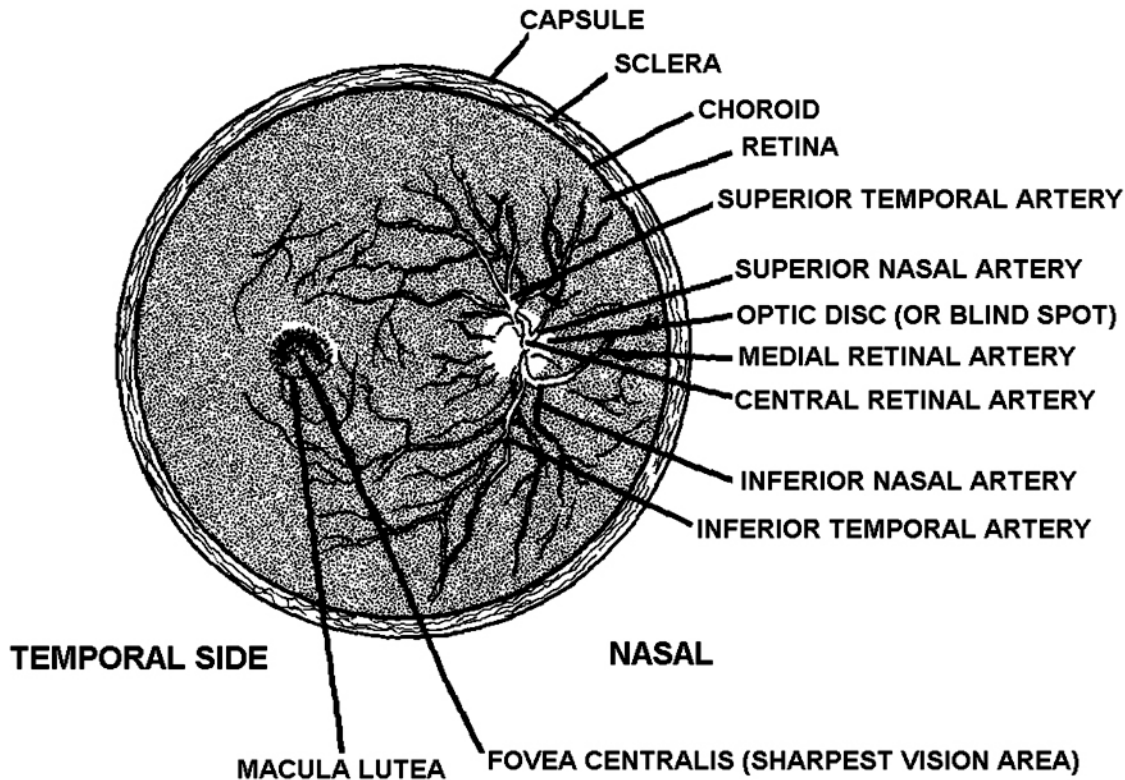


Figure 1-2. Posterior portion of the right retina viewed from the front.

Cavities and refractive media

The eye is basically a hollow sphere divided into two main cavities—the anterior cavity and the posterior cavity. Each cavity contains a substance that helps bend and focus light rays on the retina. In addition, there is a tissue lens—the crystalline lens—located between the anterior and posterior cavities that focuses light rays on the retina.

Anterior cavity

The anterior cavity is located in front of the crystalline lens and is subdivided into *anterior* and *posterior chambers*.

Chamber	Location
<i>Anterior</i>	Forms the space behind the cornea and in front of the iris.
<i>Posterior</i>	Is the small space that lies behind the iris and in front of the crystalline lens and ciliary bodies.

Both the anterior and posterior chambers are filled with a clear, watery fluid called *aqueous humor*.

The aqueous humor helps maintain the anterior curvature of the eyeball, refracts (bends) light rays after they pass through the cornea, and provides a medium for supplying nutrients to the cornea and lens. This fluid is formed in the anterior folds of the ciliary processes. It then flows through the zonular fibers, into the posterior chamber, and through the pupil into the anterior chamber. As mentioned earlier, excess aqueous humor drains out of the anterior chamber into the venous circulation via the canal of Schlemm at the angle between the iris and cornea. Aqueous humor is constantly being produced and reabsorbed in the eye.

When the drainage of this fluid fails to keep pace with the production, the intraocular pressure in the anterior cavity increases, creating a condition called *glaucoma*. If this condition goes untreated, the

patient will experience severe pain, and the unabated pressure may permanently damage the delicate nervous tissue in the retina. Damage is most likely to occur at the optic disk because the pressure forces the nerve fibers that form the optic nerve against the sides of the opening in the retina. In addition, the optic artery, which enters the eye at the optic disk, may become occluded by the increased pressure, thereby compromising blood supply to the retina. As the intraocular pressure increases, the extent of retinal damage increases and the patient eventually goes blind. Eye drops that constrict the pupil may be administered to help relieve excess intraocular pressure in certain mild cases. This is possible because constriction of the pupil decreases the angle between the cornea and iris, thereby promoting better drainage into the canal of Schlemm.

Posterior cavity

The posterior cavity is the large space that lies behind the lens and ciliary bodies. This cavity is filled with a clear, gel-like substance called the *vitreous body*. There is a shallow depression in the anterior portion of the vitreous body that cradles the posterior surface of the lens. A lymph canal, called the *hyaloid canal*, runs through the middle of the vitreous body from the lens to the optic disk of the retina. This canal is the remnants of an artery that supplies the lens with blood during embryonic development. The main purpose of the vitreous body is to support and maintain the shape of the eyeball. It also supports the retina and further refracts light rays after they have passed through the crystalline lens. Although it has a gel-like consistency, the vitreous body is mostly water and bends light rays about the same amount as water.

Crystalline lens

The lens is a clear, transparent mass of tissue situated posterior to the pupil and iris, and anterior to the vitreous body. When viewed from the front, the lens appears round. From the side, an adult lens appears almost elliptical or football-shaped due to the outward curvature of its anterior and posterior surfaces (the posterior surface is curved more than the anterior surface). The outward curvature of both sides of the lens makes it a *biconvex* lens. In adults, the lens is approximately 10mm in diameter and 4 millimeter (mm) thick. The lens is enclosed by a clear, elastic capsule. There is a thin layer of epithelial tissue beneath the capsule on the anterior surface only. The majority of the lens body beneath the capsule is composed of specialized fibers arranged in concentric layers, similar to the layers of an onion.

You should recall that the lens is attached to the ciliary body by suspensory ligaments or zonular fibers. The curvature or convexity of the lens surfaces is changed by the contraction and relaxation of the ciliary body and the resultant change in pull exerted on the lens capsule via the zonular fibers. This ability of the lens to change shape causes variations in the bending of light rays that pass through it, thereby allowing us to focus our vision at different distances.

As we get older, the lens starts to lose its elasticity and convexity, and we experience greater difficulty in focusing on near objects. Another change that sometimes occurs in the aging lens is a progressive clouding or whitening of the lens tissue, which gradually reduces the lens' transparency. This condition is known as a *cataract*. If a person develops cataracts, vision can be restored. The patient has the affected lens surgically removed, and then wears special glasses with strong corrective lenses. The powerful glasses are needed to replace the focusing ability originally provided by the tissue lens. An alternative to wearing these thick glasses is the surgical implantation of artificial lenses inside the eye. To save the patient from having to undergo an additional operation, this intraocular lens implantation is normally done during the surgery to remove a cataract.

Extrinsic eye muscles

There are six muscles attached to the outside surface of each eyeball that control the movement of the eyes within the bony orbits (fig. 1–3). Four of these muscles are classified as rectus (straight) muscles, while the other two are called oblique muscles. Acting together, these three pairs of muscles enable the eyes to move in all directions. The extrinsic eye muscles are composed of skeletal muscle tissue and are under voluntary nerve control.

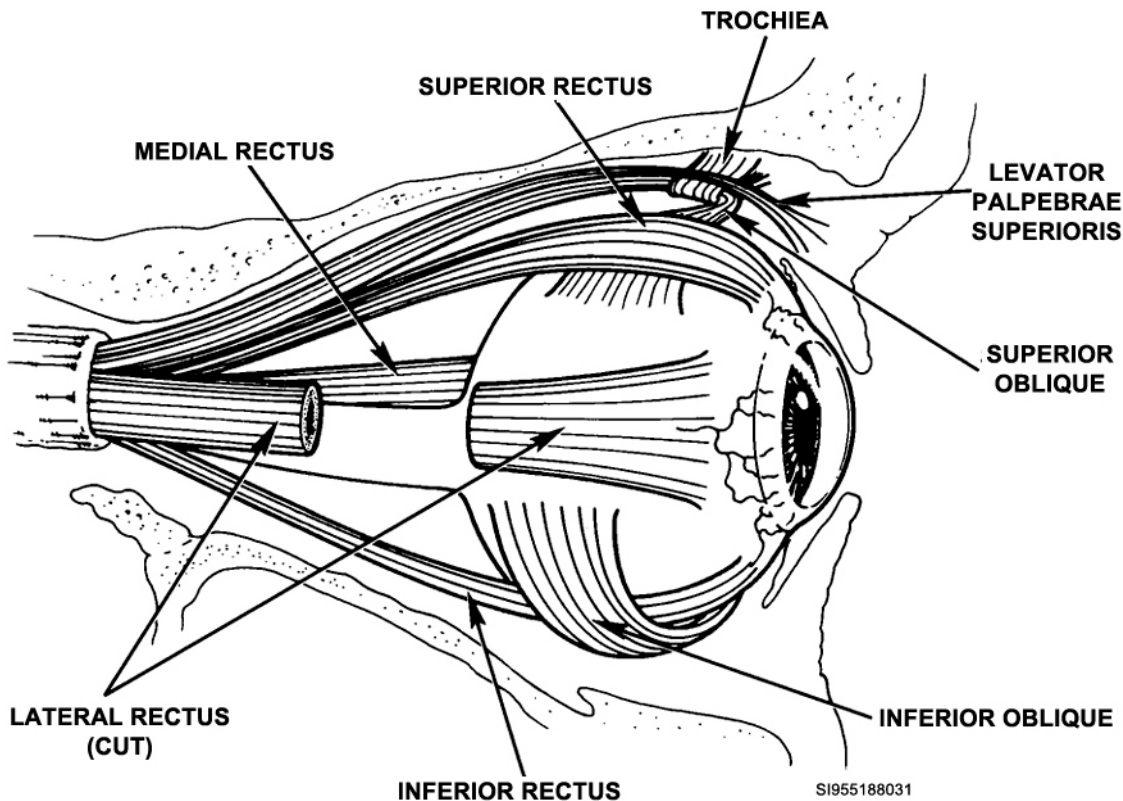


Figure 1-3. Extrinsic eye muscles.

Rectus muscles

Each eye has four rectus muscles, named for their point of insertion on the eyeball. They are the *superior*, *inferior*, *lateral*, and *medial rectus muscles*. All four of these muscles originate from a circular tendon, which surrounds the optic nerve at the back of the orbit. The superior rectus muscle inserts on the superior portion of the sclera near the limbus, and elevates the eye when it contracts. The inferior rectus is attached to the bottom of the eyeball, and pulls the eye downward. The lateral rectus inserts on the side of the eye towards the ear and abducts the eye; the medial rectus inserts on the side closest to the nose and adducts the eye.

Oblique muscles

The two oblique muscles are also named for their points of insertion on the eyeball— superior oblique muscle and inferior oblique muscle.

Superior oblique muscle

This is the longest of all the extrinsic eye muscles. It originates from the top part of the circular tendon surrounding the optic nerve and travels forward on the upper nasal side of the eye between the superior and medial rectus muscles. Above the eye on the medial side, it passes through a small loop of cartilage called the *trochlea*. At the point where it passes through the trochlea, the superior oblique becomes tendinous. After looping through the trochlea, it once again becomes a muscle, turns down and backward, passes under the superior rectus muscle, and inserts on the posterior-lateral aspect of the eyeball. The superior oblique muscle rotates the eye downward and laterally.

Inferior oblique muscle

This muscle arises from the anterior-medial floor of the orbit near the fossa for the lacrimal sac. It runs laterally between the inferior rectus muscle and the floor of the orbit, and inserts on the posterior-lateral aspect of the eyeball, below the lateral rectus muscle. The inferior oblique muscle is

the shortest of the extrinsic eye muscles. Its primary action is to rotate the eyeball upward and laterally.

Innervation of the extrinsic muscles

The extrinsic eye muscles are innervated by three different cranial nerves—the *oculomotor*, *trochlear*, and *abducens*.

The oculomotor (third cranial) nerve innervates all the rectus muscles except the lateral rectus, which is innervated by the abducens (sixth cranial) nerve. The oculomotor nerve also innervates the inferior oblique muscle. The trochlear (fourth cranial) nerve innervates the superior oblique muscle. One way to remember which nerves supply which eye muscle is to look for similarities between the nerve names and the muscles they innervate. For example, the superior oblique muscle passes through a cartilage loop called the trochlea, and the trochlear or fourth cranial nerve sounds the most like the name given to this loop of cartilage. The *trochlear* nerve innervates the superior oblique.

To remember which nerve innervates the lateral rectus muscle, remember what the muscle's primary action is. The lateral rectus turns the eye laterally or *abducts* it. Relating this action to the cranial nerves, the *abducens*, or sixth cranial nerve, innervates the lateral rectus. If you can remember these two examples, remembering the nerve that innervates the remaining muscles is easy because the only nerve remaining is the oculomotor, and it innervates the rest of the extrinsic eye muscles.

Tendon's capsule

In addition to the muscles we just discussed, the eye is suspended in the orbit by numerous ligaments and connective tissues. One of the most important of these additional support structures is *Tenon's capsule* (also called the bulbar fascia). This is a serous sac that attaches to the anterior eyeball adjacent to the periphery of the cornea. Posteriorly, Tenon's capsule completely surrounds the eyeball. Whenever eye muscle surgery is done, the surgeon incises this thin, membranous sac to gain access to the muscle insertions.

Accessory structures of the eye

Even though the eyes are the main organs of sight, they cannot function to their fullest capability without the help of various external accessory structures. These accessory structures include the eyebrows and eyelashes, eyelids, lacrimal apparatus, and conjunctiva. Each of these structures has a distinct and specialized function.

Eyebrows, eyelashes, and eyelids

The eyebrows overhang the orbits, shading the eyes from light. The bony ridge that forms the eyebrows helps protect the eye by breaking the force of blows coming from head-on. The hairs on the eyebrows obviously serve a cosmetic purpose, but they also help divert sweat and trap foreign bodies that come from above before they can enter the eyes. The long hairs of the eyelashes also serve a cosmetic purpose and act as a protective barrier against the entrance of foreign material. In addition, there are small glands located at the base of the eyelashes, which secrete a lubricating fluid that tends to retain tears and keep the eyelids from sticking together. When one of these glands clogs up and becomes infected, an inflammation develops at the base of the eyelash. The painful swelling that results is commonly called a *sty*.

The eyelids are movable folds of tissue that act as a protective curtain for the anterior portion of the eye. They are composed of skin, muscle, connective tissue, and a mucous membrane lining. The skin that covers the outer surface of the eyelids is the thinnest on the body. It fuses with the membranous inner lining at a ridge of firm connective tissue along the edge of the lid called the *tarsal plate*. The upper eyelid is larger than the lower lid and is raised by the *levator palpebrae superioris muscle*. As you may recall from your study of facial muscles, a sphincter muscle, called the *orbicularis oris*, contracts to close the eyelids.

The mucous membrane that lines the eyelids also covers the anterior surface of the eye except for the region occupied by the cornea. This membrane is called the *conjunctiva*. The conjunctiva is relatively thick on the inside of the lids, but becomes much thinner and transparent where it covers the surface of the eye. The conjunctiva is well supplied with blood vessels and nerve endings. Irritation of the membrane causes the blood vessels to become plainly visible, resulting in “blood-shot” eyes. The pain you experience when a foreign body becomes lodged in your eye is caused by stimulation of the numerous nerve endings in the conjunctiva. Inflammation of the conjunctiva (conjunctivitis) appears in several forms. One of the most common and highly contagious types of conjunctivitis is called “pinkeye.” It is given that name because it produces a pink coloration on the anterior surface of the eye.

Lacrimal apparatus

The lacrimal apparatus consists of a lacrimal gland, along with a series of ducts that connect the gland to the nasal cavity. The lacrimal gland, which is about the size and shape of an almond, produces tears. It is located in a depression of the frontal bone above the outer angle of the eye (fig. 1–4).

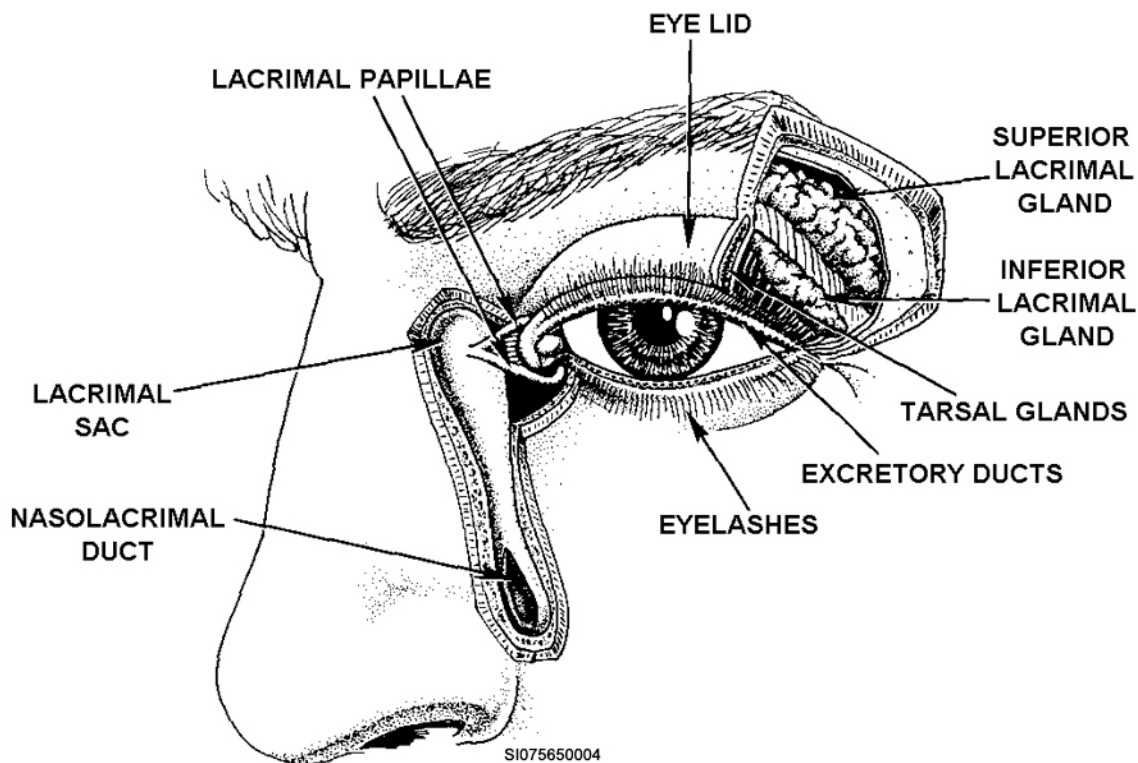


Figure 1–4. Lacrimal apparatus.

About a dozen small ducts carry the tear fluid from the lacrimal gland to the conjunctiva of the upper eyelid and to the surface of the eyeball. Once it reaches these surfaces, much of the tear fluid evaporates. The remaining tear fluid flows from the surfaces of the conjunctiva of the eyelids and eyeball along the following path:

1. Medially across the surface of the eye, toward the inner angle formed by the junction of the upper and lower eyelids; this junction area is called the *canthus*.
2. The tear fluid then drains into two small openings called *lacrimal puncta*, which are on the medial border of the upper and lower eyelids.
3. From the lacrimal puncta it flows into two small ducts called *lacrimal ducts* or *canaliculi*.
4. The fluid then flows into in a deep groove in the lacrimal bone called the *lacrimal sac*.

5. The *nasolacrimal duct*, an extension of the lacrimal sac, drains the secretion into the nasal cavity.

Tear or lacrimal fluid is basically a solution of various salts dissolved in water along with a small amount of mucin. Mucin is a secretion of the mucous membranes that line the entire lacrimal system. The primary purpose of this fluid is to moisten the surface of the eyes. Lacrimal fluid also contains the enzyme *lysozyme*, which has a bactericidal action. So we can say that a secondary purpose of tears is to help prevent eye infections. Irritation of the conjunctiva and nasal membranes, as well as emotional upset, increases the production of tears. When this happens, the excess fluid spills over the edges of the eyelids and the nose fills with fluid; we commonly call this “crying.”

Now that you know more about the anatomical structure of the eye and its accessory structures, let’s look at how the eye functions to enable us to see.

202. The eye as an optical instrument

The human eye functions just like a camera because they both have a biconvex lens to refract and focus light rays. The camera has a mechanical diaphragm or variable aperture to control the amount of light admitted into the camera body; the eye has the iris, which performs the same function. Light rays enter the camera and alter light-sensitive chemicals on the film, creating changes that later show up as a perceptible images. Light enters the interior of the eye and stimulates light sensitive neurons in the retina, creating nervous impulses that are interpreted as visual images by the brain.

For clear vision, the eye must refract most of the light received from each point on an object in order to focus it on a corresponding point on the retina. As previously mentioned, there are many refracting surfaces or media in the eye, but the most important is the cornea, where the greatest refraction occurs, and the lens, whose curvature changes for fine focusing adjustments. The eye focuses light rays by progressively bending them as they pass through the cornea, aqueous humor, crystalline lens, and finally the vitreous body. The degree to which light is refracted when passing from one medium to another depends on the following:

- The index of refraction of one medium relative to that of an adjacent medium.
- The curvature of the surface between them.
- The angle at which light strikes the surface of the medium.

Let’s look at the refractive mediums and their respective refractive indices. They are listed in the order that light rays pass through the eye as they travel from the air to the retina.

Medium	Refractive Index
Air	1.00
Cornea	1.376
Aqueous humor	1.336
Lens	1.42 (because of its thickness and curvature)
Vitreous body	1.336

As you can see, the greatest difference in refractive indices is between the air and the cornea (the difference is .376). This means the greatest amount of refraction in the ocular system occurs when the light passes from the air outside the eye, through the cornea. You should recall that the cornea does the primary job of converging light rays, while changes in the crystalline lens serve as a fine adjustment to sharpen the images of close objects.

Lens and visual acuity

A biconvex lens, like the one that is found in the normal eye, converges light rays, causing them to focus or meet behind the lens. This is the kind of lens found in a magnifying glass or simple reading glasses.

A convex lens focuses parallel light rays at its principal focal distance. This focal distance varies according to the curvature of the lens surface or surfaces and the refractive index of the material from which the lens is made. In a normal human eye, the refractive media collectively bend parallel light rays so they focus on the retina if the object is 20 or more feet away. Closer focusing requires varying the curvature of the lens as we previously described when we discussed the ciliary body and accommodation. To focus on very close objects, the lens becomes more convex (i.e., fatter and more curved). As the distance from the eye to the object being viewed increases, the convexity of the lens decreases to keep the image sharply focused on the retina.

At 20 feet, the normal eye can focus parallel light rays from an object without the accommodating action of the lens. Wall eye charts, used to test visual acuity, are placed 20 feet from the viewer and contain lines of printed letters that become increasingly smaller from the top to bottom of the chart. At the end of each row is a number that indicates the eye's ability to read the type of that particular size. A rating of 20/20 means that the person can read the line of sized type marked 20 at a distance of 20 feet. This numerical rating is considered normal visual acuity. The eyes are tested one at a time to determine the variance in acuity, if any, between them and from the normal 20/20 standard.

If the person being tested has a right eye that is rated 20/40 and a left eye that is 20/20, the left eye is normal and the right eye has some type of defect that enables the person to only clearly read the line of larger printed letters marked 40. The 40 rating for this eye means that the normal eye could still clearly see these letters at 40 feet.

If the person has better than normal vision, he or she may be able to clearly read smaller lines of print, maybe one that the normal eye could only read from a distance of 15 feet. The rating given to the eye with this exceptional vision would be 20/15. There are many defects and diseases that can cause errors in refraction, resulting in deteriorated (less than normal) vision. Three of the most common conditions that result in errors of refraction are *myopia* (nearsightedness), *hyperopia* (farsightedness), and *astigmatism*.

Myopia

The *myopic* eye cannot focus clearly on distant objects because it focuses light rays reflected from an object in front of the retina, in the vitreous body. One possible reason for this is that the eyeball is too long, thereby making the distance from the lens to the retina greater than it is in the normal eye (fig. 1-5). Glasses with biconcave lenses correct this condition by lessening the convergence of the light rays before they enter the eye. This, in turn, causes the light rays to focus farther back in the eye, on the retina. This is the same principle that allows the controversial surgical procedure, radial keratotomy (and other refractive surgical procedures) to surgically correct myopia.

Hyperopia

Just the opposite condition exists in the *hyperopic* eye. A farsighted eye cannot focus on nearby objects. Presumably, this is due to the fact that the eyeball is shorter than in a normal eye, which, in turn, causes light rays to focus at a point that would be behind the retina. In order to correct this condition, glasses or contact lenses with convex lenses may be prescribed. The convex lenses cause a greater refraction of light rays before they enter the eye (fig. 1-5). There is a type of farsightedness that occurs in a normal-sized eye as a result of the natural aging process. This condition is called *presbyopia*. It occurs when the tissues in the crystalline lens lose their elasticity. When the tissues can no longer stretch to increase the convexity of the lens, despite the strong contractions of the ciliary muscles, the presbyopic person is unable to focus on close objects such as fine newspaper print. In this case, corrective convex lenses are needed to restore the eyes' ability to focus at close distances. Because of this gradual loss of lens accommodation, people who are myopic during the early years of their lives may experience an improved ability to read fine print up close without their glasses as they get older.

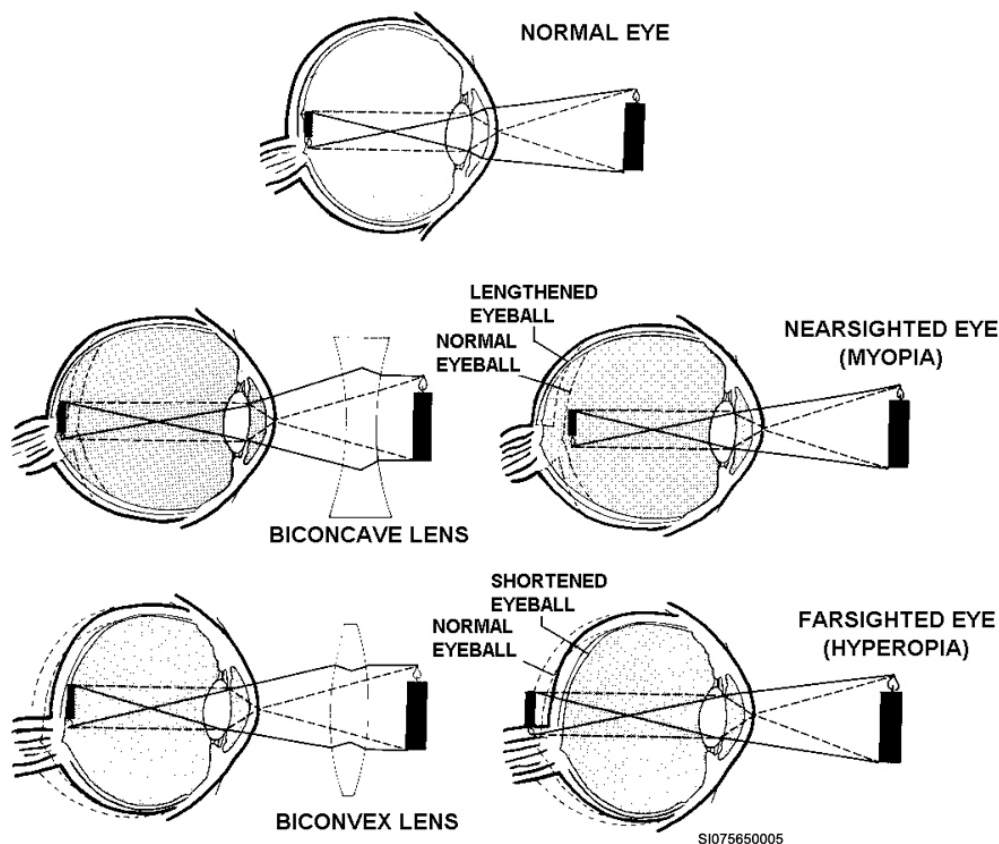


Figure 1-5. Refraction disorders.

Astigmatism

Astigmatism is normally caused by imperfections in the curved surface of the cornea. If the curved arcs of the cornea were equal, all the light rays entering the eye would be refracted equally, forming a cone of light behind the lens. In addition, the light rays would form an image at a single point on the retina. The corneal deviations associated with astigmatism cause light rays passing through the cornea to be refracted at varying angles. This creates multiple focus points on the retina. The images created are poorly defined, blurred, and bright lights often appear to have shafts of light radiating outward in star-shaped patterns.

Image inversion

One of the properties of convex lenses is that they will converge light rays to such an extent that the rays crisscross. This produces images that appear inverted on whatever surface the rays fall on after passing through the lens. If you look at figure 1-5, you will notice the candle appears inverted when it is projected to the back of the eye (on the retina). This is because the convex surfaces of the cornea and lens refract light rays (illustrated by the lines in the figure) from the top of the candle, to the bottom of the retina, and light rays from the bottom of the candle are refracted to the top of the retina. In addition to this top-to-bottom image inversion, the image created by the lens is also reversed from right to left by the same type of refraction. However, we do not perceive these images as being upside down or laterally flip-flopped, partly because we learn by experience to distinguish objects in proper relation to their surroundings. It is important to remember that the images that fall on the retinas of your eyes are not the same as those that your brain “sees.” The nervous impulses created by the light patterns falling on the retina are what the brain interprets as visual images.

The visual area of the brain is located in the right and left occipital lobes of the cerebrum. Nerve fibers from the right half of each retina carry impulses to the right visual area, while nerve fibers from the left side of the retinas carry impulses to the left visual area. In contrast, the fibers that originate from the inner halves of each retina cross each other and go to the opposite visual area. This crossing occurs behind the eyeballs in an area known as the *optic chiasma*. The crossing of nerve fibers contributes towards correlating the movements of both eyes and visual perception of images in the field of view. It also explains why retinal images are not perceived as having been flip-flopped from right to left. Visual impulses are transmitted to the visual areas of the cerebrum in the same relative position that correlates with the retinal images.

Not only are right and left halves correlated, but neurons from the upper half of the retinas carry impulses to the upper part of the visual area and vice versa. This means that the inverted image on the retina is transmitted to the visual center as an inverted image. The activity of the brain turns the image right side up as the impulses are interpreted.

Light reflex

As you already know, the pupils of the eyes dilate and contract depending on the amount of available light. This response is called light reflex. The pupils constrict in bright sunlight, and dilate in the dark or in dim light conditions. The most active part of the light reflex is the instantaneous constriction of the pupil when the eye is exposed to bright light. This swift response is controlled by the parasympathetic division of the autonomic nervous system.

The pupil also plays a role in accommodation. The radial muscles in the iris contract a bit for distant vision, which causes a slight dilation of the pupil. For close-up vision, the iris relaxes causing the pupil to constrict. How does this improve accommodation? If you are a camera enthusiast, you know that the clearest photos are taken with a small aperture and good lighting. This is because the narrower opening forces light rays through the center of the lens where there is a more consistent curvature of the lens surface. The same effect occurs in the eye when the pupil constricts in bright light, especially when close focusing is needed (e.g., reading fine print). The narrowing of the pupil allows passage of light rays through just the central portion of the lens. This not only results in less distortion by the lens, but it also causes the focused light rays to fall mostly on the central portion of the posterior retina. If you recall, the fovea centralis, which contains the greatest density of cone cells, lies in the center of the retina. Clearer, sharper images are produced when light rays are concentrated on this area.

Stereoscopic vision and depth perception

The eyes make every effort to maintain the visual field as the head is moved. The eyes move simultaneously in the orbits to keep a fixed view on an object as the head is moved from side to side. They also converge to maintain focus on objects as they are brought nearer to the viewer. These eye movements are necessary to achieve stereoscopic or binocular vision, and to view objects in three dimensions.

Binocular vision refers to the blending of two images into one image that has three-dimensional depth. When the eyes converge and focus on an object, the right eye sees a little bit more of the right side of the object while the left side sees more of the left side. The two images are not identical; the differences in the images focus on different regions in each eye's retina. The brain fuses these two slightly dissimilar images and interprets them as one image with depth. Other factors that influence the brain's interpretation of depth and dimension are included in the following table.

Factor	Explanation
<i>Overlap</i>	If an object overlaps another object, the overlapping object is closer.
<i>Relative size</i>	Objects seen as being larger are usually closer to the viewer.
<i>Perspective</i>	Two-dimensional drawings and photographs produce the illusion of depth by proper use of perspective (i.e., the relationship of lines on the objects to one or two points on an imaginary horizon in the drawing or photograph).
<i>Distance haze</i>	An object in the far distance may be partially obscured by haze while objects closer to the viewer appear to be much clearer. The brain knows this and interprets the haze-covered object as being farther away.
<i>Convergence</i>	Near objects may be judged as to relative depth by the brain measuring the amount of convergence of the eyes needed to maintain single binocular vision when looking at each object in a visual field.
<i>Accommodation</i>	The amount of change in the shape of the lens needed to maintain clear focus on each object within a visual field may also provide the brain with information regarding depth perception.
<i>Coloration and shading</i>	Variations in the coloration and the shading of objects enhance the brain's interpretation of an object's shape and dimensions.

Now that you know more about the anatomy and physiology of the human eye, it's time to learn more about the structure and function of another intricate sense organ—the human ear.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

201. Anatomy of the eye and its accessory structures

1. What bony cavity is formed by the union of seven cranial bones and serves as a protective encasement for the majority of the eye?
2. What layer of the eye helps maintain the shape of the eyeball?
3. What component of the outer layer of the eye bends (refracts) light rays as they enter the eye?
4. Name the three subdivisions of the eye's middle layer.
5. What is the colored portion of the eye called?
6. Which portion of the eye converts light to nervous impulses?
7. What is the area of sharpest vision on the retina?

8. What area of the retina is totally devoid of rods and cones?
9. What clear, watery fluid helps maintain the anterior curvature of the eyeball?
10. What condition is created by an increase in intraocular pressure in the anterior cavity?
11. Which cavity is filled with a clear, gel-like substance called vitreous body?
12. What is a clear, transparent mass of tissue situated posterior to the pupil and iris, and anterior to the vitreous body called?
13. What condition is created by progressive clouding or whitening of the lens tissue?
14. What is the function of the medial rectus?
15. What is the longest extrinsic eye muscle?
16. What eye muscle rotates the eyeball upward and laterally?
17. The extrinsic eye muscles are innervated by what three cranial nerves?
18. What muscle raises the upper eyelid?
19. What is the mucous membrane that lines the eyelids called?
20. Lacrimal fluid contains what enzyme that provides bactericidal action?

202. The eye as an optical instrument

1. At what distance can the normal eye focus parallel light rays from an object without the accommodating action of the lens?
2. Name the three most common conditions that result in errors of refraction in the eye.
3. What type of farsightedness occurs in a normal-sized eye as a result of the natural aging process?
4. The visual area of the brain is located in what part of the cerebrum?
5. What division of the autonomic nervous system controls the swift response of the pupil when the eye is exposed to bright light?
6. What type vision refers to the blending of two images into one image that looks real and has three-dimensional depth?

1-2. The Ear and the Senses of Hearing and Balance

The ear is a very intricate structure that acts as a receptor for both the sense of hearing and the sense of balance or equilibrium. Most of the structures found in the ear are associated with the sense of hearing. We discuss these structures and their respective functions in the beginning of this section. The second part of this section is devoted to looking at the structures in the ear that produce the sense of equilibrium.

203. Anatomy of the ear and the hearing process

The ear is a three-part organ composed of an outer, middle, and inner section (fig. 1-6). It is capable of collecting sound waves from the air; changing these waves to vibrations; amplifying the vibrations; and transferring them through bone, fluid, and various tissues. It also stimulates the auditory (hearing) receptors in the inner ear, causing them to convert the transferred vibrations into nervous impulses that are then relayed to the brain for interpretation as sounds. We call this “hearing.”

Outer ear

The outer ear closely resembles a funnel in shape and function. It consists of the *auricle* (also called the pinna) and the *external auditory meatus or canal*.

The auricle is the cartilaginous framework that collects sound waves and directs them through the external auditory meatus to the *tympanic membrane* (eardrum). The meatus is an S-shaped tube approximately 1 inch long. It passes into the cranium through the temporal bone. The external opening of the auditory meatus is surrounded by protective hairs, and the walls of the meatus is lined with a thin layer of skin containing numerous modified sweat glands—*ceruminous glands*. These glands secrete a waxy substance, called *cerumen*, which helps keep the meatus moist and traps dust

and other foreign particles that might otherwise enter the ear. As the sound waves pass through the meatus, they cause changes in the air pressure around the tympanic membrane. These changes in air pressure cause the tympanic membrane to start vibrating. These vibrations are then transferred to structures found in the middle ear.

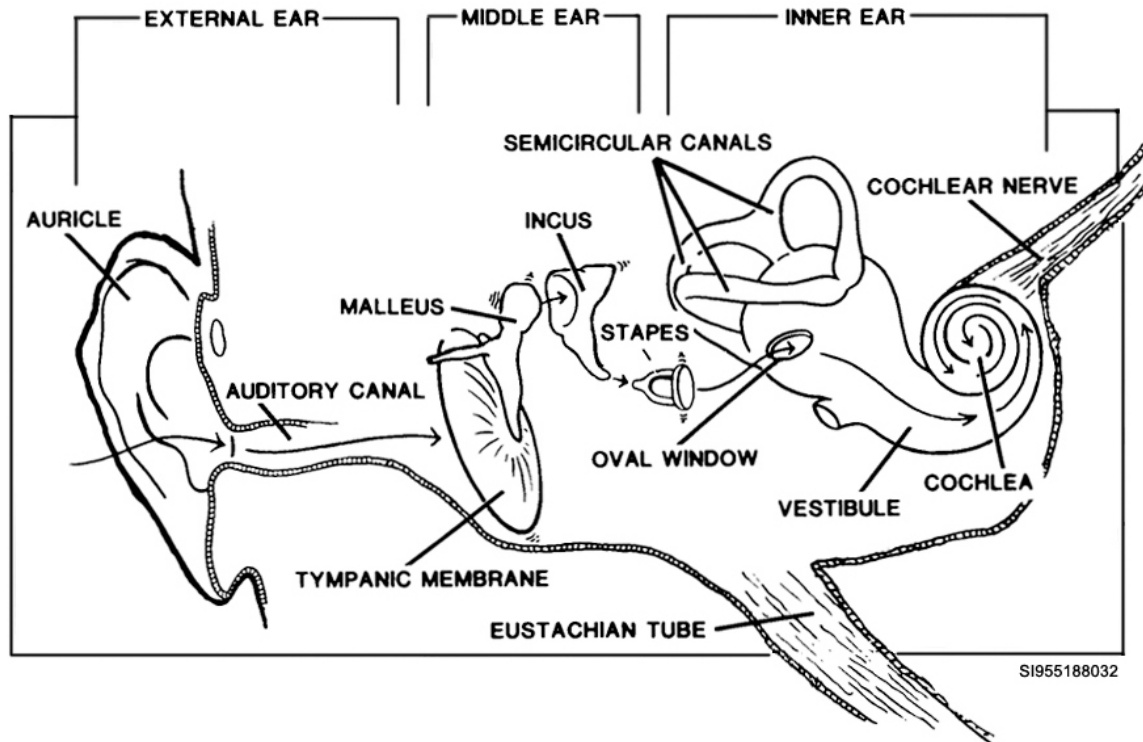


Figure 1-6. Major components of the ear.

Middle ear

The middle ear is located within a cavity of the temporal bone called the *tympanic cavity*. The cavity is lined with mucous membrane and contains the tympanic membrane and the auditory ossicles.

Tympanic membrane

The tympanic membrane, commonly called the “eardrum,” stretches across the ear canal and separates the external ear from the middle ear. It is a thin, tough, almost transparent membrane, lined externally with skin and internally with mucous membrane. The tympanic membrane has an oval, somewhat concave shape, with the curve directed inward towards the middle ear. At the point or apex of the curve, the membrane is attached to one of the ossicles. In addition to receiving sound waves and converting them to mechanical vibrations, the tympanic membrane protects the middle and inner ears from foreign particles and fluid permeation. As we mentioned earlier, the tympanic membrane vibrates in response to sound waves, much like the head of a drum vibrates in response to being struck with a drum stick. The pattern of varying vibrations set up in the tympanic membrane is transferred to the auditory ossicles, then on to structures in the inner ear.

Auditory ossicles

The auditory ossicles, or middle ear bones, are the smallest bones in the human body. These three bones are named according to their shape.

Name	Description	Attachment
<i>Malleus</i>	Shaped like a hammer.	The handle of the malleus is attached to the tympanic membrane, while the head is attached to the second ossicle.
<i>Incus</i>	Shaped something like a blacksmith's anvil (incus/anvil).	Connects to the stapes.
<i>Stapes</i>	Shaped like a stirrup; the base, or footplate, of the stirrup is oval shaped.	The arch of the stirrup connected to the incus and the base connected to a part of the inner ear.

The impact of sound waves on the stretched tympanic membrane causes it to vibrate. The energy of the vibrations is carried across the middle ear by a lever system formed by the joined ossicles. The rocking motion of the stapes sets up waves in the fluid of the inner ear. The surface area of the tympanic membrane is about 20 times greater than the footplate of the stapes; therefore, the pressure exerted on the fluid in the inner ear is about 20 times greater than the pressure placed on the tympanic membrane by the impact of the sound waves. This increase of pressure on the footplate of the stapes and the fluid of the inner ear is necessary to equalize the strength of the vibrations' effect on air and the fluid within the inner ear. Because the fluid is denser than the air, it takes more energy to set up the wave motion in the fluid than it does in the air.

Ligaments

The ossicles are held in place by ligaments that attach to the wall of the tympanic cavity. Ligaments also attach the malleus to the tympanic membrane and the stapes to the inner ear.

Muscles

One muscle, the *tensor tympani*, is attached to the medial aspect of the malleus and acts to pull the malleus towards the inner ear. The other muscle, the *stapedius*, is attached to the posterior portion of the stapes and acts to pull the stapes towards the outer ear.

The combined effect of these two muscles is to tighten the connections between the ossicles. This, in turn, reduces the vibrations transferred from the tympanic membrane to the inner ear. This damping action is called the *tympanic reflex*, and it is a protective reaction to prevent loud noises from damaging the delicate structures in the inner ear. The tensor tympani maintains a constant tension on the malleus and helps keep the eardrum tight, except when the protective reflex is activated by severe vibrations.

Openings in the middle ear

There are a number of openings in the middle ear. The tympanic membrane covers the opening to the external meatus. The footplate of the stapes covers another opening into the inner ear called the *oval window*. A similar opening, the *round window*, also opens into the inner ear. There are also a number of air spaces that open into the middle ear which act as resonating chambers. These spaces are found in the mastoid bone of the skull and are appropriately named *mastoid spaces*. Finally, there is another opening in the base of the middle ear which leads to the *eustachian tube*.

The eustachian tube is about $1\frac{1}{2}$ inches long and $\frac{1}{8}$ inch in diameter at its narrowest point. It connects the middle ear with the pharynx and serves to equalize the air pressure inside the middle ear with that of the atmosphere outside the tympanic membrane. This pressure adjustment is necessary to prevent the tympanic membrane from rupturing. It is particularly important in maintaining equal pressure on either side of the eardrum at high altitudes, where the outside air pressure significantly decreases the higher you go, and underwater, where inward pressure on the eardrum greatly increases the deeper you go.

The pharyngeal openings for the eustachian tubes are covered with flaps of skin. Chewing, swallowing, or yawning causes these flaps to temporarily open so that air can enter the middle ear to equalize the pressure. The "popping" sensations you experience in your ears when ascending or

descending in an airplane are caused by the adjustments in pressure on either side of the eardrum. You can help this pressure equalization process by chewing gum or widely opening your mouth. If the eustachian tubes become blocked or do not open properly, the unequal air pressure may cause the eardrum to bulge in or out. In these circumstances, the eardrum is stretched tighter than normal and does not vibrate freely. The end result is a marked impairment of hearing.

Although the eustachian tube serves a vital protective purpose, it can also be a source of chronic problems. Because it links the middle ear with the pharynx, it can act as a pathway for infectious microorganisms to travel from the throat to the middle ear. If the infection is undetected or left untreated, it can spread into the mastoid spaces and infect the mastoid bone. Once the infection gets into the bone, it becomes extremely difficult to eradicate and can require removal of the infected portions of the mastoid bone. In serious cases, the infection may spread even further and invade the meninges that cover the brain.

Middle ear infections are more prevalent in young children because the eustachian tube is shorter and positioned more horizontally than in adults. Also, children are more predisposed to getting throat and upper respiratory tract infections because their immune systems are not as fully developed as the normal adults. If a child has recurring middle ear infections, he or she may be treated with a procedure where the eardrum is lanced—a myringotomy. This allows pus that accumulates behind the eardrum to drain from the middle ear. In nearly every instance, the myringotomy is followed by insertion of a small plastic (polyethylene or PE) tube into the slit in the eardrum to provide ongoing drainage until the infection can be checked by antibiotic therapy. In addition, implantation of the tube allows for instillation of antibiotic drops to help eliminate the infection more rapidly.

Inner ear

The inner ear (refer back to fig. 1-6) contains the receptors for both hearing and equilibrium. It consists of a series of complicated canals located in a hollow portion of the temporal bone. Because of its complicated shape, the inner ear is sometimes called the *labyrinth*. There are two different sets of labyrinths in each ear, one inside the other. The outer one is called the *osseous* or *bony labyrinth*, and the inner one is called the *membranous labyrinth*. A fluid called *perilymph* is found between the two labyrinths. The membranous labyrinth contains another type of fluid that is known as *endolymph*.

The bony labyrinth can be divided into three main parts (fig. 1-7).

Bone	Location/Use
Vestibule	This is the expanded, bony chamber between the semicircular canals and the cochlea. It is involved in both hearing and equilibrium.
Cochlea	Is the innermost structure that resembles a snail shell. It contains receptors that produce nervous impulses that the brain interprets as sound.
Semicircular canals	The outermost structure of the inner ear consists of three loop-shaped structures. They are involved in maintaining equilibrium.

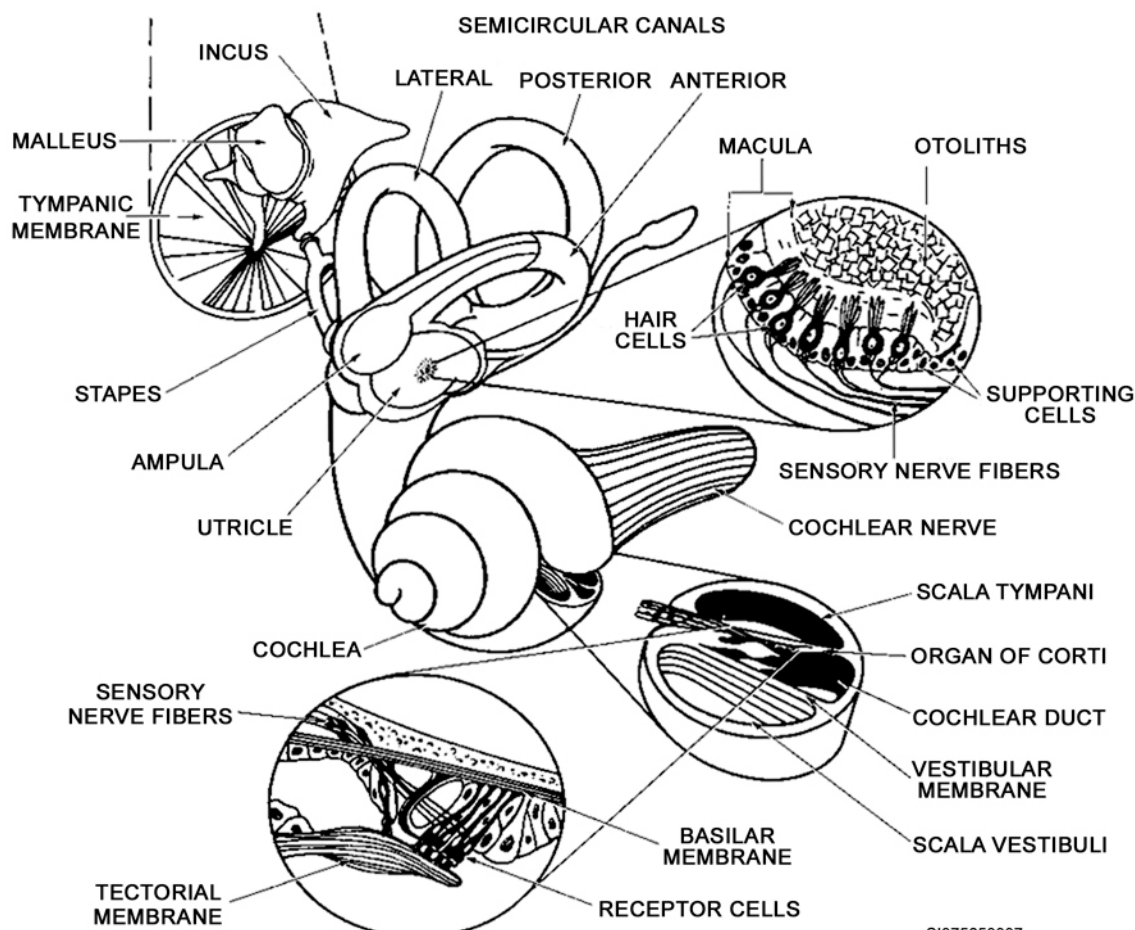


Figure 1-7. Bony labyrinth of the inner ear.

The cochlea is further divided into three additional labyrinths—two bony labyrinths and a middle membranous labyrinth (fig. 1-7, cutout).

Labyrinth	Location/Use
Scala vestibuli	Leads from the oval window (the footplate of the stapes rests here) to the apex of the cochlear spiral.
Scala tympani	Extends from the tip of the cochlear spiral to the round window in the inner ear.
Cochlear duct (also called the scala media or membranous labyrinth).	Along with a thin projection of bone called the <i>spiral lamina</i> , divides the scala vestibuli and tympani.

There are two membranes—*vestibular membrane* and *basilar membrane*—separating the membranous labyrinth from the upper and lower bony chambers.

The vestibular membrane forms the floor of the upper chamber (scala vestibuli) and the roof of the cochlear duct (middle chamber).

The basilar membrane (cutout of the cutout in fig. 1-7) is the lower membrane; it forms the floor of the cochlear duct and the roof the scala tympani. It is lined with elastic fibers of varying lengths. On the surface of the entire length of this membrane is a structure called the *organ of Corti*. It consists of rows of special receptor cells that have tiny, hair-like projections extending into the endolymph contained within the scala media.

Another membrane, the *tectorial membrane*, extends from the spiral lamina into the scala media. The hairs of the organ of Corti just barely make contact with the surface of the tectorial membrane. Movement of the hairs against this membrane creates a generator potential that is then converted to a sensory nervous impulse. This sensory impulse is then transmitted to the brain via the auditory nerve.

Did you follow all that? Let's try to simplify things a bit.

1. After vibrations pass through the ossicles of the middle ear, they pass through the oval window and enter the scala vestibuli in the inner ear.
2. The scala vestibuli is full of a fluid called perilymph; the vibrations stimulate this fluid and create a ripple effect (like throwing a rock into a pool of water).
3. This ripple continues along the scala vestibuli in a spiral pattern, all the way to the tip of the cochlea.
4. As the vibrations pass through the scala vestibuli, they also stimulate and pass through the vestibular membrane, stimulating the fluid in the other side of the membrane, endolymph, that fills the cochlear duct. This continuing ripple effect causes movements in the elastic fibers of the basilar membrane, which in turn, causes the hairs of the organ of Corti to move.
5. The hairs of the organ of Corti rub against the tectorial membrane and create a generator potential for a sensory impulse.
6. The sensory impulse travels to the hearing centers in the brain by way of the cochlear branch of the vestibulocochlear or auditory (8th cranial) nerve and, finally, the sound is heard.
7. After the vibrations pass through the basilar membrane, they enter into the perilymph of the scala tympani.
8. From there, they are carried back down the cochlear spiral to the membrane-covered round window at the base of the cochlea.
9. The round window opens into the middle ear. The vibrations pass through the thin membrane covering the round window and are lost in the air in the middle ear.

The different lengths of elastic fibers found in the basilar membrane correspond to different frequencies of vibrations (step 4 above). Short fibers react to rapid vibrations, and long fibers react to slow vibrations. The fibers gradually increase in length with the shortest fibers located at the base of the cochlea and the longest at the apex. This means that the base of the cochlea is sensitive to high pitch frequencies (e.g., high notes created by a flute or violin) and the apex is sensitive to low pitch frequencies (e.g., notes created by a bass guitar or kettle drum). Other frequencies are located somewhere in the middle.

After studying this lesson, you should have a better understanding of the structures of the ear that are responsible for the sense of hearing and how they work together to create the perception of sound. Now, we will look at the structures of the ear that allow you to maintain your balance and sense of spatial positioning.

204. The physiology of balance

The mechanism for the sense of equilibrium is considerably simpler than the physiology of hearing. Basically, the sensation of balance is just a matter of the brain detecting changes in the position of sensory hairs within a fluid. These sensory hairs and fluid are located in the inner ear. We'll talk about two different types of equilibrium—static and dynamic—but the basic principle is the same for both.

Static equilibrium

Static equilibrium is the position of the head when it is at rest. The receptors for static equilibrium are located within the vestibule of the inner ear. The membranous portion of the inner ear is divided into two smaller chambers called the *utricle* and the *sacculle* (refer back to fig. 1-7). The sacculle connects

with the cochlea, and the utricle connects with the semicircular canals. There is a small patch of receptor cells called a *macula* located on the side of each of these chambers. Each macula cell has several little hair-like projections that extend out into a thick, viscous substance. There are particles of calcium carbonate called *otoliths* embedded on the surface of the substance. When the head moves, this substance also moves. This causes the hairs to move and creates a generator potential. The maculae are positioned so that the hairs of the utricle project vertically and those of the saccule project horizontally when the head is in the upright position. The otoliths in the macula detect the direction and intensity of gravity, or G-forces, such as those that are felt when you tip backwards in a chair or when you fall to the ground (fig. 1–8). The supporting cells transmit the impulses generated by the G-forces to the brain for interpretation.

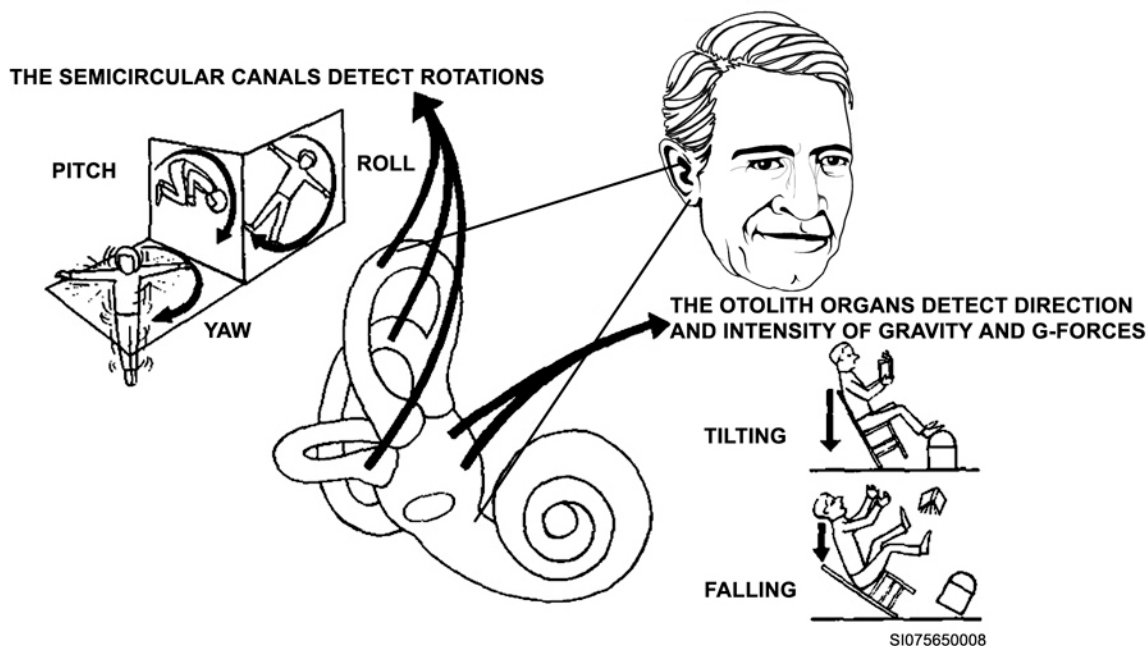
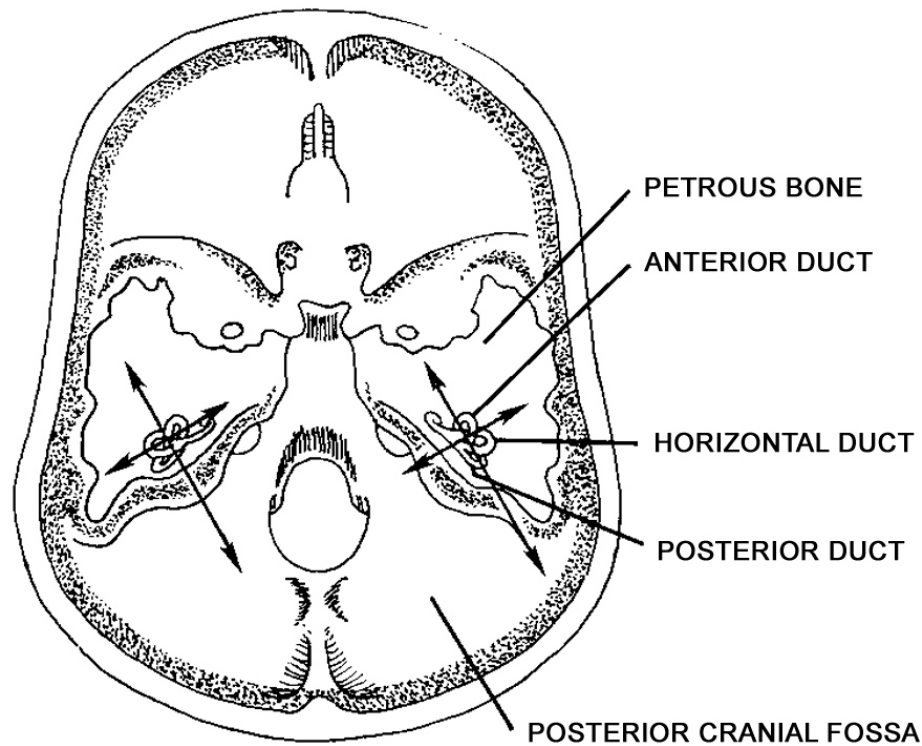


Figure 1–8. Movements detected by the vestibular apparatus and semicircular canals.

Dynamic equilibrium

The mechanism for detecting dynamic (moving) equilibrium is the same as the mechanism for detecting static equilibrium except that it involves the *semicircular canals*. These canals are arranged at right angles to each other, with two vertical and one horizontal (fig. 1–8). There is a little expanded portion called the ampulla at the end of each canal (fig. 1–7). Each ampulla contains a patch of hair receptor cells called the *crista ampullaris*. The hairs of the crista ampullaris extend into a viscous substance called the *cupula*. When the head moves rapidly, the cupula tends to stationary (inertia). This causes the hairs to bend in a direction opposite the movement and creates a generator potential. Each of the three cristae in the ampullae of the semicircular canals reacts slightly differently to movement. Between the three, the brain is able to detect just what type of movement took place. The vestibular branch of the vestibulocochlear (auditory) cranial nerve transmits impulses created in the vestibule and semicircular canals to the balance centers in the brain. The semicircular canals are mainly involved with detecting rotational movements such as pitch (backward or forward tumbling), roll (cartwheel-style, lateral rotational movement), and yaw (upright spinning movement), as shown in figure 1–8. The orientation and location of the two sets of semicircular canals in relation to the base of the skull is shown in figure 1–9.



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Figure 1-9. Semicircular canal orientation in relationship to the base of the skull (superior view).

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

203. Anatomy of the ear and the hearing process

1. What is another name for the auricle?
2. What is the waxy substance that helps keep the meatus moist and traps dust that might otherwise enter the ear?
3. Where are the auditory ossicles located?
4. What structure receives sound waves and converts them to mechanical vibrations?
5. Which ossicle is shaped like a stirrup?

6. What muscle maintains constant tension on the malleus and helps keep the eardrum tight?
7. What structure equalizes the pressure between the atmosphere and the middle ear?
8. What fluid is found between the bony and membranous labyrinth of the inner ear?
9. What structure is found on the surface of the entire length of the basilar membrane?
10. What is the function of the elastic fibers of the basilar membrane?

204. The physiology of balance

1. Where are the receptors for static equilibrium located?
2. What are otoliths?
3. What is the patch of hair receptor cells in each ampulla of the semicircular canals called?
4. Name the three rotational movements detected by the semicircular canals.

1-3. Smell, Taste, and General Sensory Receptors

Up to this point, we have concentrated on the two major sense organs in the body—the eyes and ears. Now, we will wrap up our lessons on the special senses by familiarizing you with the structures that allow you to taste and smell your food. We will also take a look at various specialized receptors located in your skin and elsewhere in your body. They allow you to sense movement of body parts, heat and cold, pressure and pain, and changes in the internal chemical environment. Let's begin this section by discussing a sense that often dominates the others when unpleasant odors are encountered—the sense of smell.

205. The senses of smell and taste

Smells, called olfaction, and taste, called gustation, are two of the most important senses for most humans. Both are associated with sensory structures in the upper region of the nasal cavity and the mouth.

Olfactory receptors

The olfactory receptors are specialized cells located in the epithelial tissue in the roof of each nostril. As you can see in figure 1-10, these receptors are actual neurons embedded in the epithelial tissue. These are the only neurons in the body that are actually located on the surface of the body. The end of each neuron is shaped like a little knob and covered with fine hairs. These hairs project into the nasal cavity and are thought to react to different odors.

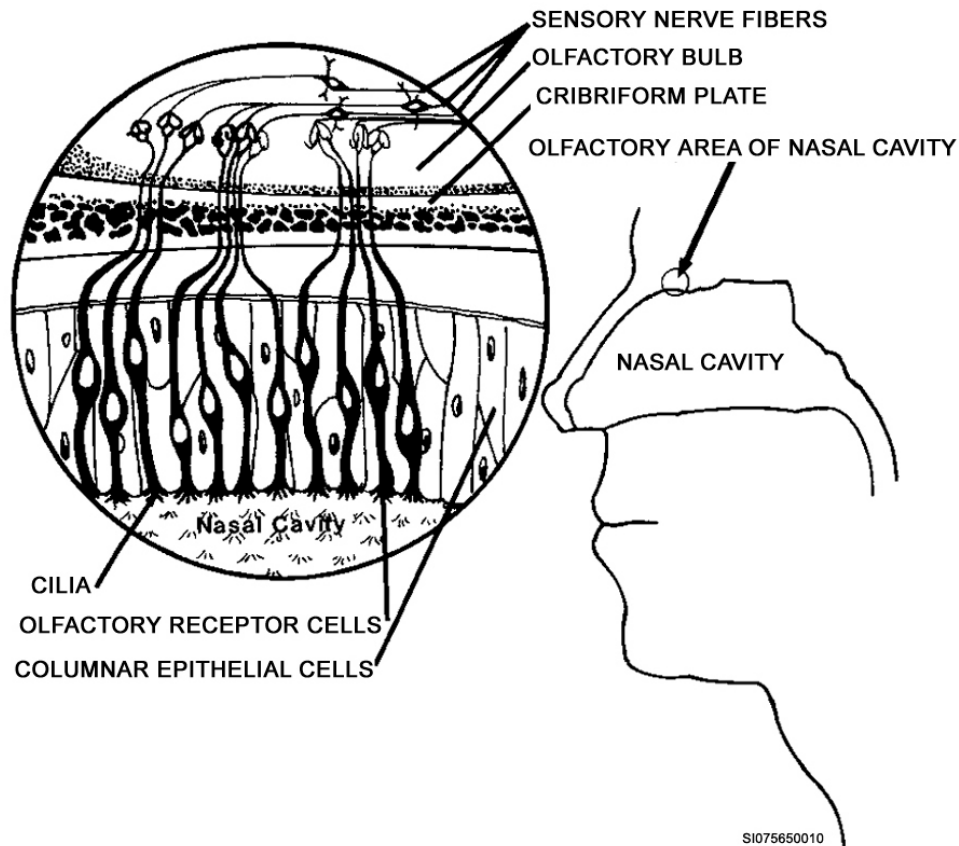


Figure 1-10. Olfactory receptors.

Mechanism of smell

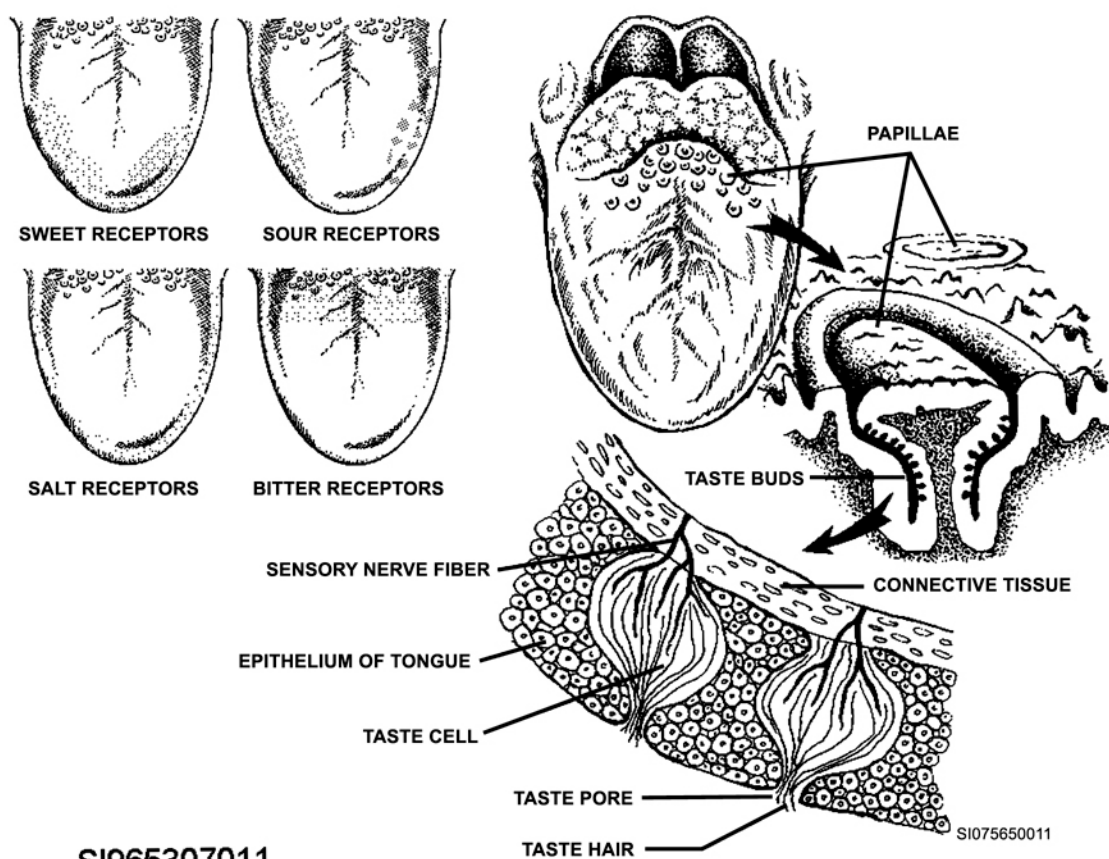
The process by which odors are detected is not as well understood as that of taste (which we discuss next). The olfactory hairs, or cilia, seem to function as chemoreceptors that react to the different chemicals in the air we breathe. These receptors are concentrated in about a 1-inch square area in each nostril. Although the receptors are capable of detecting specific types of smell, the neurons are not differentiated according to what odor they react to. When a gas containing smell-producing chemicals enters the nasal cavity, the chemicals are dissolved in the mucous fluid surrounding the olfactory cilia. The cilia react to this stimulus by producing a sensory impulse. Once the neurons have been stimulated, the impulse passes through the roof of the nostril to a structure called the *olfactory bulb*. These bulbs are located on either side of the crista galli (a part of the ethmoid bone, remember?). They receive the impulse from the sensory neuron and transfer it along the olfactory tract to the central nervous system.

The olfactory receptors are capable of recognizing a number of different smells and combinations of smells. The distinct odors so recognized include *camphor*, *musk*, *floral*, *peppermint*, *ether*, *pungent* (*spicy*), and *putrid* (*decaying meat*). These receptors adapt fairly quickly. Within a minute or so, a specific odor is gone. Olfactory receptors are not replaced on a regular basis. As they wear out and

become nonfunctional, your sense of smell gradually deteriorates. From the day you are born until the day you die, you will lose your sense of smell at a rate of about one percent each year.

Taste receptors

The taste receptors are specialized cells located in the tongue, roof of the mouth, and sides of the pharynx. These cells, or taste buds, as they are more commonly called, are structured much like the encapsulated nerve fibers we discuss in the next lesson. They are spherical structures consisting of specialized epithelial cells with a supporting network of sensory nerve fibers. The taste buds (fig. 1–11) are embedded in and supported by the epithelial tissue along the sides of the papillae on the surface of the tongue. At one end, they are anchored to the connective tissue. At the other end, they open through tiny pores onto the epithelial surface. There are a number of tiny projections called *taste hairs* protruding through these pores. These hairs are thought to be responsible for producing the actual taste sensations.



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Figure 1–11. Taste buds.

Mechanism of taste

Taste buds function as a sort of chemoreceptor. That is, they produce sensations in response to various chemical stimulations. The chemicals in food are first dissolved in saliva and then filtered down among the taste hairs where they react with the ions at the receptor membranes. This reaction produces a potential which is changed into a sensory impulse and transmitted to the brain. Taste receptors adapt fairly quickly. Flavor can be maintained by moving the food about on the tongue so that various receptors are involved. Unlike most tissue related to the nervous system, taste cells are replaced fairly quickly. This is fortunate since the tongue is frequently burned or damaged in various ways.

Types and locations of taste buds

There are four basic types of taste cells, each producing a specific type of taste sensation. These sensations are *sweet*, *sour*, *salty*, and *bitter*. The flavors we taste are the result of combinations of these sensations, plus some input from the olfactory (smell) receptors.

The taste cells are concentrated in different areas of the tongue (fig. 1-11).

Receptors for:	Location/Stimulation
Sweet sensations	Located on either side of the tip of the tongue. They are primarily stimulated by foods containing carbohydrates (e.g., sugar).
Sour	Are concentrated along the sides of the tongue. They respond to foods containing high concentrations of hydrogen compounds (acids) (e.g., vinegar).
Salt	Are located on the tip and along the edges of the tongue. They, of course, respond to salty foods (i.e., foods containing high concentrations of sodium ions).
Bitter	Are located at the back of the tongue. They respond to various organic and inorganic compounds such as alkaloids (e.g., nicotine and morphine), caffeine, quinine, and some calcium salts.

Our taste buds are an important part of our body. When they are nonfunctional (e.g., a severe cold), our appetites decrease and we don't eat properly. Eventually, this results in malnutrition. Like other sensory receptors, impulses from the taste buds are carried through the peripheral nervous system to the central nervous system. The specific peripheral nerves involved are the *facial nerve*, *glossopharyngeal nerve*, and *vagus nerve*.

206. General sensory receptors and their sensations

General sensory receptors are the millions of cells throughout the body responsible for providing us with environmental information. Unfortunately, there are almost as many ways to classify them as there are receptors. We look at these classifications briefly, and then go on to study the function of individual types of sensory receptors.

Basically, sensory receptors are classified according to their type of structure, their location in the body, the kind of stimulus they detect, and their function.

Structure

Structure is probably the simplest classification. As you can see in figure 1-12, there are two types of receptors:

1. Free nerve endings.
2. Encapsulated nerve endings.

Free nerve endings

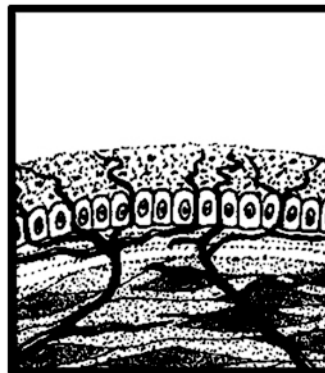
Free nerve endings are terminal branches of sensory nerve fibers, which have no protective outer covering. These fibers extend up into and around various tissues and organs. Most free nerve fibers are found in the skin. There they detect sensations of pain, temperature, crude touch, pressure, and itch. Free nerve endings are also found in muscles, tendons, and joints, as well as in abdominal organs and blood vessels (viscera). Those found in muscles, tendons, and joints detect movement, position, deep pain, and deep pressure. The visceral receptors detect changes in internal pressures, shapes, and chemical concentrations of body fluids. They do produce some sensations of pain, hunger, and nausea, but most of the changes they detect result in reflex, or autonomic body activities, and are not felt by us. Visceral receptors have the crucial task of maintaining homeostasis—the state of balance within the body.

Encapsulated nerve endings

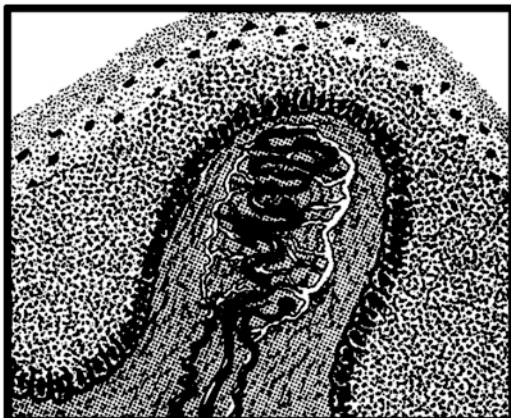
Encapsulated nerve endings (fig. 1-12) differ widely in shape and structure; however, they all have some type of protective outer covering. Encapsulated nerve endings are found in the skin,

subcutaneous tissue, mucous membranes, around and in muscles, joints and tendons, and in male and female external reproductive organs. In addition to detecting muscle position and movement, they produce sensations of light, normal, and heavy touch, pressure, and vibration. Refer to the following table for an overview of the types, locations, and functions of the general sensory receptors found in the body.

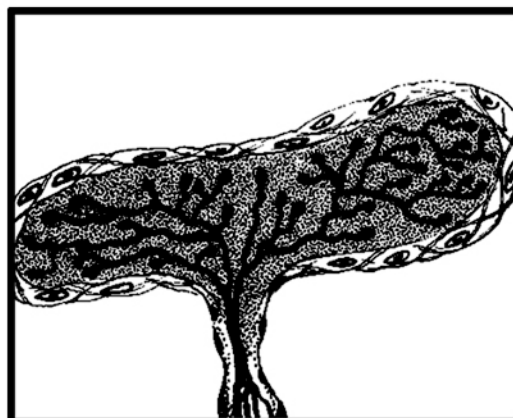
FREE NERVE ENDINGS



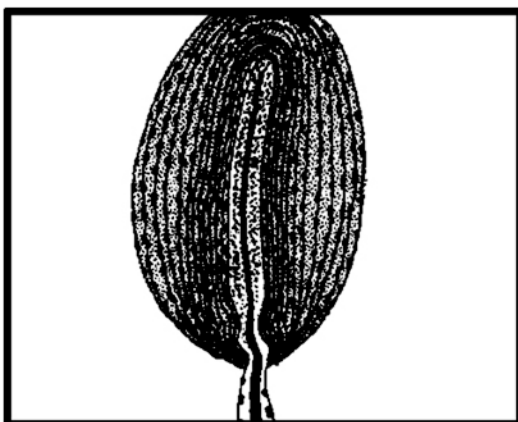
MEISSNER'S CORPUSCLE



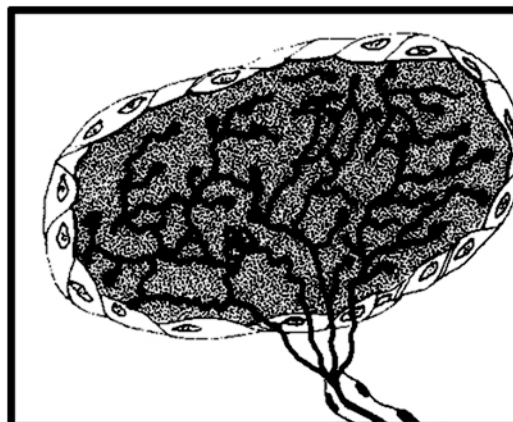
RUFFINI'S CORPUSCLE



PACINIAN CORPUSCLE



KRAUSE'S END-BULB



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Figure 1-12. General sensory receptors.

Receptor	Location	Function	Remarks
Free nerve endings	Throughout skin, heavily concentrated in respiratory tract, surface of eye contains only free nerve endings.	Touch, pressure, some itching, some temperature, pain receptors of the skin (e.g., cutaneous touch receptors, principle pain receptors).	Pain receptors appear to be triggered by tissue destruction. Pain receptors adapt very little, some adapt in reverse (i.e., pain becomes more intense, rather than diminishes with time).
Tactile hair (root hair plexus)	Hairy parts (nearly all) of the body	Touch. Respond to movement of hair (e.g., cutaneous touch receptors)	Adapt readily. Best suited to detect moving stimulus. Able to discriminate several types of stimuli.
Meissner's corpuscles	Hairless parts of the body (e.g., fingertips, lips, eyelids, soles of feet, external genitalia, breasts.	Touch (e.g., cutaneous touch receptors)	Adapt very quickly. Best suited to detect moving rather than static stimuli. Often necessary to reduce their sensitivity when trying to discern specific information.
Pacinian (lamellated) corpuscles.	Beneath skin and deeper tissues, including joints and viscera. Also in fingertips, soles of feet, external genitalia, breasts.	Respond to heavy pressure, especially constantly applied. Also respond to very rapid tissue movement such as vibration (e.g., cutaneous touch receptors)	Plentiful in soles of feet; help in posture orientation and determining joint rotation.
Krause's corpuscles (end bulbs)	Generally in skin, but also in muscles, tendons, and in mucous membranes of mouth and genital organs	Associated with cold stimuli (e.g., thermoreceptor)	Most sensitive to temperatures below 68°F (20°C). Felt as freezing pain below 50°F (10°C).
Ruffini's corpuscles (end organs)	Deep in dermis	Associated with heat stimuli (e.g., thermoreceptor)	Most sensitive to temperatures above 77°F (25°C). Felt as burning pain above 113°F (45°C).
Golgi tendon organ	Tendons	Detects tension of tendon (e.g., neurotendinous receptors or stretch receptors)	Adapts slowly. Afferent basis inhibits muscular contraction. Serves to dampen contraction; serves to prevent excessive contraction.
Muscle spindle	Within skeletal muscle	Feedback and control of muscle tone. Detect length and rate of muscle change (e.g., neurotendinous receptors or stretch receptors)	Detects changes in posture and position of body parts. Input goes to cerebellum, not perceived consciously. Primary afferent fiber responds to actual passive lengthening of muscle; secondary afferent fiber responds to stretched muscle fiber.

Location

There are three different location classifications:

1. Exteroceptors (superficial).
2. Proprioceptors (deep).
3. Visceroceptors (internal organ or structure).

Receptor	Location	Description
Superficial receptors or exteroceptors	In the skin and mucous membranes near the surface of the body.	Produce sensations of touch, pressure pain, and temperature.
Deep receptors or proprioceptors	In and around muscles, joints, and tendons.	Detect changes in position, movement, vibration, and deep pressure and pain.

Receptor	Location	Description
Internal receptors or visceroreceptors	In the blood vessels and gastrointestinal organs.	Usually produce no sensations; exceptions are hunger, nausea, and internal pain caused by abnormal conditions.

Although certain types of sensory receptors tend to be found in some parts of the body, there is no definite distribution pattern. For example, the great majority of touch receptors are located in the skin and mucous membranes. The concentration of these receptors is much greater around your hands than it is on an area like your back. Generally speaking, receptor concentration is related to function. You use your hands constantly to touch and feel things, but the skin on your back is more of a simple protective layer.

Stimulus

As you can see, there is a lot of overlap in the first two classifications. You will find that the same is true of the third classification—by type of stimulus produced. The different types of stimulus include *touch and pressure*, *pain*, *temperature*, *chemical concentrations*, and *stretch*.

Touch and pressure

Receptors that produce touch and pressure sensations are called *mechanoreceptors* because they detect mechanical activity that results in some deformity or movement in the structure of the organ. Regardless of how lightly you touch something; there is some displacement of the cells. The type of displacement that occurs produces the different sensations. *Free nerve endings*, *Meissner's corpuscles*, and *Pacinian corpuscles* all produce sensations of touch and pressure.

Pain

Receptors that produce pain sensations are called *nociceptors*. Nociceptors are sensitive to a wide variety of activities that cause tissue damage. For example, excessive heat will activate one type of nociceptor, and actual tearing of the tissue will activate another. Some nociceptors are sensitive to chemical changes in the body, and others respond to excessive stretching of tissue. The common denominator seems to be any kind of excessive stimulation.

Pain receptors are unique in that the pain can be caused by activity in one part of the body, but may be felt in another part. This characteristic is called *referred pain*, and is usually seen when visceral organs are damaged. The pain that occurs during a myocardial infarction is an excellent example of this. That pain is caused by a deficiency in the oxygen supply to the heart, but it is sometimes felt only in the left arm, shoulder, and jaw. The best explanation for this phenomenon is that the damaged area shares a neural pathway with the area where the pain is felt. When the brain receives the sensory impulse from the heart, it somehow misinterprets where the signals come from and refers them back to the wrong place.

Visceral organs have another unique characteristic relating to pain. Some forms of stimulation (damage) produce pain sensations, but others do not. For example, stretching the tissue of the stomach and small intestine (i.e., “pigging out”) can cause severe abdominal pain, but cutting (i.e., surgery) or burning (i.e., cauterization) of the same organ may not produce any sensations at all. This characteristic is probably due to the presence of specific types of nociceptors in these organs.

Temperature

Two different types of temperature receptors (*thermoreceptors*) exist. *Heat receptors* are sensitive to temperatures between 77 and 113 degrees Fahrenheit (°F). *Cold receptors* respond to temperatures between 50 and 68 °F.

Chemical concentrations

Receptors that respond to changes in chemical concentrations are called *chemoreceptors*. Some chemoreceptors monitor carbon dioxide levels in the blood and play a key role in regulating

respiration and acid-base balance in the body, while others help regulate blood glucose (sugar) levels. These homeostatic mechanisms cannot be felt the way touch and pain are felt, but they do result in reflex activities to correct the situation that activated the chemoreceptors. Chemoreceptors are forms of free nerve fibers.

Stretch

Stretch receptors are actually a form of mechanoreceptor and could be included with the receptors for touch and pressure. However, because they refer specifically to changes in muscles and tendons, they are more commonly referred to as *proprioceptors*. These stretch receptors also differ from touch and pressure receptors in their response to stimulation. When they are stimulated, reflex activity is produced instead of sensations. Proprioceptors are located in the tendons near the attachment point to the muscle, and in the muscle fiber near the attachment point of the tendon. Those in the tendon are called *Golgi tendon organs*. They are sensitive to the tension of the tendon. When there is an extreme amount of tension, they act to inhibit or slow down the muscle activity. Golgi tendon organs are important in maintaining posture and preventing muscle-tendon separations.

Proprioceptors located in the muscle fiber are called *muscle spindles* and are also sensitive to tension. These spindles consist of nerve fibers wrapped around muscle fibers. When the muscle fibers relax, the muscle spindle stimulates muscle activity called the stretch reflex. This reflex causes the muscle to contract and maintain its position. The stretch reflex is important in maintaining posture and muscle tone.

Function

The whole purpose of sensory receptors is to detect change and produce a sensory impulse in response. An *impulse* is the electrical activity produced by a change in the ion concentrations around the neural membrane. The amount of activity required to produce change in the membrane of a sensory receptor is called the generator potential or receptor potential. Unlike the “all-or-nothing” law that controls the action potential of other neurons, the generator potential is graded. An increase in the amount of activity or change produces a corresponding increase in the strength of the generator potential. If the generator potential is strong enough to overcome the action potential of the neurons of the nerve fiber, the impulse is transmitted to the brain.

Not all sensory receptors are nerve fibers. The encapsulated nerve endings are composed of an outer layer (layers) of epithelial, connective, or muscle tissue surrounding an inner core containing a sensory nerve fiber. Before the impulse can be transmitted to the brain, these receptors have to transmit the generator potential to the sensory fiber.

Sensory neural pathways

Sensory impulses are transmitted to the spinal cord and brain through the routes in the peripheral nervous system we discussed earlier. All sensory inputs are alike in that they are all electrical charges. The difference is the destination of these electrical charges. Different areas of the brain interpret these impulses differently and produce a response based on that interpretation. This response is in the form of a feeling (sensation) or reflex activity. If it were possible to switch fibers and brain areas around, conceivably a stimulus that normally produces a touch sensation, for example, could produce a deep pain sensation. There are an infinite number of variables, and we all rely heavily on the brain to keep these sensory interpretations organized.

In addition to producing a specific sensation in response to a specific impulse, the brain reflects the sensation back to where the impulse originated. This is called *projection*. Except in the case of referred pain, as we discussed earlier, projection allows you to identify the point where the impulse originated. You may wonder why that makes any difference. Consider an example of what could happen if there was no projection. Let’s say you just carelessly put your hand on a hot burner. Your brain immediately lets you know you are hurting! However, since there is no projection, you have no idea where you are hurting or what to do about it. While you try to untangle your synapses to

manually figure it all out, your hand is getting more and more burned, causing more and more pain! You can see projection is very valuable.

Receptor adaptation

The last characteristic of general sensory receptors we discuss is adaptation. Adaptation is the ability of the receptor to adjust to a continual stimulus. Over a period of time, the change produces less and less generator potential. Eventually, there will not be enough potential to overcome the action potential threshold, and no impulse will be transmitted. A good example of this characteristic is the body's ability to adapt to heat and cold. When you first get into a hot tub, you feel almost like the water is burning you. After a short time, your body adjusts and the water feels comfortable or maybe even a little cool. That is adaptation.

Different sensory receptors adapt at different rates. Receptors for pressure, touch, vibration, heat, and cold all adapt fairly quickly. By contrast, receptors for pain, muscle position, and homeostatic mechanisms adapt very slowly. In other words, your hand will hurt for as long as you manage to keep it on that burner, it will not adapt and make the burner feel comfortable!

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

205. The senses of smell and taste

1. What are the only neurons in the body that are actually located on the surface of the body?
2. What are the basic odors recognized by the olfactory receptors?
3. Name the three places where taste buds are located.
4. What are the basic sensations recognized by taste receptors?

206. General sensory receptors and their sensations

1. How are sensory receptors classified?
2. What type of sensory receptor is primarily located in the skin and produces sensations of pain, temperature, crude touch, and itch?
3. What type of sensory receptor detects changes in position, movement, vibration, and deep pressure and pain?
4. List the activities that will stimulate nociceptors.

5. What is the normal sensation ranges for the two types of thermoreceptors?
6. What proprioceptors are important in maintaining posture and preventing muscle-tendon separations?
7. What is the electrical activity produced by a change in the ion concentrations around the neural membrane called?
8. What sensory mechanism allows you to detect where an impulse originated?
9. What is receptor adaptation?
10. Name the types of sensory receptors that adapt fairly quickly.

Answers to Self-Test Questions

201

1. Orbit.
2. Outer layer (sclera).
3. Cornea.
4. Choroid, ciliary muscle (body), and iris.
5. Iris.
6. Retina.
7. Fovea centralis.
8. Optic disk (blind spot).
9. Aqueous humor.
10. Glaucoma.
11. Posterior.
12. Crystalline lens.
13. Cataract.
14. Adducts the eye.
15. Superior oblique muscle.
16. Inferior oblique muscle.
17. Oculomotor, trochlear, and abducens.
18. Levator palpebrae superioris.
19. Conjunctiva.
20. Lysozyme.

202

1. 20 feet.

2. Myopia (nearsightedness), hyperopia (farsightedness), and astigmatism.
3. Presbyopia.
4. Right and left occipital lobes.
5. Parasympathetic.
6. Binocular.

203

1. Pinna.
2. Cerumen.
3. Tympanic cavity.
4. Tympanic membrane.
5. Stapes.
6. Tensor tympani.
7. Eustachian tube.
8. Perilymph.
9. Organ of Corti.
10. To respond to different frequencies of vibrations.

204

1. Vestibule of the inner ear.
2. Particles of calcium carbonate.
3. Crista ampullaris.
4. Pitch, roll, and yaw.

205

1. Olfactory receptors.
2. Camphor, musk, floral, peppermint, ether, pungent (spicy), and putrid (decaying meat).
3. Tongue, roof of the mouth, and sides of the pharynx.
4. Sweet, sour, salty, and bitter.

206

1. By structure, location, stimulus, and function.
2. Free nerve endings.
3. Proprioceptors (deep receptors).
4. Excessive heat, tearing of the tissue, certain chemical changes, and excessive stretching of some tissues. The common denominator seems to be any kind of excessive stimulation.
5. Cold receptors—50 and 68°F; hot receptors—77 and 113°F.
6. Golgi tendon organs.
7. Impulse.
8. Projection.
9. Ability of the receptor to adjust to continual stimulus.
10. Pressure, touch, vibration, heat and cold.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to a field scoring answer sheet.

Do not return your answer sheet to AFCDA.

1. (201) A transparent structure that permits the eye to focus vision at different distances is the
 - a. lens.
 - b. retina.
 - c. sclera.
 - d. cornea.
2. (201) Which ocular rectus muscle *abducts* the eye?
 - a. Inferior.
 - b. Lateral.
 - c. Medial.
 - d. Superior.
3. (202) Depth perception and three-dimensional viewing is made possible by
 - a. refraction.
 - b. reflection.
 - c. binocular vision.
 - d. monocular vision.
4. (203) What structure is responsible for collecting the sound waves and directing them to the tympanic membrane?
 - a. Incus.
 - b. Stapes.
 - c. Auricle.
 - d. Cochlea.
5. (203) Which structures equalize the air pressure inside the middle ear with that of the atmosphere outside, and also connect the middle ear with the pharynx?
 - a. Scala vestibuli.
 - b. Eustachian tubes.
 - c. Auditory ossicles.
 - d. Semi-circular canals.
6. (204) The portion of the ear that contains receptors for equilibrium is the
 - a. auricle.
 - b. inner ear.
 - c. middle ear.
 - d. tympanic membrane.
7. (204) Which ear structure is responsible for maintaining static equilibrium?
 - a. Incus.
 - b. Auricle.
 - c. Mastoid.
 - d. Vestibule.

8. (204) What inner ear structure is involved in detecting dynamic equilibrium?
- a. Auricle.
 - b. Mastoid.
 - c. Semicircular canals.
 - d. Tympanic membrane.
9. (205) The cells responsible for the sense of smell are known as
- a. odoriferous receptors.
 - b. olfactory receptors.
 - c. parosmic receptors.
 - d. tactile receptors.
10. (206) The sensory receptors located in the skin and mucous membranes are called
- a. visceroreceptors.
 - b. proprioceptors.
 - c. deep receptors.
 - d. superficial receptors.

Student Notes

Unit 2. The Circulatory and Respiratory Systems

2–1. The Circulatory System	2–1
207. Characteristics and composition of blood.....	2–1
208. Structure and function of the heart	2–10
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210. Blood circulation; the arterial system, the venous system, and pulmonary circulation	2–21
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212. Respiratory structures and their functions	2–44
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BY NOW you know that the body systems are interrelated and that every system is essential for life to exist. The circulatory and respiratory systems are certainly no exception to this statement. The circulatory system is the body's transport system. It moves life-essential nutrients and oxygen to all the cells and transports the waste products of metabolism away from the cells to areas of the body where they can be effectively eliminated. It also plays a key role in protecting us from infections. The respiratory system works closely with the circulatory system to provide the exchange of oxygen and waste gases necessary to sustain life. Because these two systems are so closely interrelated, we discuss them together in this unit. We begin by discussing the structures and functions of the different parts of the circulatory system. In the second section you will become familiar with respiratory anatomy and the processes of external and internal respiration.

2–1. The Circulatory System

The circulatory system is actually made up of several subsystems. One of these sub systems, the cardiovascular system, consists of the heart and blood vessels. The other subsystem is the lymphatic system. The lymphatic system consists of the lymphatic tissue, nodes, vessels, and fluid that are found throughout the body.

As we said, the cardiovascular system consists of the heart and blood vessels, but it also includes the blood that carries the oxygen and nutrients throughout the body. The heart acts as a muscular pump. When it contracts, blood is squeezed out into the blood vessels. These blood vessels are a closed network of arteries, veins, and capillaries that extend throughout the body. We begin our discussion of the cardiovascular system by talking about the fluid tissue that circulates through this system—the blood.

207. Characteristics and composition of blood

Blood is much more than just the “red stuff” that oozes when you cut yourself. It is one of the major fluid components of the body, and the medium through which oxygen and nutrients are delivered to the cells, and carbon dioxide and waste materials are removed.

Blood is made up of a combination of *formed elements*, or cells; and a thick, sticky fluid called *plasma*. There are three types of cells in blood:

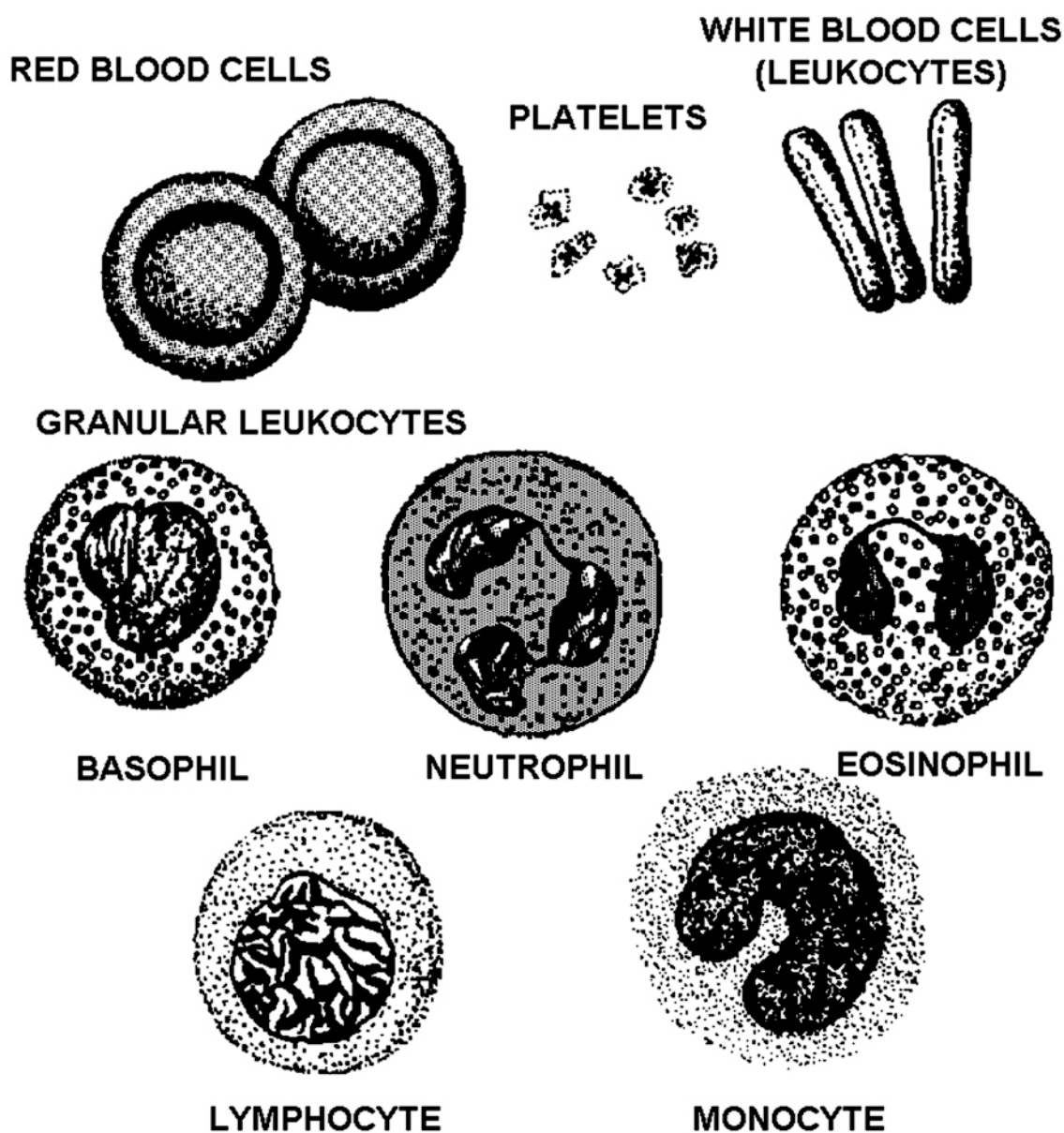
1. Red blood cells (*erythrocytes*).
2. White blood cells (*leukocytes*).
3. Platelets (*thrombocytes*).

The plasma portion of blood is not just a simple liquid. It is made up of numerous organic and inorganic substances dissolved in a water base. The average adult has about 5 liters (5.3 quarts) of blood, but that varies with the percent of body fat, age, sex, and body type. For example, a big-boned, healthy male with a small percentage of body fat has more blood than an obese male of the same

weight but with a higher percentage of body fat. Blood makes up about eight percent of the total weight in the body.

Blood cells

The formed elements or blood cells make up about 45 percent of the total blood volume. Of that 45 percent, the vast majority of the formed elements are erythrocytes (red blood cells). The remainder is leukocytes and thrombocytes. Leukocytes are further divided into granular and nongranular leukocytes. Granular leukocytes, also called granulocytes, include neutrophils, eosinophils, and basophils. Nongranular leukocytes, also called agranulocytes, include the lymphocytes and monocytes. Figure 2-1 shows the different types of blood cells. Refer to this as we discuss each type of cell.



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Figure 2-1. Blood cells.

The following table also provides an overview of where the different blood cells are formed, where they are destroyed or broken down in the body, and the functions they perform.

Element	Source	Area of Destruction	Function
<i>Erythrocytes</i> (red cells)	Red bone marrow	Spleen, liver	Respiration: hemoglobin portion carries oxygen to the cells and carbon dioxide away.
<i>Leukocytes</i> (white cells) <i>Granulocytes:</i> • <i>Neutrophils</i> • <i>Eosinophils</i> • <i>Basophils</i> <i>Agranulocytes:</i> • <i>Lymphocytes</i> • <i>Monocytes</i>	Red bone marrow Lymph nodes Red bone marrow	Spleen, liver	Fight infection. Fight infection. Form scar tissue and some antibodies.
<i>Thrombocytes</i> (platelets)	Red bone marrow	Blood clots	Coagulation of blood.

Erythrocytes

Erythrocytes, commonly called red blood cells, are very small, enucleated cells (i.e., they have no nucleus). They are flat and round with thick edges and a thin center. Figure 2–1 shows the erythrocytes in two planes, the two cells on the left are lying flat on the slide, the three on the right are on their sides. Their overall appearance is something like a doughnut. The sides of the erythrocytes are flexible, which allows the cells to change shape as needed when passing through blood vessels. Developing erythrocytes do have nuclei, but these nuclei are extruded or lost before the erythrocytes enter the blood stream. When the nuclei are lost, the sides of the cell cave in. This results in the characteristic biconcave shape of the mature erythrocyte (i.e., they look like a disk instead of a sphere). Because they are missing nuclei and other cellular structures (i.e., mitochondria and ribosomes), erythrocytes are unable to carry out reproduction or protein synthesis. They are active in many other cellular activities. Erythrocytes have a life span of between 105 and 120 days. During that time they are exposed to continual wear and tear as they pass through the blood vessels.

Function

The primary function of erythrocytes is to form bonds with oxygen molecules and transport those molecules through the bloodstream to the cells. At the cells, the erythrocytes release the oxygen molecules and form bonds with the carbon dioxide molecules, and then transport the carbon dioxide back to the heart. This is a simplified description of a process known as internal respiration. (The entire respiratory process is discussed later in this unit.)

Production

Production of erythrocytes is affected by a number of factors. For example, the vitamins B₁₂ and folic acid are necessary for growth and reproduction of the cells. If these vitamins are not available in the diet, or cannot be absorbed by the body, the erythrocytes will not grow and reproduce normally. Iron is necessary for the production of hemoglobin. If iron is not present in the diet or cannot be absorbed for some reason, erythrocyte production is adversely affected. Anything that disturbs the normal production of erythrocytes also disturbs the homeostasis of the body. For the body to maintain homeostasis there must be a certain number or normal range of erythrocytes in the blood. The normal range varies with the age and sex of the individual.

Age/Sex	Range
Adult males	Between 4.6 to 6.2 million erythrocytes per cubic millimeter of blood.
Adult females	Between 4.2 and 5.4 million erythrocytes per cubic millimeter.
Children	Between 4.5 and 5.1 million erythrocytes per cubic millimeter of blood.

These numbers fluctuate between individuals, but continued significant differences from the norm indicate the presence of a disease process.

NOTE: Normal ranges for blood cell counts may vary between different patient populations and by the laboratory techniques used to obtain the cell count. The laboratory manual in your hospital outlines the reference values that apply to your patients. The numbers we cite in this text are a composite of the generally accepted ranges often published in laboratory textbooks. They are provided to give you a rough idea of the numbers of different types of blood cells normally found in the blood, and *should not* be considered as absolute values.

Hemoglobin

Erythrocytes contain a special substance—*hemoglobin*—that makes the gas exchange possible. Hemoglobin is a pigment-containing chemical compound. Each hemoglobin molecule consists of four protein molecule chains and iron-containing complexes called *heme*. Each of the protein chains surrounds a heme complex. Each atom of iron in the hemoglobin molecule is capable of bonding to one molecule of oxygen. The total capacity of each hemoglobin molecule is four molecules of oxygen. If you consider that each erythrocyte contains approximately 280 million hemoglobin molecules (about 30 percent of total cell volume), that's a lot of oxygen! Hemoglobin is also responsible for the color of the blood. When the hemoglobin combines with oxygen it forms *oxyhemoglobin*, giving the molecule a bright red color. When the oxygen is released at the cells, the *deoxyhemoglobin* formed is a much darker color.

Leukocytes

Leukocytes, commonly called white blood cells, circulate throughout the body to defend it against infectious microorganisms. While individual types of leukocytes have a common function—fighting infection—they also have a number of different individual characteristics. These characteristics include the size of the cells, shape of the nuclei, presence of granules in the cellular cytoplasm, and staining characteristics.

Leukocyte population is measured by a procedure called a *white blood cell count* (which is part of a CBC or complete blood count). As a part of this procedure, the erythrocytes in the sample are destroyed so that they will not be mistaken for leukocytes. Typically, the total number of leukocytes in the body ranges between 5,000 and 10,000 leukocytes per cubic millimeter of blood. An excessive number of leukocytes—*leukocytosis*—is usually a sign of an infection somewhere in the body. An excessive deficiency of leukocytes results in a condition called *leukopenia*. Individuals that have leukopenia are more susceptible to infection.

Leukocytes are divided into five different types that fall under two categories. The two categories are based on the presence or absence of cytoplasmic granules. They are *granulocytes* (with granules), or *agranulocytes* (without granules). The granulocytes are the basophils, neutrophils, and eosinophils; the agranulocytes are the lymphocytes and the monocytes. Figure 2-1 may help you to see the differences. The different types are based on the characteristics previously cited.

Granulocytes

Granulocytes are about twice as large as erythrocytes. Like the erythrocytes, they are produced by hemocytoblasts in the red bone marrow. Granulocytes have a life span of about 12 hours. There are three types of granulocytes.

Type	Explanation
Neutrophils (polymorphonuclear leukocytes)	Contain many fine granules in their cytoplasm. These granules give the neutrophils a coarse or grainy appearance. The neutrophilic granules stain weakly, either a light pink or a light purple color (depending on the dye). The nucleus of a neutrophil is multilobed (two to five lobes separated by strands of chromatin). Neutrophils are the most numerous—50 to 60 percent—of the white blood cells.
Eosinophils	Are characterized by uniform, coarse granules. These granules stain either deep orange or red. Eosinophils have bilobed, oval-shaped nuclei. The nuclei may appear either as one large structure with two oval ends, or two oval structures separated by a strand of chromatin. Eosinophils make up about 2 percent of the total leukocytes in the body.
Basophils	Are roughly similar to eosinophils. Basophils contain fewer granules and these granules stain either dark purple or blue. Basophils also have bilobed, oval-shaped nuclei, but these nuclei are not as uniform as eosinophilic nuclei. Basophils make up less than 1 percent of the total leukocytes.

Agranulocytes

There are two types of agranulocytes—lymphocytes and monocytes. They are formed by hemocytoblasts in the red bone marrow. Lymphocytes are also formed by organs of the lymphatic system.

Type	Explanation
Lymphocytes	Are slightly larger than erythrocytes. Each lymphocyte has a large round nucleus with a slight indentation on one side. The nucleus is surrounded by a thin layer of cytoplasm. Lymphocytes have longer life spans (several years) than the other leukocytes, and they make up 25 to 33 percent of the total leukocyte population. Lymphocytes play a key role in dealing with infections. They function within the lymphatic system to release antibodies and produce immunities. These functions are discussed in the section on the lymphatic system.
Monocytes	Are the last type of leukocyte. Usually around two or three times as big as erythrocytes, they are also the largest of the leukocytes. The nucleus of a monocyte may be either round, oval, or kidney-shaped, and there is a large amount of cytoplasm surrounding the nucleus. Monocytes have a life-span of several weeks to several months, and they make up between 3 to 9 percent of the leukocyte population.

Thrombocytes

Thrombocytes are incomplete cells or *platelets* found in the blood. Their primary function is hemostasis (blood standing or stopping) and blood clotting. Hemostasis is both a part of the clotting process and a separate function in itself. As a separate function, hemostasis involves the release of the substances prostaglandin and thromboxanes. These substances are normally released in response to tissue damage. Prostaglandin is a naturally occurring fatty acid that stimulates contraction of the blood vessels, and clumping or sticking together of the platelets. Thromboxane is similar to prostaglandin in structure and function. When the blood vessel contracts (i.e., constricts) and the platelets stick to each other and to the walls of the blood vessels, a plug is formed and the blood pools in the area.

Thrombocytes are actually cell fragments from giant cells called *megakaryocytes*. Thrombocytes are about half the size of erythrocytes, and they are normally between 150,000 to 400,000 per cubic millimeters of blood. Thrombocytes are small, colorless structures shaped like spindles or oval discs. Because they are cell fragments, platelets have no nuclei. They do, however, contain a plentiful supply of adenosine triphosphate (ATP) molecules, as well as many other cellular organisms. ATP is a chemical compound found in all cells that store energy in the form of high-energy phosphate bonds within the molecules. It is a compound that is essential for providing energy to “fuel” various complex chemical reactions in the cells.

Like erythrocytes and leukocytes, thrombocytes are produced in the red bone marrow. The megakaryocytes that produce the thrombocytes are produced by the hemocytoblasts in the red bone

marrow. The megakaryocytes are large, irregular cells that have large, multilobed nuclei. These nuclei are very irregular in shape. Tiny fragments of the megakaryocytes break off and enter the blood stream where they become thrombocytes. Thrombocytes have a life span of about 10 days.

Blood clotting mechanism

The end result of the blood clotting mechanism, also called the coagulation process, is the blood clot, or *thrombus*. The thrombus acts to “plug” the damaged vessel and stop the flow of blood. The actual process of blood clotting involves several steps.

Preliminary steps of blood coagulation

First, there are a number of preparatory steps that are similar to the steps of hemostasis.

1. Tissue damage occurs and platelets immediately accumulate in the area. These platelets clump together and also adhere to the wall of the damaged blood vessel. This clumping action is called *agglutination*.
2. At the same time, the nearby blood vessels constrict.
3. Within a short period of time, the platelet clump develops into a solid mass that temporarily seals the injury.
4. When the platelets clump together near a break in the blood vessel, they release a substance called *serotonin*. Serotonin stimulates a second, longer lasting contraction of the blood vessel.

The actual coagulation process begins after the release of the serotonin and constriction of the blood vessel.

Clotting process

This process involves the interaction of two of the proteins that are found dissolved in the blood plasma. These proteins are *fibrinogen* and *prothrombin*.

In phase I of the actual blood clotting process, the prothrombin is converted into an enzyme called *thrombin*. Because prothrombin is an inactive protein, this conversion requires the presence of a prothrombin activator substance called the thromboplastin. This prothrombin activator is produced by either of two systems of reactions—the extrinsic clotting system or the intrinsic clotting system. If the thromboplastin is released from either the injured tissue or the injured blood vessel, the prothrombin is produced via the extrinsic clotting system. If the thromboplastin is released from damaged platelets, the prothrombin is produced via the intrinsic clotting system. The end result of either system is the same—thrombin is produced—the difference is that each system uses different *coagulation factors* to achieve the result.

In phase II of the actual blood clotting process, the fibrinogen is converted into insoluble strands of protein known as *fibrin*. The thrombin created in phase I works with two additional coagulation factors to convert the fibrinogen into fibrin.

A discussion of each of the 13 known coagulation factors is beyond the scope of this career development course (CDC).

Latter steps of blood coagulation

After the thrombin has been produced and has acted upon the fibrinogen to produce strands of fibrin, the fibrin threads form a mesh across the opening of the damaged vessel. Blood cells and platelets are trapped by this mesh and form a mass that results in a blood clot. After the clot is formed, the fibers connecting the platelet membrane and the fibrin strands shrink, and the clot begins to retract or grow smaller. This results in the whole fibrin network being pulled closer together, pulling the damaged edges of the blood vessel inward. As the network and vessel constrict, a fluid made up of the blood plasma, minus the plasma elements that have now solidified (prothrombin and fibrinogen), is squeezed out of the clot. This pale-yellow fluid is called *serum*. The prothrombin and fibrinogen remain in the tissue as they have become part of the clot.

Conditions affecting blood clotting

Numerous conditions exist that affect blood clotting. Some conditions interfere with the clotting mechanism, others promote it.

Conditions that interfere with clotting

As stated previously, the series of reactions that result in the release of thromboplastin requires the presence of special substances called coagulation factors. Though an in-depth discussion of these factors is beyond the scope of this CDC, it is important for you to know that if any of these factors are missing or malfunctioning, the patient has a tendency to bleed. The most common condition resulting from this bleeding tendency is known as *hemophilia*.

The clotting process also depends on the normal production of prothrombin and fibrinogen. These blood plasma components are manufactured in the liver. Normal production of prothrombin and fibrinogen depends on an adequate supply of vitamin K in the liver. Vitamin K is one of the fat soluble vitamins. It is produced by bacteria in the liver and is also obtained through the diet. Absorption of vitamin K into the bloodstream requires bile. If bile and/or vitamin K are not present, the patient will develop a bleeding tendency.

There is a substance called *heparin* that limits the clotting ability of the blood. Because of its ability to stop blood clotting, heparin is also called an *anticoagulant*. It activates the antithrombin, which interferes with the action of the thrombin. It also interferes with the action of the coagulation factors, which prevent the formation of the prothrombin activator. Heparin is found in the basophils of the blood and in the mast cells of connective tissue. Normally, there is not a high enough concentration of heparin in the blood to significantly hamper the clotting process. As you may recall from your study of surgical pharmacology, there is also a man-made drug called heparin that is administered to patients (particularly cardiovascular surgery patients) to prevent blood clotting.

It is actually beneficial to the body to have substances (e.g., heparin) that interfere with the formation of clots. Spontaneous clot formation can obstruct blood vessels and result in tissue damage and possibly even in death.

Conditions that promote clotting

Just as there are factors that oppose the clotting process, there are also factors that promote or speed up the process. The two most common conditions are the development of rough spots on the endothelium of blood vessels and an abnormally slow flow of blood circulation; both of these conditions can lead to spontaneous clots.

There is a disease process called *atherosclerosis* that leads to deposits of plaques of fatty acids and cholesterol on the endothelial lining of arteries. This creates a rough area and increases the tendency for clots. Abnormally slow blood flow also increases the tendency for clots to form; this may result from injury or damage to vessels from diseases such as diabetes or atherosclerosis, from immobility such as extensive bed-rest without movement, or from other physical conditions. As the blood slows down, the chance of clot formation increases.

A condition directly related to these blood clot promoting conditions is the formation of an abnormal clot thrombus. When an abnormal clot forms and is anchored to a vessel, it can obstruct the blood vessel and prevent the blood from reaching the tissues. Another dangerous condition occurs when a clot breaks loose and freely circulates in the arterial system. A loose clot is called an *embolus*. It is dangerous because it may eventually reach a smaller vessel through which it cannot pass, and obstruct one of the more vital blood vessels in the heart, brain, or lungs.

There are also clinical conditions that increase blood clotting—we use these frequently in surgery, where they are referred to as methods of hemostasis. We covered them extensively in volume 5 of CDC A4N151.

Blood plasma

Blood plasma is the liquid component of blood. It is a straw-colored fluid consisting of water and dissolved substances. Water makes up about 90 percent of the plasma content. The other 10 percent is made up of plasma proteins (8 percent) and a combination of inorganic salts, carbohydrates, lipids, amino acids, hormones, vitamins, and blood gases (about 2 percent).

Blood plasma has a number of important functions.

1. It is involved in the transportation of nutrients, gases, and vitamins.
2. It functions in maintaining a balance in the fluid and electrolyte composition of the body.
3. Certain plasma components are active in maintaining the body's defenses against infectious microorganisms.
4. The plasma helps to maintain the proper acid/base balance in the body.

Plasma proteins

Plasma proteins are substances that are manufactured in the liver and found in the interstitial (tissue) fluid and blood. They are normally not used as energy sources, but they do have a number of other important functions. Plasma proteins differ from each other in their functions and chemical structures.

Plasma nutrients

Plasma nutrients is a general term that refers to several components of plasma—amino acids, simple sugars, and assorted lipids. Amino acids and sugars (simple carbohydrates) are absorbed from the intestinal tract and stored in the liver until needed. At that time they are released back into the blood stream. Basically, lipids are transported in blood plasma as lipoproteins. Lipoproteins are complexes of protein and lipids, which enable the lipids to pass through the cell membranes. The lipid portion of the lipoprotein is made up of varying concentrations of triglycerides, cholesterol, and phospholipids.

Blood gases

The gases found in the plasma are oxygen and carbon dioxide. These are the normal components of the respiratory process and are discussed in the section on the respiratory system.

Nonprotein nitrogenous substances

Nonprotein nitrogenous (nitrogen-containing) substances include amino acids, urea, uric acid, creatine, and creatinine. The amino acids are an end-product of protein digestion and absorption. Urea is a byproduct of protein breakdown, and uric acid is a byproduct of nucleic acid breakdown. Creatinine is a byproduct of the metabolism of the nitrogenous compound creatine. Creatine is found in muscle and brain tissue as *creatine phosphate*. Creatine phosphate is active in the storage of various high energy compounds.

Plasma electrolytes

The last plasma component we discuss is the plasma electrolytes. Electrolytes are substances that break up into ions when placed in a solution. These substances are capable of carrying an electrical charge. Plasma electrolytes include sodium, potassium, calcium, magnesium chloride, bicarbonate, phosphate, and sulfate. The sodium and chloride ions are the most common. For a quick summary of the constituents of blood plasma, refer to the table on the next page.

Substance	Purpose
Water (90% of plasma volume)	Regulation of body temperature. Acts as solvent carrying substances to and from cells.
Proteins: Albumin Globulin Fibrinogen	Buffer; regulates osmotic pressure. Immunity Blood clotting

Substance	Purpose
Food Glucose Amino acids Fat	Nourishment of the body
Vitamins Inorganic salts + <i>ions</i> - <i>ions</i> sodium chlorides potassium carbonates calcium bicarbonates magnesium sulfates iron phosphates iodides	Metabolism: Acid-base balance Osmosis Water distribution throughout body Irritability in muscles and nerves
Gases Oxygen Carbon dioxide Nitrogen	Respiration
Hormones	Regulation of body functions
Enzymes	Digestion
Antibodies	Immunity to disease
Waste products	To rid the body of unnecessary products of cell metabolism.

Blood types

When the medical profession first attempted to perform a transfusion of blood from one person to another, there were a variety of results. A few transfusions were successful. Other transfusion attempts were also successful but the patient had some degree of reaction. Still other transfusion attempts were totally unsuccessful and the patient died. Later, the medical profession discovered that these results were due to the fact that individuals have different blood types, and that all these types are not compatible.

Blood is classified according to the type of *antigen* (agglutininogen) present in the erythrocyte membrane. Antigens are substances that stimulate the production of antibodies when exposed to certain foreign substances. The antibodies are specific against those substances, and combine with and destroy the substances.

Antigens

Three antigens are involved in the blood classification process—*A*, *B*, and *Rh*. Antigens *A* and *B* are combined together in various ways to make four blood groups.

Type Blood	Type of Antigen
A	Has an A antigen on the erythrocyte.
B	Has a B antigen on the erythrocyte.
AB	Has both an A and a B antigen on the erythrocyte.
O	Has neither A nor B antigen on the erythrocyte.

The Rh factor is named for a group of Rh antigens. The Rh factor is found in conjunction with the different blood types. If the Rh factor is present on the erythrocyte, the blood type is called *Rh positive*. If the Rh factor is missing, the blood type is called *Rh negative*.

Antibodies

Blood plasma develops antibodies against any antigens that are not already present on the erythrocytes in that particular bloodstream.

- Type A blood has antibodies against type B and type AB bloods.
- Type B blood has antibodies against types A and AB bloods.
- Since type AB blood has both antigens present, it does not develop antibodies. People with type AB blood are commonly called *universal recipients* because they can receive transfusions of type A, B, and O blood without developing antibodies.
- Type O blood has no antigens and can safely be mixed with the other three blood types. For this reason, type O blood is called the *universal donor* blood. However, type O blood does have antibodies against the other three blood types. In other words, an individual with type O blood can give blood to anyone else, but can only receive blood from another person with type O blood.

An individual's blood must be checked prior to each transfusion even if the blood types of both donor and recipient are already known. There are a number of lesser factors that could cause an adverse reaction even if everything else seems compatible. This procedure is called a *type and crossmatch*.

Rh factor

Blood plasma does not normally have antibodies against the Rh factor. These antibodies develop only after blood with the Rh negative antigen is exposed to blood with the Rh positive antigen. The Rh negative blood is sensitized in that initial exposure. There is usually no reaction with the first exposure, but from that point on, the Rh negative blood has antibodies and reacts to the Rh positive blood.

The Rh factor is of the most concern when dealing with pregnancies. If a woman with Rh negative blood is married to a man with Rh positive blood, the children may be either Rh positive or Rh negative. If one of the children happens to be Rh positive, the woman's blood develops antibodies against that Rh positive blood. This probably will not affect the first Rh positive child since it is unlikely that any of the child's blood will enter the mother's bloodstream until late in the pregnancy. The mother's blood reacts to any Rh positive children from that point on by clumping with or destroying that child's blood. This condition occurs while the child is still in the uterus and is called *erythroblastosis fetalis*. It has been discovered that the mother's blood can be prevented from developing these antibodies by an injection of Rh positive antibodies within 72 hours after the delivery.

Now that you know more about the makeup of the blood, it is time to begin our discussion of the system that transports the blood throughout the body. We begin with the "pump" that keeps the blood circulating—the heart.

208. Structure and function of the heart

The heart is a hollow, muscular organ, roughly oblong-shaped and about the size of a man's fist. As shown in figure 2-2, it consists of four chambers that are connected to each other and to external blood vessels by one-way valves.

The heart is located between the lungs and above the diaphragm, in the mid-section (mediastinum) of the thoracic cavity. The top of the heart is about even with the second rib, and the bottom part is even with the fifth rib. The heart lies directly beneath the sternum, with the bulk of the heart on the left side of the body. The heart is positioned in the body so that the top part, or base, is on the right; and the bottom part, or apex, is located on the left. The right side of the heart is anterior, and the left side is posterior.

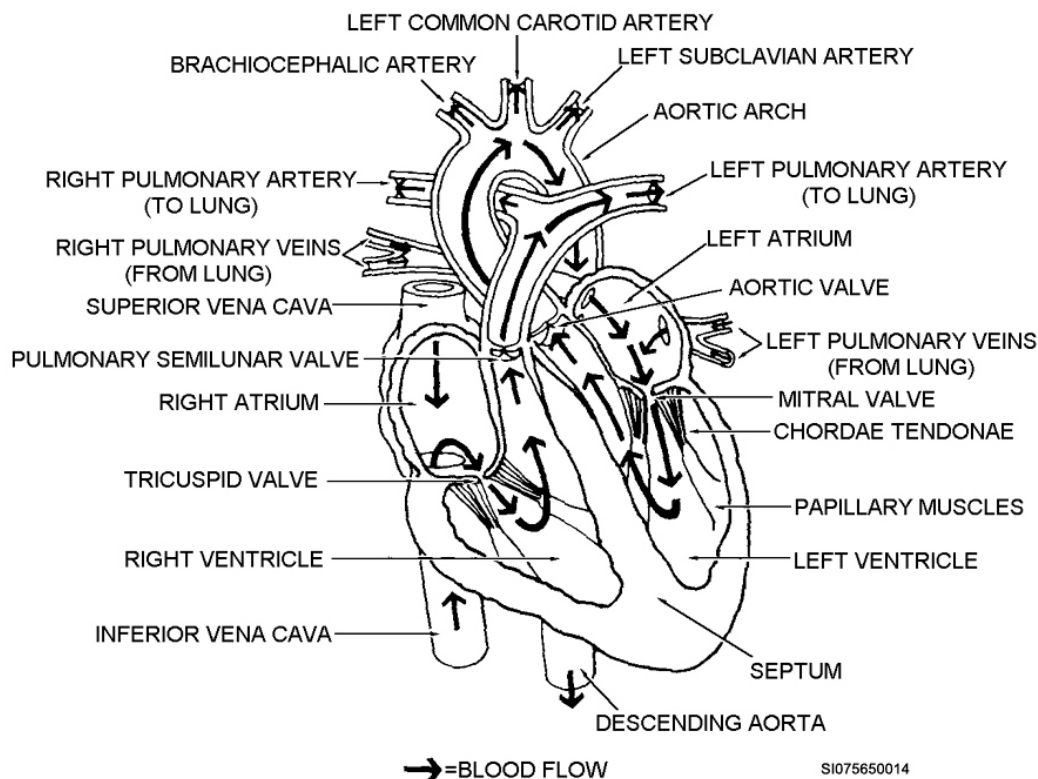


Figure 2-2. The heart and great vessels.

NOTE: All directions given in this text are from the patient's point of view, that is, the patient's right side or the patient's left side.

The heart is made up of epithelial tissue, connective tissue, cardiac muscle tissue, nerves, and blood vessels. These components are arranged in the multilayered wall of the heart, and in the fibrous sac that surrounds the heart. Of these components, the cardiac muscle tissue deserves special mention. The special properties possessed by this muscle tissue enable the heart to maintain its rhythmic beat.

Cardiac muscle tissue

Cardiac muscle tissue is the major component of the heart. Cardiac muscle tissue is made up of striated cells, or fibers. These fibers are similar in structure to skeletal muscle fibers, but cardiac fibers have only one central nucleus per cell and are separated by specialized sections of cell membranes called *intercalated discs*. Also, the cardiac fibers are joined end-to-end to form branching networks instead of being arranged in bundles.

Cardiac cells merge together to form networks that are spread throughout the heart. When the cells in one of these networks are stimulated, the impulse travels through all the cells in the network. The network then contracts as a unit. This type of functional network is called a *syncytium*. (A syncytium is a multinucleated mass of protoplasm formed by a merging of several cells.) There are two such networks in the heart—atrial and ventricular. The *atrial syncytium* is composed of the walls and septum that make up the upper portion of the heart. The *ventricular syncytium* is composed of the walls and septum of the lower portion of the heart.

The cardiac muscle cells have special properties not shared by other types of muscle cells. They are capable of doing the following:

1. Contracting without direct nervous system stimulation (automaticity).
2. Generating the impulses that cause contractions.

This ability to generate impulses is normally restricted to a few clumps of specialized tissue; but, in cases where this specialized tissue is damaged, other cardiac tissue can take over and generate impulses. We talk about this more when we discuss the cardiac conduction system.

Layers of the heart

The wall of the heart is made up of three separate layers:

1. Epicardium (outer layer).
2. Myocardium (middle layer).
3. Endocardium (inner layer).

The whole structure is enclosed in a special sac called the *pericardium*.

Pericardium

The pericardium (sac surrounding the heart) is made up of two layers—fibrous pericardium and serous pericardium.

The outer layer of the pericardium, the *fibrous pericardium*, consists of tough, white fibrous connective tissue. This fibrous tissue forms a loose protective sac around the heart. It is attached anteriorly to the sternum, posteriorly to the vertebral column, inferiorly to the diaphragm, and superiorly to the large blood vessels leaving the top of the heart.

The inner layer of the pericardium is called the *serous pericardium*. The serous pericardium consists of two layers—the parietal layer and the visceral layer. The parietal layer is attached to the inner surface of the fibrous pericardium, and the visceral layer is attached to the outer layer of the heart itself. The two layers of the pericardium are actually one continuous serous membrane that is folded back on itself at the base of the heart. Between the visceral and parietal pericardium there is a small space called the *pericardial cavity*. Within the pericardial cavity there is a small amount of serous fluid called *pericardial fluid*.

The function of the pericardial layer is to provide protection from friction during normal heart movements. A combination of a smooth serous membrane and pericardial fluid within the pericardial cavity allows the visceral and parietal pericardium to slide easily over each other as the heart beats. At the same time, the fibrous pericardium protects the heart from injury due to trauma.

Epicardium

The epicardium (outer layer of the heart itself) is actually a continuation of the visceral pericardium. As we said, this is a thin serous membrane. This membrane consists of an inner layer of connective tissue and an outer layer of epithelial tissue. There are also capillaries, lymph vessels, nerves, and some adipose tissue within the epicardium. The epicardium functions as the protective outer layer of the heart.

Myocardium

The myocardium is the thick middle layer of the heart. It consists mostly of cardiac muscle fibers. These fibers are intertwined and connected in networks called syncytiums. The syncytiums are further arranged in sheets of muscle tissue that wind around the chambers of the heart. Between the sheets of muscle tissue are sheets of connective tissue. This connective tissue contains the nerves, capillaries, and lymph vessels that supply the muscle fibers. The winding arrangement allows the cardiac muscles to provide a squeezing effect when the muscles contract.

The thickness of the myocardium varies from one part of the heart to the next. The myocardium is thinnest around the upper chambers (atria), and thickest around the lower left chamber (left ventricle). This is because the two atria do not have to do as much work as the left ventricle, and therefore, require less muscle tissue. The atria just pump blood into the adjacent ventricles, while the ventricles are tasked with pumping blood outside the heart. Since the left ventricle pumps blood to all areas of the body, it has to be the strongest chamber in the heart. The myocardium is the working layer of the

heart. When the muscle fibers contract and the chambers are squeezed, blood is moved through and out of the heart to various parts of the body.

Endocardium

The endocardium is the thin inner layer of the heart. Like the epicardium, it consists of layers of connective tissue covered by layers of epithelial tissue. The endocardium contains a nerve and blood supply as well as a number of specialized cardiac muscle fibers called *Purkinje fibers*. The Purkinje fibers are part of the nervous impulse conduction system that controls the heartbeat, which we discuss later.

The endocardium functions as a protective inner coat for the heart. It lines the chambers and valves, and is continuous with the outer linings of the large blood vessels inside the heart.

Chambers and valves of the heart

Internally, the heart is divided into four sections, or chambers (fig. 2-2). The two upper chambers are called *atria*. The atria are divided into right and left atrium by a muscular wall called the *interatrial septum*. The lower chambers are called *ventricles*, and are also divided into right and left halves by the *interventricular septum*.

There are indentations or grooves on the surface of the heart that mark the divisions between the upper and lower chambers, and between the right and left halves.

Name	Location	Description
<i>Atrioventricular or coronary sulcus</i>	Between the atria and the ventricles	The deepest of the indentations. Contains the major blood vessels that provide oxygen and nutrition for the heart itself.
<i>Anterior interventricular sulcus</i>	On the anterior surface of the heart	Contains the major blood vessels that provide oxygen and nutrition for the heart itself.
<i>Posterior interventricular sulcus</i>	On the posterior surface of the heart	Contains the major blood vessels that provide oxygen and nutrition for the heart itself.

Heart valves

The atria and ventricles of the heart are connected by openings called valves.

Valve	Location
<i>Tricuspid</i>	Between the right atrium and ventricle.
<i>Bicuspid (mitral valve)</i>	Between the left atrium and ventricle.
<i>Pulmonary semilunar</i>	On the right.
<i>Aortic semilunar (aortic valve)</i>	On the left.

The valves of the heart are encircled by rings of strong fibrous connective tissue. This tissue provides a site for attachment of the valves and various heart muscles. The rings also help maintain the shape of the openings of the heart during ventricular contractions. These rings and the cardiac septa form the cardiac skeleton. In addition to the heart valves, there are also valves that control the openings to the blood vessels that leave the ventricles of the heart.

Right atrium

The right atrium receives the blood that has been used by the body. This blood has a high concentration of carbon dioxide and a low concentration of oxygen. It is called *deoxygenated* or *venous blood*. There are three blood vessels that drain venous blood into the right atrium.

Blood Vessel	Receives blood from:
<i>Superior vena cava</i>	Upper portion of the body.
<i>Inferior vena cava</i>	Lower portion of the body.
<i>Coronary sinus</i>	The heart itself.

The wall of the right atrium is relatively thin, and has a limited amount of myocardial tissue. The right atrium receives the blood from the body and pumps that blood through the tricuspid valve into the right ventricle.

Tricuspid valve

The tricuspid or right atrioventricular (AV) valve is made up of three irregular flaps of fibrous tissue or cusps. These cusps project inward from the inner wall of the atrioventricular opening. There are strong fibrous cords attached to the inner edge of each of the cusps. These cords extend down into the right ventricle and are attached to small clumps of muscle that project from the inner wall of the ventricle. The fibrous cords are called *chordae tendineae*, and the muscles that they are attached to are called *papillary muscles*. The function of the chordae tendineae is to prevent the cusps of the tricuspid valve from everting back into the right atrium when the valve closes. The tricuspid valve opens to allow movement of blood from the right atrium to the right ventricle, and closes to prevent backflow of blood into the atrium.

When the right atrium contracts and there is an increase in pressure, the cusps of the tricuspid valve fold down into the right ventricle and the blood flows on through the opening. This action is assisted by the chordae tendineae and the papillary muscles. When the right ventricle is in a relaxed position, they exert a downward pull on the cusps. This increases the size of the atrioventricular opening. When the right ventricle contracts, the chordae tendineae and papillary muscles allow the cusps to close but not to fold back into the right atrium. In this manner, the tricuspid valve acts as a one-way valve.

Right ventricle

The right ventricle is a larger structure than the right atrium. It also has thicker walls due to increased myocardial tissue. The right ventricle receives the deoxygenated blood from the right atrium, and pumps that blood to the lungs. Since the lungs lie on either side of the heart, there is not much resistance and only a limited amount of myocardial tissue is needed to force the blood on its way. When the right ventricle contracts the blood is squeezed out into the pulmonary trunk by way of the pulmonary semilunar valve.

Pulmonary semilunar valve

The pulmonary semilunar valve also consists of three fibrous flaps or cusps. The pulmonary cusps have a much more regular (crescent) shape than the tricuspid cusps. Also, there are no chordae tendineae attached to the pulmonary cusps to prevent their folding back into the right ventricle. The pulmonary semilunar valve allows blood to move into the main pulmonary artery or pulmonary trunk, and closes to prevent backflow of blood from the pulmonary artery into the right ventricle. From the pulmonary trunk, deoxygenated venous blood flows to the lungs by way of the *right and left pulmonary arteries*.

Left atrium

After the blood has been oxygenated in the lungs, it travels back to the heart and empties into the left atrium. There are four blood vessels (two from each lung) that empty into the left atrium. These blood vessels are called the *pulmonary veins*. The left atrium is similar in structure and function to the right atrium. It is relatively thin-walled and it pumps oxygenated blood through the bicuspid (mitral) valve into the left ventricle.

Bicuspid valve

The bicuspid, or *mitral*, valve controls the flow of blood through the left atrioventricular opening. Like the tricuspid valve, the bicuspid valve is made up of flaps of fibrous tissue or cusps. There are

only two cusps in the bicuspid valve, and they are heavier in structure than the tricuspid cusps. These cusps are also attached to chordae tendineae and papillary muscles. The structure of the bicuspid valve is heavier to accommodate the greater force of the left ventricular contraction.

Left ventricle

The left ventricle is responsible for pumping the blood that flows throughout the body. Because this requires much more force, the myocardium of the left ventricle is about three times as thick as the myocardium of the right ventricle. The left ventricle pumps oxygenated blood through the aortic semilunar valve into the aorta.

Aortic semilunar valve

The aortic semilunar valve has the same structure as the pulmonary semilunar valve. When the left ventricle contracts, it allows the blood to pass into the aorta. When the left ventricle is relaxed, the aortic semilunar valve closes and prevents backflow of blood into the left ventricle.

Blood supply to the heart

Because the heart is made up of living cells, it requires a blood supply to provide oxygen and nourishment to these cells. This blood supply is an extremely critical factor. When one or more of the major vessels that supply the heart become occluded, part of the heart muscle dies and the heart can no longer function. This is known as a *myocardial infarction* (in laymen's terms, a heart attack), and it is one of the most common causes of death in this country.

Oxygenated blood flow

The *coronary arteries* are the major vessels that supply the heart with oxygenated blood (fig. 2-3). The coronary arteries branch off of the aorta at a point just past the aortic semilunar valve. These branches are the *right* and *left coronary arteries*.

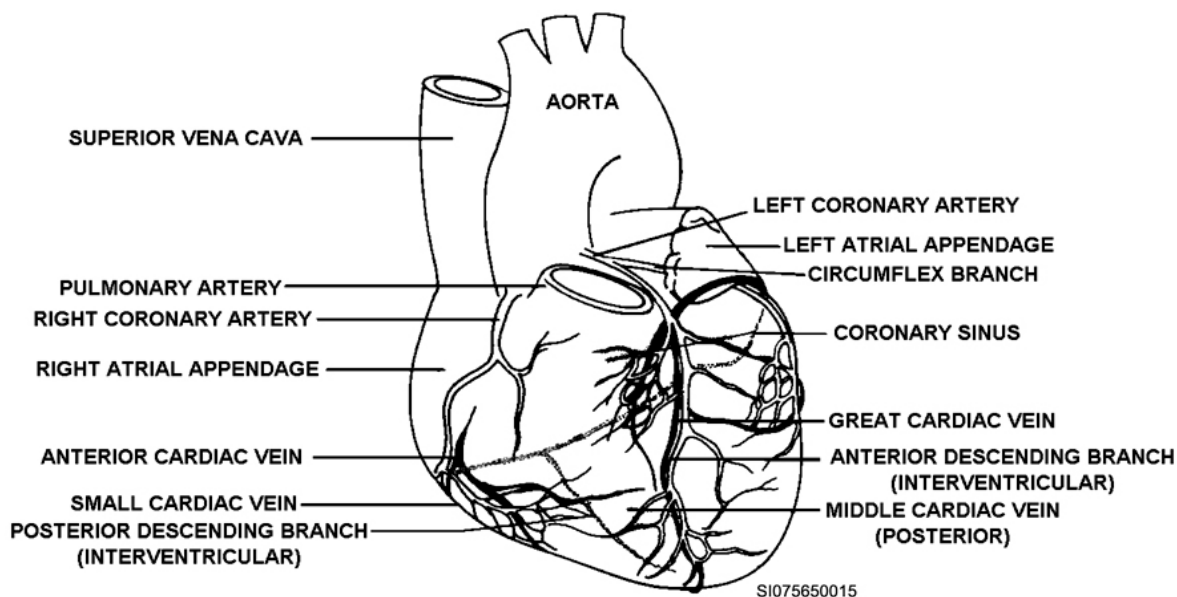


Figure 2-3. Coronary arteries and veins.

Right coronary artery

The right coronary artery then passes down along the right atrioventricular sulcus. It further branches into the posterior interventricular artery and the marginal artery. The posterior interventricular artery passes down along the posterior interventricular sulcus and supplies the walls of both ventricles with oxygenated blood. The marginal artery angles down the posterior inferior aspect of the heart and branches out to supply parts of the right atrium and right ventricle.

Left coronary artery

The left coronary artery also divides into two main branches—the circumflex artery and the anterior interventricular artery. The *circumflex artery* travels down the left atrioventricular sulcus. It further branches out to supply blood to the left atrium and ventricle. The *anterior interventricular artery* passes along the anterior interventricular sulcus. It branches out to supply parts of both ventricles with oxygenated blood.

Deoxygenated blood

After the cells of the heart have used the oxygen in the blood, most of the now deoxygenated blood is returned to the right atrium via the *coronary veins* (fig. 2–3). The coronary veins follow a path that is roughly parallel to the coronary arteries. These veins come together at the posterior atrioventricular sulcus in a blood vessel called the *coronary sinus*. As we mentioned earlier, the coronary sinus drains into the right atrium.

The blood that does not return by way of the coronary veins drains directly into the ventricles through certain deep channels. These channels are the *arterioluminal*, *arteriosinusoidal* and *Thebesian vessels*. About 25 percent of the heart's deoxygenated blood travels through these deep channels. The heart is controlled by a highly specialized system of nerves and muscle tissue. Because this system is so specialized, a separate section is specifically devoted to it.

Cardiac conduction system

The heart really has only one function, to pump blood to various parts of the body. The right side of the heart pumps the blood to the lungs, and the left side pumps blood to the rest of the body. The peculiar structure and specialized conduction system of the heart enables it to carry out this function on a continuous basis without any active input from us.

All cardiac muscle tissue is specialized to some extent, but there is a network of cardiac tissue that is specially modified to initiate and conduct the impulses that cause cardiac contractions. The components (fig. 2–4) of this network or system are listed below:

- Sinoatrial node.
- Atrioventricular node.
- Atrioventricular bundle.
- Purkinje fibers.

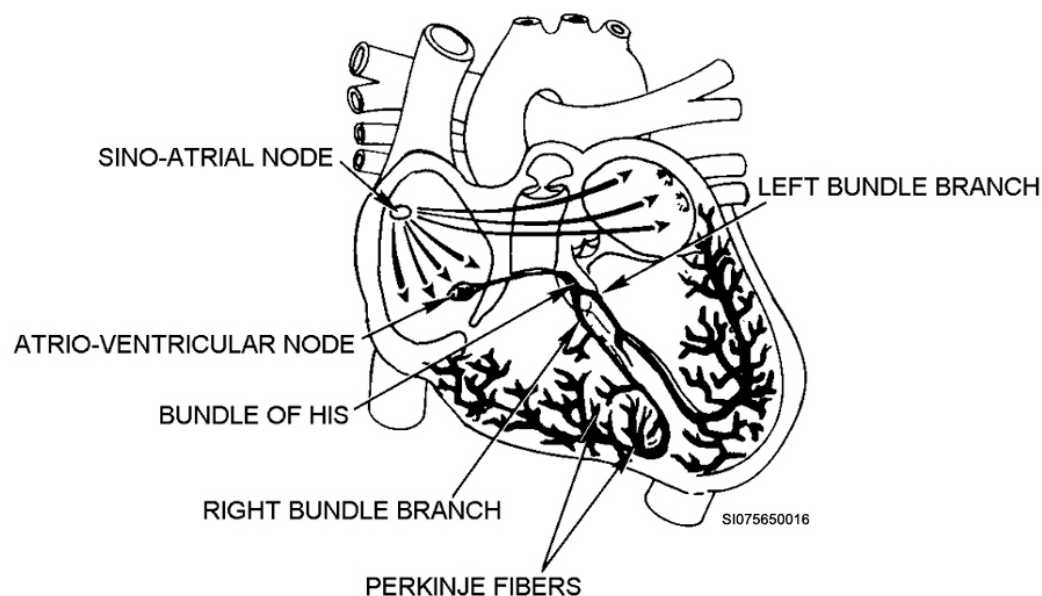


Figure 2–4. Cardiac conduction system.

Sinoatrial node

The sinoatrial node, or SA node, is a specialized mass of neuromuscular tissue. It is located beneath the epicardial tissue in the posterior wall of the right atrium near the opening of the superior vena cava. The fibers of the SA node are connected to the fibers of the atrial syncytium.

The cells of the SA node have the dual capability of spontaneously initiating cardiac impulses and initiating these impulses on a rhythmic or regular basis. All of this occurs without any nervous system stimulation. For this reason, the SA node is commonly called the *pacemaker of the heart*. The ability to generate impulses is called *excitability*. The ability to spontaneously generate these impulses over and over is called an *intrinsic rhythm*. The normal rate of the SA node in an adult is between 70 to 80 impulses per minute.

As the impulses are generated, they pass into the atrial syncytium. The impulses spread through the syncytium like a wave resulting in an almost simultaneous contraction of both atria. At the same time that the impulses pass through the atrial syncytium, they also pass along a pathway of nodal fibers called the *internodal tract*. This internodal tract rapidly conducts the impulses to the next mass of specialized tissue, the atrioventricular node.

Atrioventricular node

The AV node is located on the floor of the right atrium near the interatrial septum. It is embedded in the myocardium just beneath the endocardial layer. The muscle fibers leading into and making up the AV node are smaller in diameter than the fibers that make up the SA node or the internodal pathway. Here there is a slight delay in the impulses initiated by the SA node because they cannot travel through the smaller fibers as quickly. This delay allows the atria to finish contracting and the ventricles to fill with blood before the impulse passes through the AV node and triggers ventricular contraction.

Atrioventricular bundle

When the impulses have passed through the AV node, they enter into a bundle of large cardiac fibers called the atrioventricular bundle or *bundle of His*. The atrioventricular bundle extends from the atrioventricular node to the top of the interventricular septum. At the atrioventricular septum, the atrioventricular bundle divides into the *right* and *left bundle branches*. These bundle branches continue down either side of the interventricular septum. Like the atrioventricular node, the fibers of the atrioventricular bundle and bundle branches lie just below the endocardial layer. Because these fibers are larger than the fibers in the AV node, the impulses regain some speed as they travel through the atrioventricular bundle into the Purkinje fibers.

Purkinje fibers

The Purkinje fibers are large fibers that are a continuation of the right and left atrioventricular bundle branches. They begin about halfway down the interventricular septum, and continue on around the tip and up the lateral walls of the ventricles.

The Purkinje fibers are different than the bundle branches because they divide into many smaller branches that extend into the papillary muscles and the ventricular syncytium. When the impulses (initiated in the SA node) finally reach these fibers, they initiate ventricular contractions. Like the atria, the ventricular contractions occur almost simultaneously. The winding sheet-like arrangement of the ventricular myocardium causes the ventricles to contract in a twisting, squeezing motion. This motion starts near the apex of the heart and essentially squeezes the blood up and out of the ventricles.

Ectopic impulses

The pattern we have described is the normal pathway of an impulse traveling through the heart. However, if something happens to the SA node, other parts of the conduction system are capable of generating impulses. Normally, the atrioventricular node would take over next; if it also failed, the atrioventricular bundle, then the Purkinje fibers may generate the impulses. Impulses generated from

parts other than the SA node of the conduction system occur at a slower rate. Generally speaking, the lower the point in the conduction system “chain” that is generating the impulses, the slower those impulses are.

Impulses generated from any point other than the SA node are called *ectopic impulses*. As the impulses travel through the heart, they generate tiny electrical impulses. These electrical impulses are caused by the exchange of ions in and around the cardiac muscle fibers. These impulses are measurable by an electrocardiograph machine. The readings (electrocardiograms or EKGs) from this machine enable doctors to detect abnormalities in the heart.

Cardiac cycle

The last aspect of the heart that we discuss is the cardiac cycle. The cardiac cycle refers to the actual heartbeat. This cycle consists of the contraction and relaxation of the atria followed by contraction and relaxation of the ventricles. The term for contraction is *systole*, and the term for relaxation of the heart is *diastole*. The cycle in a normal heart is timed so that the ventricles are contracting while the atria are relaxing. Between cycles there is a slight pause to allow the heart muscle a chance to recover.

You can hear the stages of the cardiac cycle through a stethoscope—lubb-dub, pause; lubb-dub, pause; lubb-dub, pause. The “lubb” (systole) is caused primarily by contraction of the ventricles and vibration from closing cuspid valves, and the “dub” (diastole) is caused by the vibration of the closing semilunar valves as the heart relaxes.

209. Blood vessel types, structure, and function

The blood vessels of the body consist of a closed system of tubes that carry blood from the heart to the body, or to the lungs, and back to the heart again. The blood vessels that go to and from the lungs make up the *pulmonary circulation*. The blood vessels that carry oxygen and nutrients to the cells of the body and bring back carbon dioxide and waste products make up the *systemic circulation*.

The three main types of blood vessels and their function are listed in the following table.

Blood Vessel	Function
Arteries	Carry blood <i>away</i> from the heart.
Veins	Bring blood <i>back</i> to the heart.
Capillaries	Connect veins and arteries, and participate in cellular exchanges.

Arteries and arterioles

As shown in the table, arteries carry blood away from the heart. Generally, we refer only to the larger vessels carrying blood from the heart as arteries; when artery branches become extremely small, they are called arterioles.

Arteries

Arteries are strong-walled elastic vessels that carry blood away from the heart. With the exception of the pulmonary arteries, all arteries carry oxygenated blood to the cells of the body. The pulmonary arteries carry deoxygenated blood to the lungs to pick up oxygen.

The walls of arteries are under a constant high pressure. When the ventricles contract, blood is forced into the arteries. The walls of the arteries first expand or dilate to accommodate the blood, and then constrict back to their normal diameter. This constriction forces the blood down the artery. This dilation-constriction occurs all along the artery.

The walls of the arteries (fig. 2-5) are specially modified to withstand the high pressure and to perform vasodilation and vasoconstriction. The walls consist of three layers, or tunics:

1. Tunica intima.
2. Tunica media.

3. Tunica adventitia.

The *tunica intima*, or inner layer, consists of three tissue layers. The inner surface is composed of a smooth layer of epithelial cells. This layer is called the endothelium. The endothelium is surrounded by a layer of connective tissue that contains a number of smooth muscle cells. The outer layer of the tunica intima is called the internal elastic lamina. It consists of a network of strong elastic fibers.

The *tunica media*, or middle layer, surrounds the tunica intima. This is the thickest layer of the artery. It consists of smooth muscle fibers intermingled with elastic fibers and arranged in spiraling layers around the tunica intima. In large arteries, the tunica media consists primarily of elastic fibers. As the artery becomes progressively smaller, the tunica media becomes progressively more muscular with fewer elastic fibers.

The *tunica adventitia*, or outer layer, consists of connective tissue with a few elastic and collagenous fibers. The tunica adventitia is thin in large arteries. It grows progressively thicker as the arteries get smaller. The number of elastic fibers also increases as the arteries grow smaller. In small arteries, these elastic fibers form a distinct layer next to the tunica media. This layer is called the external elastic lamina. The tunica adventitia is permeated by small blood vessels called vasa vasorum. The vasa vasorum provide nourishment for the outer layers of the artery. (The inner layers of the artery are nourished by the blood that flows through the artery.) The tunica adventitia also attaches the arteries to the surrounding structures. Arteries branch to form smaller diameter vessels called *arterioles*.

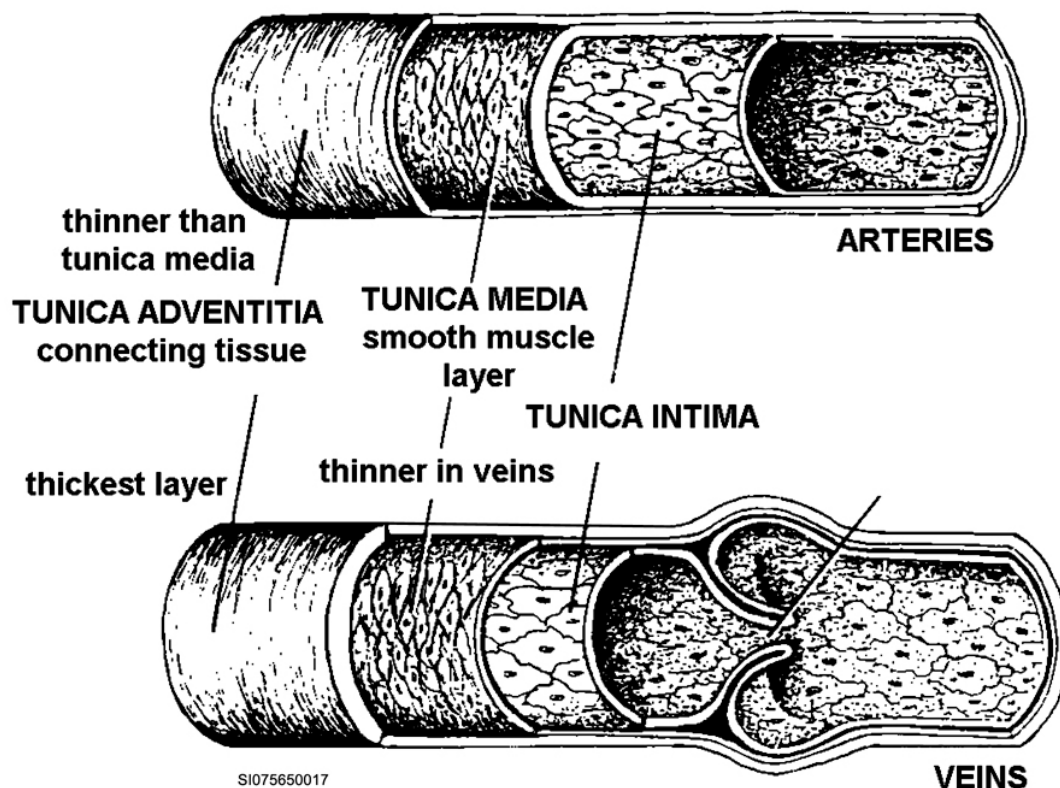


Figure 2-5. Blood vessel structure.

Arterioles

The walls of arterioles consist of the same three layers found in the walls of arteries. As the arterioles get progressively smaller, the layers in the wall get thinner and the inside opening, or lumen, gets

smaller. The number of elastic fibers decreases and finally disappears altogether in the smallest arteries. In the smallest arterioles, the tunica intima consists of a layer of smooth endothelial tissue. The tunica media consists of a spiraling layer of smooth muscle fibers, and the tunica adventitia consists of a layer of connective tissue.

The smooth muscle fibers in the walls of arteries and arterioles are controlled by sympathetic impulses from the involuntary or autonomic nervous system. These impulses cause the muscles to contract. Because of the spiraling arrangement of the muscles, contraction of the muscle fibers causes constriction of the lumen of the vessel.

Arterioles play a very important role in the circulatory process. They are the control valves through which blood is released to the capillaries. Because the walls of the arterioles are thin, they are capable of undergoing significant changes in size. These changes—vasoconstriction and vasodilation—help to direct the blood where it is needed in the body.

Arterioles branch and form even smaller vessels called *metarterioles*. These metarterioles, or metacapillaries as they are sometimes called, connect the arterioles to the capillaries. They are neither true arterioles nor true capillaries. Their walls consist of endothelial tissue with an occasional spiraling smooth muscle fiber. At the same time, they are larger than true capillaries. In some cases, the metarterioles are connected directly to the venules (i.e., small veins). This type of connection is called an arteriovenous shunt.

Capillaries

The capillaries are microscopic vessels that carry blood from arterioles to venules, and they form branching networks that extend into all the living tissue of the body.

While the capillaries are microscopic in size, they are the most important vessels in terms of function—they are the exchange components of the entire circulatory system. The primary function of the circulatory system is to transport blood throughout the body; the primary function of blood is to transport essential substances to, and waste substances from, the various body tissues. What sense would it make to transport blood around the body if there was no mechanism to exchange the “good” substances for the “bad” waste? The capillaries are the structures where this exchange takes place. Capillary walls are made up of a single layer of endothelial cells surrounded by a basement membrane. These walls become a semipermeable membrane through which oxygen and nutrients in the blood are exchanged for carbon dioxide and waste products in the tissue fluid.

The extent of the capillary network varies with activity of the tissue. Muscle tissues have a very extensive network of capillaries, but tendons and ligaments have very limited networks. The arrangement of the capillary network also varies from one type of tissue to the next. Some capillaries are simple tubes connecting arterioles and venules, while others are very complex, multibranched networks. This variety of arrangements helps the body to direct the blood where it is needed. For example, if you are exercising, as much blood as possible is sent to the muscle tissue. At the same time, blood is directed away from less active tissue, such as the digestive tract. The body is able to control the direction of the blood flow by the bands of smooth muscles found around the capillary entrances. These muscle bands are called *precapillary sphincters*. The precapillary sphincters respond to the needs of the cells by either contracting (i.e., closing the opening) or dilating (i.e., opening the opening).

Capillaries also vary in the degree of permeability of their walls. There are openings, or pores, in the endothelial membrane at points where the cells overlap. These pores vary in size. The pores are extremely small in capillaries that permeate muscle tissue. These capillaries are called continuous. The pores are larger in the capillaries of glands and the intestines. These capillaries are called fenestrated because the pores appear to be covered by a thin membrane. The largest pores are found in the capillaries of the liver, spleen, and bone marrow. These capillaries are called *discontinuous capillaries*, or *sinusoids*.

All that you learned about filtration, osmosis, and diffusion is applicable to capillaries. The capillaries are not directly connected to the cells that they supply. Instead, they are surrounded by tissue (interstitial) fluid. When blood enters the capillaries, it has a high concentration of oxygen and nutrients. The tissue fluid has a high concentration of waste products and carbon dioxide. The oxygen and nutrients diffuse out while the carbon dioxide and waste products are diffusing in. Some substances are not soluble in the lipids that make up most of the membrane of the endothelial tissue. If these substances are small enough, they are diffused through the pores in the membranes. Water, sodium ions, and chloride ions (lipid insoluble) diffuse through the pores. Oxygen, carbon dioxide, and fatty acids (lipid soluble) diffuse directly through the membrane. Molecules that are too large to pass through the pores and are not lipid soluble can be forced through the membrane by filtration. There are two forces that help force these molecules through the capillary walls. One of these forces is blood pressure, which is caused by the contractions of the ventricles, arteries, and arterioles. The other force is hydrostatic pressure. Hydrostatic pressure is caused by the weight of the substances inside the capillaries. These substances are the blood and blood products that are too large to pass through them, but help to push other molecules through.

Osmosis also takes place in the capillaries. Generally, osmotic pressure is greater inside the capillary. At the arteriole end of the capillary, this osmotic pressure is opposed by the even greater force of blood pressure and hydrostatic pressure. At the other end of the capillary (venule end), the blood pressure and hydrostatic pressure have decreased and osmotic pressure is now greater. As the result of all this, water is forced out of the capillary at the arteriole end, and water and dissolved substances are forced in at the venule end. The total fluid out is greater than the total fluid in. The excess is normally drained off by the lymphatic vessels.

Venules and veins

Venules are microscopic branches of veins. They are the first part of the blood's journey back to the heart. Venules are made up of the same three layers that make up arteries and arterioles. However, the proportions of each layer are different. Initially, venules consist of endothelial tissue surrounded by a small amount of collagenous tissue. As the venules get larger, they develop a layer of smooth muscle between the endothelial layer and the collagenous layer. Venules come together to form veins.

Veins carry the blood back from the venules to the superior and inferior vena cava and the heart. The tunica intima of veins (refer back to fig. 2-5) is very thin with no elastic lamina. The tunica media is not as well developed as that of arteries, and there are fewer elastic fibers. The tunica adventitia is thick and well developed. It consists primarily of connective tissue. In addition to the three layers, veins have one additional characteristic. Periodically, along the veins, there are one-way valves similar in structure and function to the aortic and pulmonary semilunar valves found in the heart. There is very little pressure from the blood flowing through the veins. The inelastic walls combined with the one-way valves keep the blood flowing in the direction of the heart.

Like arteries, the smooth muscle in veins is controlled by sympathetic impulses of the involuntary nervous system. If there is a drop in the blood pressure in some part of the body, the peripheral blood vessels are stimulated to constrict. This raises the overall blood pressure in the body.

210. Blood circulation; the arterial system, the venous system, and pulmonary circulation

Blood is circulated through two routes in the body. Blood that circulates throughout most of the body is referred to as *systemic* circulation. As mentioned earlier, blood that is sent to the lungs goes through the *pulmonary* circulation and pulmonary circulation begins at the pulmonary trunk. Both systems can be further subdivided into the arterial and venous circulation, but because pulmonary circulation is so different from systemic circulation, it is considered separately. To make it easier for you to remember the major vessels in the body, we limit the information in this lesson to a brief overview of the flow of blood through the arterial system, then through the venous system, and finish with a look at pulmonary circulation.

Arterial system

The arterial system (fig. 2-6) consists of all the arteries and arterioles that carry oxygen and nutrients to the cells in the body. Here, we describe the major arteries as well as the body systems that they supply.

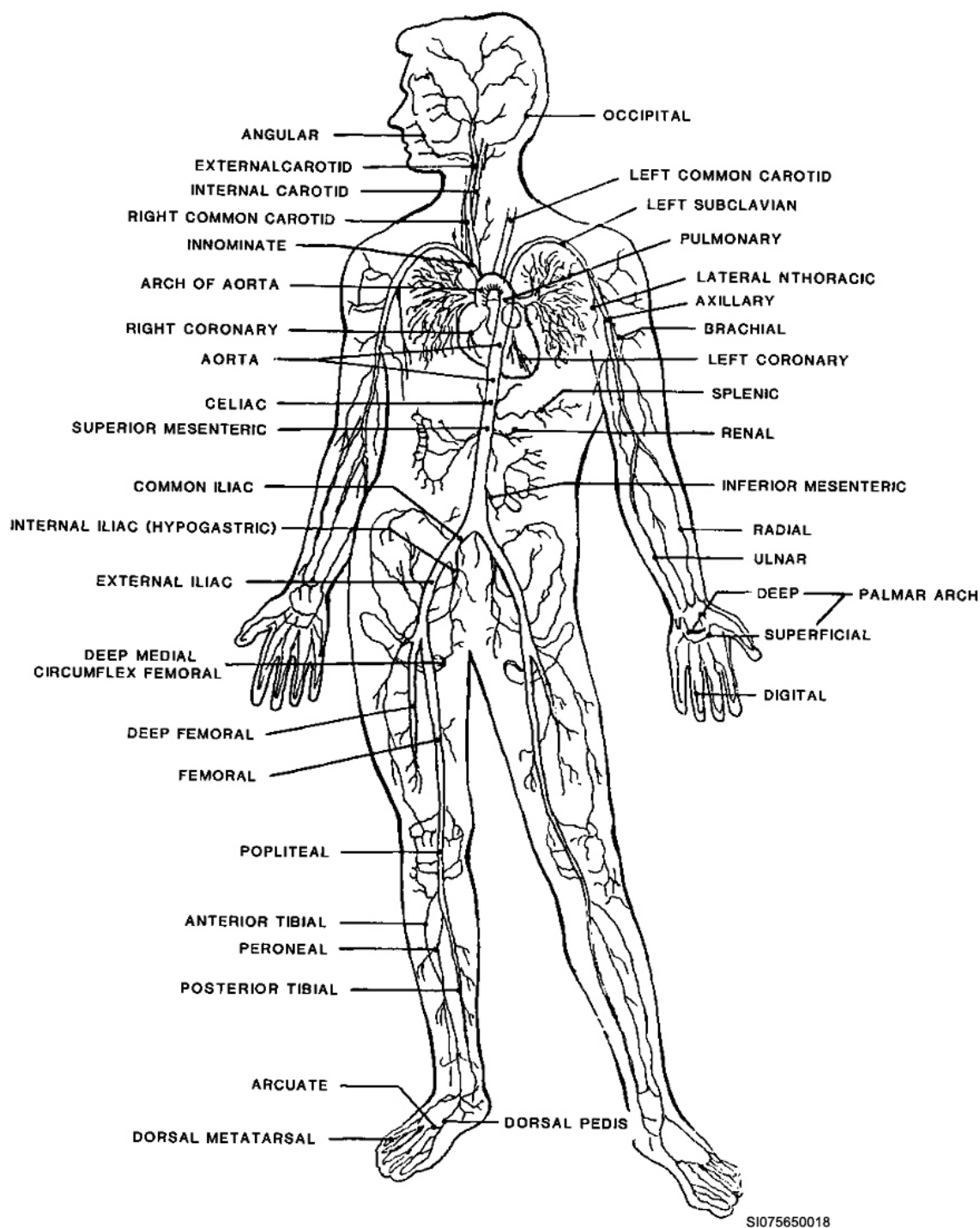


Figure 2-6. Major arteries of the body.

Arteries in the chest and abdomen

We begin our trip through the body with the aorta. *The aorta is the largest artery in the body.* It arises from the left ventricle on the superior aspect of the heart. The aorta is often referred to in three segments.

1. The first part of the aorta extends upward from the heart as the ascending aorta.
2. Then, it arches to the left over the heart, where it is called the aortic arch.
3. From the arch, it extends inferiorly (down) just anterior to the vertebral column and forms the *descending aorta*.

The aorta terminates into two branches—common iliac arteries—around the level of the fourth lumbar vertebra.

The descending aorta passes through the diaphragm. Above the diaphragm, the descending aorta is referred to as the *thoracic aorta*. Below the diaphragm, it is called the *abdominal aorta*.

Thoracic aorta

There are a number of important arteries that arise from the thoracic aorta. At the base of the ascending aorta, there are three outgrowths into the aortic wall. Each of these outgrowths lies opposite one of the cusps of the aortic semilunar valve. These outgrowths are called *aortic sinuses*, and they contain small structures called aortic bodies embedded within the epithelial layer of the wall. The *aortic bodies* contain chemoreceptors that detect changes in the oxygen/carbon dioxide concentrations of the blood. The aortic bodies also contain pressoreceptors. The right and left coronary arteries arise from two of the aortic sinuses. As discussed earlier, these arteries supply the heart muscle itself with oxygen and nutrients. Three major arteries arise from the aortic arch.

Artery	Explanation
Brachiocephalic (innominate artery)	Is the first branch off the aortic arch. It extends upward to about the level of the sternoclavicular joint. There, the brachiocephalic artery branches to form the <i>right common carotid</i> and the <i>right subclavian arteries</i> . <ul style="list-style-type: none"> • Right common carotid – Carries blood to the right side of the head and neck. • Right subclavian – Carries blood to the right arm and parts of the right shoulder, neck, and head.
Left common carotid	Carries blood to the left side of the head and neck.
Left subclavian	Carries blood to the left arm and parts of the left shoulder, head, and neck.

The thoracic aorta also gives rise to a number of other arterial branches. The following table lists these branches and the part of the body supplied with blood. In many cases, the name of the artery gives a clue to its location in the body.

Arterial Branch	Body Part
Bronchial artery	Tissues of the lungs, bronchi, and lymph nodes
Pericardial artery	Pericardium of the heart
Esophageal artery	Esophagus
Mediastinal artery	Tissues of the mediastinum
Superior phrenic artery	Posterior superior surface of the diaphragm
Intercostal arteries	Intercostal muscles, chest muscles, pleura of the lungs, spinal cord, and vertebral column

Abdominal aorta

The abdominal aorta supplies the organs and structures in the abdominal and pelvic cavities as well as the lower extremities. The major branches of the abdominal aorta and their functions are listed in the following table.

Aorta Branches	Divisions/Functions
Celiac artery	Divides into the: <ul style="list-style-type: none"> • Left gastric artery – supplies the stomach and esophagus. • Splenic artery – supplies the stomach, spleen, and pancreas. • Hepatic artery – divides into the right gastric artery, which supplies the liver and stomach, • Gastroduodenal artery - supplies the stomach and duodenum • Cystic artery - supplies the gallbladder.
Phrenic arteries	Supply blood to the superior and inferior surfaces of the diaphragm.
Superior mesenteric artery	Branches off the aorta below the phrenic arteries and forms branches that supply the jejunum, ileum, cecum, ascending colon, and transverse colon—parts of the intestinal tract.
Suprarenal arteries	Supply the suprarenal or adrenal glands on the superior aspects of the kidneys.
Renal arteries	Supply the kidneys with blood, as their name implies.
Gonadal arteries	Supply the sexual glands of the male and female. In the male, the gonadal arteries are called the testicular or spermatic arteries; they supply the testes. In the female, the gonadal arteries are called the ovarian arteries; they supply the ovaries.
Inferior mesenteric artery	Like the superior mesenteric artery, it supplies parts of the intestinal tract— the descending colon, sigmoid colon, and the rectum.
Lumbar arteries	Supply the muscles of the skin and abdominal wall, the lumbar vertebrae, the spinal cord, and the meninges—(lining of the spinal cord).
Middle sacral artery	A relatively small artery that carries blood to the sacrum and coccyx.
Right and left common iliac arteries	Formed at the pelvic brim where the abdominal aorta <i>bifurcates</i> (i.e., splits into two branches). After traveling a short distance, each common iliac artery divides into an <i>internal</i> and <i>external iliac artery</i> . <ul style="list-style-type: none"> • Internal iliac – is the smaller of the two branches and gives rise to several other branches, which supply the pelvic walls and organs, the external genitalia, the buttocks, the medial aspect of the thigh, and in the female, the uterus. • External iliac arteries – continue down into the legs and branch into a number of smaller arteries that supply the legs and feet.

You have probably noticed that most structures receive a blood supply from more than one source. This is known as *collateral circulation*. Collateral circulation is the body's "fail-safe" device to ensure adequate supply of blood to all areas. If one artery supplying a certain area of the body is severed or occluded, other adjacent arteries continue to provide blood to the area. The only structure in the body that is not supplied by collateral vessels is the heart. When the blood supply in the coronary arteries or their branches is interrupted, the region of the heart distal to the obstruction is shut off from its blood supply and dies. The result is a myocardial infarction.

Arteries in the pelvis and lower extremities

As we just mentioned, the abdominal aorta ends in the common iliac arteries, which divide to form the internal and external iliac arteries. These arteries also divide.

Internal iliac artery

The internal iliac artery divides to form the following:

Branch of Internal Iliac Artery	Blood Supplied To
Iliolumbar artery	Ilium and back muscles.
Superior artery and inferior gluteal artery	Gluteal muscles, pelvic muscles, and skin of buttocks.
Internal pudendal artery	Distal muscles of alimentary canal, external genitalia, and hip joint.
Superior and inferior vesicle arteries	Urinary bladder and seminal vesicles and prostate gland in males.
Middle rectal artery	Rectum.
Uterine artery	Uterus and vagina in females.

External iliac artery

The external iliac artery passes down the leg through the rim of the pelvic girdle. Its first two branches are the *inferior epigastric* and *deep circumflex arteries*. These two arteries supply the muscles and skin of the lower abdominal wall. The external iliac artery then passes under the inguinal ligament between the pubic symphysis and the iliac spine to become the *femoral artery*.

Femoral artery

The femoral artery passes along the anterior medial surface of the upper thigh. Its branches supply the groin, lower abdominal wall, muscles, and other structures of the upper thigh. The following table matches the femoral artery branches with the location receiving its blood.

Branch of Femoral Artery	Blood Supplied To
1 st —Superficial circumflex iliac artery	Lymph nodes and skin of the groin.
2 nd —Superficial epigastric artery	Skin of the lower abdominal wall.
3 rd —Superficial and deep external pudendal arteries	Skin of the lower abdomen and external genitalia.
4 th —Profunda femoris artery (largest branch of the femoral artery)	Supplies the hip joint and thigh muscles.
5 th —Deep genicular artery	Supplies the distal ends of the thigh muscles and parts of the knee joints.

Popliteal artery

When the femoral artery passes behind the knee, it becomes the *popliteal artery*. The popliteal artery supplies the knee joint and muscles of the thigh and calf. The popliteal artery unites (forms an anastomosis) with the deep genicular artery to supply the popliteal area. When the popliteal artery passes into the lower leg, it branches to form the *anterior* and *posterior tibial arteries*.

Anterior tibial artery

The anterior tibial artery passes along the lateral aspect of the lower leg, between the tibia and fibula. It supplies the skin and muscles of the anterior and lateral aspects of the lower leg. It also joins the anastomosis at the knee and ankle. It continues along the medial-dorsal foot as the *dorsalis pedis artery*, which supplies the foot and toes.

Posterior tibial artery

The posterior tibial artery passes under the calf muscles and down the lower leg to the foot. It supplies the skin, muscles, and other structures of the lower leg. It also forms part of the anastomoses at the knee and ankle. One major branch of the posterior tibial artery is the *peroneal artery*. The peroneal artery passes down the lower leg along the fibula. It joins the anastomosis at the ankle and branches at the foot to form the *medial* and *lateral plantar arches*.

Arteries in the neck, head, and upper extremities

As we said before, the head and neck are supplied by the subclavian and common carotid arteries. Like the other major arteries we've mentioned, these arteries also form smaller branches. The

subclavian artery is divided into the *vertebral*, *thyrocervical*, and *costocervical arteries*. The common carotid artery divides into the *internal* and *external carotid arteries*.

Vertebral arteries

The vertebral arteries branch off the subclavian arteries near the base of the neck. They extend up into the skull through the foramina in the transverse processes of the cervical vertebrae, and through the foramen magnum of the atlas. In addition to supplying the head, the vertebral arteries also supply the structures that they pass through. Inside the skull, the vertebral arteries come together to form the *basilar artery*. The basilar artery forms branches that supply the pons, midbrain, and cerebellum (all parts of the brain, in case you've forgotten). The basilar artery divides again to form the *posterior cerebral arteries* that supply the occipital and temporal lobes of the cerebrum. The posterior cerebral arteries also form a part of the *circle of Willis*, which is an arterial circle around the base of the brain and a connecting point between the vertebral arteries and the internal carotid arteries.

The thyrocervical arteries branch off the subclavian arteries just distal to the vertebral arteries. They supply blood to the thyroid glands, parathyroid glands, larynx, trachea, esophagus, pharynx, and muscles of the neck, shoulder, and back.

The *costocervical arteries* also branch off the *subclavian arteries*. These arteries supply blood to the muscles of the neck, back, and thoracic wall.

The *internal carotid arteries* lie deep in the tissues of the neck and follow the pharynx up to the base of the skull. They provide the major portion of the blood supply to the brain. The internal carotid arteries branch to form the:

- *Ophthalmic arteries*, which supply the eyeballs and the muscles and structures of the bony orbits.
- *Posterior communicating artery*, which unites with the posterior cerebral arteries to form the circle of Willis.
- *Anterior choroid artery*, which supplies the choroid plexus in the lateral ventricle of the brain as well as other nerve structures within the brain.

The internal carotid artery ends in the *anterior* and *middle cerebral arteries*. The anterior cerebral artery runs between the cerebral hemispheres and supplies the medial surface of the brain. The middle cerebral artery runs through the lateral sulcus and supplies the lateral surface of the cerebrum. Near the base of the internal carotid arteries are chemoreceptors called *carotid bodies*. These carotid bodies are similar in structure and function to the aortic bodies discussed earlier.

The *external carotid arteries* are the more superficial branch of the common carotid arteries. They run up along the side of the head, and branch to form the following five arteries:

1. Superior thyroid artery – supplies the hyoid bone, larynx, and thyroid gland.
2. Lingual artery – supplies the structures of the tongue and the salivary glands beneath the tongue.
3. Facial artery – supplies the pharynx, palate, chin, lips, and nose.
4. Occipital artery – supplies the posterior scalp, the meninges, the mastoid process, and assorted neck muscles.
5. Posterior auricular artery – supplies the ear and the scalp over the ear.

The external carotid artery ends in the *maxillary* and *superficial temporal arteries*. The maxillary arteries supply the teeth, gums, jaws, cheek, nasal cavity, eyelids, and meninges. The superficial temporal arteries supply the parotid salivary gland as well as superficial areas of the face and scalp.

In addition to supplying parts of the neck and brain, the subclavian arteries also give rise to branches, which supply the arms and hands. The subclavian artery enters the upper arm by passing between the clavicle and first rib. In the upper arm, the subclavian artery becomes the *axillary artery*.

The axillary artery extends down the posterior medial aspect of the upper arms. It supplies the axilla, part of the chest wall, shoulder skin, part of the mammary gland, proximal end of the humerus, shoulder joint, and muscles of the neck, shoulder and back. When the axillary artery leaves the axillary area, it forms the *brachial artery*.

The brachial artery continues on down the upper arm to the elbow. It forms a branch called the deep brachial artery. The deep brachial artery extends posteriorly and supplies the triceps muscle. The main brachial artery supplies the muscles on the anterior aspect of the upper arm. The brachial arteries pass along the anterior and posterior aspects of the elbow to the lower arm. There they form a network of interconnecting arteries. At the elbow, the main brachial artery branches to form the *medial ulnar artery* and the *lateral radial artery*. The ulnar artery continues down the medial side of the lower arm to the wrist. Along the way, the ulnar artery supplies the flexor and extensor muscles of the forearm, and forms branches that connect with the branches from the radial artery.

The radial artery continues down the lateral aspect of the forearm to the wrist. It supplies the lateral muscles of the forearm and forms part of a network with the ulnar artery. The radial artery combines with the ulnar artery at the wrist to form a network of blood vessels that supply the hand and fingers.

In addition to supplying blood to the arm, head, and face, the subclavian artery also supplies parts of the thoracic and abdominal walls. It forms a branch called the *internal thoracic artery* at the base of the neck. The internal thoracic artery passes between the pleura and the costal cartilages of the first six ribs. It forms two *anterior intercostal arteries*, which extend into and supply the intercostal muscles of the first six ribs. The anterior intercostal arteries also supply the other intercostal tissues and the mammary glands. The internal thoracic artery joins with the external iliac arteries in supplying structures in the anterior abdominal wall.

Venous system

The venous system (fig. 2-7) is slightly more complex, but generally parallels the arterial system. Rather than repeat a description of the entire system, we confine our discussion to the major veins in relation to the arteries to which they correspond. The arteries supply the body parts with blood and the veins bring back or drain the blood to the heart.

Veins of the head, neck, and upper extremities

The superficial areas of the face, scalp, and neck are drained by the *external jugular veins*. The external jugulars pass down on either side of the neck and empty into the *right* and *left subclavian veins* at the base of the neck. The external jugular veins correspond to the external carotid arteries. The *internal jugular veins* drain the structures within the face and skull. They correspond to the common carotid arteries and to the basilar branch of the subclavian artery. These veins pass down the neck along the pharynx and unite with the subclavian veins to form the *brachiocephalic veins*. The brachiocephalic veins unite to form the *superior vena cava*, which drains into the right atrium.

The *radial, ulnar, brachial, and axillary veins* drain the internal or deep structures of the arm. They parallel the arteries of the same name. The superficial structures of the arm are drained by the *cephalic* and *basilic veins*. The basilic vein runs along the posterior medial aspect of the forearm. Just before it reaches the elbow, it curves anteriorly. It continues about halfway up the medial aspect of the upper arm. There it unites with the deeper brachial vein to form the axillary vein. The cephalic vein runs up the arm to the shoulder. At the shoulder it unites with the axillary vein. As the axillary vein continues medially it becomes the subclavian vein. The brachial and cephalic veins correspond to the superficial branches of the radial and ulnar arteries. At the anterior aspect of the elbow, the *median cubital vein* unites the brachial and cephalic veins. It corresponds to part of the arterial anastomosis at the elbow.

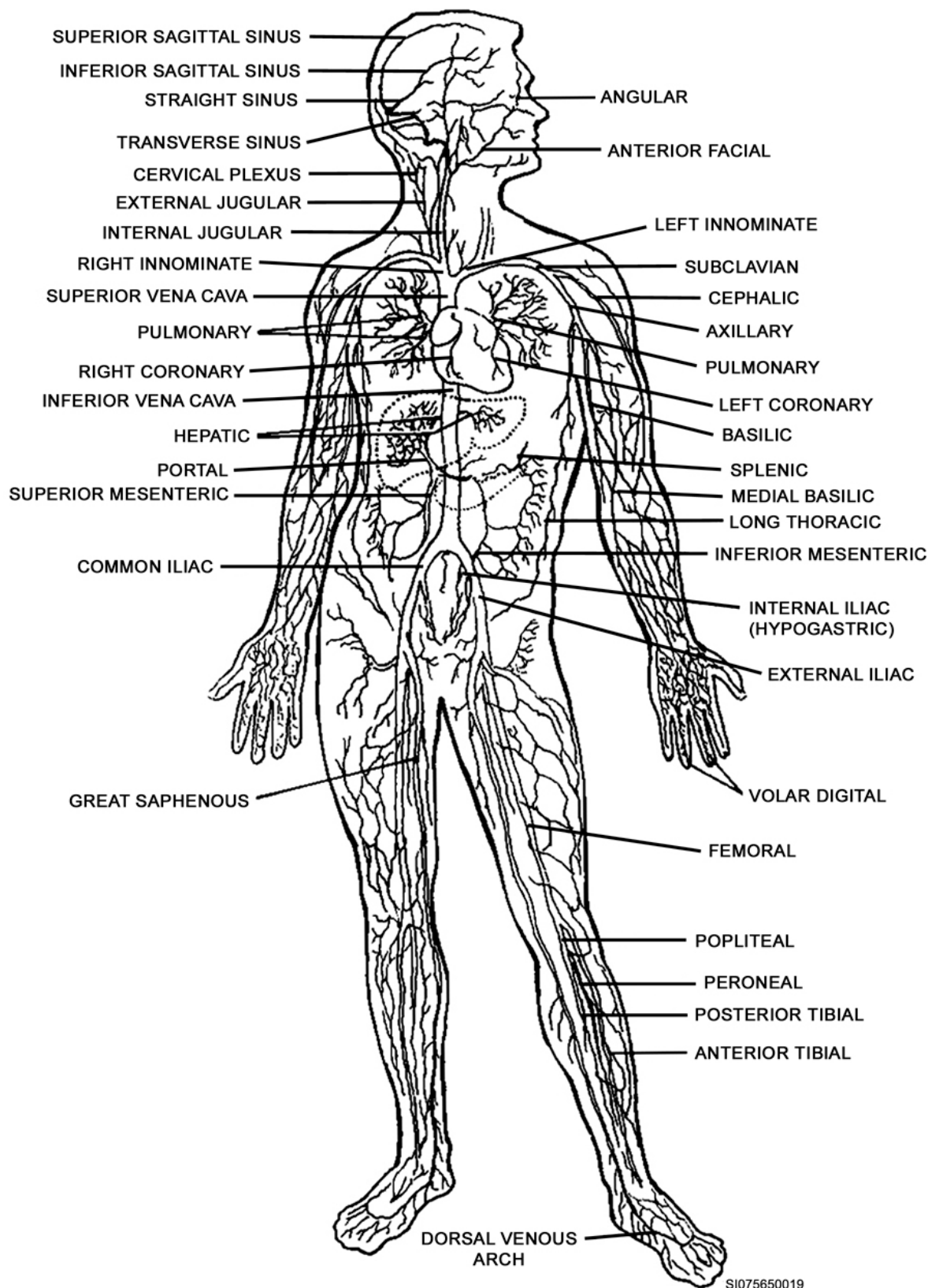


Figure 2-7. Major veins in the body.

Veins of the chest and abdomen

The *internal thoracic vein* parallels and drains the structures supplied by the internal thoracic artery. The internal thoracic vein then drains into the brachiocephalic vein. Some of the *intercostal veins* (which correspond to the intercostal arteries) also drain into the brachiocephalic vein.

The large *azygos vein* extends along the dorsal abdominal wall on the right side of the vertebral column. It unites with the right subclavian vein to drain into the superior vena cava. The azygos vein drains the abdominal and thoracic structures and corresponds to the descending aorta.

The veins that all drain into the azygos vein are the (1) posterior intercostal veins; (2) superior and inferior hemiazygos veins; and (3) right and left ascending lumbar veins.

The posterior intercostals drain the intercostals. The right and left posterior intercostals are connected by the superior and inferior hemiazygos veins. The lumbar and sacral regions are drained by the right and left ascending lumbar veins. These veins correspond to the intercostal network of arteries.

All veins, except the veins that drain abdominal organs, bring blood directly back to the superior or inferior vena cava and the right atrium of the heart. The exception, the blood from the portal vein, enters into the capillary network of the liver (called the *hepatic sinusoids*). This system is called the *hepatic portal system*, and is illustrated in figure 2-8. As you can see in the figure, all the veins that drain the abdominal organs unite to form the portal vein, which, in turn, takes the blood to the liver.

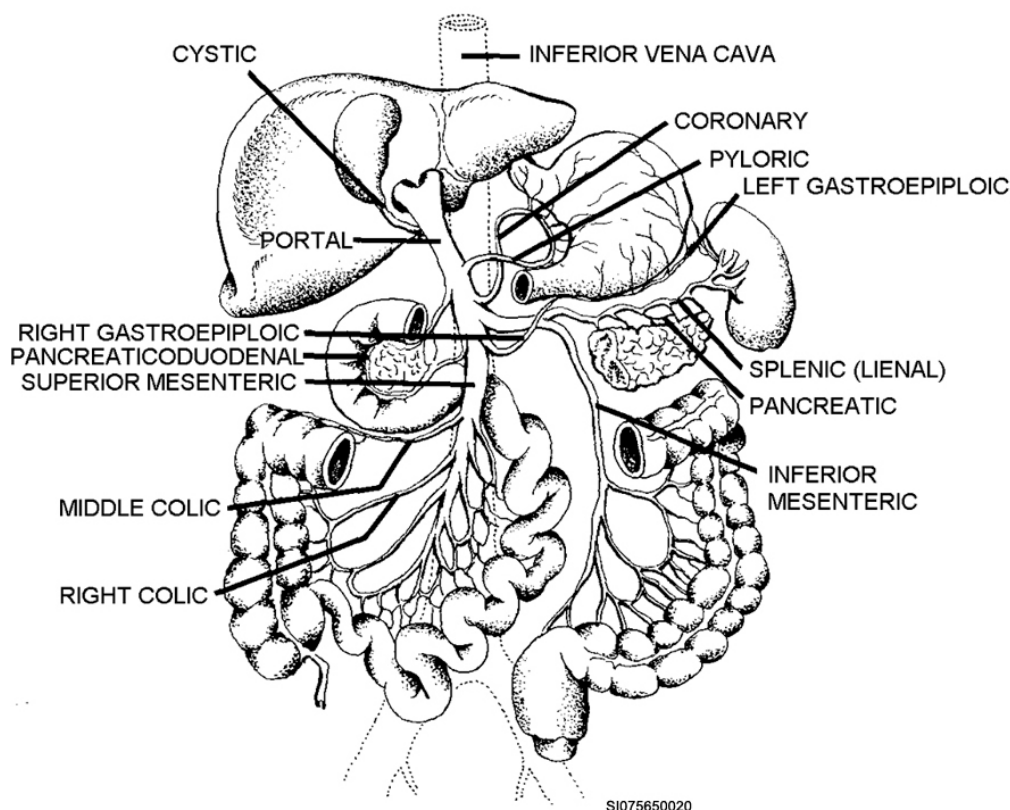


Figure 2-8. Portal circulation.

There are a number of veins that drain into the portal vein. They include the (1) right and left gastric veins (stomach); (2) superior mesenteric vein (small intestine, ascending colon, and transverse colon); and (3) splenic vein (spleen, pancreas, and a portion of the stomach).

The *inferior mesenteric vein* (descending colon, sigmoid colon, and rectum) drains into the splenic vein.

When the blood from the portal vein enters in the liver, the blood is filtered and detoxified. Nutrients in the blood are converted and/or stored. The liver also regulates blood concentrations of lipids and amino acids. Excesses are converted, stored, or destroyed. The liver also stores some vitamins and removes bacteria from the blood. After the blood leaves the liver, it enters into the *hepatic vein*, which, in turn, empties into the *inferior vena cava*. The vena cava finally transports the blood back to the heart.

NOTE: It is interesting to note that there is no arterial system that corresponds to the portal venous system.

The following veins drain into the inferior vena cava, but do not go through the hepatic portal system:

1. Lumbar vein.
2. Gonadal vein.
3. Renal vein.
4. Suprarenal vein.
5. Phrenic vein.

They correspond to arteries of the same name.

Veins of the pelvis and lower extremities

The legs are drained by both deep and superficial veins. The deep veins are as follow:

1. Anterior and posterior tibial veins.
2. Popliteal veins.
3. Femoral veins.
4. External iliac veins.

These veins correspond to the arteries of the same name.

The superficial veins are the *great* and *small saphenous veins*. The great saphenous vein begins on the medial side of the foot, continues up the medial side of the lower and upper legs, and unites with the femoral vein just below the inguinal ligament. The great saphenous vein drains the superficial structures along the medial side of the foot and leg, as well as parts of the upper thigh, groin, and lower abdominal wall. Because of its size and superficial location, the great saphenous vein is commonly harvested to form bypass grafts for diseased coronary arteries. It is also the vein that is ligated and stripped out of the leg to treat *varicose veins*. The small saphenous vein begins on the lateral aspect of the foot. It runs along the posterior aspect of the lower leg and unites with the *popliteal vein* in the popliteal fossa. The small saphenous vein also drains the superficial structures along its route.

The *internal iliac vein* drains the organs in the pelvic region. The following veins drain into the internal iliac vein:

1. Gluteal vein.
2. Pudendal vein.
3. Vesical vein.
4. Rectal vein.
5. Uterine vein.
6. Vaginal vein.

These veins drain the structures that they are named for, and correspond to the branches of the internal iliac artery. The internal iliac veins extend to the pelvic brim where they unite with the *external iliac veins* to form the *common iliac veins*. The common iliac veins unite about the level of

the fifth lumbar vertebra to form the inferior vena cava. These veins correspond to the arteries that branch from the common iliac arteries and the abdominal aorta.

Pulmonary circulation

Although pulmonary circulation also involves arteries and veins, it is considered a separate system because it performs such a specific function—reoxygenating the blood. As stated previously, all venous blood from systemic circulation is returned to the right atrium via the vena cava. However, this blood is not ready to be immediately recirculated through the body, it must first pass through the lungs so the red blood cells can pick up oxygen to supply the body; this is the function of pulmonary circulation.

Blood from the vena cava is dumped into the right atrium of the heart, then pumped into the right ventricle. As mentioned previously, pulmonary circulation then begins in the *pulmonary trunk*.

Branch	Path	Notes
Pulmonary trunk	Receives the deoxygenated blood from the right ventricle and dumps it into the <i>right and left pulmonary arteries</i> .	
Right and left pulmonary arteries	Branch out to supply each lobe of the lung. These branches are called the <i>lobar arteries</i> .	There are three lobar branches in the right lung and two on the left (which correspond to the number of lobes in the right and left lungs).
Lobar arteries	Continue to branch out into smaller and smaller arteries, and finally into arterioles.	
Arterioles	Eventually branch into the <i>pulmonary capillaries</i> .	In the pulmonary capillaries, carbon dioxide is diffused out of the blood and oxygen is diffused in. (We will explain this further when we talk about the respiratory system.)
Pulmonary venules	After the gas exchange has occurred, the blood begins its return journey to the heart via the <i>pulmonary venules</i> .	These pulmonary venules come together to form larger and larger veins.
Pulmonary arteries	Eventually, the oxygenated blood returns to the left atrium by way of the four <i>pulmonary arteries</i> .	

NOTE: The *pulmonary arteries* are the *only* arteries in the body that carry deoxygenated blood, and the *pulmonary veins* are the *only* veins that carry oxygenated blood. When the reoxygenated blood is finally returned to the left atrium of the heart, it is pumped into the left ventricle, and returns to systemic circulation to begin the journey again.

There is one more important part of the circulatory system that we need to cover, and that is the lymphatic system.

211. The lymphatic system

The lymphatic system consists of a network of lymph vessels with specialized clumps of tissue, called lymph tissue, lymph nodes, and lymph organs, located at various points along the system. The network transports fluid called lymph throughout the body. Many consider the lymphatic system to be an entirely separate system on its own. However, since lymph is partially derived from blood, and since lymph vessels parallel and empty into the blood vessels, we cover the lymphatic system as a specialized part of the overall circulatory system.

The table shows the lymphatic system (fig. 2-9) and its composition.

Part	Composition
Lymph	A specialized fluid
Lymphatics	Lymph vessels and lymph capillaries.
Lymphatic trunks	Large lymph vessels that collect lymph from many smaller lymphatics.
Collecting ducts	Thoracic duct and right lymphatic duct.

At various points along this system, there are specialized structures called *lymph nodes* and *lymph organs* (e.g., tonsils, spleen, and thymus). These structures act to filter the lymph as it goes through the system.

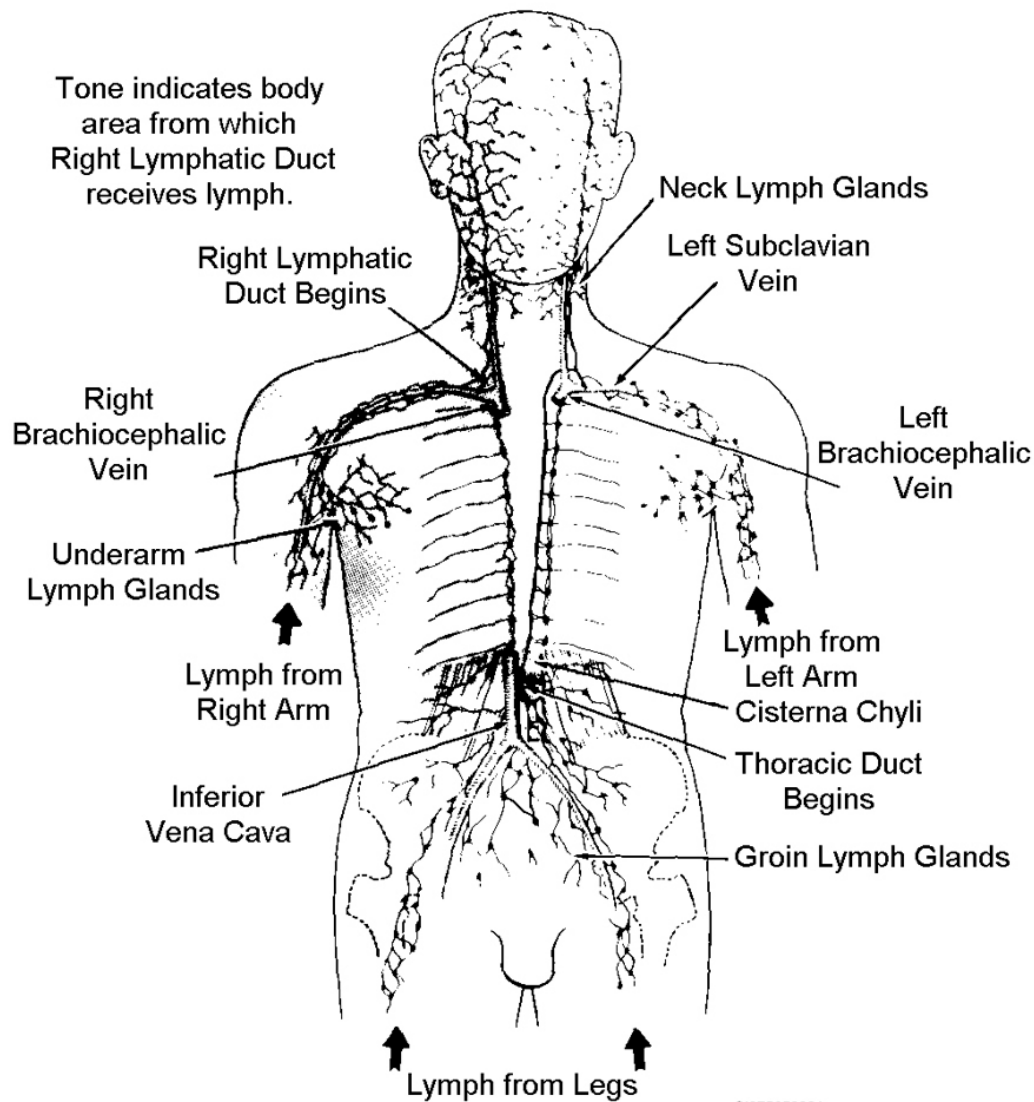


Figure 2-9. Lymphatic structures.

Lymph

Just as blood is the basic component of the cardiovascular system, lymph is the basic component of the lymphatic system. Lymph is a clear, watery fluid that is made up of a combination of blood plasma that has leaked out of the capillaries and tissue fluid from around the cells. Components are similar to the blood plasma except that there is a lower concentration of proteins. Lymph contains a high concentration of leukocytes, especially lymphocytes.

Earlier, we mentioned the osmosis, diffusion, and filtration that take place in the capillaries. Fluid and various substances (e.g., proteins and nutrients) leave the blood vessels as the result of these cellular actions. Some of this fluid, along with the waste products from the cells and a few of the protein molecules, is reabsorbed into the venule end of the capillaries. The total effect of this capillary action is to raise the solute (particle) concentration of the tissue fluid. This raises the osmotic pressure of the tissue fluid, which causes additional fluid to be drawn out of the cells and the capillaries.

It is difficult for protein molecules and particles to pass through the walls of the cells or through the walls of the blood vessels. By contrast, the walls of the lymphatic capillaries are constructed so that some molecules and particles can pass through more easily. The membranes of the cells that form the lymph capillary walls overlap on the inside of the capillary. This creates a door-like effect, which allows substances to push through easily from the outside. Increased pressure on the inside of the capillary closes the door. Once the substances are inside the capillary, they are trapped.

Lymphatics

Lymphatics is a term that refers to all the vessels that carry the lymph through the body. This is a one-way system. The lymph enters the system at the microscopic lymphatic capillaries, travels through various lymph vessels and tissues, and leaves the system at the subclavian or thoracic veins where the lymphatic vessels empty into the blood vessels. The lymphatic vessels parallel the venous system in the body.

Lymphatic vessels

The lymphatic system is very much like the venous system. Tiny vessels come together to form larger vessels, which come together to form still larger vessels, and so on. In the lymphatic system, the lymphatic capillaries come together to form lymphatic vessels. The walls of lymphatic vessels have a three-layered structure similar to veins. The lymphatic vessel walls are a little thinner and have more one-way valves than the veins. Lymph is moved through these vessels by the dual action of the one-way valves and by the squeezing action of the skeletal muscle structures around the vessels. When a muscle contracts, it puts pressure on the lymphatic vessels around it. This forces the lymph in those vessels into the next segment of the lymphatic system.

Lymphatic capillaries

The lymphatic capillaries are the smallest of the lymphatic vessels. They are microscopic tubes that extend into the interstitial spaces. As described above, the capillary walls consist of a single layer of squamous cells that overlap on the inside of the vessel. These cells are attached to the connective tissue so that they can easily be pushed apart or opened from the outside. The lymphatic capillaries drain off the excess tissue fluid. Once this fluid has entered the capillary, it becomes lymph. The lymphatic capillaries located around the intestinal tract are called *lacteals*. The lacteals transport fats away from the digestive tract. Lymphatic fluid in the lacteals is called *chyle*.

Lymph nodes

Lymphatic vessels come together into specialized clumps of lymphatic tissue called lymph nodes, often called *glands*. The lymph nodes are small oval- or bean-shaped structures. The medulla of the node is also made up of lymphocytes. These lymphocytes are loosely arranged as irregular strands.

The following table lists the parts of the lymph nodes and their description:

Lymph Node Part	Description
Afferent vessels	Lymphatic vessels leading into the nodes.
Efferent vessels	Lymphatic vessels leading out of the nodes.
Hilum	An indentation on one side of the node.
Medulla	The inner region and the area around the hilum.

Lymph Node Part	Description
Cortex	The outer region of the node.
Nodules	The lymphatic tissue in the cortex is made up of dense concentrations of lymphocytes and macrophages. These concentrations, or masses, are isolated from each other and are called nodules.
Lymph sinuses	The spaces around the nodules.

Nodules are the structural units of the lymph nodes. The easiest way to describe the nodules is to compare a lymph node to a cross-section of an orange. However, this picture is only an aid—lymph nodes are more random and not as organized as the structures of the orange. Using the orange cross-section example, the nodules are each of the triangular segments. The central sections of the nodules are called the germinal centers, and are the reproductive centers of the cells. If our orange segments had a single seed in the center of each segment, the seed would be the germinal center. Lymphocytes are produced within the germinal centers, and pushed towards the outside of the nodules as they mature.

The node itself is enclosed in a membrane of fibrous connective tissue. This membrane, or capsule, has numerous branches that extend into the body of the lymph node. These branches are called *trabeculae*, and they separate the different nodules (like the membranes separating the orange slices). Blood vessels, nerves, and the efferent vessel enter and leave through the hilum. The afferent vessels enter at various points on the (convex) surface of the node.

Node distribution in the body

Lymph nodes are located throughout the body except around the tissues of the central nervous system. They range in size from about the size of a pinhead to about the size of a bean. Like the nodules, the lymph nodes may be found alone. Usually, however, they are found in groups or chains in certain areas of the body. The following table gives the name of the node, the major body region where concentrations of lymph nodes are found, and the function of these nodes.

Name	Location	Function
Cervical	Along the lower edge of the mandible, before and behind the ears, and along the blood vessels inside the neck	Filter the lymphatic vessels that drain the tissues of the scalp, face, nasal cavity, and pharynx.
Axillary	Underarm area	Filter the lymph vessels that drain the arm, thoracic and upper abdominal walls, and the mammary gland.
Inguinal	In the groin.	Filter the lymph from the legs, external genitalia, and lower abdominal wall.
Pelvic	Near the iliac blood vessels	Filter the lymph from the organs in the pelvic cavity.
Abdominal	In chains along the main mesenteric arteries and the abdominal aorta	Filter the lymph from the abdominal organs.
Thoracic	Within the mediastinum and along the trachea and bronchi	Filter the lymph from the internal thoracic wall and from the thoracic organs.

As already mentioned, the lymph nodes act to filter and phagocytose the microorganisms and foreign particles that are carried in the lymph. These nodes are also major centers for lymphocyte production, and they are highly efficient body defense mechanisms. Occasionally, they may be overwhelmed with microorganisms to the point where the microorganisms attack the lymph tissue itself. If that happens, the lymph node becomes swollen and tender, and the associated lymph vessels may become inflamed. *Lymphangitis*, the term for extreme cases of inflammation of a lymph vessel, is characterized by red streaks on the skin over the lymphatic vessel.

When the lymph enters the node, it filters down through the cortex to the medulla. Along the way, foreign particles and microorganisms are removed from the lymph by the macrophages and lymphocytes lining the lymphatic sinuses. This system of filtration is similar to the filtration that occurs in the reticuloendothelial cells of the blood vessels. After the filtration process is complete, the lymph leaves the lymph node by way of the efferent vessel. The lymph then travels on to the next node in the chain, to the next larger lymph vessel, or to one of the associated lymphatic organs.

Lymphatic trunks

The lymphatic trunks collect lymph from many lymphatic vessels. These lymphatic trunks are named for the body regions that they drain:

Trunk	Body Region They Drain
Lumbar	Drains the lymph from the legs, lower abdominal wall, and pelvic organs.
Intestinal	Drains the intestinal tract.
Intercostal and bronchomediastinal	Drain portions of the thorax.
Subclavian	Drains the arm.
Jugular	Drains parts of the head and neck.

These lymphatic trunks come together to form the still larger collecting ducts.

Collecting ducts

All the lymph in the body is drained into one of two major collecting ducts—thoracic duct and right lymphatic duct.

Thoracic duct

The thoracic duct is the larger of the collecting ducts. (It is also the largest lymph vessel in the body.) The thoracic duct begins at a collecting point called the *cisterna chyli* in the abdomen, passes through the diaphragm beside the aorta, runs up the thoracic cavity in front of the vertebral column, and empties into the left subclavian vein near the junction of the left jugular vein. The thoracic duct drains the entire body except the right upper quadrant. It receives lymph from the intestinal, lumbar, intercostal, left subclavian, left jugular, and left bronchomediastinal trunks.

Right lymphatic duct

The right lymphatic duct is considerably shorter than the thoracic duct. It begins in the right thorax as the union of the right jugular, right subclavian, and right bronchomediastinal trunks. It empties into the right subclavian vein near the junction of the right jugular vein. The right lymphatic duct drains the right upper quadrant of the body.

A tremendous amount of lymph passes through the lymphatic vessels. Each day about 50 percent of the body's total plasma proteins leak through the capillaries and are returned via the lymphatic system. Obstructions in this system lead to an increase in the plasma proteins in the tissue fluid. This increases the pressure, which causes a fluid accumulation (edema) in that area of the body. Serious body disfigurement can result from excessive fluid accumulation. The increase in the tissue osmotic pressure causes a decrease in the blood osmotic pressure. This plus the decrease in the blood plasma protein level result in a fluid imbalance in the body and possibly even in death.

Lymphatic organs

There are several organs, particularly the spleen, tonsils, and thymus, that are associated with the function of the lymphatic system (fig. 2-10). These organs are made up of a framework of reticular connective tissue with large numbers of lymphocytes inside the framework.

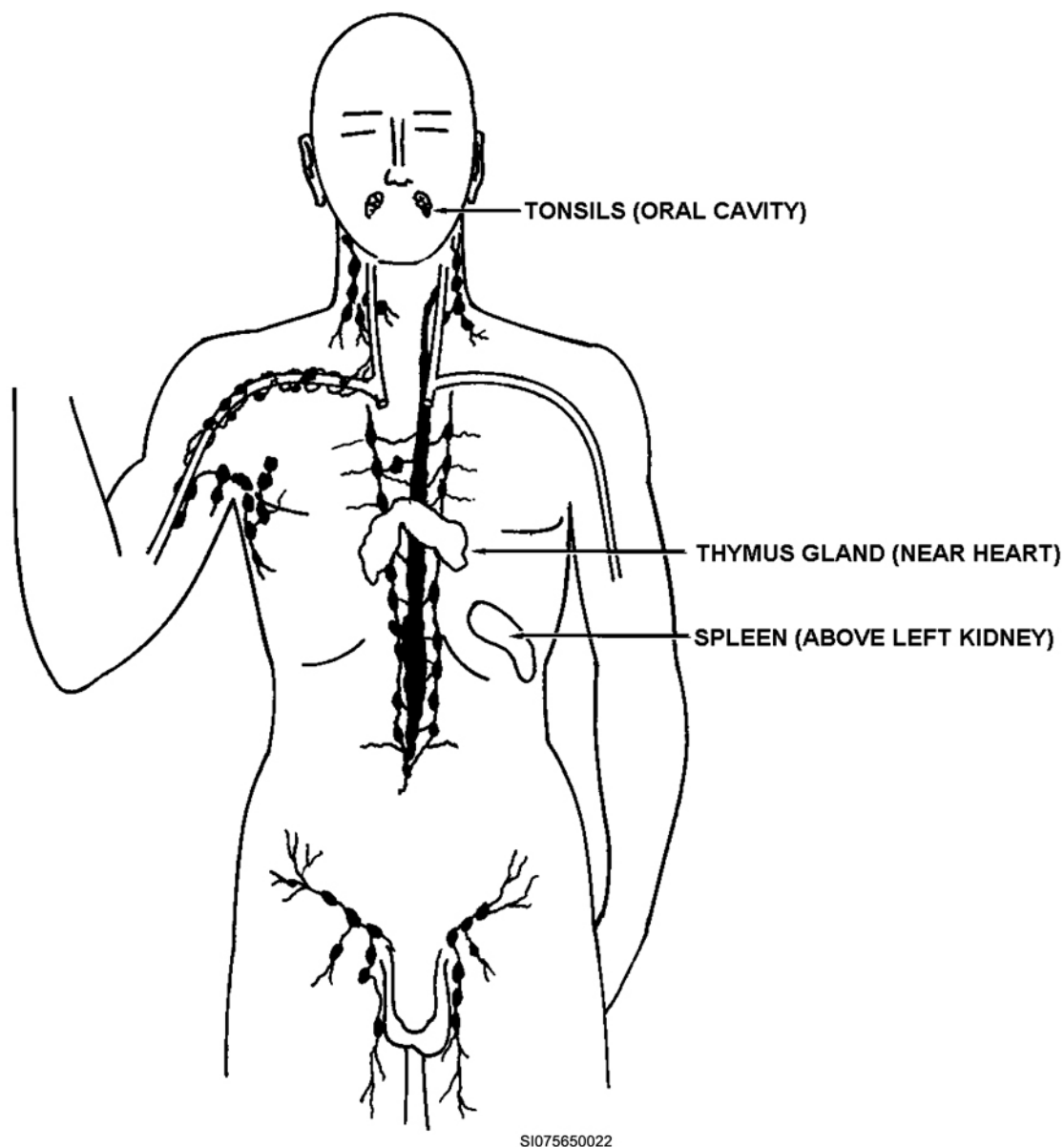


Figure 2-10. Lymphatic organs.

Tonsils

There are several groups of tonsils (fig. 2-11). Tonsils are usually associated with the respiratory system, but also play a role in the lymphatic system. These tonsils are composed of partially encapsulated lymph nodules. The main three groups of tonsils are shown in the table:

Tonsils	Description/Location
Palatine (commonly referred to as the tonsils.)	Small oval structures located in the posterior part of the mouth on either side of the tongue.
Lingual	Mass of lymphoid tissue located at the base of the tongue.
Nasopharyngea (commonly called the adenoids)	Mass of lymphoid tissue located in the posterior wall of the pharynx above the edge of the soft palate.

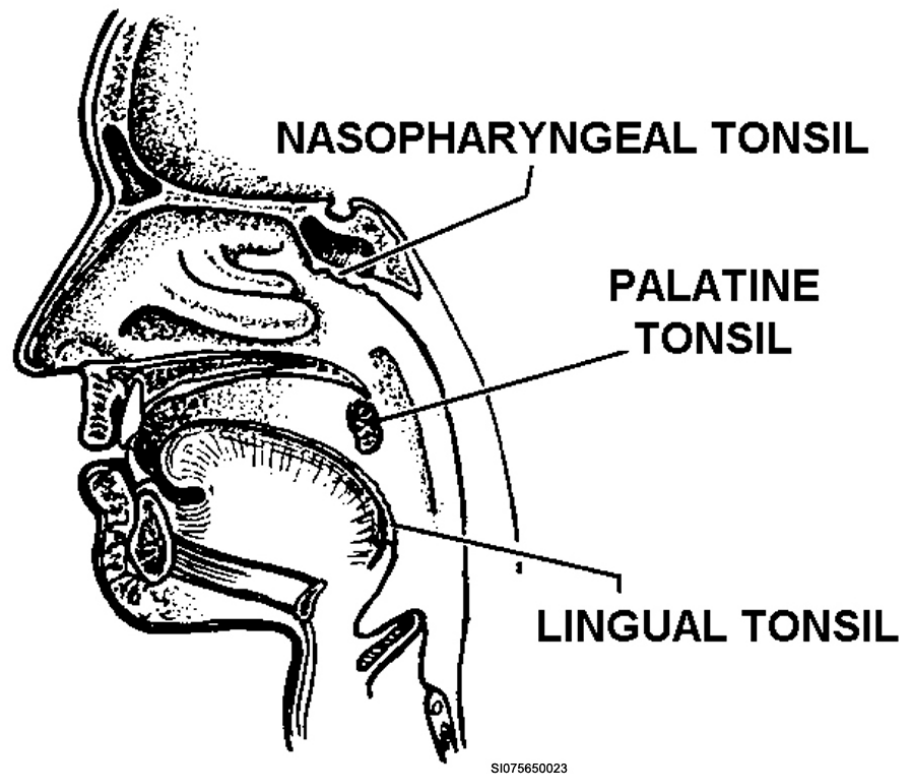


Figure 2-11. Tonsils.

All of the functions of the tonsils are not known. Because of their possible infection-fighting roles, their removal by tonsillectomy and adenoidectomy, once routine, is now controversial. They do filter lymph, and they frequently become swollen and tender due to upper respiratory infections.

Spleen

The spleen is a soft, oval structure about 5 inches long and 3 inches wide. It is shaped like a large lymph node, and is the largest of the lymphatic organs. The spleen is located in the upper left abdomen beneath the diaphragm and behind the stomach. It is enclosed in a capsule of connective tissue and muscle fibers.

Like lymph nodes, the capsule has trabeculae extending into, and dividing the spleen into compartments (remember the orange slices?). The tissue in these compartments is divided into red pulp and white pulp. The white pulp is made up of lymphocytes, which form a sheath around the arterioles. These lymphocytes form an occasional nodule, and these nodules have germinal centers that produce more lymphocytes. The red pulp is made up of erythrocytes, lymphocytes, and macrophages. The red pulp makes up the sinuses of the spleen. The spleen consists primarily of white pulp until a person reaches early adulthood. From that time, the white pulp atrophies or decreases, and the red pulp increases.

The reticuloendothelial system in the spleen is the major center in the body for the destruction of worn-out erythrocytes. The spleen also functions as a storage reservoir for blood. During periods of body relaxation, the spleen becomes distended with erythrocytes trapped in sinuses of the red pulp. When the body is active, the spleen contracts and the erythrocytes are returned to the circulation. In addition to storage, the spleen also partially filters the blood that passes through it. Finally, the spleen functions as a part of the body's immune defense system.

Thymus

The thymus is a flat, two-lobed structure located within the mediastinum posterior to the upper sternum and anterior to the aorta. It extends from the base of the neck to the pericardium. The thymus is made up of lymphatic tissue that is divided into lobules by connective tissue that extends in from the surface. The thymus grows until puberty. After puberty, it gradually atrophies and is replaced by fat and connective tissue in the elderly.

The lobules consist of a dense lymphocyte cortex surrounding a less dense lymphocyte medulla. Both cortex and medulla are contained in a network of epithelial tissue. The lymphocytes that make up the thymus originate from precursor cells from the bone marrow. The majority of these cells remain inactive. A few of the lymphocytes leave the thymus and enter into the circulation as *T-lymphocytes*. The T-lymphocytes play a role in the body's immune defense system. The epithelial cells in the thymus are thought to secrete a hormone called thymosin, which may stimulate the maturation of the T-lymphocytes.

Functions of the lymphatic system

The lymphatic system performs a number of vital functions in the body.

Function	How
Defend the body against disease (main function)	The lymphocytes perform part of this function by filtration and phagocytosis. The other part of the defense is the immune defense system. The lymphocytes produce antibodies that provide an immunity against infectious organisms.
Fluid balance	The lymphatic system returns proteins and fluids that have leaked out of the blood capillaries back to the blood circulation. This action helps to maintain the osmotic pressures of the tissue fluid and the blood, which helps to maintain the fluid balance in the body.
Absorption of lipids from the intestinal tract	These lipids are absorbed as fats by the lacteals.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

207. Characteristics and composition of blood

1. What are the three types of cells in blood?
2. What are lymphocytes and monocytes?
3. What is the primary function of erythrocytes?
4. What substance is responsible for the color of blood?
5. What type of granulocytes is most numerous of the white blood cells?
6. Name the two types of agranulocytes.

7. What condition is caused by an excessive deficiency of leukocytes?
8. What are megakaryocytes?
9. What action is a result of platelets clumping together and adhering to the wall of a damaged blood vessel?
10. What is the end result of the coagulation process?
11. What fluid is made up of blood plasma minus prothrombin and fibrinogen that have become part of a clot?
12. What is the most common bleeding tendency called?
13. What substance limits the clotting ability of the blood?
14. Why is it beneficial for the body to have factors that interfere with the clotting process?
15. What are the nine components of blood plasma?
16. Where are plasma proteins manufactured?
17. What is the general term that refers to several of the components of plasma?
18. Name the two blood gases found in plasma.
19. Urea is a byproduct of what?

20. What are the two most common ions in plasma electrolytes?
21. Name the three antigens involved in the blood classification process.
22. People with what blood type are said to be universal recipients?
23. What condition occurs while a child is still in the uterus and determined to be RH positive?

208. Structure and function of the heart

1. Where is the heart located within the chest?
2. What is the name given to the functional networks of cardiac muscle cells formed into a multinucleated mass of protoplasm by the merging of several cells?
3. What is the function of the pericardial layer of the heart?
4. Where is the myocardium thickest?
5. What specialized cardiac muscle fibers found in the endocardium help control the heartbeat?
6. What indentation on the surface of the heart marks the division between the atria and ventricle?
7. Name three blood vessels that drain venous blood into the right atrium.
8. What fibrous cords prevent the cusps of the tricuspid valve from everting back into the right atrium when the valve closes?
9. What is the function of the right ventricle?

10. What blood vessels empty blood from the lungs into the left atrium, and how many of these vessels are there in total?
11. Which chamber of the heart pumps oxygenated blood through the aortic semilunar valve into the aorta?
12. What is the name given to the condition in which a portion of the heart muscle dies due to occlusion of one or more of the major vessels supplying the heart with blood?
13. Deoxygenated blood that does not return to the right atrium by way of the coronary veins drains directly into the ventricles through what channels?
14. What is the normal impulse rate of the SA node in an adult?
15. Where is the atrioventricular node located?
16. What is the bundle of His?
17. What fibers in the cardiac conduction system are a continuation of the right and left bundle branches and give off many smaller branches that extend into the papillary muscles and the ventricular syncytium?
18. What are impulses generated from any point other than the sinoatrial node called?
19. During what phase of the cardiac cycle is the heart relaxed?

209. Blood vessel types, structure, and function

1. What are the three main types of blood vessels in the body?
2. What is the thickest layer of an artery?

3. What are the small vessels that branch off of the arteries called?
4. How is the body able to control the direction of blood flow?
5. What are venules?

210. Vessels and blood flow of pulmonary circulation and the arterial system

1. Where does pulmonary circulation begin?
2. Describe the path of the descending aorta.
3. List the three major arteries that arise from the aortic arch.
4. What is the body's "fail-safe" device to ensure adequate blood supply to all areas?
5. What artery supplies the sexual glands of the male and female?
6. What are the two branches of the common iliac artery?
7. What two arteries supply the muscles and skin of the lower abdominal wall?
8. What is the largest branch of the femoral artery?
9. What artery supplies the foot and toes?
10. Where is the circle of Willis located?
11. What arteries provide the major portion of the blood supply of the brain?

12. Where does the external carotid artery end?
13. What two arteries branch off of the main brachial artery at the elbow?
14. What veins unite to form the superior vena cava?
15. What four veins drain the internal or deep structures of the arm?
16. List the veins that drain into the azygos vein.
17. Which vein takes blood to the liver?
18. The hepatic vein empties into where?
19. What vein begins on the medial side of the foot, continues up the medial side of the lower and upper legs, and unites with the femoral vein just below the inguinal ligament?
20. What vein drains the organs in the pelvic region?

211. The lymphatic system

1. What are the main components of the lymphatic system?
2. What is the clear, watery fluid that is made up of a combination of blood plasma that has leaked out of capillaries and tissue fluid from around the cells?
3. What are lacteals?
4. What are the structural units of lymph nodes called?

5. In what part of the body will you *not* find lymph nodes?
6. What lymphatic region filters the lymph that drains from the mammary gland?
7. What is lymphangitis?
8. What lymphatic trunks drain portions of the thorax?
9. Name the two major collecting ducts through which lymph is drained.
10. Name three lymphatic organs.
11. What are adenoids?
12. The white pulp of the spleen consists of what?
13. What is the major center in the body for the destruction of worn out erythrocytes?
14. Where do lymphocytes that make up the thymus originate?
15. What is the main function of the lymphatic system?

2-2. The Respiratory System

One of the last organs we discussed, the tonsils, is often considered as part of the system we discuss next, the respiratory system. In the previous section, we discussed the circulation of blood from the heart to the lungs and back to the heart. We also covered the role of the blood in supplying the cells of the body with oxygen and removing waste carbon dioxide. Now we take a closer look at how the exchange of gases takes place, and the specialized organs that make this exchange possible.

212. Respiratory structures and their functions

Oxygen is a substance necessary for any cellular activity to occur. It is also necessary for carbon dioxide to be removed before any cellular activity takes place. The exchanges of these gases in the

body are a process called *respiration*. Respiration is the primary function of the organs and cells that make up the respiratory system. Gas exchange is the primary, but not the only function carried out by the respiratory system. This system also plays an important role in the body's fluid balance, temperature control, infection control, speech, sense of smell, and regulation of acid/base balance.

The respiratory system (fig. 2-12) is made up of a series of passages that end in two large, multilobed structures called *lungs*. These organs are specialized; they draw oxygen into the body, exchange it for carbon dioxide at the lungs, and eliminate the carbon dioxide through the same passages. In addition to these basic structures, there are a number of accessory muscles and bones that are involved in the respiratory process. In our discussion of this system, we begin with the structure and function of the organs that make up the upper respiratory tract. Following that, we talk about the components of the lower respiratory tract.

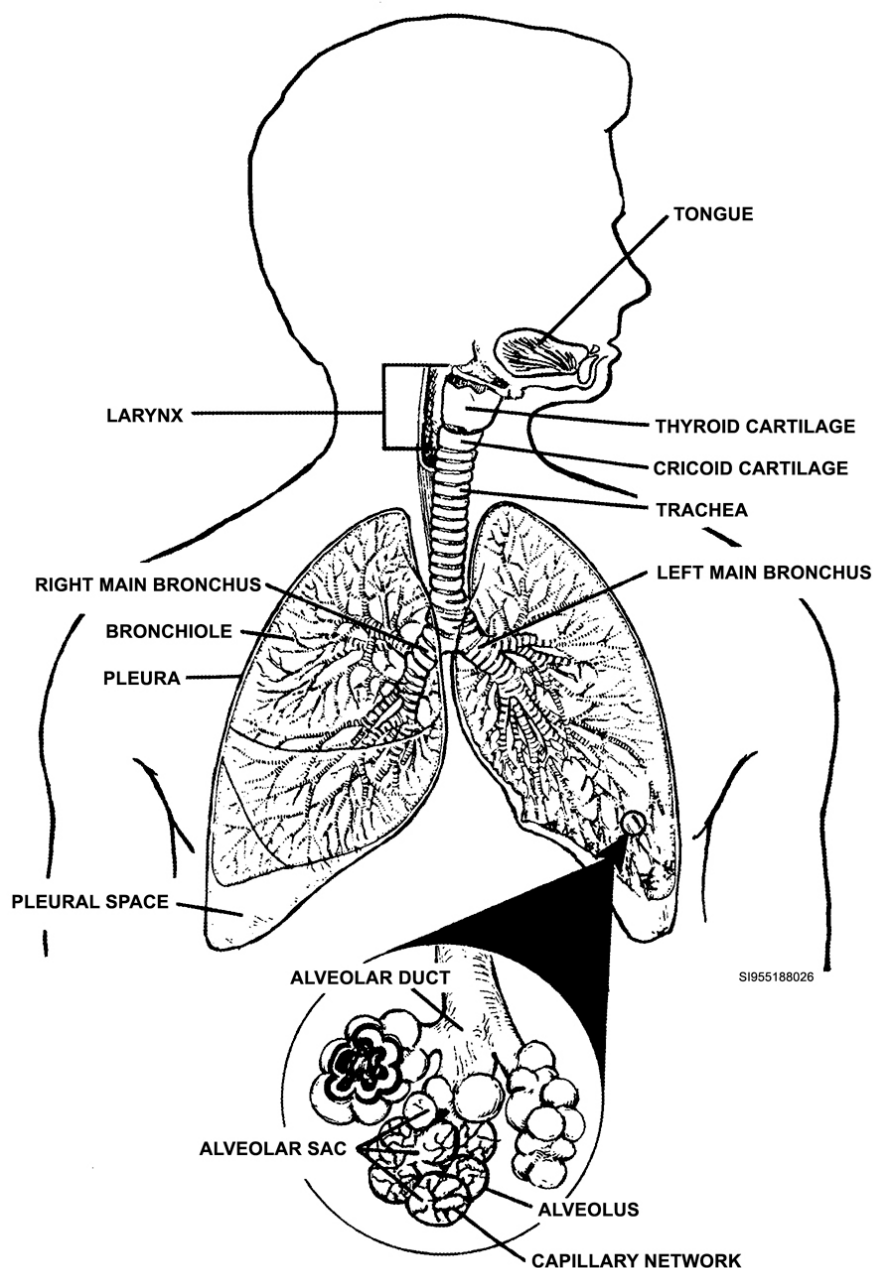


Figure 2-12. The respiratory system.

Upper respiratory tract

The upper respiratory system (fig. 2-13) is made up of the respiratory organs, located outside of the thorax. These organs are the nose, pharynx, and larynx. The organs function as an open passage that directs the air down into the thorax. There are also several small ancillary structures called sinuses associated with the upper respiratory system.

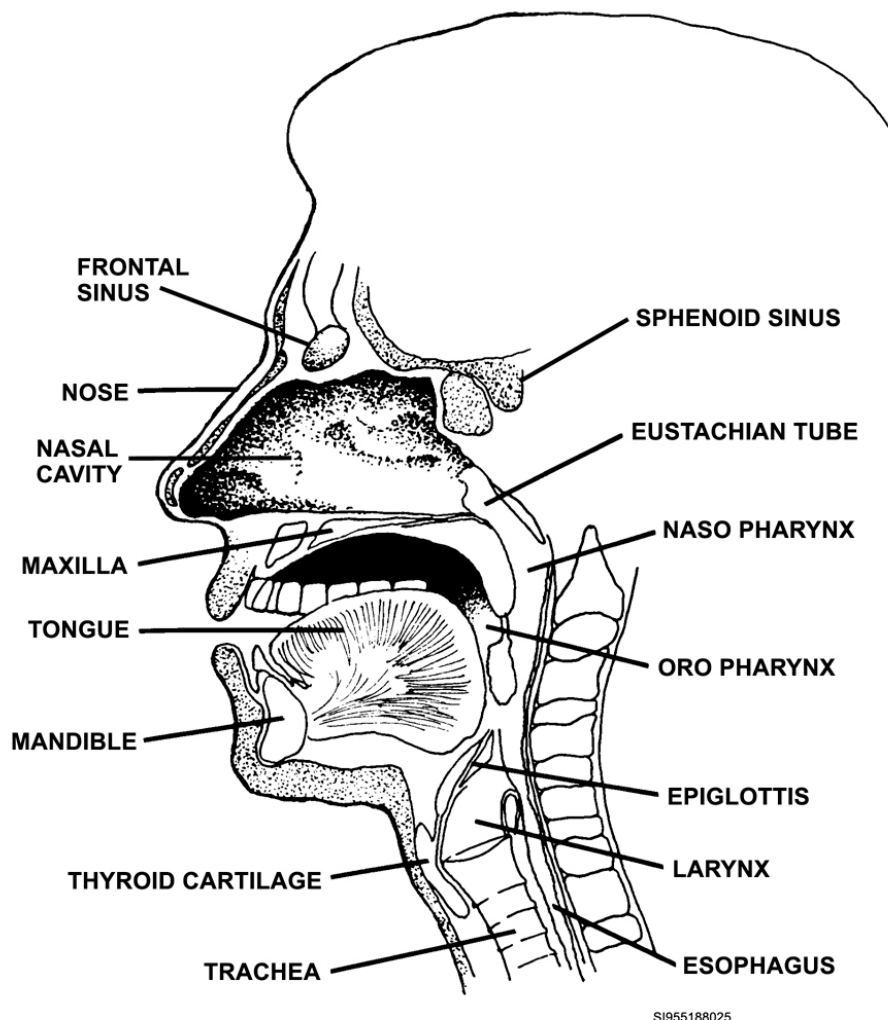


Figure 2-13. Parts of the upper respiratory tract.

Nose

The nose is divided into a small external part, and a larger, internal part. The internal part is also referred to as the *nasal cavity*.

External nose

The external part of the nose consists of a bony and cartilaginous structure, which is covered by skin and projects from the front of the face. The external nose has a somewhat triangular shape. The top part, or bridge, of the nose consists of a short section of paired nasal bones connected to a longer section of *nasal cartilage*. (The nasal bone is connected posteriorly to the frontal bone.)

The nasal cartilage extends from the nasal bone to the tip of the nose. The sides of the nose are made up of two lateral cartilages that extend down and out from the bridge of the nose. The tip of the nose is formed by two horseshoe-shaped *alar cartilages*.

The alar cartilages also form the external openings, or *nares*, of the nose. The nares are divided by the septal cartilage, which extends anteriorly from the ethmoid and vomer bones. The nares are the openings through which the air enters the nose.

The area just inside the nares is called the *vestibule*. The skin of the vestibule is lined with sweat glands, sebaceous glands, and coarse hairs called *vibrissae*. The vibrissae filter large particles from the air as it enters the nose. Once the air has passed through the vestibule, it enters the internal part of the nose.

Nasal cavity (Internal nose)

The nasal cavity is much more extensive than the external nose. It extends posteriorly from the nostrils to the back of the throat. The cavity is formed by bones. The parts of the nasal cavity and their location and function are discussed in the table below:

Parts of Nasal Cavity	Location/Function
Roof	
Frontal bone	Anterior portion
Cribriform plate of the ethmoid bone	Middle portion
Parts of the sphenoid and vomer bones	Posterior portion
Floor or base:	
Maxilla	Anterior
Palatine bones	Posterior
Cribriform plate	Separates the nasal cavity from the cranial cavity, and perforated by a number of small openings. Branches of the olfactory nerve pass through these openings and are responsible for the sense of smell.

The nasal cavity is actually two separate cavities. It is divided into right and left halves by the *nasal septum*. The septum is formed by the union of two bones and two cartilages. The two bones are the vomer and the perpendicular plate of the ethmoid bone. The cartilages are the septal cartilage and the vomeronasal cartilage. The perpendicular plate extends down from the ethmoid bone in the posterior part of the cavity. It connects inferiorly to the vomer and anteriorly to the septal cartilage. The vomer extends up from the maxillary and palatine bones. It connects posteriorly to the ethmoid plate, and anteriorly to the septal cartilage. The septal cartilage extends anteriorly from the ethmoid and vomer bones to the tip of the nose. The vomeronasal cartilage is a small structure located just beneath the septal cartilage. It connects posteriorly to the vomer bone. The nasal septum is connected superiorly to the nasal bone and the nasal cartilage. Inferiorly, it is connected to ridges on the maxillary and palatine bones.

Each half of the nasal cavity is further divided by the *superior*, *middle*, and *inferior nasal conchae* that project inwards from the lateral walls of the nasal cavity. There is an air passage called a *meatus* beneath each concha. The nasal conchae support the mucous membrane that lines the nasal cavity. The superior and middle nasal conchae are part of the ethmoid bone. The inferior nasal conchae are separate bones. The outer layer of the mucous membrane lining the nasal cavity is made up of pseudostratified ciliated columnar epithelium. If you remember your chapter on cells and tissues, this type of epithelium has a number of mucus secreting cells called *goblet cells*. The mucous membrane also contains a plentiful supply of blood vessels.

Air initially enters the nasal cavity through the vestibule. It passes simultaneously through the three meatuses, and then passes into a small cavity called the *sphenoethmoidal recess*, located just above the superior meatus. From the sphenoethmoidal recess, the air passes through two, small, funnel-shaped openings into the *pharynx*. These openings are called the *posterior nares*, or *choanae*. As the air passes through the nasal cavity it is filtered, warmed, and moistened. The initial filtering is done

by the hairs in the vestibule. Additional filtering takes place when the air passes through the meatuses. Fine particles are trapped by the sticky mucus found on the surface of the mucous membrane. The action of the cilia pushed the trapped particles back toward the pharynx. Later, these fine particles are swallowed and destroyed through the action of digestive enzymes. The incoming air is also warmed and moistened as it passes through the nasal cavity. The numerous small blood vessels in the mucous membrane radiate heat which warms the air. The air is moistened by water that evaporates from the mucous membrane.

Sinuses

There are a number of air-filled spaces called sinuses in the bones of the skull and face. The sinuses (maxillary, frontal, ethmoid) are named for the bones that they are within. The sinuses are connected by passages to the nasal cavity. The mucous membrane that lines the nasal cavity also lines the sinuses. The primary function of the sinuses is to *reduce the weight of the face and skull*. They also affect the tonal quality of speech. Normally, the sinuses drain into the nasal cavity. If the passage should become blocked, the secretions accumulate within the sinus and cause a sinus headache.

Pharynx

The pharynx, or throat, is a muscular tube about 5 inches long. It is located just anterior to the cervical vertebrae, between the nasal cavity and the larynx. The pharynx is divided into three sections—the *nasopharynx*, *oropharynx*, and *laryngopharynx*. The nasopharynx is located posterior to the nasal cavity. It extends from the posterior nares to the upper surface of the soft palate. The oropharynx is located behind the mouth. It extends from the soft palate to the hyoid bone. The last section, the laryngopharynx, is located posterior to the larynx, between the hyoid bone and the esophagus.

There are seven openings into the pharynx:

No.	Opening	Explanation
2	Auditory tubes (eustachian tubes)	Extend from the middle ears and open into the nasopharynx.
2	Choanae	Opens into the nasopharynx from the nasal cavity.
1	Oropharynx	Has a single opening called the <i>isthmus of the fauces</i> . It connects the oropharynx with the mouth.
2	Laryngopharynx	Has two openings—the <i>larynx</i> and the <i>esophagus</i> .

As stated in the lesson on the lymphatic system, the *pharyngeal* and *palatine tonsils* are also located within the pharynx. The *pharyngeal tonsils* (adenoids) are located on the posterior wall of the nasopharynx near the choanae. The palatine tonsils are located in the isthmus of the fauces, near the border of the mouth and the oropharynx. In addition to their role in the lymphatic system, the tonsils are believed to help filter some of the air in the respiratory system.

The pharynx is actually a component of both the respiratory and digestive systems. It serves as a passageway for both food and air. The pharynx is also involved in the function of speech. Different vowel sounds are produced when the pharynx changes shape.

Larynx

The larynx is the last component of the upper respiratory system. It is also called the “voice box” because it contains the *vocal cords*. The larynx is an expanded, triangularly-shaped structure located anterior to the lower pharynx, between the base of the tongue and the upper end of the trachea. It serves as a passageway for the air that enters and leaves the trachea. It prevents the entrance of foreign objects into the trachea by means of a structure called the *epiglottis*.

The inner wall of the larynx is lined with a ciliated mucous membrane that is continuous with the mucous membrane lining the nasal cavity and pharynx. This mucous membrane forms two pairs of folds that extend into the laryngeal passageway, and result in the formation of three chambers within the larynx. The upper pair of folds are called the *vestibular* or *false vocal folds*. (The vestibular folds are not involved in making sounds.) The lower pair of folds are called the *true vocal cords*. There is a

narrow space called the *rima glottidis* or *glottis* between the lower folds. The glottis is the narrowest part of the larynx. The larynx has three chambers.

Chamber Name	Chamber Placement
Vestibule	Upper chamber of the larynx
Ventricle	Middle chamber of the larynx
Infraglottic larynx	Bottom chamber of the larynx

The larynx is made up of nine cartilages connected to each other by muscles and ligaments. Three of the cartilages—the thyroid, cricoid, and the epiglottic cartilages—occur individually. The other six cartilages occur in pairs; they are the arytenoid cartilages, cuneiform cartilages, and corniculate cartilages.

Thyroid cartilage

The thyroid is the largest of the laryngeal cartilages. It is located just inferior to the hyoid bone on the anterior aspect of the neck. The V-shaped structure of the thyroid cartilage accounts for the overall shape of the larynx. Anteriorly, the larynx forms a narrow ridge called the *laryngeal prominence*. The top part of the laryngeal prominence protrudes from the front of the neck to form the distinctive “Adam’s apple.” Just above the Adam’s apple, the thyroid cartilage forms a V-shaped notch called the *superior thyroid notch*. From the laryngeal prominence, the sides of the thyroid cartilage flare out and back. Posteriorly, the sides of the thyroid cartilage form two horn-like structures extending up to the hyoid bone. Along its upper border, the thyroid cartilage is connected to the epiglottic cartilage. It is also connected to the hyoid bone by its posterior horns and by a membrane called the *thyrohyoid membrane*. Inferiorly and posteriorly, the thyroid cartilage is connected to the cricoid cartilage.

Cricoid cartilage

The cricoid cartilage is located just below the thyroid cartilage. It is a round, strong structure shaped something like a signet ring. The narrow part of the cricoid cartilage is anterior, and the expanded part is posterior. Inferiorly, the cricoid cartilage is connected to the trachea.

Epiglottis cartilage

The epiglottic cartilage is attached to the superior border of the thyroid cartilage. It supports the leaf-shaped epiglottis. During breathing, the epiglottis remains upright to allow air to pass into the larynx. When swallowing occurs, the larynx is pulled upwards and the base of the tongue forces the epiglottis over the laryngeal opening.

Arytenoid and corniculate cartilages

The pyramid-shaped arytenoid cartilages are connected to the superior lateral border of the *cricoid cartilage*. The small, cone-shaped corniculate cartilages (fig. 2-14a) are attached to the tips of the arytenoid cartilages. These cartilages serve as points of attachment for the muscles that control the tension of the vocal cords.

Cuneiform cartilages

The small, cylindrical cuneiform cartilages (fig. 2-14b) are located in the mucous membrane between the epiglottis and arytenoid cartilages. They stiffen the tissues around the epiglottis. The larynx is supplied with both *intrinsic* and *extrinsic* muscles. The intrinsic muscles are located entirely within the larynx. They control the opening and closing of the glottis during breathing and swallowing, and regulate the tension of vocal cords during speech. The extrinsic muscles have insertion points on the larynx, but originate elsewhere. These muscles move the entire larynx. The extrinsic muscles are also involved in swallowing, breathing, and speech.

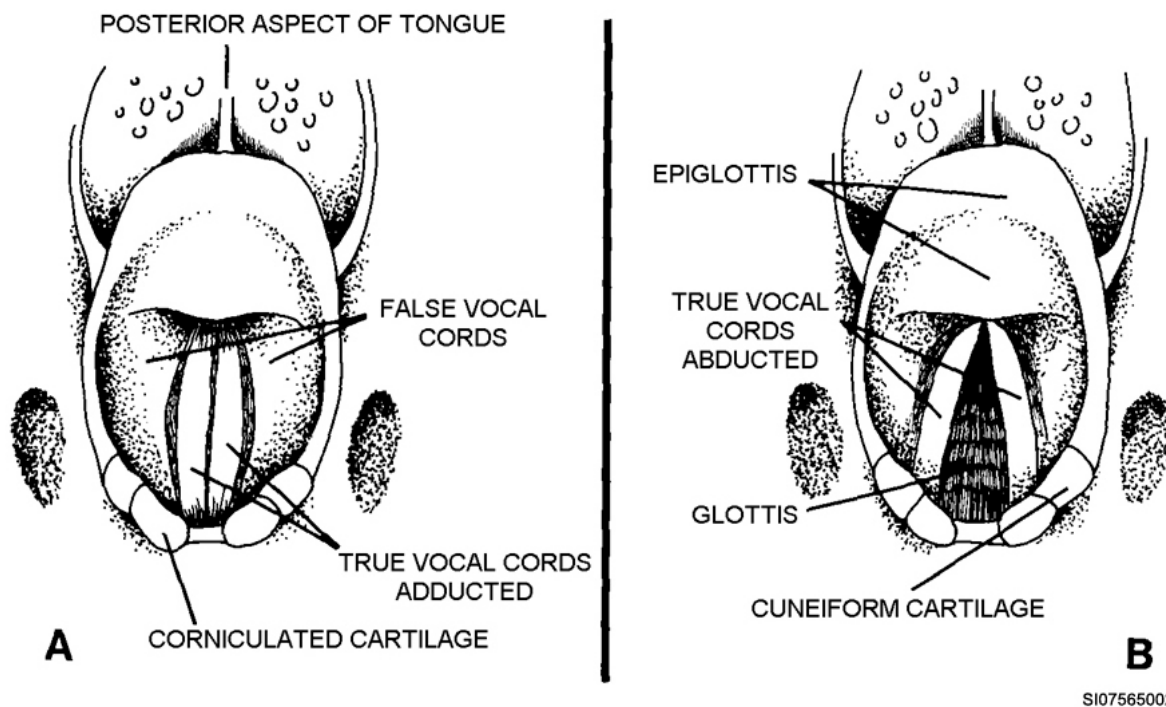


Figure 2-14. Arytenoid, corniculate, and cuneiform cartilages.

Lower respiratory tract

The lower respiratory system (fig. 2-15) is made up of all the respiratory structures that lie within the thorax. These structures include the trachea, bronchi (and branches), lungs, and thorax.

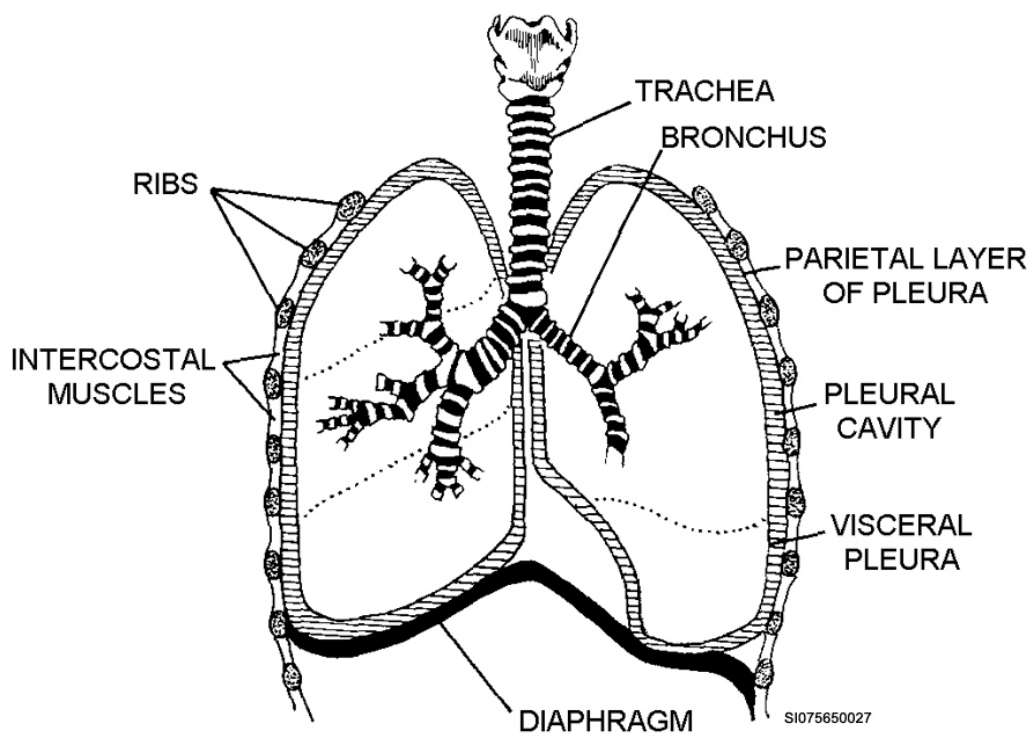


Figure 2-15. Structures in the lower respiratory tract.

Trachea

The trachea is a flexible, tube-like structure about 5 inches in length. It is located anterior to the esophagus between the larynx and the bronchi. The top of the trachea is about level with the sixth thoracic vertebra. The bottom of the trachea comes to the fifth thoracic vertebra. The tracheal wall is made up of four layers.

1. The inner layer is the same pseudostratified ciliated columnar epithelium that makes up the mucous membrane found throughout the respiratory system. This epithelial layer is attached to a basement membrane, which connects the epithelial layer to the underlying submucosa.
2. The second layer, the submucosa, is made up of connective tissue containing numerous glands and fat cells.
3. The third layer is made up of horseshoe-shaped rings of hyaline cartilage. There are about 20 of these rings in the trachea. The open parts are on the posterior aspects of the rings. Also, the open parts are filled with smooth muscle fibers and connective tissue. The rings are connected to each other by dense connective tissue with bands of collagenous and elastic fibers and they maintain the shape of the trachea.
4. The outermost layer of the trachea is called the *adventitia*. The adventitia is made up of a loose connective tissue. It contains the autonomic nerves and blood vessels that supply the trachea.

The trachea has only one function. It is a passageway for the air that is either entering or leaving the lungs.

Bronchi

The next step in the path of oxygen molecules are the bronchi. The bronchi are formed by the division of the terminal end of the trachea, which occurs about the level of the fifth thoracic vertebra. These initial branches are called the *right* and *left primary or main stem bronchi*. The openings to the right and left bronchi are separated by a ridge of cartilage called the *carina*. The right bronchus is larger and follows a more vertical course. Each primary bronchus enters a lung and immediately divides again.

The first branches from the primary bronchi are the secondary or *lobar bronchi*. The lobar bronchi supply the lobes of the lungs. There are three lobar branches on the right side, and two lobar branches on the left. The lobar branches separate again to form the *tertiary or segmental branches*. Each of the segmental branches supplies a lung unit called a *bronchopulmonary segment*. Usually, there are 10 segmental branches in the right lung and eight in the left.

Like the blood vessels, the bronchi continue to divide to form smaller and smaller branches. Very small branches called *bronchioles* supply the basic units of the lung. These basic units are called *lobules*. Within the lobules, the bronchioles divide to form *terminal bronchioles*. There are about 80 of these terminal bronchioles in each lobule. The terminal bronchioles separate again to form two or more *respiratory bronchioles*. Each of the respiratory bronchioles opens into several *alveolar ducts*. The alveolar ducts lead to the *alveolar sacs*. The alveolar sacs are tightly packed outgrowths of the alveolar ducts. The alveolar sacs are made up of clusters of *alveoli* (one cluster per alveolar sac).

The structure of the primary bronchi is very similar to that of the trachea. There are the same four-layered walls and the same incomplete rings of cartilage. About the only noticeable difference is a gradual decrease in the diameter of the bronchi. The bronchi grow smaller and smaller as they continue to branch out. After the bronchi enter the lungs, the rings of cartilage become more complete. Eventually, these rings completely circle the bronchi. As the bronchi continue to get smaller, the amount of cartilage in the bronchial wall decreases. By the time the bronchi reach the bronchiole stage, the cartilage has completely disappeared. As the cartilage decreases, it is replaced with smooth muscle fibers mixed with elastic fibers.

The epithelial layer of the bronchial wall gradually changes and becomes thinner as the bronchi change to bronchioles and grow smaller in size. This change is illustrated by changes in the types of cells that make up this lining. In the bronchi, the epithelial layer is made up of pseudostratified ciliated columnar epithelium. At the bronchiole level, these cells have changed to become simple ciliated columnar epithelium. As the bronchioles continue to grow smaller, the cilia gradually disappear and the cells change to cuboidal epithelium. Alveolar ducts are made up of a single layer of squamous epithelium surrounded by fibrous and elastic tissue. There are also smooth muscle fibers surrounding the openings to the alveolar sacs.

The alveolar walls are special structures made up of three types of cells—epithelial, cuboidal, and macrophages. As we said, the inner lining is made up of simple squamous epithelial cells. Just beneath these cells is a layer of cuboidal epithelial cells. These cuboidal cells secrete a substance called *surfactant*, which is important in maintaining the surface tension of the alveoli (we discuss this later). The third type of alveolar cells is macrophages. These macrophages migrate throughout the alveoli, trapping and destroying foreign particles. Beneath all these cells, is a basal layer of collagenous fibers. The basal layer lies next to a network of reticular and elastic fibers called the *alveolar septa*.

The alveolar septa contain the capillary network that participates in the gas exchange with the alveoli. The branches of the bronchi and bronchioles function together to distribute the air to the alveoli. The alveoli provide a large surface area where the oxygen/carbon dioxide exchange can occur. This exchange occurs by diffusion. Oxygen diffuses into the capillaries and carbon dioxide diffuses into the lungs.

Lungs

The lungs (fig. 2-16) are large, soft, cone-shaped organs located within the thoracic cavity. They are separated medially by the heart and mediastinum. Except for these mediastinal structures, the lungs completely fill the thoracic cavity. They extend from the diaphragm to just above the clavicles. (The part of the lung above the clavicle is called the cupula.)

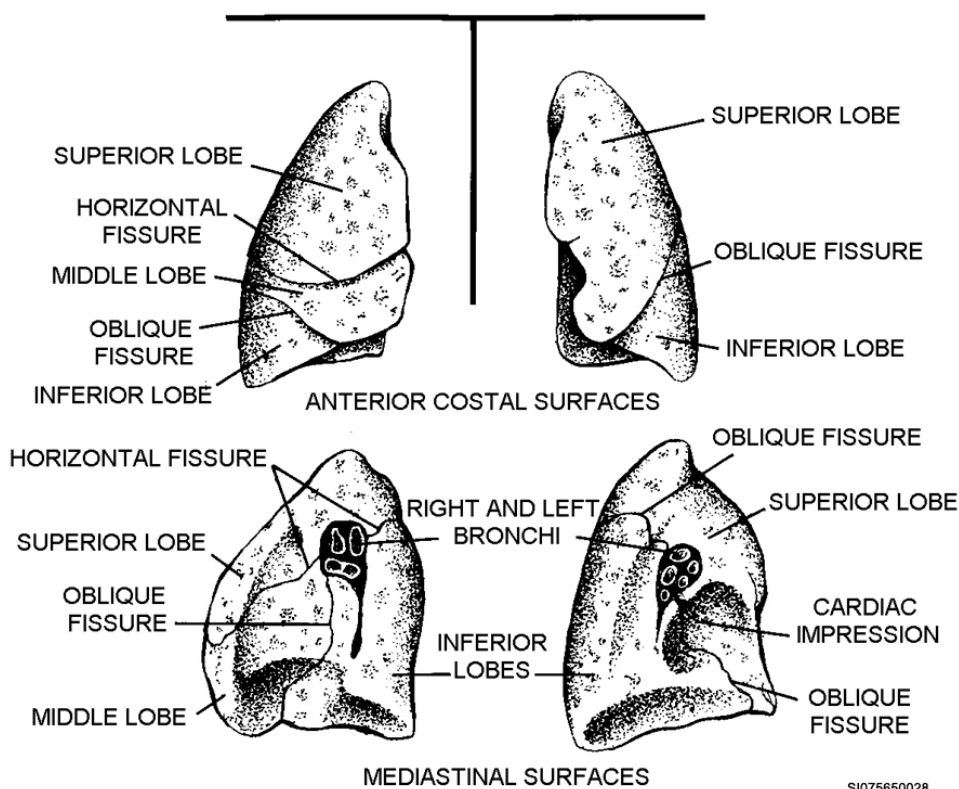


Figure 2-16. Mediastinal surfaces.

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The pointed, upper part of the lungs is the *apex*, and the broad, slightly concave lower surface is the *base*. There is a concave indentation on the medial surface of each lung to allow for the heart and mediastinum. Because most of the heart is positioned on the left side, the concavity is greater on the left. There is also a slit on the medial surface of each lung. This slit is called the *hilum*, and it is the entry point for bronchi and blood vessels into the lungs.

The lung surface where it contacts the ribs is called the *costal surface*. The costal surface is rounded to match the contour of the ribs. Each lung is divided into several lobes by deep grooves called *fissures* (fig. 2-16). The left lung is divided into two lobes—superior and inferior—by an oblique fissure. The right lung is divided into three lobes—superior, middle, and inferior. The inferior lobe is separated from the superior and middle lobes by an oblique fissure. The middle lobe is further separated from the superior lobe by a horizontal fissure.

The interior of the lungs has the appearance of a tree. The large branches, or bronchi, give rise to smaller branches. The smaller branches continue to divide until they eventually end in the smallest branches or alveolar ducts. The alveolar ducts lead to the working units of the lung, the alveoli. The alveoli are coated with a substance called surfactant. Surfactant, a form of lipoprotein, reduces the surface tension inside the lungs, and is necessary to prevent collapse of the lungs during exhalation. In addition to the bronchi, bronchioles, and alveoli, the lungs contain blood vessels, nerves, connective tissues, and lymphatic tissues. The internal surface area of the lungs is tremendous. Normal body requirements are about 1 square meter of lung surface per kilogram of body weight. Translated to pounds and feet, if you weigh around 150 pounds, you need about 732 square feet of lung surface!

The outer surface of the lungs is covered by a thin, serous membrane called the *visceral pleura*. Like the visceral pericardium, the visceral pleura folds back on itself at the hilum. It then forms a second layer around the lungs, called the *parietal pleura*. The parietal pleuron is firmly attached to the walls of the thoracic cavity and the mediastinum. Between the two pleura, there is a potential space called the *pleural cavity*. There is a thin layer of serous fluid. This fluid lubricates the pleural surfaces as they move against each other during the breathing process. The fluid also helps to hold the pleural surfaces together.

Thorax

The thorax, or thoracic cavity, is located in the upper part of the chest. It is actually divided into three separate spaces.

On either side, there is a pleural space, which is occupied by a lung. The *mediastinum* occupies the center of the thoracic cavity. It contains the heart, large blood vessels, thymus, vagus nerve, trachea, and esophagus. The thoracic cavity is bounded by the sternum, ribs, and vertebral column (anteriorly, laterally, and posteriorly), by the diaphragm (inferiorly), and by the thoracic inlet (superiorly). The inner surface of the thoracic cavity is lined with a serous membrane called the parietal pleura.

The thoracic cavity plays an integral role in the breathing process. The expansion and contraction of the thoracic cavity allows inhalation and exhalation to take place. There are many different factors involved in this process that we call “respiration.” Somehow the air must be induced to come into the lungs. Just getting the air into the lungs involves the central nervous system, a number of muscles, and every organ in the respiratory system itself. After the air is in the lungs, it must somehow be separated. Oxygen is then loaded into the bloodstream and, at the same time, carbon dioxide is removed. This process involves another system (the circulatory system) as well as several cellular processes. These are only the first two steps of the respiratory process, but you should begin to see just how complex it really is.

You should have a fairly good idea of what the respiratory organs are and how they function individually. In the next lesson, you learn how all these components work smoothly together to produce breathing. Since there is only limited voluntary control over respiration, you learn how breathing is initiated and maintained.

213. Understanding respiration

Even though most of us take breathing for granted it is important for you to understand what the process of ventilation is and how it works.

Pulmonary ventilation

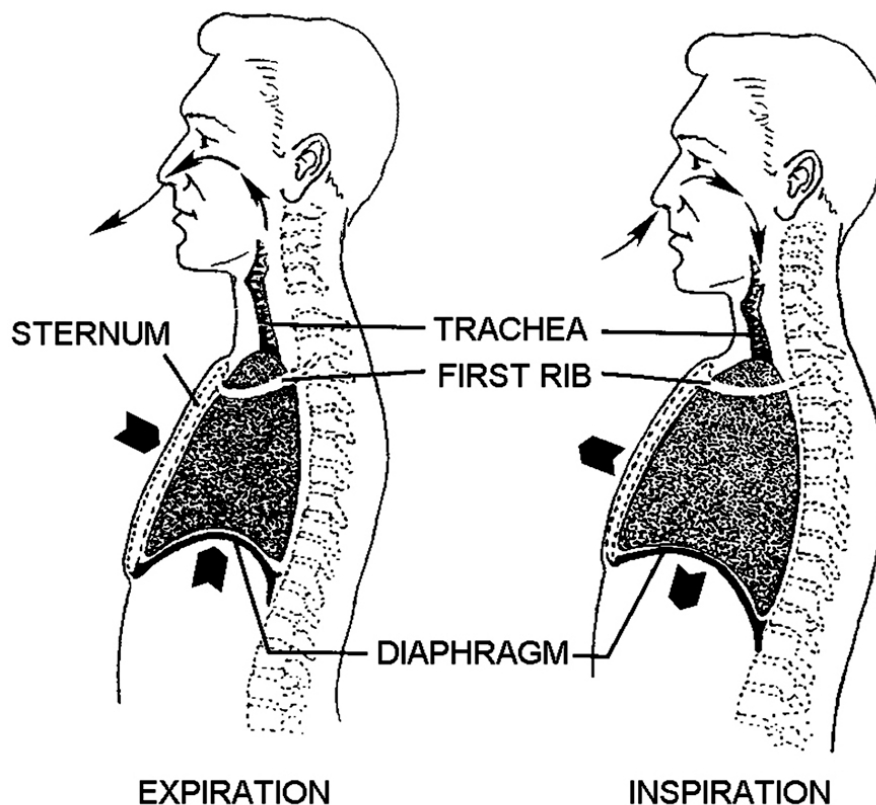
Pulmonary ventilation is commonly referred to as “breathing.” Breathing involves the movement of air into the lungs, or inspiration (inhalation), and the movement of air out of the lungs, or expiration (exhalation). These movements include changes in the thoracic cavity with corresponding changes in the respiratory organs.

Inspiration

A number of factors are involved in inspiration:

1. The pressure exerted by the weight of air.
2. The muscular activity of the diaphragm and the external intercostals.
3. The surface tension between the visceral and parietal pleura.

The force that causes air to move into the lungs is atmospheric pressure. Atmospheric pressure is a fairly constant force exerted on all surfaces by the weight of the air. Because the lungs are in contact with air, this force is also exerted on them. Before and after a respiration, the atmospheric pressure and the pressure in the lungs and alveoli (intra-alveolar pressure) are the same. If something causes the intra-alveolar pressure to decrease, the atmospheric pressure forces air into the lungs. If the intra-alveolar pressure increases, air is forced out of the lungs. Inspiration begins when the respiratory muscles are stimulated to contract. When the diaphragm contracts, it pulls downward (fig. 2-17). As a result, the thoracic cavity vertically increases in size. The external intercostal muscles also contract, raising the ribs and sternum. This action increases the size of the thoracic cavity horizontally.



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Figure 2-17. Movement of the diaphragm and chest cavity during respiration.

Earlier we described the pleural membrane that surrounds the lungs. As you know, there is a visceral and a parietal pleura separated by a potential space. The word “potential” is very important here. There is no actual space between the visceral and parietal pleura. The two membranes are separated only by the serous fluid. The molecules of this fluid have a high degree of attachment for each other. This creates a high degree of surface tension between the two membranes. In addition to the surface tension, there is also a negative pressure in the intrapleural space. This means that the pressure between the visceral and parietal pleura is less than the atmospheric pressure. The negative pressure creates a vacuum-type effect which increases the attraction of the two membranes. The attraction between the visceral and parietal pleura is strongest when the thoracic cavity enlarges. There is a slight increase in the negative intrapleural pressure as the parietal pleura tries to pull away from the visceral pleura. The combined force of the increased negative pressure plus the surface tension between the pleural membranes is stronger than the resistance of the lung membranes. These membranes stretch and the visceral pleura follow the parietal pleura outward. This increases the size of the lungs and reduces the intra-alveolar pressure. The atmospheric pressure then causes the air to rush into the lungs. At the end of the inspiration the lungs are expanded and the atmospheric and intra-alveolar pressures are the same once more.

Expiration

Expiration is essentially the reverse of inspiration. The respiratory muscles relax, and the thoracic cavity decreases in size (fig. 2-17). The lungs are returned to their original size by the combined forces of elastic recoil and surface tension. Both the lungs and thoracic walls contain a number of elastic fibers. During inspiration, these fibers are stretched. Once inspiration is over, these fibers spring back to their original position. This elastic recoil increases the intra-alveolar pressure and forces the air out of the lungs.

There is a certain amount of surface tension present in the alveoli. As we discussed earlier, this surface tension is reduced by the surfactant secreted by the alveolar cells. There is, however, enough surface tension to cause the alveoli to decrease in diameter after the inspiration. This also increases the intra-alveolar pressure and helps to force air out of the lungs.

In addition to the action of the elastic fibers and alveolar surface tension, expiration is aided by the contraction of the internal intercostal muscles and the abdominal muscles. The external intercostal and abdominal muscles come into play more during strenuous physical exertion that requires larger volumes of air to be exhaled during each respiratory cycle. The contraction of the internal intercostal muscles pulls the ribs and sternum down and inward. This decreases the size of the thoracic cavity and puts additional pressure on the lungs. The muscles of the anterior abdominal wall contract and put more pressure on the internal abdominal organs. The resulting increase in intra-abdominal pressure causes more upward pressure on the diaphragm which, in turn, squeezes more air out of the lungs.

As we have said, the attraction between the pleural membranes is a major factor in the breathing process. If anything disturbs these membranes, the lungs are not able to expand normally. As an example, follow what happens when a patient suffers a puncture of the chest wall. In this event, the pleura are exposed to atmospheric pressure, eliminating the negative intrapleural pressure. In addition, air gets into the pleural space and disturbs the surface tension between the membranes. The thoracic cavity still expands and contracts, but there is not enough attraction between the pleural membranes to overcome the resistance of the lungs. In this case the lungs do not expand and breathing does not take place. In fact, the increased pressure on the surface of the lungs plus the elastic recoil and intra-alveolar surface tension causes the lung to collapse. This condition, where there is air in the intrapleural space, is called *pneumothorax*. If there is blood in the intrapleural space, the condition is referred to as a *hemothorax*.

External respiration

Two gas exchanges occur in the body. The first exchange occurs in the lungs and is called external respiration. Using the mechanism that we just discussed, oxygen diffuses into the blood and carbon

dioxide diffuses into the alveoli of the lungs. The rate of this diffusion depends on a number of factors:

1. The pressure gradient between the alveolar PO_2 (partial pressure of oxygen dissolved in the blood) and the venous PO_2 .
2. The total functional surface area of the alveolar-capillary membrane (this functional area varies with the type of breathing and presence of diseases in the lungs).
3. The minute respiratory volume (the amount of new air that is moved into the lungs each minute).
4. The alveolar ventilation rate.

Oxygen that enters the blood stream is transported in one of two ways—either as a solute in a solution of blood, or as part of a molecule in a chemical compound. Because the plasma can only hold a small amount of oxygen in solution, most of the oxygen combines with the molecules of hemoglobin found in the erythrocytes (discussed earlier). The result of this combination is a new molecule called oxyhemoglobin. The PO_2 level in the blood controls the amount of bonding that occurs between the hemoglobin and the oxygen. If the PO_2 is high, more bonding takes place. If the PO_2 is low, less bonding takes place.

The amount of bonding that does take place is referred to as the *saturation level*. Each hemoglobin molecule is capable of binding to four oxygen molecules, or each gram of hemoglobin is capable of combining with 1.34 milliliters (ml) of oxygen. There are 15 grams of hemoglobin per 100 ml of blood. As an example, a totally saturated 100 ml of blood contains about 20 ml of oxygen ($1.34 \times 15 = 20.1$). The chemical bonds that form between the oxygen and the hemoglobin are relatively unstable. As the PO_2 decreases, or as the PO_2 increases, the bonds weaken.

Another factor that affects the amount of oxygen that diffuses is the amount of carbon dioxide in the blood. As the blood PCO_2 (partial pressure of carbon dioxide dissolved in the blood) decreases, more bonding takes place. The chemical bonds that are formed are formed very quickly. This is fortunate because the blood is not in the lungs very long. Even so, by the time that the blood leaves the lungs, it normally has about a 97 percent oxygen saturation level. Carbon dioxide is not carried in the blood in the same manner as oxygen. Only a small amount of carbon dioxide is carried as a solute in the blood. (However, this amount does account for the percentage PCO_2 of the blood.) About 70 percent of the carbon dioxide found in the blood is carried as bicarbonate ions. The remainder of the carbon dioxide combines with protein compounds and is carried as carbamino compounds in the erythrocytes. (If the hemoglobin molecule combines with the carbon dioxide, the new molecule is called carbaminohemoglobin.) The amount of these bonds that are formed depends on the PCO_2 and PO_2 levels. An increase in the PCO_2 level also increases the number of bonds that are formed. A decrease in the PO_2 has the same effect. Reversal of these conditions (the case in the lungs) has the opposite effect.

Internal respiration

Internal respiration takes place between the circulating blood and the cells themselves. The pressure gradients are now going in the opposite direction. The arterial PO_2 is about 100 mm Hg. The interstitial PO_2 is lower still. These PO_2 levels decrease even further when there is any type of cellular activity that uses up oxygen. Any such increase in the pressure gradient speeds up diffusion of the oxygen out of the blood. By the time the blood completes the trip through the capillaries and is in the veins, both the oxygen saturation and the PO_2 have decreased. The oxygen saturation is now about 75 percent and the PO_2 is about 37 millimeters (mm) Mercury (Hg). Because carbon dioxide is one of the byproducts of cellular metabolism (catabolism), large amounts of carbon dioxide are present in the cells. (This amount increases with increased cellular activity.) As a result of the pressure gradient, carbon dioxide diffuses from the cells into the bloodstream. The PCO_2 of the blood increases from about 40 mm Hg to about 46 mm Hg. Changes in the PO_2 and PCO_2 levels produce two effects. The

rate that the oxygen separates from the hemoglobin molecules increases and the rate that carbaminohemoglobin molecules are formed also increases.

The cycles that we have described here occur continuously. The only changes are slight increases or decreases to accommodate the body's need for more or less oxygen. The ability of the body to detect oxygen and carbon dioxide levels and take appropriate action is part of the body's respiratory control system.

Control mechanisms

The respiratory system is subject to control by both the voluntary and involuntary nervous systems. Since the diaphragm and intercostals are skeletal muscles, they are subject to some degree of voluntary control. However, normal breathing is an unconscious, involuntary action. Also, the involuntary system overrides voluntary controls if the respiratory system is compromised. (You might be able to voluntarily hold your breath until you "pass out," but the involuntary controls will take over and start you breathing again after you lose consciousness.)

Involuntary control mechanism

The involuntary control mechanism is located in an area of the medulla oblongata and the pons of the brain stem. Together these areas are called the *respiratory center*. There are two areas in the pons—the *pneumotaxic center* and the *apneustic center*. The area in the midbrain is called the *rhythmicity area*. In addition to these, a number of sensory receptors in the lungs called stretch receptors (pressoreceptors) are involved in the involuntary control mechanism. The participation of these receptors is also known as the Hering-Breuer reflex.

The respiratory center is probably the most important factor in respiratory control. If it is destroyed, respirations stop completely. The respiratory center is responsible for establishing the basic rhythm of breathing, but the actual smooth breathing pattern is a coordinated effort between the respiratory center and impulses from the apneustic and pneumotaxic areas.

The respiratory center is made up of *inspiratory* and *expiratory centers*. When some of the neurons in the inspiratory center are stimulated, they send out impulses to the other neurons in the center. This continues in what is called a self-perpetuating circuit. The impulses travel over and over through the circuit until the neurons become fatigued (usually around two seconds). At the same time, the impulses are traveling out to the inspiratory muscles (the diaphragm and external intercostals). These muscles contract and cause inspiration of air into the lungs. The impulses are also going out to the expiratory center. These impulses inhibit the action of the expiratory center. When the inspiratory center becomes fatigued, it stops sending inhibitory impulses to the expiratory center. The expiratory neurons are then stimulated and follow the same type of self-perpetuating circuit. Impulses are sent out to the expiratory muscles and also to the inspiratory center. There, impulses cause the expiratory muscles to contract and inhibit the action of the inspiratory center. This continues until the expiratory neurons become fatigued (usually around three seconds). Then the cycle starts again with the inspiratory center.

The respiratory action we just described is slightly oversimplified. There are many factors that modify the basic breathing pattern. For example, if the apneustic center is stimulated, it produces long, forceful inspirations and weak expirations. The pneumotaxic center inhibits the apneustic center and also changes the normal breathing rate.

In addition to the apneustic and pneumotaxic centers, the *Hering-Breuer vagal reflex* plays a major role in establishing the breathing pattern. The stretch receptors (baroreceptors) in the visceral pleura, bronchioles, and alveoli become stimulated during an inspiration. These stretch receptors then send sensory impulses to the respiratory center by way of the vagus nerves. These impulses inhibit the action of the inspiratory center and the inspiratory muscles relax. Expiration (expiratory reflex) follows the relaxation of the inspiratory muscles. This reflex action prevents over-inflation of the lungs. Once the lungs have deflated to a certain point, the stretch receptors become inhibited and stop

sending impulses to the inspiratory center. This causes the inspiratory center to once more send impulses that cause inspiration (inspiratory reflex).

The pneumotaxic center also plays a role in the Hering-Breuer reflexes. When the inspiratory center becomes stimulated, it sends impulses to the pneumotaxic center as well as to the inspiratory center. After a short delay, the pneumotaxic center stimulates the expiratory center which sends inhibitory impulses to the inspiratory center. The inspiratory impulses stop and the expiratory impulses begin. When the lung deflation triggers the Hering-Breuer inspiratory reflex, inspiration begins again. The pneumotaxic center and the Hering-Breuer reflex work together to produce a rhythmical breathing pattern.

Voluntary control mechanism

As we said, there is some degree of voluntary control over the respiratory muscles. The impulses that provide this control are initiated from the cerebral cortex of the brain. These impulses allow you to stop, start, slow down, or speed up breathing. The degree of voluntary control is limited. For example, if you are trying to hold your breath, you begin to build up the PCO_2 of the blood. When chemoreceptors sense this increase in carbon dioxide, they stimulate the inspiratory center and breathing takes place.

Chemical control factors

The mechanisms we just discussed play key roles in establishing and regulating the normal respiratory rhythm. However, these mechanisms are not capable of adjusting respirations to meet the changing needs of the body. That sort of control is exercised by the responses of different chemically sensitive receptors to certain chemicals within the blood. The chemicals that are involved in this control are the PCO_2 and PO_2 of arterial blood, and the pH of the blood. You already know about PCO_2 and PO_2 . The pH refers to the acidity or alkalinity of the blood. The body tries to maintain a stable level (homeostasis) of these chemicals.

The pH of the blood is directly related to the PCO_2 level. In fact, carbon dioxide (CO_2) combines with water or spinal fluid in the blood to produce *carbonic acid* (H_2CO_3). This carbonic acid ionizes (i.e., becomes electrically charged) and releases hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). The bicarbonate ions carry most of the carbon dioxide in the blood plasma. The hydrogen ions act together with the PCO_2 to produce breathing changes.

Sensory receptors are centrally located in the medulla oblongata, and peripherally located in the carotid and aortic bodies. Of the two, the centrally located receptors have a much stronger and more direct effect. These receptors detect changes in the PCO_2 and the hydrogen ion concentration of the blood. When the PCO_2 or the H^+ concentrations in the blood increase, the blood becomes more acidic and both the peripheral and the central chemoreceptors are stimulated. This results in faster and deeper breathing until the levels drop again. A decrease in the PCO_2 and H^+ concentrations has the opposite effect—the blood becomes more alkaline or basic and breathing slows and becomes more shallow.

Changes in the PO_2 levels normally play a minor role in the control of respiration. When the PO_2 drops below a certain level, the peripheral carotid and aortic bodies are stimulated and the breathing rate is increased. This is sort of an emergency mechanism because the PO_2 rarely drops below the critical level necessary to stimulate the peripheral chemoreceptors. A secondary effect from a decrease in the PO_2 level is a decrease in the effectiveness of the neurons in the respiratory center.

These neurons cannot respond properly to the changes in the PCO_2 and H^+ concentrations if they themselves are not receiving adequate oxygenation. In cases of certain disease processes, it is possible for the PO_2 to assume primary control over the respiratory process. Patients, who have chronic obstructive pulmonary diseases (COPD), such as emphysema, routinely have very high PCO_2 levels. Their bodies adapt to these high levels, and the low PO_2 becomes the primary control mechanism.

Miscellaneous control factors

The mechanisms we have discussed are the primary control mechanisms in establishing and regulating breathing. A number of other factors also cause temporary changes in the breathing patterns: arterial blood pressure, skin thermal receptors, superficial and deep pain receptors, the choking reflex, emotions, and changes produced by exercise.

Factors	Changes
Arterial blood pressure	Causes reflex changes in the respiratory control mechanism. A sudden increase in the arterial blood pressure acts on the aortic and carotid baroreceptors to produce a reflex slowing of respirations. A sudden drop in blood pressure produces an increase in the rate and depth of respirations.
Skin thermal receptors	Sudden cold stimuli applied to the skin (<i>thermal receptors</i>) cause a temporary halt in respirations (apnea).
Superficial and deep pain receptors	Sudden painful stimulation produces a reflex apnea (i.e., opposite effects as sudden cold stimuli). Continued painful stimulation produces rapid, deep respirations.
Choking reflex	Is produced by stimulation of either the pharynx or the larynx by chemicals or by touch. This stimulation results in a temporary apnea. It is a protective device designed to prevent aspiration of food or fluids while swallowing.
Emotions	Known to produce changes in breathing patterns. Sudden emotions may produce a temporary apnea. Prolonged emotions, such as fear or excitement, produce rapid respirations, similar to those produced by pain.
Exercise	When you exercise, your breathing becomes faster and deeper. Part of this change is due to the increase in the PCO_2 and H^+ levels as the cells metabolize faster. The respiratory changes are also attributed to the cerebral cortex and proprioceptors (sensory receptors) associated with the joints. The cerebral cortex is thought to stimulate the respiratory center at the same time that it stimulates the skeletal muscles. The proprioceptors are stimulated when the muscles start moving. Both proprioceptors and cerebral cortex stimulation cause increases in the respiratory rate.

After studying the foregoing material, you should better understand the “pieces and parts” within the respiratory and circulatory system that your surgeons operate on, and more fully appreciate why the surgeons and anesthetists pay such close attention to the status of these two systems.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

212. Respiratory structures and their functions

1. What are the organs of the upper respiratory system?
2. What are the external openings of the nose called?
3. What is the function of the cribriform plate?
4. The superior and middle nasal conchae are part of what bone?

5. Briefly describe how air is filtered as it passes through the nose.
6. What is the primary function of the sinuses?
7. Describe the location of the pharynx.
8. What connects the oropharynx with the mouth?
9. What are the functions of the larynx?
10. What is the largest of the laryngeal cartilages?
11. What are the three chambers within the larynx?
12. What are the two types of muscles found in the larynx?
13. What is the function of the rings of cartilage in the trachea?
14. What is the carina?
15. What are lobules?
16. What is the purpose of surfactant?
17. What is the entry point for bronchi and blood vessels into the lungs?
18. What is visceral pleura?

19. What structure occupies the center of the thoracic cavity?
20. The expansion and contraction of the thoracic cavity allows what to take place?

213. Understanding respiration

1. Pulmonary ventilation is commonly referred to as what?
2. What is the force that causes air to move into the lungs?
3. When does inspiration begin?
4. Expiration is aided by the contraction of what muscles?
5. What is a pneumothorax?
6. Where does the first exchange of gases in the body take place and what is it called?
7. What controls the amount of bonding that occurs between the hemoglobin and the oxygen?
8. What is carbamino hemoglobin?
9. Where does internal respiration take place?
10. What parts of the brain provide involuntary control?
11. What centers make up the respiratory center?
12. Name three things that play a major role in establishing breathing patterns.

13. Where are the impulses that provide voluntary control initiated?
14. What chemicals are involved in controlling the respiratory system?
15. List the six miscellaneous factors that can cause temporary changes in breathing patterns.

Answers to Self-Test Questions

207

1. Red (erythrocytes), white (leukocytes), and platelets (thrombocytes).
2. Nongranular leukocytes.
3. Internal respiration.
4. Hemoglobin.
5. Neutrophils.
6. Monocytes and lymphocytes.
7. Leukopenia.
8. Giant cells.
9. Agglutination.
10. Blood clot or thrombus.
11. Serum.
12. Hemophilia.
13. Heparin.
14. They prevent the formation of spontaneous clots that could result in tissue damage or death.
15. (1) Inorganic salts, (2) carbohydrates, (3) lipids, (4) amino acids, (5) hormones, (6) vitamins, (7) blood gases, (8) water, and (9) proteins.
16. The liver.
17. Plasma nutrients.
18. Oxygen and carbon dioxide.
19. Protein breakdown.
20. Sodium and chloride.
21. A, B, and Rh.
22. AB.
23. Erythroblastosis fetalis.

208

1. Between the lungs and above the diaphragm, in the mid-section (mediastinum) of the thoracic cavity.
2. Syncytiums.
3. Provide protection from friction during normal heart movements.
4. Lower left chamber (left ventricle).
5. Purkinje fibers.
6. Atrioventricular or coronary sulcus.
7. Superior vena cava, inferior vena cava, and coronary sinus.
8. Chordae tendineae.

9. To receive the deoxygenated blood from the right atrium and pump that blood to the lungs.
10. Pulmonary veins; four.
11. Left ventricle.
12. Myocardial infarction.
13. Arterioluminal, arteriosinusoidal, and thebesian vessels.
14. Between 70 to 80 impulses per minute.
15. On the floor of the right atrium near the interatrial septum.
16. Large cardiac fibers that conduct impulses from the atrioventricular (AV) node to the right and left bundle branches.
17. Purkinje fibers.
18. Ectopic impulses.
19. Diastole.

209

1. Arteries, veins, and capillaries.
2. Tunica media.
3. Arterioles.
4. By muscle bands called precapillary sphincters.
5. Microscopic branches of veins.

210

1. Pulmonary trunk.
2. It passes through the diaphragm.
3. Brachiocephalic, left common carotid, and left subclavian artery.
4. Collateral circulation.
5. Gonadal arteries.
6. The internal and external iliac arteries.
7. Inferior epigastric and deep circumflex.
8. The profunda femoris artery.
9. Dorsalis pedis.
10. At the base of the brain.
11. Internal carotid arteries.
12. Maxillary and superficial temporal arteries.
13. Medial ulnar and lateral radial artery.
14. Brachiocephalic vein.
15. Radial, ulnar, brachial, and axillary veins.
16. Posterior intercostal, superior and inferior hemiazygos, and right and left ascending lumbar veins.
17. Portal vein.
18. Inferior vena cava.
19. Great saphenous vein.
20. Internal iliac vein.

211

1. Lymph, lymph capillaries, lymph vessels, lymphatic trunks, thoracic duct, and right lymphatic duct.
2. Lymph.
3. Lymphatic capillaries located around the intestinal tract.
4. Nodules.
5. Around tissues of the central nervous system.
6. Axillary region.

7. Inflammation of a lymph vessel.
8. Intercostal and bronchomediastinal trunks.
9. Thoracic and right lymphatic duct.
10. Tonsils, spleen, and thymus.
11. Nasopharyngeal tonsils.
12. Lymphocytes that form a sheath around the arterioles in the spleen.
13. Reticuloendothelial system in the spleen.
14. Precursor cells from the bone marrow.
15. Defend the body against disease.

212

1. Nose, pharynx, and larynx.
2. Nares.
3. Separates the nasal cavity from the cranial cavity.
4. Ethmoid bone.
5. The initial filtering is done by hairs in the vestibule. Additional filtering takes place when the air passes through the meatuses. Fine particles are trapped by sticky mucous on the mucous membrane. Later these particles are swallowed and destroyed through the action of digestive enzymes.
6. Reduce the weight of the face and skull.
7. Anterior to the cervical vertebrae, between the nasal cavity and the larynx.
8. Isthmus of the fauces.
9. Passageway for air and to prevent the entrance of foreign particles into the trachea.
10. Thyroid.
11. Vestibule, ventricle, and infraglottic.
12. Intrinsic and extrinsic.
13. Maintain the shape of the trachea.
14. Ridge of cartilage that separates the openings to the right and left bronchi.
15. Basic units of the lung.
16. It reduces the surface tension of the alveoli inside the lungs.
17. The hilum.
18. Thin, serous membrane that covers the outer surface of the lungs.
19. The mediastinum.
20. Inhalation and exhalation.

213

1. Breathing.
2. Atmospheric pressure.
3. When the respiratory muscles are stimulated to contract.
4. Internal intercostal muscles and the abdominal muscles.
5. Air in the intrapleural space.
6. In the lungs; external respiration.
7. The PO_2 level in the blood.
8. A new molecule formed when the hemoglobin molecule combines with carbon dioxide.
9. Between the circulating blood and the cells themselves.
10. The medulla oblongata and the pons of the brain stem.
11. The inspiratory and expiratory center.
12. The apneustic and pneumotaxic centers and the Hering-Breuer vagal reflex.
13. The cerebral cortex of the brain.

14. PCO_2 and PO_2 of arterial blood and the pH of the blood.
15. (1) Arterial blood pressure, (2) thermal receptors, (3) pain receptors, (4) choking reflex, (5) emotions, and (6) changes produced by exercise.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to a field scoring answer sheet.

Do not return your answer sheet to AFCDA.

11. (207) Which type of blood cells *primarily* fight infection?
 - a. Platelets.
 - b. Leukocytes.
 - c. Erythrocytes.
 - d. Thrombocytes.
12. (207) Which type of blood cells *primarily* aid in hemostasis and blood clotting?
 - a. Monocytes.
 - b. Erythrocytes.
 - c. Lymphocytes.
 - d. Thrombocytes.
13. (207) Patients with which blood type are considered *universal recipients*?
 - a. Type O.
 - b. Type A.
 - c. Type B.
 - d. Type AB.
14. (208) The *apex*, or bottom of the heart, is positioned in the mediastinum beneath the
 - a. sternum on the left side of the body.
 - b. sternum on the right side of the body.
 - c. second rib on the left side of the body.
 - d. second rib on the right side of the body.
15. (208) Venous blood returning from the body to the heart flows to which chamber of the heart?
 - a. Left atrium.
 - b. Right atrium.
 - c. Left ventricle.
 - d. Right ventricle.
16. (208) The major vessels that supply the heart with oxygenated blood are the
 - a. coronary veins.
 - b. coronary arteries.
 - c. pulmonary veins.
 - d. pulmonary arteries.
17. (208) The *basic* function of the heart is to
 - a. filter blood.
 - b. pump blood.
 - c. detoxify blood.
 - d. oxygenate blood.

18. (209) The vessels that carry blood away from the heart are called
- veins.
 - venules.
 - arteries.
 - capillaries.
19. (210) The *only* arteries in the body that carry *deoxygenated* blood are the
- uterine arteries.
 - hepatic arteries.
 - coronary arteries.
 - pulmonary arteries.
20. (210) Aortic bodies contain chemoreceptors that detect changes in
- the rate of blood flow to the liver.
 - the amount of pressure that is within the artery.
 - oxygen and carbon dioxide concentrations of the blood.
 - oxygen and nutrients within the epithelial layer of the artery
21. (210) The veins that drain the head, neck, and skull, and correspond to the common carotid arteries are
- jugular veins.
 - pulmonary veins.
 - subclavian veins.
 - brachiocephalic veins.
22. (210) Unlike all other veins that take blood to the heart, the veins that drain the abdominal organs unite to form the *portal vein*, which takes the blood to the
- brain.
 - liver.
 - lungs.
 - stomach.
23. (211) Blockage of the lymphatic capillaries would result in
- fat cells entering the thymus.
 - nutrients not entering the gallbladder.
 - the tonsil becoming inflamed and swollen.
 - lymph fluid not being able to enter the lymphatic system.
24. (211) Except for the right upper quadrant, lymph from the entire body is collected by the
- jugular trunk.
 - lumbar trunk.
 - thoracic duct.
 - right lymphatic duct.
25. (211) The *main* function of the lymphatic system is
- restoring fluid to blood circulation.
 - defending the body against disease.
 - absorbing lipids from the intestinal tract.
 - maintaining osmotic pressures of tissue fluid and the blood.

26. (212) Which upper respiratory structure is commonly referred to as the voice box?

- a. Larynx.
- b. Pharynx.
- c. Bronchus.
- d. Epiglottis.

27. (212) The trachea and the lungs are connected by the

- a. larynx.
- b. pharynx.
- c. bronchi.
- d. epiglottis.

28. (212) The lungs are divided into

- a. two lobes on the right, three on the left.
- b. two lobes on the left, three on the right.
- c. three lobes on the right, four on the left.
- d. three lobes on the left, four on the right.

29. (213) Which type of gas exchange takes place in the lungs?

- a. Internal expiration.
- b. External expiration.
- c. Internal respiration.
- d. External respiration.

Unit 3. The Digestive and Endocrine Systems

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WHEN you look at the surgical schedule on any given day, you most likely see procedures listed that involve some area of the digestive system. This system is extensive, and involves so many structures that it has many parts that may need surgical attention. When you count surgical procedures at the end of the month, you probably find that the majority involve digestive structures, particularly those procedures performed by your general surgeons. This unit looks at the composition and function of the digestive system and also covers the anatomy and physiology of the closely related endocrine system. We discuss them together because the organs of the two systems are generally situated very close together in the body, and because operations involving both systems are most often performed by general surgeons.

3–1. The Digestive System

In this unit we discuss how something you eat—like a hamburger—changes from food on the table to chemical compounds that your body can use to sustain life. Obviously, we cannot just take a food item and place it where we want in our bodies. Just about everything we eat must be processed and converted before it can be used. Processing and conversion are the functions of the digestive system. Think of the digestive system as a factory with a conveyor belt running through the middle. As the food (raw material) is carried through the factory (system), it is altered until there is a final product that can be used by the body, and some waste products that must be eliminated.

214. Digestive system and alimentary canal

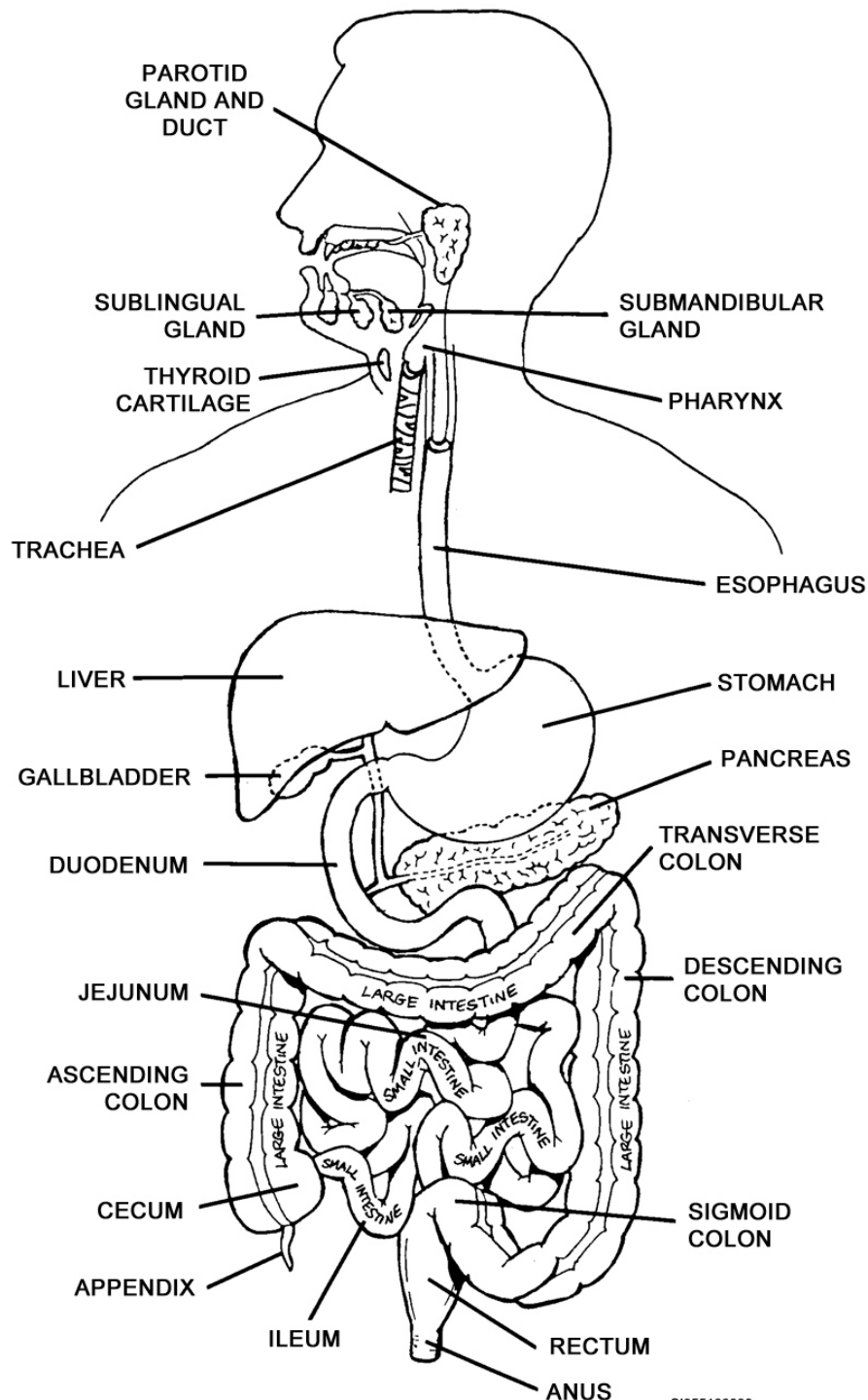
The digestive system consists of all the organs and related structures that are involved in the intake, breakdown, movement, and absorption or elimination of foods by the body. Intake, breakdown, and movement are all part of the process called digestion. *Digestion* involves both a physical and chemical breakdown of foods. Physical breakdown is achieved in two stages: first, by the mechanical actions of chewing, swallowing, mixing, and peristalsis; and second, by the chemical action of various enzymes and digestive juices. After digestion comes absorption. *Absorption* is just what the term implies. Food is absorbed through the wall of the alimentary canal into the blood stream, and then transported to where it can be used by the body. *Elimination* involves the removal of undigested foods and waste products through the anus. We begin our discussion of these topics by describing the general anatomy of the digestive system.

Digestive system

As you see in figure 3–1, the digestive tract (system) is essentially a long, muscular tube that extends from the mouth to the anus. This tube, or tract, is called the *alimentary canal*, and its components make up the major organs of digestion. There are also a few associated structures that are not part of the canal itself, but do connect or feed into it. These structures are called *accessory organs of digestion*. Most of the digestive system is located within the abdominal cavity, between the pelvis and

the diaphragm. The remaining structures (mouth, pharynx, and esophagus) are located in the head, neck, and posterior thoracic cavity.

The abdominal cavity is lined with a serous membrane called the peritoneum. The peritoneum secretes a small amount of serous fluid that lubricates the organs and allows them to move against each other without friction. Specialized folds of the peritoneum, called the *mesentery* (discussed later), provide attachment, support, nourishment, and insulation for some of the digestive organs. We begin by looking at the general structure of the wall of the alimentary canal.



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Figure 3-1. Components of the digestive system.

Alimentary canal

The alimentary canal is a muscular tube approximately 30 feet long. It includes the mouth, pharynx, esophagus, stomach, small intestine, large intestine, rectum, and anus. Although each of these structures has a different shape and function, most structures in the “food tube” are very similar with regard to the construction of the canal walls.

The wall of the alimentary canal consists of four separate layers; each specialized for a particular function.

Layer	Description/Location	Function
Mucosa or mucous membrane	Is the innermost layer. It, too, is made up of layers. The surface layer of the mucosa consists of glandular epithelial tissue. It is connected by a basement membrane to a layer of connective tissue called the <i>lamina propria</i> . Beneath the lamina propria, there is a thin layer of smooth muscle tissue called the <i>muscularis mucosae</i> . In some areas, the mucosa is arranged in folds (and/or little projections) for increased absorption. The epithelial glands located in the mucosa along the alimentary canal secrete either mucus or digestive enzymes.	The mucous membrane functions are protection, secretion, and absorption.
Submucosa	Consists of areolar connective tissue, blood vessels, lymphatic vessels, and nerves (Meissner's plexus). The blood vessels found in the submucosa provide nourishment to tissues that form the alimentary canal wall and transport absorbed nutrients to other areas of the body.	The submucosal functions are nutrition and transportation.
Muscularis externa	It consists of two layers of smooth muscle tissue with a network, or plexus of nerves in the middle. The inner muscle layer is arranged in a circular pattern around the canal. When this layer contracts the diameter of the canal is reduced. The outer layer is arranged lengthwise along the canal. When it contracts the canal is shortened.	The combined effects of these two layers create two different forms of movement. A mixing, churning movement occurs when there is a series of small contractions in one segment of the canal. A pushing movement occurs when there is a series of wavelike contractions. As one segment of the canal contracts, the next segment relaxes (receptive relaxation). This rhythmic, wavelike movement is called <i>peristalsis</i> , and it pushes food through the alimentary canal.
Serosa	This is the outermost layer of the alimentary canal. It consists of epithelial and connective tissues that are specialized to secrete a serous fluid. This fluid lubricates and moistens the external surface of the alimentary canal. This external layer is also called the <i>visceral peritoneum</i> . The visceral peritoneum is similar in structure and function to the abdominal (parietal) peritoneum mentioned earlier. The serous fluid prevents friction when these two membranes rub against each other during digestive movements.	The function of the serosa is protection.

The alimentary canal is supplied with nerves from the sympathetic and parasympathetic nervous systems. These nerves are responsible for regulating the contractions of the canal. Parasympathetic nerves stimulate muscular activity; sympathetic nerves retard activity.

215. Structures of the mouth and pharynx and their role in digestion

Most of time you may only think of the mouth as an organ of speech that allows you to verbalize your thoughts. However, the mouth along with the pharynx plays a vital role in the digestive system and the reduction of solid particles. Let's take a look at each and see what their roles are in digestion.

Mouth

The mouth, which is the beginning of the alimentary canal, receives food. Food is softened, mixed, and chewed, beginning the digestive process. As shown in figure 3-2a, the mouth contains the teeth, tongue, and salivary glands; and it is surrounded by the lips, cheeks, and hard and soft palates. The space between the tongue and palate is called the *oral cavity*; and the space between the teeth, cheeks, and lips is called the *vestibule*. The mouth is involved in the digestive functions of *mastication* (chewing) and *deglutition* (swallowing). It is also involved in respiration and formulating the sounds of speech.

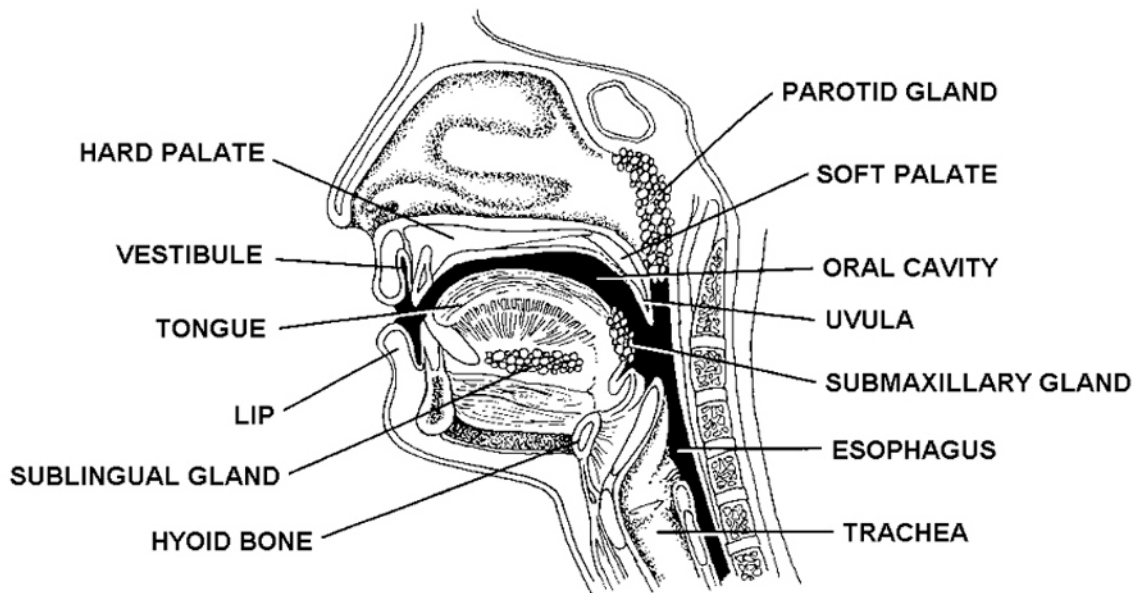


Figure 3-2a. Anatomy of the mouth.

Lips

The lips surround the opening and control the entry of food into the mouth. They are formed of skeletal muscle (primarily orbicularis oris), connective tissue, sensory receptors, and have an excellent blood supply. The skeletal muscle gives the lips great flexibility and mobility. The receptors enable the lips to detect the temperature and texture of substances entering the mouth. On the inside, the lips are lined with the same mucous membrane that lines the remainder of the oral cavity. The outside of the lips is lined with skin. The reddened area of the lips is the transition area between the skin and mucous membrane. In addition to digestion and respiration, the lips are involved in the formulation of sounds (speech) and in changing facial expressions.

Cheeks

The cheeks form the sides of the mouth. Like the lips, they are lined with skin on the outside and mucous membrane on the inside. The buccinator muscles are located within the cheeks, and are lined on either side by pads of adipose tissue. The cheeks are involved in making sounds, changing facial expressions, and helping to digest by keeping the food between the teeth.

Hard and soft palates

The hard and soft palates form the roof of the mouth. The hard palate (anterior portion) is formed by a union of projections from the maxillary and palatine bones. The soft palate is a sheet of muscular tissue shaped like an arch. It forms the border between the oral cavity and the nasopharynx. The space between the posterior margin of the soft palate and the tongue is called the *fauces*, and is the opening into the oropharynx. There is a small, finger-like projection called the *uvula* hanging down from the center of the posterior edge of the soft palate. The palates are involved in the swallowing process and combine with the tongue to create certain sounds.

Tongue

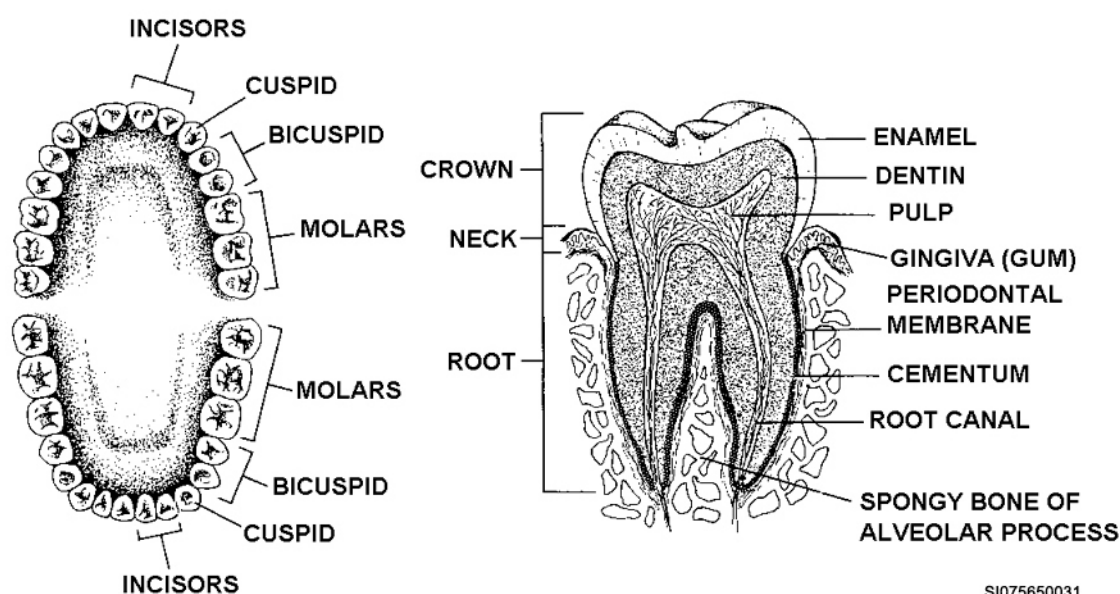
The tongue is a large muscular structure located on the floor of the mouth, and occupies most of the oral cavity. It is made up of intrinsic and extrinsic skeletal muscles. Intrinsic muscles are located completely (origin and insertion) within the tongue. The intrinsic muscle fibers run in all directions and enable the tongue to change size and shape. Extrinsic muscles originate in the mandible, temporal, and hyoid bones and they insert in the tongue. They enable the tongue to move up, down, or sideways within the mouth. The tongue is attached to the floor of the mouth by a fold of mucous membrane called the *frenulum*. The tongue is covered by a mucous membrane, which has little projections called *papillae* along its superior surface. The papillae provide friction that helps to hold food on the tongue. They also contain taste buds that stimulate the salivary and gastric glands.

The tongue is an important structure for both speech and digestion. It moves the food around and mixes it with saliva during chewing, and helps with swallowing by pushing the food back toward the pharynx. It helps with speech by altering the sounds as they come out through the pharynx.

Teeth

Teeth are very special structures. They are located in bony sockets along the inferior border of the maxillary bone and along the superior border of the mandible. We normally grow two sets during our lifetimes.

The 20 “baby” or *deciduous* teeth usually appear within the first 2.5 years. Somewhere between the ages of 6 and 13, these deciduous teeth are replaced by 32 permanent teeth. (Some permanent teeth, particularly “wisdom” teeth, may appear as late as early adulthood.) The arrangement and structure of the teeth are shown in figure 3–2b.



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Figure 3–2b. Anatomy of the permanent teeth.

As you can see in the following table, each type of tooth is specialized to perform a certain function.

Tooth	Description
Incisors	Have sharp, flat edges and are designed to penetrate and cut through (initially bite) tough foods.
Cuspids or “canine” teeth	Come to a point and are used to hold and tear food.
Bicuspid and molars	Have broad, flat surfaces and are primarily used to grind food.

Teeth play a major role in the mechanical breakdown of food. This breakdown is necessary to enable the saliva to reach as much of the food as possible and reduce the size of the food chunks so that they can be swallowed safely. In addition to their digestive functions, teeth act with the lips and tongue to create certain sounds.

Salivary glands

Although the salivary glands are “accessory organs,” we talk about them here because they do play an integral role in both the physical and chemical digestive activities of the mouth. Salivary glands secrete a substance called *saliva*, which moistens, softens, and aids in the chemical breakdown of certain foods. It also lubricates, moistens, and helps clean the mouth. Salivary glands are *exocrine glands*, meaning whatever solution they produce is carried through small tubes called ducts to a target organ or area of the body.

Salivary glands respond to sympathetic and parasympathetic stimulation. Parasympathetic impulses primarily affect serous cells and cause secretion of large amounts of thin, serous fluid. Sympathetic impulses primarily affect mucous cells and cause secretion of small amounts of mucus. These impulses are activated by the sight, smell, taste, or even thought of food. Pleasant foods stimulate parasympathetic impulses, and large amounts of serous fluids are produced. Unpleasant foods inhibit parasympathetic impulses, and the resulting secretion is mostly mucus. Salivary secretion is also affected by the type and temperature of food, fluid balance in the body, emotional stress, and gastrointestinal disorders.

There are numerous small salivary glands located throughout the mucous membrane lining the mouth. They are called *buccal glands*, and they help keep the mouth moist and clean. There are also three sets of major salivary glands:

1. Parotid.
2. Submandibular.
3. Sublingual.

Together, the salivary glands secrete around 1.5 liters of saliva a day! The parotid, submandibular, and sublingual glands are responsible for around 95 percent of this fluid production.

Parotid glands

The parotid glands are the largest of the salivary glands. They are located at the angles of the jaw in front of the ears. The external carotid artery and posterior facial vein pass through each of the parotid glands. The ducts of the parotid glands (Stensen’s duct) pass across the surface of the masseter, turn inward, pass through the buccinator muscle, and open through the mucous membrane lining of the cheeks at small orifices opposite the crown of the upper second molars. The parotid glands secrete a clear, watery fluid that is loaded with a digestive enzyme called *amylase*. People who contract the viral disease *mumps* have an infection of the parotid glands that causes the glands to become severely inflamed and enlarged.

Submandibular glands

The submandibular glands are the next largest in size. They are located in the floor of the mouth along the medial surface of the mandible. The submandibular glands produce both serous and mucous fluids, but mostly serous fluids. As you might expect, this fluid is somewhat thicker than the parotid

secretion. The submandibular (Wharton's) ducts open into the mouth near the base of the frenulum on either side of the tongue.

Sublingual glands

The sublingual glands are also located in the tube floor of the mouth, but are directly beneath the tongue. They are the smallest of the three sets of salivary glands. They produce a primarily mucous secretion. The sublingual glands are drained by multiple ducts (ducts of Rivinus) that open into the floor of the mouth.

Pharynx

The pharynx is a muscular passage that connects the nose and mouth with the esophagus and trachea. It functions both in respiration and digestion. (We discussed the structure of the pharynx in the last unit.) The pharynx works together with the structures of the mouth to carry out the act of swallowing (deglutition). Basically, this is a three-stage procedure.

In the first stage, food is taken into the mouth, masticated, and mixed with saliva. The food is then formed into a ball or mass called a *bolus*. The first stage ends when the tongue rolls back against the soft palate and forces the bolus back into the oropharynx. The first stage is under voluntary nervous control.

The swallowing reflex is activated at the beginning of the second stage. When the bolus enters the pharynx, it stimulates the sensory receptors located around the pharyngeal opening. These receptors trigger a variety of reflex muscular actions. First, the tongue remains pressed up against the soft palate and blocks off the entrance to the mouth. At the same time, the muscular soft palate lifts up and blocks off the entrance to the nasopharynx; and the hyoid and larynx (epiglottis) lift up and block the laryngeal opening. The longitudinal pharyngeal muscles tense and lift the pharynx toward the food. The bolus slides over the epiglottis and into the laryngopharynx. The inferior circular muscle of the pharynx relaxes and opens the entrance to the esophagus. The superior circular muscles constrict to begin the peristaltic wave and push the bolus into the esophagus. The second stage is under control of the involuntary nervous system.

The third stage is a relatively simple one; the bolus moves through the esophagus and into the stomach. This is accomplished by a series of muscular contractions that generate waves, propelling the bolus along inside the tube. This is known as *peristalsis*. Like the second stage, the third stage of swallowing consists of reflex actions and is triggered by the involuntary nervous system.

216. The esophagus and stomach

Now that you have an understanding of the initial phase of digestion, let's take a closer look at the structure that **transports** the bolus into the stomach and what happens once it arrives **there**.

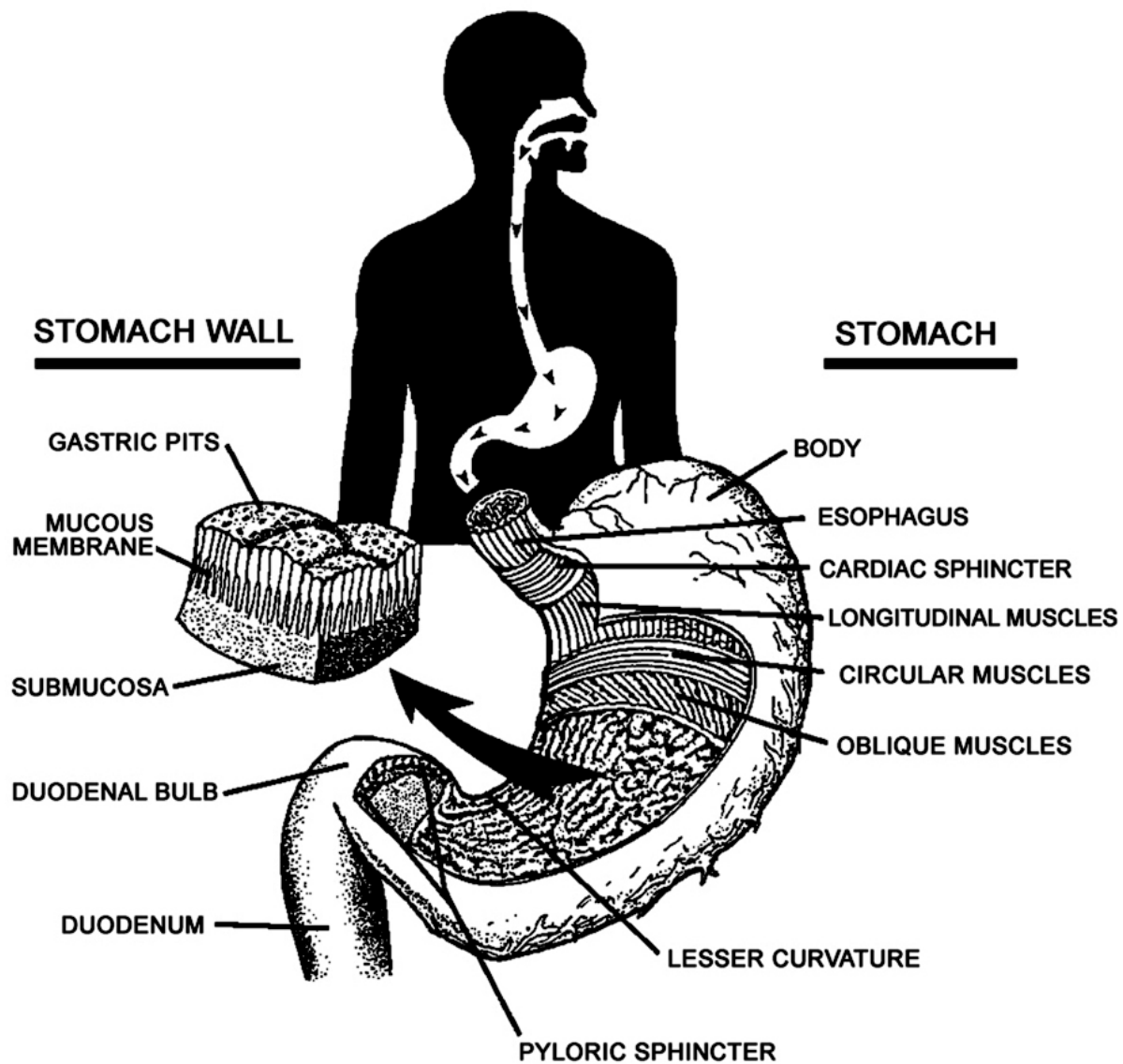
Esophagus

The esophagus is a straight tube about 10 inches long that connects the pharynx with the stomach. Located between the trachea and vertebral column, it passes through the thoracic cavity and into the abdominal cavity through an opening in the diaphragm called the *esophageal hiatus*. The esophageal wall is composed of the same structures we mentioned earlier in our discussion of the alimentary canal. The mucous glands keep the mucosal layer moist and lubricated. The muscular layer differs slightly from the general structure previously described in that the muscle fibers in the upper portion of the esophagus are striated rather than smooth. In addition, the circular muscle layer is thickest near the stomach opening. These fibers usually remain contracted to keep the opening closed and prevent regurgitation of stomach contents. The fibers relax and open when the peristaltic wave reaches the stomach. This thick area is also referred to as the *cardiac sphincter*, and is considered by some authorities to be a part of the stomach. The only function of the esophagus is to transport the bolus from the pharynx to the stomach. It does not mix or breakdown the food in any way.

Stomach

The stomach (fig. 3-3) is a large, saclike, muscular enlargement of the alimentary canal, connecting the esophagus with the small intestine. It is about 10 inches long and shaped roughly like a gourd. The expanded left border is called the *greater curvature*, and the shorter right border is the *lesser curvature*. The stomach is located in the left upper quadrant of the abdomen beneath the liver and diaphragm. There are four divisions of the stomach.

Division	Location
<i>Cardiac region</i>	The area immediately around the opening (cardia) between the esophagus and stomach.
<i>Fundic region or fundus</i>	The upper portion of the greater curvature.
<i>Body</i>	The main portion of the stomach.
<i>Pyloric region or antrum</i>	The constricted lower portion.



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Figure 3-3. The stomach.

Stomach wall

The external, serous layer of the stomach is modified to form large folds called *omenta*, which extend from the stomach to other abdominal organs. The *greater omentum* is an apron-like structure hanging down over the intestines from the greater curvature of the stomach. The omentum cushions the intestines and acts as a storage place for fat. It also prevents infection from spreading by matting itself around the infected area. There is a similar structure called the *lesser omentum* between the lesser curvature and the liver. The omenta are also referred to as *omental bursa*. Figure 3-4, views A, B, and C, shows the omenta and their relationship to other major structures in the digestive system and abdominal cavity.

The muscular layer of the stomach wall is also modified from the general description we provided earlier. In addition to the circular and longitudinal layers, there is an inner layer of oblique muscles (refer back to fig. 3-3). This layer is most pronounced around the cardia and body of the stomach. The circular fibers in the pyloric region are thickened to form a constrictive valve called the *pyloric sphincter*. This structure controls the release of stomach contents to the small intestine.

The internal wall of the stomach is specialized to carry out certain functions. When the stomach is empty, the mucosal lining is arranged in folds called *rugae*, which flatten out as the stomach fills with food. This feature permits tremendous expansion. Fully expanded, the stomach is capable of holding more than a quart of food and/or fluid.

The mucosal surface is covered with numerous tiny pores called *gastric pits*. These pits are the external openings for *gastric glands*, which secrete mucous and digestive enzymes. There are three different types of secretory cells—*mucous cells*, *chief cells*, and *parietal cells*—in the stomach.

Cells	Secretion	Function
Mucous	Mucus	This mucus, together with the mucus secreted by the goblet cells on the surface, protects and lubricates the stomach lining.
Chief	Digestive enzymes	The most important of these is an inactive enzyme called <i>pepsinogen</i> . Chief cells also secrete the enzyme <i>lipase</i> , which breaks up or emulsifies fats.
Parietal	Hydrochloric acid (the <i>intrinsic factor</i>)	When pepsinogen contacts hydrochloric acid, it is converted to an active enzyme called <i>pepsin</i> . Pepsin is responsible for digesting or breaking up dietary proteins. Intrinsic factor is involved in the absorption of vitamin B ₁₂ . As we mentioned in the circulatory system, vitamin B ₁₂ is essential for the normal development of erythrocytes.

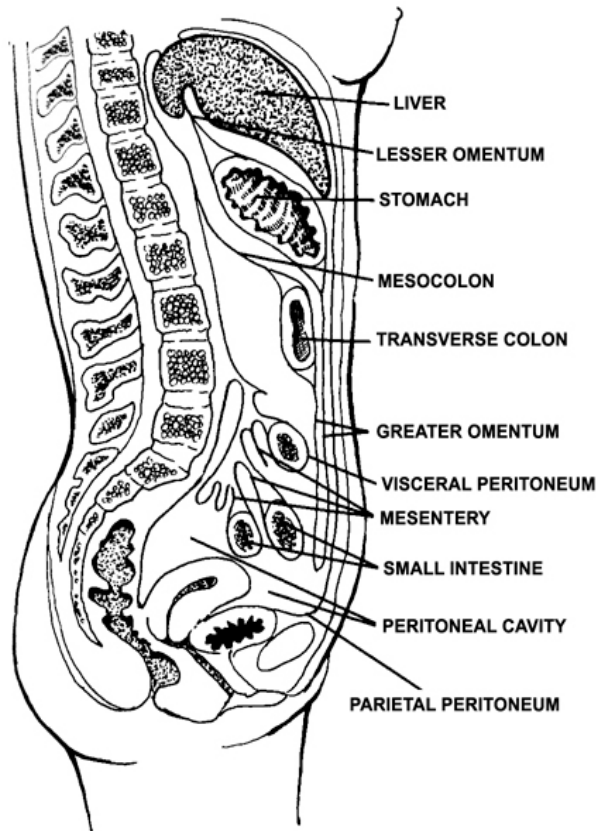
Primary functions of the stomach

The primary functions of the stomach involve intermediate food processing. After the food is received, stored, and mixed, the digestive process begins in earnest.

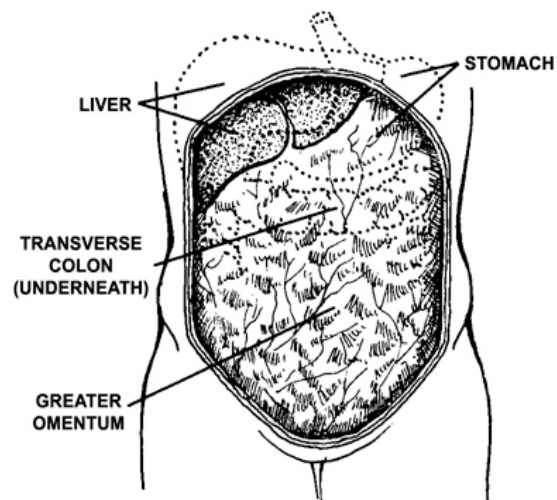
Chemical gastric digestion

Gastric gland secretion is the result of the interaction of neurological, chemical, and physical factors. The neurological factor consists of the sympathetic and parasympathetic impulses received from the autonomic nervous system. Parasympathetic impulses transmitted via the right and left vagus nerves cause an increase in gastric secretion, and sympathetic impulses cause a decrease in gastric activity. The chemical factor consists of the activities of assorted digestive hormones. The physical factor is the presence of partially digested food products in various places in the stomach. These factors interact in three distinct stages or phases.

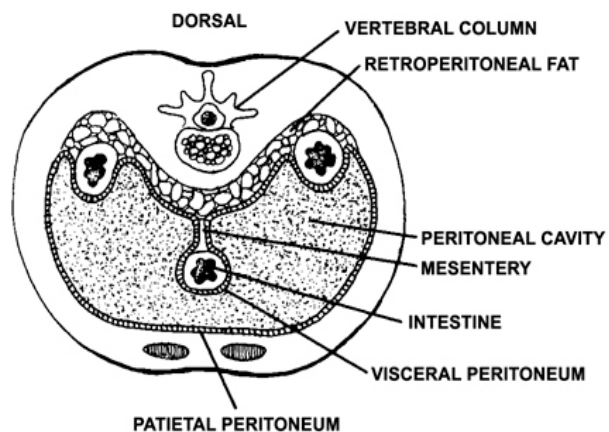
1. Cephalic or head phase.
2. Gastric phase.
3. Intestinal phase.



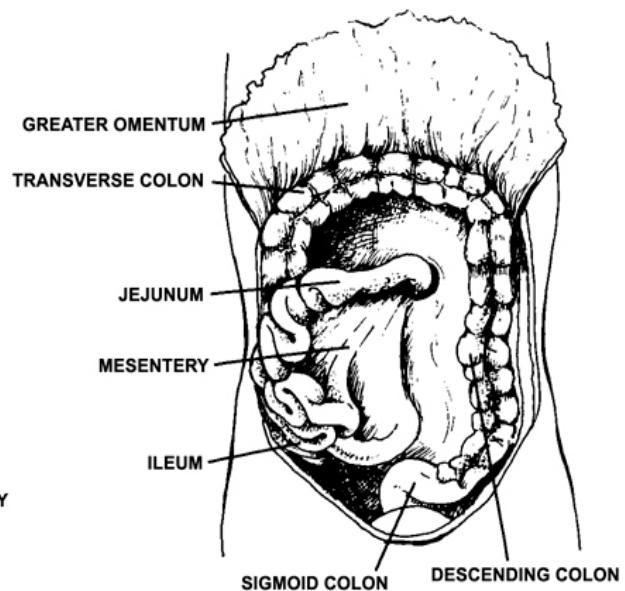
A Sagittal section through abdomen showing greater omentum, lesser omentum, mesentery, mesocolon and peritoneum.



B Front cutaway view of abdomen showing normal position of greater omentum.



D Cross sectional view of abdomen illustrating relationship of mesentery and parietal and visceral peritoneum.



C Front cutaway view of abdomen showing mesentery and mesocolon. (Greater omentum and transverse colon raised - small intestine retracted laterally)

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Figure 3-4. Relationship of structures in the abdominal cavity.

In the first phase, *the cephalic or head phase*, parasympathetic impulses cause an increase in gastric secretions as a result of the sight, smell, taste, or thought of food. Hunger causes an increase in the amount of secretions produced. The impulses also cause specialized epithelial cells in the pyloric region to release a hormone called *gastrin*. Gastrin is absorbed into the bloodstream and taken to the gastric glands where it promotes additional secretion of gastric juices.

The second phase, *gastric phase*, is triggered by the entrance of food into the stomach. Expansion of the stomach wall causes release of additional gastrin. At the same time, the presence of food activates parasympathetic impulses. These impulses stimulate the secretory cells directly to produce gastric juice, and cause the epithelial cells to produce more gastrin. Certain foods, such as meat products, proteins, spices, caffeine, and alcohol, also cause release of gastrin from the epithelial cells.

The third phase, *intestinal phase*, is triggered by the entry of food into the small intestine. The initial contact with the intestinal wall causes a hormone similar to gastrin to be released into the bloodstream. This unknown hormone causes still more gastric juice to be secreted in the stomach. When additional food enters the small intestine, gastric secretions are decreased. The exact mechanism for this decrease is not too well known yet, but it is thought to involve the presence of acids and fats. Acids seem to trigger sympathetic reflexes. Fats cause several hormones to be released into the bloodstream. Two of these—*enterogastrone* and *cholecystokinin*—cause a decrease in gastric activity. (Cholecystokinin also interacts with the accessory organs of digestion.)

Mechanical digestion

In addition to the chemical digestive processes, the stomach helps break down foods through mechanical action. As food accumulates in the stomach, it is subjected to a series of rhythmic contractions that move back and forth from one end of the stomach to the other. The effect of these contractions is the mixing of food particles with the gastric juice to produce a semifluid substance called *chyme*. About every 20 seconds, a peristaltic wave begins as a small contraction near the middle of the stomach. This contraction grows progressively stronger as it approaches the pylorus. It takes about a minute for the wave to travel from the initiation point to the pyloric sphincter, so there are usually two or three traveling through the stomach at any given time. Periodically, the pyloric sphincter relaxes and allows a small amount of chyme to pass through to the small intestine. These peristaltic waves have an additional mixing effect on the stomach contents. The pyloric region is narrower than the rest of the stomach. As the contractions travel through this area, they exert a rhythmic, squeezing effect on the contents.

Food storage

One of the functions of the stomach is storage. The length of time food remains in the stomach is variable. Fatty foods usually remain the longest (3 to 6 hours), followed by proteins and carbohydrates. Liquids usually travel through very quickly. The length of time also depends on how much food is in the stomach. The stomach is larger than the small intestine, and therefore, can hold much more partially digested food than the small intestines. As a result, several mechanisms prevent the stomach from dumping all its contents into the small intestine at once. The first of these is the *enterogastric reflex*. When the duodenal (first part of small intestine) wall becomes stretched, baroreceptors activate the reflex and parasympathetic impulses to the stomach are inhibited. As we mentioned earlier, fatty foods in the duodenum cause the release of the hormone enterogastrone, which also slows down peristalsis.

As you can see, the stomach is the site for all kinds of physical and chemical activity. Food is received, stored, mixed, broken down, and transported to the small intestine. The chemical activity includes the breakdown of proteins to form *proteoses* and *peptones*, and the emulsification of some fats to form *fatty acids* and *glycerol*. In addition to all this activity, the stomach even manages to absorb a few substances (e.g., water, glucose, salts, alcohol, and some lipid-soluble drugs). The stomach serves as an intermediate food processing station. It stores and breaks down masses of food and liquid into a paste-like substance that can be readily transferred to the next area of the alimentary

canal for final processing. The final stages of food digestion occur in the areas of the alimentary canal we discuss next—the small and large intestines.

217. The intestinal tract

The small and large intestines are the primary locations where the majority of digestion and absorption occurs. We begin this lesson by discussing the long, narrow, convoluted tube that connects the stomach to the large intestines.

Small intestine

The small intestine (refer back to fig. 3-1 and fig. 3-5) is a multicoiled muscular tube, extending from the pyloric sphincter of the stomach to the ileocecal valve of the large intestine. The coils of the small intestine occupy most of the space in the abdominal cavity. It is divided into three sections—the *duodenum*, *jejunum*, and *ileum*. A structure closely associated with the small intestine, though not actually part of it, is the *mesentery*.

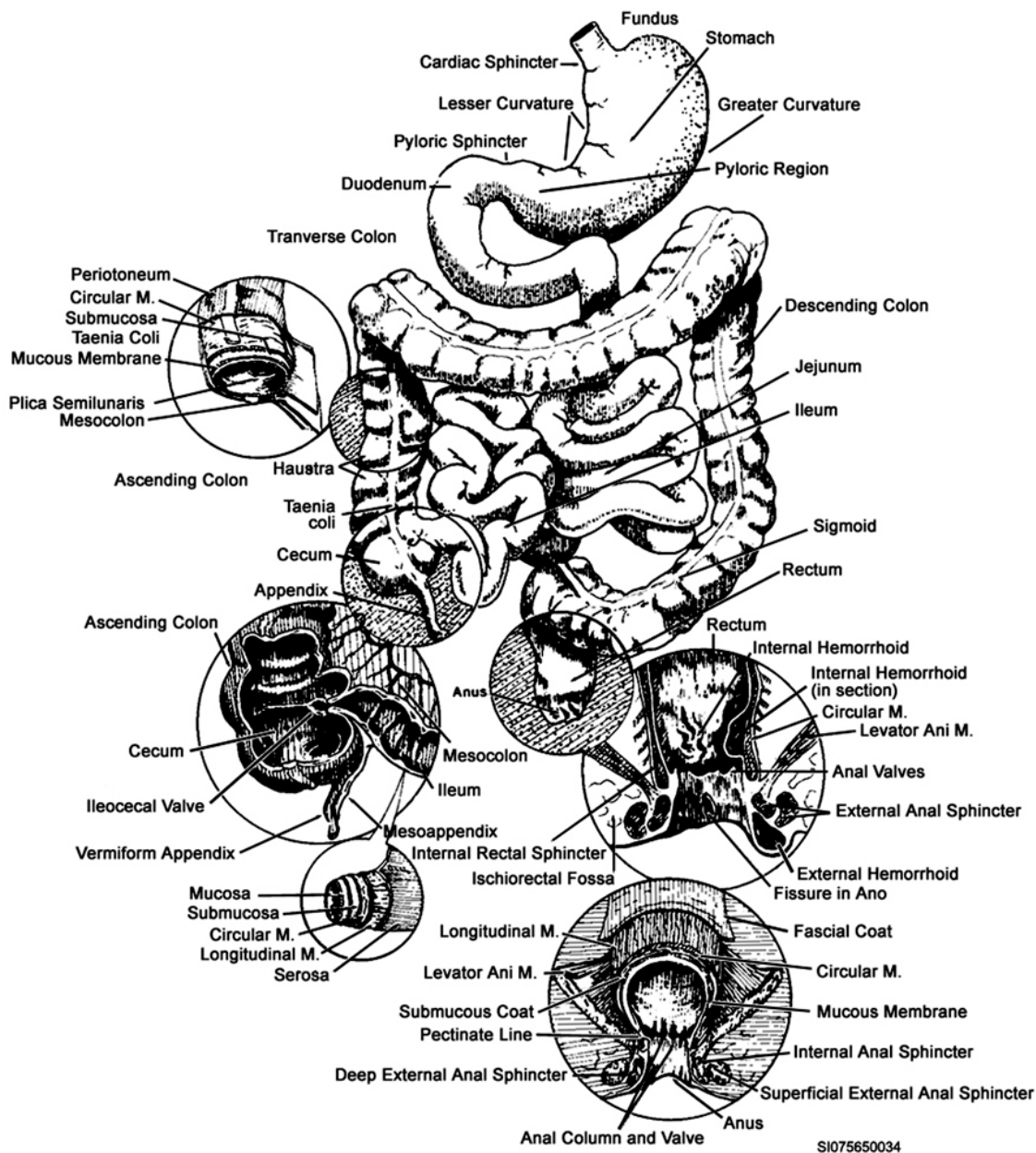


Figure 3-5. The stomach and intestinal tract.

Duodenum

The duodenum is the first and smallest section of the small intestine. It is approximately 10 inches long and 2 inches in diameter, and forms a C-shaped curve just below the liver and around the head of the pancreas. The duodenum is attached to the posterior abdominal wall in the retroperitoneal space (behind the parietal peritoneum). It receives the food from the stomach through the pyloric sphincter. The duodenum also receives secretions from the liver, pancreas, and gallbladder through an opening called the Ampulla of Vater.

Jejunum

The jejunum is the middle section of the small intestine. It is approximately 8 feet long and 1 inch in diameter. The jejunum joins the duodenum at the point where the small intestine takes a downward curve. This junction is also the point of attachment for a muscular band coming down from the diaphragm (suspensory muscle of the duodenum).

Ileum

The ileum is the last and longest portion of the small intestine. It is approximately 12 feet long and 1 inch in diameter. There is no distinct separation point between the ileum and the jejunum, but the ileum has a slightly smaller diameter. Both the jejunum and the ileum are suspended from the posterior abdominal wall by a fan-like extension of the parietal peritoneum called the *mesentery* (refer back to fig. 3-4, views A, C, and D).

Mesentery

The mesentery is similar in structure to the omentum we discussed earlier. It suspends the coils so that each coil can move freely, yet the coils cannot become twisted together and strangulated. The mesentery also carries the blood vessels, nerves, and lymph vessels for the small intestine. When a surgeon does a bowel resection, the blood vessels that run through the mesentery to the section of bowel that is to be removed must be clamped and ligated. This may require the use of several medium size hemostats and numerous free ties (i.e., ligature reels), or the use of a special staple gun that ligates, divides, and staples both ends of the severed vessels.

Digestive action and absorption in the small intestine

Most of the chemical breakdown and absorption of food for the body occurs in the small intestine. For this reason, the wall of the small intestine is more specialized than any other area in the gastrointestinal tract. Most of this specialization is seen in the mucosal layer of the wall. The wall is arranged in large circular folds called *plicae circulares*. These folds are especially prominent in the duodenum and jejunum, and less-defined in the ileum. Another form of adaptation is finger-like projections called *villi*. Each of these projections is supplied with nerve fibers, blood capillaries, and a lymphatic capillary called a *lacteal*. These capillaries and nerves are surrounded by connective tissue, and the entire structure is covered with a layer of simple columnar epithelium. The epithelial cells are also lined with microscopic projections called *microvilli*. The *plicae circulares*, villi, and microvilli all serve to increase the surface area of the small intestine. This, in turn, allows for greater absorption of nutrients from the digested food into the bloodstream.

The mucosal lining of the small intestine also contains several types of secretory cells. There are numerous *mucus-secreting goblet cells* similar to those found in other parts of the alimentary canal. The first part of the duodenum also contains specialized mucus-secreting glands called *Brunner's glands*. Brunner's glands secrete a thick, alkaline fluid. In addition to the mucus-secreting goblet cells and the Brunner's glands, there is a third type of secretory cell, *tubular intestinal glands*, located near the base of the villi. (Intestinal glands are also referred to as crypts of Lieberkühn.) Intestinal glands secrete large amounts of thin, watery fluid. This fluid serves as a medium for the absorption of digestive products into the villi. As the fluid is reabsorbed into the villi, it carries the digestive products with it.

We mentioned that the small intestine is where most of the chemical breakdown of food occurs. This breakdown is accomplished by *enzymes*. These enzymes include the following:

Enzyme	Function
Peptidases	Break down proteins into amino acids.
Sucrase, maltase, and lactase	Reduce disaccharides into monosaccharides.
Intestinal lipase	Breaks down fats into fatty acids and glycerol.

These enzymes are found in the epithelial cells of the microvilli, and they break down food products just prior to absorption. In addition to these, the small intestine also receives enzymes from the pancreas to help break down food products. We discuss the actions of these enzymes in our discussion of the accessory organs of digestion.

The regulation of intestinal secretions is much the same as the regulation of gastric secretions. Mechanical, neurological, and hormonal factors are all involved in promoting secretions. Stomach contents normally have a fairly high acid content (from the hydrochloric acid in gastric juice). When these contents enter the duodenum, goblet cells and Brunner's cells are stimulated to secrete large amounts of mucus. This activity is caused by the distention of the intestinal wall (mechanical factor) and direct contact of chyme with the intestinal wall (chemical/neurological factor). A hormone called *enterocrinin* is released by intestinal cells and is also thought to stimulate production of secretions.

The whole purpose of breaking down food products is to change these products into a form that can be absorbed into the bloodstream. As we said, the small intestine is the site for almost all of this absorption. This is partially due to the fact that almost everything is reduced to its simplest form, either before or in the small intestine, and partially due to the tremendous surface area that is available for absorption in the small intestine. If you took your small intestine and flattened out all the plica, villi, and microvilli, you would multiply the initial area by more than 150 times! Other than waste products and a small amount of water and electrolytes, very little of the food you consume passes through the small intestine without being absorbed.

Food breakdown

The major components of the food we consume are carbohydrates, proteins, and fats. Each of these are chemically broken down and absorbed in the small intestine.

Carbohydrates

Through the action of amylase, sucrase, maltase, and lactase, carbohydrates are converted into monosaccharides (the simplest form of sugar) and absorbed into the bloodstream through the villi. This absorption involves the active transport and diffusion mechanisms.

Proteins

Pepsin, peptidase, and proteinase convert proteins into amino acids so that they can be absorbed through the villi into the bloodstream. This absorption is through the active transport mechanism.

Fat

Fat absorption is a little more complex than either protein or carbohydrate absorption. To begin with, fats are broken down into fatty acids and glycerol by lipase in the stomach and small intestine (intestinal and pancreatic secretions). The fatty acid molecules are diffused into the epithelial cells. The endoplasmic reticulum within the epithelial cells resynthesizes, or remakes, a fat molecule similar to the one that was initially broken down. Fat molecules collect in little droplets or globules and are covered by a thin layer of protein. These protein-covered fat droplets are called *chylomicrons*. The chylomicrons are absorbed into the lacteal, and are then carried through lymphatic vessels to the bloodstream. From there, most of the chylomicrons are deposited in the adipose tissue in various places in the body. The majority of the fat taken into the body is broken down and absorbed through

the process described here. Some fatty acid molecules with comparatively simple structures are absorbed through the epithelial cells directly into the bloodstream.

Ileocecal valve

There is a strong sphincter muscle called the *ileocecal valve* at the distal end of the ileum. This valve protrudes slightly into the *cecum* of the large intestine (refer back to fig. 3-5), and marks the junction of the small and large intestines. The ileocecal valve normally remains in the contracted state to prevent backup, or regurgitation, of the contents of the large intestine. When digestive activity is taking place in the small intestine, the valve opens periodically to allow a small amount of chyme to enter the cecum. This activity is accelerated after a meal through the action of the *gastroileal reflex*.

Large intestine

The large intestine is the last food stop along the alimentary canal. It is a short, thick tube, approximately 5 feet long and 2.5 inches in diameter. As shown in figure 3-5, the large intestine begins at the ileocecal valve in the right lower quadrant, runs up the right side, crosses over to the left upper quadrant, runs down the left side, and then angles over to the pelvic cavity. It is divided into three major sections:

1. Cecum.
2. Colon.
3. Rectum.

Cecum

The cecum is a short, expanded, pouch-like structure located in the right lower quadrant of the abdomen. As we mentioned, it is connected by the ileocecal valve to the small intestine. The cecum opens up below this connection to create a sort of blind pouch or dead-end effect. There is a short, thin tube called the *vermiform appendix* extending down from the lower end of the cecum. The appendix is a blind tube—opens at the proximal end and closed at the distal end. The appendix has no known function, but it does contain lymphatic tissue and may function as an infection control device. Occasionally, it becomes obstructed and infected to produce an inflammatory condition called *appendicitis*.

Colon

The entrance of the ileocecal valve makes a sort of “T” connection to mark the junction of the colon with the cecum. The colon is divided into four sections.

Section	Location
Ascending colon	Begins in the right lower quadrant and extends up the right side along the posterior abdominal wall.
Transverse colon	At the lower margin of the liver, the colon makes a turn to the left called the <i>hepatic flexure</i> , and curves across the abdominal cavity just below the stomach and anterior to the small intestine.
Descending colon	In the left upper quadrant, near the spleen, the transverse colon makes a sharp, downward turn called the <i>splenic flexure</i> . From the splenic flexure, the colon extends down the left side of the abdomen.
Sigmoid colon	Near the left iliac crest, the colon makes an S-shaped curve across to the pelvic brim. This S-shaped section is known as the sigmoid colon.

Rectum

The rectum makes up the last 7 or 8 inches of the large intestine. It connects to the sigmoid colon near the pelvic brim, and extends down through the pelvic cavity along the anterior surface of the sacrum and coccyx. The last inch or so is called the *anal canal*, which terminates in an external opening called the *anus*. There are two strong sphincter muscles that control the movement of waste products out of the anus. They are the *internal anal sphincter* and *external anal sphincter* (refer back to fig. 3-

5). The superior margin of the internal anal sphincter muscle is called the *pectinate line* (a landmark that is used in classifying types of hemorrhoids).

Structure of the intestinal wall

Although the large intestine has less of a digestive function than other parts of the alimentary canal, its wall is still specialized to perform certain absorptive and excretory functions. The mucosal layer does not have the villi and plicae circulares seen in the small intestine, but there are a large number of intestinal glands lined with mucus-secreting goblet cells. These intestinal glands are concentrated in the cecum, colon and upper rectum, but become fewer in the lower rectum and are absent altogether in the anal canal.

Just above the anal canal, the mucous membrane changes from columnar to stratified squamous. The membrane also develops longitudinal folds called *anal columns*, or *columns of Morgagni*. There are usually between six and eight of these columns, each containing an artery and a vein. Occasionally, the veins in these columns swell and become inflamed and painful due to obstructed blood flow. This condition is called *hemorrhoids*. Hemorrhoids that develop in the anal canal above the pectinate line are called internal hemorrhoids; those that form below this line are called external hemorrhoids.

Mucus is the primary secretion of the intestinal glands. The intestinal glands respond to contact (mechanical and parasympathetic stimulation) with chyme by increasing the rate of mucus secretion. The mucus helps to hold the feces together and protects the intestinal wall.

The most significant differences between the wall of the small and large intestine are in the structure of the muscular layer. The longitudinal muscle layer of the cecum and colon has been compressed into three narrow bands called *teniae coli*. The pressure exerted by the teniae coli cause periodic inward folding along the intestinal wall. This creates a series of pouches called *haustra*. The circular smooth muscle layer is thickened in the anal area to form the internal anal sphincter. This internal sphincter is surrounded by a ring of skeletal muscle fibers called the external anal sphincter.

The serosal layer also has modifications similar to the jejunum and ileum. The transverse colon is attached to the posterior abdominal wall by a fold of parietal peritoneum called the *transverse mesocolon* (refer back to fig. 3-4, view A). Like the mesentery mentioned earlier, the mesocolon supplies the transverse colon with blood, nerves, and lymph vessels. The sigmoid colon is supported by a similar mesocolon. The serosal layer also has small collections of adipose tissue called *epiploic appendages* along the outer surface of the intestine.

Peristaltic action

Movement in the large intestine is similar, but much slower than movement in the small intestine. The segmenting contractions break up the intestinal contents and keep the contents moving for maximum exposure to the intestinal mucosa. At the same time, these contractions cause a gradual movement toward the distal end of the colon. Peristaltic movements only occur three or four times a day, and are referred to as mass movements. Mass movements are strong, slow contractions involving large segments of the colon. They cause rapid movement of intestinal contents through the colon, and sometimes even into the rectum. Mass movements usually occur either during or just after a meal, as the result of stimulation of a reflex known as the duodenocolic reflex. Mass movements can also be stimulated by excessive irritation of the intestinal wall.

Function of the large intestine

Earlier, we mentioned that the small intestine absorbed everything except waste products, a few electrolytes, and some water. A large amount of mucus is added to this waste material in the large intestine. The collective term for the resulting substance is *feces* or *fecal material*. In addition to the components mentioned, feces also contain bacteria and bile pigments (which gives the feces a dark, brownish color). The fecal odor is caused by chemical compounds created by the action of the bacteria on the waste products.

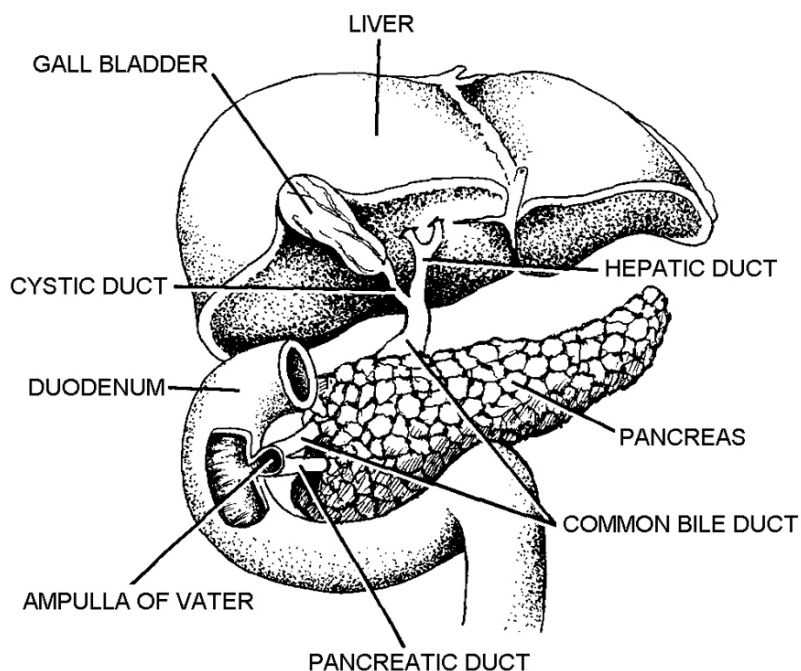
When the fecal material moves from the colon into the rectum, receptors are stimulated to trigger the *defecation reflex*. This reflex causes impulses to be sent from the brain to the colon, rectum, and anus. These impulses cause strong peristaltic contractions of the colon and relaxation of the internal anal sphincter. At the same time, the individual feels the sensation or urge to defecate. If the individual then strains the abdominal muscles, the external anal sphincter relaxes and defecation occurs. If the individual ignores the urge, the feces remain in the rectum. Eventually, the fecal material dries out and becomes hardened, and then defecation is difficult and painful. This condition is called *constipation*.

In addition to forming solid waste, a small amount of absorption also takes place in the large intestine. This is usually restricted to water (absorbed by osmosis) and a few electrolytes (absorbed by active transport). In addition, intestinal bacteria break down some substances that cannot be broken down by enzymes. The various types of intestinal bacteria use these substances as an energy source. They also manufacture certain vitamins (e.g., K, B₁₂, thiamine, and riboflavin) to supplement dietary intake. (The vitamins manufactured by intestinal bacteria are also absorbed by the large intestine.) Finally, gas (flatus) is developed as a result of bacterial actions.

218. Accessory organs of digestion

As we mentioned at the beginning of the unit, the accessory organs of digestion are those structures that lie outside the alimentary canal but contribute in some way to the process of digestion. Of these accessory organs, the salivary glands have the closest relationship with the alimentary canal. The buccal, submandibular, and sublingual glands are located within the structure of the mouth itself. The other set, parotid glands, are located just outside the mouth. In addition, the salivary glands account for all of the chemical activity, and provide the fluid necessary for the physical activity of the mouth. For these reasons, we chose to include the salivary glands in the previous section with the discussion of the mouth. This section discusses the structure and function of the remaining three accessory digestive organs. Refer to fig. 3-6, in the discussion these three organs:

- Liver.
- Gallbladder.
- Pancreas.



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Figure 3-6. Accessory organs of digestion.

Liver

The liver is a large, irregularly-shaped glandular organ. It is located in the upper portion of the abdomen, just below the diaphragm and behind the ribs. *The liver is the largest gland in the body.* It occupies most of the right upper quadrant and part of the left upper quadrant of the abdomen and is surrounded by a very fibrous visceral peritoneum. One fold of this peritoneum, called the *coronary ligament*, attaches the liver to the diaphragm. Another fold, the *falciform ligament*, attaches the liver to the anterior abdominal wall and divides it into right and left lobes. The right lobe is much larger than the left and is further divided into the *right lobe proper*, *quadrate lobe*, and *caudate lobe*. Each of these lobes is further divided into *hepatic lobules*, which are the working units of the liver.

The liver is also a highly vascular organ. Arterial blood is diverted into the liver by the hepatic artery, and venous blood is brought in from the alimentary canal by the portal vein. The hepatic artery and portal vein enter the liver together with lymphatic vessels and branches of the bile duct. These vessels repeatedly branch out until they reach the level of the lobules. At the end of all this dividing, each lobule is surrounded by several sets of interlobular arteries, veins, and bile ducts.

Each liver lobule consists of a central vein surrounded by networks of hepatic cells that radiate outwardly. These networks, or plates as they are sometimes called, are separated by spaces called *hepatic lacunae*. There are channels called *hepatic sinusoids* within each of the lacunae. These sinusoids are lined with phagocytic cells called *Kupffer cells*. Blood from the branches of the hepatic artery and portal vein drains into the sinusoids. The arterial blood supplies the hepatic cells along the sinusoids with oxygen, while the venous blood supplies nutrients. As the blood flows toward the central vein, the phagocytic cells remove bacterial toxins. Blood from the central veins collects in intralobular veins and eventually into the two main hepatic veins. The hepatic veins carry the blood out of the liver and empty into the inferior vena cava.

The hepatic cells are surrounded by fine networks of minute bile ducts called *bile canaliculi*, or bile capillaries. These canaliculi drain the secretions from the hepatic cells. They unite to form larger and larger bile ducts until they form the *right* and *left hepatic ducts*, which merge to form the *common hepatic duct*. The common hepatic duct, in turn, joins with the *cystic duct* from the gallbladder to form the *common bile duct*, which drains into the duodenum (fig. 3-6).

The liver performs a great number of vital functions. One major digestive function is the formation of *bile*—a yellow-green, viscous liquid. The hepatic cells secrete bile continuously, with slight increases just after meals. It consists of water, bile salts, bile pigments, cholesterol, and assorted electrolytes. (We discussed bile pigments earlier in the circulatory system.) Of these substances, only the bile salts have any sort of digestive function.

The liver is also involved in the metabolism, or cellular utilization, of fats, carbohydrates, and proteins. The carbohydrate metabolism includes storing glucose, changing glucose to glycogen, changing it back to glucose, and manufacturing glucose from noncarbohydrate sources to meet the energy needs of the body. Fat metabolism includes the oxidation of fatty acids; creation of phospholipids, lipoproteins, and cholesterol; and the manufacture of fats from carbohydrate and protein sources. Protein metabolism includes manufacture of urea and blood proteins (including the clotting factors heparin and fibrinogen), and deamination and conversion of amino acids.

In addition to metabolic functions, the liver also detoxifies harmful substances such as alcohol and byproducts of protein digestion. It destroys wornout blood cells and foreign substances (phagocytic cells). In addition to storing glucose in the form of glycogen, the liver also stores vitamins A, D, B₁₂, and iron. Finally, the cellular activities of the liver aid in the production of heat.

Gallbladder

The gallbladder is a small, oblong structure shaped roughly like a crook-neck squash. It is approximately 3 inches long and 1 inch wide (widest point), and has a maximum capacity of about 50

cubic centimeters (milliliters) of fluid. As mentioned, the gallbladder is attached to the inferior surface of the liver by the cystic duct (refer back to fig. 3–6).

The wall of the gallbladder is made up of three separate layers. The inner mucosal layer is columnar epithelium and arranged in folds (rugae). Like the stomach, the rugae allow the gallbladder to expand. The middle layer consists of muscle tissue, and the outer layer consists of serous tissue.

The gallbladder stores and concentrates bile, releasing it when needed. The bile accumulates in the gallbladder between meals. At this time, the sphincter muscle (sphincter of Oddi) at the end of the common bile duct is contracted. This causes the bile coming out of the liver to back up into the gallbladder. As the bile sits in the gallbladder, water and electrolytes are absorbed into the mucosal lining. This action concentrates the bile salts, bile pigment, and cholesterol contained in the bile. In certain instances, the cholesterol, which normally remains dissolved in solution even in concentrated bile, may precipitate out of the solution and begin to form solid crystals. If this process continues over a long period of time, solid, pebble-like structures called *gallstones* form in the gallbladder. These stones can migrate out of the gallbladder and become lodged in the cystic duct or common bile duct, causing an obstruction to the flow of bile into the gallbladder and duodenum.

Bile salts are the only part of the bile with any digestive function. These salts break up large fat globules into smaller droplets (emulsification). This increases the surface area of the droplets and promotes the action of the enzyme lipase. Bile salts also improve the absorption of fatty acids and cholesterol by combining with these substances to form complexes called *micelles*. Micelles are highly soluble in chyme and easily absorbed. Fat soluble vitamins (A, D, E, and K) are absorbed with the fat-containing micelles. If the bile salts are unavailable for mixing with the chyme in the duodenum due to blockage of the bile duct system by a stone or tumor, or a disease process that affects production of bile in the liver, a person's ability to break down and absorb fats in the food he or she consumes is significantly reduced. In addition, vitamin absorption is hindered and may result in vitamin deficiencies.

The release of bile from the gallbladder into the common duct is triggered by hormonal and mechanical stimulation. When fatty foods enter the duodenum, a hormone called *cholecystokinin* is secreted into the bloodstream by glands in the upper small intestine. This hormone stimulates the muscular layer of the gallbladder to contract. Meanwhile, the sphincter of Oddi relaxes when it is approached by the peristaltic wave. This allows a small amount of bile to enter the duodenum just ahead of the peristaltic wave (and the chyme).

Pancreas

The pancreas is a large, irregularly-shaped, elongated gland located in the retroperitoneal space just posterior to the stomach. As shown in figure 3–6, the head of the pancreas lies in the curve of the duodenum with the tail extending out in a lateral, slightly upward direction towards the spleen. It is attached to the duodenum by the pancreatic duct.

The pancreas is made up of lobular tissue, similar to that found in the salivary glands. These lobes are compound acinar glands, which secrete pancreatic juice. The pancreatic juice is secreted into minute ducts that combine to form larger ducts. These smaller ducts unite to form the *pancreatic duct*. Normally, the pancreatic duct then merges with another structure, the common bile duct, just proximal to the duodenum. The area or junction where the pancreatic duct merges with the common bile duct is known as the *hepatopancreatic ampulla*, or *ampulla of Vater*. These combined ducts not only attach the pancreas to the duodenum, but the opening of these combined ducts enters the duodenum. This opening is surrounded by a sheath of muscle fibers that we mentioned previously—the sphincter of Oddi. This tiny sphincter muscle acts as a valve to control not only the release of bile into the duodenum, but also pancreatic juice.

There are also little clusters of endocrine cells embedded among the acinar glands. These clusters are called *islets of Langerhans*, or pancreatic islets, and they consist of alpha and beta endocrine cells.

These cells release their secretions into the blood or lymph. Although these secretions have no direct digestive function, they do play a role in the utilization of glucose. The function of the islets of Langerhans is discussed in more detail in the section on the endocrine system. The pancreatic juice contains the enzymes *amylase*, *lipase*, *trypsin*, *chymotrypsin*, and *carboxypeptidase*. Like the salivary amylase, pancreatic amylase breaks down complex carbohydrates into disaccharides. The action of pancreatic amylase is similar but more effective than gastric lipase. Pancreatic lipase breaks down fats into fatty acids and glycerol. Trypsin, chymotrypsin, and carboxypeptidase are *protease enzymes*. Like gastric pepsin, they break down various protein molecules. Inactive proteases are stored in cellular structures called *zymogen granules*. They are activated by other enzymes after they enter the alimentary canal. There are also two forms of *nuclease* in the pancreatic juice. These nucleases reduce nucleic acid molecules. All these enzymes and nucleases are carried in a strong alkaline solution.

The release of pancreatic secretions is controlled by hormonal and neurological factors. Parasympathetic impulses are sent to the pancreas during the various phases of gastric digestion. Additional parasympathetic impulses are triggered by the entry of chyme into the duodenum. Contact with chyme causes the duodenal mucosa to release the hormone *secretin*, which stimulates the release of pancreatic juice. Chyme contact also causes another pancreas-stimulating hormone, *cholecystokinin*, to be released. Secretin stimulates release of pancreatic juice that has a high concentration of alkaline solution and a low concentration of digestive enzymes. Cholecystokinin, on the other hand, produces a pancreatic juice with a high concentration of digestive enzymes.

You should now have a basic knowledge and understanding of the organs of digestion and the digestive process. Before moving on to the next system, the endocrine system, answer the following questions. Review the areas you haven't fully grasped.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

214. Digestive system and the alimentary canal

1. What is the tube that goes from the mouth to the anus called?
2. Name the four layers of the alimentary canal wall.
3. What are the wavelike contractions that push food through the alimentary canal called?

215. Structures of the mouth and pharynx and their role in digestion

1. What digestive function is deglutition?
2. What gives the lips great flexibility and mobility?
3. What muscles are located in the cheeks?

4. What structures form the roof of the mouth?
5. What type of tongue muscles allows the tongue to change size and shape?
6. What attaches the tongue to the floor of the mouth?
7. Which teeth have sharp, flat edges and are designed to penetrate and cut through tough foods?
8. What substance is secreted by the salivary glands?
9. Name the three sets of major salivary glands.
10. What enzyme is found in the watery fluid secreted by the parotid glands?
11. Where are the submandibular glands located?
12. Which set of salivary glands are the smallest in size?
13. What structure connects the nose and mouth with the esophagus and trachea?

216. The esophagus and stomach

1. What is the function of the esophagus?
2. List the four divisions of the stomach.
3. What structure cushions the intestines and acts as a storage place for fat?
4. What structure controls the release of stomach contents to the small intestine?

5. Name the three types of secretory cells in the stomach.
6. What enzyme is responsible for digesting or breaking up dietary proteins?
7. Gastric gland secretion is the result of what factors?
8. What are the three phases of gastric digestion?
9. What is chyme?
10. What does the hormone enterogastrone do?

217. The intestinal tract

1. Name the three sections of the small intestine.
2. What opening in the duodenum receives secretions from the liver, pancreas, and gallbladder?
3. Approximately how long are the jejunum and the ileum?
4. What three structures serve to increase the surface area of the small intestine?
5. Name the mucous-secreting glands found in the first part of the duodenum.
6. List the five enzymes responsible for the chemical breakdown of food located in the small intestine.
7. Carbohydrates are chemically broken down into what?

8. What structure marks the junction of the small and large intestine?
9. Name the three major sections of the large intestine.
10. What structure extends down from the lower end of the cecum?
11. Name the four sections of the colon.
12. What is the superior margin of the internal anal sphincter muscle called?
13. What are columns of Morgagni?
14. What is the most significant difference between the wall of the small and large intestine?
15. What attaches the transverse colon to the posterior abdominal wall?
16. What factor initiates the defecation reflex?
17. What is developed as a result of bacterial action in the large intestine?

218. Accessory organs of digestion

1. What digestive accessory organ is considered to be the largest gland in the body?
2. What are the phagocytic cells that line hepatic sinusoids called?
3. What two ducts combine to form the common bile duct?
4. List the three functions of the liver.

5. What is the function of the gallbladder?
6. What triggers the release of bile from the gallbladder into the common duct?
7. What are the little clusters of endocrine cells embedded among the acinar glands of the pancreas called?
8. What hormone secreted by the duodenal mucosa triggers the release of pancreatic juice?

3-2. The Endocrine System

In the previous units, we frequently mentioned substances called hormones that acted to regulate various body processes. In fact, the reproductive system is almost totally controlled by hormones! The hormones that are found in the reproductive system, as well as the hormones that are found throughout the rest of the body, are chemical substances that are secreted by specialized cells and glands. These cells and glands make up the system we call the endocrine system.

The endocrine system interacts with the nervous system to exercise control over various body activities. This control is established through the actions of the hormones that are secreted directly into the interstitial fluid. The hormones then travel through the bloodstream until they reach the part of the body that contains the appropriate receptors. The hormones stimulate these receptors to produce a specific type of activity from that body part. Through the activities of these hormones, the endocrine system regulates metabolic activities of the body and helps to maintain body homeostasis.

219. Basic characteristics of endocrine glands and hormone activity

The endocrine system is unlike any of the other systems we have discussed. The functions are very diverse and the glands are spread throughout the body. We discuss it as a system simply because of the common characteristics among its components—secreting *hormones* into the body's internal environment. Collectively, the glands of the endocrine system function to help regulate metabolic processes, aid in the transportation of chemicals through membranes, regulate chemical reactions, help control water and electrolytic balances, and control the rate of chemical reactions. In addition, endocrine hormones also play a vital role in the growth and reproductive processes. As you will see from studying the various functions of this system, some of its effects are very quick, while some are spread out over a lifetime. We begin this system with a discussion of hormones.

A hormone is a substance secreted by a specialized cell that has an effect on another cell or tissue. Normally the effect has to do with the metabolic activity of the cell or tissue. The word “hormone” literally means “to excite” or “to arouse.” Normally, hormones stimulate or inhibit metabolic activity but generally do not initiate a process. In this light, hormones affect certain cells by stimulating or inhibiting the cells' metabolic rate.

General chemical characteristics

Hormones are organic substances with very specialized molecular structures. They fall into five general categories, depending on the substance from which they are produced.

Hormones	Explanation
Amines, amino acid	Are produced from an amino acid. You are already familiar with two of the amines, epinephrine and norepinephrine synthesized in the adrenal medulla and certain neurons.
Peptides, amino acid	Are also derived from amino acids. Some of these are associated with the posterior pituitary gland and the hypothalamus.
Proteins, amino acid	Composed of amino acids, are produced by the anterior pituitary gland and the parathyroid gland.
Glycoproteins, protein and carbohydrates	Are produced in the anterior pituitary gland. These hormones are based on protein and carbohydrate molecules.
Steroids, carbon, and hydrogen atoms	Are compounds whose molecules are made up of carbon and hydrogen atoms. Different steroids have different molecular structuring. These groups include the hormones produced by the ovaries and testes of the reproductive system and those secreted by the adrenal cortex.

Actions of hormones

You now know that hormones are produced in various parts of the body, released into the blood, and are made up of different substances and molecular structures. How does the hormone “know” what tissues or cells to stimulate or inhibit when flowing through the blood? The answer is not with the hormone, but rather with the tissue and cells that the hormones act upon.

Because some 30 to 40 different types of hormones are in the blood at any given time, the ability of a hormone to influence a cell depends upon the presence of a receptor molecule in the cell or its membrane. Thus, the cell or its membrane “attracts” the hormone. The cells associated with a particular hormone (i.e., those that can be influenced) are called *target cells*. Think of the process like this: the endocrine gland shoots out (secretes) a hormone into the blood; it travels through the circulatory system until it hits the right “target” (effector tissue). In other words, the target cell receptors are sensitive to certain hormones that other cells do not have receptors for. Some hormones travel great distances to reach the target cells while others are very close to their target. Target cells may be general in nature (i.e., they may be affected by many different hormones). General target cells may be found in tissues of an organ or even another endocrine gland.

Many protein, peptide, and amino hormones cannot pass through a cell’s membrane. In such instances, they combine with specific receptors in the cell membrane and activate an enzyme on the other side of the membrane. This enzyme catalyzes adenosine triphosphate (ATP) to become adenosine monophosphate or cyclic adenosine monophosphate (AMP). The AMP then triggers another set of protein enzymes to change the cell’s metabolism. In this way, these hormones use a “second messenger” to effect a change. The information is delivered to the target cell’s membrane which triggers an intracellular enzyme reaction, which in turn, leads to the cellular response to the hormone. Steroid-type hormones, unlike the ones mentioned above, can pass through or dissolve through the lipid layer of the cell membrane. They can enter a cell very easily. Once inside the cell, they combine with protein molecules. This complex of steroids and protein can then enter the nucleus of the cell and activate genes. This produces messenger molecules from the nucleus which can enter the cytoplasm causing the cell to manufacture specific proteins.

As you can see, a cell’s response to a hormone is determined by the type of protein molecules it contains. The cell’s response or the action of the hormone can alter membrane permeability, induce the synthesis of enzymes and proteins, stimulate or inhibit specific metabolic pathways, promote cellular movement, or cause other hormone secretions. Most effector organs, with the exception of muscle, are regulated by both nerve and endocrine systems. Each system uses secretions to hit the target cells; each helps to maintain the balance between the organism and its environment.

220. Endocrine system anatomy and hormone physiology

The endocrine system consists of organs, often called glands, located throughout the body. These organs include the following:

- Pituitary gland.
- Pineal gland.
- Thyroid gland.
- Parathyroid glands.
- Adrenal glands.
- Pancreas.
- Other endocrine glands.

Each of these glands secretes certain hormones, and each hormone produces a different action.

Pituitary gland

The pituitary gland or *hypophysis* is about the size of a marble and is located in the base of the brain (fig. 3-7) in a depression of the sphenoid bone called the *sella turcica* or Turk's saddle. It is connected to the *hypothalamus* by a funnel-shaped stalk of tissue called the *infundibulum*. The pituitary gland is often referred to as the master gland because the hormones it secretes exert a regulatory effect over the activity of all other endocrine glands.

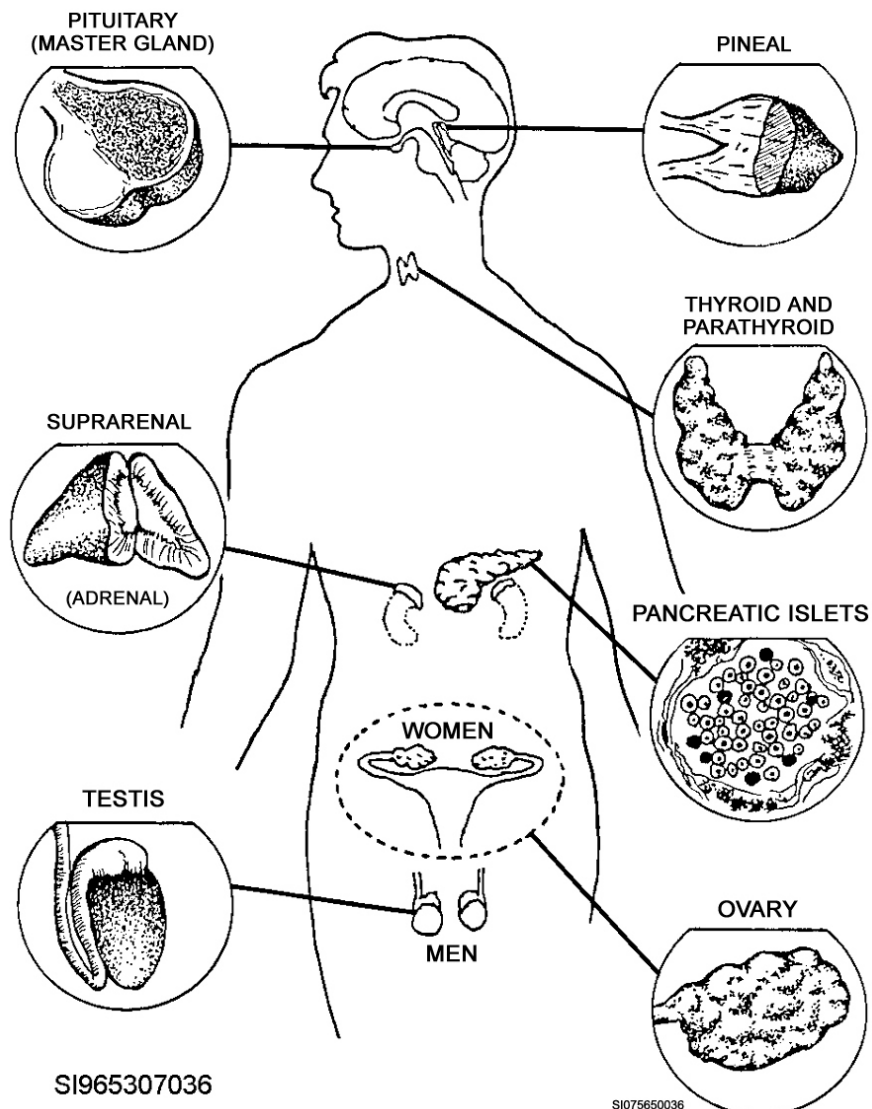


Figure 3-7. Endocrine glands.

The pituitary gland is divided into anterior and posterior lobes. The anterior lobe is derived from tissues of the mouth which differentiate to form glandular tissue. Because of the glandular cells found in this lobe, it is also called the *adenohypophysis*. The posterior lobe is derived from the brain and is composed chiefly of nervous tissue. As a result of its origins, the posterior lobe is sometimes called the *neurohypophysis*. Because of their different origins and tissue composition, the two lobes are essentially two different endocrine glands. They are commonly called the anterior and posterior pituitary glands. Let's discuss the anterior pituitary gland first.

Anterior pituitary gland

The anterior lobe of the pituitary gland (fig. 3-8) is the larger of the two lobes and secretes more hormones than the posterior lobe. Seven hormones are produced and secreted by the anterior lobe.

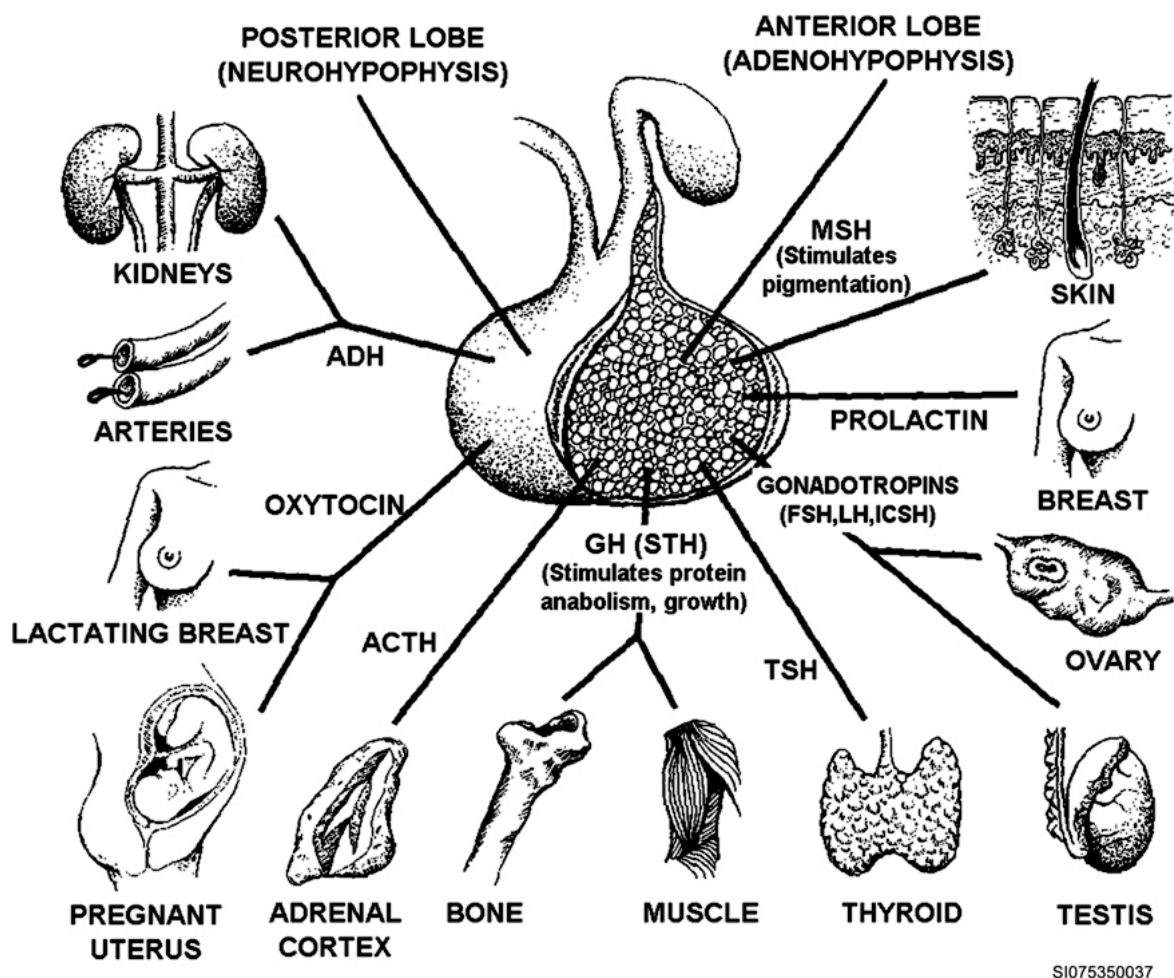


Figure 3-8. Pituitary hormones and target organs.

Tropic or Trophic Hormones	
Hormone	Function
Thyrotropic or thyroid-stimulating hormone (TSH)	Helps regulate the production of the thyroid gland's hormones.
Adrenocorticotrophic hormone (ACTH)	Controls the manufacture and secretion of certain hormones from the cortex of the adrenal gland.

Tropic or Trophic Hormones	
Hormone	Function
Follicle-stimulating hormone (FSH)	<p>Acts differently depending on sex.</p> <ul style="list-style-type: none"> In the female, FSH promotes the growth of the ovarian follicles which produces the egg and estrogen. In the male, FSH stimulates the development of the seminiferous tubules and maintains the production of sperm.
Luteinizing hormone (LH) and interstitial cell-stimulating hormone (ICSH)	<p>Both produce different effects in each sex.</p> <ul style="list-style-type: none"> In females, the hormone is called LH because it stimulates further development of the egg and its release. It also stimulates the formation of the corpus luteum which produces estrogen. LH is called ICSH in males because it stimulates interstitial cells in the testes to develop and secrete testosterone.

These four hormones (LH and ICSH are considered to be the same hormone) are commonly called *tropic* or *trophic hormones* because they have a stimulating effect on other endocrine glands. Look at the names of the hormones. You should be able to figure out what target organ or tissues the hormone stimulates by breaking the word down into its parts. For example, adrenocorticotrophic hormone (ACTH) is a hormone that affects the growth or development (-trophic) of the hormones produced by the cortex (cortico-) of the adrenal (adreno-) gland. The acronym associated with the hormone (in this case, ACTH) should help you remember the hormone and its function. The two hormones which act on the male and female reproductive organs, FSH and LH, are sometimes referred to as *gonadotropic hormones* because the sex organs are also called *gonads*.

Other Hormones	
Hormone	Function
Somatotrophic hormone (STH) or growth hormone (GH)	Stimulates the growth of the body in relation to body weight and rate of skeletal growth.
Lactogenic hormone (LTH) or prolactin	Stimulates the production of milk by the mammary glands and general development of the mammary glands during pregnancy.
Melanocyte-stimulating hormone (MSH)	Stimulates the laying down of melanin in the skin for pigmentation.

Posterior pituitary gland

The posterior pituitary gland (refer back to fig. 3-8) secretes at least two known hormones—antidiuretic hormone (ADH) and oxytocin.

Antidiuretic hormone

ADH plays a very important role in the control of water volume excreted by the kidneys. A *diuretic* is a substance that increases the production of urine, so an antidiuretic helps limit the volume of urine excreted. This is particularly important following severe bleeding. If blood volume is lost, ADH secretion is increased to help retain blood volume and blood pressure. If, on the other hand, a person drinks an excessive amount of water, ADH secretion is decreased and the kidneys excrete more dilute urine. The release of ADH is regulated by the hypothalamus, which uses osmoreceptors (water concentration receptors) and pressure receptors (blood pressure/volume receptors) as sensory input.

Oxytocin

Oxytocin is the other hormone released by the posterior pituitary. It is also an antidiuretic but is much weaker. Its prime function is to promote generalized smooth muscle contraction. It is especially plentiful during the later stages of childbirth where it plays a key role in promoting uterine contraction during labor. In addition, it aids in the secretion of milk from the mammary glands in lactating women. Milk secretion is initiated by sensory impulses initiated by the sucking action on the

nipples. These sensory impulses are relayed to the hypothalamus, which, in turn, sends a signal to the posterior lobe of the pituitary telling it to release oxytocin. The oxytocin causes the smooth muscles in the mammary gland of the female breast to contract, thereby promoting the excretion of the milk. Although present in the male's posterior pituitary gland, oxytocin has no established function.

Pineal gland

The pineal gland, also called the pineal body or epiphysis cerebri (refer back to fig. 3-7), is located deep between the cerebral hemispheres in the brain. It is not well understood, so it is often called the mystery gland. It produces at least one known hormone called *melatonin*, thought to control the biological clock in some animals. Its suggested function in humans seems to be a control mechanism for the onset of puberty and other body stages associated with aging. The gland seems to respond to varying light conditions. Apparently, light reaches the gland by way of nerve fibers from the retina of the eye; a decrease in light exposure seems to increase the secretion of melatonin. It also is thought to help control the menstrual cycle in women by influencing the release of gonadotropins. A second hormone, *adrenoglomerulotropin*, may be secreted by the pineal to affect the adrenal glands' secretion of aldosterone.

Thyroid gland

The thyroid gland is a very vascular gland that lies just below the larynx, on both sides, and in front of the trachea (refers back to fig. 3-7). It consists of two wing-shaped lobes connected by a narrow bridge of tissue called the *isthmus*. The thyroid gland produces three hormones:

1. Calcitonin.
2. Thyroxine.
3. Triiodothyronine.

Calcitonin influences the calcium and phosphate levels in the blood. It accomplishes this function by inhibiting the rate at which these substances leave the bones and enter the extracellular fluids. It also affects the kidneys by increasing the amount of calcium and phosphate that is excreted. Both actions help decrease the blood levels of calcium and phosphorus.

Thyroxine and triiodothyronine are synthesized from iodine and are discussed together as their functions are similar. They function to regulate the body's metabolism by providing an oxidative catalyst. An oxidative catalyst provides oxygen for the production of tissue energy. These hormones are vital for normal growth and development of children and for the maturing process of the nervous system. When the secretion of these hormones increases, there is a corresponding increase in metabolic rate and energy consumption.

Hypersecretion of thyroxine and triiodothyronine (hyperthyroidism) causes a condition known as *exophthalmic goiter* (Grave's disease). This disease is characterized by moderate enlargement of the thyroid gland (goiter), protrusion of the eyeballs (that's where the term *exophthalmic* came from), and a high basal metabolism rate. Exophthalmic goiter should not be confused with *simple goiter*, which is an enlargement of the thyroid gland caused by a deficiency of iodine in the diet. To help reduce the incidence of simple goiter, iodine is included with the everyday table salt that we use to season our food (that's why the salt container labels read, "iodized salt").

Parathyroid glands

The parathyroid glands, as the name implies, lie on either side of the posterior thyroid gland. They are small, brownish-yellow glands ranging in number from two to ten, but usually four. Unlike the other endocrine glands, the parathyroids are not controlled by any known secretion of the pituitary gland. Release of parathyroid hormones is regulated by the amount of calcium ions in the blood.

The glands are about 0.5 centimeter (cm) in diameter, very vascular, and contain two different kinds of cells—*oxyphil cells* and *chief cells*. The oxyphil cells' function is not clear; the chief cells produce

parathyroid hormone (PTH), also known as *parathormone*. This hormone is essential to life because it regulates the calcium and phosphate levels in the blood. The target cells for this hormone are the tubules of the kidney, the bone, and (indirectly) the intestine. In simple terms, PTH stimulates the release of calcium from the bones (thereby increasing blood calcium levels), activates vitamin D to do the same, lowers phosphate levels in the blood, and stimulates calcium reabsorption by the kidneys. A proper calcium level in the blood is needed for nerve and muscle function, blood clotting, bone metabolism, and cell membrane permeability.

Calcitonin, which is produced by the thyroid gland, works in direct opposition to parathyroid hormone to balance the level of calcium in the blood. Calcitonin works to provide a reduction of blood calcium levels when they are too high, whereas PTH causes an increase in calcium levels.

Hypersecretion of parathyroid hormone (hyperparathyroidism) can cause calcium to leech out of the bones. If uncorrected, the bones become soft and deformed, and eventually may develop holes in their structure (a condition called osteoporosis). This can lead to spontaneous bone fractures and other complications. In addition, the excess amounts of calcium and phosphorus in the blood and interstitial fluid can lead to the formation of crystallized deposits in certain areas of the body, such as the kidneys. Eventually, these deposits turn to stones, which can also cause serious complications.

Hyposecretion of PTH (hypoparathyroidism) can seriously reduce blood calcium levels and create a condition called *hypocalcemia*. Hypocalcemia produces neuromuscular irritability, which triggers muscle cramps and spasms, and can lead to uncontrolled muscle contraction throughout the body—a condition known as *tetany*. In severe cases, seizures can develop and the patient may die. Because the parathyroid glands are so small, so closely associated with the thyroid gland, and so important to proper function of the skeletal muscles, surgeons take great care when excising portions of the thyroid gland. This is necessary to ensure enough parathyroid tissue remains to secrete the PTH needed to adequately regulate blood calcium levels. If you scrub on a thyroidectomy, you will notice that the surgeon takes numerous tissue samples to send for frozen section so the pathologist can tell if the thyroid tissue also contains parathyroid tissue. These multiple specimens help the surgeon gauge how much thyroid tissue can be safely removed without destroying PTH secretion.

Adrenal glands

The adrenal glands, also called the suprarenal glands, are located on top of each kidney like little caps (refer back to fig. 3-7). Each adrenal gland is made up of two parts, the outer layer or *cortex* and a middle layer called the *medulla*. Although the parts are not distinctly separated structurally, the hormones each part produces vary considerably. Let's first discuss the medulla of the gland and the hormones it produces.

Adrenal medulla

The cells in this portion of the gland receive sympathetic nervous stimulation from preganglionic neurons. Unlike the other effector organs, the medulla receives its stimulation without the extra neuron, the sympathetic postganglionic neuron. The medulla is actually modified sympathetic postganglionic neurons! The hormones secreted from the adrenal medulla are *epinephrine* and *norepinephrine*. The sympathetic impulses from the hypothalamus trigger their release to prepare the body for stressful or energy expending activity. (Remember the “fight-or-flight” reaction we discussed in the unit on the nervous system?) In a nutshell, both these hormones cause an increase in heart rate, blood pressure, and breathing rate. They also decrease the activity of the digestive system. As you may recall, the effects of epinephrine and norepinephrine on the body closely resemble those caused by sympathetic nerve impulses to effector organs. Sympathetic nervous stimulation gets the effector organs “warmed up” and the hormones released in the blood stream maintain the responses. In other words, the hormones perpetuate the energy-releasing responses initiated by sympathetic nervous stimulation.

Epinephrine also constricts peripheral blood vessels and dilates bronchioles. These characteristics make it a useful drug in its synthetic form. As you should already know, epinephrine is added to local

anesthetic agents to reduce local capillary bleeding and to prolong the action of the agent. Because of its bronchodilating effects, it is also used in treating bronchial asthma. It is also used during cardiac resuscitation to stimulate the heart muscle to contract.

Adrenal cortex

This part of the adrenal gland also secretes hormones; however, unlike the hormones produced by the medulla of the adrenal, the effects of the hormones produced by the cortex of the adrenal are vital—a person can die within weeks without them. Although the cortex produces over 30 different hormones, we only discuss the three most important ones—aldosterone, cortisol, and the sex hormones.

Hormone	Function
Aldosterone	Functions to regulate the concentration of mineral electrolytes. The main electrolytes are <i>sodium</i> and <i>potassium</i> . Specifically, the aldosterone helps to conserve sodium and causes potassium to be excreted. It also plays a role in water retention and reduction of urine output.
Cortisol (commonly called <i>hydrocortisone</i>)	Helps keep the blood glucose level stable between meals by promoting glycogen synthesis in the liver. It also acts to help block the inflammation of tissues subjected to stress, and reverse inflammatory processes such as rheumatoid arthritis and allergies.
Sex hormones	The function of the sex hormones produced by the adrenal cortex is not well understood. They are thought to supplement the hormones produced by the gonads. In addition, they are believed to stimulate the early development of the reproductive organs and the female sex drive. Male adrenal sex hormones are called <i>androgens</i> ; female sex hormones are called <i>estrogens</i> .

Pancreas

The pancreas (refer back to fig. 3-7) is an elongated gland that lies behind the stomach and next to the first part of the small intestine, the duodenum. The cells of the pancreas have two functions—one group of cells produces digestive enzymes and releases them to the duodenum, and the other group of cells produces hormones. Since we already covered the digestive role of the pancreas, its role as a hormone-producing endocrine gland is the subject of our discussion.

Within the pancreas there is a group of three types of cells that produce hormones.

Cells	Hormone Produced
Alpha cells	Glucagon
Beta cells	Insulin
MDUL delta cells	Somatostatin

Collectively, the group of cells that produce hormones is called *islets of Langerhans*. Let's discuss the function of these hormones.

Glucagon stimulates the liver to convert glycogen to glucose and to convert non-carbohydrates into glucose. It also stimulates the breakdown of fats into glycerol and fatty acids. Insulin does just the opposite. It stimulates the liver to produce glucagon from glucose and inhibits the conversion of non-carbohydrates into glucose. A system of “checks and balances” is set up. The action and interaction of these two hormones helps keep the glucose level of the blood stable.

When too little insulin is secreted by the pancreas (hypoinsulinism), carbohydrate, protein, and fat metabolic processes are severely disrupted. Glycogen formation is decreased which causes a rise in blood sugar levels. The excess sugar begins to be excreted by the kidneys and appears in the urine. The excess sugar in the urine increases the osmotic pressure, which causes more electrolytes and water to be excreted from the kidneys. The increase in urine output and water loss causes the person to become dehydrated and chronically thirsty. The condition just described is known as *diabetes mellitus*. Regulation of sugar-producing food and beverage consumption (e.g., alcohol, breads, pasta, raw sugar, and sweets) helps lessen the side effects of mild diabetes mellitus. In more severe cases, parenteral administration of synthetic insulin is required to control carbohydrate metabolism.

Diabetes mellitus should not be confused with another form of diabetes, *diabetes insipidus*, which has nothing to do with the pancreatic hormones. Diabetes insipidus is characterized by severe diuresis and is caused by insufficient antidiuretic hormone secretion by the posterior lobe of the pituitary gland. This lack of ADH results in insufficient water reabsorption in the kidney tubules, and produces greater amounts of urine of low concentration.

The third hormone produced in the islets of Langerhans, somatostatin, is believed to function as a regulator of glucagon and insulin.

Other endocrine glands

The endocrine glands presented are the major ones you will encounter. There are other glands in the reproductive and digestive systems that secrete important hormones. We have already mentioned those in the digestive system, and will discuss the endocrine glands of the male and female reproductive systems (testes and ovaries) in the next unit.

As you can see, the endocrine system, in conjunction with the nervous system, very carefully monitors the body's internal environment. It is a delicate balance between the body's needs and the electrochemical substances that give the body its state of homeostasis.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

219. Basic characteristics of endocrine glands and hormone activity

1. What does the word "hormone" mean?
2. List the five types of hormones and the substance from which they are produced.
3. What is the name given to cells that can be influenced by hormones?
4. What enables a hormone to influence a target cell?
5. Briefly describe the process by which hormones that cannot pass through a cell membrane effect a change on a cell.
6. What type of hormone easily passes through a cell membrane?
7. What determines a cell's response to a hormone?

220. Endocrine system anatomy and hormone physiology

1. List the seven hormones produced by the anterior pituitary gland.
2. Which hormone produced by the posterior pituitary gland plays an important role in water volume regulation?
3. Which pituitary hormone is primarily responsible for growth?
4. Where is the pineal gland located, and what hormone does it produce?
5. What two hormones produced by the thyroid gland are vital for normal growth in children and maturing of the nervous system?
6. List the two hormones secreted by the adrenal medulla.
7. Which type of pancreatic cell produces insulin?

Answers to Self-Test Questions**214**

1. The alimentary canal.
2. Mucosa (mucous membrane), submucosa, muscularis externa, and serosa.
3. Peristalsis.

215

1. Swallowing.
2. Skeletal muscle.
3. Buccinator muscles.
4. The hard and soft palates.
5. The intrinsic muscle.
6. The frenulum.
7. Incisors.
8. Saliva.
9. Parotid, submandibular, and sublingual.
10. Amylase.
11. In the floor of the mouth along the medial surface of the mandible.

12. Sublingual glands.
13. The pharynx.

216

1. To transport food from the pharynx to the stomach.
2. Cardiac, fundic, body, and pyloric region.
3. The greater omentum.
4. The pyloric sphincter.
5. Mucous, chief, and parietal cells.
6. Pepsin.
7. Interaction of neurological, chemical, and physical factors.
8. Cephalic or head phase, gastric, and intestinal phase.
9. Semiliquid state of food that is a mixture of food particles mixed with gastric juices.
10. It slows down peristalsis.

217

1. Duodenum, jejunum, and ileum.
2. The ampulla of Vater.
3. The jejunum is about 8 feet long, and the ileum is about 12 feet long.
4. The plicae circulares, villi, and microvilli.
5. Brunner's glands.
6. (1) Peptidases, (2) sucrase, (3) maltase, (4) lactase, and (5) intestinal lipase.
7. Monosaccharides (the simplest form of sugar).
8. The ileocecal valve.
9. Cecum, colon, and rectum.
10. The vermiform appendix.
11. Ascending, transverse, descending, and sigmoid colon.
12. The pectinate line.
13. Longitudinal folds containing an artery and a vein just above the anal canal. Also called anal columns.
14. The structure of the muscular layer.
15. A fold of parietal peritoneum called transverse mesocolon.
16. When fecal material moves from the colon into the rectum, receptors are stimulated to trigger the reflex.
17. Gas (flatus).

218

1. The liver.
2. Kupffer cells.
3. The common hepatic duct and the cystic duct.
4. (1) Forms bile; (2) is involved in the metabolism, or cellular utilization of fats, carbohydrates and proteins; and (3) detoxifies harmful substances.
5. To store and concentrate bile, and release it when needed.
6. Hormonal and mechanical stimulation.
7. Islets of Langerhans or pancreatic islets.
8. Secretin.

219

1. To excite or to arouse.
2. (1) Amine, amino acid; (2) peptide, amino acid; (3) protein, amino acid; (4) glycoproteins, protein and carbohydrates; (5) steroids, carbon and hydrogen atoms.

3. Target cells.
4. Receptor molecules.
5. The hormones combine with specific receptors in the cell membrane, which then activate a “second messenger” enzyme on the other side of the membrane. The “second messenger” enzyme triggers the conversion of ATP to AMP which, in turn, activates protein enzymes within the cell. The activated protein enzymes trigger intracellular changes.
6. A steroid.
7. The kinds of protein molecules it contains.

220

1. (1) Thyrotropic or thyroid-stimulating (TSH), (2) adrenocorticotrophic (ACTH), (3) follicle-stimulating (FSH), (4) luteinizing (LH) and interstitial cell-stimulating (ICSH), (5) somatotrophic (STH) or growth (GH), (6) lactogenic (LTH), or (7) prolactin, and melanocyte-stimulating hormone (MSH).
2. The antidiuretic hormone (ADH).
3. Somatotrophic hormone (STH), also called the growth hormone (GH).
4. It is located deep between the cerebral hemispheres and produces melatonin.
5. Thyroxine and triiodothyronine.
6. Epinephrine and norepinephrine.
7. The beta cells.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to a field scoring answer sheet.

Do not return your answer sheet to AFCDA

30. (214) The digestive tract is also called the
- a. small intestine.
 - b. large intestine.
 - c. esophagus.
 - d. alimentary canal.
31. (214) The serous membrane lining the abdominal cavity is called the
- a. perineum.
 - b. peristalsis.
 - c. periosteum.
 - d. peritoneum.
32. (214) Which is a function of the serosa layer of the alimentary canal?
- a. Protection.
 - b. Absorption.
 - c. Elimination.
 - d. Transportation
33. (215) How many permanent teeth are *normally* in the adult mouth?
- a. 20.
 - b. 24.
 - c. 28.
 - d. 32.
34. (215) Which is *not* a type of salivary gland?
- a. Parotid.
 - b. Adrenal.
 - c. Sublingual.
 - d. Submandibular.
35. (216) The tube that connects the pharynx with the stomach is the
- a. colon.
 - b. trachea.
 - c. bronchus.
 - d. esophagus.
36. (216) Which sphincter muscles prevent gastric juices and food particles from regurgitating into the esophagus while peristalsis takes place in the stomach?
- a. Cystic.
 - b. Pyloric.
 - c. Cardiac.
 - d. Ileocecal.

37. (216) The external serous layer of the stomach, which extends from the stomach to other abdominal organs, cushioning the intestines and acting as a storage place for fat, is the
- rugae.
 - vesicles.
 - omentum.
 - gastric pits.
38. (217) Which part of the small intestine is the smallest and receives food from the stomach?
- Colon.
 - Ileum.
 - Cecum.
 - Duodenum.
39. (217) Which structure is *not* a section of the large intestine?
- Ileum.
 - Colon.
 - Cecum.
 - Rectum.
40. (218) The common bile duct is formed by the union of the cystic
- artery and hepatic duct.
 - artery and cystic duct.
 - duct and hepatic duct.
 - duct and hepatic vein.
41. (218) Which accessory digestive organ detoxifies harmful substances such as the end products of protein digestion?
- Liver.
 - Ileum.
 - Pancreas.
 - Gallbladder.
42. (218) When cholesterol precipitates out of a concentrated bile solution,
- enzymes and nucleases are produced.
 - secretin is released from the pancreas.
 - blockage of the pancreatic duct occurs.
 - gallstones are likely to form in the gallbladder.
43. (219) Normally, most hormones affect cells by
- initiating phagocytosis.
 - initiating cellular reproduction.
 - dissolving the cells' membrane and nucleus.
 - stimulating or inhibiting the cells' metabolic rate.
44. (220) The general location of the thyroid gland is
- just below the larynx.
 - on top of each kidney.
 - next to the duodenum.
 - between the cerebral hemisphere.

45. (220) The adrenal glands are located

- a. just below the larynx.
- b. on top of each kidney.
- c. next to the duodenum.
- d. between the cerebral hemisphere.

46. (220) Which endocrine gland is responsible for the secretion of insulin?

- a. Pineal.
- b. Adrenal.
- c. Thyroid.
- d. Pancreas.

Unit 4. The Urinary and Reproductive Systems

4–1. The Urinary System	4–1
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WHEN any body system is mentioned it is easy to say, “This is the most important one.” However, the body is designed to run smoothly only if all systems are working in unison. If most of the systems are working together and just one fails to function properly, then the body’s internal balance is disrupted. The urinary system is particularly important in eliminating the waste byproducts of metabolism. If the kidneys (the main organs within this system) malfunction, toxic chemicals build up in the blood stream, and literally poison the cells of all other body systems. Death eventually occurs if steps are not taken to correct the problem. In addition, the urinary system plays a vital role in regulating and maintaining fluid and electrolyte balance within the body.

Another body system that shares many of the same structures with the urinary system is the reproductive system. Although having a fully functional reproductive system is not absolutely essential for day-to-day survival, it goes without saying that this system is important. Why? Because without functional male and female reproductive systems, the human species would not be able to perpetuate itself, and would soon become extinct. The function of the other body systems would be of little concern if there were no living bodies around!

Although the urinary and male and female reproductive systems have vastly different functions, we will discuss them both in this unit because they share so many anatomical structures. We begin by taking a look at the structures that comprise the urinary system and how they help maintain homeostasis. Then, we discuss the anatomical and physiological processes associated with the male and female reproductive systems.

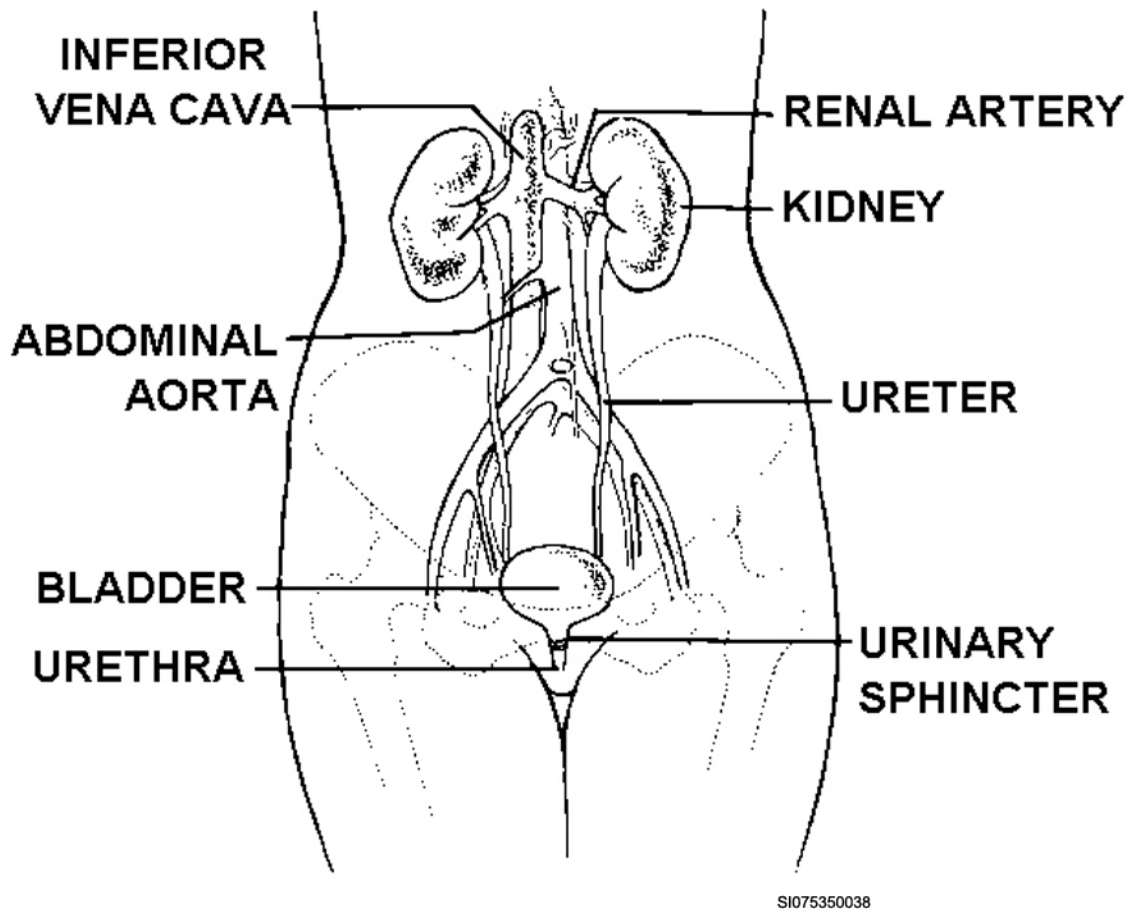
4–1. The Urinary System

The urinary, or renal, system is one of the most remarkable systems in the body. Most of us think that the urinary system simply forms urine. Although urine production and excretion is one of its primary functions, the renal system also plays a major role in regulating blood pressure and volume, fluid balance and homeostasis, and red blood cell production. The basic function of urine production and elimination is relatively simple, but the mechanism through which the renal system maintains homeostasis is quite detailed. This section explores the structures of the urinary system and their functions, with special emphasis on the kidneys.

221. Anatomy of the kidney

The urinary system (fig. 4–1) is made up of two kidneys, two ureters, which transport urine to the bladder, and a urethra (which conveys the urine from the bladder to the outside of the body). The kidneys are the main functional organs of the system—the remainder of the system is basically

“plumbing.” In this lesson, you will learn about the location and external appearance of the kidneys, and the intricate internal structure of these remarkable organs. We begin by discussing the external characteristics and location of the kidneys.



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Figure 4-1. Gross anatomy of the urinary system.

External structure and location

The kidneys are a pair of bean-shaped organs about 4.5 inches long, 2.5 inches wide, and about 1 inch thick. They are located in deep depressions high in the abdominal cavity behind the parietal peritoneum (in the retroperitoneal space) on either side of the vertebral column. A heavy cushion of fat holds the kidneys in position. Further support and protection is provided by the *renal fascia*, which connects the kidneys to surrounding structures. Because of the kidneys' posterior location, the deep muscles of the back also provide protection. The kidneys are reddish brown in color and have a smooth fibrous surface underlying the renal fascia. This fibrous sheath is called the *tunica fibrosa*, or *Gerota's capsule*. Although the kidneys move slightly with breathing and general postural changes, they are normally located between the levels of the twelfth thoracic vertebra and the third lumbar vertebra. The left kidney is usually positioned about an inch higher than the right. This is because the liver occupies a great deal of space on the right side of the abdominal cavity and pushes down on the right kidney.

The lateral surface of each kidney is convex while the medial side of each is concave. The concavity gives rise to a hollow chamber called the *renal sinus*; the entrance to the sinus is called the *hilum*. The renal artery, which rises from the abdominal aorta; the renal vein, which empties into the inferior vena cava, lymph vessels, nerves; and a ureter all pass through the hilum into each kidney (fig. 4-2).

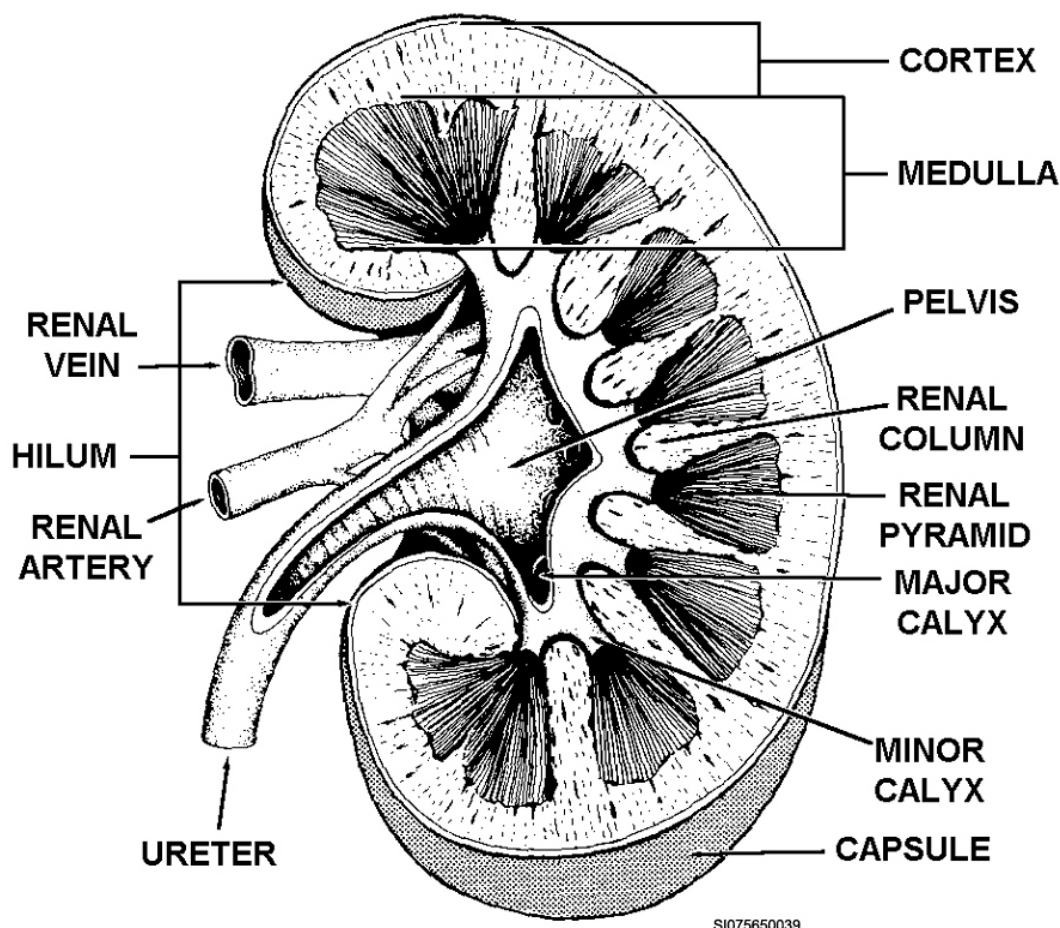


Figure 4-2. Internal structure of the kidney (coronal section, left kidney).

Internal structure

When the kidney is cut in half lengthwise (fig. 4-2), specific anatomical areas and structures can be readily identified. There are two main regions within the kidney. The inner region is called the *medulla*. The outermost region, lying just beneath Gerota's capsule, is called the *cortex*.

Medulla

The medulla is composed of tissue lighter in color than that of the cortex and contains the *renal pyramids*. These are funnel or pyramid-shaped structures (hence, the name renal pyramids), which contain collecting tubules and have a striated appearance. (The collecting tubules within the pyramids are responsible for the striated appearance.) Tissue from the cortex projects between adjacent renal pyramids to form the *renal columns*. The apices of the pyramids project toward the center or hilum of the kidney, while the bases face the cortex. The narrow apex of each pyramid forms a *renal papilla*, which projects into a small, tube-shaped collecting chamber called a *minor calyx*. The minor calyces (the plural of calyx) join together to form larger collecting areas called *major calyces*. Each papilla contains several small openings through which urine passes from the collecting tubules of the renal pyramids into the minor and major calyces. The major calyces empty urine into a large central cavity called the *renal pelvis*. From the renal pelvis, urine then passes into the expanded proximal end of the ureter, which joins with the kidney at the hilum.

Cortex

The cortex has a granular, reddish brown appearance and contains blood vessels, *renal corpuscles*, and the functional units of the kidney called *nephrons*. The granular appearance of the cortex is due to

the million or more nephrons in each kidney and the tubules associated with them. Nephrons close to the medulla of the kidney are called *juxtamedullary nephrons*, while those in the outer part of the cortex are called *cortical nephrons*.

The nephron is the functional unit of the kidney. That is, it is the smallest unit performing the work or main function of the kidney. Before we discuss how the nephron works, we discuss the parts of the nephron. Then later on, we put the parts together and discuss how the unit functions. Refer to the drawing of a nephron unit in figure 4-3 as we discuss the different components.

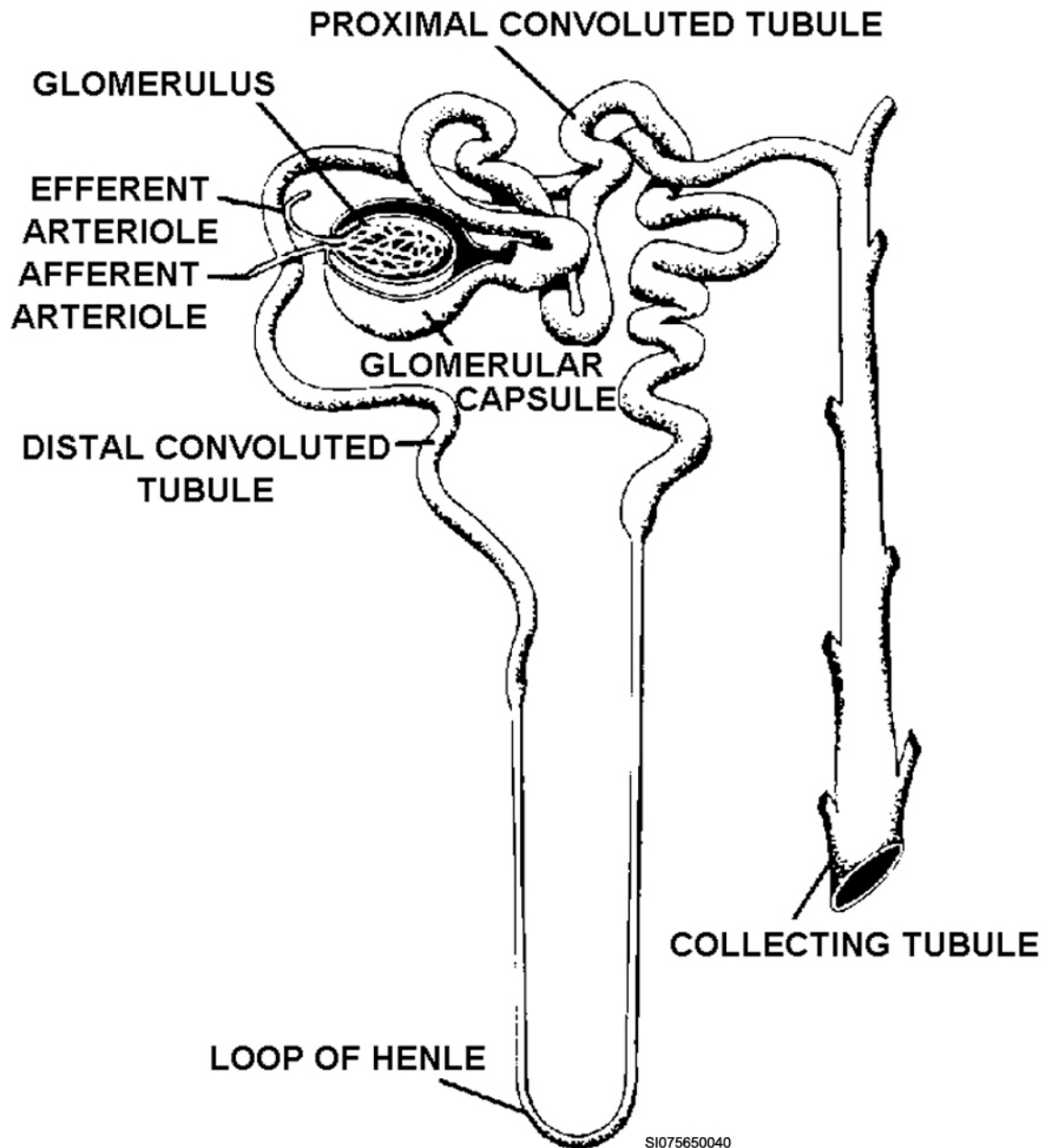


Figure 4-3. Nephron unit.

Glomerulus and Bowman's capsule

The glomerulus of the nephron is a collection of capillaries that invaginates into a capsule. The combination of these two structures is often called a *renal corpuscle*. The capsule can be compared to a bean bag chair. The chair would represent the capsule, and your body sitting in the chair would be

like the glomerulus. As you sit in the chair, the sides of the chair wrap around your legs, rear end, and trunk. The capsule folds around the glomerulus in much the same manner. With this type of arrangement, there are two membranes between the blood in the capillaries and the inside of the capsule—the capillary membrane and the capsule membrane (the one created by the invagination of the capillaries). Of course, the membranes are separated by a small space. The capsule extends completely around the glomerulus to seal and completely surround the capillary bed. The only area where the capsule is not sealed completely is where the afferent and efferent arterioles enter the capsule.

Tubules

Before we discuss the flow of blood through a nephron unit, let's move back to the capsule. The structure that connects to the capsule is called a *tubule* (i.e., small tube). Portions of the tubule are twisted and, therefore, referred to as being *convoluted*. The tubule is divided into three sections—the *proximal* and *distal convoluted tubules*, and the *loop of Henle*. The loop of Henle separates the proximal and distal convoluted tubules. As the name infers, the loop of Henle is not twisted, but is simply a loop of the tubule. The point of reference for determining whether the tubule is proximal or distal is the capsule. Keeping this in mind, the proximal convoluted tubule attaches to the capsule, the loop of Henle separates the proximal and distal tubule, and the distal tubule connects to the *collecting tubule*. The collecting tubule runs inside a renal pyramid and empties into a renal papilla.

Renal blood supply

The kidney receives its blood supply from the *renal artery*. This artery branches into several small arteries, usually one to a pyramid. From there, the arteries further divide, forming the *afferent arterioles*, which supply the nephrons. Likewise, the *renal vein* divides and subdivides to complete the blood circuit through the kidney. Like most blood vessels, the arteries and veins share the same pathway, running parallel with each other. Within the kidney, the blood vessels divide and travel through the renal columns, then further divide and run between the cortex and medulla.

Arterioles

The *afferent arteriole* supplies the renal corpuscle with blood and the *efferent arteriole* receives the blood from the corpuscle. In this way, the efferent arteriole acts much like a venule in systemic circulation in as much as it receives the blood from the capillaries. So why isn't it called a venule? Because the efferent arteriole establishes another capillary bed after it leaves Bowman's capsule. This capillary bed is called the *peritubular capillary network*.

Peritubular capillaries

The name given to this capillary bed describes its location. This network of capillaries surrounds the tubules and the loop of Henle. As mentioned previously, the efferent arteriole establishes the capillary network and a renal venule completes the circuit or receives the blood from the peritubular capillary network. There is a loop of the capillaries that looks much like the loop of Henle. This capillary loop is called the *vasa recta*.

Nephron fluid circuits

The nephron can, generally, be subdivided into two fluid circuits—the blood circuit and the filtrate (urine) circuit. It is the interaction between these two circuits that performs the absorption function of the kidney. Let's quickly review the structures of both circuits, then begin the discussion on their interaction.

Blood circuit

As we just mentioned, the kidney receives its blood supply from the renal artery entering the kidney through the hilum. The artery subdivides into smaller arteries and, finally, into arterioles to provide blood to the nephron unit. The blood enters the unit by way of the afferent arteriole, circulates through the glomerulus invaginated in Bowman's capsule, and leaves the capsule through the efferent

arteriole. The efferent arteriole then gives rise to the peritubular capillary network and vasa recta. The blood leaves the peritubular capillary network through a venule, which joins with other venules to form the renal vein. The renal vein passes through the hilum of the kidney to empty the blood into the inferior vena cava. Now let's review the filtrate circuit.

Filtrate circuit

The filtrate (urine) circuit begins in Bowman's capsule as the filtrate passes through the capsule's membrane. From this point it passes through the proximal convoluted tubule, the loop of Henle, the distal convoluted tubule, and into the collecting duct. The filtrate from several nephrons empty into a single collecting duct. From the collecting duct, the fluid empties into the minor and major calyx, then into the pelvis of the kidney, and finally into the ureter. The ureter passes through the hilum and on to the bladder and urethra.

Now that you have a better understanding of the kidney's structure let's take a look at how the human kidneys functions.

222. Functions of the kidneys

In this lesson we will discuss the interaction of the two circuits that we discussed previously along with how the kidneys form urine, maintain body fluid homeostasis, regulate blood pressure, and produce red blood cells.

Urine production

The removal of metabolic waste from the blood and secretion of the waste products from the body is the major function of the kidney and urinary system. The kidney uses two processes for the urine production—filtration and reabsorption. Let's discuss the process of filtration first.

Filtration

Filtration occurs as water and dissolved substances are forced out of the glomerulus and into Bowman's capsule, where urine production begins. The process of filtration is random. That is, any blood, fluid, or dissolved substance small enough to pass through the pores of the glomerular capillaries does! (It is not quite that simple, but not too difficult either.)

As blood passes through the glomerulus, about one-fifth of the blood plasma volume is filtered out of the capillaries and into the capsule. Once the fluid is filtered out of the capillaries, it is called *glomerular filtrate*. It is composed of amino acids, urea, uric acid, creatine, water, and a host of ions including sodium, potassium, chlorine, phosphate, sulfate, calcium, and bicarbonate. The concentrations of these substances in the filtrate are much the same as the concentrations found in blood plasma. So, the glomerulus essentially filters out blood plasma from the blood. About the only difference between filtrate and plasma or interstitial fluid is the very small amount of protein in the filtrate. As you can see, the process of filtration does very little to produce urine; the composition of the filtrate is very similar to that of interstitial fluid. It is critical, however, to initiate the processes of urine production.

Changes in the systemic blood pressure have little effect on the rate of filtration in the glomerulus. You would think that an increase in blood pressure would increase the filtration rate as capillary hydrostatic pressure is the major force "pushing" fluid through the capillary membranes. Fortunately, other pressures oppose the loss of fluid from the glomerulus. For example, the osmotic (inward) pressure of the protein that remains in the glomerulus capillaries attracts water and counteracts some of the hydrostatic (outward) pressure of the blood.

Another mechanism involves the *juxtaglomerular apparatus*. This apparatus is made up of the distal tubule passing between the afferent and efferent arterioles. Basically, special cells of the tubule at their contact with the arterioles sense a decrease in the concentration of chloride ions as a result of decreased filtration rate (pressure). The cells then signal the afferent arteriole to relax (dilate) in order to increase blood flow through the glomerulus. At the same time, the enzyme *renin* (pronounced

renin) is released to stimulate the production of a vasoconstrictor. The vasoconstrictor acts on the efferent arteriole causing a decreased flow through the glomerulus. This backup of blood also causes an increase in blood pressure and filtration rate. With these regulating mechanisms, the glomerular filtration rate remains relatively constant despite changes in systemic blood pressure. Now that Bowman's capsule has received the filtrate, let's discuss the next process of urine formation, reabsorption.

Reabsorption

The process of reabsorption takes place in the tubules of the nephron. As just mentioned, about one-fifth of the blood's fluid is filtered into Bowman's capsule. If some mechanism did not exist to reabsorb this fluid, you would become severely dehydrated.

The structures of the nephron lend themselves very well to this process. For example, the diameter of the efferent arteriole is smaller than that of the peritubular capillaries. So, as the fluid flows from the efferent arteriole into the peritubular capillaries, the pressure drops remarkably. This allows the filtrate in the tubules to diffuse easily into the interstitial space and be reabsorbed by the capillaries. Also, the peritubular capillaries have very large pores to ease the reabsorption. As you can see, the tubules alone cannot perform the function of reabsorption; it is the interaction of the tubules and peritubular capillaries that accounts for the reabsorption. It may be easier for you to think of the tubules as allowing reabsorption to occur.

Reabsorption involves the use of several different mechanisms to remove fluid, ions, and other dissolved substances from the tubules. Since a large percent of the filtrate is water, osmosis occurs between the tubules and capillaries. Osmosis is possible because the concentration of water in the tubules is greater than that of the peritubular capillaries. Stated differently, the water moves from an area of lesser solute concentration (hypotonic) to an area of greater solute concentration (hypertonic). If the last sentence seems contradictory to the one before it, remember a greater solute concentration has less water than a lesser solute concentration.

Active transport is used to remove sodium from the tubules. Since sodium is a positively charged ion, some negatively charged ions like chloride, phosphate, and bicarbonate are attracted to the sodium and move with it. This is called *passive transport*. Other substances are diffused out of the tubules into the capillaries. The small amount of protein in the filtrate is reabsorbed by the epithelial cells of the tubules by pinocytosis. The protein is then converted to amino acid and released to the interstitial fluid for capillary absorption.

As the filtrate continues through the tubules, more water is reabsorbed by the capillaries until approximately 99 percent is recovered. Ions, dissolved substances, and waste products in the filtrate are either reabsorbed or left to remain in the tubule according to the body's needs. By the time the filtrate enters the collecting duct, all that remains is excess to the needs of the body. It is the waste product called urine.

Body fluid homeostasis

The kidneys would not have much to do if our fluid intake was always in equilibrium with our fluid loss! When our fluid intake is low and output high, the body calls on the kidneys to further concentrate urine to help conserve fluids. Likewise, if the input is high, the kidneys must increase output to keep from "flooding" the internal environment.

To help regulate urine concentration or dilution, the kidney uses a countercurrent mechanism, which increases the concentration of solutes. Basically, a countercurrent mechanism is made up of a long, hairpin-U-shaped tube with the limbs close to each other. Fluid travels down the descending limb, through the U bend, then up the ascending limb. Because the fluid travels in a downward direction in one limb, but an upward direction in the other, the flow or current in one limb is counter to the flow in the other. This allows the contents in one limb to differ from the contents of the other. It may help you to refer back to figure 4-3 as we discuss this process.

In the kidney, the nephron's loop of Henle and the vasa recta extend deep into the medulla. Fluid containing NaCl enters the descending limb of the U. The walls of the descending limb and bottom of the U are much thinner than those of the ascending limb, and they are also more permeable; they freely allow water and solutes to pass through. This means as urine flows down the loop of Henle, it becomes approximately equal in concentration to the interstitial fluid around the descending limb. However, the walls of the ascending limb are much thicker, and tissue forming the walls is highly impermeable to water, but not as impermeable to NaCl. As the urine travels up the ascending limb, the NaCl passes through the walls, while the water remains trapped. Thus, the fluid emerging from the ascending limb has a lesser concentration than the urine within the limb. This also means that the interstitial fluid in the medulla is highly concentrated, and increases in concentration as more NaCl is absorbed. Keep this countercurrent mechanism in mind as you read the next two paragraphs.

The dilution of urine is fairly simple; the kidney simply allows water to remain in the tubules of the nephrons and enter the renal pelvis. In the absence of the antidiuretic hormone (ADH), produced by the posterior pituitary, the walls of the distal tubule and collecting duct are nearly impermeable to water. So, water remains in the tubules and enters the collecting duct and pelvis of the kidney; from the renal pelvis, the urine travels through the ureters to the bladder.

Concentrating urine uses the high concentrations of interstitial fluid in the medulla established by the vasa recta and loop of Henle by the countercurrent process. When ADH is secreted into the body tissue, the target cells in the walls of the nephron's distal tubule and collecting duct respond by dramatically increasing their permeability to water. As the fluid passes through the distal tubule into the cortical portion of the collecting duct, water freely osmoses into the interstitial fluid and is absorbed. The water also osmoses from the medullary portion of the collecting duct into the interstitial fluid of the medulla because of the concentration differences. Therefore, a very concentrated filtrate (urine) remains in the collecting duct as water is removed and absorbed by the capillaries—including the vasa recta. Concentrating urine, then, is one of the main functions of the juxtamedullary nephron. Again, it is accomplished by high concentrations of NaCl in the medulla's interstitial fluid and the increased permeability of the distal tubule and collecting duct from ADH secretion.

Blood pressure regulation

Blood pressure is determined by several factors. For the purpose of our discussion, we only talk about how the kidneys' responses to changes in blood volume influence blood pressure. When blood volume in the body is increased, blood pressure throughout the arterial vascular network increases. The converse also is true; decreased volume leads to decreased pressure. The kidneys play an important role in regulating blood volume, so indirectly they help regulate blood pressure. Here's how the kidneys accomplish this feat.

When blood volume increases, cardiac output and arteriole pressure increases. As a result, afferent arteriole pressure in the renal corpuscle increases and the rate of glomerular filtration increases. Urine output continues to rise until a normal blood volume is established. The urine produced in this instance is very dilute (i.e., mostly water). If blood volume is low and blood pressure drops, filtration is decreased. ADH is secreted by the posterior lobe of the pituitary, increasing the permeability of the tubules. More water is reabsorbed by the capillaries, which helps elevate the fluid volume in the blood. The urine produced when this occurs is more concentrated because it contains a higher ratio of solutes to water.

Red blood cell production

Another important function of the kidney is helping to regulate the production of the red blood cells. They accomplish this by secreting an enzyme called the *erythropoietic factor*. This enzyme acts on a protein in the plasma and forms *erythropoietin*. This substance stimulates the cells of the bone marrow which eventually produce red blood cells.

We've covered all you need to know (and then some!) about the structure and functions of the kidneys. Now we discuss the rest of the structures that make up the urinary system, namely, the ureters, urinary bladder, and the urethra.

223. Urinary system components

In order for the urine that is formed in the kidneys to be eliminated from the body it must have an excretory passage. The ureters, urinary bladder, and the urethra are the main structures that make up this passage to the exterior of the body.

Ureters

The ureter transports the urine, produced in the kidney, to the urinary bladder for storage. Each ureter is about 10 inches long and connects the pelvis of the kidney to the urinary bladder's inferior aspect (refer back to fig. 4-1). They are located behind the parietal peritoneum (in the retroperitoneal space) and run parallel with the vertebral column. Towards the bottom of the pelvic cavity, they start running forward, enter the peritoneal cavity, and converge to meet the bladder. The ureters are made up of three coats or layers.

Coat	Make Up	Function
Mucous	Made up of several layers of epithelium that is continuous with the epithelium of the bladder and pelvis of the kidney.	Helps protect the ureter from the chemical actions of the urine.
Middle	Made up of circular and longitudinal smooth muscle.	This arrangement of smooth muscle helps move the urine by peristalsis, initiated by the presence of urine.
Outer	Made up of connective tissue.	Like most organs, the connective tissue gives protection and a means of securing (connecting) the organs to surrounding structures.

Where the ureters join the bladder, small folds of mucous membrane cover the openings. These folds act as flap valves to prevent urine from reentering the ureters. Remember, the ureters connect to the bladder on the bottom. When a peristaltic wave of urine reaches the bladder and spurts into it, a valve is needed to prevent gravity and the constant tone of the bladder's muscle layer from forcing urine back into the ureter.

Bladder

The urinary bladder (fig. 4-4) is a hollow organ that acts as a reservoir for urine before voiding. It is located within the pelvic cavity, behind the pubic symphysis, and below the parietal peritoneum. Its size ranges from about the size of a walnut when empty to about the size of a small melon when fully distended or full. The ability to distend so dramatically is a result of its unique composition. In an adult, the bladder is capable of holding about 500 milliliter (ml) of urine when filled to maximum capacity. However, it takes far less urine than this to cause a distended feeling and trigger the urge to urinate. The bladder is made up of four layers.

1. Mucous epithelium.
2. Connective tissue.
3. Smooth muscle.
4. Serous coat.

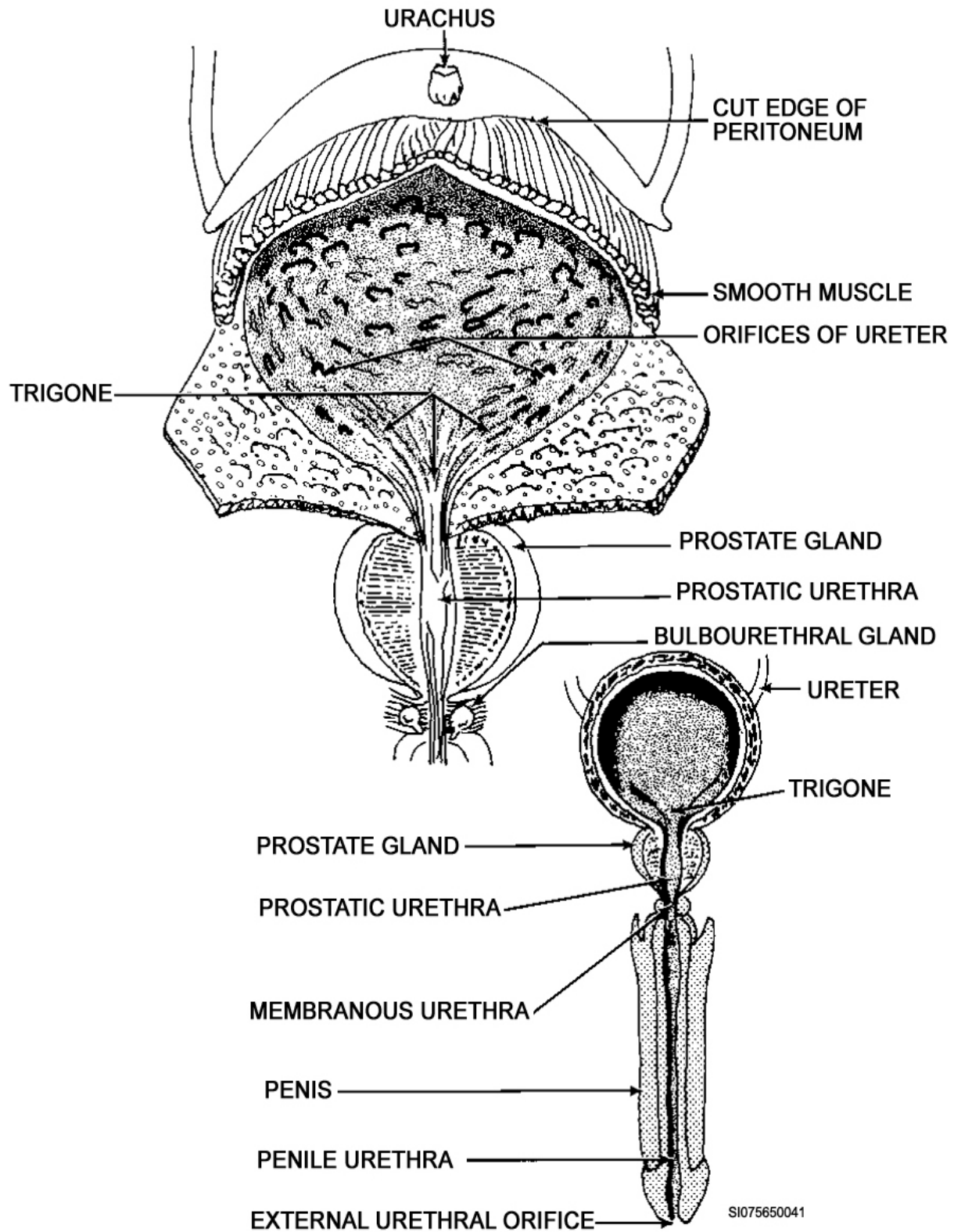


Figure 4-4. The urinary bladder and related male genitourinary structures.

Layer	Explanation
Mucous epithelium	The innermost layer, like the ureters, is made up of several layers of mucous epithelium for protection against the urine. Unlike the epithelium of the ureters, the bladder's epithelium has rounded cells that look like the cortex of the cerebrum. As the bladder distends, these cells flatten out to increase the surface area and hence the volume capacity of the bladder. The layers of epithelium tend to slide out until, with a full bladder, the epithelial cell layers become as few as two! This can be compared to the changes a balloon goes through as it is inflated. A deflated balloon has its wrinkles and folds, and the wall of the balloon is relatively thick. As the balloon inflates, the rubber in the wall stretches and becomes thinner, just like the wall of the bladder as it inflates with urine.
Connective tissue	The second layer of the bladder is composed mainly of connective tissue. Below the connective tissue layer is the smooth muscle.
Smooth muscle	The fibers of the smooth muscle run at right angles to each other. This ensures that the bladder contracts and shrinks uniformly during urination.
Serous coat	The outermost layer is called the serous coat and is made up of the parietal peritoneum on the top part of the bladder and connective tissue on the bottom.

The internal floor of the bladder is triangular in shape. The posterior part of the floor forms the base of the triangle with the ureters entering approximately at the corners. The apex of the triangle is roughly where the urethra connects to the bladder. This triangular-shaped region is called the *trigone*. The floor of the bladder does not change much when the bladder is full. Rather, the sides and top project outward and upward as the bladder fills with urine.

As the bladder fills with urine, stretch receptors send impulses to the sacral spinal cord to trigger the *micturition* (urination) *reflex center*. This reflex center, located in the sacral segments of the spinal cord, sends out parasympathetic impulses to the smooth muscle layer (*detrusor muscle*) of the bladder and rhythmic contractions begin. The sensation of “I gotta go” accompanies the contractions. This usually occurs when the bladder contains about 150 ml of urine. As the bladder fills to about 300 ml, the urge to void becomes very strong.

Fortunately, conscious nervous control from the midbrain and cerebral cortex can override the micturition reflex. In addition, conscious control keeps the external urethral sphincter contracted to prevent the flow of urine from the bladder. With flap valves at the urine inflow sites (ureters), and a sphincter at the output site (urethra), you can see how the bladder can become distended with urine as peristalsis continues.

Urethra

The urethra is a tube-like structure that drains urine from the bladder and conveys it to the outside of the body. Like the other structures of the urinary plumbing, its innermost wall is made up of a mucous membrane. The outer part of the urethra is a relatively thick layer of smooth muscle with its fibers generally running longitudinally.

The urethra has two sphincters—the *internal urethral* and the *external urethral sphincters*. The external urethral sphincter is made up of involuntary muscle tissue subject to reflex activity. Both are stimulated by reflex impulses, but the reflex impulses of the external urethral sphincter can be inhibited. Voluntary control of this sphincter is possible only with a mature nervous system, hence the need for diapers for small children. Voluntary control usually develops at about two years of age as the nervous system matures.

The female urethra is about $1\frac{1}{2}$ inches long, passes below the symphysis pubis, and has its opening between the labia minora. The opening is called the *external urinary orifice*, or *meatus*, and is located about an inch posterior to the clitoris, anterior to the vaginal opening.

The male urethra has an overall length of about 8 inches and is divided into three sections (refer back to fig. 4-4): prostatic, membranous, or penile urethra

Section	Length	Explanation
Proximal (closest to the bladder)	About 1 inch long.	Is called the <i>prostatic urethra</i> because it passes through the prostate gland.
Second	About 1 inch long.	Is called the <i>membranous urethra</i> . This part is surrounded by the external urethral sphincter.
Last	About 6 inches long.	Is called the <i>penile urethra</i> as it passes through the penis.

The urinary meatus ends at the tip of the penis. The male urethra serves a double function as it also conveys cells and secretions produced by the reproductive system. The female urethra acts only as an outlet for urine.

Only two sections remain before you complete this volume. They just happen to deal with subjects that are probably very near and dear to your heart—the male and female reproductive systems.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

221. Anatomy of the kidney

1. What provides protection for the kidneys?
2. What are nephrons?
3. What large collecting areas empty urine into the renal pelvis?
4. Which part of the nephron is a collection of capillaries that invaginates into a capsule?
5. What are the three sections of a tubule?
6. What capillary bed is formed by the efferent arteriole after it leaves Bowman's capsule?
7. Interaction between what two circuits performs the absorption function of the kidney?

222. Functions of the kidneys

1. The kidneys perform what two processes?
2. What is renin?

3. Reabsorption is accomplished by interaction between what two structures?
4. How do the kidneys regulate urine concentration or dilution?
5. Briefly describe the relationship between an increase in blood pressure and urine output.
6. What substance stimulates the cells of bone marrow, which eventually produce red blood cells?

223. Urinary system components for urine transport, storage, and elimination

1. Describe the three layers of the ureters.
2. Where is the bladder located?
3. What is the triangular-shaped region of the internal floor of the bladder called?
4. Where is the micturition (urination) reflex center located?
5. Which urethral sphincter is made up of involuntary muscle tissue subject to reflex activity?
6. What structure is located about an inch posterior to the clitoris, anterior to the vaginal opening?
7. What are the three sections of the male urethra?

4-2. The Male Reproductive System

Earlier we stated that every system in the body is essential for survival. As usual, with most rules, there is at least one exception. By themselves the reproductive system and the functions it performs are not essential for survival. They are, however, necessary for the survival of the species. The organs that make up the male and female reproductive systems perform a number of specialized functions. They are responsible for the production of the sex cells, or gametes, which contain the genetic information to be passed on to offspring. The organs are structured to bring these gametes together

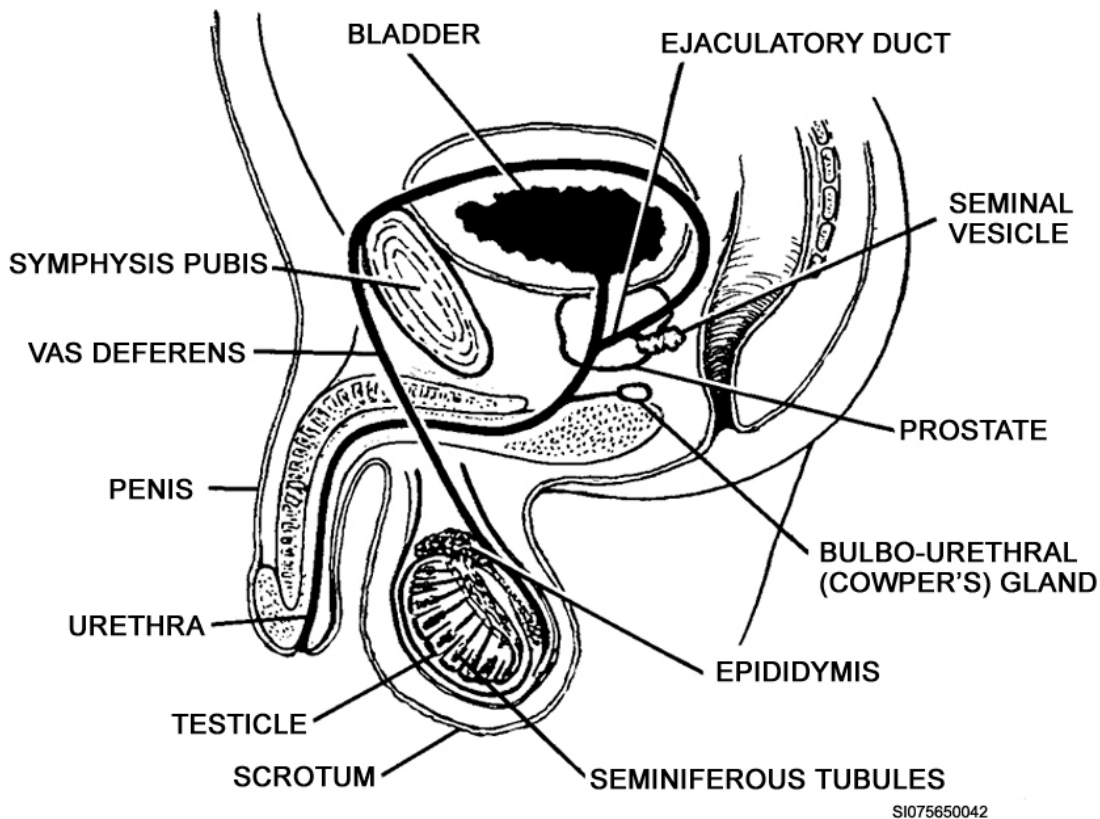
and sustain them until they develop into another human being. These organs also secrete the hormones that account for certain sexual characteristics and enable us to function sexually.

Since the structures and functions of the male and female reproductive systems are significantly different, we discuss them separately. This section is devoted to a discussion of the structures and functions of the male reproductive organs. It also outlines the sequence of events that occurs during the male sexual response and the role of hormones in regulating the male reproductive system.

224. Male reproductive structures and their functions

The male reproductive system produces and develops the male gamete, or sperm. The system also transports its sperm to the female so that it can fertilize the female gamete. Further, it produces the hormones that account for the male secondary sexual characteristics.

Male reproductive organs (fig. 4-5) are classified as either primary organs, internal accessory organs, or external accessory organs. The primary organs are the testes. The internal and external accessory organs are all the glands, ducts, and other structures responsible for the nourishment, maturation, transportation, and protection of the sperm cells.



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Figure 4-5. Male reproductive system (sagittal view).

Testes

As stated previously, the primary organs of male reproduction are the *testes* (also known as male gonads). They are two small, oval-shaped structures located within the *scrotal sac*. Each testis (testicle) is about 2 inches long and 1.2 inches wide. The testes are suspended by scrotal tissue and the *spermatic cords*. The left testis normally hangs about 1 cm lower than the right.

Development

During the early stages of uterine life (i.e., fetal stage), the testes develop from masses of tissue behind the parietal peritoneum. A month or so before birth, the testes descend through the inguinal canal of the abdominal cavity into the scrotum. This descent is stimulated by the male sex hormone *testosterone*. (The testosterone is produced and secreted by the developing testes.) Each testis is guided in its descent by a fibromuscular cord called the *gubernaculum*. The gubernaculum extends from the developing testis, through the inguinal canal, and attaches to the skin on the outside of the body. As the testis descends, it remains attached to the gubernaculum. There are also nerves, blood vessels and a developing vas deferens attached to the testis. Later, these structures combine to form the *spermatic cord*.

Structure

Each testis is surrounded by a layer of tough, white fibrous connective tissue called the *tunica albuginea*. The tunica albuginea is thicker along the posterior aspect of the testis, where it extends into the testis to form a septum. This septum is called the *mediastinum testis*, and numerous thin-layered septa branch out from it to form small, cone-shaped lobules. Each testis contains over 200 of these lobules.

Each lobule contains several tiny, highly coiled structures called *seminiferous tubules*. (Each of these tubules is about 28 inches long when uncoiled.) The tubules from each lobule come together in the mediastinum testis to form a network called the *rete testis*. The rete testis is drained by a series of ducts called the *efferent ductules*, which pass through the tunica albuginea and into the *epididymis*. The inner linings of the seminiferous tubules are covered with several layers of specialized tissue called the *germinal epithelium*. The germinal epithelium is responsible for the production of the male gametes. The spaces between the seminiferous tubules contain other specialized cells called the *interstitial cells*, or *cells of Leydig*. These cells are responsible for the production and secretion of the male sex hormone (testosterone).

Sperm cell production

The germinal epithelium is made up of *spermatogenic cells* and *supporting cells* (Sertoli's cells). The supporting cells are responsible for the support, nourishment, and regulation of the spermatogenic cells. They are columnar cells that extend from the base of the germinal epithelium to the lumen of the seminiferous tubule. There are numerous tiny projections extending from the supporting cells to the spaces between the spermatogenic cells.

The spermatogenic cells perform one of the major functions of the testis. They produce the male sex cells, or gametes. Prior to puberty, the spermatogenic cells are undifferentiated and called *spermatogonia*. Each of the spermatogonia contains the diploid number of chromosomes, which in humans is 46.

During adolescence, the spermatogonia are stimulated by hormones to become active. Some of the spermatogonia undergo mitosis to produce new cells and provide a reserve supply of spermatogonia. The remainder of the spermatogonia enlarges and become *primary spermatocytes*. The primary spermatocytes undergo meiosis, which reduces the number of chromosomes in each cell to the haploid number, or 23. During the process of meiosis, the spermatocytes first divide to form two *secondary spermatocytes*, and then divide again to form four *spermatids* (two from each secondary spermatocyte). The spermatids develop into the *sperm cells* (spermatozoa). At the end of meiosis, there are four spermatids, each containing 23 chromosomes. This process is called *spermatogenesis*.

Near the base of the germinal epithelium, projections from the supporting cells unite to form complexes that divide the tissue into two layers. These unions are called *occluding junctions*. The spermatogonia are located on the base side of the complexes, and the spermatocytes that are in a more advanced stage of spermatogenesis are closer to the lumen. The membranous complexes provide a

favorable environment for the development of sperm cells. They keep large molecules from the interstitial fluid away from the developing cells.

The spermatogonia produce spermatocytes on a continuous basis. As new cells are produced, cells in a more advanced stage of spermatogenesis are pushed closer to the lumen. This process continues throughout the reproductive life of the male. The spermatozoa are collected in the lumens of the seminiferous tubules. From there, they pass through the rete testis to the epididymis, where they develop and mature.

A mature spermatozoa is shaped like a tiny tadpole (fig. 4–6). It has a flattened head, cylindrical body, and elongated tail. The entire structure is about 0.06 mm long. The oval head contains a nucleus and the chromatin of the 23 chromosomes. The head is covered by a cap-like structure called the *acrosome*. This acrosome is derived from the Golgi apparatus of the cell. It contains a number of digestive enzymes that aid in the penetration of the female gamete, or ovum. The tail of the sperm cell is a complex structure composed of four parts—the *neck*, *midpiece*, *mainpiece*, and *endpiece*. The short neck connects the midpiece to the head. The midpiece contains the cytoplasm of the cell. It contains a large number of mitochondria arranged end-to-end in a spiral around the central core. The mainpiece and endpiece comprise the rest of the tail. These segments are made up of several longitudinal fibers, which are enclosed in an extension of the cell membrane. The tail provides the mobility of the sperm cell with rapid, back-and-forth lashing movements.

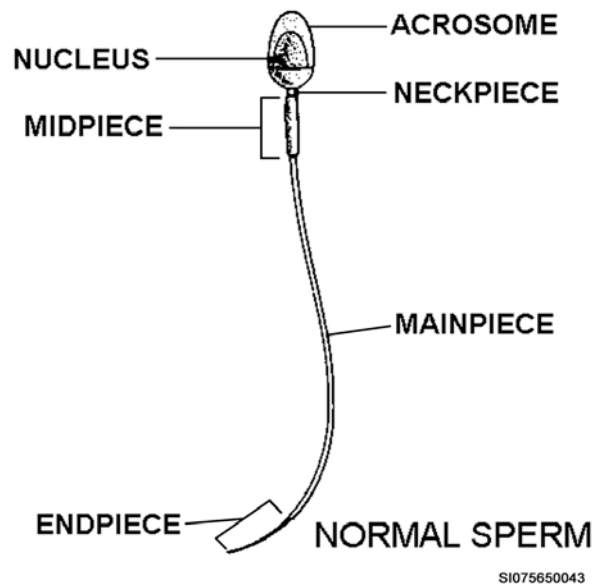


Figure 4–6. Normal sperm cell.

Internal accessory organs

The internal accessory organs include the following:

- Epididymis.
- Vas deferens.
- Ejaculatory ducts.
- Urethra.
- Seminal vesicles.
- Prostate gland.
- Bulbourethral glands.

Refer to figures 4-5 and 4-7 in the discussion of the internal accessory organs.

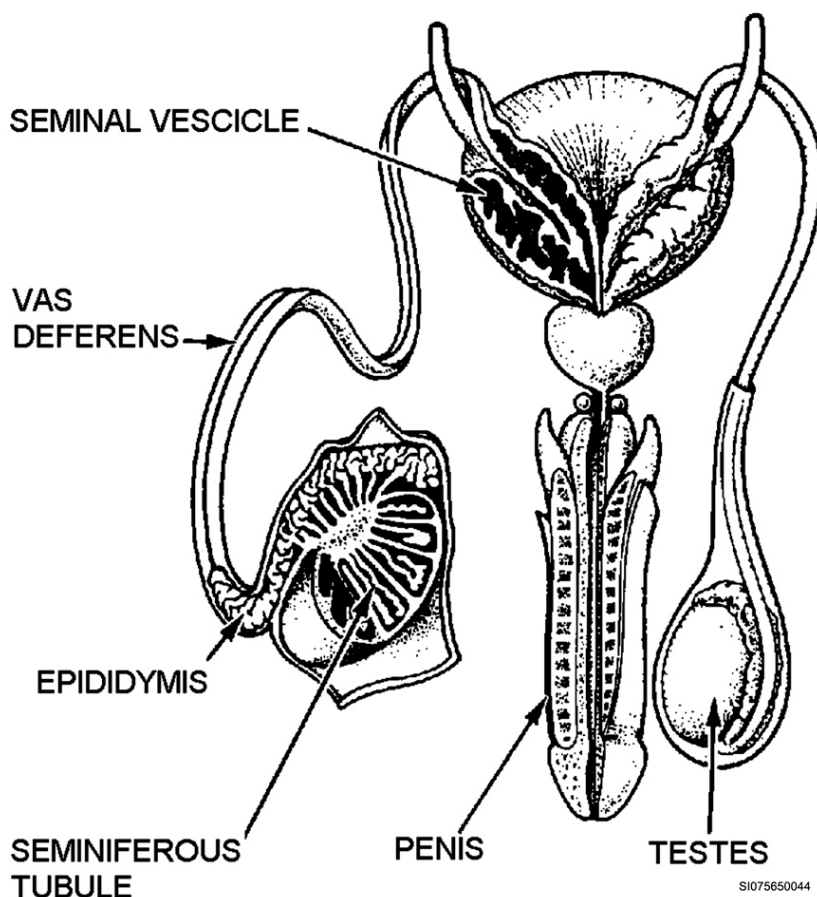


Figure 4-7. Male reproductive organs (posterior view).

Epididymis

The epididymis is a tightly-coiled tube of relatively small diameter, but considerable overall length (about 6 meters). It originates on the superior aspect of each testis, runs along the posterior border, and angles up towards the pelvis. The epididymis is made up of a rounded head, central body, and tapered tail. The entire structure is enclosed in a layer of fibrous tissue. The head of the epididymis connects to the efferent ductules that drain the rete testis. The tail is continuous with the *vas deferens*. The inner lining of the epididymis is made up of pseudostratified columnar cells that contain nonmotile cilia (cilia that don't move). These cells are involved in the production of nourishment (probably glycogen) necessary to maintain the developing sperm cells. The epididymis also secretes a small amount of the *seminal fluid* that becomes the *semen* of ejaculation.

The sperm cells that enter the epididymis are immature. They are incapable of movement or fertilization. The sperm cells mature as they pass slowly through the epididymis. The time spent in the epididymis varies from one to three weeks. Gradually, they become capable of moving independently, but actual swimming motions do not usually begin until after ejaculation.

Vas deferens

The vas deferens (ductus deferens) is a muscular tube about 18 inches long. It begins as a continuation of the epididymis near the inferior aspect of the testis. The vas deferens continues up along the side of the testis, and becomes a part of the spermatic cord. It then passes through the inguinal canal into the abdominal cavity and arches up over the top and down the posterior medial

surface of the urinary bladder. Near their distal ends, each vas deferens enlarges to form an expanded section called the *ampulla*. The tube narrows again just prior to entering the *prostate gland*. At the point where it narrows, it unites with a duct from the *seminal vesicle* to form the *ejaculatory duct*.

The wall of the vas deferens consists of three layers. The muscle fibers of the inner and outer layers are arranged in a longitudinal pattern. In contrast, the muscle fibers of the thick intermediate layer are arranged in a circular pattern. The contraction of these muscles aids the movement of the spermatozoa through the vas deferens. In addition to acting as a connecting passage and helping with the movement of the spermatozoa, the vas deferens acts as a storage area for the sperm awaiting ejaculation. Length of storage depends on frequency of sexual activity and ejaculations.

Seminal vesicle

The seminal vesicles are convoluted pouch-like structures, about 2 inches long, located along the lower part of the posterior surface of the bladder. Just outside the prostate gland, ducts from the seminal vesicles combine with the vasa deferentia (the plural of vas deferens) to form the ejaculatory duct.

The inner lining of the seminal vesicles is composed of a glandular tissue that secretes a viscous, slightly alkaline fluid, which makes up a part of the liquid portion of the semen. This fluid helps to regulate the pH of the tubular contents as the sperm passes through. The fluid contains fructose and prostaglandins. The fructose is a simple sugar and acts as an energy source for the spermatozoa. The prostaglandins are thought to influence the muscular activity of the female organs to move the sperm towards the female gamete. The secretory activity of the seminal vesicles depends on the levels of the male hormone, testosterone. When there is an ejaculation, the seminal vesicles empty into the ejaculatory duct. This greatly increases the volume of the fluid that is discharged.

Prostate gland

The prostate gland (refer back to fig. 4-5) is a doughnut-shaped gland located just inferior to the bladder. The gland is about 1.6 inches in diameter and 1.2 inches thick. It surrounds the urethra just below its origination point.

Internally, the prostate is made up of many compound tubuloalveolar glands. It is surrounded by a layer of connective tissue that extends into the prostate to form septa between the individual glands. The ducts from these glands open into the urethra.

The prostate gland secretes a thin alkaline substance that makes up the bulk of the seminal fluid. The alkali in this secretion helps to protect the sperm from the acid it encounters in the seminal fluid and in the vaginal secretions. Since acid acts to slow down or kill sperm, the motility of the spermatozoa passing through the urethra is greatly increased by the prostate secretions. The prostate releases its secretions into the urethra at the same time that the ejaculatory duct is emptying into it from above. These secretions add to the volume of the seminal fluid.

The prostate gland is relatively small until the age of puberty. It grows from the period of early adolescence until it reaches its adult size a few years later. The prostate gland usually enlarges in older males. When that happens, it may constrict the urethra and interfere with urine production.

Bulbourethral glands

The bulbourethral glands, or *Cowper's glands* (refer back to fig. 4-5), are small structures about the size and shape of peas. They are located within the muscle fibers of the external urethral sphincter just below the prostate. They are connected by a short duct to the urethra. The bulbourethral glands are compound, tubuloalveolar glands. They secrete a mucus-like alkaline fluid that helps to protect the spermatozoa from acid. This fluid also helps to lubricate the end of the penis during intercourse. (Most of the lubrication is provided by the female reproductive organs.)

Seminal fluid

The seminal fluid (semen) is the substance that is expelled from the urethra during ejaculation. This fluid has an alkaline pH with a thick, milky appearance. The most important component of the seminal fluid is, of course, the sperm. As we have mentioned, the secretions from the seminal vesicles, prostate, and bulbourethral glands make up much of the bulk of the seminal fluid. It also contains a number of nutrients and the prostaglandins, which enhance the survival and movement of the sperm through the female reproductive tract. With each ejaculation, there is between 2 and 6 ml of seminal fluid expelled from the urethra. Each ml of seminal fluid expelled has an average sperm count of around 120 million.

Because of the slightly acidic content of the seminal fluid, the sperm are relatively immobile in the testes and epididymis. Once this seminal fluid becomes mixed with the alkaline contents of the other accessory organs, the sperm become much more active. The spermatozoa are capable of living for many weeks as long as they are inside the protective climate of the male reproductive organs. Once they have been exposed to the external environment, the sperm only last for a day or so.

External accessory organs

The external male accessory organs include the scrotum and the penis.

Scrotum

The scrotum is a pouch-like structure that surrounds the testes. It is located posterior to the penis, suspended from the lower anterior pelvic region. The scrotum (scrotal sac) is composed of skin and subcutaneous tissue. The wall of the scrotum also contains a layer of smooth muscle fibers called the *dartos muscle*. When it is contracted, the dartos muscle draws the scrotal sac closer to the testes.

Internally, the scrotum is divided by a medial septum. On either side of this septum, there is a testis, epididymis, and section of the spermatic cord. Each half of the scrotal sac is lined with a serous membrane that covers the anterior and lateral aspects of the testis and epididymis. This covering helps ensure friction-free movement of the testes.

Besides providing a convenient storage pouch for the testes and related structures, the scrotum keeps the testes suspended away from the body. This arrangement prevents the high internal temperatures of the body cavity from destroying the heat-sensitive spermatozoa after they are produced. Optimum temperature for spermatogenesis is accomplished by the movement of the testes in response to the temperature of the external environment. In cold weather, the testes are drawn upwards in the scrotum so they are closer to the body. In warm weather, muscular relaxation allows the testes to lie deep in the scrotum, away from the body.

Penis

The penis is a cylindrical organ suspended from the anterior medial region of the lower pelvis. It performs a dual function. As a part of the urinary system, the penis transports the urine out of the body from the bladder. As a part of the reproductive system, the penis transports the seminal fluid out of the body. It has a specialized structure that allows it to become enlarged and hardened through a process called *erection*. The erection permits the penis to be inserted into the female vagina during intercourse.

The main part, or body, of the penis is made up of three columns of specialized tissue called erectile (cavernous) tissue. Each column is enclosed in a layer of white fibrous connective tissue called the *tunica albuginea* (similar to that which covers the testes). The two columns on the upper dorsal aspect of the penis are similar to each other and are called the *corpora cavernosa penis*. The column on the inferior aspect of the penis is called the *corpus spongiosum*, or *corpora cavernosa urethrae*. The *corpora cavernosa penis* is larger than the *corpus spongiosum*. Additionally, the *corpus spongiosum* encloses the urethra. The three columns are surrounded by layers of subcutaneous and elastic tissue, and skin.

The distal end of the corpus spongiosum is enlarged to form a structure called the *glans penis*. This structure overlaps the distal ends of the corpora cavernosa penis. There is an opening at the end of the glans penis called the *external urethral meatus*, through which the urine and semen are expelled from the body. The skin of the glans penis is hairless and very sensitive and delicate. The glans penis is enclosed in a loose fold of skin called the *prepuce* (foreskin). The prepuce originates just proximal to the glans and extends forward to cover it as a sheath. The prepuce is often removed for religious or medical reasons in an operation called a *circumcision*.

At the base, or root, of the penis, the three columns divide. The corpora cavernosa penis extends laterally into the perineum and is connected to the medial surfaces of the pubic arch. Each point of attachment is called a *crura*. The corpora cavernosa urethrae attaches to perineal membranes between the crura. The point where the corpora cavernosa urethra attaches is enlarged and called the *bulb of the penis*.

225. Male sexual responses, hormone control, and sexual development of the male reproductive system

The basic function of the male reproductive organs is to produce and transport the sperm cells to the female vagina. We have already discussed how sperm cells are formed, so let's take some time to study how the transportation process works in conjunction with male sexual response.

Male sexual responses

The transportation process is accomplished through the activities of erection, orgasm, emission, and ejaculation.

Erection

The columns of erectile tissue in the penis consist of networks of vascular spaces called *venous sinusoids*. These networks are lined with endothelial tissue and separated from each other by smooth muscle fibers and connective tissue. Between periods of sexual activity, the smooth muscle fibers remain in a state of partial contraction. This contraction reduces the size of the vascular spaces. When the body is sexually stimulated, these muscle fibers relax. As the smooth muscles relax, parasympathetic impulses from the sacral area of the spinal cord cause the arteries of the penis to dilate, and the veins to constrict. Blood enters the penis under high pressure and is unable to leave. This blood fills up the vascular spaces, and the penis becomes elongated, enlarged, and erect. This condition is called an erection.

Orgasm

Continued sexual stimulation results in a sensation of physical and emotional release called an orgasm. Physical responses include an accelerated heart rate, increased blood pressure, hyperventilation, dilated blood vessels in the skin, and intense sexual excitement. A male orgasm is normally accompanied by emission and ejaculation.

Emission

Emission involves the movement of the sperm from the testes and the secretions from the prostate and seminal vesicles into the urethra. The sperm and secretions mix to form the seminal fluid. This occurs when sympathetic impulses from the spinal cord trigger activity from the smooth muscles in the walls of the testicular ducts, epididymides, vasa deferentia, and ejaculatory ducts. The impulses cause a series of wavelike contractions (peristalsis). While this peristalsis is going on, other sympathetic impulses cause the smooth muscles of the prostate and seminal vesicles to contract rhythmically. The combined muscular activity propels the sperm and secretions into the urethra.

Ejaculation

When the seminal fluid accumulates in the urethra, sensory receptors are stimulated. Sensory impulses travel to the spinal cord and motor impulses return. These motor impulses cause the skeletal

muscles at the base of the penis to contract rhythmically. This action increases the pressure within the erectile columns and helps to force the seminal fluid (sperm and other secretions) through the urethra. This process is called ejaculation.

The entire emission-ejaculation process is staged so that the various secretions are expelled into the urethra in a certain order. The first secretion is from the bulbourethral glands, followed by the secretions from the prostate, followed by the sperm, and ending in the secretions from the seminal vesicles.

After ejaculation, the arteries of the penis receive sympathetic impulses that cause them to constrict. The flow of blood into the penis is reduced, and the veins carry off the blood that has accumulated in the vascular spaces. The smooth muscles between the vascular spaces resume a state of partial contraction. This aids the removal of the blood from the vascular spaces. The penis resumes its normal flaccid (limp) condition, and is usually not responsive to sexual stimulation for another 10 to 30 minutes.

Hormonal factors

Both sexual development and sexual activity are controlled, to a large part, by the actions of hormones. These hormones are produced and secreted by the hypothalamus, anterior pituitary gland, and testes.

Hypothalamus

Before the age of puberty, the spermatogonia are undifferentiated. The male body is childlike and reproductively nonfunctional. Around the age of 10, the hypothalamus begins to secrete a hormone that initiates the changes that lead to the development of a functional reproductive system. This hormone is called gonadotropin-releasing hormone (GnRH). The GnRH is released into the blood vessels leading into the pituitary, and it stimulates the pituitary to secrete its hormones.

Pituitary

The hormones secreted by the anterior pituitary are called gonadotropins. There are two of these gonadotropins—luteinizing hormone (LH) and follicle-stimulating hormone (FSH).

Gonadotropins	Function
Luteinizing hormone	Influences the development of the interstitial cells of the testes. These cells begin to secrete the male sex hormone, testosterone. (Also known as interstitial cell-stimulating hormone)
Follicle-stimulating hormone	Influences the action of the columnar supporting cells in the testes. The supporting cells become responsive to testosterone. Under the combined effect of testosterone and the follicle-stimulating hormone, the columnar cells initiate the process of spermatogenesis from the spermatogonia.

Testes

The hormones secreted by the testes (male gonads) are generally referred to as *androgens*. A few of the androgens are secreted by the adrenal cortex, but the majority is produced by the interstitial cells and is called testosterone.

When the testosterone is transported through the bloodstream, it is loosely attached to plasma proteins. When it reaches its target cells, the testosterone combines with the receptor molecules in the cytoplasm. Testosterone is converted to another androgen form prior to combining with the target cells of the prostate, seminal vesicles, and external male accessory organs. Androgens that do not reach target cells are absorbed, converted, and excreted by the liver.

The stage of puberty occurs somewhere between the ages of 13 and 15 (approximately). Androgen production increases drastically, and the reproductive organs become functional. This androgen production normally continues throughout the life of the male.

Male sexual development

Testosterone is first secreted by a structure called the genital ridge and later by the developing testes in the fetal infant. The secretions continue but are extremely limited until the age of puberty. The early secretions influence the development of the male reproductive organs. The testosterone also initiates the descent of the testes into the scrotal sac in the fetal infant.

The development that occurs during puberty includes enlargement of the testes and other reproductive organs. It also involves the development of the secondary sexual characteristics associated with the adult body. These characteristics include an increase in the growth of hair on the face, head, chest, axillary areas, and pubic area. This increase of body hair is occasionally accompanied by a decrease of scalp hair. During puberty, the voice usually changes—becomes low-pitched. This change is caused by the enlargement of the larynx and thickening of the vocal cords. The skin also thickens during puberty. This is accompanied by an increase in skeletal and muscular development. The male assumes adult-like body proportions. The shoulders become wider, the waist becomes narrower, and the bones become heavier. Cellular metabolism and erythropoiesis both increase during puberty. Finally, the testosterone affects the cells of the brain to stimulate sexual activity.

Hormonal secretion is regulated by a process called the *negative feedback system*. This system involves the release of GnRH by the hypothalamus. The cells of the hypothalamus are sensitive to concentrations of testosterone in the blood. When these concentrations increase, the hypothalamus decreases its production of GnRH. This causes a chain reaction in which the anterior pituitary decreases its production of LH and FSH, and the testes decrease their production of testosterone. When testosterone levels in the blood drop, the production of GnRH is increased and the chain reverses itself.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

224. Male reproductive structures and their functions

1. What are the primary organs of male reproduction?
2. What hormone stimulates the testes to descend into the scrotum about a month before birth?
3. What cells are responsible for the production and secretion of the male sex hormone?
4. Briefly describe the process of spermatogenesis.
5. Where does the male sperm get the energy necessary to move through the fluid?
6. What does the epididymis secrete?

7. What structures combine to form the ejaculatory duct?
8. Where are the seminal vesicles located?
9. What protects sperm from acids in the vagina?
10. What is another name for the bulbourethral glands?
11. What are the components of seminal fluid?
12. What is the purpose of the serous lining of the scrotal sac?
13. What is the loose skin covering the glans penis called?

225. Male sexual responses, hormone control, and sexual development of the male reproductive system

1. What are the steps involved in the transportation of sperm?
2. What are the physical responses during an orgasm?
3. How does the penis change after ejaculation?
4. What hormone released from the hypothalamus leads to the development of a functional male reproductive system?
5. What two hormones cause the columnar cells in the testes to initiate the process of spermatogenesis?
6. What happens to androgens that do not reach target cells?

7. During puberty, what happens to the voice and why?
8. How does the negative-feedback system regulate hormonal secretions?

4-3. The Female Reproductive System

The female reproductive system is specialized to produce, develop, and transport the female sex cell, or ovum, to a place where it can be fertilized. The system is also specialized to maintain the fertilized ovum throughout its development into a fetus, and deliver the fetus outside the body. Finally, the female reproductive system produces the female hormones that account for the female secondary sexual characteristics and control reproductive activities.

226. Female reproductive organs and their functions

Like the male, the female reproductive system is divided into primary organs, internal accessory organs, and external accessory organs (fig. 4-8). The primary organs are the ovaries. The internal and external accessory organs include all the structures that support and make possible the function of the ovaries.

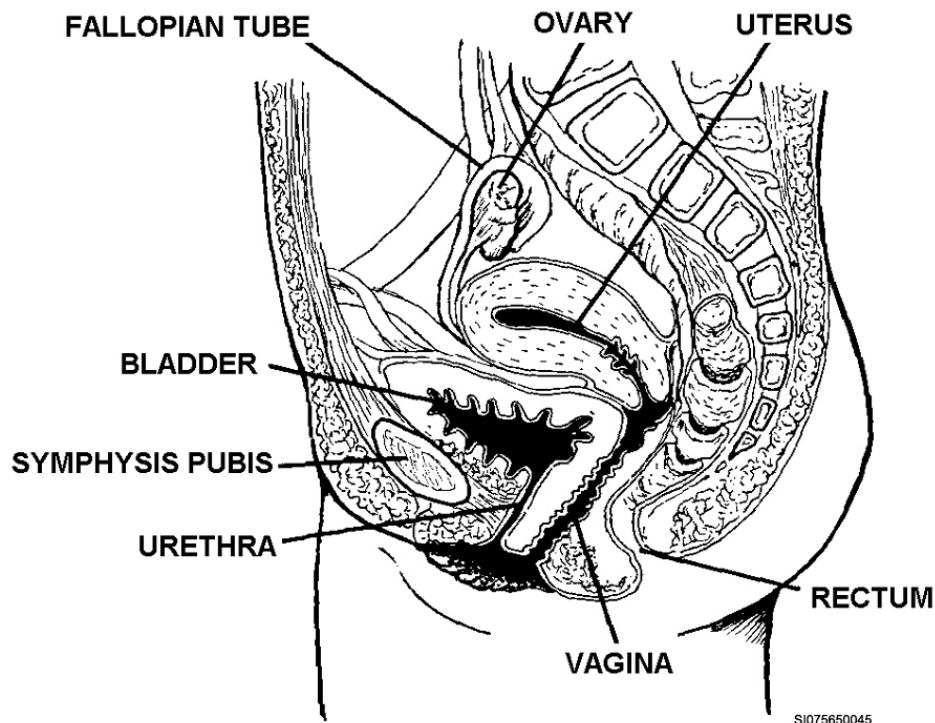


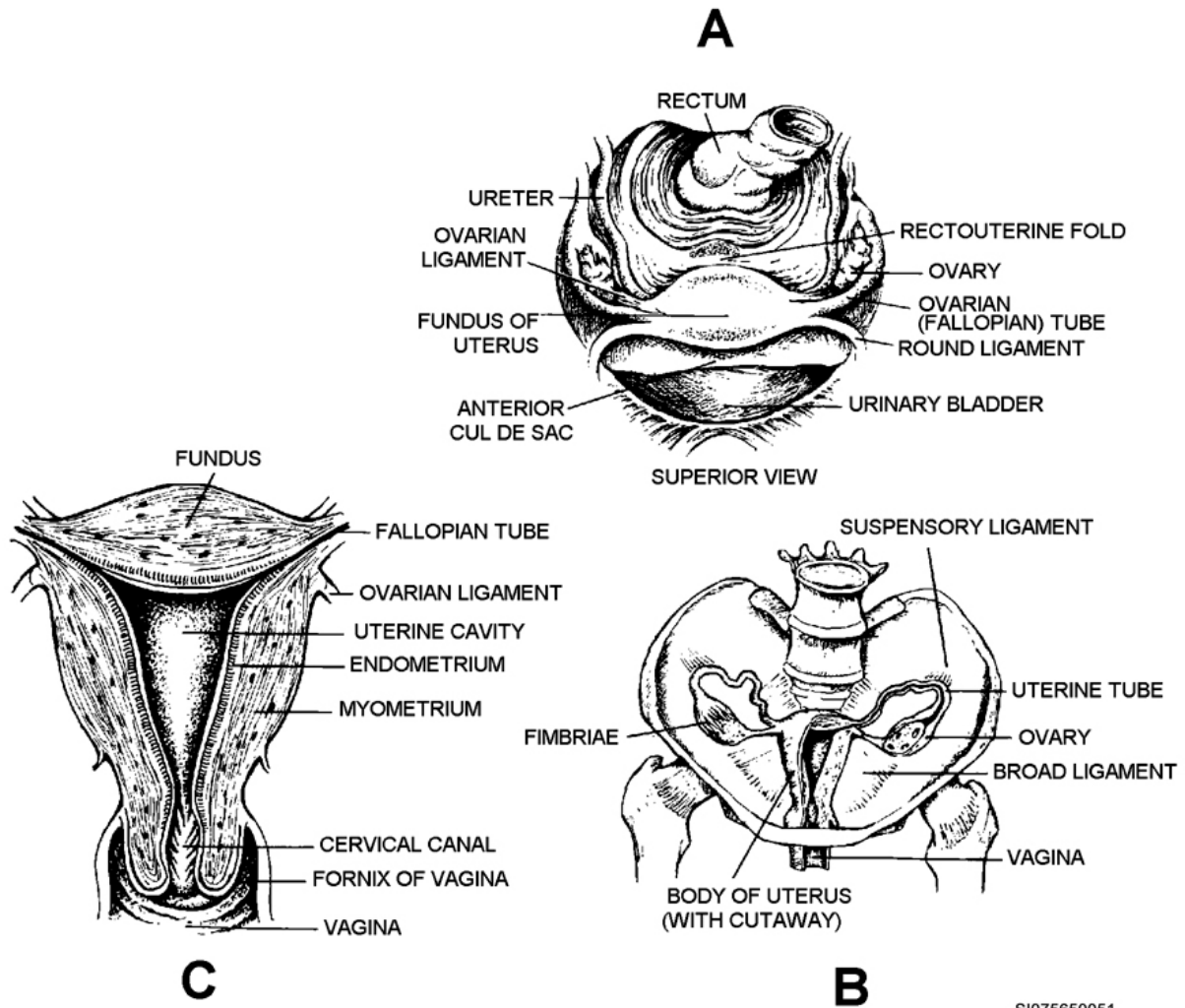
Figure 4-8. Female reproductive system.

Ovaries

As we said, the ovaries are the primary organs of the female reproductive system. They are oval-shaped structures located on either side of the pelvic cavity within the ovarian fossa (fig. 4-9a). They are small structures—about 1.5 inches long and about 0.75 inches wide. The ovaries are suspended by ligaments, have a structure similar to a kidney or lymph node, and produce the eggs, or ovum, required for reproduction.

Ligament attachments

The ovaries are attached to the uterus and the wall of the pelvic cavity by ligaments. The largest of the ligaments is the *broad ligament* (fig. 4–9b). It is formed by a fold in the peritoneum and extends along the wall of the pelvic cavity between the uterus and the ovaries. The ovaries are connected to the posterior surface of the broad ligament and are attached superiorly by a small fold of the peritoneum called the *suspensory ligament*. The suspensory ligament connects to the wall of the pelvic girdle and also contains the blood vessels and nerves that supply the ovaries. The inferior surface of the ovaries is connected to the uterus by the *ovarian ligament* (fig. 4–9c). The ovarian ligament is actually just a rounded extension of the broad ligament.



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Figure 4–9. Female reproductive organs and pelvic contents.

Structure

The structure of an ovary is somewhat similar to the structure of a kidney or a lymph node. There is an outer cortex and an inner medulla. In an ovary, however, there is not a clear-cut distinction between the cortex and the medulla. The ovary's medulla is a mesh-like arrangement of loose connective tissue, blood vessels, lymphatic vessels, and nerve fibers. The outer cortex is made up of more compact tissue. The cells that make up this tissue have a granular appearance due to the presence of masses of *primordial ovarian follicles*. The entire structure is surrounded by a layer of

white fibrous tissue (tunica albuginea). The outer surface of the tunica albuginea is covered with cuboidal cells called the germinal epithelium.

Primordial follicles

During fetal development, the germinal epithelium produces a number of primitive (primordial) germ cells. These cells go through mitosis to form *primitive ova* (oogonia). The oogonia also go through mitosis to produce cells that contain a diploid number of chromosomes. These cells eventually develop into *primary oocytes*. The primary oocytes produced during fetal development are the source of all the ovum that is produced later. The primary oocytes begin the first stage of meiosis, but further meiotic development is stopped until puberty is reached.

Each of the primary oocytes that are formed is surrounded by a layer of germinal cells. When the primary oocyte begins meiosis, it is called a *primary follicle*. Very little change occurs in these primary follicles until puberty is reached. Several million of these primary follicles are produced initially, but this number decreases as the cells degenerate. By the time puberty is reached, only about 400,000 are left.

Oogenesis

Several events occur with the onset of puberty. The primary follicles begin to grow and develop and, periodically, some of the oocytes within the follicles are stimulated to continue with the first stage of meiosis. At the end of the first stage of meiosis, the chromosome number in the cell nucleus has been reduced to 23. Two types of cells are produced in the first division. One of the cells is much larger than the other and is called the *secondary oocyte*. The other, a much smaller cell, is called a *polar body*. The polar body is nonfunctional and may either simply degenerate or reproduce to form two other nonfunctional polar bodies.

When the secondary oocyte goes through the second stage of meiosis, a mature ovum and another polar body are produced. (This result differs from the result of spermatogenesis where four functional spermatids are produced.) A mature ovum is much larger than mature spermatozoa. It can be seen without a microscope, and is made up of a nucleus surrounded by cytoplasm. The cytoplasm contains a small amount of nutrients called yolk granules.

Follicle maturation

The primary follicle must go through a number of changes before the oocyte within it can be fertilized. These changes are called the maturation process. As in the male, the production and secretion of hormones by the female greatly increases at the onset of puberty. The anterior pituitary secretes large amounts of FSH, and the ovaries begin to grow in response. At the same time, some of the primary follicles are stimulated and begin the maturation process. This process occurs in cycles about every 28 days. The changes in the ovaries that eventually result in the production of a mature ovum are called the *ovarian cycle*. Only one of the group of primary follicles that begins maturation will complete the process and become a mature ovum. The other follicles degenerate through a process called *atresia*.

The germinal cells (follicular cells) that surround the remaining primary follicle begin to multiply through mitosis. The cells organize themselves into layers and gradually create a cavity (antrum) around the oocyte. The follicular cells secrete a fluid (follicular fluid) that fills the cavity and bathes the oocyte. The oocyte is also going through changes. It grows larger and continues with the first stage of meiosis. At this point, the follicle is referred to as a *secondary follicle*. (Meiosis is halted again at the metaphase of the second stage and is not completed until ovulation and fertilization occur.)

The ovaries also contribute to the developing follicle. Ovarian cells surround the follicle to form two layers. The inner layer is called the *theca interna*. It is made up of a vascular structure of loose, connective tissue and blood vessels. The outer layer is made up of dense fibrous connective tissue and is called the *theca externa*.

The cavity (antrum) of the follicle continues to enlarge and fill with fluid. The fluid forces the oocyte off to one side of the cavity. A clear, tough membrane, called the *zona pellucida*, develops around the oocyte and separates it from the antrum. At this stage of development, the follicle is called a *vesicular follicle*. The zona pellucida is surrounded by a mound of cells called the *cumulus oophorus*. These cells project out into the antrum.

The enlarged follicle moves toward the surface of the ovary. The oocyte is pressed up the side of the follicle that is next to the ovarian wall. As the fluid continues to accumulate, the oocyte is pressed outward to form a slight bulge on the surface of the ovary. The follicle is considered to be mature at this point. It is referred to as a *Graafian follicle*. The oocyte within the follicle has developed into a large, oval-shaped cell, surrounded by a thick, tough zona pellucida. The zona pellucida is covered by a layer of follicular cells called the *corona radiata*. Processes from these cells extend through the zona pellucida to supply nutrients to the oocyte.

Ovulation

The process of ovulation involves the rupture of the follicle and release of the secondary oocyte and polar body onto the surface of the ovaries. The process occurs on a cyclic basis—about every 28 days. Ovulation is triggered by the secretion of LH from the anterior pituitary gland. The LH stimulates the follicular cells to secrete the female sex hormone *progesterone*. The progesterone stimulates the production of an enzyme, which weakens the theca externa of the follicle. At the same time, the LH causes the follicle to swell rapidly. The follicular wall eventually ruptures, and the follicular fluid and oocyte ooze out onto the surface of the ovaries.

Usually, the newly released oocyte is propelled to the opening of the uterine (fallopian) tube. Once there, the oocyte begins the trip through the tube to the uterus. Since the oocyte is nonmotile, it is moved by the peristaltic action of the uterine tube. The entire trip takes six to eight days. Along the way, the oocyte is either fertilized or eventually disintegrates.

A number of changes take place in the ovaries after the oocyte is released. A blood clot called the *corpus hemorrhagicum* forms in the ruptured follicle. The cells within the follicle become altered to form a mass called the *corpus luteum*. (The corpus luteum is a large yellow structure.) The corpus luteum absorbs the corpus hemorrhagicum, and then begins to secrete quantities of the female sex hormones estrogen and progesterone. It continues to secrete these hormones until the oocyte is either fertilized or the corpus luteum degenerates. If the oocyte is fertilized, pregnancy occurs, and after the third month of the pregnancy, the placenta takes over the function of the corpus luteum. Then, the corpus luteum begins to gradually degenerate. The role of the ovaries in the production of hormones is discussed later in this unit.

Internal accessory organs

The internal accessory organs are the uterine tubes, uterus, and vagina.

Uterine (fallopian) tubes

The uterine tubes (refer back to figs. 4-8 and 4-9b) are short, muscular tubes responsible for transporting the ovum to the uterus. They are also referred to as the fallopian tubes or *oviducts*. The uterine tubes are located on either side of the uterus, between the uterus and the ovaries. Each tube is about 4 inches long and about 0.3 inches in diameter. The uterine tubes are attached to the broad ligament. There is a funnel-shaped opening called the *infundibulum* at the distal end of the tube near the ovary. The infundibulum partially surrounds, but is not attached to, the ovary. A number of irregular projections extend out from the margin of the infundibulum. These extensions are called *fimbriae*. One of the larger of these fimbriae (the ovarian fimbriae) is attached to the ovary. The fimbriae are like the fingers on a baseball glove. They entrap the oocyte discharged from the mature ovarian follicle and guide it into the infundibulum of the uterine tube.

The proximal (medial) end of the uterine tube is attached to the superior end of the uterus. It penetrates through the wall of the uterus and enters the uterine cavity (refer back to fig. 4-9c). The

uterine tube is made up of three layers—an outer peritoneal layer, a middle muscular layer, and an inner mucosal layer. The mucosal layer consists of numerous longitudinal folds, and is covered with a layer of simple columnar epithelial cells. Some of the epithelial cells are ciliated while others secrete mucus. The cilia create a wave-like motion towards the uterus. This helps to draw the oocyte into the uterus following ovulation. As we mentioned earlier, the uterine tube moves the ovum with peristaltic contractions of the muscular layer. The movement of the cilia also helps to move the ovum along the tube.

Uterus

The uterus (refer back to fig. 4-9c) is a hollow, pear-shaped, muscular organ located in the anterior medial portion of the pelvic cavity just above the bladder and in front of the rectum. In its normal state, the uterus is about 3 inches long and about 2 inches wide. Blood is supplied to the uterus via the uterine arteries, which branch off the two internal iliac arteries.

Uterine ligaments

Like the ovaries, the uterus is supported by ligaments. Eight ligaments are involved, and they occur in pairs.

Ligaments	Explanation
Broad	The uterus is attached to both sides of the pelvic cavity by wide sheets of tissue called the <i>broad ligaments</i> . The broad ligaments are also connected to the uterine tubes and ovaries, and the uterine arteries run through them.
Cardinal	The main supports of the uterus are the <i>cardinal ligaments</i> . The cardinal ligaments are located at the base of the round ligaments and attached to the sides of the lower uterus and vagina.
Round	Attach to either side of the superior portion of the uterus. They extend anteriorly to connect the uterus to the anterior pelvic wall.
Uterosacral	The uterus is connected posteriorly to the sacrum by the <i>uterosacral ligaments</i> . The uterosacral ligaments attach to the lower body of the uterus, run along the floor of the pelvic cavity, and terminate in the sacrum.

Divisions of the uterus

The uterus is divided into two sections – the body and the cervix. The triangularly-shaped upper portion is called the body and makes up about 60 percent of the uterus. The superior, dome-shaped portion of the body is the connecting point for the uterine tubes. The dome-shaped portion of the uterus is sometimes referred to as the *fundus* of the uterus. The lower, narrow neck of the uterus is called the *cervix*. The cervix extends down into the superior aspect of the vagina. The opening between the uterus and the vagina is called the *cervical orifice*, or *ostium uteri*.

Uterine wall

The wall of the uterus is also made up of three layers. Like the uterine tubes, there is an outer peritoneal layer, a middle muscular layer, and inner mucosal layer.

Layer	Explanation
Inner (endometrium)	It is lined with columnar epithelium and contains numerous tubular glands.
Middle (myometrium)	Is made up of bundles of smooth muscle fibers arranged in longitudinal, circular, and spiral patterns. There are also layers of connective tissue between the muscle bundles.
Outer (perimetrium)	Consists of an extension of the parietal peritoneum (serous membrane) that also covers the broad ligament. The perimetrium covers most of the body (except for the lower one-fourth of the anterior surface) and none of the cervix.

The walls of the uterus are capable of undergoing tremendous changes. Once a month, during the female reproductive cycle, the entire inner lining of the uterus is sloughed off. If the female becomes pregnant, the uterus undergoes tremendous changes in size and shape.

Position of uterus

In a normal female, the uterus flexes between the cervix and body, with the body tipped forward (anteriorly) over the superior surface of the bladder. The cervix is angled down and slightly posteriorly, and meets the superior portion of the vagina at an approximate right angle (fig. 4–8). In some females, the position of the uterus may be radically different than the one just described.

VARIATIONS IN UTERINE POSITION

Name	Description
Retroversion	A backward tilting of the entire uterus that puts the uterus almost in a straight line with the vaginal canal (most common variation).
Anteversion	The entire uterus is tipped forward more than normal. This causes the cervix to enter the vagina at greater than a 90 degree angle.
Retroflexion	Involves a backward flexing of just the body of the uterus, while the cervix remains angled down and slightly posteriorly (as in the normal anatomical arrangement).
Anteflexion	Puts the body of the uterus angled straight forward (towards the symphysis pubis), perpendicular to the cervix.

Vagina

The vagina (refer back to fig. 4–8) is a muscular tube extending from the cervix of the uterus to the external opening, or *vestibule*. It extends superiorly and posteriorly from the vestibule into the pelvic cavity. The vagina is located between the urinary bladder and urethra, and the rectum. The *rectouterine pouch* (also called the pouch of Douglas) is a cavity between the superior portion of the vagina and the rectum. The upper end of the vagina overlaps the cervix. The small recesses, or spaces, that occur in the area of the overlap are called *fornices* (singularly, a fornix) (refer back to fig. 4–9c).

The slit-like opening at the inferior end of the vagina is called the *vaginal orifice*. In the virginal vagina, this orifice is partially covered by a thin membrane called the *hymen*. The hymen is made up of connective tissue and stratified squamous epithelium. There is an opening near the center of the hymen to allow secretions to drain from the vagina. The hymen may be distended or slightly torn during the first sexual intercourse.

Like the uterus and uterine tubes, the vaginal wall consists of three layers. The inner mucosal layer is lined with stratified squamous epithelium and formed into longitudinal and transverse ridges called *rugae*. Unlike the mucosal layer of the uterus, the vaginal mucosa only has a few glands. The middle muscular layer is made up of smooth muscles arranged in longitudinal and circular patterns. Near the vaginal orifice, there is a thin band of striated muscle that helps to close the vagina. (The bulbospongiosus muscle is primarily responsible for closing the vagina.) The outer layer of the vagina consists of dense fibrous connective tissue that connects the vagina to the structures around it.

The vagina has three basic functions.

1. It serves as a passageway for uterine secretions.
2. It is the birth canal through which the fetus is delivered.
3. It receives the penis during sexual intercourse.

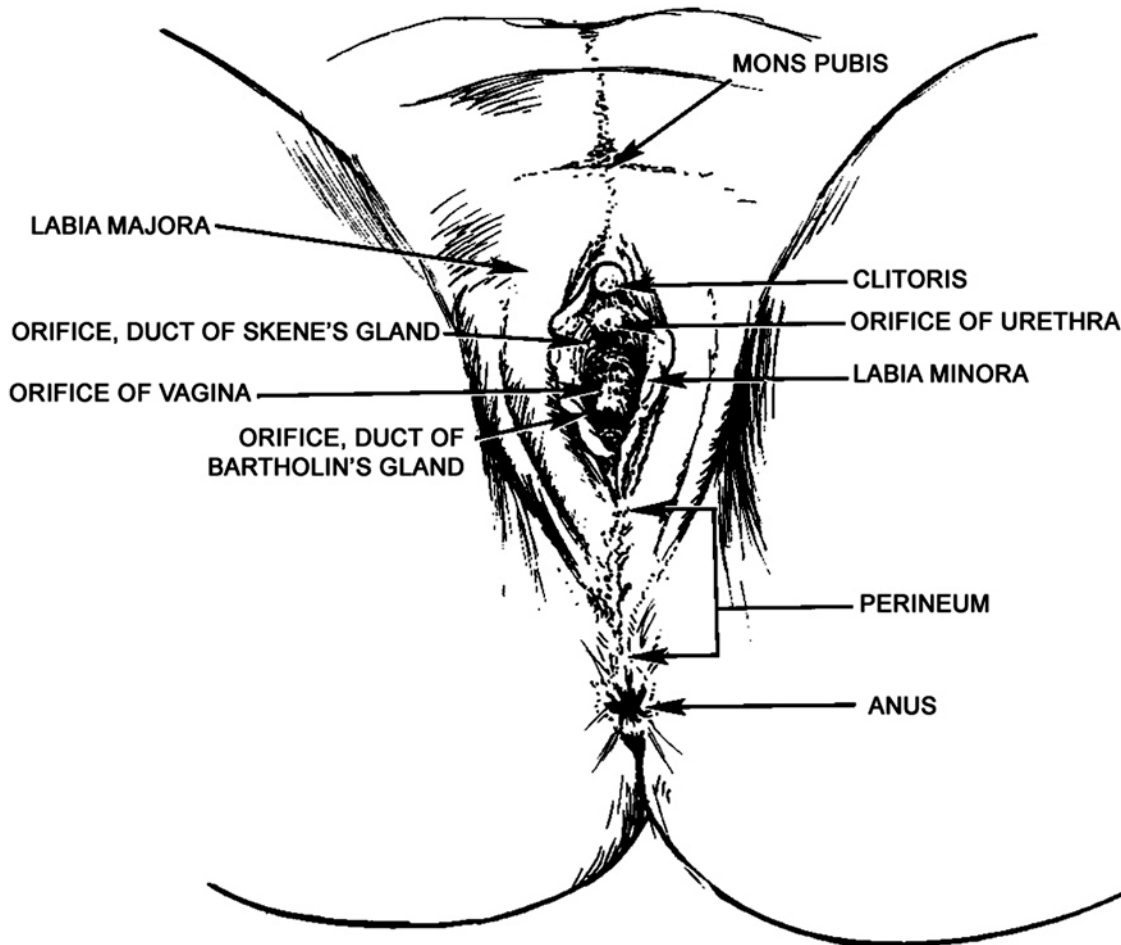
External accessory organs

The external accessory organs are as follows:

- Labia majora.
- Labia minora.
- Clitoris.
- Vestibule.
- Vestibular glands.

- Breasts.

Except for the breasts, which are located over the pectoral muscles of the chest, these organs are found around the external openings of the vagina and the urethra. The entire area is referred to as the *vulva* (fig. 4-10).



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Figure 4-10. Female genitalia (vulva).

Labia majora

The labia majora are lip-like structures that surround and protect other external reproductive organs. They consist of folds of adipose tissue covered by skin. The skin on the external surface of the labia majora is covered with hair and contains numerous sweat and sebaceous glands. The skin on the internal surface is much thinner and does not contain hair. The labia majora are located between the pubic symphysis and the anus. They are separated lengthwise by an opening called the *pudendal cleft*. The labia come together anteriorly to form a mound of fatty tissue called the *mons pubis*, located over the pubic symphysis. Posteriorly, the labia majora taper off and merge into the perineum near the anus. The labia majora correspond to the scrotum in the male.

Labia minora

The labia minora are flattened folds of very vascular connective tissue located within the pudendal cleft. The surface of the labia minora is covered with stratified squamous epithelium that extends longitudinally along either side of the vestibule. Anteriorly, the labia minora form a hood-like structure around the clitoris. Posteriorly, they merge into the perineum with the labia majora.

Clitoris

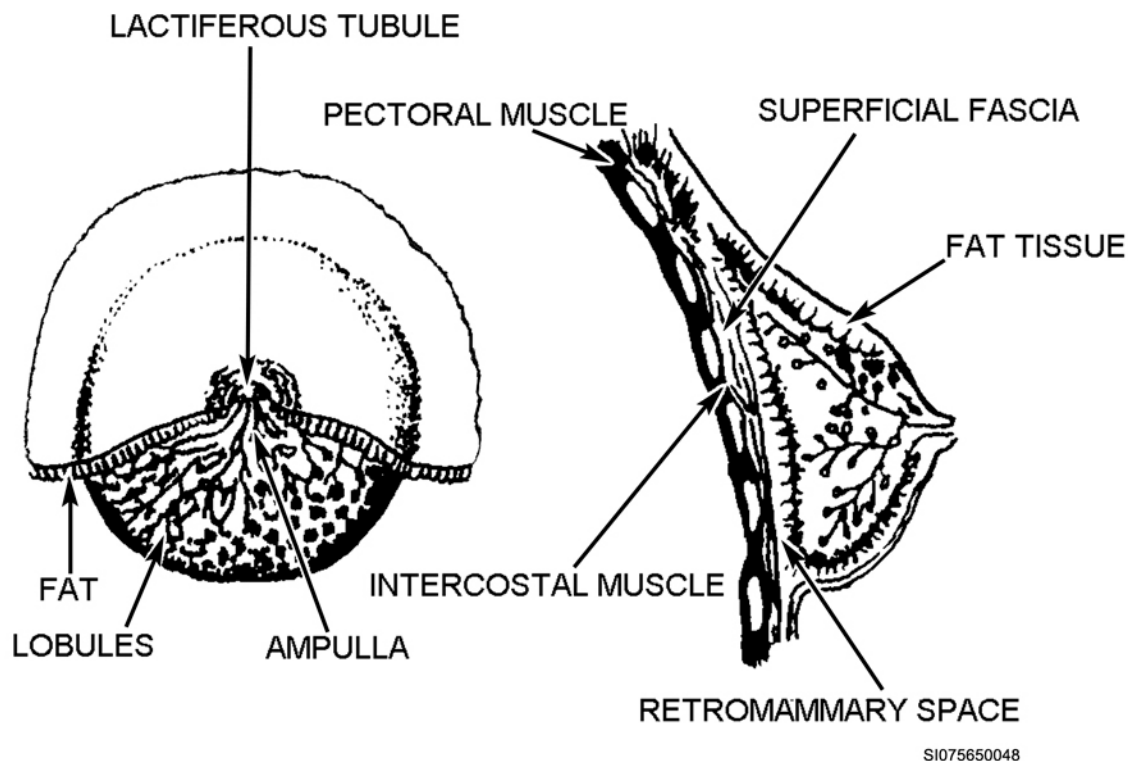
The clitoris is a small projection located at the anterior end of the vulva between the labia minora. It is about 0.8 inches long, and 0.2 in diameters. The clitoris corresponds to the male penis. It consists of two columns of erectile tissue called corpora cavernosa covered by dense fibrous connective tissue. Like the penis, these columns diverge posteriorly to form crura, which connect to the pubic arch. There is a mass of erectile tissue at the tip of the clitoris that forms a glans. The glans is well supplied with sensory nerve fibers.

Vestibule

The vestibule is the space around the vaginal and urethral openings (between the labia minora). The vaginal opening is located in the posterior part of the vestibule. The urethral opening is just anterior to the vaginal opening, and just posterior to the clitoris. A pair of *vestibular glands* (Bartholin's glands) is on either side of the vaginal opening. These glands correspond to the bulbourethral glands in the male. They produce a mucus secretion that lubricates and moistens the vaginal opening. The glandular secretions enter the vestibule through ducts that open near the sides of the vaginal orifice. A group of tiny mucous glands, the *lesser vestibular* or *Skene's glands*, also secrete mucus through two ducts that open into the vestibule just below and on either side of the urethral meatus. There is a mass of erectile tissue just beneath the mucosal layer on either side of the vestibule. These erectile tissues are called *vestibular bulbs*. These bulbs extend beneath the mucosa, from the vaginal opening to the clitoris.

Breasts

The breasts (mammary glands) are large, round, modified sweat glands located in the subcutaneous tissue on either side of the anterior thorax (fig. 4-11). They lay over the pectoralis major muscles and cover the area from about the second to the sixth rib and from the sternum to the axilla. (The exact amount of chest area covered by the breasts varies with individual development.)



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Figure 4-11. Breast structure.

The breasts consist primarily of adipose (fatty) tissue and alveolar glands. The alveolar glands are arranged in a number of irregularly shaped lobes. In addition to the alveolar glands, each lobe also has a *lactiferous* (milk-producing) *duct*, or *tubule*, leading to the nipple. The lobes are separated and supported by connective and adipose tissues. The glands are attached to the fascia of the pectoral muscles by the connective tissue. Additional strands of dense connective tissue extend from the pectoral fascia to the dermal layer of the breasts. These strands of tissue help to support the breasts and are called suspensory ligaments. A small round projection called a nipple is located near the tip of each breast. The nipples are surrounded by a round area of darkly pigmented skin called the *areola*.

Prior to puberty, male and female breasts are very similar. At the onset of puberty, ovarian hormones stimulate development of the female breasts. When the breasts are stimulated, the ducts and glands grow larger, and adipose tissue is deposited around the glands. Eventually, the breasts become totally surrounded (except in the nipple area) by adipose tissue. Increased levels of the hormones estrogen and progesterone during pregnancy stimulate additional growth and development of the breasts. High levels of estrogen cause growth and branching of the ducts, while the progesterone stimulates the growth of alveolar glands at the ends of the ducts. Estrogen also promotes deposits of fatty tissue around the ducts. The placental hormone, *lactogen*, also promotes the changes that occur. As a result of the changes that occur during pregnancy, the breasts may actually double their original size.

During pregnancy much of the breasts' fatty tissue is replaced by glandular tissue. Eventually, the breasts develop the capability of secreting milk (i.e., lactation). Early milk secretion is prevented by the *prolactin inhibiting factor* (PIF) secreted by the hypothalamus. The PIF suppresses the release of the prolactin from the anterior pituitary. (In case you've forgotten, prolactin is the hormone that stimulates the production of milk.) After giving birth, the levels of estrogen and progesterone drop significantly. The hypothalamus detects this drop and signals the anterior pituitary to begin production of prolactin. The prolactin promotes the production of large amounts of milk; however, it is several days before the hormonal effects are felt. During that time, the breasts secrete a small amount of a substance called *colostrum*, which contains nutrients, but no fat.

Milk is produced from the breasts by reflex action of specialized myoepithelial cells that surround the alveolar glands. When they contract, milk is forced from the breasts. This reflex action is produced when the breast is sucked or otherwise mechanically stimulated. Sensory receptors detect breast stimulation and send a signal to the hypothalamus. The hypothalamus signals the posterior pituitary to release the hormone oxytocin into the blood. When the oxytocin reaches the myoepithelial cells, the cells contract and milk squirts out of the breast. There is about a 30-second delay between the stimulation and the actual ejection of milk from the breast. The sensory impulses that cause the release of oxytocin also cause the hypothalamus to continue to secrete prolactin. As long as milk is removed from the breasts, prolactin is produced. When the milk is no longer removed, the prolactin secretion stops. About a week later, the breasts dry up or lose their ability to produce milk.

An additional side effect of breast feeding is inhibition of the menstrual cycle. It is possible for women to become pregnant while they are breast feeding, but the menstrual cycle may be halted for several months.

227. Female sexual responses, hormones, and reproductive cycles

As we said before, the female reproductive system has a number of specialized functions. It is responsible for the following:

1. Production of the female sex cell, or ovum (egg), and for the transportation of the ovum to a place where it can be fertilized by the male sperm.
2. Reproductive (sexual) activities that allow the male sperm to come into contact with the ovum.
3. Production of hormones that control reproductive activities and development.

4. Support and protection of the fetus that develops from the fertilized ovum and for the delivery of the fetus during the birth process.

Since we have already discussed the production of the ovum, this section discusses the remaining reproductive functions.

Sexual activity

Sexual activity in the female involves the processes of erection, lubrication, and orgasm. These processes correspond to, and are usually associated with sexual activity in the male.

Erection

Erectile tissues in the female are found in the clitoris and the vestibular bulbs. The actions of these tissues are very similar to the actions of the male erectile tissues. When the female is sexually stimulated, parasympathetic impulses cause the arteries in the erectile tissue to dilate and the veins to constrict. The tissue then becomes engorged with blood, and becomes swollen and erect.

Lubrication

At the same time that the erectile tissue is responding to stimulation, the vagina is beginning to enlarge and elongate. As the sexual stimulation begins to intensify, parasympathetic impulses promote the secretion of mucus by the vestibular glands. This mucus lubricates and moistens the vestibular area and lower end of the vagina. The enlargement and lubrication prepares the vagina to receive the erect penis during sexual intercourse. The vestibular glands usually continue to secrete mucus during intercourse. The mucus prevents irritation of the tissues from the friction caused by sexual activity.

Orgasm

The glands of the clitoris contain numerous sensory nerve fibers. Continued stimulation of the clitoris leads to a sensation of great physical and emotional release called an orgasm. Physical responses of the female are similar to those of the male. There is an increase in the pulse, respiration, and blood pressure. This may be accompanied by dilation of peripheral blood vessels (which causes the skin to appear flushed), hardening of the nipples, and intense sexual excitement.

Just before the orgasm occurs, the tissues at the lower end of the vagina become swollen with blood. This increases the friction on the penis during intercourse, and increases the stimulation of the clitoris and other erectile tissue. When the orgasm occurs, a series of nervous reflex actions are triggered. First, the muscles of the vagina begin to contract spasmodically. This is followed by involuntary rhythmic contractions of the muscles of the perineal area and muscles of the uterus and uterine tubes. (The uterine contractions help to move the sperm into the uterine cavity.)

After the orgasm, the muscles relax and the blood flow to the erectile tissue is reduced. The reproductive organs return to their presexual activity condition.

Hormonal factors

The second major function of the ovaries is the production of the female sex hormones. In addition to ovarian hormones, female reproductive activities and development are controlled by hormones produced by the hypothalamus and anterior pituitary gland.

Hypothalamus

The hormone produced by the hypothalamus is GnRH. The female increases secretion of this hormone around the age of eight. The GnRH stimulates the secretion of hormones from the anterior pituitary. (As we discussed earlier, the hypothalamus also secretes hormones that control milk production during and after pregnancy.)

Anterior pituitary

The hormones secreted by the anterior pituitary are the gonadotropins—FSH and LH. These hormones affect the development of the ovum as well as the production of female sex hormones.

Ovaries

The hormones produced by the ovaries are *estrogen* and *progesterone*. These hormones can also be produced by other structures such as the adrenal cortex and, in pregnant females, by the placenta.

Estrogen

Estrogen is primarily produced by the ovaries. It is responsible for the initial development of many of the accessory, as well as the development of the secondary sexual characteristics. Accessory organs, such as the vagina, uterus, uterine tubes, ovaries, and external organs, become enlarged under the influence of increasing amounts of estrogen. The secondary sexual characteristics stimulated by estrogen include: development of the glands and ducts within the breasts and increase in overall size of the breasts; increased deposits of fatty tissue in the areas of the breasts, thighs and buttocks; and increases in the blood vessels (vascularization) supplying the skin.

Other characteristics associated with the female form are thought to be controlled by an androgen hormone that is secreted by the adrenal cortex. (Androgens are the hormones responsible for producing masculine characteristics.) These characteristics include growth of hair in the axillary and pubic regions and the skeletal and muscular configuration of the female.

Progesterone

Progesterone is also primarily produced by the ovaries. (Both estrogen and progesterone can be produced by other structures, e.g., the placenta in a pregnant female). Progesterone stimulates the changes that occur in the uterus during the female reproductive cycle. It also affects the development of the breasts and helps to regulate the release of FSH and LH from the anterior pituitary.

Reproductive cycles

The female reproductive cycle (menstrual cycle) is directly related to the development of the primary follicle that we talked about earlier. This cycle is characterized by periodic (i.e., monthly) changes in the uterine lining that terminate in *menses* (menstrual bleeding). The menstrual cycle usually begins somewhere around age 13 and continues until the female reaches menopause—sometime between 40 and 60, depending on the individual.

Menstruation

Menarche, or the first menstrual cycle, begins when the GnRH from the hypothalamus promotes increased secretions of LH and FSH from the anterior pituitary. The FSH triggers the maturation process of some of the follicles. At the same time, the LH promotes secretion of estrogen from the follicular cells. This estrogen stimulates the development of secondary sexual characteristics. The estrogen secreted in later cycles stimulates the completion of this development and helps in the maintenance of various female traits.

Other changes produced by estrogen include thickening of the glandular endometrium of the uterine lining. This thickening continues for about 14 days while the follicle matures. By the 14th day, the follicle is mature and pressing outward on the surface of the ovaries. This is about the time that ovulation occurs. The anterior pituitary secretes a large amount of LH and an increased amount of FSH. The ovarian and follicular walls are weakened, and the follicle swells suddenly. The walls rupture and the ovum (secondary oocyte) is released into the peritoneal cavity. The ovum and follicular fluid are drawn into the fimbriae and infundibulum through the action of the uterine cilia.

After ovulation, a structure called the corpus luteum (yellow body) develops from the remnants of the ruptured follicle. This corpus luteum begins to secrete large amounts of estrogen and progesterone into the bloodstream. The increased progesterone causes additional changes to the endometrial lining

of the uterus. The lining becomes more vascular and glandular. The uterine glands begin to secrete large amounts of nutrients such as glycogen and lipids. All of this activity creates an environment that is favorable for the development of an embryo (the early stage of a fetus). The hypothalamus detects the high blood concentrations of estrogen and progesterone, and reacts by decreasing secretions of GnRH. This inhibits production of gonadotropins from the anterior pituitary and prevents the stimulation of other follicles during the menstrual cycle.

If the ovum is not fertilized by about the 24th day, the corpus luteum begins to degenerate. This causes a decrease in the blood concentrations of LH and FSH. The endometrial lining then begins to deteriorate. Blood vessels in the endometrium constrict, which reduces the supply of oxygen to the area. The thickened endometrial tissues begin to disintegrate and slough (i.e., peel) off. Capillaries in the lining are damaged as the tissue sloughs off. This causes bleeding. The blood from the capillaries and remnants of the endometrial tissue flow through the cervix, into and through the vagina. This flow of blood and cellular particles is called menses (menstrual flow). Menses usually begins around the 28th day of the cycle and continues for three to five days. At this time, the estrogen concentrations are very low. Menses marks the end of one cycle and the beginning of the next.

The low concentrations of estrogen in the blood result in the release of GnRH, LH, and FSH from the hypothalamus and anterior pituitary. The production of these hormones results in the stimulation of more follicles, and the cycle begins over again.

Menopause

As we said, menstrual cycles continue until the female is between 40 and 60. Around that time, the cycles become more and more irregular, and finally stop altogether. This is called menopause. The depletion of follicles in the ovaries appears to cause menopause. With no follicles, there is no ovulation. This results in a decrease in estrogen and progesterone concentrations, and an increase in gonadotropin secretion. The changes in hormonal levels usually cause a number of physical changes. Internal and external accessory reproductive organs may decrease in size. Pubic and axillary hair usually grows thinner, and the female may experience various unpleasant sensations such as characteristic “hot” flashes (a sensation of heat in the face and upper body).

228. The reproductive process from fertilization to birth

The basic function of both the male and female reproductive systems is the continuation of the species by the development of offspring. This is accomplished through a condition called pregnancy, during which there is a developing fetus (offspring) in the uterus of the female. This condition is achieved when there is successful fertilization of the female ovum by the male sperm.

Fertilization

Fertilization requires the presence of an ovum in the uterine tube. Fertilization normally occurs in the outer one-third of the fallopian tube. The secondary oocyte enters the tube after ovulation and is slowly transported down the tube by the action of the uterine cilia and peristaltic action of the tube itself. Early in the cycle, high estrogen levels trigger the uterus to secrete a watery fluid that promotes sperm movement and survival. (Towards the end of the cycle, high levels of progesterone cause the secretion of a thick, sticky fluid that inhibits the sperm.) This is important if fertilization is to take place. Time is another critical factor.

The ovum can only survive for 12 to 24 hours after ovulation. In contrast, the sperm usually reach the uterine tubes within an hour of intercourse and can survive for 72 hours in the uterine tubes. This means that the optimal period for fertilization is between 72 hours before ovulation to 24 hours after ovulation. When sexual intercourse results in the deposit of seminal fluid in the vagina, the sperm is transported from the vagina into the uterus. This is achieved by the lashing action of the sperm tails and the muscular contractions of the uterus and uterine tubes. (These contractions are supposedly stimulated by the prostaglandins in the seminal fluid.) Of the millions of sperm released in a single

ejaculation, only a few hundred will survive to reach the ovum. When those few hundred reach the egg, only one will fertilize it.

The actual fertilization takes place when a sperm cell penetrates the zona pellucida of the oocyte. This penetration is helped by the digestive actions of an enzyme called *hyaluronidase*. This enzyme is released by the acrosome that covers the head of the sperm. The hyaluronidase digests its way through the corona radiata and the zona pellucida. Once a single sperm has entered the zona pellucida, the oocyte undergoes structural changes and begins to secrete enzymes that prevent other sperm cells from entering. When the sperm enters the cytoplasm of the ovum, it loses its tail and the head enlarges to form a structure called a *pronucleus* (a precursor form of a nucleus). At the same time, the secondary oocyte completes the second meiotic division to form a polar body and female pronucleus. The two pronuclei come together to form a single nucleus that has 46 chromosomes. The structure is then called a *zygote* (fertilized ovum).

Gestation

The term gestation refers to the period of development that begins the moment the ovum is fertilized by a sperm cell and lasts until the fetus is ready to be born. In humans, this gestation period lasts roughly nine calendar months or 40 weeks. *Pregnancy* is the term more commonly associated with this developmental period. Pregnancy means a condition characterized by the presence of a developing offspring in the female uterus. The term applies only to mammals.

Embryonic development

Soon after it is formed, the zygote begins to multiply through mitosis. This phase is called *cleavage* since the cells are dividing to form smaller and smaller daughter cells. While the cleavage is taking place, the cell mass is slowly moving through the uterine tube into the uterus. This trip takes about three days. By this time, the structure has developed into about 16 cells still within the original zona pellucida. The structure is now referred to as a *morula*.

The morula continues to float around in the uterus for several days while the zona pellucida disintegrates. The structure now consists of a hollow ball of cells called a *blastocyst*. The blastocyst begins to attach itself to the endometrial lining and, by the end of the first week, is superficially implanted. After it becomes implanted, cells within the blastocyst begin to organize into the structure that will be the body of the offspring. The blastocyst is then termed an *embryo*. But, technically, it is a blastocyst until the end of the eighth week, when it is then called a *fetus*. Figure 4-12 shows the changes that take place between ovarian follicle maturation and blastocyst implantation in the uterine lining.

The outer cells of the embryo combine with cells from the endometrium to form a structure called the *placenta*. The placenta connects the embryo to the endometrium and serves as an exchange point for oxygen and nutrients from the maternal blood, with waste products and carbon dioxide from the embryonic blood. The placenta also secretes certain hormones.

Hormonal changes

The outer layer of embryonic cells, which combines with endometrial cells to form the placenta, is called the *trophoblast*. Shortly after the embryo becomes implanted, the trophoblast begins to secrete a hormone called *human chorionic gonadotropin* (HCG). The HCG has properties similar to the LH, and helps maintain the corpus luteum, which then continues to secrete estrogen and progesterone. The estrogen and progesterone maintain the endometrial lining and inhibit the secretion of gonadotropins.

If the HCG is not secreted soon enough, the corpus luteum begins to degenerate within two weeks of ovulation. When that happens, the estrogen and progesterone levels drop, and the endometrial lining is sloughed off. If the embryo has been implanted, it will be lost (i.e., spontaneously aborted). HCG secretion continues for several months and then gradually declines. The corpus luteum is maintained throughout the pregnancy, but replaced as a source of hormones after the first trimester (three months).

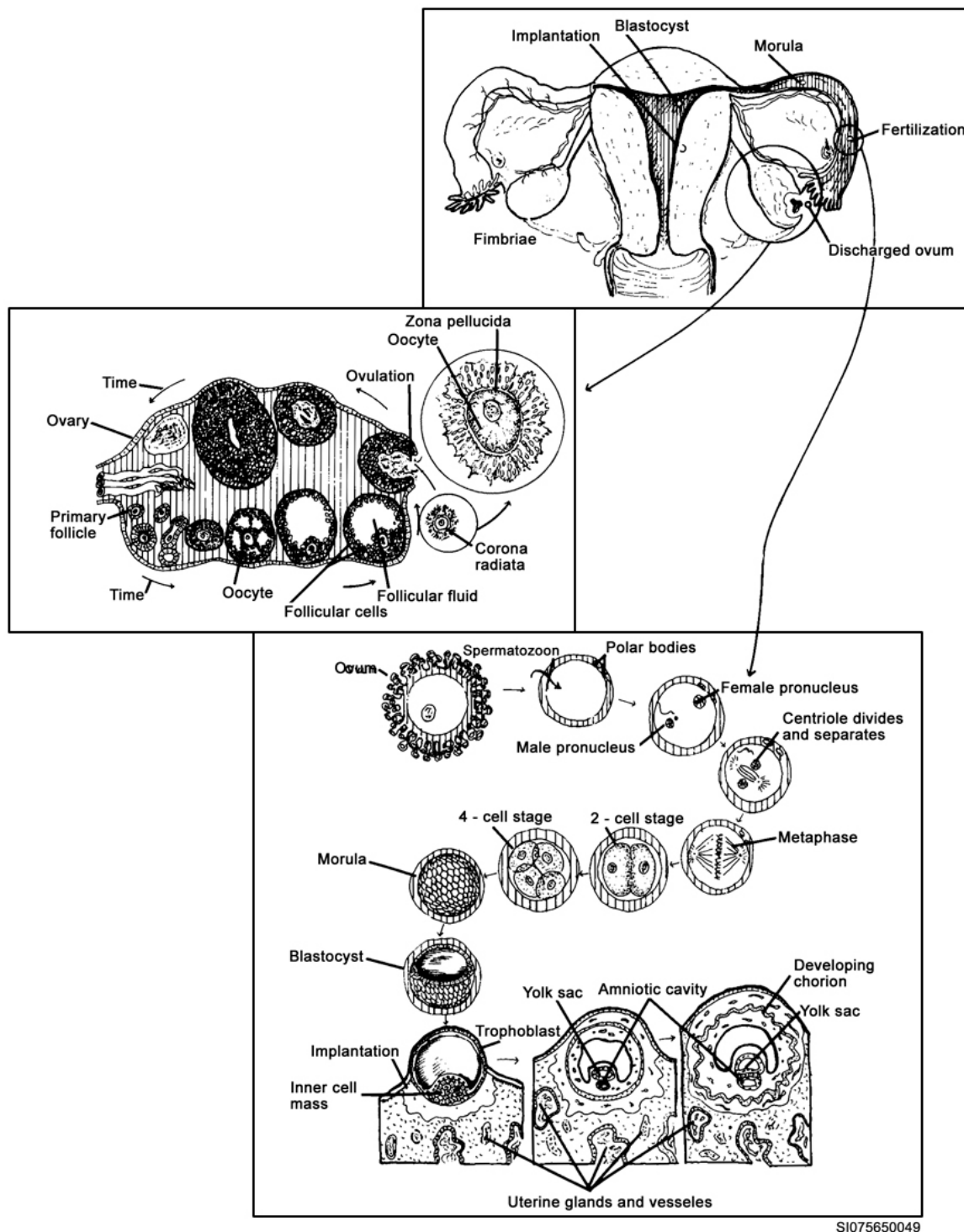


Figure 4-12. The reproductive cycle from ovulation to uterine implantation.

From the end of the first trimester to the end of the pregnancy, the placenta secretes the estrogen and progesterone necessary to maintain the endometrial lining. The placenta also secretes a hormone called *placental lactogen*. Placental lactogen causes enlargement of the breasts and prepares the breasts to secrete milk.

Placental progesterone acts together with a hormone called *relaxin* from the corpus luteum to prevent contraction of uterine muscles until the time of the delivery. The relaxin also helps to soften the cervix and the ligaments holding the pubic symphysis and sacroiliac joints together. This is necessary to allow the fetus to pass out of the uterus and through the pelvic girdle. High concentrations of *placental estrogen* are also involved in the softening of the ligaments as well as the enlargement of the vagina and external reproductive organs.

Levels of the hormones aldosterone and parathormone are also increased during pregnancy. The aldosterone promotes sodium reabsorption which leads to fluid retention. The parathormone causes increased levels of calcium in the blood.

Physical changes of pregnancy

Obviously there are many physical changes in the female body as the fetus grows and develops. The uterus enlarges to accommodate the growing fetus, and extends upward out of the pelvic cavity. As it does this, the abdominal organs are displaced and compressed against the diaphragm. This interferes with both maternal breathing and digestion. At the same time, the uterus presses down on the bladder resulting in urinary frequency.

The growing fetus requires more and more oxygen and nutrients. The maternal metabolic rates increase to meet these demands and to remove the waste products produced by the fetus. This also creates a need for increased dietary intake by the mother. This does not necessarily mean eating twice as much; it simply means increasing intake of proteins, vitamins, and minerals as needed. The fetus absorbs nutrients faster than the mother. An inadequate diet affects the mother before it affects the fetus.

Birth process

After approximately 40 weeks, the pregnancy terminates in the birth of the fetus. After about the seventh month, placental levels of estrogen began to exceed progesterone. As we already mentioned, the progesterone inhibits contractions of the uterus. Estrogen has the opposite effect. As a result, the uterine wall becomes more contractile. The estrogen and progesterone also trigger the secretion of prostaglandins, which are thought to initiate the birth process. The stretching of the uterine and vaginal tissues sends sensory impulses to the hypothalamus. The hypothalamus promotes the release of the hormone, oxytocin, from the posterior pituitary gland. Oxytocin is a potent stimulant of uterine contractions, and is involved in the later stages of the labor process.

Labor

Labor is the term for the muscular activity that forces the fetus through the vaginal canal. Rhythmic uterine contractions signal the beginning of labor. These contractions begin at the fundus of the uterus and move in a wave-like fashion down to the cervix. These contractions force the contents of the uterus through the cervix. In a normal delivery, the fetus is positioned head-first in the uterus. When the contractions begin to push downwards, the head is forced against the cervix. This causes stretching of the cervix and initiates a reflex which causes stronger contractions. This reflex is called a positive feedback system. There are stretch receptors in the cervical tissue. As the cervix is stretched, these receptors trigger stronger uterine contractions. This cycle continues until maximum effort is reached. Meanwhile, the stretching of the cervix causes the release of oxytocin which intensifies the contractions. This positive feedback system also affects the abdominal muscles. They begin to contract to help force the fetus through the cervix and vagina.

Within 10 to 15 minutes after delivery of the fetus, the placenta is also delivered (also through uterine contractions). The placenta and associated tissues are called the *afterbirth*. There is a great deal of capillary bleeding when the placenta separates from the uterine wall. This bleeding is halted by continued contractions of the uterus, which are stimulated by the oxytocin. The contractions constrict the blood vessels in the area.

Involution

For several weeks after the birth process, the uterus goes through a process called *involution*. Involution involves a gradual decrease in the size of the uterus. The endometrial lining that developed during the pregnancy is also sloughed off and is replaced with the normal uterine epithelial lining. Figure 4-13 summarizes the reproductive development that occurs from fertilization through the end of the gestation period.

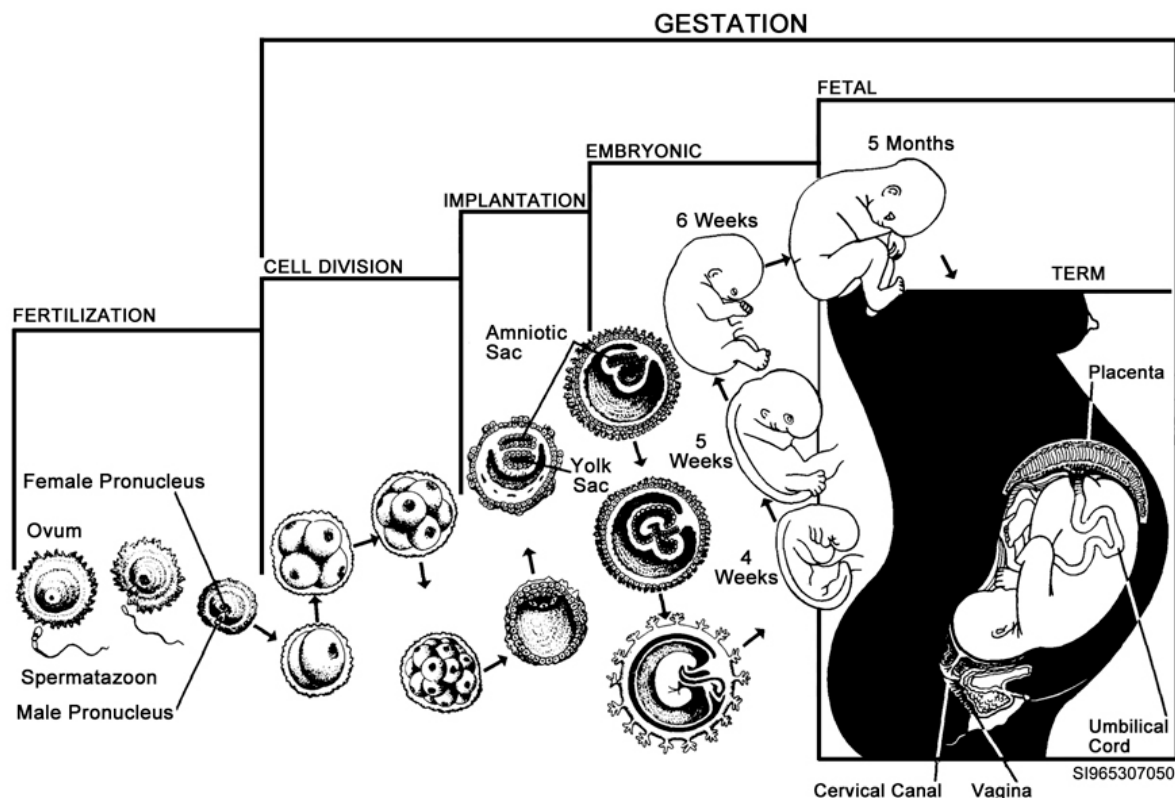


Figure 4-13. Gestation.

Congratulations! You've come a long way since you began this course, and now you're in the "homestretch." There's just one more volume to go before you're at the end. We've bombarded you with a great deal of information thus far, but it is all necessary to truly upgrade your knowledge of surgical technology. If you feel like you've been raked over hot coals, just remember—the more you learn about all aspects of your job and your patients, the better the care you will be able to provide.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

226. Female reproductive organs and their functions

1. What are the three categories of female reproductive organs?
2. Which ligament contains blood vessels and nerves that supply the ovaries?
3. How does the structure of an ovary resemble that of a lymph node?

4. What two changes occur in female follicles with the onset of puberty?
5. What are the periodic changes in the ovaries that result in the production of a mature ovum called?
6. How is a corpus luteum formed?
7. What are the three layers of a uterine tube?
8. What are the two sections of the uterus?
9. List the three layers of the uterus.
10. Describe retroversion and antelexion of the uterus.
11. What are the three basic functions of the vagina?
12. What are the female external accessory organs?
13. Where is the clitoris located?
14. Which glands produce a mucous secretion that lubricates and moistens the vaginal opening?
15. The breasts are primarily composed of what?
16. What prevents the secretion of milk before the birth of a baby?
17. Describe the mechanism that results in the secretion of milk.

227. Female sexual responses, hormones, and reproductive cycles

1. What is the purpose of the mucus secreted by the vestibular glands?
2. The hormones that control female reproductive activities and development are produced where?
3. What hormone primarily controls the development of the female secondary sexual characteristics?
4. Describe the processes that result in menarche.
5. What prevents production of gonadotropins by the pituitary during the menstrual cycle?
6. What appears to be the cause of menopause?

228. The reproductive process from fertilization to birth

1. What is the basic purpose of both the male and the female reproductive systems?
2. Describe the timeframe necessary for successful fertilization.
3. What is gestation?
4. What process results in the formation of a morula?
5. What hormone is necessary to prevent spontaneous abortion of the embryo?
6. What hormones are involved in the softening of the sacroiliac ligament and the pubic symphysis?
7. What muscular activity marks the onset of labor?

8. Describe involution.

Answers to Self-Test Questions

221

1. Renal fascia and the deep muscles of the back.
2. Functional units of the kidney.
3. Major calyces.
4. Glomerulus.
5. Proximal tubules, distal convoluted tubules, and the loop of Henle.
6. Peritubular capillary network.
7. Blood and filtrate (urine) circuits.

222

1. Filtration and reabsorption.
2. An enzyme that stimulates the production of a vasoconstrictor.
3. Tubules and peritubular capillaries.
4. Through the use of a countercurrent mechanism, which multiplies or concentrates solutes.
5. When blood volume increases, cardiac output and arteriole pressure increases. Afferent arteriole pressure in the renal corpuscle increases and the rate of glomerular filtration increases. Urine output rises until a normal blood pressure is established. The urine produced is very dilute.
6. Erythropoietin.

223

1. The inner layer is a mucous coat made up of several layers of epithelium. The middle layer is circular and composed of longitudinal smooth muscle. The outer layer is made of connective tissue.
2. Behind the pubic symphysis and below the parietal peritoneum within the pelvic cavity.
3. Trigone.
4. In the sacral segments of the spinal cord.
5. External urethral sphincter.
6. The external urinary orifice or meatus.
7. The prostatic, membranous, or penile.

224

1. Testes.
2. Testosterone.
3. Interstitial cells, or cells of Leydig.
4. The primary spermatocytes undergo meiosis and form two secondary spermatocytes, each with 23 chromosomes. The secondary spermatocytes also divide to form four spermatids. The spermatids develop into sperm cells.
5. From the mitochondria in the body of the cell.
6. A small amount of seminal fluid that becomes the semen of ejaculation.
7. Vas deferens and a duct from the seminal vesicle.
8. Along the lower part of the posterior surface of the bladder.
9. Alkaline secretion of the prostate.
10. Cowper's glands.

11. Sperm and secretions from the prostate, bulbourethral glands, seminal vesicles, nutrients, and prostaglandins.
12. To reduce friction around the testes.
13. The prepuce.

225

1. Erection, orgasm, emission, and ejaculation.
2. Increases in heart rate, blood pressure, and breathing, accompanied by dilation of the blood vessels in the skin and intense sexual excitement.
3. The arteries constrict, and the blood is drained off through the veins. The smooth muscles resume partial contraction, and the penis becomes limp.
4. Gonadotropin-releasing hormone (GnRH).
5. Testosterone and follicle-stimulating hormone.
6. They are absorbed, converted, and excreted by the liver.
7. The voice becomes low-pitched because of the enlargement of the larynx and thickening of the vocal cords.
8. When the levels of testosterone in the blood increase, the hypothalamus responds by decreasing production of GnRH. This results in a decrease in the production of LH and FSH by the anterior pituitary and testosterone production decreases. When testosterone levels are low, the procedure reverses itself.

226

1. Primary organs, internal accessory organs, and external accessory organs.
2. Suspensory ligament.
3. An outer cortical layer and an inner medullary layer exist in both the ovaries and the lymph nodes.
4. The primary follicles begin to grow and develop; and periodically, some of the follicles are stimulated to continue with meiosis.
5. Ovarian cycle.
6. A clot forms within the ruptured follicle. Then the follicular cells become altered to form a mass of cells called corpus luteum.
7. An outer peritoneal layer, a middle muscular layer, and an inner mucosal layer.
8. Body and cervix.
9. Endometrium, myometrium, and perimetrium.
10. Retroversion is when the uterus is tilted backwards, almost in a straight line with the vaginal canal. Antelexion puts the body of the uterus angled straight forward, perpendicular to the cervix.
11. (1) It serves as a passageway for uterine secretions, (2) it is the birth canal through which the fetus is delivered, and (3) it receives the penis during sexual intercourse.
12. Labia majora, labia minora, clitoris, vestibule, vestibular glands, and breasts.
13. At the anterior end of the vulva, between the labia minora.
14. Vestibular glands.
15. Adipose tissue and alveolar glands.
16. Secretion of prolactin-inhibiting factor (PIF) by the hypothalamus.
17. Sensory impulses go to the hypothalamus when the breasts are stimulated. The hypothalamus signals the posterior pituitary to release oxytocin into the blood. When the oxytocin reaches the myoepithelial cells surrounding the alveolar glands, they contract and milk is squirted out of the breast.

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1. To prevent irritation of the tissues from sexual activity.
2. In the ovaries, the hypothalamus, and the anterior pituitary gland.
3. Estrogen.

4. Menarche begins when the GnRH from the hypothalamus promotes increased secretions of LH and FSH from the anterior pituitary. These hormones stimulate the maturation process of some of the follicles and initiate the development of secondary sexual characteristics.
5. High concentrations of estrogen and progesterone in the blood.
6. The depletion of follicles in the ovaries.

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1. The continuation of the species through the development of offspring.
2. Fertilization must occur no more than 72 hours prior to ovulation, and not more than 24 hours after ovulation.
3. The period of development that occurs from the moment the ovum is fertilized by a sperm cell, until the fetus is ready to be born (40 weeks).
4. Cleavage.
5. Human chorionic gonadotropin (HCG).
6. Relaxin and placental estrogen.
7. Uterine contractions.
8. Involution involves a gradual decrease in the size of the uterus. The endometrial lining developed during pregnancy is sloughed off and replaced with normal uterine epithelial lining.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to a field scoring answer sheet.

Do not return your answer sheet to AFCDA.

47. (221) A main functional organ of the urinary system is the
- a. gonad.
 - b. uterus.
 - c. kidney.
 - d. scrotum.
48. (221) The renal artery, the renal vein, lymph vessels, nerves, and a ureter all enter the kidney through the
- a. hilum.
 - b. cortex.
 - c. medulla.
 - d. nephrons.
49. (222) The kidney produces urine through the processes of reabsorption and
- a. filtration.
 - b. oxidation.
 - c. peristalsis.
 - d. hydrolysis.
50. (222) Indirectly, the kidneys help regulate blood pressure by regulating
- a. blood volume.
 - b. synaptic activity.
 - c. heart contractions.
 - d. pituitary secretions.
51. (223) The structure that transports urine from the kidney to the bladder is the
- a. hilum.
 - b. ureter.
 - c. urethra.
 - d. loop of Henle.
52. (223) What adult urinary structure has the ability to greatly distend and expand to hold approximately 500 milliliters?
- a. Ureter.
 - b. Kidney.
 - c. Urethra.
 - d. Bladder.
53. (223) Which is *not* a true statement concerning the male urethra?
- a. Is divided into three sections.
 - b. Serves in the reproductive system.
 - c. Is approximately 1½ inches long.
 - d. Serves to drain the bladder of urine.

54. (224) The testes are suspended by scrotal tissue and
- a. semen.
 - b. the urethra.
 - c. round ligaments.
 - d. the spermatic cords.
55. (224) Which is *not* an internal accessory organ of the male reproductive system?
- a. Penis.
 - b. Epididymis.
 - c. Vas deferens.
 - d. Ejaculatory duct.
56. (224) Which penile structure is removed in an operation called a circumcision?
- a. Bulb.
 - b. Glans.
 - c. Prepuce.
 - d. Smegma.
57. (225) Which activity does *not* normally involve the propelling of sperm and other secretions into the urethra?
- a. Ejaculation.
 - b. Emission.
 - c. Erection.
 - d. Orgasm.
58. (225) Which structure does *not* produce and secrete hormones that control male sexual development and activity?
- a. Testes.
 - b. Pituitary.
 - c. Pancreas.
 - d. Hypothalamus.
59. (225) Which hormone is secreted by the male gonads?
- a. Testosterone.
 - b. Luteinizing hormone.
 - c. Follicle-stimulating hormone.
 - d. Gonadotropin-releasing hormone.
60. (226) Ligaments attach the ovaries to the wall of the pelvic cavity and the
- a. uterus.
 - b. bladder.
 - c. omentum.
 - d. diaphragm.
61. (226) The oocyte is transported from the ovary to the uterus by the
- a. ureter.
 - b. urethra.
 - c. fallopian tubes.
 - d. round ligament.

62. (226) In a virginal vagina, the vaginal orifice is partially covered by a thin membrane called the
- a. hymen.
 - b. clitoris.
 - c. perineum.
 - d. endometrium.
63. (227) In addition to estrogen, which hormone is produced by the ovaries?
- a. Adrenaline.
 - b. Testosterone.
 - c. Progesterone.
 - d. Gonadotropine.
64. (228) Fertilization of the ovum normally occurs in the
- a. ovary.
 - b. uterus.
 - c. placenta.
 - d. fallopian tube.
65. (228) Human gestation is commonly referred to as
- a. infancy.
 - b. pregnancy.
 - c. fertilization.
 - d. menstruation.

Student Notes

Glossary

Terms

Abduction – Moving a body part away from the median plane of the body.

abductor – A muscle that moves a body part away from the median plane of the body.

absorption – Passage of a substance through a membrane, cell, or vessel.

active transport – A process of moving a substance across a cell membrane that requires the release and use of energy.

adduction – Moving a body part toward the midline of the body.

adductor – A muscle that moves a body part toward the midline of the body.

adipose tissue – Tissue that stores fat.

aerobic – Requiring oxygen for survival or growth.

afferent – Carrying towards the center, as afferent neurons transmit impulses from the peripheral to the central nervous system.

alimentary canal – The long tube extending from the mouth to the anus; also called the gastrointestinal or digestive tract.

amino acid – Organic compounds that are the “building blocks” of proteins.

anabolism – A constructive process by which living cells convert simple substances into more complex compounds.

anaphase – Stage of mitosis when chromosomes move to poles of dividing cell.

anastomosis – The communication between vessels by collateral channels.

anatomy – Study of the structure of an organism and its parts.

anesthesia – Loss of sensation with or without the loss of consciousness.

anterior – In front of; the ventral surface.

antibodies – Protein containing substances produced by the body’s immune system that attack specific foreign substances (antigens) that enter the body.

antigens – Used to describe any foreign substances entering the body that trigger the immune system to produce antibodies.

aponeurosis – A sheet-like tendinous expansion, mainly connecting a muscle with parts it moves.

approximate – To bring together; join. In wound closure, bringing cut tissue layers together through the use of sutures or staples.

arachnoid – Weblike; the weblike middle layer of the meninges.

artery – A blood vessel that carries blood away from the heart.

atlas – The first cervical vertebra; it articulates with the occipital bone of the skull and the axis, or second cervical vertebra.

auditory ossicles – The three tiny bones of the middle ear; malleus, incus, stapes.

avascular – Lacking blood supply.

axon – The neuron process that carries the impulses away from (efferent process) the nerve cell body or system.

capillary – The smallest blood vessel; food, oxygen, and other substances pass from the capillaries to the cells.

cardiac muscle – Specialized muscle found only in the heart.

cartilage – The connective tissue at the end of long bones.

catabolism – A process by which living cells break down complex compounds into more simple substances. Destructive metabolism.

caudal – In human anatomy, the lower portion of the anatomy; the “tail-end.”

cell – The basic unit of body structure and all living organisms.

cell membrane – The outer covering that encloses the cell and helps the cell to hold its shape; it is selectively permeable.

centrioles – Organelles (usually a pair in each cell) found in cytoplasm, near the nucleus, that play a role in cell division.

cerumen – The waxy substance secreted in the ear.

cholinesterase – An enzyme that helps break-down acetylcholine.

chromatin – Genetic material in the nucleus of cells that divides into chromosomes during mitosis.

chromosomes – Rod-shaped structures, composed of genes, in the animal cell nucleus containing DNA which transmits genetic information.

cilia – Tiny hair-like projections on the surfaces of certain membranes that filter and trap foreign bodies, keeping them from entering other tissues.

conductivity – Ability to transmit electrical impulses.

condyle – The rounded projection at the end of a bone; it usually articulates with another bone.

congenital – Present at or existing from the time of birth.

constrict – To narrow.

corium – The dermis.

coronal suture – The articulations of the bones of the skull.

cortex – The outer surface of an organ or structure.

crenation – Shrinking of a cell (such as a red blood cell) when it is placed in a hypertonic solution.

crest – A ridgelike projection of bone.

cross-contamination – Transmitting potential pathogens from one individual or object to another.

cutaneous membrane – The skin; composed of the dermis and epidermis.

cytoplasm – The protoplasm of a cell excluding that of the nucleus (nucleoplasm).

dehydration – A decrease in the amount of water in body tissues.

dendrites – The branches of motor neurons that transmit the nerve impulse to the cell body; the cell receptors.

dermatome – (1) Area of skin or body supplied by a particular root of a spinal nerve. (2) An extremely sharp surgical instrument used to remove thin layers of skin from a patient's body for the purpose of skin grafting.

dermis – The deep, inner layer of the skin.

desmosome – A specialized junction between cells; a cellular “spot weld.”

diffusion – Random movement of molecules from an area of higher concentration to one of lower concentration.

digestion – The process of physically and chemically breaking down food so that it can be absorbed for use by the cells of the body.

dilate – To expand or open up wider.

diluent – An agent (solution) used to dilute an existing solution or reconstitute a powdered substance.

distal – Farthest from the point of attachment (extremity) or reference.

dorsal – Pertaining to the back or posterior.

edema – Swelling caused by an abnormal build-up of fluid in injured or infected tissues.

effector – A muscle or gland that contracts or secretes, respectively, in direct response to nerve impulses.

efferent – Carrying away from the center, as efferent neurons transmit impulses away from the central nervous system to the peripheral.

encapsulated – Enclosed by a “capsule” or sheath of material not normally found in that part. Most nonabsorbable sutures will become encapsulated by fibrous connective tissue after implantation in the body.

endocrine gland – A ductless gland that secretes hormones directly into the blood.

endocrine system – Body system that includes the internal organ and glands that secrete hormones.

endomysium – A sheath of connective tissue that surrounds each skeletal muscle fiber; it is between the individual muscle fibers (inner sheath).

endothelium – A single layer of simple squamous cells lining the heart and vessels containing blood and/or lymph.

epidermis – The outer layer of the skin.

epimysium – A sheath of connective tissue that surrounds the entire skeletal muscle; the outer muscle sheath.

epithelial tissue – A primary tissue type; covers the surface of the body and lines body cavities, ducts, and vessels.

equilibrium – State of balance.

erythrocytes – Red blood cells.

erythropoiesis – The process that forms red blood cells.

etiology – Refers to the cause of a disease when used in a medical context.

exhalation – The act of breathing out; expiration.

exocrine gland – A gland with a duct to carry its secretions to a particular area.

extracellular – Outside a cell.

fascia – Layers of fibrous connective tissue under the skin and covering muscles.

fascicle (also fasciculus) – A bundle of nerve or muscle fibers separated by connective tissue.

fertilization – The process whereby the male sex cell (sperm) unites with the female sex cell (ovum) to form one cell.

fibrillation – Irregular, uncoordinated contraction of muscle cells, especially heart muscle cells.

filtration – Passage or straining of solvent and dissolved substances through a membrane or filter.

fissure – (1) The deepest depressions or inward folds of the brain (2) Any groove or cleft.

flaccid – Soft, flabby, relaxed, especially pertaining to muscles.

flagella – Long, whip-like extensions of the cell membrane of some cells (bacteria and sperm) that propel the cell.

follicle – Small sac or gland.

fomite – Any inanimate object or substance capable of harboring and transmitting a disease.

fontanel – Baby's "soft-spots" or membranous areas that have not yet ossified in the skull.

foramen – A hole or opening in a bone or between body cavities.

forebrain – The front of the brain; cerebrum and basal ganglia.

fossa – A depression in bone or other structure.

gametes – Male or female reproductive cells (sperm/egg); sex cells.

ganglion – Group of nerve cell bodies located in the peripheral nervous system.

gene – One of the biological units of heredity located in chromatin.

gland – An organ specialized to secrete or excrete substances

golgi apparatus – Organelles in the cytoplasm that assist with cellular secretion.

gomphoses – An immovable joint in which a peg-shaped projection fits into a bony socket.

gonads – Organs producing gametes; ovaries or testes.

hair follicle – Tubelike depression in the skin where hair develops.

Haversian system – (also osteon)The basic unit of bone tissue; a system of interconnecting microscopic canals in adult compact bone.

hematopoiesis – The formation or development of blood cells. Hemopoiesis

hemoglobin – The substance in the red blood cells that gives blood its color; hemoglobin carries oxygen in the blood.

hemolysis – Lysis or bursting of red blood cells.

hemopoiesis – The formation or development of blood cells. Hematopoiesis.

heparin – A substance that prevents clotting of blood.

homeostasis – The tendency for organisms to seek a stable physiological state.

hormone – A chemical substance secreted by glands that regulate specific effects on individual organs or parts.

hyaline cartilage – Glassy, transparent cartilage.

hydrolysis – A chemical process whereby water molecules split chemical bonds, splitting a substance into smaller particles.

hydrostatic pressure – Pressure exerted by a fluid within a closed system.

hypertonic – The term used to describe the tonicity of a solution which has a higher solute concentration than that of the body cells. When cells are placed in a hypertonic solution, water will move out of the cells across their semipermeable membranes into the hypertonic solution, causing the cells to shrink.

hypogastric – The lower middle region of the abdomen.

hypotension – A condition in which the blood pressure is below normal.

hypothalamus – Region of the diencephalon forming the floor and walls of the third ventricle.

hypotonic – A term used to describe the tonicity of a solution which has a lower solute concentration than that of the body cells. When cells are placed in a hypotonic solution, water will move into the cells across their semipermeable membranes, causing the cells to swell.

infection – A disease state that results from the invasion and growth of micro organisms in the body.

insertion – The movable attachment of a muscle; the part of the muscle that moves during its action while the origin stays anchored.

intercellular – Between cells.

interphase – The resting phase between two mitotic divisions.

intracellular – Within a cell.

inversion – Turning inward.

involuntary muscles – The muscles that work automatically and cannot be consciously controlled.

lactation – The production and secretion of milk.

leukocytes – General term used to describe all types of white blood cells.

ligament – A strong band of connective tissue that holds bones together.

lipid – Fat or fat-like substances such as fatty acids, waxes, steroids, and natural fats; serves as source of fuel for the body.

lumen – (1) Passageway or tubular space within a body structure. (2) The channel within a hollow, tube-shaped instrument, or needle.

lymph – Watery fluid, collected from tissue fluids, found in lymph vessels.

lymphatic system – A system of vessels carrying lymph; closely related to circulatory system.

lymphocytes – Leukocytes (white blood cells) produced in lymphatic tissue. They attack, engulf, and destroy invading microorganisms. as part of the immune system.

lysis – Bursting of a cell (such as a red blood cell) when it is placed in a hypotonic solution.

mast cells – A cell to which antibodies become attached, usually in response to allergens.

matrix – The intercellular substance of any tissue, usually applies to bone and other connective tissue.

meatus – The external opening of a canal, such as the opening at the end of the urethra.

medial – Toward the midline of the body.

mediastinum – A septum or cavity between two principle portions of an organ.

medulla – The central portion of certain organs.

meiosis – The process of cell division whereby gametes (egg and sperm cells) are formed.

menisci – The crescent shaped pieces of fibrocartilage that separate the articulating surfaces of the bones in the knee.

menopause – The period of time when a woman no longer menstruates.

menstruation – The process in which the endometrium of the uterus breaks up and is discharged from the body through the vagina.

merocrine – A process of secretion that does not result in cell injury or death when the secretion is discharged; opposite of holocrine.

mesothelium – The layers of cells, derived from the mesoderm, lining the body cavities of an embryo. In the adult, it forms the serous membrane covering all true serous membranes.

metabolism – The burning of food for heat and energy by the cells; the sum total of all chemical reactions in the body.

metaphase – The second stage or phase of mitosis; the chromosomes align in the middle of the spindle.

microphage – A small phagocyte; see also phagocyte.

microscopic – Visible only by using a microscope.

microvilli – Tiny projections on the surfaces of some epithelial cells that increase the surface area for absorption.

mitochondria – Rod-shaped cytoplasmic organelles responsible for generating the metabolic energy for cellular activities.

mitosis – A type of cell division where each daughter cell contains the same number of chromosomes as the parent cell.

motor neurons – A neuron that transmits impulses from the central nervous system to an effector.

mucous membrane – Membrane that lines all body cavities open to the exterior; such as the digestive, respiratory, urinary and reproductive tracts

mucus – A thick, sticky fluid secreted by mucous glands and membranes that keeps the surface of mucous membranes moist.

nuclear envelope – The membrane surrounding the cell nucleus; it functions similarly to the cell membrane.

organ – A part or structure of the body, formed of two or more tissues, that performs a specialized function.

organ system – A group of organs that work together to perform a body function.

- organelle** – A specialized part of a cell which performs a definite function; many are found in the cytoplasm.
- origin** – Attachment point of a muscle that remains relatively fixed or immobile during actions of the muscle.
- osmosis** – Movement of a pure solvent (such as water) across a semipermeable membrane, from an area of lesser solute concentration to an area of greater solute concentration.
- ossicles** – The three tiny bones of the middle ear.
- osteoblast** – A cell involved in bone formation.
- osteoclast** – A cell that “cleans” tissue by absorbing and removing unwanted tissue; particularly useful in fracture healing.
- osteocyte** – An osteoblast that has become embedded in the bony matrix.
- ovary** – The female gonad; produces the egg.
- palate** – The roof of the mouth.
- parietal** – Pertaining to the walls of a cavity.
- passive transport** – Transport of material across cell membranes that does not require the cell to expend energy.
- pericardium** – The membranous sac surrounding the heart.
- peristalsis** – The involuntary muscle contractions in the digestive system that move food through the alimentary canal.
- peritoneum** – The serous lining of the interior abdominal cavity.
- permeability** – The property of membranes that allows passage of substances.
- pH** – The symbol relating the hydrogen ion (H) concentration of a solution to a standard solution. A measure of the solution’s acidity or alkalinity. A pH of 7 is considered neutral; above 7 is alkaline, below 7 is acidic.
- phagocyte** – A cell having the capability to ingest and destroy substances such as bacteria, protozoa, cells and cell debris, and microphages.
- phagocytosis** – A process by which cells absorb or ingest and destroy solid substances.
- pinocytosis** – A process by which cells absorb or ingest and destroy liquid substances.
- pituitary gland** – The neuroendocrine gland beneath the brain that regulates functions of numerous organs, including: water balance, gonads, thyroid, adrenal cortex, and other glands. Considered by some to be the “master” gland of the body.
- plasma** – The fluid portion of the blood.
- platelet** – A disk shaped structure found in the blood of all mammals which plays a key role in blood clot formation.
- pleura** – The serous membrane covering the lungs.
- polar bodies** – A minute, non-functioning cell produced during meiosis during egg cell formation in the ovary.
- process** – (1) A prominence or projection. (2) A series of actions with a specific purpose.

pronator – A muscle that moves the palm of the hand downward or backwards.

prophase – The first stage of mitosis; chromosomes become visible.

proprioceptor – The awareness of posture, movement, and changes in equilibrium and the knowledge of position, weight, and resistance of objects in relation to the body.

protoplasm – A viscous material which constitutes the basis of all living activities.

puberty – The period of life during which the reproductive organs begin to function and secondary sex characteristics begin to appear.

pulse – The beat of the heart felt at an artery as a wave of blood passes through the artery.

pupil – The circular opening in the center of the iris, through which light enters the eye.

ramus – A branch of a nerve, artery, vein, or bone.

receptor – A peripheral nerve ending specialized to respond to a particular type (or types) of stimulus.

recruitment – Increase in the number of motor neurons that are activated as the intensity of a stimulus increases.

reflex – Automatic reaction to stimulus.

rotation – Turning about an axis (imaginary or real).

sclera – The white of the eye.

somatic – Pertaining to the body.

sperm – The male gamete.

sphincter – A muscle surrounding an opening; acts as a valve.

stimulus – An excitant or irritant that generates a response.

stool – Feces that have been excreted.

stratified – Layered.

stratum – A layer.

stress – The internal responses caused by application of a stressor or unwanted factors.

subcutaneous – Beneath the skin.

sublingual – Beneath the tongue.

supination – The outward rotation of the forearms that causes the palms to face anteriorly (toward the

system – Organs that work together to perform special functions.

tachypnea – Rapid breathing; the respiratory rate is greater than 24 respirations per minute.

telophase – Mitotic stage in which daughter cells become separate structures.

tendon – The tough, connective tissue that connects muscles to bones.

tendon sheath – A covering of synovial membrane surrounding a tendon.

testis – The male gonad; produces sperm.

tetanic contraction – A severe muscle contraction and spasm.

thalamus – A mass of gray matter in the diencephalon of the brain.

threshold stimulus – The weakest or minimum amount of stimulus required to produce a nerve impulse or muscle contraction.

tissue – A group of cells with the same function.

urethra – The tubal structure through which urine passes from the bladder and is eliminated from the body.

urination – The process of emptying the bladder; voiding; micturition.

vein – A blood vessel that carries blood back to the heart.

ventral – Anterior or front.

virus – An extremely small microscopic organism that grows in living cells.

viruses – Extremely tiny microorganisms that can only be seen with an electron microscope and are capable of passing through bacterial filters. Viruses are pathogenic parasites that can only grow and multiply within living cells.

viscera – Internal organs.

visceral effector – The organ or organs, usually in the abdominal cavity, stimulated by a particular impulse causing a commensurate response.

viscosity – Sticky or gummy; resistance offered by a liquid to change of form or relative position of its particles due to attraction of molecules to each other.

vital signs – Temperature, pulse, respirations, and blood pressure.

voiding – Urination or micturition.

Volkmann's canals – Minute ducts through which nerves and blood vessels penetrate compact bone; also called perforating canals.

voluntary muscles – The muscles that can be consciously controlled, such as the skeletal muscles.

Wormian bones – Bones that sometimes form in the joints of the bones of the skull, also called suture bones.

zygote – The union of the sperm and egg; a fertilized ovum.

Glossary of Abbreviations and Acronyms

ACTH	adrenocorticotrophic hormone
ADH	antidiuretic hormone
AMP	adenosine monophosphate
ANS	autonomic nervous system
ATP	adenosine triphosphate
AV	atrioventricular

CBC	complete blood count
cm	centimeter
CNS	central nervous system
CO₂	carbon dioxide
COPD	chronic obstructive pulmonary diseases
DNA	deoxyribonucleic acid
EKG	electrocardiogram
FSH	follicle-stimulating hormone
HCG	human chorionic gonadotropin
Hg	mercury
GH	growth hormone
GnRH	gonadotropin-releasing hormone
ICSH	interstitial cell-stimulating hormone
LH	luteinizing hormone
LTH	lactogenic hormone
mm	millimeter
MSH	melanocyte-stimulating hormone
NaCl	sodium chloride
PCO₂	partial pressure of carbon dioxide dissolved in blood
PE	pressure equalization
PIF	prolactin inhibiting factor
PO₂	partial pressure of oxygen dissolved in blood
PTH	parathyroid hormone
RNA	ribonucleic acid
SA	sinoatrial node
STH	somatotrophic hormone
SNS	sympathetic nervous system
TSH	thyrotropic stimulating hormone

Student Notes

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