Chapter 1: Applied Anatomy, Physiology and Embryology of the Ear

The ear contains two specialized sensory organs, the cochlea and the vestibular apparatus, enclosed in the extremely hard protective casing of the temporal bone. The various components that together make up the functional unit of the ear may be conveniently divided into three parts:

- The outer ear.
- The middle ear.
- The inner ear.

Each has a different embryological origin, a specific structure and function and is affected by different disease processes.

Anatomy and Physiology

The Outer Ear

The outer ear consists of the pinna (auricle), the external ear canal (external auditory meatus) leading to the tympanic membrane.

The Pinna

This is composed of elastic cartilage, perichondrium, skin and adnexae. It has a convoluted shape, reflecting its complex embryological origin and serves to direct sound towards the external ear canal.

The External Ear Canal

This curved tube, 2.5-3 cm in length, transmits sound from the auricle to the tympanic membrane.

The outer 1/3 is cartilaginous and supports the auricular cartilage. It is covered by thick, non-tender skin that bears hairs, sebaceous and ceruminous glands.

The inner 2/3 is bony and has closely applied, sensitive skin, devoid of hairs and with few adnexae. It is curved antero-inferiorly. In order to get an unimpeded view of the tympanic membrane the pinna must be gently pulled postero-superiorly to bring the cartilaginous canal in line with this bony curve.

The Tympanic Membrane

The tympanic membrane lies obliquely across the end of the external ear canal, separating the external and the middle ear. It has three layers (derived from the partition between the 1st branchial groove and the pharyngeal pouch):
- Outer squamous layer - continuous with the skin of the external ear canal.

- Middle fibrous layer - attached peripherally to the fibrous annulus, centrally to the handle of the malleus and superiorly to the malleolar ligaments. These fibres give the tympanic membrane its strength. However, superiorly, above the ligaments (pars flaccida) they are loose and randomly oriented.

- Inner mucous membrane - continuous with the lining of the middle ear cavity.

The features of a normal tympanic membrane are shown. The light reflex seen in healthy eardrums is reflected from that portion of the tympanic membrane which is at right angles to the incident light (acting as a mirror). The cone of light will alter when the eardrum is diseased and has lost its ability to reflect light or when its position changes (as in middle ear disease) so that light is not reflected back down the ear canal. The presence of a light reflex does not necessarily signify normality as it is commonly retained in otitis media, with effusion.

Wax

Wax is a mixture of:

- Ceruminous secretions - from the glands in the outer 1/2 of the canal.
- Keratin - shed from the drum and ear canal.

The quantity and consistency of cerumen appears to be genetically determined. It keeps the external ear canal skin waterproof, has antibacterial and antifungal properties and may also act as 'fly paper' for errant insects!

The squamous epithelium of the tympanic membrane normally migrates outwards towards the external meatus, making the external ear self-cleansing. If this natural process is interrupted by enthusiastic cleaning with cotton buds or by alteration of the natural shape of the canal, eg, following mastoidectomy, wax may accumulate. However, as long as air pressure differences can be transmitted to the collecting tympanic membrane, hearing will be normal. Only when the ear canal is completely occluded by impacted wax does a significant hearing loss occur. Wax may be removed under direct vision or by syringing.

The Middle Ear

The middle ear is a small air-containing chamber in the petrous temporal bone and serves to conduct airborne sound arriving at the tympanic membrane to the fluid-filled inner ear. The cavity is lined with cuboidal epithelium and spanned by the ossicular chain. It communicates with the mastoid air cells postero-superiorly and with the nasopharynx, via the eustachian tube, antero-inferiorly.

The Ossicular Chain

Sound energy in air is absorbed by the tympanic membrane which is firmly attached to the malleus handle. It is then transmitted by the ossicular chain cantilever system to the
oval window and into the inner ear fluids. This arrangement of bones and membranes is necessary to overcome two problems:

- Resistance to the movement of sound energy from air to fluid.
- Simultaneous movement at the oval and round windows.

The impedance of perilymph to sound is many times greater than that of air. If sound were to strike the oval window directly, most of the energy would be reflected. This *impedance mismatching* is overcome by the mechanical advantage of the lever system and the surface area differential between the tympanic membrane and the oval window. Together these mechanisms increase the sound energy transfer by a factor of 23.

Simultaneous vibration of the membranes at the oval and round windows is avoided by targeting the sound waves, via the footplate of the stapes, onto the oval window. This leaves the round window free to bulge towards the middle ear cavity when the oval window is pushed inwards and vice versa, allowing changes in fluid pressure to be set up within the cochlea.

Disease of the membranes or ossicles (eg, otosclerosis, where the footplate of the stapes becomes locked *in situ*) leads to the loss of the advantages of this conduction system and produces conductive deafness.

The middle ear structures have a resonant frequency of about 3000 Hz the frequency around which human hearing is most acute.

**The Eustachian Tube**

The eustachian (auditory) tube connects the middle ear cavity with the nasopharynx. It is 3.5 cm in length, bony in its upper, outer 1/3 and fibrocartilaginous in its inner nasopharyngeal portion. The tube is at its narrowest, 2 mm, at the junction of the cartilaginous and bony portions (the isthmus). The nasopharyngeal orifice is marked by a small collection of lymphoid tissue.

Although the bony portion is patent, the cartilaginous portion is passively closed. Opening occurs on swallowing or yawning: contraction of the tensor palati (also aided by salpingopharyngeus) pulls down the edge of the tubal cartilage, which is supported by the contraction of the levator palati.

The mucosa of the nasopharyngeal portion is truly respiratory (columnar, mucous secreting and ciliated) gradually changing to the much flatter cuboidal epithelium of the aditus and antrum.

**Function**

The eustachian tube allows pressure equalization between the middle ear cavity and the external auditory meatus, essential for the efficient functioning of the middle ear. It also drains secretions from the epithelium of the middle ear. The normal eustachian tube is kept
patent by a combination of frequent automatic opening (on swallowing or yawning) and the ciliary action of the mucosa.

**Pathology**

Malfunction of the tube, due to obstruction, disrupted ciliary or muscular function or abnormal patency, underlies both acute and chronic inflammatory conditions of the middle ear (acute otitis media, barotrauma, otitis media with effusion (OME)).

If the tube is not patent, air resorption by the middle ear mucosa results in a reduction in middle ear pressure with consequent retraction of the membrane and exudation into the tympanic cavity. This leads to a loss in sound conduction and an increased susceptibility to infection.

An abnormally patent tube may produce similar effects (following a fall in pressure due to sniffing) as well as impairing the protective function of the tube in preventing the entry of infection.

Some of the causes of eustachian tube malfunction include:

*External obstruction*

- Lymphoid hyperplasia.
- Nasopharyngeal tumours.

*Internal obstruction*

- Infection.
- Allergy.
- Congenital abnormality.

*Muscular failure*

- Surgery for cleft palate.

*External Obstruction*

Lymphoid hyperplasia, either at the tubal opening or of the adenoids may distort the tubal orifice.

A nasopharyngeal tumour may obstruct the orifice and special attention must be paid to unilateral otitis media with effusion in an adult.

*Infection*

Infection of the upper respiratory tract will affect not only the nose, throat and trachea, but may also extend to involve the respiratory epithelium of the eustachian tube. The increased production of mucus, disruption of ciliary function and oedema of the tubal orifice
within the bony canal (particularly at the isthmus) will all cause obstruction - patients complain of feeling 'bunged up' and not being able to make their ears pop.

Secondary infection with commensal bacteria may result in acute otitis media. Otic barotrauma may occur with air travel as the middle ear pressure fails to equalize with the surrounding cabin pressure. The significant negative pressure in the middle ear results in an effusion or haemorrhage into the middle ear space.

**Allergy**

It would seem logical to expect that in atopic children tubal oedema would predispose to otitis media. However, this does not appear to be common and the role of respiratory allergy in children with otitis media probably relates to other factors such as a co-existent rhinosinusitis.

**Failure of the Muscular Opening Mechanism**

Children who have surgery for repair of a cleft palate frequently have otitis media. This is probably because the tensor palati has lost some of its mechanical advantage as in surgical repair of the cleft palate the pterygoid hamulus is usually fractured to permit closure of the soft tissues. However not all children with a cleft palate repair develop otitis media and there are obviously other mechanisms of maintaining tubal patency.

**The Mastoid Air Cells**

The mastoid air cells are in close relationship with the dura and the contents of the middle and posterior cranial fossae. Infection may spread from the middle ear to the mastoid antrum and related structures:

- Meninges of the posterior and middle cranial fossae.
- Sigmoid (lateral) sinus.
- Cerebellum.
- Temporal lobe.
- Petrous apex and cavernous sinus (rarely).

**The Inner Ear**

The inner ear contains the sensory organs of hearing and balance: the cochlea and the vestibular system respectively. They are intimately related and have the same basic structure: a bony outer shell, an inner bath of perilymph surrounding a membranous sensory end organ filled with endolymph. Hence it is common for disorders of the ear that affect these fluids to cause a combination of deafness, tinnitus and vertigo.

**The Cochlea**

The cochlea is a coiled tubular structure composed of 2 3/4 turns divided into three chamber. Sound energy is transduced into electrical energy by the organ of Corti:
- Motion of the stapes footplate displaces perilymph and sets up a standing wave within the cochlea.

- The basilar membrane vibrates at a highly specific point of maximum natural resonance - high frequency sound in the basal turn and low frequencies towards the apex.

- Shearing forces between the hair cells and the attached tectorial membrane stimulate auditory nerve fibres.

- Impulses are relayed, via auditory nuclei in the brain stem, to the auditory centre in the contralateral temporal lobe.

The Vestibular System

The vestibular system comprises:

- Three semicircular canals - that detect angular acceleration (dynamic equilibrium).

- The utricle and saccule - that detect linear acceleration due to gravity (static equilibrium).

The semicircular canals lie at right angles to each other (ie, in three planes) and almost at right angles to their contralateral counterparts. The ampulla (a dilation at the end of each canal) contains an elevation called the crista. Turning movements of the head (angular acceleration) deflect the hair cells in the base of the crista and stimulate sensory fibres of the vestibular nerve.

The utricle and saccule each have a small plaque-like region or macula lying in the horizontal (utricle) or vertical (saccule) plane. The resting discharge from hair cells in the maculla is important in determining the position of the head under static conditions.

Impulses from the peripheral receptors of the vestibular system are relayed centrally to the vestibular nuclei in the brainstem and to the cerebellum. Together with information from the eyes and musculo-skeletal proprioceptors these centres keep the body balanced and coordinate head and eye movements. Disorders of vestibular function cause vertigo (an abnormal sensation of movement) and nausea.

Embryology

The three parts of the ear have different embryological origins:

- Inner ear - ectodermal otic vesicle.
- Middle ear - endoderm of the 1st pharyngeal pouch.
- Outer ear - ectoderm of the 1st pharyngeal cleft.

The middle and outer ear also have mesodermal components from the 1st and 2nd pharyngeal arches.
**Inner Ear**

The specialized sensory tissue of the membranous labyrinth arises from a thickening in the ectoderm at around 3 weeks (otic placode) which by 5 weeks has invaginated to form the otic vesicle. By the 10th week the ventral part of the vesicle has developed into the saccule and cochlear duct, the dorsal part forming the utricle, semicircular canals and endolymphatic duct. During this period of rapid development, nerve fibres grow from the vestibulocochlear ganglion to supply the neuroepithelium of the maculae, cristae and organ of Corti. A cartilaginous shell forms in the mesoderm around the membranous labyrinth, eventually ossifying into the bony labyrinth.

**Middle Ear**

The tympanic cavity is derived from the endoderm of the 1st pharyngeal pouch. This outpocketing of the pharynx occurs at around 4 weeks, growing laterally towards the floor of the 1st pharyngeal cleft. The distal end becomes the tympanic cavity, the proximal part narrows to form the eustachian tube.

The auditory ossicles are formed from condensations in the mesoderm of the 1st and 2nd pharyngeal arches. They become incorporated into the tympanic cavity around the 8th month, as the surrounding mesoderm dissolves and pneumatization expands the tympanic cavity, draping the ossicles with middle ear mucosa.

The epithelium of the tympanic cavity extends dorsally to form the antrum and after birth invades the mastoid process producing epithelial-lined air sacs. It is probable that this process of pneumatization may be hampered by malfunction of the eustachian tube. Most of the mastoid air sacs eventually become connected to the antrum, allowing the possibility of the spread of middle ear infection to the mastoid cavity.

**Outer Ear**

The external auditory meatus develops from the ectoderm of the 1st pharyngeal cleft which grows inwards to reach the endodermal lining of the tympanic cavity. At around 7 months the meatal plug at the base of the cleft dissolves leaving the tympanic membrane: formed from the apposition of the ectodermal and endodermal epithelia separated by a layer of mesodermal loose connective tissue. Occasionally the meatal plug may persist until birth, resulting in congenital deafness.

Swellings in the mesenchyme of the 1st and 2nd pharyngeal arches surround the 1st pharyngeal cleft (6th week) and later fuse to form the definitive auricle. Abnormalities in this complicated process are not uncommon.

**Congenital Abnormalities**

Due to the complex interrelationships of the development of the pharyngeal pouch and clefts, it is easily understood why disorders of movement and fusion of these various tissues are linked (eg, congenital deformities of the ear, cleft lip, palate) and disordered growth of the mandible (eg, the Treacher Collins syndrome).