CHAPTER 10
THE EAR MECHANISM

The **ear** is easily divided into three parts, the **external, middle, and inner ear. Inner ears are found in all vertebrates. Middle and external ears tend to be associated with each other and are found in terrestrial vertebrates and some (such as turtles and whales) that have secondarily reverted to an aquatic existence**. Lets first look at how these structures form and then consider the anatomy.

The external ear consists of the **pinna and external acoustic meatus**. The pinna is a sound director that is composed of an elastic cartilage skeleton covered with epidermis. The **auricularis**, a skeletal muscle is attached to it and controls its movement, however, in humans, this movement is quite secondary or non-existent. **The pinna develops from tissue around the first (hyomandibular) branchial groove. The external acoustic meatus develops from the first branchial groove itself.**

The **middle ear and eustachian tube form from the first pharyngeal pouch.** Between the external and middle ear is the **tympanic membrane**. Its outer surface is technically part of the external ear and its inner surface part of the middle ear. Within the middle ear chamber itself **there are three ear ossicles in mammals**. The **stapes is the inner-most ear ossicle and is the connector between the incus and the oval window of the inner ear**. The stapes is derived phylogenetically from the second pharyngeal arch. (What do I mean when I say it is phylogenetically derived?). As with the other ear ossicles, it is absent from fishes. The stapes is the sole sound transmitting bone found in amphibians, reptiles, and birds. It has the **stapedius muscle** attached to it which serves to dampen intense vibrations that occur with continuous, loud sounds. (By the way, abrupt, loud sounds do not stimulate this muscle quickly enough and the stapes- along with the other two ear ossicles- may be damaged.) The **stapedius muscle is innervated by the VII Cranial (Facial) which serves structures derived from the second pharyngeal arch.** The **incus** was originally derived from a jaw bone (the quadrate), thus is a product of the first pharyngeal arch. It is only present as an ear ossicle in mammals. In other vertebrates it still is associated with the jaw. The **malleus** was originally the articular bone of the lower jaw, thus is derived from the first pharyngeal arch. As with the incus, it is only found in mammals as a sound transmitting bone. The **tensor tympani muscle** is associated with this bone and serves to dampen its vibrations. The fact that the tensor tympani is innervated by the **trigeminal nerve (Cranial V)** supports the argument that this one also was derived from the first pharyngeal arch structures. Also, the fact that the tensor tympani originates outside the middle ear near the eustachian tube on the greater wing of the sphenoid and adjacent petrous portion of the temporal and then travels through the tensor tympani canal into the middle ear cavity shows that it was originally in position to serve as a muscle of jaw suspension, its function in non-mammalian vertebrates.

The **inner ear** originally develops from a thickened portion of ectoderm called the **auditory placode** in the region just dorsal to the second pharyngeal arch. This placode develops a depression, the **auditory pit** which eventually internalizes, as did the neural tube, and becomes the **auditory vesicle**, a space with no external contact. The **otocyst differentiates to form the labyrinth and associated structures of the inner ear**. This all happens in close approximation to the middle ear and the inner and middle ears then develop their associations.

The **pinna (auricle)** is the large flap of the external ear.. Note the anterior projection, the **tragus**. This structure becomes fairly large in some mammals, such as bats, where it serves to direct sound. Although the function of the pinna is to direct sound into the **external acoustic meatus**, it doesn't do that job very well since it is not well developed like those of deer, etc. Also, remember that we don't rotate our pinna as do some other mammals. If you flatten your pinna to the side of your head, you will be aware of minor sound reception differences. The placement of the two pinnae on the opposite sides of the head allow us to locate the origin of sound since if the sound comes from the left, the left ear detects it first and then the right. The brain is able to measure the time lag between the arrival of sound at the two ears and discern the origin of the sound. By the way, we do not have a comparable device to enable us to locate sound origins on the vertical axis, thus it is difficult for us to pinpoint sound origins in that plane. Generally, we rely on knowledge of source origins of familiar sounds in order to locate sounds on the vertical axis. Thus, we know that an airplane noise is up in the air and a lawnmower noise is on the ground.

The **external acoustic meatus** is the tube that connects the external and middle ear. The meatus allows the **tympanic membrane** to be recessed and protected from mechanical injury. In newborns until about 3 years of age, the external acoustic meatus is not deep and the tympanic membrane is near the surface. In many terrestrial vertebrates, such as frogs and lizards, the tympanic membrane is out at the surface with no protection of an external acoustic meatus. Within the meatus are **ceruminous glands** that produce the **cerumen (earwax)** that helps lubricate the skin of the meatus. Also, because it is waxy and bitter to the taste, critters tend to keep out of the meatus. (Earwigs, a common Pennsylvania insect, got their name from the false assumption that they crawl into people's external acoustic meatus and live there. They do not do this, at least, not on purpose!) There are also numerous **hairs** that line this canal that help keep foreign items out of the meatus.

The **tympanic membrane** is a three-layered membrane that intercepts airborne vibrations and converts them into tissue vibrations. The **outer** (towards the external acoustic meatus) **layer** is a continuation of the ectodermally-produced epithelium of the external acoustic meatus. The **inner layer** is a continuation of the endodermally-produced middle ear lining. The **middle layer** is a mesenchymally-produced connective tissue layer with circular and radial fibers. The **radial fibers** are superficial in this middle layer and radiate like spokes on a wheel from the central focus. The **circular fibers** are located medially to the radial ones and are more concentrated near the periphery of the eardrum. They are sparse near the center of the drum. The fibrous nature of this middle layer is responsible for the resilience of the eardrum.

The upper portion of the tympanic membrane, the **pars flaccida** (Schrapnell's membrane), is devoid of most of the fibers of the middle layer and thus, quite flaccid. It is responsible for allowing a small degree of pressure equilibration during minor pressure changes between the middle and external ear. The remainder of the membrane, the **pars tensa**, is the part responsible for vibration during sound reception.

An otoscope is a device used by your doctor to allow her/him to visualize your ear canal and tympannic membrane. Upon direct otoscopic observation, the **tympanic membrane** appears as a pearl-gray membrane. The otoscope light produces a cone of light, revealing that the membrane is concave externally, thus, bulging slightly into the middle ear chamber. The **cone of light** is one of the signs of a healthy tympanic membrane. Also, in the right ear, at about 1 o'clock there is a whitish streak, the **malleolar stria**, which is produced by the **malleolar handle**. The proximal end of the malleolar handle attaches near the center of the tympanic membrane near the **umbo**. Since the **umbo** is the most depressed portion of the **tympanic membrane**, it is the origin of the cone of light mentioned above. If one were to follow the malleolar handle superiorly to the point where the lateral handle of the malleus attaches to the tympanic membrane, just above this point is the **pars flaccida**. The remainder of the tympanic membrane is the **pars tensa.**

The **middle ear** is a small chamber that houses the three (in mammals) middle ear bones plus their associated ligaments, muscles, and nerves. The **Eustachian tube (auditory tube)** connects the **middle ear** with the **nasopharynx**. Review its position on the sectioned temporal bone you studied in lab several weeks ago when you examined the skull.

Review the **malleus, incus and stapes** also on the sectioned temporal bone from the skull lab. Note the shape of each auditory ossicle from and compare with the real bones on the sectioned temporal preparation.

Also, review the **tensor tympani and stapedius muscles** from Lab 7. The **tensor tympani** originates from the edge of the eustachian tube opening, greater wing of the sphenoid, and petrous portion of the temporal bone. It inserts on the manubrium of the malleus. **It is innervated by the mandibular division of the trigeminal nerve (Cranial nerve V)**. The **stapedius** originates from the wall of the middle ear and inserts at the dorsal surface of the neck of the stapes. The **stapedius is innervated by fibers from the facial nerve (Cranial VII)**. The function of these two muscles is to dampen the vibrations of the ossicular chain during intense sound reception.

The **inner ear** is housed within the **petrous portion of the temporal bone.** The two functions it serves, **equilibrium and hearing,** are not related to each other and will be discussed separately. An interesting similarity of the two parts is the fact that each has an outer **bony labyrinth** which surrounds the inner **membranous labyrinth**. The membranous labyrinth has a fluid called **endolymph** inside it. Between the bony and membranous labyrinth is the fluid called **perilymph**. The membranous labyrinth of both has sensory cells called **hair cells** that project into the endolymph and react to movement or vibrations within that fluid. These hair cells are connected to Cranial Nerve VIII, the **Vestibulocochlear**. The hair cells in the vestibule are connected to the vestibular division of Cranial VIII and those in the cochlea are connected to the cochlear division.

Equilibrium is the function of the **vestibule and semicircular canals**. Lets discuss the **semicircular canals** first. These are the three canals in the three planes of motion. Each canal has a dilated region called an **ampulla**. The ampulla has **hair cells** that project into the **endolymph** and are sensitive to its motion. As with the remainder of the inner ear, the semicircular canals and ampullae have an outer bony and inner membranous labyrinth. Here is how this mechanism works. When you are stationary or moving at a constant rate of speed, the semicircular canals and endolymph are moving at the same speed. If you accelerate, the semicircular canal with its hair cells will immediately accelerate, however, the endolymph lags behind. Thus, the endolymph has an apparent movement over the hair cells. Actually what happens is that the hair cells move forward through the endolymph and bend backward in the opposite direction of forward movement. Bending sets up shear forces in the hair cells. This triggers Cranial Nerve VIII, telling the brain that you have accelerated.

If you slow down, the opposite thing happens. The endolymph keeps moving forward but the hair cells stop. Again, the fluid bends the hair cells, however, this time they bend forward in the direction of the movement.

This again sets up shear forces that trigger the VIII cranial, telling the brain that you have stopped or slowed down.

Since the semicircular canals are oriented in the three planes of motion, they can detect acceleration or deceleration in all three planes. Interestingly, they are not capable of detecting constant, steady motion. You are totally unaware of the fact that you are moving at the rate of a bit less than 1,000 miles an hour. The reason for this is that the earth is spinning at that rate but it is a constant rate and you can't detect it. This same situation occurs in airplanes, etc. In some situations this acceleration sense leads to problems. If you are out on a boat, the boat is in waves that make it accelerate and decelerate in all three planes at the same time. You are being bombarded with sensory information telling your brain that you are obviously on a structure that is moving a great deal. However, if you look at the boat, your visual sense tells you that the boat is not moving or only slightly. Thus, your brain receives conflicting signals. For some of us it resolves this conflict by making us seasick. Thus, motion sickness is caused by conflicting signals from the semicircular canals and the visual input. This problem can sometimes be rectified by taking a number of precautions. First, when you go out on a boat, always look off at the distant horizon when you start to feel seasickness coming on. This allows your visual sense to also detect the motion since you are looking at a stationary horizon and comparing it with the movement of the water near you. Second, there are medications that sometimes help. Some of these are folk medicines with no known method of action. Copper bracelets fall into this category. Others, such as Dramamine and scopolamine work by having an effect on the nervous system. **Scopolamine** is the motion-sickness drug that is administered through the patches that are worn like small bandages on the mastoid region. **Scopolamine** is an **antagonist of acetylcholine** at receptor sites in the eye, smooth muscle, cardiac muscle and glandular cells. It inhibits the vestibular input to the Central Nervous System, thus controlling the vomit reflex.

At the base of the semicircular canals is the **vestibule**, a part of the **osseous labyrinth**. Inside the vestibule are the **utricle and saccule**, two parts of the membranous labyrinth. They are connected by a small tube off which passes the **endolymphatic duct** and **endolymphatic sac**. The endolymphatic duct leads to the endolymphatic sac which is located within the layers of the **dura mater** covering the brain at the petrous portion of the temporal bone. The function of the endolymphatic apparatus in higher vertebrates is not clear. In fishes such as sharks this structure actually opens to the outside as a tiny endolymphatic pore located between the eyes on the top of the head. The shark uses this opening and tube to direct sand grains into the vestibule where they are used as otoliths for balance. The membranous **utricle and saccule** have patches of **hair cells** in the region called the **maculae** over which are located **otoliths.** Otoliths are complex protein-calcium carbonate sand-like grains embedded in a polysaccharide-protein complex of jelly-like material. The apparent function of the otoliths is to provide the **gravitational sense**. In the upright position, the otoliths exert a downward force on the hair cells. If you shift in any direction from the upright position, this causes the weight of the otoliths to exert on the hair cells in a different plane. This bends the hair cells causing **shear forces which stimulate the VIII Cranial.** This provides you with one of several inputs of the gravitational sense. There are other senses that provide this same type of input. When you sit or stand, you are aware that your body weight is forcing your body down through the force of gravity. Also, your visual sense tells you that familiar objects are in their proper place based on the effects of gravity.

The **cochlea** is a coiled tube that looks much like a snail. Check out the various cochlear models including the cochlear cross section when you study the cochlea. Again, as with the remainder of the inner ear, the cochlea consists of the outer **bony labyrinth** and an inner **membranous labyrinth**. Also, the sensory cells are **hair cells** found on the membranous labyrinth and projecting into the endolymph.

Externally the bony labyrinth has two connections with the outside world, the **oval and round windows**. The stapes of the middle ear is in contact with the membrane of the oval window. The general external appearance of the cochlea is that of a coiled snail.

The saccule of the vestibule and the scala media of the cochlea are connected by a small duct called the **ductus reuniens**. In cross section the cochlea reveals three tubes. The superior-most of the three is the **scala vestibuli**. The **scala media** is the middle and **scala tympani** the inferior-most. The scala vestibuli and scala tympani are continuous at their distal ends. Within the scala media is the **organ of Corti**. This is the sensory region of the cochlea where sound is perceived. It consists of a series of sensory cells (**hair cells**) which rest on a **basilar membrane** and are overlain with a **tectorial membrane**. The scala vestibuli and scala tympani are filled with perilymph while the scala media contains endolymph. The **cochlear division of the vestibulocochlear nerve** passes within the basilar membrane to the hair cells.

Sound is transmitted to the scala vestibuli by the stapes vibrating the membrane of the oval window. These vibrations pass through the endolymph of the scala vestibuli to the scala tympani. The membrane of the round window at the end of the scala tympani allows the perilymph to vibrate. The vibrations then affect the basilar membrane which itself vibrates and shoves the hair cells into the tectorial membrane. The hair cells bend and the resulting shear forces trigger the neuronal discharge of the attached cochlear nerve. This nerve then travels to the brain where in the auditory cortex the brain tells you that you heard a sound.

THE END!!!!!!!!!

(yeah!!)