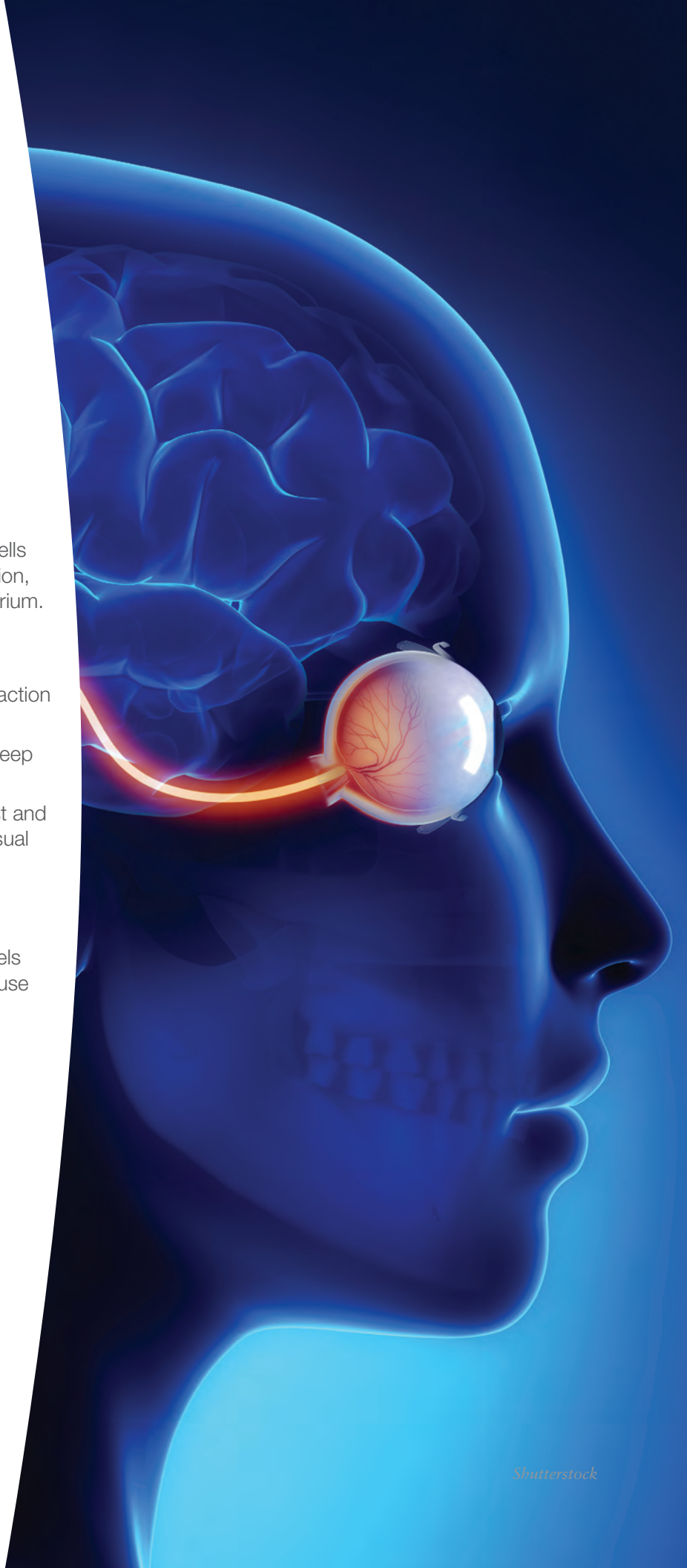
Chapter 2

Special Senses

Objectives

1. Histologically examine the receptor cells for the 5 major special senses: olfaction, gustation, vision, audition and equilibrium.
2. Test the concept of central olfactory adaptation.
3. Examine the relationship between olfaction and gustation.
4. Understand eyeball anatomy via a sheep eye dissection.
5. Use the Snellen test, astigmatism test and blind spot mapping to understand visual physiology.
6. Examine the importance of sight in maintaining equilibrium.
7. Examine ear anatomy using lab models and auditory physiology through the use of tuning forks.



The previous lab asked you to test the general senses found throughout most of skin, muscles and joints. This lab focuses on the special senses, those that reside within the head. Our special senses are **gustation** (taste), **olfaction** (smell), **vision**, **audition** (hearing), and **equilibrium**. This lab will introduce you to the anatomy of each system and their receptors, including performing an eyeball dissection. Activities in this lab demonstrate physiological aspects of each system. The receptors for all the special senses are housed in specialized organs and the information they receive is then sent to specialized areas of cerebral cortex. In addition to these specialized areas, sensory information is often sent to different areas of the brain for integration with other sensory input.

2.1 Olfaction

Olfactory receptor cells are located in the **olfactory epithelium**, which lines the roof of the nasal cavity (**Figure 2-1**). The receptors themselves are located on cilia at one end of these bipolar receptor cells. As we inhale, much of the air passes through the nasal cavity and into the pharynx. Sniffing enhances our sense of smell since it forces more air to pass by the receptors (**Figure 2-1c**). Along with the **olfactory receptor** cells, the olfactory epithelium contains two other types of cells. **Basal cells** are stem cells that continuously divide in order to replace dying olfactory receptor cells. Thus, the olfactory receptor cells are one of very few kinds of neurons that regenerate. **Supporting cells** (*sustentacular cells*) function as support for the receptor cells, helping to maintain a nourishing environment. Just deep to the epithelium is a layer of connective tissue, the lamina propria, containing olfactory glands (Bowman's glands), which work to secrete mucus. Mucus is important for the function of the olfactory system, as the constantly moving molecules in the air, which pass into the nasal cavity, get trapped and diffuse through the mucus to bind and activate the receptors. When sick with a cold, the increase in mucus production reduces your sense of smell, as there is a greater amount of mucus for odorants to pass through in order to activate receptors. Once receptor cells are activated, the impulses generated by the receptor cells pass through the **cribiform plate** of the ethmoid bone within Cranial Nerve I, and enter the brain at the **olfactory bulb**. The **olfactory tract** is a large set of axons that deliver the olfactory information to the olfactory cortex. An important difference between the olfactory system and many other sensory systems, is that information does not have to form a synapse within the thalamus prior to reaching cortex. In addition, a large amount of olfactory information also travels to the hypothalamus and limbic system (amygdala), which underlies our strong emotional responses associated with our sense of smell.

2-1 Histological Examination of the Olfactory Epithelium

Materials: slide of the olfactory epithelium, compound light microscope

1. Examine the slide of the olfactory epithelium under low then medium power. Draw the image that you see in the lab report.
2. Label the olfactory epithelium, lamina propria, olfactory receptor cells, cilia.

FIGURE 2-1 Nasal Cavity Anatomy

a) Nasal cavity anatomy. b) Histological view of the Olfactory Epithelium. c) Odorant molecules entering the nasal cavity and activating olfactory receptor cells on the olfactory epithelium. Axons of these cells travel to the Olfactory Bulb through the cribiform plate and synapse on neurons that become the Olfactory Tract, traveling into the brain. *(Shutterstock)*

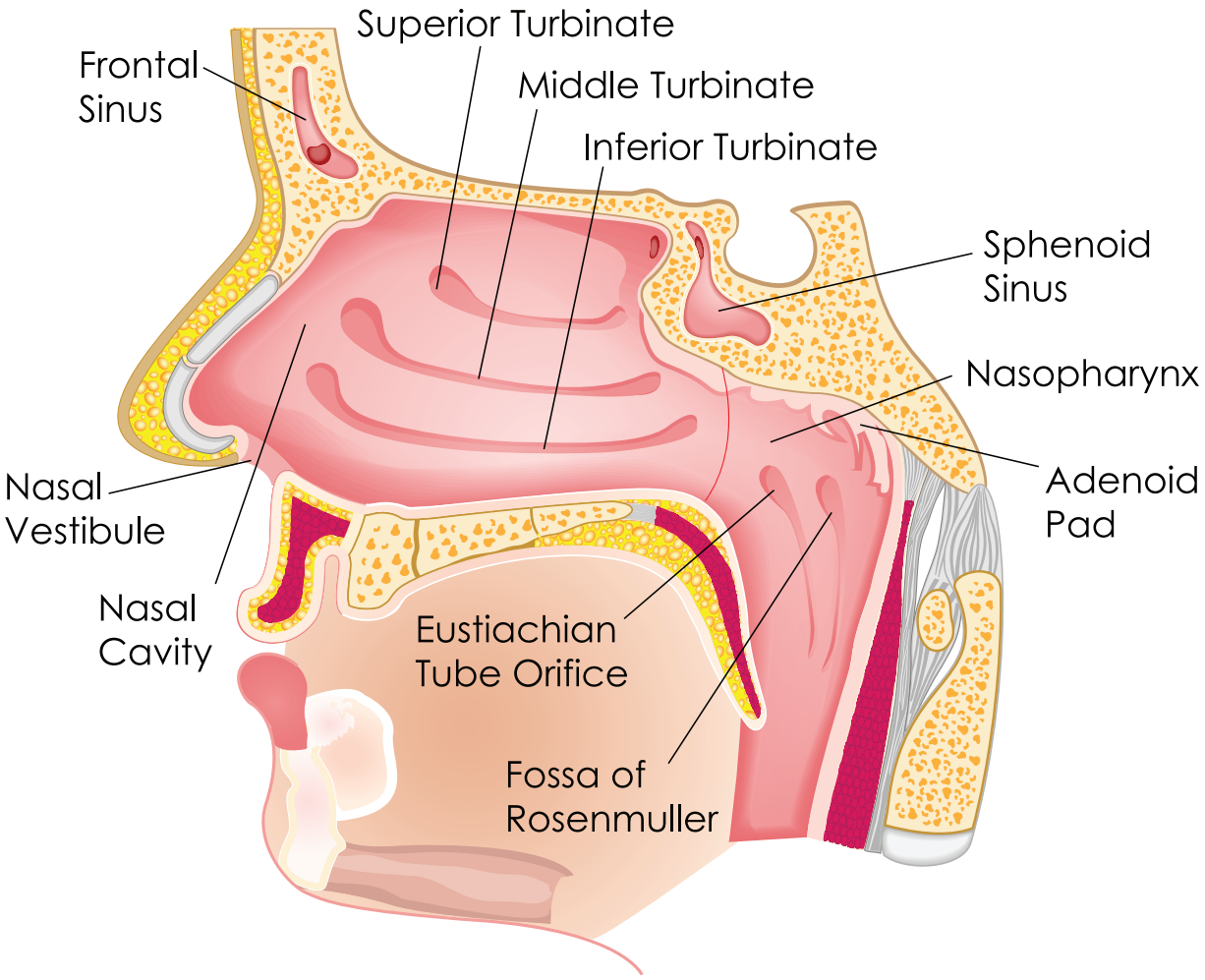


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FIGURE 2-1 Nasal Cavity Anatomy *(continued)*

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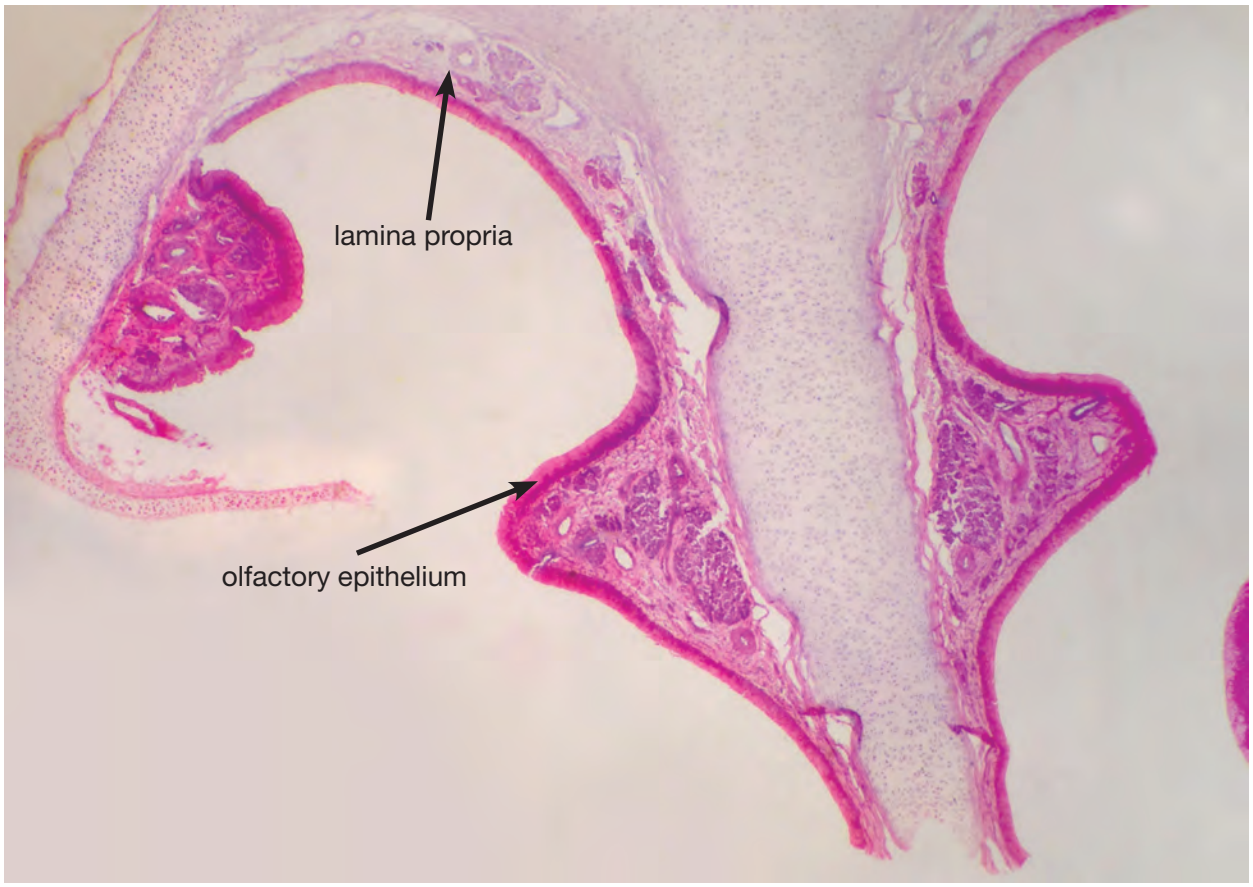

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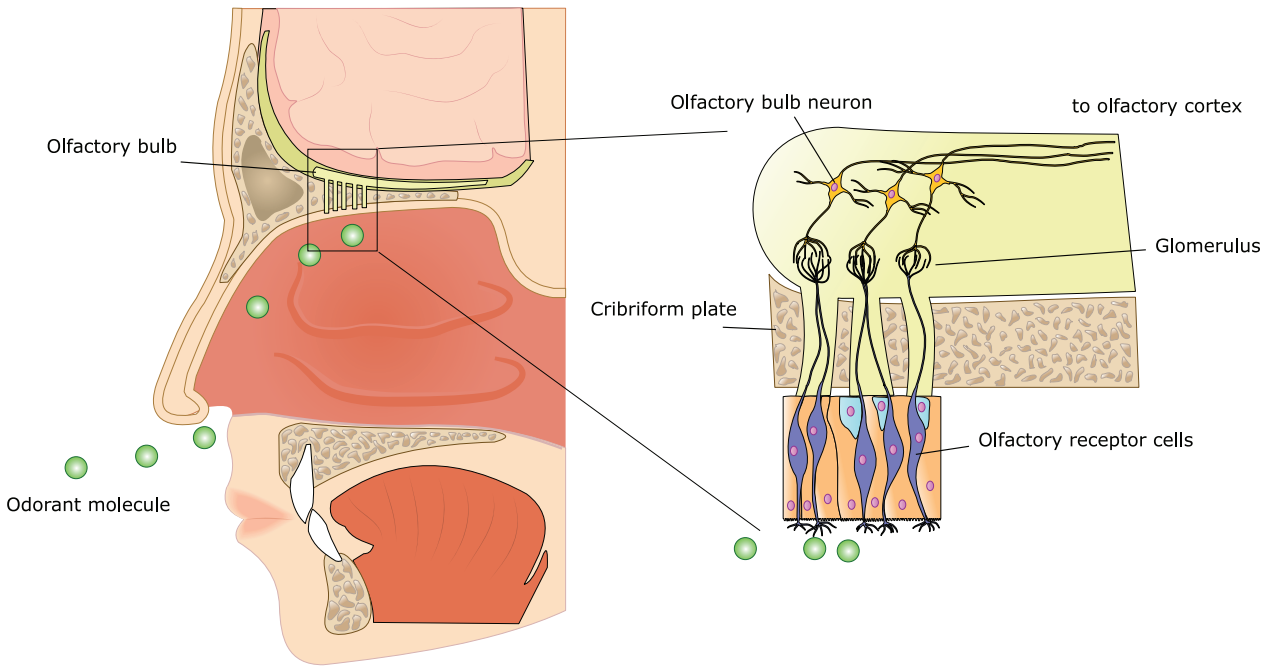

2.1a Olfactory Adaptation

Adaptation is the reduction of sensitivity to a continuous or repeated stimulus (introduced in the previous lab). When first activated, receptors respond strongly, but this response declines with repeated stimulus exposure. **Peripheral adaptation** is adaptation due to desensitization of the receptor, leading to a reduction in the amount of sensory information that is sent to the Central Nervous System (CNS). **Central adaptation** is found in the CNS, due to the inhibition of sensory neurons along a sensory pathway. Central adaptation is what permits us to smell a new odor after adapting to an initial odor.

The olfactory system rapidly adapts to odors. Typically, after several minutes exposed to an odor, such as walking into a smelly room, you do not smell it as much as you initially did. Once a new odor becomes present, the nose is immediately capable of sensing the new scent. This is evidence for central adaptation and not receptor fatigue. (Fatigue would result in you not being able to smell the new scent.) This lab activity will allow you to determine the length of time it takes for your olfactory epithelium to adapt to an odor. Remember not to put the odor vial too close to your nose and inhale. It is best to hold the vial about 6 inches in front of your nose and wave your hand to waft the odor towards your nose.

2-2 Olfactory Adaptation

Materials: vial containing essence oil; vial containing isopropyl alcohol; stopwatch

1. Hold the vial of oil near your face and waft fumes toward your nose, and have your lab partner start the stopwatch.
2. As you breath through your nose to smell the oil, continue wafting and smelling until you no longer sense the odor. Once this happens, have your lab partner stop the watch and record the time in the table provided in your lab report. This is the time that it took for adaptation to occur.
3. Immediately after losing the sensitivity of the oil, smell the alcohol. In your lab report, explain why you think you can smell the alcohol but not the oil.
4. Repeat Steps 1–3 after about 3 minutes of not smelling either vial, but use the alcohol as your initial odor to determine adaptation time. Record the time to adaptation in your lab report.
5. Repeat Steps 1–4 with your lab partner as the one smelling the vials. Record your partner's adaptation times in the table provided in your lab report.

2.2 Gustation

Gustation refers to our sense of taste. The receptors for gustation are called **gustatory cells**, located in the taste buds that are found on the surface of the tongue, pharynx and soft palate often in structures called **papillae** (small elevations) (**Figure 2-2**). Each taste bud can contain up to 100 gustatory cells. Like the olfactory receptor cells, gustatory cells are also replaced every 1–2 weeks by the basal cells, located just deep to the

receptor cells. Microvilli on the surface of the gustatory cells project into a small taste pore and are the part of the cell that makes contact with the food as it passes throughout your mouth. This leads to a gustatory impulse. There are about 10,000 taste buds located inside the papillae. The base of the tongue, arranged in the shape of a "V", contains circular papillae called **vallate papillae**. The tip and sides of the tongue contain **fungiform papillae**, shaped like small mushrooms. **Filiform papillae** are found on most of the anterior portion of the tongue but do not contain taste buds and are primarily a source of friction to move food around the mouth.

We are able to detect 5 basic tastes: sweet, salty, sour, bitter and umami (often described as a savory, protein sense). Once the receptor cells are activated, the impulse is carried to the brain along 3 cranial nerves: the vagus nerve (X) serving the pharynx, the facial nerve (VII) arising from the anterior two-thirds of the tongue, and the glossopharyngeal nerve (IX) serving the posterior one-third of the tongue. As we age, the density of our taste buds declines and basal cells regenerate more slowly, which explains in part why children often are more sensitive to tastes compared to older adults.

FIGURE 2-2 Tongue Anatomy

a) Tongue anatomy with the presence of elevated papilla b) Enlarged view of a papilla c) View of a single taste bud d) Histological view of tongue epithelia, papilla and taste buds (arrow) *(Shutterstock)*

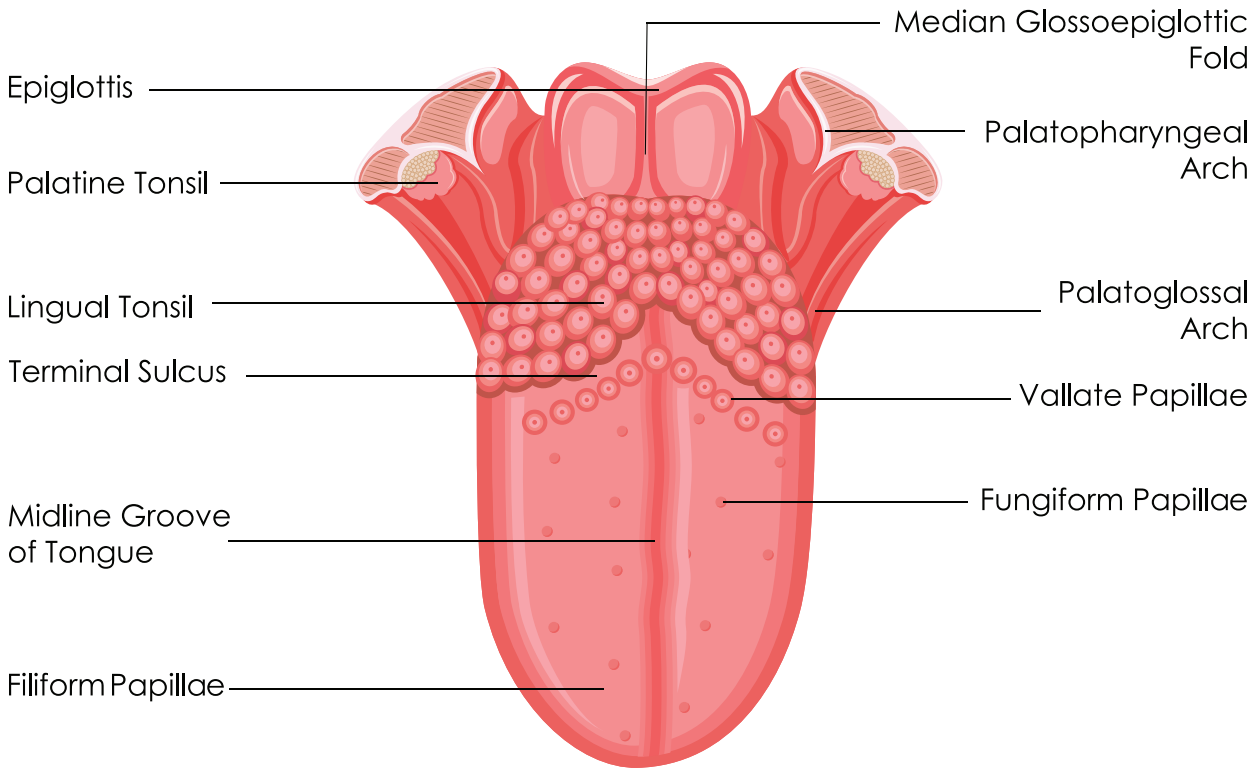

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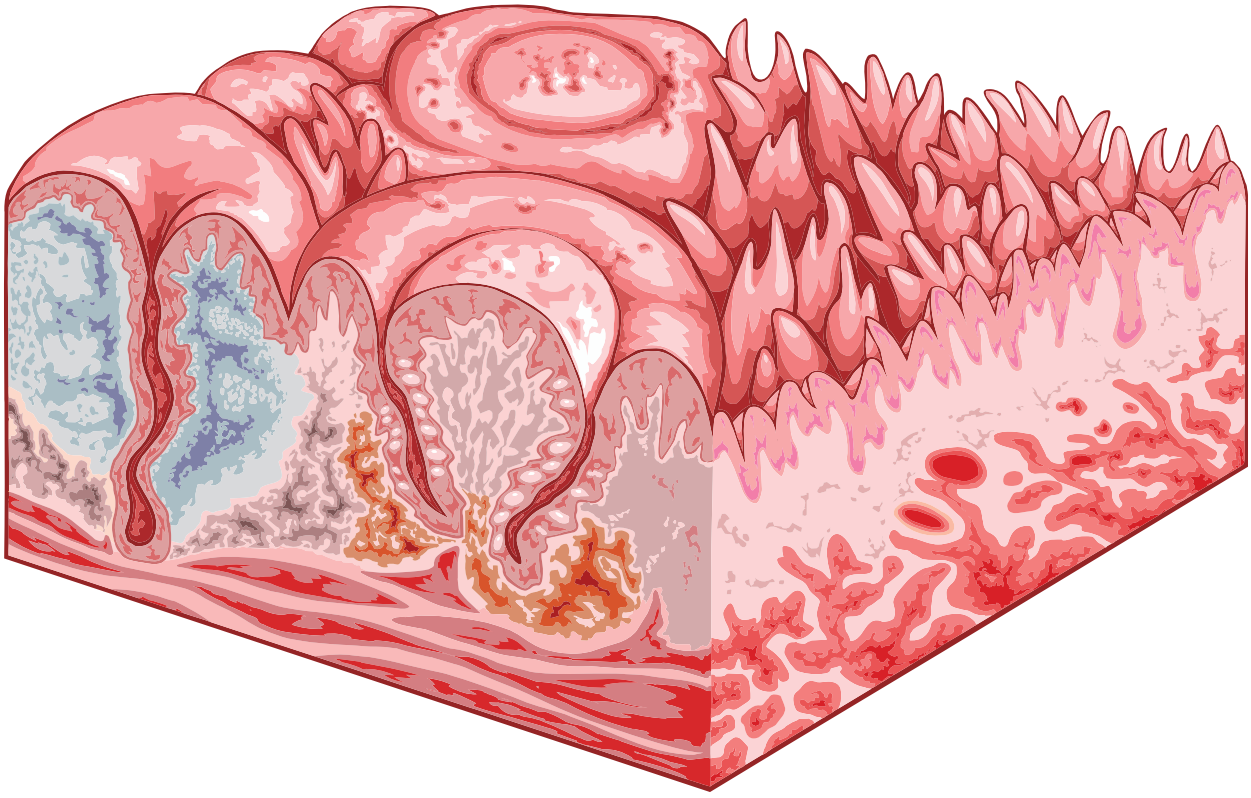
FIGURE 2-2 Tongue Anatomy *(continued)*



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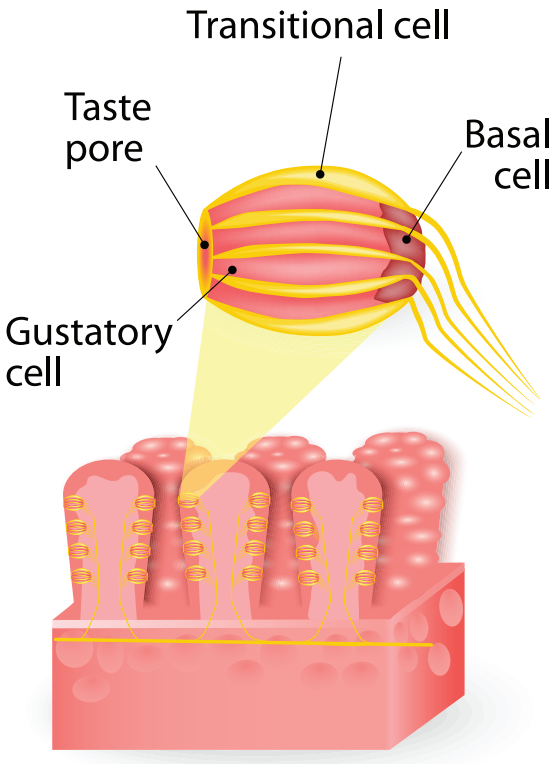

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FIGURE 2-2 Tongue Anatomy *(continued)*

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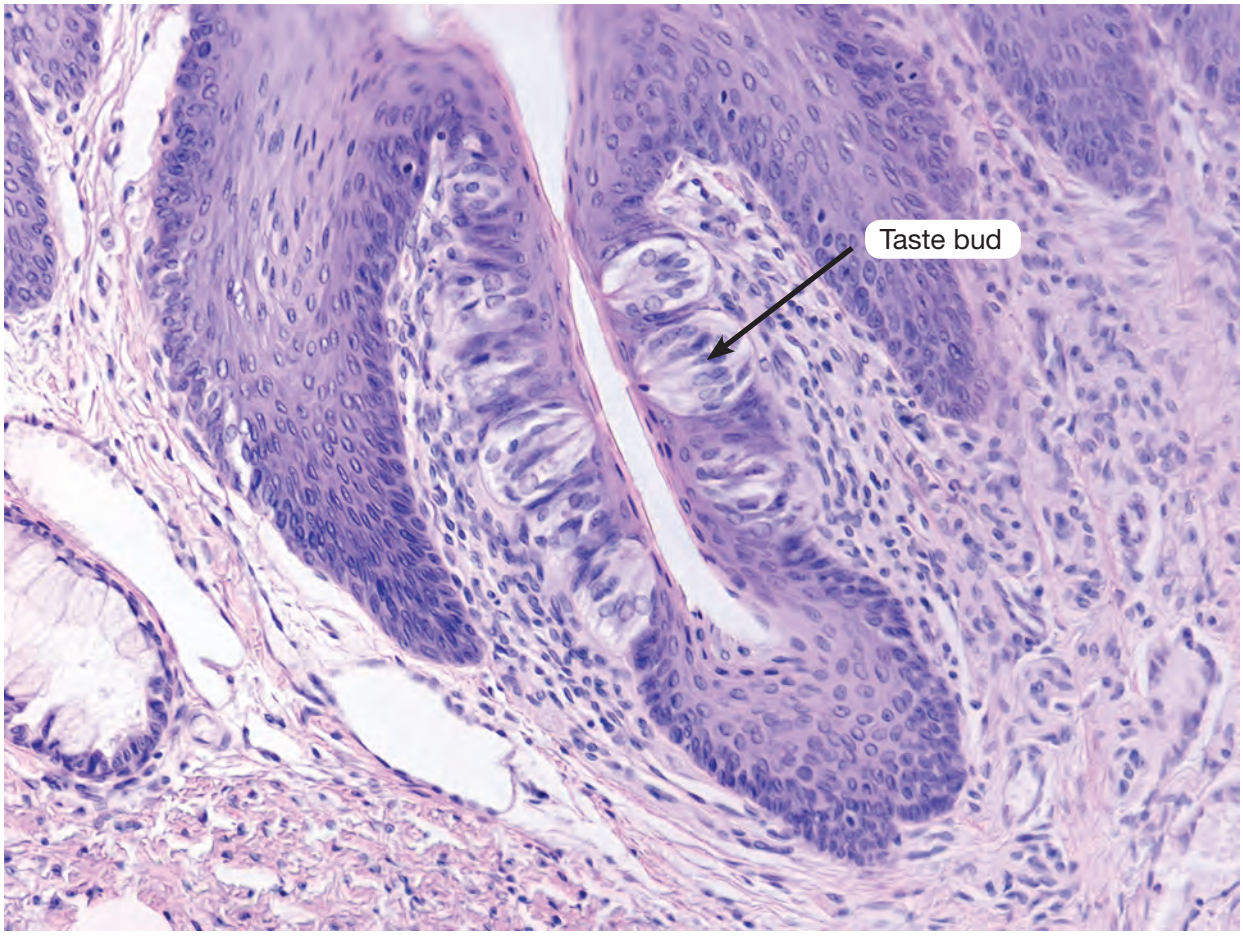


2-3 Histological Observation of a Taste Bud

Materials: Slide of the tongue, compound light microscope

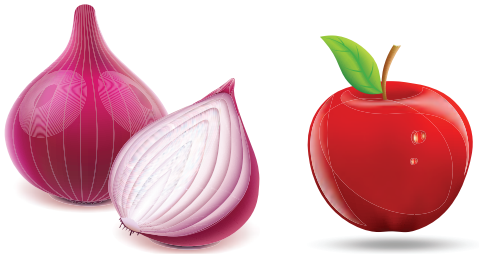
1. Examine the slide of the tongue under low then medium power and focus on a papilla with taste buds. Draw the image that you see in the lab report.
2. Draw your view of the papilla at medium power. *Label* the papilla and taste bud.

2.2a Relationship Between Olfaction and Gustation

Our sense of taste is over a 1000 times more sensitive if our olfactory system is active simultaneously with the gustatory system. If our sense of smell is compromised, as is the case when we experience a cold, our sense of taste suffers and food tastes bland. In this activity, you will test the impact of smell on your sense of taste by closing your nose while tasting food (**Figure 2-3**).

FIGURE 2-3 Relationship Between Olfaction and Gustation

This activity will test whether you can discriminate between onion and apple without your smell sense.



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2-4 Relationship Between Olfaction and Gustation

Materials: diced apple and onion, paper towels, lab partner

1. Have your partner dry his or her own tongue with a paper towel.
2. Have your partner stand with eyes closed and nose pinched shut, then place either a piece of onion or apple on the dried tongue. Have your partner try to identify the food. Record the results in the table in your lab report as a "yes" or "no".
3. Now have your partner chew the food, while eyes and nose are **still** closed. Can the food now be identified? Record the results in the table.
4. Finally, have your partner open his or her eyes and nose. Can the food now be identified? Record your results and repeat with yourself as the subject.

2.3 Vision and Eyeball Anatomy

The eyes are highly specialized organs, allowing us to view a wide range of light levels and colors with high resolution. In order to view both changes in light levels as well as different colors, the eye contains two types of visual receptors, one for night vision and one for bright light and colors. In addition to the receptor cells, the eye also contains structures to help adapt to changing light levels by changing the size of our pupils. Our eyeball is also able to move and track objects we see in the world as a function of the six extraocular muscles that surround the eyeball and are innervated by four of the cranial nerves. Finally, there is a tear production, or lacrimal system, that works to cleanse the eye surface and keep it moist. This part of the lab will introduce you to the anatomy of the eyeball by studying the human eye model and with a dissection of a sheep eyeball.

2.3a External Anatomy

The human eyeball is a spherical organ about 2.5cm in diameter, with only a small portion (about 1/6th) of the organ visible between the eyelids. There are many accessory structures of the eyeball that are not physically a part of the eyeball but help with

its function. These include the **upper** and **lower eyelids**, **eyebrows**, **eyelashes**, **lacrimal apparatus**, and **extraocular muscles** (six on each eye) (**Figure 2-4** and **Figure 2-5**). The eyelids (otherwise known as **palpebrae**) and separated by the palpebrae fissure, help to distribute tears across the eye surface to keep it moist. The external surface of the eyelid is covered in skin with the outer edge containing eyelashes. Along with the eyebrows, these hairs protect the eyeball from foreign substances such as dust and other particles and provides shade. **Ciliary glands** are modified sweat glands that are found at the base of the eyelashes and help to lubricate the eyeball. The medial and lateral points where the lids meet are called the **lateral canthus** and **medial canthus**. The **lacrimal caruncle** is the pink structure found at the medial canthus that contains modified sebaceous and sweat glands. Secretions from these glands accumulate at the medial canthus after long periods of sleep. Found on the inside layer of the eyelids is a thin mucous membrane called the **palpebral conjunctiva**. Glands in this tissue secrete mucus to reduce friction and moisten the eyeball surface. In contact with this is the **ocular conjunctiva**, which provides a similar function. Inside the eyelids are the **tarsal plates**, fibrous tissue, which gives them shape and support. Muscles in control of opening and closing the eyelids are the **levator palpebrae superioris** and **orbicularies oculi**, respectively.

The **lacrimal apparatus** contains glandular tissue and a series of canals and ducts that bring the tears from the eye towards the nasal cavity. The **lacrimal glands**, that produce tears, are found superior and lateral to each eyeball. Their secretions lead into **lacrimal ducts** that deliver the slightly alkaline solution to the anterior surface of the eyeball, cleaning and lubricating the eye. This fluid also contains an antibacterial enzyme, **lysozyme**, that helps to protect against bacteria that may find its way to the surface of your eyeball. Tears make their way across the eyeball towards the medial canthus and into two small holes: the superior and inferior **lacrimal puncta**. The fluid then travels down the **lacrimal canals**, leading into a larger region called the **lacrimal sac**. Finally, the **nasolacrimal duct** drains tears into the nasal cavity (**Figure 2-5**).

FIGURE 2-4 Eyeball Anatomy

a) External Eyeball Anatomy b) Eyeball cross section anatomy *(Shutterstock)*

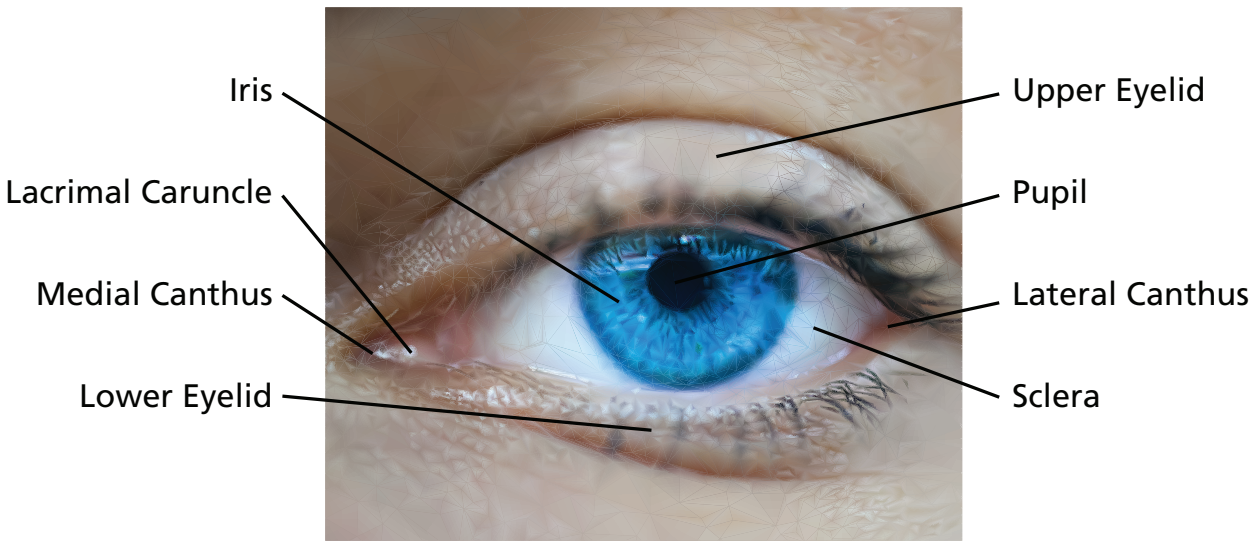

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FIGURE 2-4 Eyeball Anatomy *(continued)*

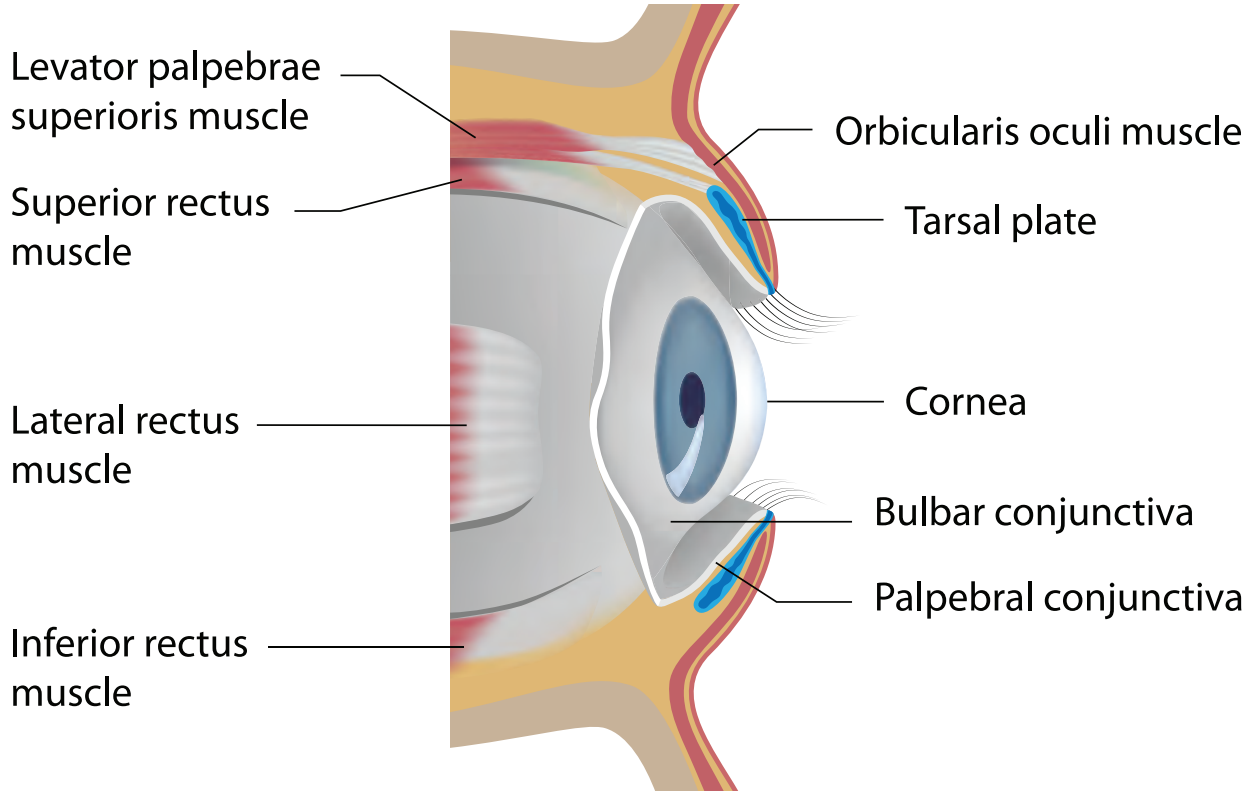

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FIGURE 2-5 Lacrimal Apparatus

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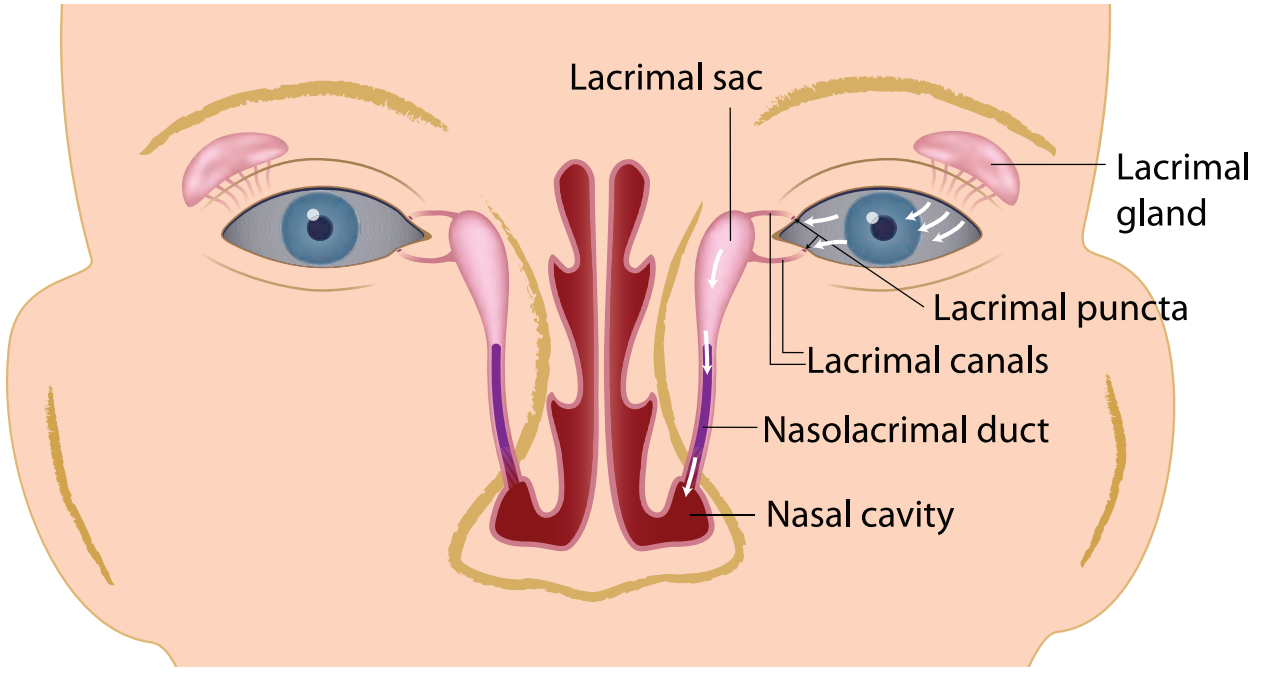

There are six **extraocular** muscles that allow your eyeball to move in many directions. The **superior, inferior, medial** and **lateral rectus** muscles are straight and help to move the eyeball up, down, and side to side. The **superior** and **inferior oblique** muscles attach at an angle and work to move your eyeball diagonally up and down (**Figure 2-6**).

FIGURE 2-6 Extraocular Muscles

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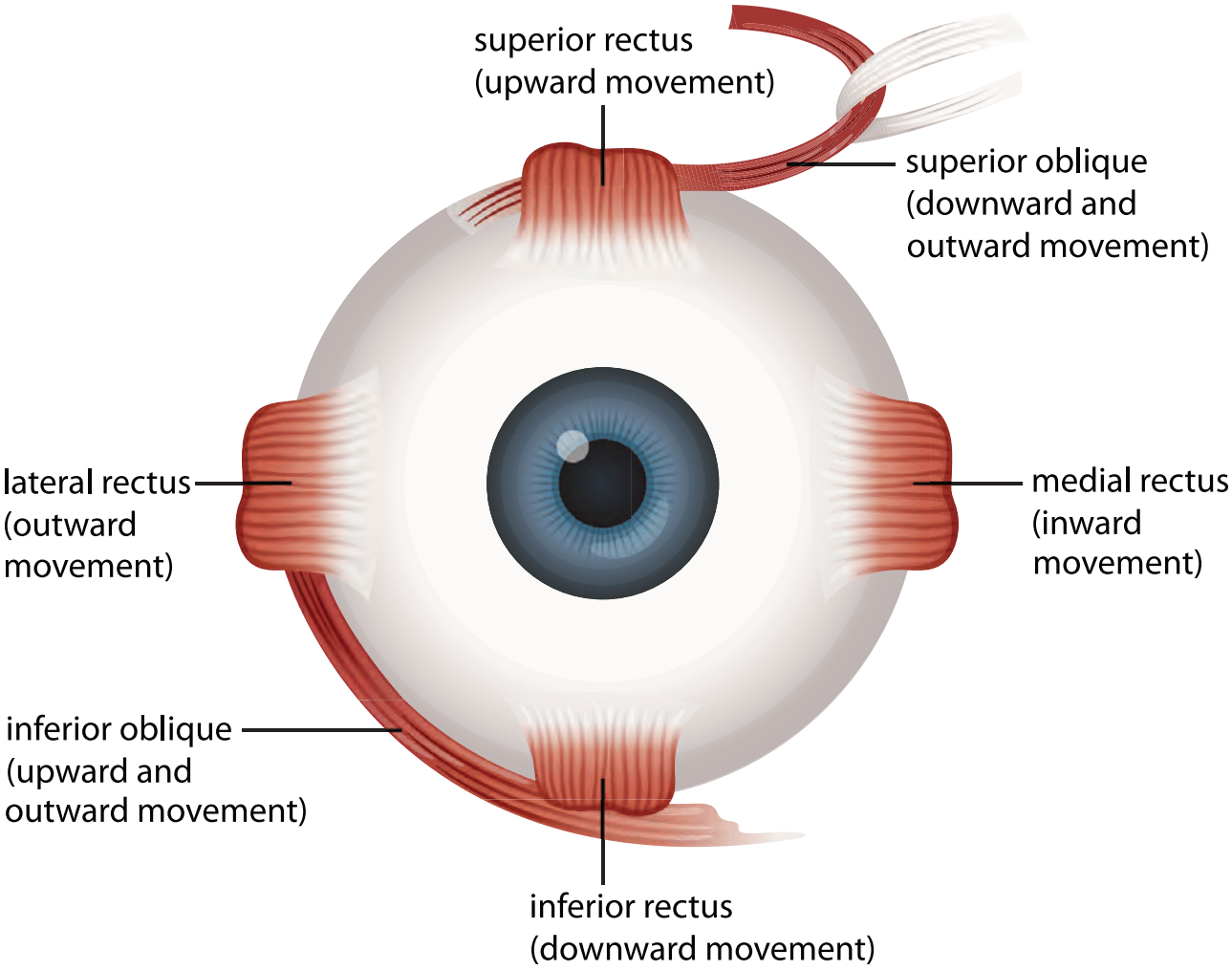

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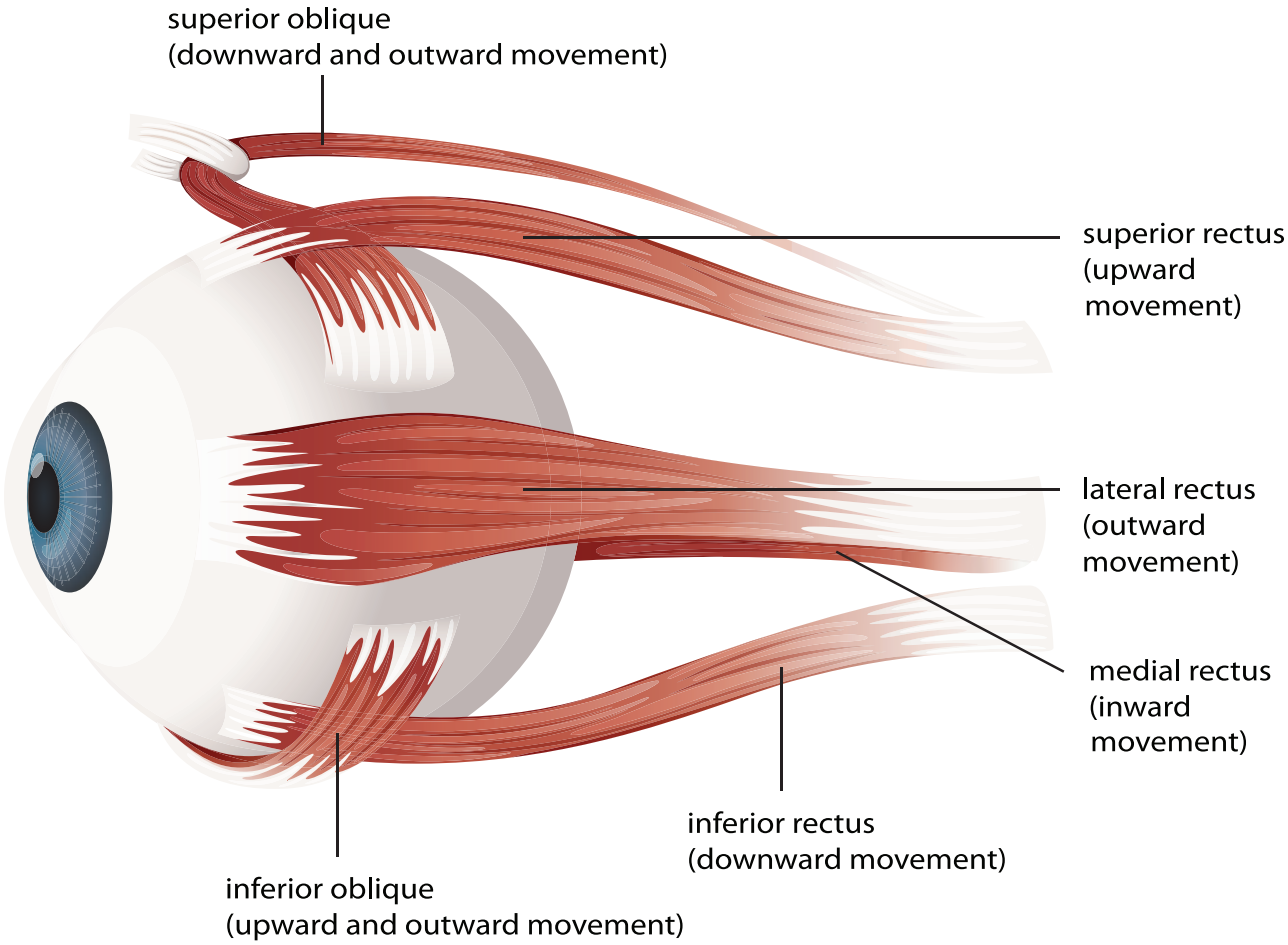
FIGURE 2-6 Extraocular Muscles *(continued)*



2.3b Internal Anatomy

The eyeball itself is made of up three anatomical layers of tissue, having different important functions. The outermost, **fibrous tunic**, is a tough layer composed primarily of dense connective tissue. One component of this layer is the **sclera**, the white part of the eye that protects against physical damage and helps to maintain the eyeball shape. A second part of this layer is the **cornea**, the clear surface of the eye that allows light to pass into the eye. The cornea is composed of layers of densely packed collagen fibers. (**Figure 2-7**)

The second layer of the eye is called the **vascular tunic** (uvea) and is composed of the **iris**, **ciliary body** and **choroid**. The most posterior portion, the choroid, is a highly vascularized tissue layer that contains a dark pigment and helps to absorb light and prevent reflection. The anterior part of the uvea is the pigmented iris. The central aperture is the **pupil**. Posterior to this is a transparent lens that helps to focus light and can change shape in order to view objects that are closer to your eye. Pupillary sphincter (circular) and radial dilator muscles change the size of the pupil diameter, allowing more or less light to enter the eye. The action of these muscles is under control of the autonomic nervous system. Parasympathetic activity causes the constriction of the sphincter muscles, shrinking the pupil diameter. Sympathetic activity causes the constriction of the dilator muscles, enlarging

the pupil diameter. The iris is attached to the ciliary body containing a ciliary muscle that adjusts the shape of the lens (for near and far vision). The **ciliary processes** are found at the edge of the ciliary body and have thin **suspensory ligaments** extending to the lens (Figure 2-7).

FIGURE 2-7 Internal Anatomy of the Eye

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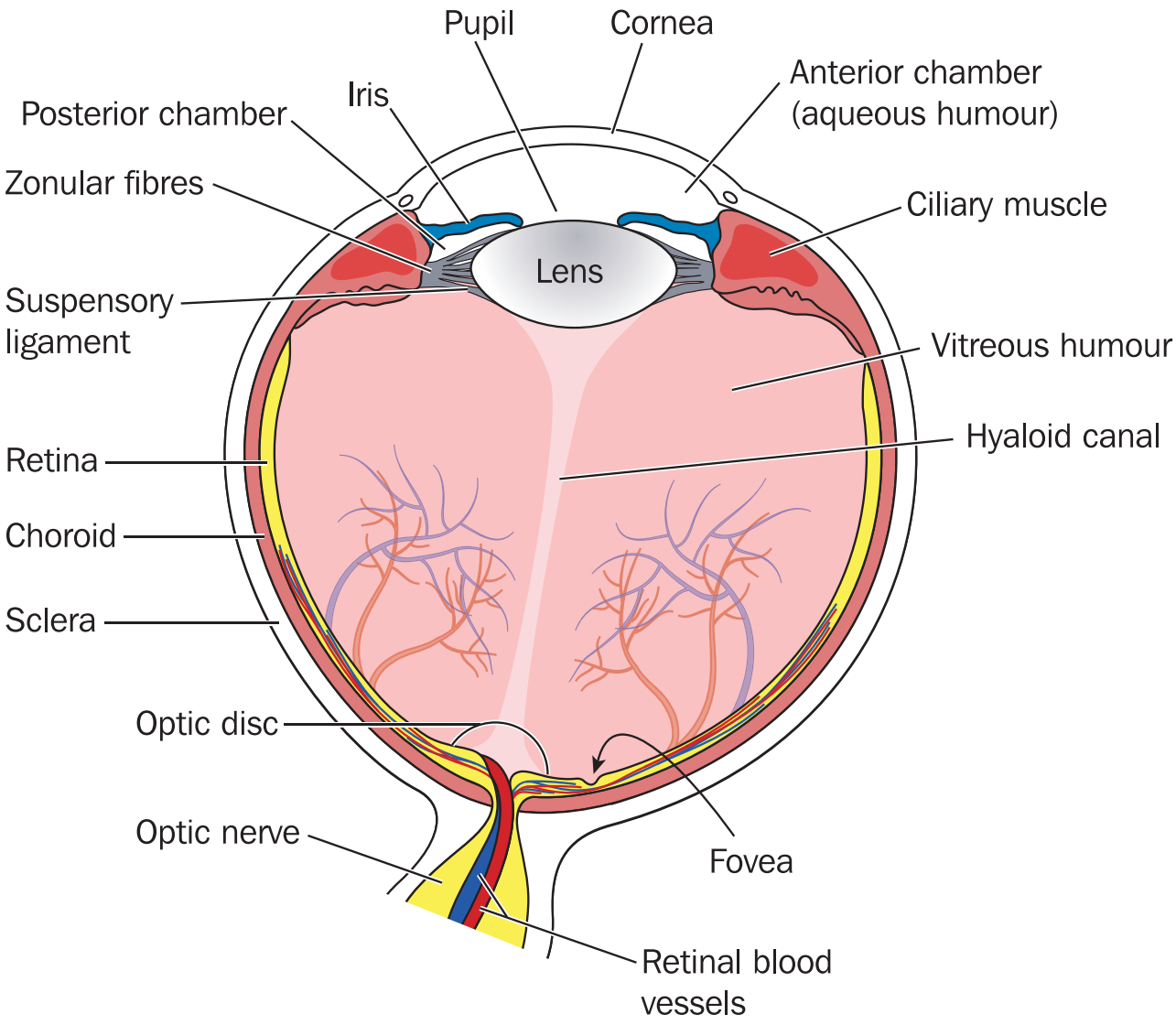

Lastly, the innermost eyeball layer is called the **neural tunic**, or the **retina.** This contains an outer-pigmented layer, covering the choroid, and inner neural part, containing the receptor cells for light, or **photoreceptors**. The retina is described in detail later in this lab.

There are two major compartments of the eyeball: the **anterior cavity** (found between the lens and cornea) and the **posterior cavity** (found between the lens and retina). The anterior cavity, which can be further divided into the anterior chamber (between the iris and cornea) and posterior chamber (between the iris and lens) is

filled with a watery fluid called **aqueous humor**. This fluid is secreted into the posterior chamber and circulates through the pupil, into the anterior chamber. The fluid is reabsorbed by a series of small veins called the **scleral venous sinus** in the cornea. This fluid helps to maintain intraocular pressure and contains nutrients. The posterior cavity is filled with a clear gelatinous substance called the **vitreous body** that helps to press the retina against the choroid.

2-5 Eyeball Anatomy: Human Eye Model and Sheep Eyeball Dissection

Materials: human eyeball model, dissection kit, gloves, preserved sheep eye, dissection pan

1. Locate the six extraocular muscles, sclera, cornea, choroid, iris, retina, as well as the anterior and posterior cavities on the human eyeball model and label the picture of the model in your lab report.
2. Once you have completed examining the human eyeball model, obtain a preserved sheep eyeball from your instructor.
3. Locate the optic nerve (NII) exiting on the posterior surface. Examine any remaining extraocular muscles, the palpebrae and eyelashes. Observe the cornea and sclera. Take a picture of the external surface to hand in with your lab report.
4. Holding the eyeball with one hand, use scissors to carefully cut away any extra adipose tissue or extraocular muscles that may be found around the eyeball.
5. Using the scalpel, make a small incision about 0.6cm away from the cornea. Using the scissors again, carefully cut around the circumference of the eyeball, using cutting action that is aimed outwards, so as not to damage any internal structure. (You may notice leaking fluid, aqueous humor) as you cut; this is normal).
6. You can now separate the anterior and posterior portion of the eye. Identify the vitreous body in the posterior cavity, as it should appear jelly-like.
7. In the anterior portion of the eye: using a blunt probe, carefully lift the lens and notice the ciliary processes connecting the lens to the ciliary body and pupil at the center.
8. Remove the vitreous body and set it aside. The retina is the first layer of tissue that you come across; it appears tan in color and often easily pulls away from the wall. Under this layer, notice a highly pigmented layer of tissue; this is the choroid of the vascular tunic. This membrane appears shiny, bluish purple in the sheep eye as it contains a membrane called the tapetum lucidum. This allows animal eyes to glow at night when light shines on them, a characteristic that humans do not share.
9. Take an image of the internal structures of the eyeball. Staple these images with your lab report, labeling the cornea, sclera, optic nerve, lens, iris, vitreous body, retina, and choroid.
10. All tissue should be discarded in the hazardous waste bags provided by your lab instructor, NEVER in the trash or sink.

FIGURE 2-8 Sheep Eyeball Dissection

a) External view showing the removal of external adipose tissue and extra skin. The optic nerve exiting the posterior side can also be viewed. b) Once a frontal section has been made, the anterior portion (right) can be separated from the posterior portion (left). The retina (neural tunic), which is a thin tan-colored tissue, is found lining the posterior cavity. The vitreous body is a clear jelly-like substance, found within the posterior cavity. The lens can be viewed here as well as it separates the anterior cavity from the posterior cavity. Finally, the iris can also be seen here around the lens. c) Under the retina lies the choroid (from the vascular tunic), which in most mammals is an iridescent darkly colored layer. d) The lens appears surrounded by the ciliary processes and small suspensory ligaments that work to flatten the lens. Behind the lens, the vitreous body can be viewed.

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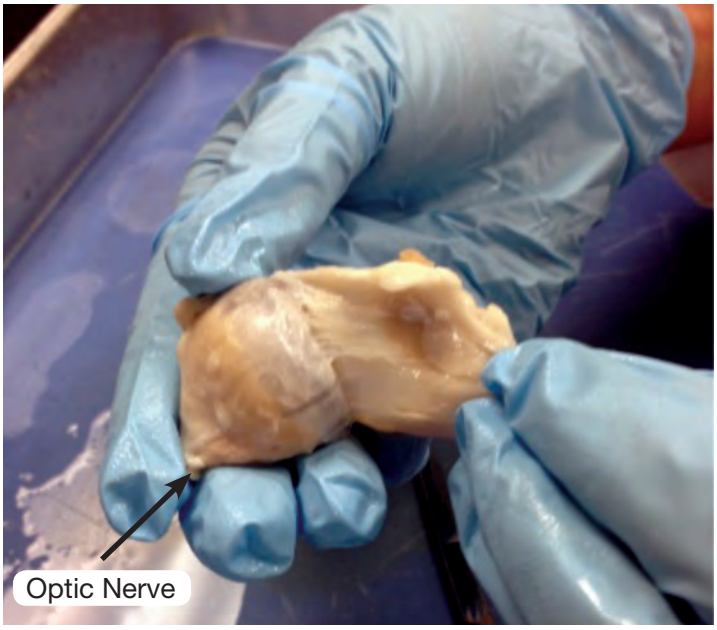

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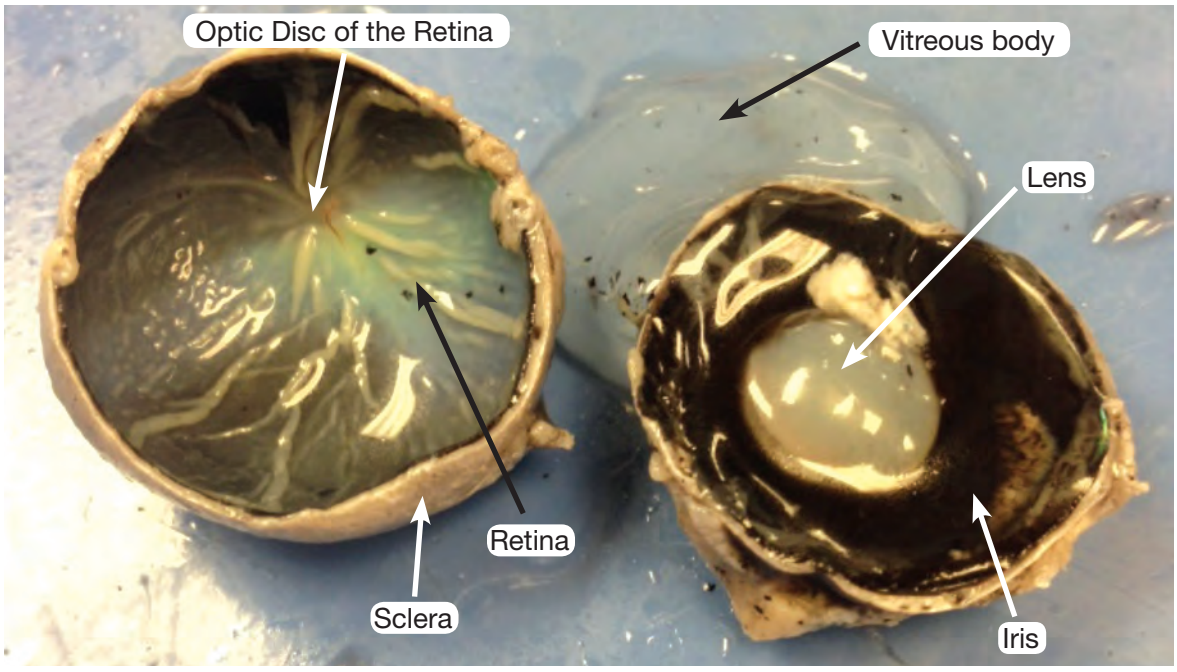

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FIGURE 2-8 Sheep Eyeball Dissection *(continued)*

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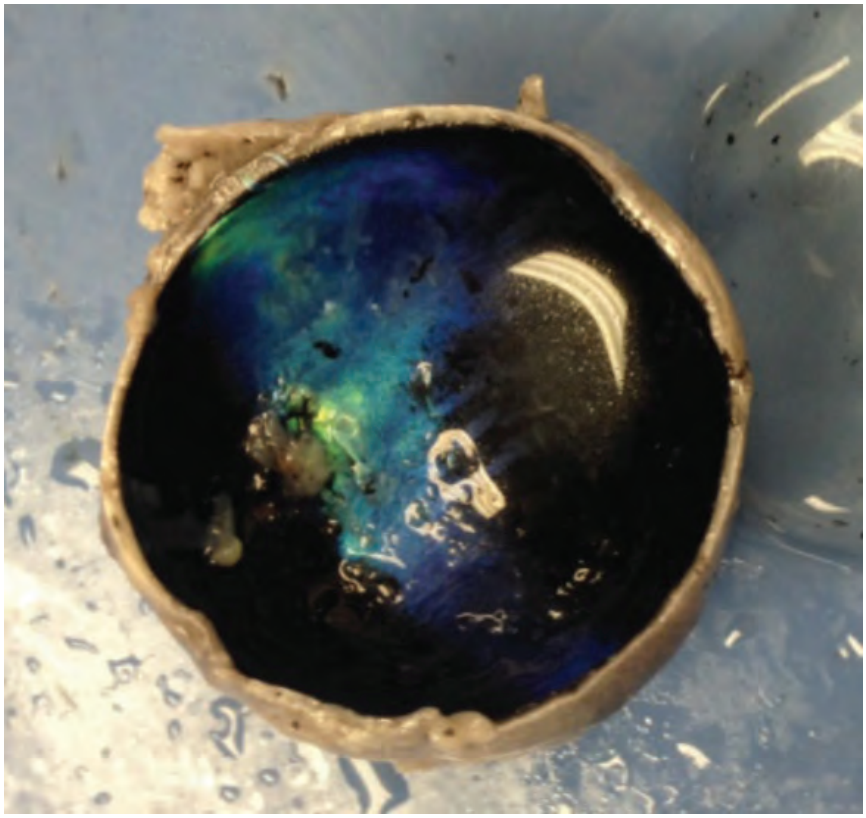

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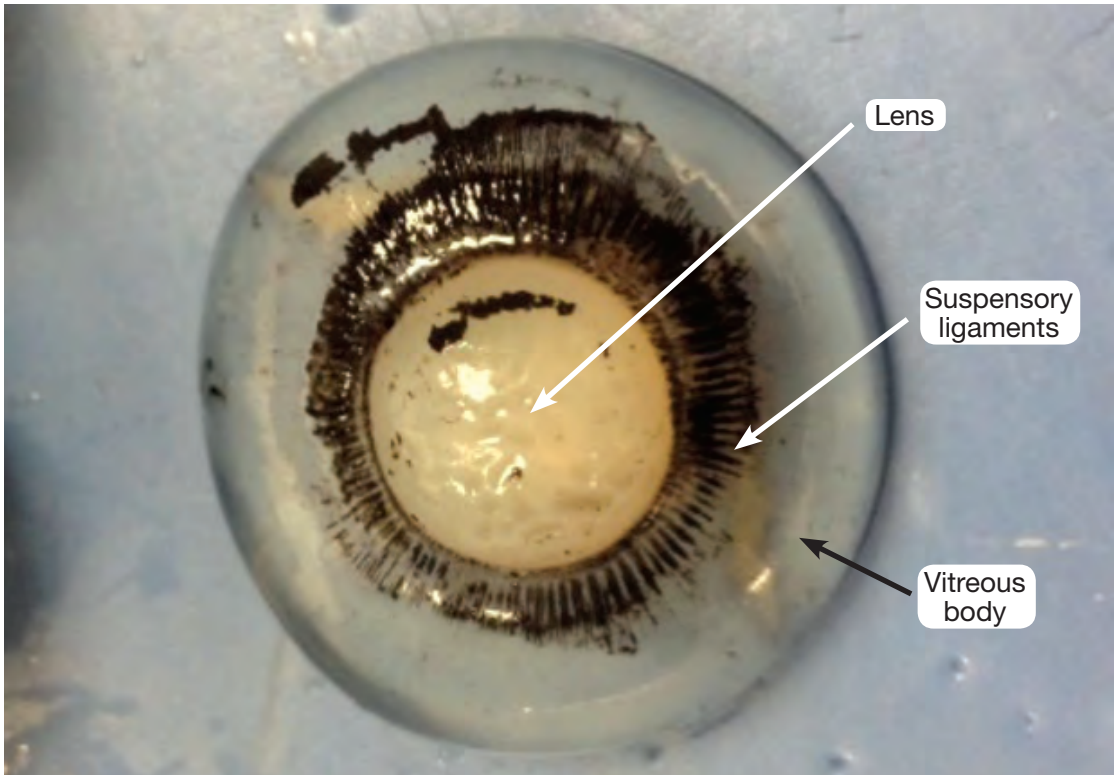

2.3c Cellular Organization of the Retina

The neural part of the retina contains the photoreceptors and two other kinds of neurons: **bipolar cells** and **ganglion cells**. The photoreceptors are the sensory cells to light and change their activity in response to photons (particles of light). There are two kinds of photoreceptors: **rods** and **cones**. Rods are most sensitive to low levels of light and motion, but not sensitive to color. Therefore, these help us to see at when light levels are low (dawn and dusk), but we are not able to see much color at night. Cones are sensitive to different wavelengths of light, allowing us to distinguish colors of light. (**Figure 2-9**)

FIGURE 2-9 Retina

a) Retinal scan image showing the presence of arteries and veins. b) Cross section of the retina, showing the sensory neurons. c) Histological view of the retinal cross section. *(Shutterstock)*

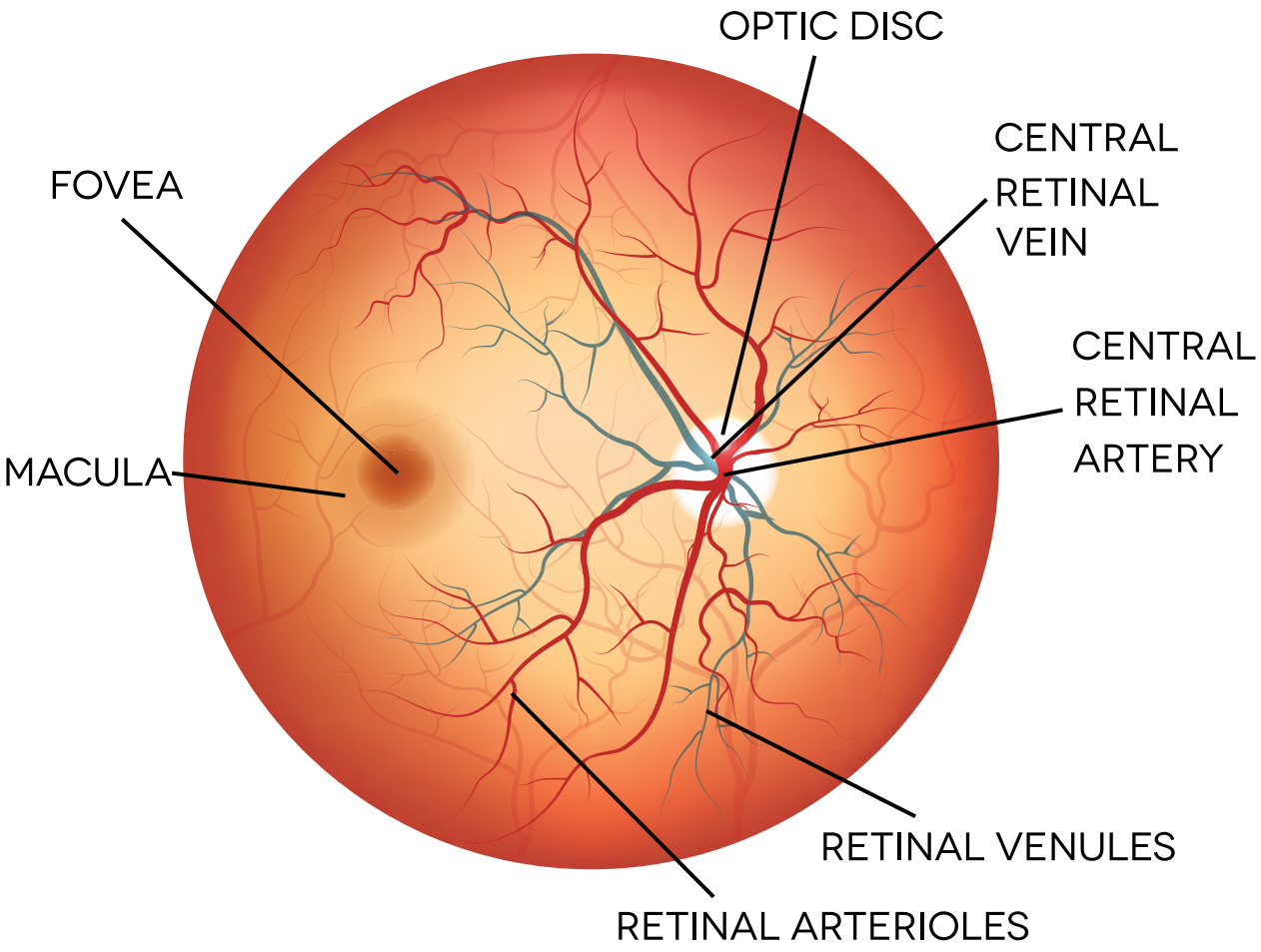

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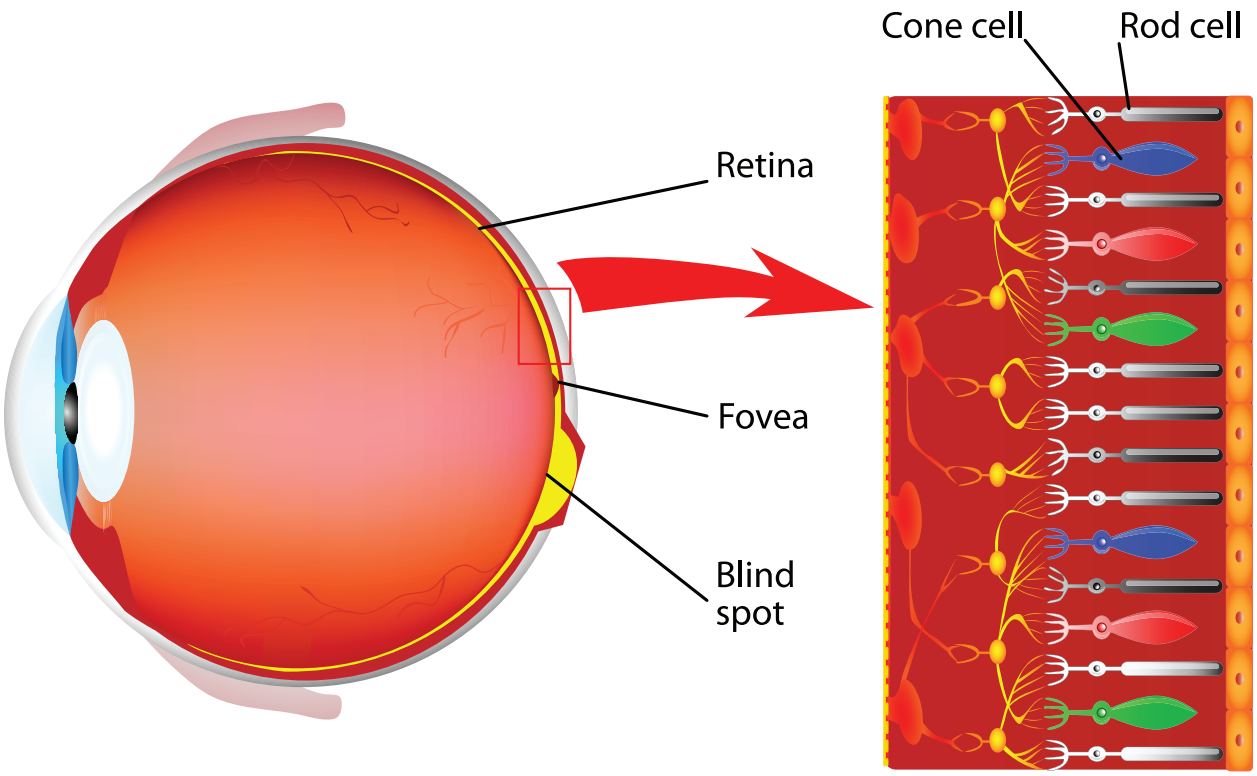
FIGURE 2-9 Retina *(continued)*



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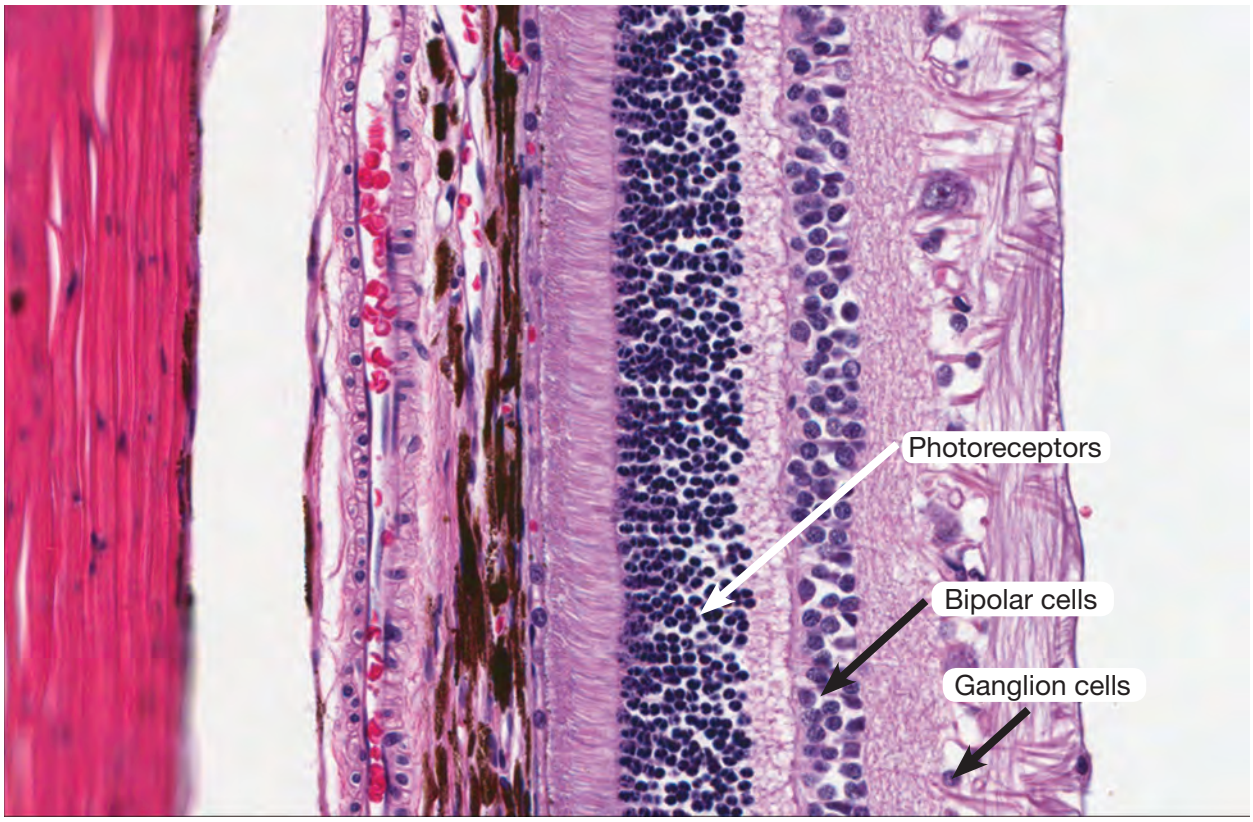


c)

The photoreceptors are positioned next to the pigmented part of the retina. Light must pass through the neural part of the retina to reach the photoreceptors after reflecting off of the pigmented layer. The signal is then passed to the bipolar and then ganglion cells. Axons of the ganglion cells form the optic nerve that leaves the eyeball at the **optic disc**. The optic disc does not contain photoreceptors (as this forms the exit point for the axons and blood vessels) and so is referred to as our "blind spot". Since we have two eyes and the visual field of each eye overlaps, we cannot usually perceive this spot. One activity that we will do in lab will reveal your blind spot. Lateral to the optic disc is the **macula lutea**, an area of highest cone density. At the center of this is the **fovea**, a small depression in the neural layer of the retina and area with the highest acuity.

2-6 Histology of the Retina

Materials: compound microscope, prepared slide of the retina

1. View the slide at low power to position the image in the center of the field of view. Now switch to medium or high power to place the neural layer into view.
2. Locate the thick vascular tunic on the edge of the specimen. Next to the choroid part, find the pigmented part of the retina.
3. The three major sensory cells are visible in the neural part of the retina and form 3 distinct bands: the photoreceptors, bipolar cells and ganglion cells. Draw the image in your lab report. Label the three sensory neurons, the retina and vascular tunic (choroid).

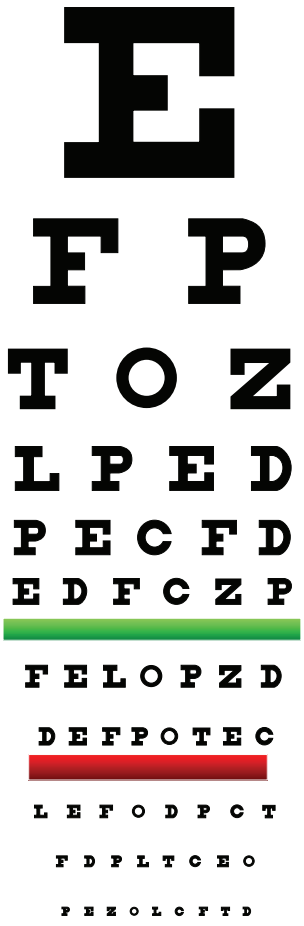
2.4 Physiology of the Eye

In this part of the lab, you will perform several eye tests that measure how your eyes focus and adjust to the changing visual environment. You will test your eye acuity or sensitivity, as well as reveal your blind spot.

2.4a Visual Acuity

Visual acuity is the sharpness or sensitivity of your eyes and can be tested using a **Snellen eye chart** (Figure 2-10), a large chart of letters organized by shrinking size. A person characterized as having normal or **emmetropic** vision, has a visual acuity measurement of 20/20. Someone with an acuity of 20/30 has less acute vision than an emmetropic person, being able to see at 20 feet what an emmetropic eye can see at 30 feet. A **myopic** or nearsighted eye focuses an image in front of the retina. This eye can see closer images but has trouble with distant ones. In contrast, an eye that is **hyperopic**, or farsighted, focuses the image behind the retina and has trouble with closer objects. In both of these conditions, corrective lenses function to shift the focal point back to the retina.

FIGURE 2-10 Snellen Eye Chart



(Shutterstock)

2-7 Visual Acuity Test

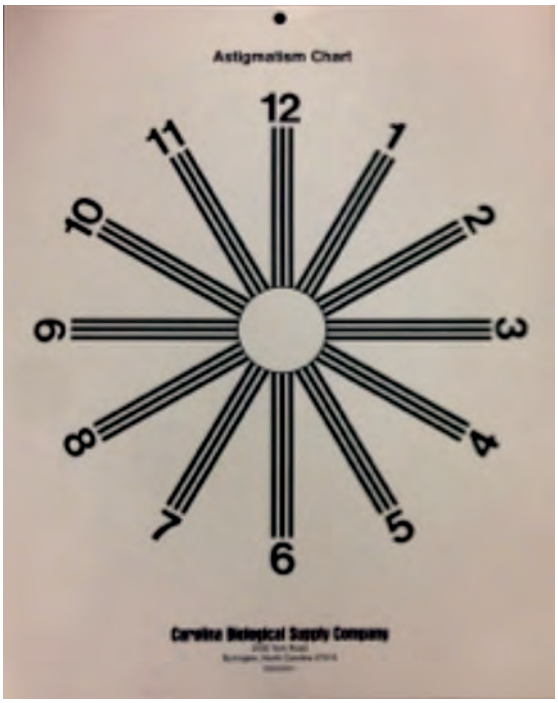
Materials: Snellen eye chart, tape, tape measure, lab partner

1. Tape the Snellen eye chart to a wall in the laboratory and measure out 20 feet from the chart. This will be where each person will attempt to read the chart. Remove any glasses. If you can, remove any contact lenses as well.
2. Stand at the 20-foot mark, cover your left eye, and read each line of the chart from top to bottom, or from large to continuously smaller letters until your lab partner indicates that you are not correctly reading the letters. Record the visual-acuity measure given at the last line of letters read correctly for your right eye in **Table 2-3** of your lab report.
3. Repeat Step 2 while covering your right eye and record your visual-acuity measure in the table.
4. Repeat Step 2 again, but this time with both eyes uncovered. Record your visual-acuity measure in the table.
5. Finally, if you removed your corrective lenses, put them back on and repeat steps 2–4.

2.4b Astigmatism

The reduction in sharpness due to an irregularly shaped cornea or lens is called **astigmatism**. Any misshape in either of these two surfaces will lead to an incorrect bending, or **refraction**, of light, resulting in blurred vision. In the following activity, you will test for the presence of astigmatism using a chart that has 12 sets of 3 lines, organized in a circular arrangement (**Figure 2-11**).

FIGURE 2-11 Test for Astigmatism



2-8 Astigmatism Test

Materials: Astigmatism chart, tape measure, lab partner

1. Attach the astigmatism chart to the wall of the lab at eye level and measure out 20 feet from the test.
2. Again, if you wear corrective lenses, remove them for this test.
3. While at the 20-foot mark, focus at the white circle in the middle. If all the lines around this appear sharp equally, you do not have astigmatism. However, if some lines appear blurry, or are not consistently dark, you have astigmatism. Record these results in your lab report.
4. Repeat with your lab partner as the subject.

2.4c Blind Spot Mapping

As introduced above, the optic disc is the location on the retina that serves as an opening for the sensory neuron axons and blood vessels to leave and enter the retina. This area lacks photoreceptors, so is a point at which you have no visual sensitivity, otherwise known as a blind spot. Normally we cannot perceive the spot since the visual fields of each eye overlap and covers the spots.

2-9 Revealing the Blind Spot

Materials: Figure 2-12

1. Hold the lab book and **Figure 2-12** about 2 inches from your face with the small "cross" right in front of your right eye. Close your left eye and focus only on the cross.
2. Slowly move the figure away from your eye. You should notice the small "dot" disappear briefly. This occurs as the "dot" falls on your blind spot (and can only occur if one eye is closed).
3. Record your observations in the lab report.

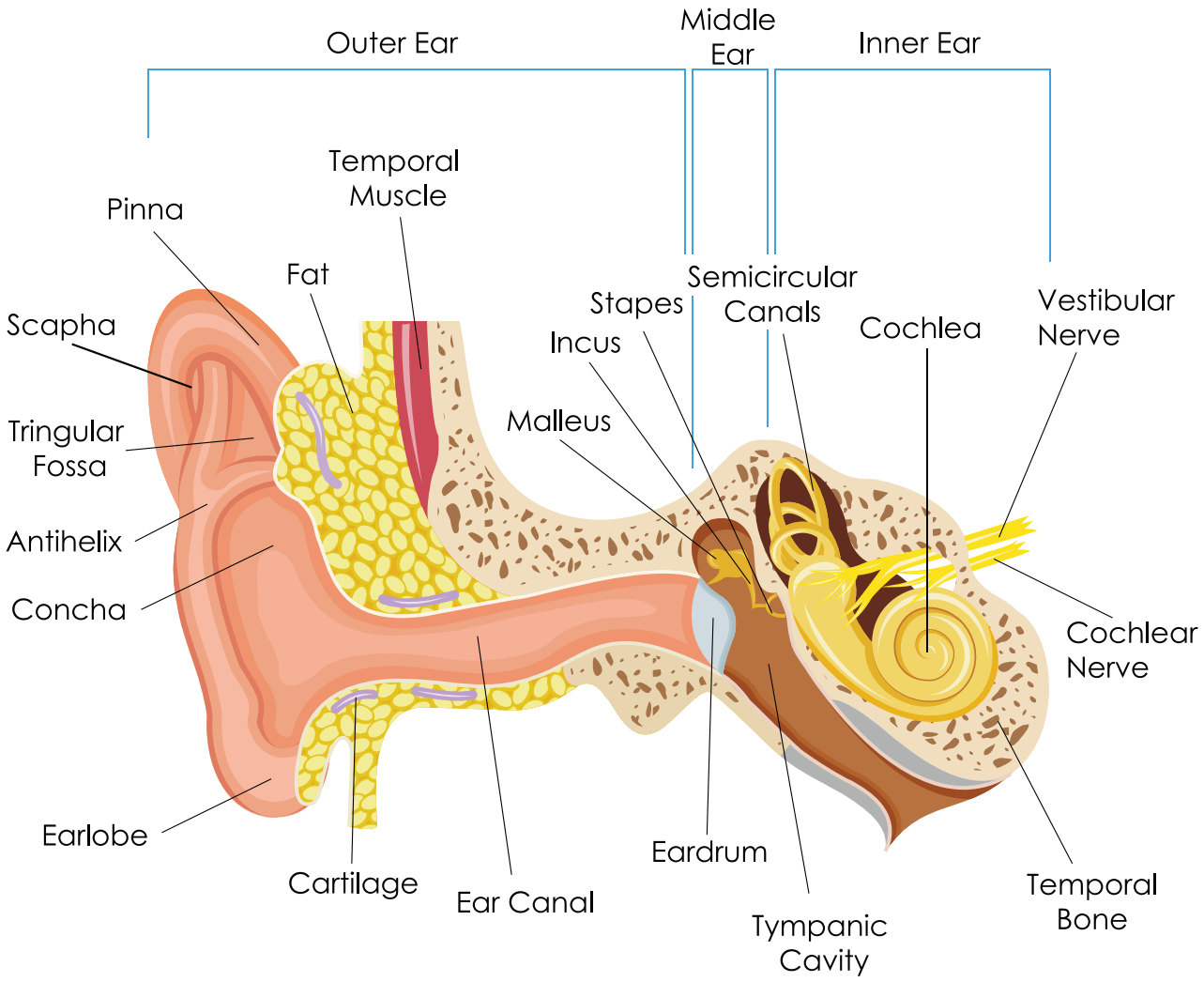
FIGURE 2-12 Blind Spot Mapping

2.5 Audition and Human Ear Anatomy

Anatomically, the ear can be divided into 3 major regions: the external or outer ear, middle ear and inner ear (**Figure 2-13**). The external ear works to direct sound waves into middle and finally the inner ear for processing. The inner ear contains the receptors that work to detect sound, allowing you to hear the world around you and communicate to others. Along with sound, the inner ear also contains receptors that detect balance, or where your body is relative to the ground. Without your sense of balance, you would unable to stand still, run outside or even dance.

FIGURE 2-13 Human Ear Anatomy

(Shutterstock)



2.5a External and Middle Ear Anatomy

The external ear consists of the **pinna**, or **auricle**. This is the outer flap that works to funnel sound waves, (compressions of air), into the **external auditory meatus**, delivering sound to the middle ear. The pinna is composed of an inner base of elastic cartilage covered by adipose tissue and skin. Also found in the meatus are **ceruminous glands** that secrete wax, as well as many small hairs that all help to protect against dust and other particles from entering the ear. The **tympanic membrane**, or ear drum, is what separates the external and middle ear. This membrane is made of a thin layer of fibrous connective tissue stretched across the ear canal. (**Figure 2-13**)

The middle ear is also called the **tympanic cavity**. Through the **auditory tube** or **Eustachian tube**, it connects to the **nasopharynx** (upper throat). This tube allows you to equalize pressure in this cavity, an experience we all have when we increase or decrease in altitude. Within the cavity are the 3 smallest bones of the body, the **ossicles**. These transfer the vibrations of the sound wave hitting the tympanic membrane to the inner ear. In the order of appearance:

the **malleus** is connected to the tympanic membrane and leads to the **incus**, which is then in contact with the final bone, the **stapes**. The vibrations from the tympanic membrane are then transferred, via the stapes, to the oval window of the inner ear and leads to the activation of auditory receptor cells. The **tensor tympani** and **stapedius** are the smallest muscles of the body, connecting to the malleus and stapes, respectively. They function to slightly reduce the movement of the bones in cases where extremely loud noises can damage the inner ear cells.

2.5b Inner Ear Anatomy

The inner ear also consists of 3 regions. These are the **cochlea**, containing the receptors for hearing, the **vestibule**, containing receptors for static equilibrium and 3 **semicircular canals**, containing receptors for dynamic equilibrium (for when the body is moving). A cross section of the structure reveals what is known as a "pipe-within-a-pipe" arrangement. The outer pipe, called the **bony labyrinth**, is found within the temporal bone and contains a fluid called **perilymph**. The inner pipe, called the **membranous labyrinth**, is filled with a liquid called **endolymph** (Figure 2-14).

The cochlea contains 3 ducts rolled into a snail-like shape. The cochlear duct is also known as the **scala media**, and contains hair cells that are sensitive to the vibrations caused by the sound waves. This duct is part of the membranous labyrinth, so is filled with endolymph. Surrounding this are the vestibular duct (**scala vestibule**) and the tympanic duct (**scala tympani**). Both are filled with perilymph. The floor of the cochlear duct is called the **basilar membrane**, and holds the hair cells. This membrane is what vibrates when the stapes pushes into the oval window, causing a transfer of air-to-fluid vibrations throughout the ducts. The waves stimulate the hair cells and then reach a second window called the **round window** that stretches as a way to dissipate the energy (Figure 2-14).

The **hair cells** are found within a specialized **organ of corti** (spiral organ) on the basilar membrane. In addition to hair cells, there are also **supporting cells**. The **tectorial membrane** reaches across the top of the hair cells, attaching to the wall of the cochlear duct, sandwiching the hair cells between the basilar and tectorial membranes. Two types of hair cells occur: **inner hair cells** are found in a single row on the proximal portion of the tectorial membrane whereas **outer hair cells** are found in 3 rows on the distal end. **Stereocilia** extending from the top of the hair cells are pushed from side to side as sound waves vibrate the basilar membrane, causing the hair cells to vibrate with it. This leads to the activation of the cells and an impulse that travels up the vestibulocochlear nerve (N VIII) to the auditory cortex of the brain (Figure 2-14).

The 3 semicircular canals are oriented perpendicular to each other (Figure 2-14 and Figure 2-15). They work to detect **dynamic equilibrium** when you are moving through space. Inside the bony shell, membranous canals called semicircular ducts are filled with endolymph. At one end is a specialized structure called the **ampulla**, an enlargement of the duct filled with the **cristae**, or receptors for balance. These are composed of hair cells and supporting cells, with the cilia of the cells extending into a **cupula** (gelatinous material). Head movements cause the fluid within the canals to move, thus pushing the cupula and dragging the cilia with it. This leads to the activation of the hair cells.

Finally, the vestibule consists of the utricle and saccule found at right angles to each other. These contain **maculae**, receptors that help to maintain static equilibrium, or balance when we are standing still. Similar to the cristae, the maculae have hair cells and gelatinous material. However, in these structures, there are calcium carbonate crystals that sit on top of the material, called **otoliths**. These are dense crystals that shift as a function of gravity when the head changes position, pulling the hair cells in any direction the crystals shift. Activation of hair cells in the semicircular canals and the vestibule both send impulses up the vestibulocochlear nerve along with auditory information. (Figure 2-15)

FIGURE 2-14 Inner Ear Anatomy

(Shutterstock)

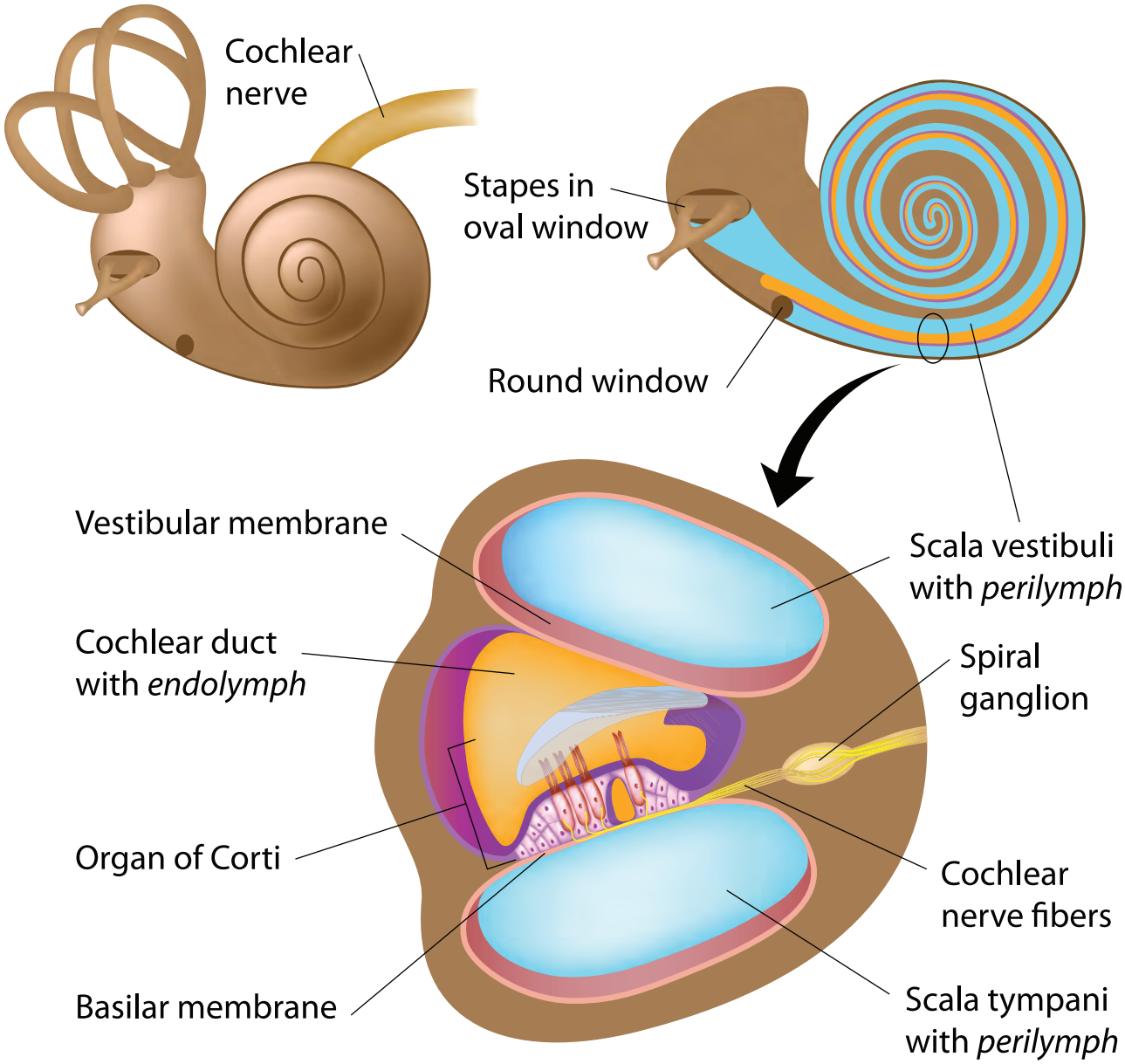


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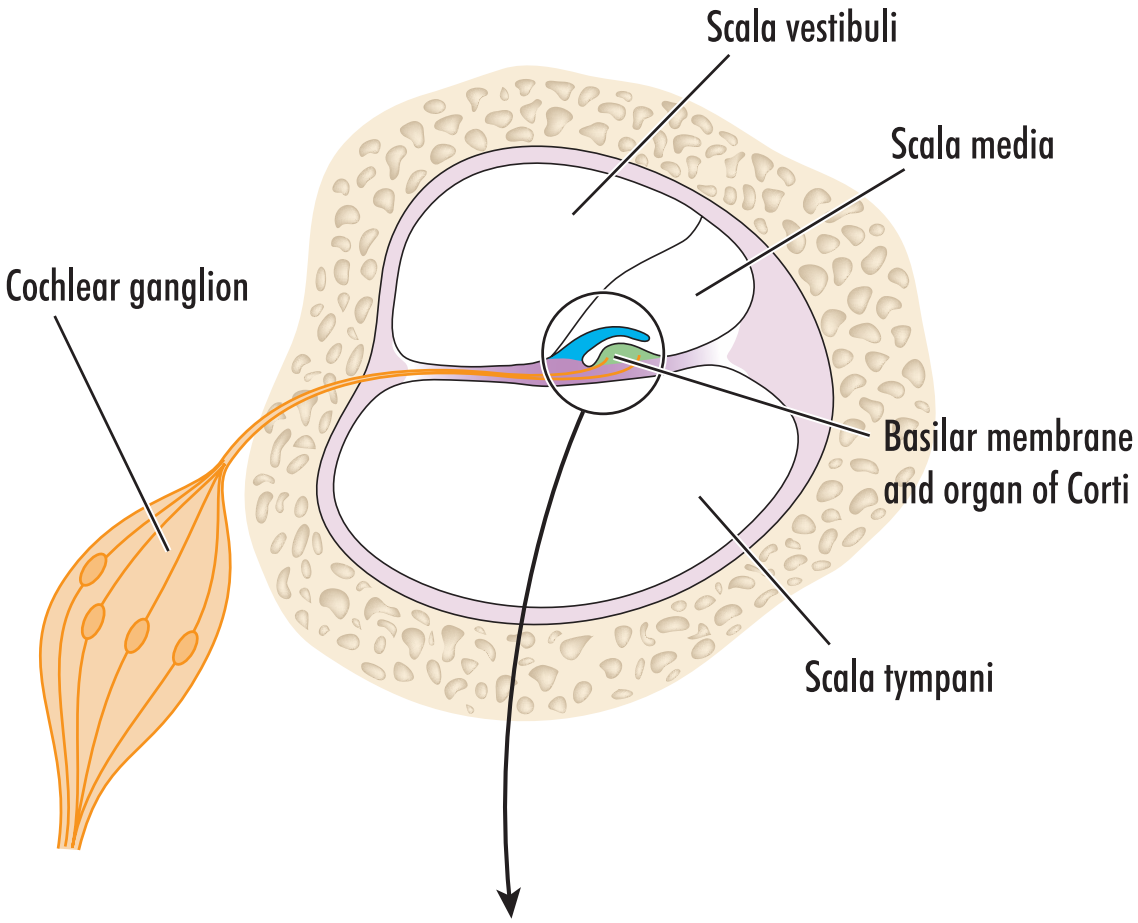
FIGURE 2-14 Inner Ear Anatomy *(continued)*



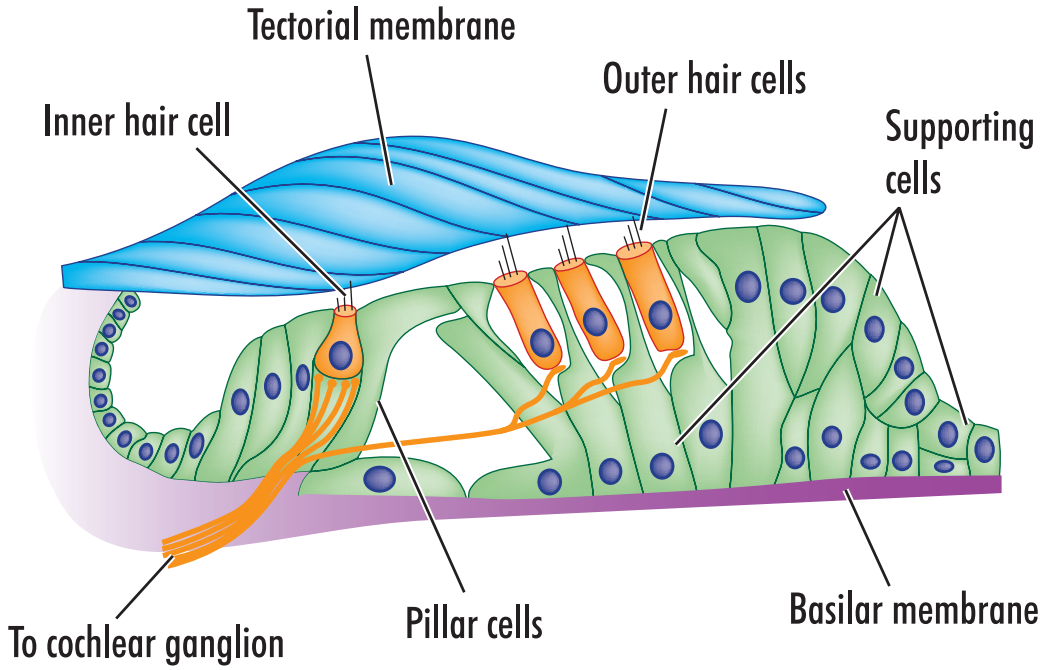


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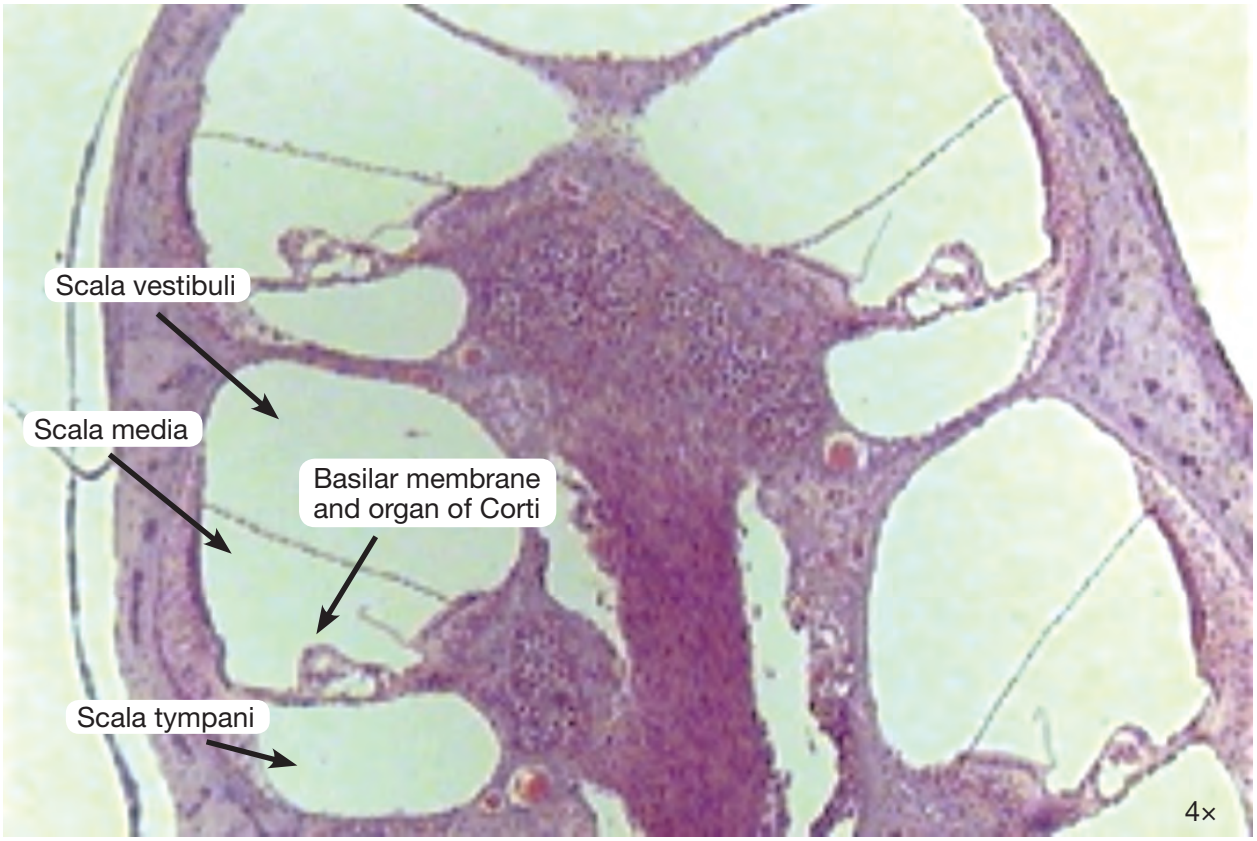
FIGURE 2-14 Inner Ear Anatomy *(continued)*



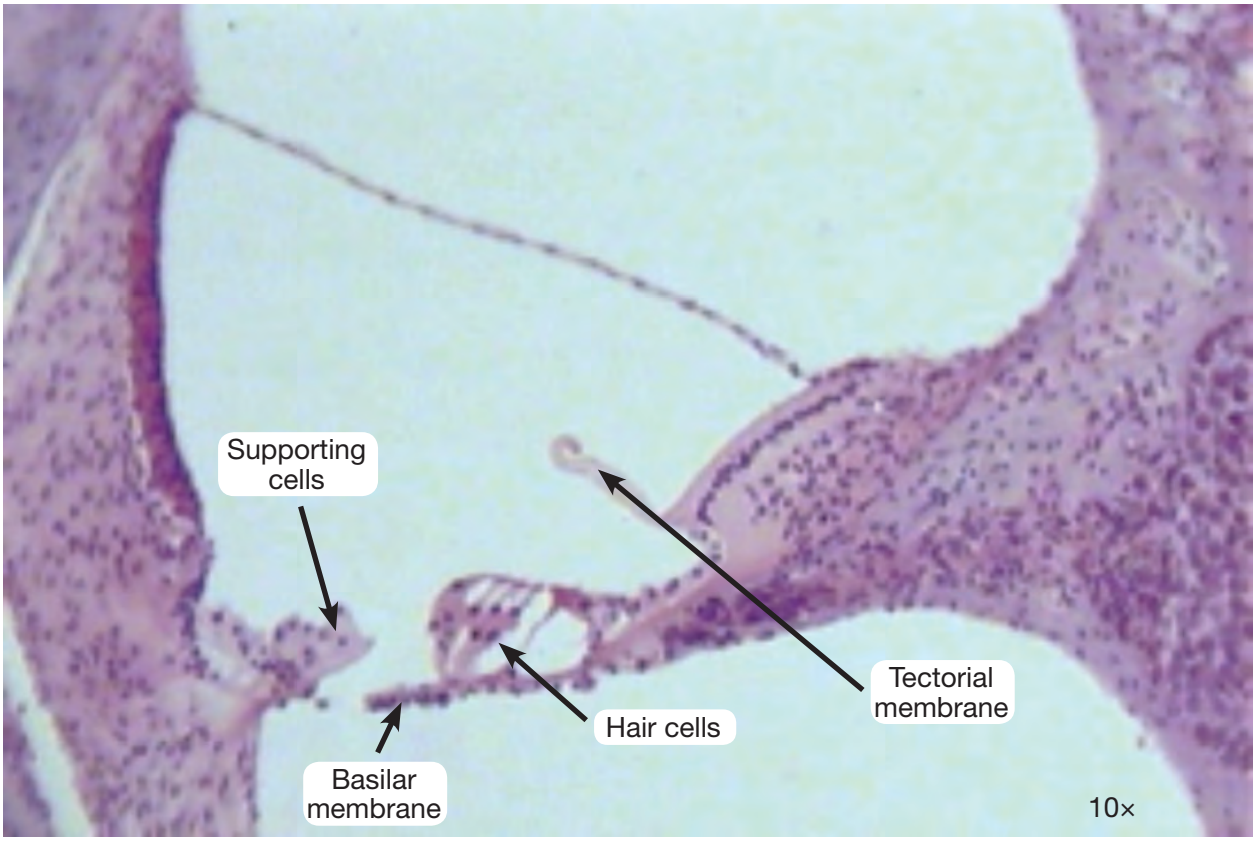


FIGURE 2-15 Vestibular Apparatus

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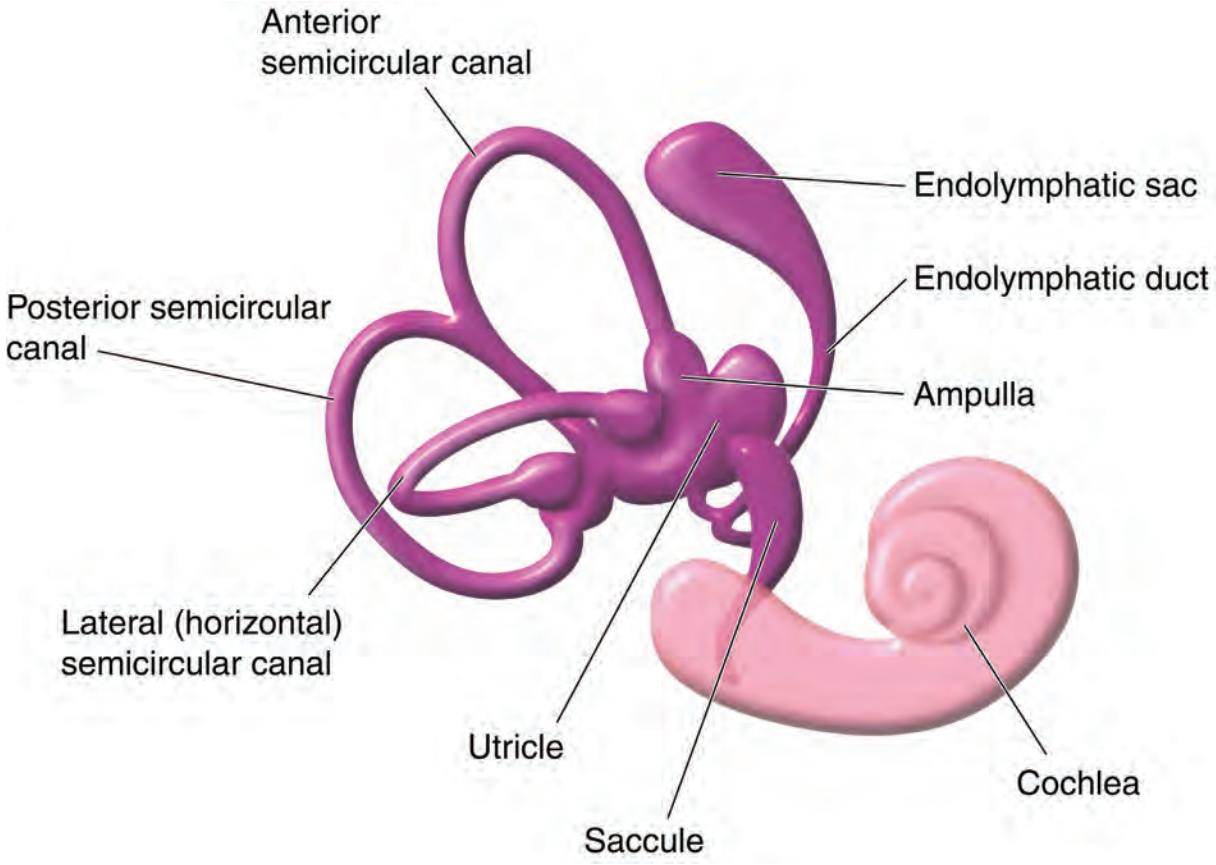

2-10 Ear Anatomy and Histological Examination of the Inner Ear

Materials: Human Ear model, ossicle model, inner ear model, prepared slide of the cochlea, compound microscope

1. Using the human ear model and ossicle model from the lab, locate the pinna, tympanic membrane, tympanic cavity, auditory canal, auditory ossicles, malleus, incus, stapes.
2. Within the inner ear, locate a semicircular canal, ampulla, the vestibule, spiraled cochlea, and finally the vestibulocochlear nerve.
3. Using the model and figures above, label the images of the ear and ossicle model in your lab report.
4. Review the anatomy of the inner ear, specifically the crista, macula and cochlea from **Figure 2-12** through **Figure 2-14**.
5. Examine the slide of the cochlea under low and then medium power and draw the image in your lab report. In the cochlea, label the hair cells, basilar membrane and tectorial membrane.

2.6 Auditory Physiology

The final piece of this lab covers the physiology of both hearing and equilibrium or balance. Equilibrium is a critical sense, allowing us to move through a three-dimensional world, and function within two dimensions (front-back, side-side). Our sense of the third dimension is based on the presence of the ground, so sometimes our sense of balance gets confused when we are in the water, and we can experience motion sickness, or vertigo. This occurs when signals from the inner ear do not match with other signals reaching the brain. For example, some people feel sick when reading in a moving car because they are focusing on a steady object, the book, while sensing their body moving.

2.6a Equilibrium

The receptors for equilibrium described above, are found in the vestibule of the inner ear, where dynamic equilibrium (like when you spin around in a circle) is based on activity from the semicircular canals, and static equilibrium (like when you stand on your head) is based on activity from the maculae. In fact, your vision helps to enhance your sense of equilibrium, since your brain is constantly comparing signals from the world around you to your body position. Closing your eyes results in a loss of balance.

2-11 Equilibrium

Materials: Lab partner

1. Using your partner as a support next to you in case you lose your balance, stand on both feet in an open area of the room.
2. With your arms at your sides and eyes open, raise one foot and stand still for about 45 seconds. Record any observations in **Table 2-4** in your lab report.
3. Keep standing on this one foot, but close both eyes and try to keep standing still for another 45 seconds. Record your observations in the table.

2.6b Hearing

Sounds in the environment are produced when objects vibrate and this vibration causes air particles to compress and decompress, sending this wave outward from the vibrating object. The **frequency** of a sound refers to the number of compressed regions passing a given point in one second, given in the units of hertz (Hz), or cycles per second (CPS); the higher the pitch of the sound, the higher the frequency. Humans can detect sounds that range from 20–20,000Hz, with the higher value declining with age. The other major component of sound is **amplitude** and this is measured in decibels (dB); this is simultaneous with the sound intensity.

As described above, hearing occurs when this sound wave hits the tympanic membrane, transferring the energy of this wave through the three ossicles, finally transferring the wave from the third ossicle, the stapes, into the oval window and creating a wave of endolymph, within the cochlear duct. This fluid wave vibrates the basilar

membrane, which pushes specific hair cells into the tectorial membrane, leading to a neural impulse that is sent down the cochlear branch of the vestibulocochlear nerve (N VIII). Different frequencies of sound activate different regions of the basilar membrane, organizing the sound signals by frequency, or pitch as it travels into the brain. Lower frequencies, or deeper sounds, have longer sound waves, and activate the distal portion of the basilar membrane. Higher frequencies or higher sounds, have shorter sound waves and can activate the proximal part of the membrane, closer to the oval window.

Deafness can occur in two major ways. **Conduction deafness** occurs when there is damage to structures of the auditory pathway that conducts the signal, such as the tympanic membrane or auditory ossicles. In this case, sounds can sometimes be heard well with the unaffected ear. Tests done with tuning forks, however, results in a louder sounding stimulus in the affected ear, due to an increased sensitivity to sounds in the ear with conduction deafness. In contrast, **nerve deafness** can result due to damage in the cochlea or cochlear nerve. One common cause of nerve deafness is repeated exposure to loud sounds, such as excessive loud music or loud machinery without protection. In contrast to conduction deafness, nerve deafness cannot be corrected as easily, and is often permanent damage to a specific set of frequencies. Sometimes cochlear implants, which bypass the hair cells and directly activate the nerve axons, can help to remedy some of the hearing sense. This last activity utilizes tuning forks, which send sound vibrations through the bones of the skull, bypassing the normal conduction of the external and middle ear, directly to the inner ear.

2-12 Hearing with Tuning Forks

Materials: 3 Tuning forks chosen at a range of frequencies, lab partner

Weber's test:

1. Have your partner strike the lower frequency tuning forks on the heel of the hand and place its base on the top, center of your head.
   - Do you hear the vibrations?
   - Are they louder in one ear over the other?
2. Repeat this procedure using a higher frequency tuning fork. Record your observations in **Table 1-5**.

Rinne Test:

1. Sit down and have your partner locate your mastoid process, behind your ear.
2. Strike one of the tuning forks and have your partner place the base of it on your mastoid process. This will conduct the vibrations directly to the middle ear.
3. Once you cannot hear the vibrations any longer, have your partner now move the tuning fork close to your external ear (**Figure 2-16**). Someone with normal hearing should be able to hear the fork, but someone with conduction deafness will not be able to hear the sound once placed near the external ear.
4. Repeat this test on your other ear and record your observations in **Table 1-6**.

FIGURE 2-16 Performing an Auditory Test Using Tuning Forks

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