Chapter one
Introduction

1.1 Background

Hearing is one of the major senses and like vision is important for distant warning and communication. It can be used to alert, to communicate pleasure and fear. It is a conscious appreciation of vibration perceived as sound In order to do this, the appropriate signal must reach the higher parts of the brain. The function of the ear is to convert physical vibration into an encoded nervous impulse. It can be thought of as a biological microphone. Like a microphone the ear is stimulated by vibration: in the microphone the vibration is transduced into an electrical signal, in the ear into a nervous impulse which in turn is then processed by the central auditory pathways of the brain. The ears are paired organs, one on each side of the head with the sense organ itself, which is technically known as the cochlea, deeply buried within the temporal bones. Part of the ear is concerned with conducting sound to the cochlea; the cochlea is concerned with transducing vibration. The transduction is performed by delicate hair cells which, when stimulated, initiate a nervous impulse. (Catherine and Gray1983)

The cochlea is the auditory portion of the inner ear. It is a spiral-shaped cavity in the bony labyrinth, in humans making 2.5 turns around its axis, the modiolus.

A core component of the cochlea is the Organ of Corti, the sensory organ of hearing, which is distributed along the partition separating fluid chambers in the coiled tapered tube of the cochlea . (Catherine and Gray1983)

Embryologically the Cochleas and vestibules are formed at the 5th week of gestation (Phelps and Lloyd 1990)

The membranous Cochleas are developed till it achieves 2.5 turns around the cone-like modiolus which contains the spiral ganglion of the Cochlear nerve by the 7th week (Phelps and Lloyd 1990)

The inner ear structures have an adult pattern by the end of 8 weeks (Jackler et al. 1987).

Congenital inner ear abnormality is a major cause of sensorineural hearing loss (SNHL) (Robson 2006). Failure of Cochlea development late in the third week of gestation results in Cochlear aplasia and the vestibule and semicircular canals are either normal, dilated or hypoplastic (Papsin 2005), in Cochlea hypoplasia the size of the cochlea is smaller than normal (Yiin et al 2011)

Globally hearing loss affects about 10% of the population to some degree. (Oishi 2011) It caused moderate to severe disability in 124 million people as of 2004 (108 million of whom are in low and middle income countries).(WHO 2008). Of these 65 million developed the condition during childhood. (Elzouki 2012) It is one of the most common medical conditions presenting to physicians. It is viewed by some in the deaf community as a condition, not an illness. Treatments such as cochlear implants. (Zadeh 2001)

Cochlear malformation is a major cause of hearing loss worldwide,the majority of hearing loss is sensorineural, particularly in the elderly, and sensorineural hearing loss (SNHL) is primarily result of damage to the cochlea of the inner ear.

Imaging of the Cochlea is difficult because of its small size and spiral character (Phelps and Lloyd 1990)

Recent improvements in imaging techniques provide increased inner ear anatomical details, there are numerous imaging techniques available for examination of the cochlea and it is essential that the most appropriate technique is applied according to any given situation. The main techniques for examining the cochlea are plain skull radiography, CT scanning, MRI . Recent improvements in imaging techniques provide increased anatomical detail, especially in small structures such as the inner ear. (Phelps and Lloyd 1990)

High-resolution Computerized Tomography (HRCT) and Magnetic Resonance Imaging (MRI) are achieved in order to investigate the aetiology of (SNHL) and also to assess patients prior to cochlear implantation. Information provided by both examinations is complementary. Axial CT scan give the best demonstration of the individual coils of the Cochlea (Phelps PD et al, 1990) and CT allows a precise identification of congenital malformations, temporal bone fractures and cochlear ossification. It can also be used to analyze the bony canal for the cochlear nerve and the Cochlea; although only (MRI) visualizes the cochlear nerve itself (Westerhof JP et al ,2001). MR can confirm the presence of fluid or fibrous tissues within the Cochlea (Harnsberger HR et al 1987). High resolution computed tomography can afford excellence cochlear images which help in the practice of otology.

Adrian F. Fernando.et. al, describe the cochlear anatomy among Filipinos through high resolution computed tomography (HRCT) imaging, by design retrospective study setted at Tertiary Private University Hospital, Patients Cochlear images retrospectively obtained from computed tomography (CT) scans of subjects who underwent cranial, facial, paranasal sinus and temporal bone computed tomography from October 2009 to July 2010, other authors sought to establish normative measurements of the inner ear using computed tomography (CT) of the temporal bone to aid in the diagnosis of inner ear malformations as prospective measurements of the inner ear structures were made on axial and coronal temporal bone CT scans on 15 patients with normal hearing and 15 patients with sensorineural hearing loss.

Natacha et al established CT measurements of the normal cochlea in children and determine radiological criteria correlated with SNHL. The study was a retrospective study of temporal bone CT performed in 159 children, age range from 3 days to 16 years between February 1999 and July 2004. A control group (n=88) comprised children without SNHL; the SNHL group comprised 71 children. The width of the second turn of the cochlea (CW), the cochlear height (CH), and the width of the bony canal for the cochlear nerve (WCN) were measured on a reference plane containing the modiolus, the posterior semicircular canal, the footplate, and the stapes arch. (Natacha et al 2009)

Hearing impairment affects a large part of the population. In cases of profound and bilateral hearing loss, patient may have problems in speech development, as well as communication and socialization. Cochlear implants have been used as a treatment option in these cases.(Jackler RK,1986)

Cochlear implants were introduced commercially in 1972; these devices stimulate the auditory nerve directly when placed in the cochlea (tympanic ramp). As these devices are currently being use more often for the treatment of patients with hearing loss, knowledge about the anatomy of the spiral canal of cochlea - into which the electrode is placed - has become paramount. (House 1976)

At present, clinicians cannot evaluate intra-cochlear anatomy, because of small size and inaccessible location, intra-cochlear structures are difficult to image. The scala media of the cochlea, which contains the Organ of Corti, is approximately 250 microns in greatest dimension Furthermore, the cochlea is located deep in skull, and except for the round and oval windows, is surrounded almost entirely by the dense bone of the otic capsule, image exams are employed routinely for a diagnostic preoperative assessment of candidates for cochlear implants; the aim is to define the anatomical status of the cochlea. Computed tomography (CT) and magnetic resonance imaging (MRI) are currently used for this evaluation.(Himi et al 1996)

Cochlear implant introduce in Sudan in 2009; at. In Sudan there was only one center performing cochlear implantation grows, Aldoha hospital had succeeded in conducting successful cochlear implants operations.

More than 4862, 14.5% of Sudanese were had hearing loss in 1993 (WHO 1998). Cochlear implantation has become an accepted treatment for severe to profound deafness in patients who derive only minimal benefit from conventional amplification, from this point we start to define some of Sudanese cochlear charactestic by this study.

To the best of our knowledge; no local studies have been reported for Sudanese Cochlea measurements. Because extra information and knowledge of cochlear dimensions among Sudanese is important, especially in cochlear implantation and also the effects of age, gender and race have to be understood for the assessment of a measured cochlea as to whether it is normal or pathological, this study aimed to characterize the cochlear anatomy among Sudanese through high resolution computed tomography scan in order to establish reference values of the normative measurements regarding the gender and age.

1.2 Problems of the study:

Cochlea implant introduce in Sudan resent and there are not reliable and accurate examination in detecting of cochlea alone, , in Sudan there is shortness of cochlea radiologic studies facilities, lack of public awareness and there is no care about patients with hearing loss, Cochlear implantation has become an accepted treatment for severe to profound deafness ,from this point we need to define some of Sudanese cochlear charactestic by this study.

1.3 Objectives of the study

1.3.1: General objective

This Study was to determine the normal measurements of cochlea in Sudanese people, compared with international reference levels if found by using HRCT to aid in define pathological changes in patient cochlear comparing with deafness patients cochlea measurements to aid in diagnosis of sensorial hearing loss.

1.3.2 Specific objectives

1. Determine normal cochlea measurements of (CW Cochlea width, CH Cochlea height, BTW Basal turn width, CNCW Cochlea nerve canal width, CT Number of the CN in Sudanese using High Resolution Computed Tomography.
2. Explain different in these measurements between male and female
3. Compare between Right and Left cochlear measurements
4. Determined the relationship of age with cochlear measurements
5. Explain different in measurements related to Transverse cranial width
6. Determine the normal value of the CT number for cochlear nerve for normal hearing population.
7. Determine SNHL cochlea measurements of (CW ,CH, BTW,CNCW, CT Number of the CN in Sudanese subjects using HRCT
8. Compare normal population measurements with congenital SNHL(Sensoral Hearing loss) patient cochlea's measurements to aid in diagnosis of SNHL.

1.4 Thesis over view

1.5 Thesis outline:

To make the aims of the project stated above true, the thesis falls into five chapters: Chapter one, which is an introduction, deals with theoretical frame work of the study. It presents the statement of the of the study problems, objectives of the study, and thesis outcome chapter two, deals with theoretical background of inner ear (anatomy, physiology and pathology) , review of the instrumentations and techniques which include cochlea assessment by clinical examination, HRCT imaging and audiometric investigations, and literature review (previous studies). While chapter three discusses the material and method and chapter four include presentation of the results and finally Chapter five deals with the discussion, recommendations, conclusions of the study performed as well as future work.

Chapter Two

Literature Review

2.1 Embryology and Development of the Ear

During week 4 of embryonic development, the human inner ear develops from the auditory placode, a thickening of the ectoderm that gives rise to the bipolar neurons of the cochlear and vestibular ganglions. As the auditory placode invaginates towards the embryonic mesoderm, it forms the auditory vesicle or otocysts.

The auditory vesicle gives rise to the utricular and saccular components of the membranous labyrinth. They contain the sensory hair cells and otoliths of the macula of utricle and of the saccule, respectively, which respond to linear acceleration and the force of gravity. The utricular division of the auditory vesicle also responds to angular acceleration, as well as the endolymphatic sac and duct that connect the saccule and utric beginning in the fifth week of development, the auditory vesicle also gives rise to the cochlear duct, which contains the spiral organ of Corti and the endolymph that accumulates in the membranous labyrinth.

The vestibular wall separates the cochlear duct from the perilymphatic scala vestibuli, a cavity inside the cochlea. The basilar membrane separates the cochlear duct from the scala tympani, a cavity within the cochlear labyrinth. The lateral wall of the cochlear duct is formed by the spiral ligament and the stria vascularis, which produces the endolymph. The hair cells develop from the lateral and medial ridges of the cochlear duct, which together with the tectorial membrane make up the spiral organ of Corti.(PATTS 2000)

2.2 Ear Anatomy

The ears are paired sensory organs comprising the auditory system, involved in the detection of sound, and the vestibular system, involved with maintaining body balance. The ear divides anatomically and functionally into three regions: the external ear, the middle ear, and the inner ear. All three regions are involved in hearing. .(PATTS 2000)

The external ear (or pinna, the part you can see) serves to protect the tympanic membrane (eardrum), as well to collect and direct sound waves through the ear canal to the eardrum. About 1¼ inch long, the canal contains modified sweat glands that secrete cerumen, or earwax. Too much cerumen can block sound transmission. .(PATTS 2000)

The middle ear, separated from the external ear by the eardrum, is an air filled cavity (tympanic cavity) carved out of the temporal bone, it connects to the throat/nasopharynx via the Eustachian tube, this ear-throat connection makes the ear susceptible to infection (otitis media), the Eustachian tube functions to equalize air pressure on both sides of the eardrum. .(PATTS 2000)

Normally the walls of the tube are collapsed, swallowing and chewing actions open the tube to allow air in or out, as needed for equalization. Equalizing air pressure ensures that the eardrum vibrates maximally when struck by sound waves.(Figure 2.1) (PATTS 2000)

Adjoining the eardrum are three linked, movable bones called "ossicles," which convert the sound waves striking the eardrum into mechanical vibrations. The smallest bones in the human body, the ossicles are named for their shape. The hammer (malleus) joins the inside of the eardrum. The anvil (incus), the middle bone, connects to the hammer and to the stirrup (stapes). The base of the stirrup, the footplate, fills the oval window which leads to the inner ear, The inner ear consists of a maze of fluid-filled tubes, running through the temporal bone of the skull. The bony tubes, the bony labyrinth, are filled with a fluid called perilymph, within this bony labyrinth is a second series of delicate cellular tubes, called the membranous labyrinth, filled with the fluid called endolymph. This membranous labyrinth contains the actual hearing cells, the hair cells of the organ of Corti.(PATTS 2000)

There are three major sections of the bony labyrinth: The front portion is the snail-shaped cochlea, which functions in hearing and the rear part, the semicircular canals, helps maintain balance, Interconnecting the cochlea and the semicircular canals is the vestibule, containing the sense organs responsible for balance, the utricle and saccule.(PATTS 2000)

The inner ear has two membrane-covered outlets into the air-filled middle ear-the oval window and the round window. The oval window sits immediately behind the stapes, the third middle ear bone, and begins vibrating when "struck" by the stapes, this sets the fluid of the inner ear sloshing back and forth. (PATTS 2000)

The round window serves as a pressure valve, bulging outward as fluid pressure rises in the inner ear. Nerve impulses generated in the inner ear travel along the vestibulocochlear nerve (cranial nerve VIII), which leads to the brain. This is actually two nerves, the cochlear nerve for hearing and the vestibular nerve for equilibrium (PATTS 2000).

The temporal bone houses the structure of the ear. The temporal bone consists of an outer bony structure that is part of the skull and part of the skull base. It meets with several other bones that are part of the skull and the skull base. (PATTS 2000)

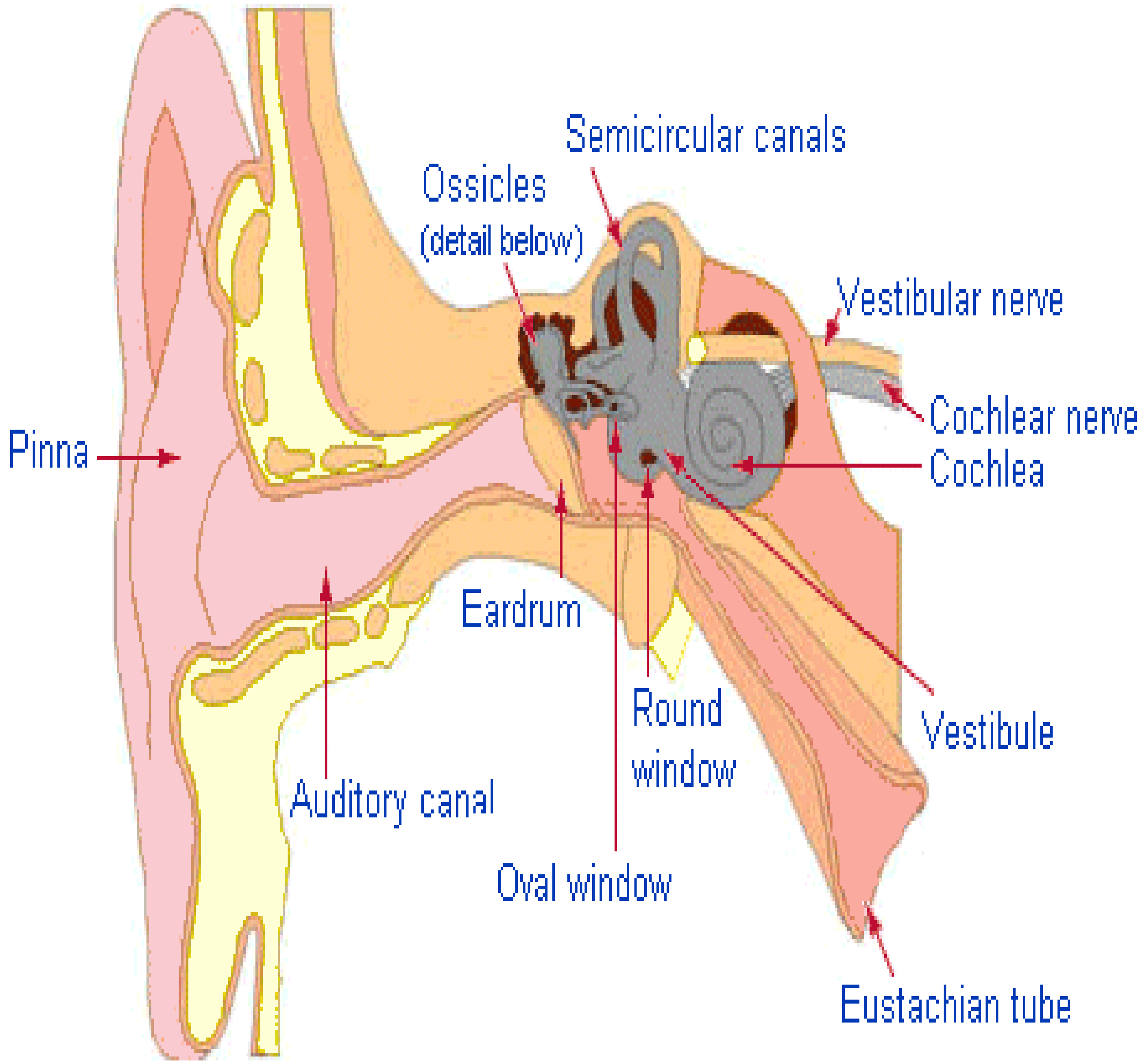


Figure 2.1. Diagrammatic representation of a cross-section through the ear (PATT 2000).

2.2.1 The outer ear

The outer ear known as the external ear and consists of the ear that is visible on the side of the head (the pinna), the external auditory meatus (ear hole) and the ear canal (external auditory canal) that leads to the ear drum (tympanic membrane).The tympanic membrane has three layers and the out layer is usually included as part of the outer ear. John (2006)

2.2.1.1 The pinna

The pinna this is, for the most part, a piece of cartilage covered by skin. There is also a fatty ear lobe in most people. The skin covering the cartilage is very thin with little subcutaneous structure. The pinna's shape enables it to funnel sound waves into the external auditory meatus (Figure 2.2). The various folds in the pinna's structure amplify some high frequency components of the sound. They also help in the localization of sound in the vertical plane, As sounds hit the pinna from above and below, their paths to the external auditory meatus vary in length. This means that they take different times to reach the meatus. The difference in time of arrival of the low-frequency and high frequency components of the sounds allows for sounds localization. John (2006)

The pinna is also involved in localization of sound from in front and behind. As sound waves pass the pinna from behind they are diffracted around the pinna to the meatus whereas sounds from in front do not do this. The slight distortion produced allows for localization. (PATT.2000)

Localization of sound in the lateral plane, i.e. left/right, is a function of the pinna as being on different sides of the head. A sound directly from the left reaches the left ear before the right. The sound is also quieter at the right ear because the head is between the sound and the ear is the head shadow effect. These two factors combine to allow localization in this plane (PATTS.2000)

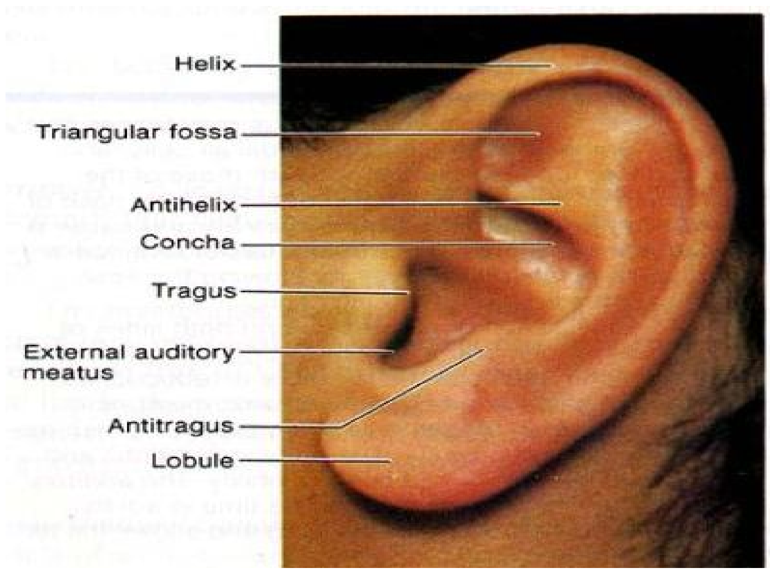


Figure2.2 The pinna (auricle) and the external auditory meatus of an adult male (John.2006)

2.2.1.2 The External Auditory Canal

Because the middle ear structures are delicate the ear has evolved a mechanism to protect it. This is a tube leading from the external auditory meatus to the tympanic membrane. The middle ear is inside the temporal bone of the skull. This part of the bone is called the petrous temporal bone because of its Stone-like density. (PATT.2000)

The external auditory canal is approximately 25 mm long and is tortuous in its path from the meatus to the ear drum. The canal has bends in both the vertical and horizontal planes. This means that it is difficult for anything poked into the meatus to hit the drum. Any trauma is likely to be to the walls of the canal The canal is lined by skin throughout its length it is the only skin-lined.. The outer one-third is a cartilaginous tube and the skin here has ceruminous glands that secrete wax (cerumen), sweat glands and hairs. The skin of the inner two-thirds is closely adherent to the underlying bone and there is again very little subcutaneous structure, skin is a living, growing tissue that is constantly renewed. on the rest of the body, skin grows vertically to the surface, and as it does so the skin cells flatten and die. Dead cells are constantly shed. These dead skin cells form the basis of house dust and sustain the house dust mites, which trigger allergies in some people. The skin of the external canal starts growing from a point near the center of the ear drum. As the skin cells are replaced by new ones they migrate out along the ear drum to the canal wall and then along the canal to the meatus. The wax and hairs have some protective properties by trapping air-borne particles before they get too deep into the canal. The wax also has some mild antibacterial properties and helps with moisture regulation in the canal: fresh wax is moisture giving and old wax absorbs water. As the skin cells migrate along the canal walls they carry the wax, and anything trapped therein, out of the ear. The outer ear is thus a self-cleaning system. The external ear canal has one other function. As a cylinder closed at one end it has a resonant frequency whose wavelength is four times the length of the canal or approximately 100 mm.This equates to a sound of approximately 3 kHz and the canal does contribute some amplification of sounds around this frequency. (PATT.2000)

2.2.2 The Middle Ear

This is an air-filled space within the petrous part of the temporal bone (Figure2.3).The prime function of the middle ear is to transmit the vibrations of sound in air gathered at the tympanic membrane to the fluid of the inner ear at the oval window. It is easier to vibrate air than it is to vibrate fluid. There is greater impedance to vibration in fluid. It is difficult to transmit sound between areas of differing impedance, there is usually an echo. The middle ear functions as an impedance matching device to prevent such echoes. If it were not for the middle ear so much sound would be reflected at the air/fluid interface that there would be a hearing loss of 50–60dB.The tympanic membrane is the outer (or lateral) border of the middle ear and the air-filled space contains three small bones (Ossicles) and the facial nerve and its chorda tympani branch. There are also two muscles and the openings of both the Eustachian tube and the mastoid air cells. PATT (2000)

The temporal lobe of the brain, surrounded by its meningeal lining, lies immediately above the roof (superior) of the middle ear and the jugular vein and internal carotid artery are below the floor (inferior).The mastoid air cells in the mastoid part of the temporal bone lie behind (posterior) and the inner ear is the inner (medial) wall. (Jone.2006)

The middle ear space is lined with respiratory mucous epithelium. most of the middle ear lies above the level of the external auditory canal and cannot be seen on otoscopy. This is the epitympanic or attic region. Jone.(2006)

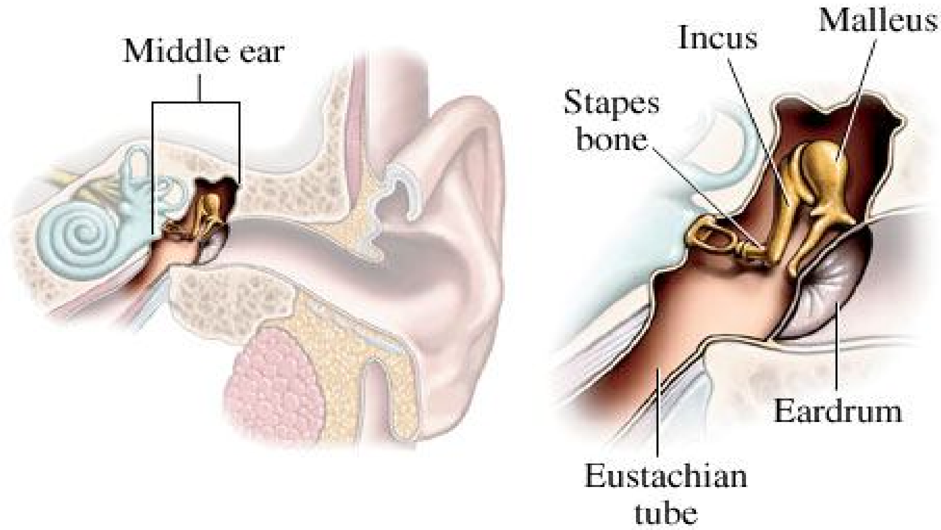


Figure 2.3. Diagram of the middle ear showing the ossicles, muscles and Eustachian tube. (Jone.2006)

2.2.2.1 The Tympanic Membrane

This is a three-layered structure, the outer layer is skin, the middle layer is supporting connective tissue and the inner layer is respiratory epithelium. It is anchored into the external auditory canal by a thickened rim , the annulus fits into a groove in the bony wall of the ear canal. (Jone.2006)

A part of the first of the ossicles, the long process of the malleus, is embedded in the lower part of the tympanic membrane. This ends at a point known as the umbo. This is the point of origin of the skin that lines the external canal. The anterior (front) and posterior (back) malleolar folds divide the tympanic membrane into two distinct parts: the upper pars flaccida and the lower pars tensa. It is the pars tensa that is involved in the transmission of sound. The vibrations are passed on to the ossicular chain via the malleus. (Jone.2006)

2.2.2.2 The Ossicles

These are the three smallest bones in the body (Figure 2.4). Their function is to transmit vibration into the inner ear at the oval window of the cochlea.The long process of the malleus (hammer) is attached to the tympanic membrane and the footplate of the stapes (stirrup) sits in the oval window. Between these two bones is the incus (anvil). The bulk of the ossicular chain lies in the attic of the middle ear. . Jone.(2006)

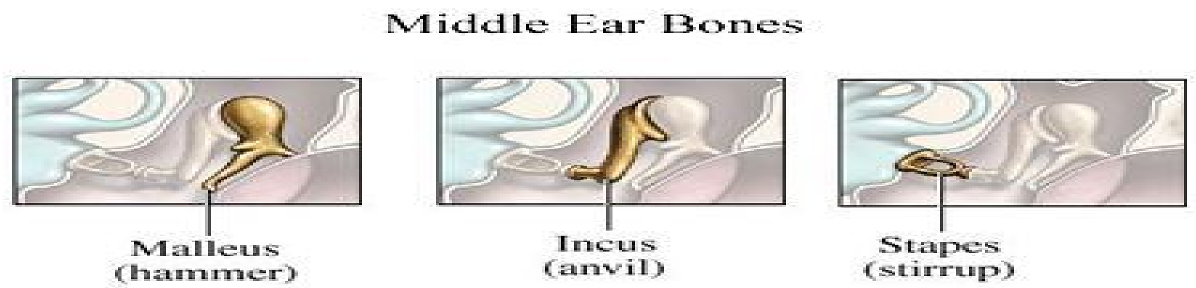


Figure 2.4 The three ossicles of the middle ear. (**Jone.2006)**

2.2.2.3The Eustachian Tube

The middle ear is an air-filled space; the air is constantly being absorbed by the mucosal lining and there must therefore be a mechanism whereby this air is replaced: this is the Eustachian tube. This runs from the middle ear to the naso-pharynx behind the nose. It is in two parts and is lined with ciliated respiratory epithelium. The cilia beat and move mucus towards the nasopharynx and away from the middle ear. the first part is a bony tube continuous with the middle ear cavity, this tube is approximately 10 mm long and runs between the carotid artery and the mandible of the jaw.The bony canal of the tensor tympani muscle runs immediately above the Eustachian tube at this point. The bony portion is oval in cross-section and is narrowest where it meets the cartilaginous part. . (Jone.2006)

The inner part of the tube is approximately 25 mm long and is angled down at about 45 degrees towards the naso-pharynx in adults. In children this portion of the tube is more horizontal, at a 10 degree angle. This portion of the tube is closed at rest and opens during swallowing , this is an active process due to contractions of the tensor veli Palatini muscle, there may be minor roles in Eustachian tube opening for the tensor tympani and the levator veli Palatini muscles. (Jone 2006)

The classic role of the Eustachian tube is to allow air from the naso-pharynx to enter the middle ear to replace air absorbed. The middle ear needs to be filled with air at, or near, ambient atmospheric pressure to allow the tympanic membrane to vibrate efficiently in response to sound. The Eustachian tube also has a protective role in preventing passage from the naso-pharynx to the middle ear and allowing drainage of mucus and fluids from the middle ear.(Jone 2006)

2.2.2.4 The Mastoid Air Cells

These lie behind the middle ear in the mastoid part of the temporal bone. They act as a reservoir of air for the middle ear. The mastoid bone develops these air cells between the ages of one and six years. The mastoid air cells are contiguous with each other and have the same epithelial lining as the rest of the middle ear. (Jone.2006)

2.2.2.5 The Middle Ear Muscles

There are two muscles in the middle ear: the tensor tympani and the stapedius muscle. The tensor tympani run in a canal along the roof of the Eustachian tube and its tendon emerges into the middle ear at the cochleari form process. The tendon attaches to the handle of the malleus.The muscle is supplied by a branch of the mandibular branch of the trigeminal (fifth cranial) nerve. Contraction of the muscle is a reflex triggered by loud sounds or a puff of air on the eyeball. Contraction pulls the tympanic membrane inwards and restricts its freedom of movement,this serves to protect the ear from loud noise or trauma. (Jone.2006)

The stapedius is the smallest muscle in the body. It arises from the pyramidal eminence on the posterior wall of the middle ear, inserts into the neck of the stapes bone and is supplied by a branch of the facial (seventh cranial) nerve. Contractions are reflex, initiated by loud sounds, and when it contracts it pulls the stapes posteriorly, so tilting its footplate. This has the effect of damping the ossicular chain vibration and hence limits the potential damage caused by loud noise. (Jone.2006)

2.2.2.6 The Facial Nerve

Facial Nerve travels along the internal auditory canal with the eighth cranial nerve. It then enters the facial canal and travels between the cochlea and the vestibule and runs just above the oval window on the medial wall of the middle ear. It reaches the posterior wall near the aditusad antrum and then turns downwards to leave the middle ear. Within the facial canal it gives off two branches, the nerve to the stapedius, which reaches the muscle in the pyramid, and the chorda tympani. .(Jone.2006)

The chorda tympani runs over the upper part of the inner surface of the tympanic membrane across the root of the handle of the malleus. The nerve supplies parasympathetic and secret motor fibres to the submandibular and sublingual salivary glands and carries fibres from the anterior two-thirds of the tongue and floor of the mouth concerned with taste.(Jone.2006)

2.2.2.7 Impedance Matching

The main function of the middle ear is to overcome the impedance mismatch between the air in the outer ear and the fluid of the inner ear. The largest contribution to this is the difference in surface area between the tympanic membrane and the stapes footplate. This means that vibrations are collected from a large area and transmitted to a much smaller area, increasing the force/mm2. There is also a small lever effect due to the way the ossicles vibrate (Jone.2006).

2.2.3 The inner ear

The inner ear is an intricately shaped membranous tube suspended within a bony tube called the labyrinth. The inner ear has two functions. The first is the transduction of sound pressure into neurochemical impulses in the auditory (eighth cranial) nerve. This takes place in the cochlea. The second function is to maintain optic fixation in the presence of movement and to help to maintain upright posture. This occurs in the vestibular system. . (Jone.2006)

the anatomy of the inner ear consists of the bony labyrinth, a system of passages making up the following 2 main functional parts: the cochlea, which is dedicated to hearing, and the vestibular system, which is dedicated to balance. The inner ear is found in all vertebrates, with substantial variations in form and function. The inner ear is innervated by the eighth cranial nerve in all vertebrates.(Adrian et al, 2011).

The superficial contours of the inner ear are established by a layer of dense bone known as the bony labyrinth, which refers to the network of canals. The walls of the bony labyrinth are continuous with the surrounding temporal bone. The inner contours of the bony labyrinth closely follow the contours of the membranous labyrinth, a delicate, interconnected network of fluid-filled tubes in which the receptors are found. .(Adrian et al, 2011).

The walls of the bony labyrinth consist of dense bone everywhere except at 2 small areas near the base of the cochlear spiral. The round window consists of a thin, membranous partition that separates the perilymph of the cochlear chambers from the air-filled middle ear. Collagen fibers connect the boney margins of the opening known as the oval window at the base of the stapes. (Catherine,1983).

A liquid called perilymph, the properties of which closely resemble those of cerebrospinal fluid, flows between the bony and membranous labyrinths. Another fluid, called endolymph, is contained in the membranous labyrinth. The endolymph has concentrations of electrolytes that differ from those of typical body fluids. (Catherine,1983)

The bony labyrinth can be subdivided into the vestibule, 3 semicircular canals, and the cochlea. The vestibule contains a pair of membranous sacs: the saccule (sacculus) and the utricle (utriculus). Receptors in the vestibule provide for sensations of gravity and linear acceleration. (Catherine,1983)

The semicircular canals enclose the slender semicircular ducts. Receptors located here are stimulated by rotation of the head. Together with the vestibule, this is called the vestibular complex. The fluid filled chambers within the vestibule are generally continuous with those of the semicircular canals. (Catherine,1983)

The cochlea is a bony, spiral-shaped chamber that contains the cochlear duct of the membranous labyrinth.The sense of hearing is provided by receptors within the cochlear duct. A pair of perilymph-filled chambers is found on each side of the duct. The entire apparatus makes turns around a central bony hub, much like a snail shell. (Catherine,1983)

2.2.3.1 The Cochlea

The cochlea is the auditory portion of the inner ear. It is a spiral-shaped cavity in the bony labyrinth, in humans making 2.5 turns around its axis, the modiolus. (PATT.2000).

A core component of the cochlea is the organ of corti, the sensory organ of hearing, which is distributed along the partition separating fluid chambers in the coiled tapered tube of the cochlea, cochlea comprises 23–24 turns of a spiral, the base of the spiral protrudes into the middle ear as the promontory of the medial wall. The bony wall of the cochlea has two defects, each covered by a thin membrane. These are the round window and the oval window. The latter contains the footplate of the stapes, which is held in place by the annular ligament. (Jone.2006)

Across-section of one turn of the cochlea (Figure 2.5.1) shows that the cochlea is divided into three segments. From above down these are the scala vestibuli, the scala media and the scala tympani. Each scala is fluid-filled. The scala media contains endolymph and the other two contain perilymph.

There is communication between the perilymph of the scala vestibuli and the scalatympani at the apex of the cochlea at a point known as the helicotrema (Figure 2.5.2).(Taylor e, 2005)

The scala media is a closed, triangular cavity bounded above by Reissner's membrane and below by the basilar membrane. The stria vascularis forms the base of the triangle lying against the bony wall of the cochlea, The organ of corti sits on the basilar membrane and it is here that the transduction of sound happens. Jone.(2006).

When sound waves from the world outside strike the eardrum, it vibrates. These vibrations from the eardrum pass through the three bones of the middle

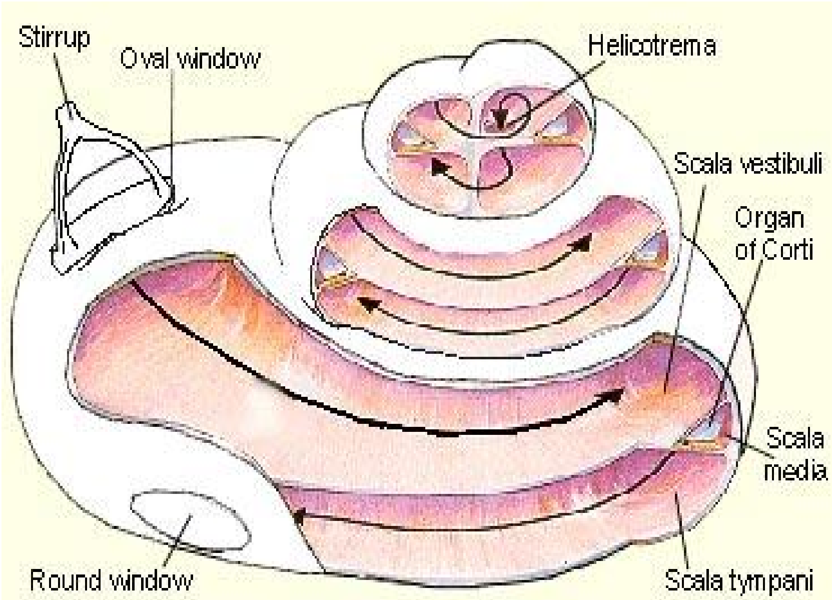


Figure 2.5.1 cross-section of the cochlea showing the organ of Corti and the stria vascularis.(Taylor e, 2005)

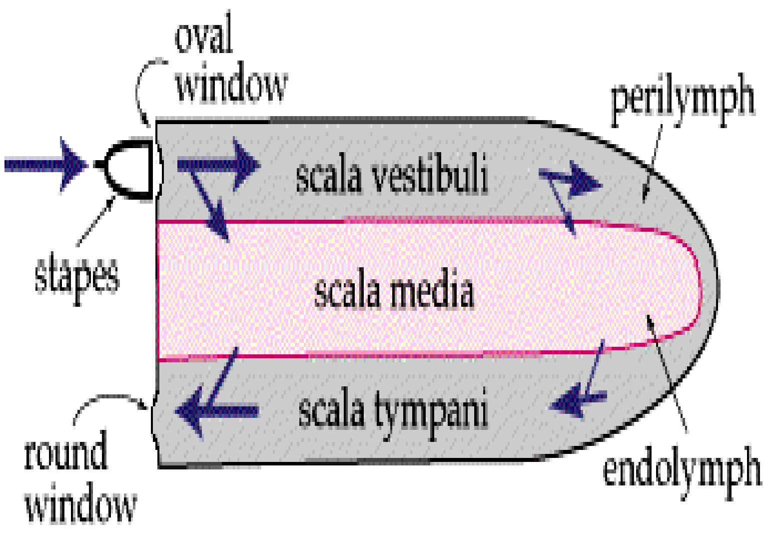


Figure 2.5.2 A diagram illustrating the movements of the fluid in the inner ear as a result of the inward movement of the stapes

ear and into the inner ear through the oval window. Action of the oval window causes fluids in the cochlea to create waves where they disturb the basilar membrane. Inner hairs attached to the basilar membrane convert the waves into electrical impulses that are transmitted to the brain by the auditory nerve. The hair cells are critical to hearing; it is the inner hairs that move in the Organ of Corti fluids, translate the fluid movements to chemical messengers that can in turn be converted to electrical impulses that the brain understands (Jone. 2006)

2.2.3.1.1 The Organ of Corti

The basilar membrane runs between the inner and outer bony spiral laminae. It is narrower and more taut at the base of the cochlea and wider and floppier at its apical end. At its inner end sits the organ of Corti. This comprises the limbus, the tectorial membrane, the inner and outer rods (or pillars) of Corti with the tunnel of Corti between them, one row of inner hair cells, three rows of outer hair cells and supporting cells of Claudius, Deiter and Hensen. There are approximately 12 000 outer hair cells and 3500 inner hair cells in humans. Jone (2006)

The auditory branch of the eighth cranial nerve (the cochlear-vestibular nerve) contains fibres that run from the cochlea to the brain stem – afferent fibres – and efferent fibres that run in the opposite direction. Around 90% of the afferent fibres come from the inner hair cells. Each fibre comes from only one cell but each cell may have up to 10 fibers. The remaining 10% of the afferent fibres and all of the efferent ones are associated with the outer hair cells. Each of the nerves associated with the outer hair cells is connected with many cells. Each hair cell has many hairs (cilia). The cilia of each outer hair cell are arranged in a ‘W’ shape (with a very shallow central notch) and those of the inner hair cells in a gentle curve. The hairs of the outer hair cells are embeddedinto the tectorial membrane whereas at rest the hairs of the inner hair cells are not. The cilia of each hair cell are connected by tip links. The outer hair cells contain contractile actin and myosin fibres which allow for the cells to alter their length. Jone.(2006)

2.2.3.1.2 The Cochlear Fluids

Perilymph is a fluid that is similar in character to extracellular fluid. Endolymph is chemically and electrically different. It has a high concentration of potassium and low concentrations of sodium and calcium similar to cerebrospinal fluid (CSF). The resting potential of endolymph is approximately +80mV.The inner and outer hair cells have resting potentials of approximately −45 and −70 mV respectively. There is therefore a resting potential difference across between the endolymph and the hair cell of between 125 and 150mV. The scala media has an endolymph-containing duct that joins with a similar duct from the vestibular system to form the endolymphatic duct. This ends in the endolymphatic sac, which lies close to the meningeal lining of the brain. There are two possible sources of endolymph. One theory is that the endolymph is produced directly from CSF at the endolymphatic sac and is actively reabsorbed by the stria vascularis. The other main theory is that the cochlear fluids are produced by effusion from the outer walls of the perilymphatic spaces.The perilymph passes across the semi-permeable Reissner membrane and is again actively reabsorbed by the stria vascularis. Small molecular weight markers introduced into the perilymph do pass into the endolymph and on into the stria vascularis. Figure 2.6 (Hallowell 1970).

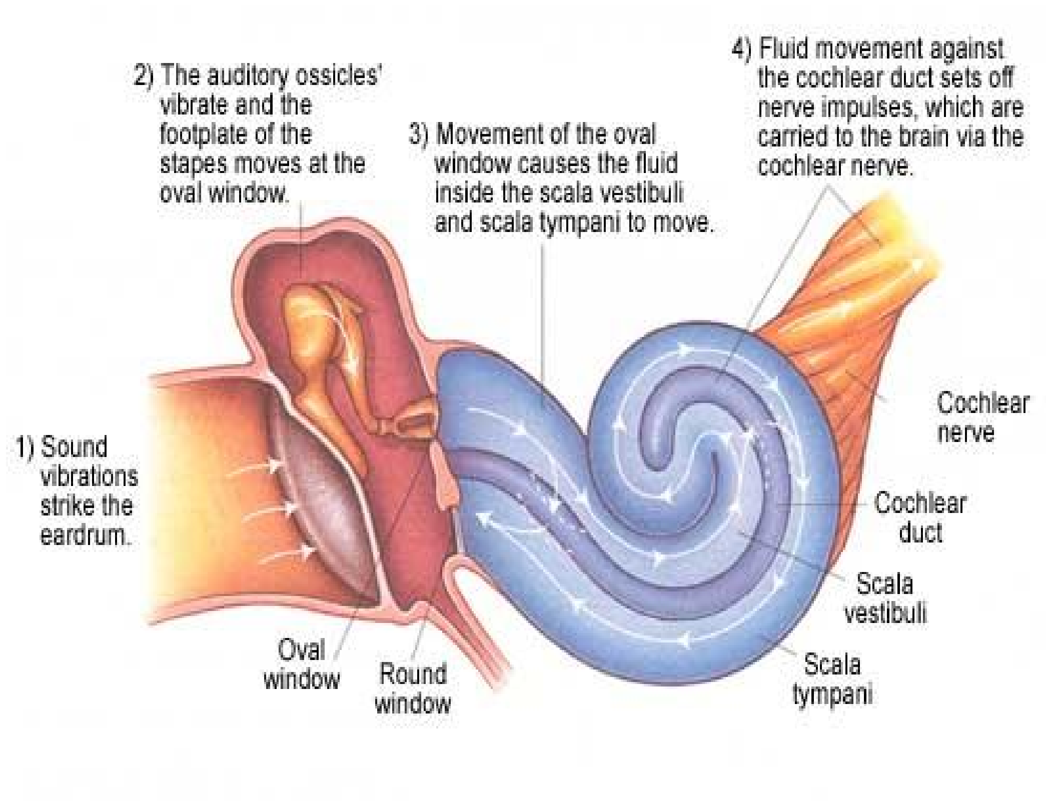


Figure 2.6 The cochlear fluids movements(Hallowell 1970).

2.2.3.1.3 The Stria Vascularis.

This is a metabolically very active structure with a rich blood supply. It is responsible for the maintenance of the chemical and electrical composition of the endolymphatic space. It is a convoluted structure with many folds and indentations to increase the surface area. There are three types of cells arranged in three layers. The inner basal are cells in one continuous layer. (Hallowell 1970).

These cells may be of neural crest or possibly mesodermal in origin.The outer layer lines the lumen of the cochlear duct and consists of epithelial cells. Between these two layers are intermediate cells, these are a type of migratory melanocyte. It is likely that these cells are responsible for the endocochlear potential and high potassium content of endolymph that are necessary for transduction of sound. The intermediate and basal cells are joined by gap junctions. Gap junction proteins such as Connexin probably also have a role in maintaining the high potassium concentration within the endolymph. (Hallowell 1970).

2.2.3.2 The Semicircular Canal

There are three semicircular canals on each side of the head. They are arranged in three planes at right angles to each other. They are the anterior (or superior) canal, the posterior (or inferior) canal and the lateral (or horizontal) canal. Each end of the canals opens into the utricle but there are only five openings as the anterior and posterior canals unite. The opposite end of these two canals is swollen into the ampulla and the lateral canal has an ampulla close to that of the anterior canal. (Hallowell 1970).

The endolymph of the vestibular system is continuous with that of the cochlea and is surrounded by perilymph. The endolymphatic space within the ampullae contains the sensory organ – the crista ampullaris. This is a crest of hair cells.The cilia are of different lengths and are arranged in order of height to the kinocilium. The hairs are embedded in a gelatinous structure the cupola. There are about 23 000 hair cells divided between the three cristae on each side of the head and there are both afferent and efferent nerve fibers to each hair cell. (Hallowell 1970).

Any change in rotation speed of the head results in motion in the endolymph. This causes the cupola to move and brings about a shearing movement of the cilia. There is the same depolarisation process as within the cochlea, resulting in action potentials in the vestibular branch of the eighth nerve. As with other sensory systems in the body there is a resting firing rate of neurons within the vestibular nerve. Deflection of the vestibular hair cells towards the kinocilium results in an increase in this firing rate and deflection away from the kinocilium reduces the rate. Because of the orientation of the semicircular canals rotation will produce an increase in firing rate in the vestibular nerve on one side of the head and a reduction on the other side. The prime function of this system is to allow the individual to maintain optic fixation in the presence of movement. This is through the vestibulo-ocular reflex at the brainstem level. Thus as the head moves in one direction the eyes are moved in the opposite direction so they can remain focused on the same point. The semicircular canals also form one of the inputs into the body's mechanism for the maintenance of upright posture in the face of movement via the vestibulo-spinal reflex. (Hallowell 1970).

2.2.3.3 The Utricle and Saccule

The utricle and saccule both contain endolymph. Within each structure is a gravitational sense organ – the macula.There are hair cells in each macula and the cilia project into the otolithic membrane.This is a gelatinous structure containing small crystals of calcium carbonate – the otoliths. Any linear motion displaces this membrane in the opposite direction.This again produces deflection of the cilia and depolarisation of the hair cells. The macula of the utricle is situated on the floor, while in the saccule itextends on to the medial wall.The macula of the utricle is thought to respond to lateral, side-to-side motion whereas that of the saccule responds to movement in the vertical plane.The hair cells within these structures are orientated with reference to a central plane – the striola. In the utricle the cilia are arranged so that the kinocillium is towards the striola whereas in the saccule the kinocilia are arranged away from the striola. (Hallowell 1970).There is again both an afferent and an efferent nerve supply to the hair cells of the maculae. (Hallowell 1970).

2.2.4 The Eight Cranial Nerve (Cochlear –vestibular nerve)

The eighth cranial nerve is, in effect, three distinct nerves. There are two vestibular nerves (superior and inferior) and the cochlear nerve. They run together through the skull in the internal auditory canal. This canal also contains the seventh cranial nerve (the facial nerve) and the blood supply to the inner ear – the internal auditory artery.The nerves pass through the meninges to the brainstem. The vestibular nerves go to the vestibular nuclei and the cochlear nerve to the cochlear nuclei. (Hallowell 1970).

2.2.5 The Central Auditory Connection

The afferent fibres travelling from the cochlear hair cells have their first synapse in the spiral ganglion within the cochlea.Thus the cochlear nerve consists of second-order neurones. The cochlear nerve runs via the internal auditory meatus, through the skull and meninges to the cochlear nuclei in the brainstem. This is at the level of the medulla oblongata. There is another synapse at this level. (Hallowell 1970).

The auditory pathway then crosses to the superior olivary nucleus on the other side of the medulla and then up towards the auditory cortex via a bundle of fibres called the lateral lemniscus. Some fibres in the lateral lemniscus cross back to the original side of the cochlear nerve. The lateral lemniscus runs to the inferior colliculus in the mid brain and then the pathway goes to the medial geniculate body of the thalamus. The auditory cortex is located in the temporal lobes of the brain in an area called the superior temporal gyrus. This is just behind and below the lateral sulcus. (Hallowell 1970).

The frequency-specific anatomy of the cochlea is mirrored in the central auditory pathway. Neurones carrying high-frequency information travel towards the outside of the cochlear nerves and specific parts of each part of the pathway up to and including the cortex have different places for different frequencies. At the level of the primary auditory cortex high frequencies are coded posterior to the low frequencies. (Hallowell 1970).

2.3 The Pathophysiology of the Ear

2.3.1. Sound Conducting Mechanisms

2.3.1.1 The Outer Ear

The outer ear transmits sound to the tympanic membrane. The pinna that part which protrudes from the side of the skull made of cartilage covered by skin collects sound and channels it in to the ear canal. The pinna is angled so that it catches sounds that come from in front more than those from behind and so is already helpful in localizing sound. Because of the relative size of the head and the wavelength of audible sound, this effect only applies at higher frequencies. In the middle frequencies the head itself casts a sound shadow and in the lower frequencies phase of arrival of a sound between the ears helps localize a sound. The ear canal is about 4 centimeters long and consists of an outer and inner part. The outer portion is lined with hairy skin containing sweat glands and oily sebaceous glands which together form ear wax. Hairs grow in the outer part of the ear canal and they and the wax serve as a protective barrier and a disinfectant. Very quickly however, the skin of the ear canal becomes thin and simple and is attached firmly to the bone of the deeper ear canal, a hard cavity which absorbs little sound but directs it to the drum head (eardrum or tympanic membrane) at its base. The outer layer of the drumhead itself is formed of skin in continuity with that of the ear canal. (Hallowell 1970).

The ear canal has a slight bend where the outer cartilaginous part joins the bony thin skinned inner portion, so that the outer part runs somewhat backwards and the inner part somewhat forwards. This bend is yet another part of the protective mechanism of the ear, stopping foreign objects from reaching the tympanic membrane. However it means that to inspect the tympanic membrane from the outside, one must pull the ear upwards and backwards. (Hallowell 1970). The tympanic membrane separates the ear canal from the middle ear and is the first part of the sound transducing mechanism. Shaped somewhat like a loudspeaker cone (which is an ideal shape for transmitting sound between solids and air), it is a simple membrane covered by a very thin layer of skin on the outside, a thin lining membrane of the respiratory epithelium tract on the inner surface and with a stiffening fibrous middle layer. The whole membrane is less than a 1/10th of millimeter thick. It covers a round opening about 1 centimeter in diameter into the middle ear cavity. Although the tympanic membrane is often called the ear drum, technically the whole middle ear space is the ear drum and the tympanic membrane the drum skin(Hallowell 1970).

2.3.1.2 The Middle Ear

The middle ear is an air filled space connected to the back of the nose by a long, thin tube called the Eustachian tube. The middle ear space houses three little bones, the hammer, anvil and stirrup (malleus, incus and stapes) which conduct sound from the tympanic membrane to the inner ear. The outer wall of the middle ear is the tympanic membrane, the inner wall is the cochlea. The upper limit of the middle ear forms the bone beneath the middle lobe of the brain and the floor of the middle ear covers the beginning of the great vein that drains blood from the head, the jugular bulb. At the front end of the middle ear lies the opening of the Eustachian tube and at its posterior end is a passageway to a group of air cells within the temporal bone known as the mastoid air cells. One can think of the middle ear space shaped rather like a frying pan on its side with a handle pointing downwards and forwards (the Eustachian tube) but with a hole in the back wall leading to a piece of spongy bone with many air cells, the mastoid air cells. The middle ear is an extension of the respiratory air spaces of the nose and the sinuses and is lined with respiratory membrane, thick near the Eustachian tube and thin as it passes into the mastoid. It has the ability to secret mucus. The Eustachian tube is bony as it leaves the ear but as it nears the back end of the nose, in the nasopharynx, consists of cartilage and muscle. Contracture of muscle actively opens the tube and allows the air pressure in the middle ear and the nose to equalize. Sound is conducted from the tympanic membrane to the inner ear by three bones, the malleus, incus and stapes. The malleus is shaped like a club; its handle is embedded in the tympanic membrane, running from its centre upwards. The head of the club lies in a cavity of the middle ear above the tympanic membrane (the attic) where it is suspended by a ligament from the bone that forms the covering of the brain. Here the head articulates with the incus which is cone shaped, with the base of the cone articulating with the head of the malleus, also in the attic. The incus runs backwards from the malleus and has sticking down from it a very little thin projection known as its long process which hangs freely in the middle ear. It has a right angle bend at its tip which is attached to the stapes(stirrup), the third bone shaped with an arch and a foot plate. The foot plate covers the oval window, an opening into the vestibule of the inner ear or cochlea, with which it articulates by the stapedio-vestibular joint. (Hallowell 1970).

2.3.1.3 The Inner Ear

The bony cochlea is so called because it is shaped like a snail shell It has two and a half turns and houses the organ of hearing known as the membranous labyrinth surrounded by fluid called the perilymph. The cochlea has a volume of about 0.2 of a milliliter. In this space lie up to 30,000 hair cells which transduce vibration into nervous impulses and about 19,000 nerve fibers which transmit the signals to and from the brain. It is easiest to think of the membranous labyrinth by imagining the cochlea to be straightened out as a bony tube closed at the apex and open at the base with the round and oval windows and a connection to the vestibular labyrinth It is in continuity with the vestibular labyrinth or organ of balance which in technical terms acts as both a linear and angular accelerometer, thus enabling the brain to know the position of the head in relationship to gravity and its surroundings. The organ of balance will not be dealt with any further. Vibration of the foot plate of the stapes vibrates the perilymph in the bony cochlea. This fluid is essentially incompressible. Therefore, there has to be a counter opening in the labyrinth to allow fluid space to expand when the stapes foot plate moves inwards and in turn to move inwards when the stapes foot plate moves outwards. The counter opening is provided by the round window membrane which lies beneath the oval window in the inner wall of the middle ear. It is covered by a fibrous membrane which moves synchronously but in opposite phase with the foot plate in the oval window. (Hallowell 1970).

The membranous labyrinth is separated into three sections, by a membranous sac of triangular cross section which run the length of the cochlea. The two outer sections are the scala vestibule which is connected to the oval window, and the scala tympani which is connected to the round window. The sections are filled with perilymph; they connect at the apex by a small opening known as the helicotrema which serves as a pressure equalizing mechanism at frequencies well below the audible range. They also connect at the vestibular end with the fluid surrounding the brain, through a small channel known as the perilymphatic aqueduct. The membranous labyrinth, also known as the cochlear duct, is filled with different fluid called endolymph. On one side it is separated from the scala vestibuli by Reissner's membrane, and on the opposite side from the scala tympani by the basilar membrane. The basilar membrane is composed of a great number of taut, radially parallel fibers sealed between gelatinous materials of very weak shear strength. These fibers are resonant at progressively lower frequencies as one progress from the basal to the apical ends of the cochlea. Four rows of hair cells lie on top of the basilar membrane, together with supporting cells. A single inner row is medial, closest to the central core of the cochlea. It has an abundant nerve supply carrying messages to the brain. The three outer rows, which receive mainly an afferent nerve supply, are separated from the inner row by tunnel cells forming a stiff structure of triangular cross section known as the tunnel of Corti. Any natural displacement of the cochlear partition results in a rocking motion of the tunnel of Corti and consequently a lateral displacement of the inner hair cells. The hair cells derive their name from the presence at their free ends of stereocilia which are tiny little stiff hair like structures of the order of a few micrometers long The stereocilia of the hair cells are arranged in rows in a very narrow cleft called the subtectorial space formed by the presence above the hair cells of the radially stiff tectorial membrane. The cilia of the outer hair cells are firmly attached to the tectorial membrane while the cilia of the inner hair cells are either free standing are loosely attached to the tectorial membrane. anatomically, the ear consists of a sound conducting mechanism and a sound transducing mechanism. The sound conducting mechanism has two parts, the outer ear consisting of the pinna and ear canal, and the middle ear consisting of the tympanic membrane. . (Hallowell 1970)

The middle ear air space is connected to the nose by the Eustachian tube and to the mastoid air cells housing the ossicular chain, the malleus, stapes and incus. The inner ear, or cochlea, transduces vibration transmitted to the perilymph via the ossicular chain into a nervous impulse which is then taken to the brain where it is perceived as sound. (Hallowell 1970)

Transduction of vibration in the audible range to a nervous impulse is performed by the inner hair cells; when the basilar membrane is rocked by a travelling wave, the cilia of the inner hair cells are bent in relation to the body of the cell, ion passages are opened or closed in the body of the cell and the afferent nerve ending which is attached to the hair cell base is stimulated. (Hallowell 1970)

The basilar membrane responds resonantly to highest frequencies at the basal end nearest the oval window and to progressively lower frequencies as one progresses toward the apical end. At the apical end the basilar membrane responds resonantly to the lowest frequencies of sound. A disturbance introduced at the oval window is transmitted as a wave which travels along the basilar membrane with the remarkable property that as each frequency component of the travelling wave reaches its place of resonance it stops and travels no further. The cochlea is thus a remarkably efficient frequency analyser. . (Hallowell 1970)

The cochlea has an abundant nerve supply both of fibres taking impulses from the cochlea to the brain (afferent pathways) and fibres bringing impulses from the brain to the cochlea (efferent fibres). When stimulated the inner hair cells trigger afferent nervous impulses to the brain. Like virtually all neural-mechanisms there is an active feedback loop.(Hallowell 1970),The range of audible sound is approximately 10 octaves from somewhere between 16 and 32 Hz (cycles per second) to somewhere between 16,000 and 20,000 Hz. The sensitivity is low at the extremes but becomes much more sensitive above 128 Hz up to about 4,000 Hz when it again becomes rapidly less sensitive. The range of maximum sensitivity and audibility diminishes with age. The head itself acts as a natural barrier between the two ears and thus a sound source at oneside will produce a more intense stimulus of the ear nearest to it and incidentally the sound will also arrive there sooner, thus helping to provide a mechanism for sound localization based on intensity and time of arrival differences of sound. High frequency hearing is more necessary than low frequency hearing for this purpose and this explains why sound localization becomes difficult with a high frequency hearing loss. Pinna crinkled shape catches higher frequency sounds and funnels them into the ear canal. It also blocks some higher frequency sound from behind, helping to identify whether the sound comes from the front or the back. The ear canal acts as a resonating tube and actually amplifies sounds at between 3000 and 4,000 Hz adding to the sensitivity (and susceptibility to damage) of the ear at these frequencies. (Hallowell 1970)

The ear is very sensitive and responds to sounds of very low intensity, to vibrations which are hardly greater than the natural random movement of molecules of air. To do this the air pressure on both sides of the tympanic membrane must be equal. The Eustachian tube provides the means of the pressure equalization. It does this by opening for short periods, with every 3rd or 4th swallow; if it were open all the time one would hear one's own every breath, because the lining membrane of the middle ear is a respiratory membrane, it can absorb some gases, so if the Eustachian tube is closed for too long it absorbs carbon dioxide and oxygen from the air in the middle ear, thus producing a negative pressure. This may produce pain (as experienced if the Eustachian tube is not unblocked during descent of an aeroplane). The middle ear cavity itself is quite small and the mastoid air cells act as an air reservoir cushioning the effects of pressure change. If negative pressure lasts too long, fluid is secreted by the middle ear, producing a conductive hearing loss. (Hallowell 1970).

The outer and middle ears serve to amplify the sound signal. The pinna presents a fairly large surface area and funnels sound to the smaller tympanic membrane; in turn the surface of the tympanic membrane is itself much larger than that of the stapes foot plate, so there is a hydraulic amplification: a small movement over a large area is converted to a larger movement of a smaller area. In addition, the ossicular chain is a system of levers which serve to amplify the sound. The outer and middle ears amplify sound on its passage from the exterior to the inner ear by about 30 dB. (Hallowell 1970).

The function of the inner ear is to transduce vibration into nervous impulses. While doing so, it also produces a frequency (or pitch) and intensity (or loudness) analysis of the sound. Nerve fibres can fire at a rate of just under 200 times per second. Sound level information is conveyed to the brain by the rate of nerve firing, for example, by a group of nerves each firing at a rate at less than 200 pulses per second. They can also fire in locked phase with acoustic signals up to about 5 kHz. At frequencies below 5 kHz, groups of nerve fibres firing in lock phase with an acoustic signal convey information about frequency to the brain. Above about 5 kHz frequency information conveyed to the brain is based upon the place of stimulation on the basilar membrane. As an aside, music translated up into the frequency range above 5 kHz does not sound musical. (Hallowell 1970), Each place along the length of the basilar membrane has its own characteristic frequency, with the highest frequency response at the basal end and lowest frequency response at the apical end. Also any sound introduced at the oval window by motion of the stapes is transmitted along the basilar membrane as a travelling wave until all of its frequency components reach their respective places of resonance where they stop and travel no further. For example, a 1 kHz tone induces resonance at about the middle of the basilar membrane. Any frequency components lower than 1 kHz must travel more than half the length of the basilar membrane, whereas high frequency components, greater than 1 kHz must travel less than half the length of the basilar membrane. Evidently the brain must suppress high frequency information in favour of low frequency information as the travelling wave on the basilar membrane passes through places of high frequency resonant response. (Hallowell 1970).

The range is so great that only the logarithmic response characteristic of variable rate processes and thus favoured by anatomical systems, is capable of encompassing it. The normal range of human hearing is from 0 to 100 dB(A), before sound becomes uncomfortably loud. Mounted on the basilar membrane close to the end nearest the central core of the cochlea are a single row of inner hair cells followed by three rows of outer hair cells which are separated from the single row of inner hair cells by a stiff structure of triangular cross section known as the tunnel of Corti. Any natural displacement of the cochlear partition results in a rocking motion of the tunnel of Corti and consequently a lateral displacement of the inner hair cells. (Hallowell 1970).

The ear has evolved a very intriguing mechanism to cope with the large range in sound intensity encountered in the environment. Only the inner hair cells initiate nervous impulses which are heard as sound. They are not particularly sensitive but they are rugged and they are placed at the inner edge of the basilar membrane which is relatively immobile. The point where the basilar membrane vibrates most is about its middle so that the inner hair cells are spared the most violent vibration of very intense sound. The question then arises role. When they are stimulated by the travelling wave they respond actively and physically contract. They have muscle proteins in their wall and literally shorten because they are attached both to the Reissner's membrane and the basilar membrane, this produces an additional shear movement of the membranous labyrinth, which amplifies the travelling wave at the point of maximal stimulation. This amplified movement is transmitted to the inner hair cells which then respond. If the amount of movement of the basilar membrane is slight, the amount of outer hair cell contracture adds significantly to the basilar cell movement; if the amount of movement is large the contracture adds nothing to the already great displacement of the membranous labyrinth. If the outer hair cells are damaged they no longer contract in response to slight sounds and the inner hair cells are not stimulated. This produces a hearing loss for low intensity sound. If the sound is more intense, the inner hair cells are stimulated directly and they respond normally so that the ability to hear louder sounds remain unimpaired. This is a common phenomenon known as loudness recruitment. The inner hair cells are much "tougher" than outer hair cells and much less likely to be damaged by ageing, noise or most ototoxic drugs, so ageing, noise and ototoxic drugs usually only produce hearing loss but not deafness. It was noted earlier that the ear is most sensitive to sounds between approximately 3000 and 4000 Hz, in part because of the amplifying mechanism of the ear canal. Prolonged exposure to loud sounds damages these hair cells and thus explains the hearing loss from noise which occurs first at 3 to 4 kHz. (Hallowell 1970).

2.3.2 CENTRAL AUDITORY PROCESSING

The nervous impulses are carried along the 8th (statico-acoustic nerve) from the cochlea to the brain stem. Here the nerve fibers reach nuclei where they relay with other nerve fibers. The fibers from each auditory nerve split, some passing to one side of the brain, others remaining on the same side. Thus, as auditory stimuli pass up each side of the brain from both ears, unilateral hearing loss cannot be caused by a brain lesion. The fibers pass up the hind brain to the mid brain and the cerebral cortex. There are many central functions such as, the ability to block out unwanted sounds and spatial localization, interaction of sound stimuli with other parts of the brain. (Hallowell 1970).

2.3.3 Hearing Loss

Hearing loss is defined as a degree of impairment such that a person is unable to understand speech even in the presence of amplification. (Elzouki,2012) . The major causes of it are genetics, age, exposure to noise, illness, chemicals and physical trauma. Hearing loss can be inherited , around 75–80% of all cases. (Lynch1997).Hearing testing may be used to determine the severity of the hearing loss, the results are expressed in decibels, hearing loss is usually described as mild, mild-moderate, moderate, moderately severe, severe, or profound. (Elzouki,2012), Hearing impairments are categorized by their type, their severity, and the age of onset (before or after language is acquired). Furthermore, a hearing impairment may exist in only one ear (unilateral) or in both ears (bilateral). There are three main types of hearing impairments, conductive hearing impairment and sensorineural hearing impairment and a combination of the two called mixed hearing loss. (Elzouki,2012)

2.3.3.1 Conductive Hearing Loss

Any problem in the outer or middle ear that prevents sound from being conducted properly is known as a conductive hearing loss. Conductive hearing losses are usually mild or moderate in degree, ranging from 25 to 65 decibels. In some cases, medication or surgery can help. (Elzouki,2012)

2.3.3.2 Sensorineural Hearing Loss

Results from missing or damaged sensory cells (hair cells) in the cochlea and is usually permanent. Also known as “nerve deafness,” sensorineural hearing loss can be mild, moderate, severe or profound. Mild to severe sensorineural hearing loss can often be helped with hearing aids or a Cochlear implants are often a solution for severe or profound hearing loss (Elzouki,2012)

2.3.3.3 Mixed Hearing Loss

A mixed hearing loss is a combination of a sensorineural and conductive hearing loss. It results from problems in both the inner and outer or middle ear. Treatment options may include medication, surgery, or hearing aids(Elzouki,2012).

2.3.3.4 Neural Hearing Loss

A problem that results from the absence of or damage to the auditory nerve can cause a neural hearing loss. Neural hearing loss is usually profound and permanent. Hearing aids and cochlear implants cannot help because the nerve is not able to pass on sound information to the brain. (Elzouki,2012)

2.4. Cochlea Imaging and Pervious Studies

2.4.1. Plain Radiography

Plain of the temporal bone, mastoid views are now almost entirely obsolete except for postoperative assessment of the position of a cochlear implant.

The view of the petoid with an extended electrode ray in the first and second coils of the cochlea,vestibule; superior electrode array in the inner ear, Stenver's or the semicircular canal; internal auditory meatus. (Gentry.Ranallo, 2009)

Perorbital view may be used become obsolete as MRI is now available for exclusion of acoustic Oblique poster anterior (Stenver's) view In this view, the neuroma in all suspected cases. Whole length of the petrous bone is demonstrated by placing it parallel to the X-ray film with the incident ray passing at right angles to it. With the radiographic baseline horizontal, the sagittal plane of the skull is rotated through 35 ° and tilted 15° away from the side to be examined. The incident ray is inclined at an angle of 12° cranially and is centred on a point 2 cm medial to the tip of the mastoid process. A radiograph in Stenver's position should demonstrate the petrous tip and internal auditory meatus (IAM), the semicircular canals (superior and lateral), the middle ear cleft, the mastoid antrum and the mastoid process. (Gentry.Ranallo, 2009)

This is the best view of the IAM if tomography is unavailable; it should be done in the postero-anterior position to reduce radiation to the eyes. The orbitomeatal line is at right angles to the film. The tube is angled 5-10° caudally, centering between the orbits. The petrous pyramids and IAM are thus projected through the orbits. (Gentry.Ranallo, 2009)

2.4.2 Ultra Sound

Group of authors develop a means for imaging cochlear anatomy using high-resolution ultrasound. (Daniel et at, 2009)

The intra-cochlear anatomy of a prepared human temporal bone was imaged using an ultra-high-frequency ultrasound transducer (70-MHz). The ultrasound transducer was mounted on a robotic arm for positioning. B-mode sector scans were obtained via the round window. (Daniel et al,2009)

Their Finding are images of the basal turn of the cochlea were obtained that clearly show the basilar membrane and Reissner’s membrane. High-resolution ultrasound is a promising approach for intra-cochlear imaging (Daniel et al, 2009).

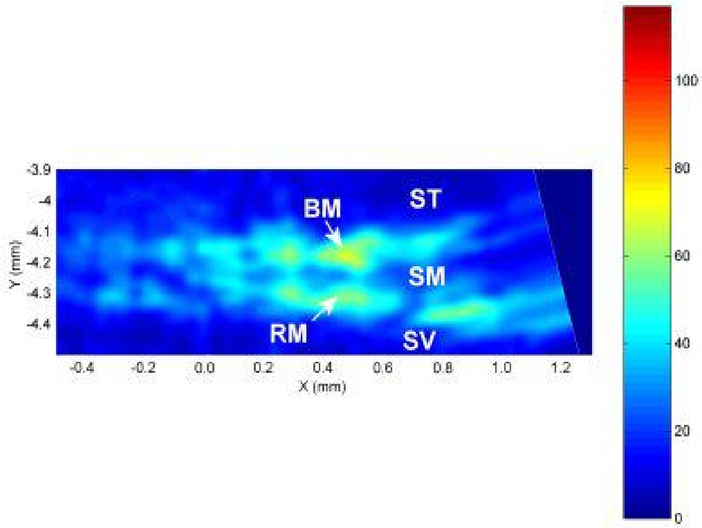


Figure2.7: High-resolution ultrasound b-scan image of the cochlea.

The basilar membrane (BM) and Reisner's membrane (RM) are both visualized. They define the spaces of the scalae media (SM), tympani (SM) and vestibuli (SV). Units in the XY plot are millimeters (mm). The intensity bar at the side provides a measure of signal intensity (0·391 millivolts per count(Daniel et al, 2009).

2.4.3 Computed Tomography

Adrian F. Fernando.et. al, describe the cochlear anatomy among Filipinos through high resolution computed tomography (HRCT) imaging, by design retrospective study setted at Tertiary Private University Hospital, Patients Cochlear images retrospectively obtained from computed tomography (CT) scans of subjects who underwent cranial, facial, paranasal sinus and temporal bone computed tomography from October 2009 to July 2010 were reconstructed and analyzed, they found that when 388 cochlear images were obtained from the scans of 194 subjects (101 males and 93 females, aged 1 to 90 years old, mean =52 years) and reconstructed for analysis, The mean coiled cochlear height measured 4,36 mm on the right (AD,) and 4.34 mm on the left (AS) Measurement from the oval window to the distal end of the basal turn (equivalent to the. horizontal dimension of the cochlea or the mean length of the basal turn) was 7,55 mm AD. and 7,60 mm AS The vertical and horizontal dimensions of right and left cochlea's were identical in all subjects (SD. = 0.35), The right and left cochlear turns were identical in each subject, exhibiting 2 1f2 turns in 92.3% of subjects and 2 l,4 turns in 7.7% of subjects. The cochlear dimensions were similar in all subjects, regardless of age. No cochlear ossification or malformation was noted on any CT image, Conclusion: The 7,55 mm mean length of the cochlear basal turn among Filipinos in this study was 1.24 mm shorter than the average length of the basal turn of 8,81 mm reported.

Other authors sought to establish normative measurements of the inner ear using computed tomography (CT) of the temporal bone to aid in the diagnosis of inner ear malformations as prospective measurements of the inner ear structures were made on axial and coronal temporal bone CT scans on 15 patients with normal hearing and 15 patients with sensorineural hearing loss, The vertical height of the cochlea on coronal scan and the size of the central bony island within the lateral semicircular canal on axial scan along with visual inspection identified 7 inner ear abnormalities in 6 patients: 5 cases of lateral semicircular canal dysplasia and 2 cases of cochlear hypoplasia. In contrast, visual inspection alone identified only 4 of the 7 abnormalities. They found that routine measurement of the cochlear height and bony island of the lateral semicircular canal, in conjunction with visual inspection of CT images, will increase recognition of common inner ear malformations. Natacha et.al (2009) established CT measurements of the normal cochlea in children and determine radiological criteria correlated with SNHL. The study was a retrospective study of temporal bone CT performed in 159 children, age range from 3 days to 16 years between February 1999 and July 2004. A control group (n=88) comprised children without SNHL; the SNHL group comprised 71 children. The width of the second turn of the cochlea (CW), the cochlear height (CH), and the width of the bony canal for the cochlear nerve (WCN) were measured on a reference plane containing the modiolus, the posterior semicircular canal, the footplate, and the stapes arch. Results Width of the canal measurements ≤1.7 mm or ≥2.5 mm supported the diagnosis of SNHL with a specificity of 97% and 91%, respectively. Cochlear width was found to be significantly smaller in the SNHL group (5.61±0.51 mm) than in the control group (5.75±0.31 mm, P<0.02), a size <5.4 mm being highly suggestive of SNHL with a specificity of 90%. No significant variations of all measurements were found with age. The conclude of the study that appropriate measurements of WCN and CW are highly correlated with SNHL. M.C. Moria and K.W. Chang, 2012 done a study using CT there aim was to establish the relationship between CH and age by using analysis of CT images in patients who underwent coronal CT scans of the temporal bone between 2001 and 2007. They measured CH on coronal CT scans of the temporal bone of 422 ears in 211 patients, 1 month to 23 years of age. Using multivariate linear regression analysis, we determined the relationship of CH to age, sex, and HL type. In addition, 11 patients with multiple scans at different ages were assessed for change in CH with age. They found that average CH was 5.3 mm (normal range, 4.4–6.2 mm). Analysis showed no statistically significant change in CH across ages from 1 month to 23 years (95% CI for regression line slope = −0.003, 0.013). Likewise, there were no statistically significant differences in CH for patients with multiple scans at different ages. ICW increased with age as expected with increased cranial size. A small difference in CH between sexes was noted with males having greater CHs than females (P < .01). All patients with hypoplastic cochleas, defined by a CH <2 SDs from the mean (4.48 mm for males and 4.25 mm for females), had HL with a positive predictive value of 86%,They concluded that CH does not change from 1 month of age to adulthood and is slightly greater in males than in females.(Moria and Chang, 2012).

Figure 2.8 (HRCT) Axial scan through the internal auditory canal

2.4.4 Magnetic Resonance Imaging

MRI of the temporal bones provides vital information; these are baseline investigations and are necessary in all patients posted for cochlear implant surgery. MRI is now increasingly being used to study the membranous labyrinth and the cranial nerves; it provides accurate information and exquisite anatomical detail.(Rev. Bras ,2009).

The MRI 3D sequence data can be used to obtain a 3D MI reconstruction, which gives a good outline of the inner ear structures, especially when complex anomalies need evaluation. The membranous labyrinth contains endolymph and is surrounded by the perilymph which, in turn, separates it from the otic capsule or bony labyrinth. The cochlea consists of two and one half turns, which extend into the vestibule. The three semicircular canals arise from the vestibule in arches along all three planes. (Rev. Bras ,2009)

The MRI 3D sequence data can be used to obtain a 3D MIP reconstruction [Figure 2d], which gives a good outline of the inner ear structures, especially when complex anomalies need evaluation. The membranous labyrinth contains endolymph and is surrounded by the perilymph which, in turn, separates it from the otic capsule or bony labyrinth. The cochlea consists of two and one half turns, which extend into the vestibule. The three semicircular canals arise from the vestibule in arches along all three planes. (Rev. Bras ,2009)

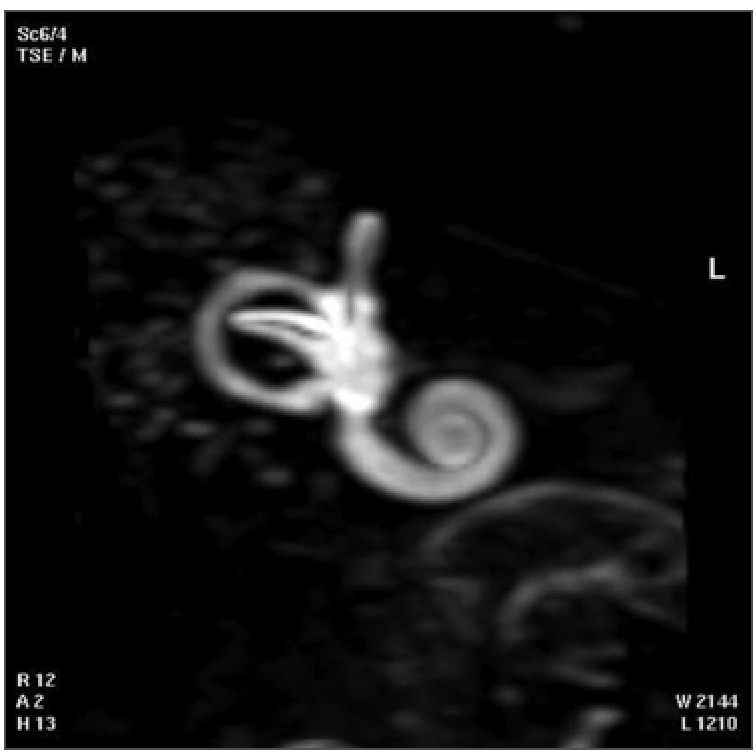


Figure 2.9 Magnetic Resonance3D Image (Rev. Bras, 2009)

2.5 Computer Tomography Instrumentation and Technique

Computed tomography (CT) is a technology that uses computer-processed x-rays to produce tomographic images of specific areas of the scanned object, allowing the user to see what is inside it without cutting it open. Digital geometry processing is used to generate a three-dimensional image of the inside of an object from a large series of two-dimensional radiographic images taken around a single axis of rotation. (Adrian F, 2011)

Medical imaging is the most common application of x-ray CT. Its cross-sectional images are used for diagnostic and therapeutic purposes in various medical disciplines. (Adrian F, 2011)

2.5.1 Historical background

CT was invented in 1972 by British engineer Godfrey Hounsfield of EMI Laboratories, England, and independently by South African born physicist Allan Cormack of Tufts University, Massachusetts. The first clinical CT scanners were installed between 1974 and 1976. The original systems were dedicated to head imaging only, but "whole body" systems with larger patient openings became available in 1976. CT became widely available by about 1980. There are now about 6,000 CT scanners installed in the U.S. and about 30,000 installed worldwide. The first CT scanner developed by Hounsfield in his lab at EMI took several hours to acquire the raw data for a single scan or "slice" and took days to reconstruct a single image from this raw data. The latest multi-slice CT systems can image an entire chest in five to ten seconds and reconstruct the images in a similar time period. (Eucid,2000)

During its 25-year history, CT has made great improvements in speed, patient comfort, and resolution. As CT scan times have gotten faster, more anatomy can be scanned in less time. Faster scanning helps to eliminate artifacts from patient motion such as breathing or peristalsis. CT exams are now quicker and more patient friendly than ever before. Tremendous research and development has been made to provide excellent image quality for diagnostic confidence at the lowest possible x-ray dose.(Eucid,2000)

Computed Tomography, widely known as a CAT scan, is medically referred to as simply CT. In its early days of development and use, it was called Computerized Axial Tomography, hence the term CAT. .(Eucid,2000)

CT is generally a relatively quick procedure that uses x-ray beams to create computer-generated image of soft tissue structures, such as tumors and internal organs, and air cavities (sinuses, lungs). It also has advantages in skeletal and neurological imaging. Its radiation doses to the human body are considered minimal due to the speed in which the X-Ray is delivered. .(Eucid,2000)

Today most CT systems are capable of "spiral" (also called "helical") and high resolution computed tomography scanning as well as scanning in the formerly more conventional "axial" mode. In addition, many CT systems are capable of imaging multiple slices simultaneously. Such advances allow relatively larger volumes of anatomy to be imaged in relatively less time**.** (FDA, 2014)

The procedure requires patient to lie in a horizontal position, and remain comfortably still. A flat, moving table goes through the center of a donut-shaped x-ray machine. X-ray beams from a number of positions are aimed at the area being studied. A special detector measures the amount of absorbed radiation. This data is transformed by a computer into a digital image. (J.AMiller et al, 2000)

Figure (2.10) shows CT machine (J.A Miller et al, 2000)

2.5.2. Modern Computed Tomography Modalities

In all original CT scanners (1974 to 1987), the x-ray power was transferred to the x-ray tube using high voltage cables wrapped around an elaborate set of rotating drums and pulleys. (J.A Miller et al, 2000)

The rotating frame (or gantry) would spin 360° in one direction and make an image (or a slice), and then spin 360° back in the other direction to make a second slice. In between each slice, the gantry would come to a complete stop and then reverse directions while the patient table would be moved forward by an increment equal to the slice thickness. (J.A Miller et al, 2000)

In the mid 1980's, an innovation called the power slip ring was developed so that the elaborate x-ray cable and drum system could be abandoned. The slip ring allows electric power to be transferred from a stationary power source onto the continuously rotating gantry. State of the art CT scanners with slip rings can now rotate continuously and do not have to slow down to start and stop. The innovation of the power slip ring has created a renaissance in CT called spiral or helical scanning.(Eucid,2000)

These spiral CT scanners can now image entire anatomic regions like the lungs in a quick 20 to 30 second breath hold. Instead of acquiring a stack of individual slices which may be misaligned due to slight patient motion or breathing (and lung/abdomen motion) in between each slice acquisition, spiral CT acquires a volume of data with the patient anatomy all in one position. This volume data set can then be computer-reconstructed to provide three dimensional pictures of complex blood vessels like the renal arteries or aorta. 3D CT images from volume data allow surgeons to visualize complex fractures, for example of facial trauma, in three dimensions and can help them plan reconstructive surgery. (Eucid,2000)

Additional major advance in CT imaging came in the early 1990s with the introduction of helical/spiral CT imaging and its slip-ring technology (Fig. 2.9).

In order to avoid anatomical gaps in the data set, the helical pitch is set lower ,that used for general body imaging. Thus the dose to the patient is higher. Nevertheless, the ability to reconstruct images in multiple phases from the same high-resolution data set can provide important information. Sub millimeter slices, as small as 0.5 mm, can be used to achieve a high spatial resolution. (Kalendar et al, 1990).

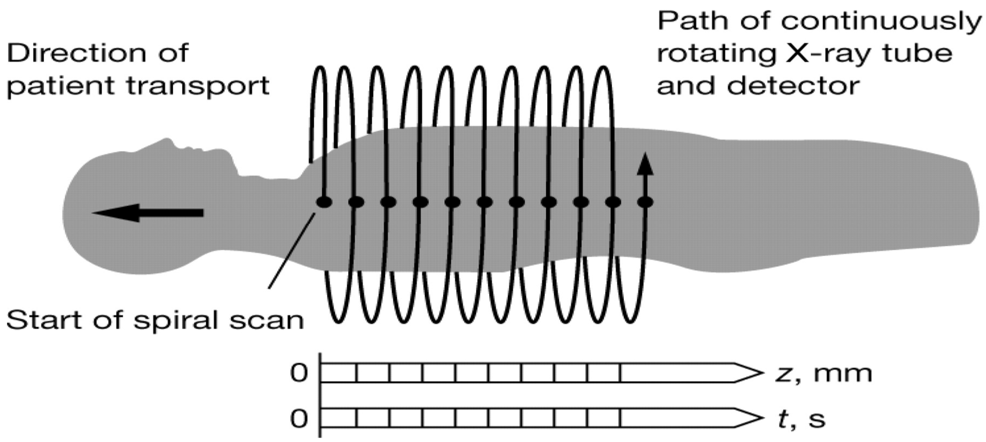


Figure (2.11) shows: show spiral CT principle. .(Eucid,2000)

Now a day High-Resolution Computed Tomography (HRCT) is a widely used. Compared to helical CT, HRCT uses a narrow beam collimation to take thin slice images. (J.A Miller et al, 2000)

2.5.4 Positioning considerations for Cochlea imaging

CT scanning of the head is typically used to detect infarction, tumours, calcifications, haemorrhage and bone trauma. Of the above, hypodense (dark) structures indicate infarction or tumours, hyperdense (bright) structures indicate calcifications and haemorrhage and bone trauma can be seen as disjunction in bone windows. Ambulances equipped with small bore multi-sliced CT scanners respond to cases involving stroke or head trauma. (Herman.2009)

CT Head patient supine, Figure (2.10) AP and lateral scouts, no gantry angle , Helical mode should be used routinely for adult head CT scans. Only use axial mode when you cannot move the patient's head into proper position (trauma, cervical collar, rigid neck). Tilt the patients head so that a line connecting the lateral canthus of the eye and the EAC is perpendicular to the CT tabletop. Use axial mode and angle the gantry if you cannot place the patient's head within 15 degrees of the proper setup angle, start scans at the bottom of C1 and scan through the top of the head (Gentry.Ranallo, 2009)

Figure 2.12 : Patient in CT Imaging System (FDA,2014)

Coronal sections Temporal Bone without contrast done; Patient Supine, AP and lateral scouts taken, no gantry angle, only use 64 slice scanners.

Patient Positioning: Tilt the patient's head so that a line connecting the lateral canthus of the eye and the EAC is perpendicular to the CT table top , Start scans at the mastoid tip and finish at the top of the petrous bone and Recon 1 and Retro Recons: Preferred 20 cm (Range 18-22 cm), Recon 2 and 3 of TB: 9.6 cm, choose the CT scan factors on the scanner for the proper age range of the patient Fig 2. 9(Gentry.Ranallo, 2009)

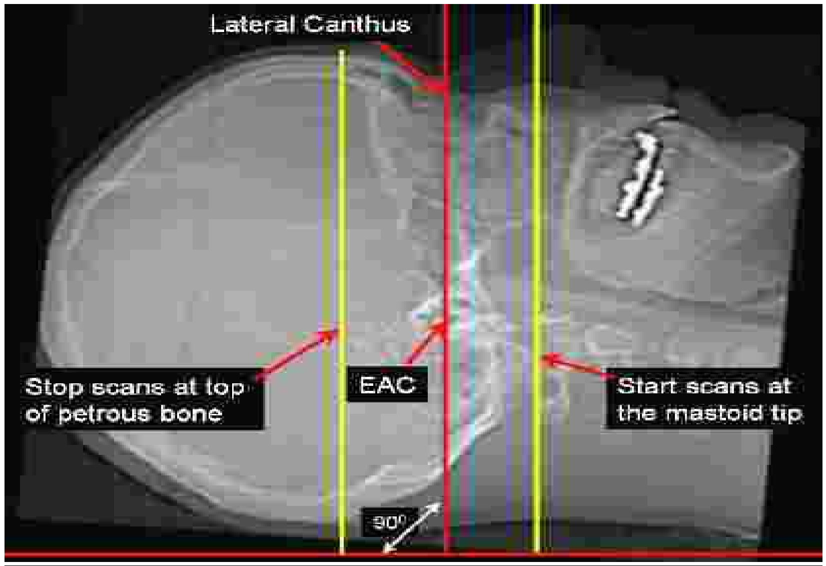


Figure 2.13 lateral scout determination of start and end scan level (Gentray-Ranallo,2009)

For child: (3 – 6 years) Recon 1: 2.5 mm axial images using a bone algorithm

And infant: (0 – 3 years) Recon 2 & 3: Obtain left and right 0.625 mm temporal bone axial images with a DFOV of 9.6 cm. Perform 1 additional Retro Recons to get the following axial images of the entire scan range:

At 20 cm DFOV, standard algorithm, 2.5 mm slice thickness, 1.25 mm increment, (WW/WL:400/30) and 1 mm by 1 mm 2D-reformats done in the coronal, Stenver's, and Pöschl planes of each temporal one using Recon 2 & 3 as source images fig 2.10. (Gentry.Ranallo, 2009)

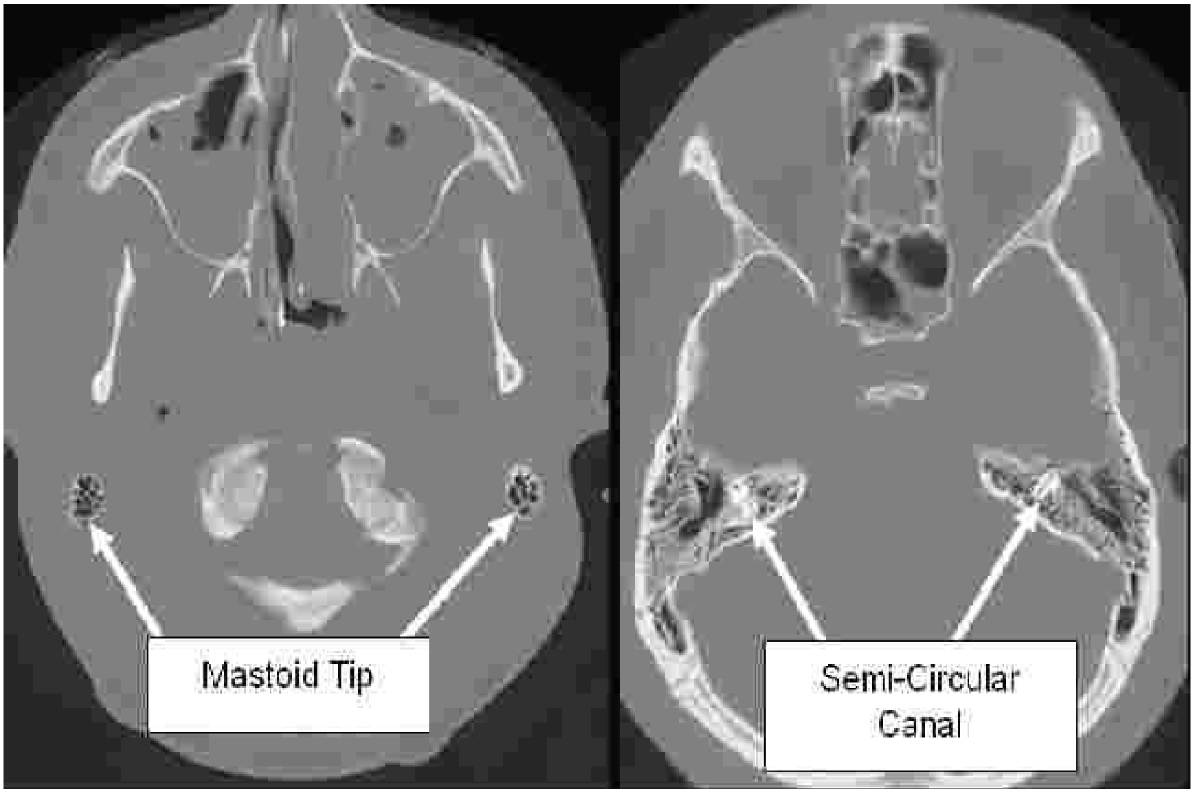


Figure 2.14 Axial images Temporal Bone CT(Gentry.Ranallo, 2009)

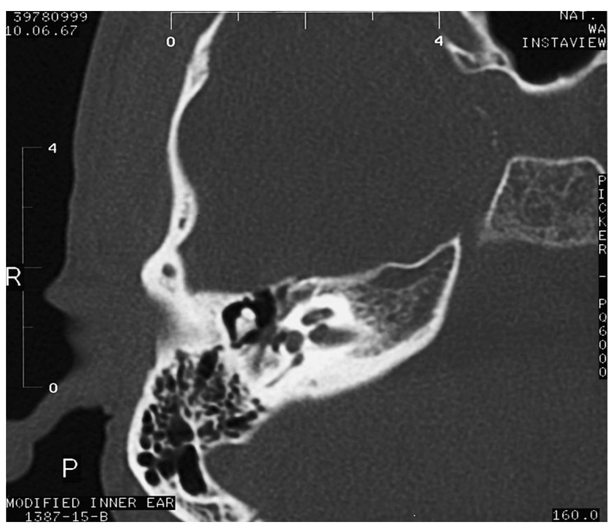


Figure 2.15 Axial scan for evaluating the auditory ossicles(Herman.2009)

Chapter Three

Materials and Methods

Retrospective Study, cross section survey study for human cochlear normal measurements**,** the study was done in Alamal diagnostic center, Military Hospital and Royal Care Hospital and Royal Scan, diagnostic departments, in the period from 2011 up to 2014.

3.1 Study population

3.1.1 Patients

A total of 230 brains CT scan for Sudanese patients were included, 460 Rt and Lt ears, in both gender , they divided into two groups, group A normal hearing subjects, group B bilateral congenital hearing loss subjects.

3.1.1.1 Group A

200 normal hearing (400 Rt and Lt ears), (137 males and 63 females), their ages were between 1 to 84 years. They were selected for brain HRCT scans, the patients came for different clinical indication for bra scan.

3.1.1.1.1including Criteria Group A

Any Patient male or female had all of the Criteria:

1- Sudanese

2- In the age of (1 – 90 years)

3- Normal hearing grade

3.1.1.2 Exclusion criteria for group A:

Subjects who had cochlear ossification were excluded or the patients for of SNHL aetiological investigation after or before cochlear implant.

3.1.2 Group B:

Group B (control group) consisted of 30 volunteers 60 Rt and Lt ears for adult known with bilateral congenital deafness confirmed by audiometric test, (12 males and 18 females),in different ages between (10 to 30 years).

3.3 Data collection

The data were collected by:

1- Measurements of different variables, Cochlea width CW,Cochlea hight CH, Cochlea nerve canal width, CNCW, Basal turn width BTW,Cochlea nerve CT number and cranium transverse diameter recorded from reconstruction of brains in HRCT scanning .ages and gender were recorded.

2- Designed clinical data collection sheet which containing all the variables of the study and CDs and external memory for recording the images.

3.4 Data Analysis

Using SPSS statistical software. It gives more specific and accurate data analysis. Statistical analyses, all data obtained in the study were documented and analyzed using SPSS program version 16. (Chicago ,IL 60606-6412).

Descriptive statistics, including mean ± standard deviation, were calculated. ANOVA test was applied to test the significance of differences, p-value of less than 0.05 was considered to be statistically significant. Linear regression models were performed between age, and the variables which have significant relations including: RT cochlear nerve canal width, RT cochlea nerve CT number and cranial transverse dimension, and equations were created.

3.4. Instrumentation and Technique Used:

3.4.1 Instrumentation

The HRCT scans for temporal bones were performed using spiral CT (64 detector row Aquilon ,Toshiba Medical System Corp-Tokyo, Japan) and (Somatom plus 64, Siemens, Erlangen, Germany).

3.4.2 Technique (Data acquisition and measurement protocol):

A volumetric acquisition was obtained with slice thickness of 0.5 mm and a reconstruction increment of 0.5 mm, 0.85 pitch, FOV of 70mm. The volumetric acquisition allowed multiplanar reconstructions. The reconstruction slice was 2 mm. A reference plane was determined parallel to the lateral semicircular canal containing the cochlear modiolus, and the canal for the cochlear nerve, the oval window along with the footplate, and the posterior semicircular canal. Reference slice was computed for each patient and all the measurements were performed exclusively on this plane. Three cochlear dimensions were measured: the width of the bony canal for the cochlear nerve at the entry of the cochlea (WCN), the height of the cochlea (CH) and the width of the cochlea (CW) defined as the second turn at the reference slice level. The measurements of the canal were always performed tangentially to the two inferior extremities of the X-shaped modiolus. The height was defined as the length between the tip of the cochlea and the orthogonal projection passing through the middle of the canal measurement. The measurement of the second turn of the cochlea was parallel to the latter. Cranial transverse width and Cochlea CT number (Hounsfield) were also been evaluated. This method is similar to the method done by (Natacha Teissier et al, 2010) All measurements were presented as a mean values in (mm) ± standard deviation (SD) and were performed by the same observer (Fig. 3.1). patient for which the plane could not be obtained or who had cochlear ossification were excluded. A strict measuring protocol was designed in order to limit inter- and intraobserver variability of the measurements. Three cochlear dimensions were measured from the axial CT scan : the width of the bony canal for the cochlear nerve at the entry of the cochlea (WCN), the height of the cochlea (CH) and the width of the cochlea (CW) defined as the second turn at the reference slice level. The measurements of the canal were always performed tangentially to the two inferior extremities of the X-shaped modiolus (Fig.3. 2). The height was defined as the length between the tip of the cochlea and the orthogonal projection passing through the middle of the canal measurement. The measurement of the second turn of the cochlea was parallel to the latter.

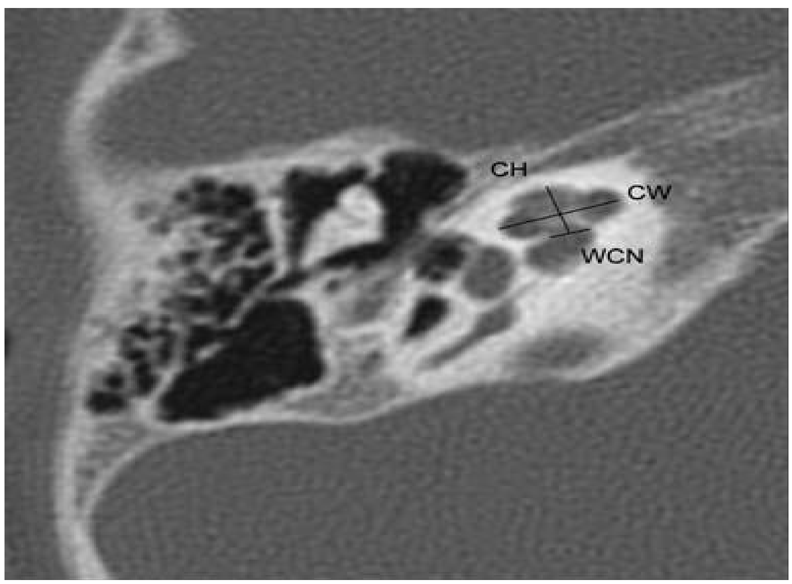


Fig. 3- 1 Axial CT of the right ear

shows the reference plane with the modiolus in a clear X shape, the branches of the stapes, and the posterior semicircular canal.

Transverse cranial width TCW measure in mm from the bony borders Rt to lt side in the same axial measured slice ,The CT number of the cochlear nerve measured in 1*1 as value of the mean at appointed part of the CN cochlear nerve.

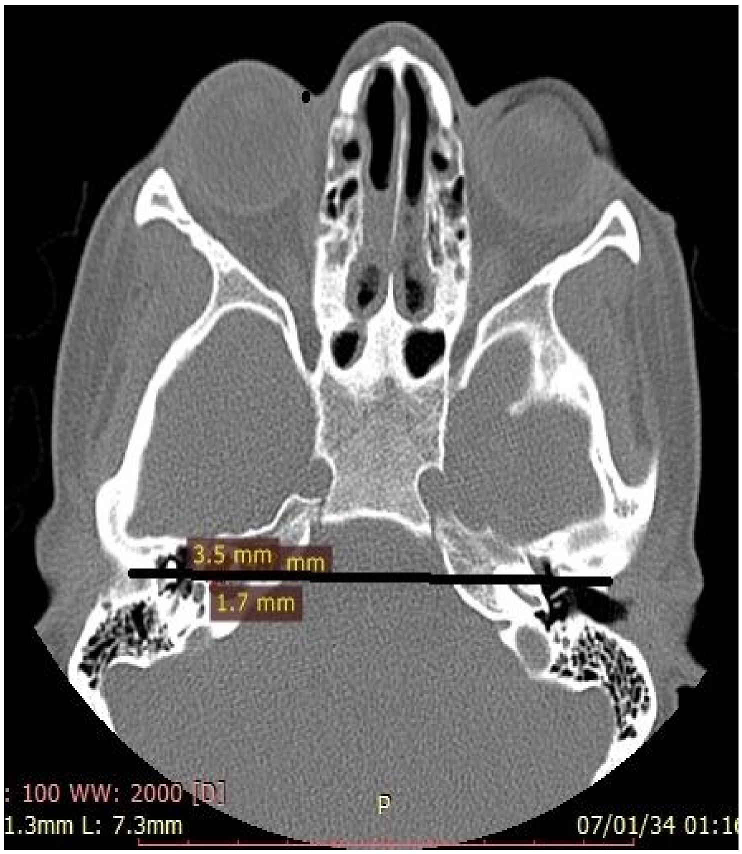


Fig 3-2 Transverse Cranial width TCW measure in mm from the bony borders Rt to Lt side in the same axial

Basal turn width (BTW) measured from sagittal section of the same slice obtained by MPR at the same slice level. **Fig 3-3**

The contrast was inverted to more precisely define the boundaries. The measurers were blinded to the patient groups.

All measurements were presented as an average value in mm ± standard deviation (SD) and were performed by the same observer (L.A.).

These data was stored on optical disks, data sheets records allowing off-line analysis of the scans without any loss of information.

Fig 3-3 Basal turn with in sagittal view

Chapter Four

Results

This chapter showed the statistical analysis results of the study group A and B in tables and descriptive figures**.**

4.1 General characteristics of the normal sample studied,

4.1.1 Gender Distribution :

Table (4.1.1) Gender Distribution, frequency and percentage

Gender	Frequency	Percentage %
Male	137	68.5
Female	63	31.5

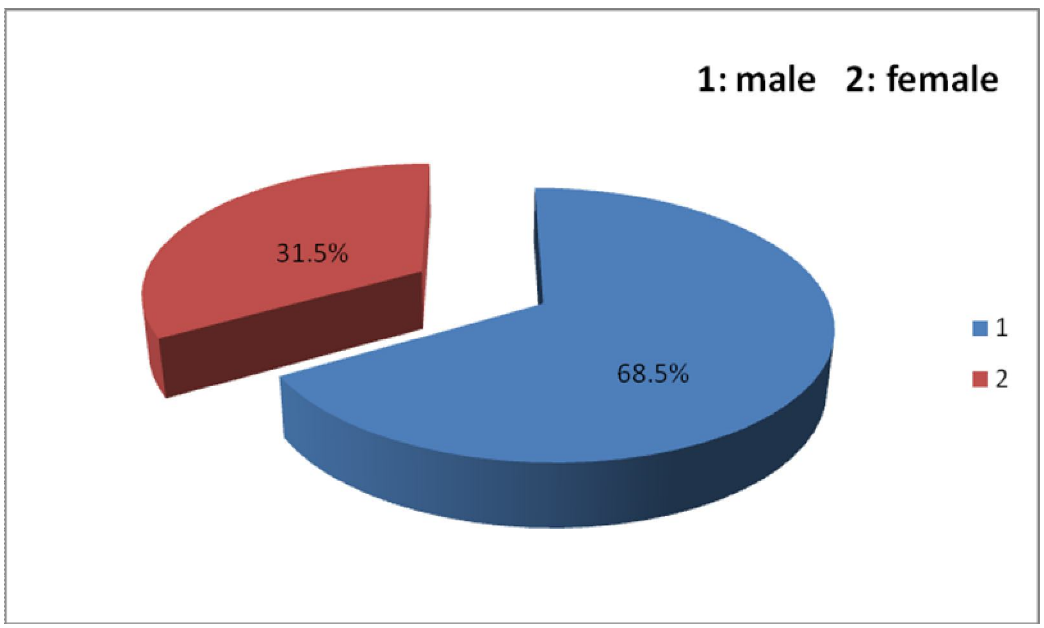


Figure 4.1.1: Gender distribution

4.1.2 Age Distribution:

The average age of the patients studied was 39 years. The peak incidence was among the age between 25-36 years of age presenting the percent of (28.9%) (Table 4. 2)

Table4.1.2: Showed age distribution frequency and percentage

Age	Frequency	Percentage %
1 - 12	13	6.7%
13 - 24	36	18.0%
25 - 36	56	28.9%
37 - 48	28	14.0%
49 - 60	38	19.0%
61 - 72	16	13.4%
73 - 84	13	6.2%

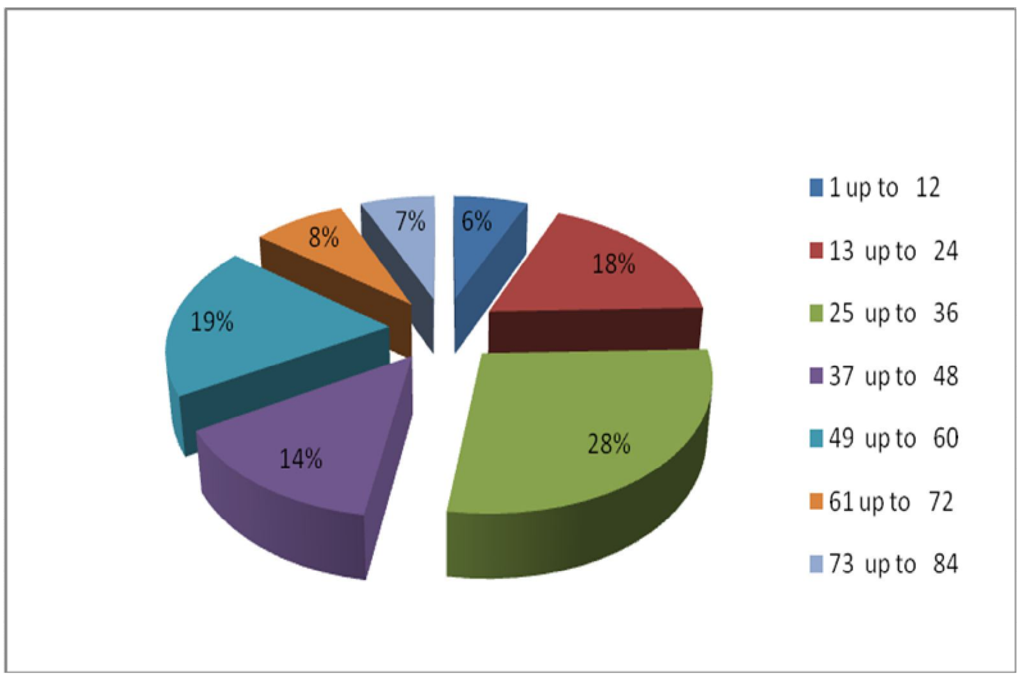


Figure 4.1.2 Diagram of age distribution in percentage

4.1.3 Statistical analysis of other variables measurements

Table 4.1.3 Normal cochlea's measurements for both gender, means and standard deviation.

Group Statistics

Variables	Gender	Mean	Std. Deviation
Age	Male	37.26	20.48
	Female	42.24	17.85
Lt cochlea width	Male	5.58	0.66
	Female	5.52	0.38
Lt cochlea height	Male	3.58	0.37
	Female	3.51	0.35
Lt cochlea nerve canal width	Male	2.08	1.47
	Female	1.89	0.21
Lt basal turn width	Male	1.87	0.19
	Female	1.89	0.17
Lt mean of CT number of the cochlea nerve	Male	277.78	153.11
	Female	282.95	172.41
Rt cochlea width	Male	5.64	0.41
	Female	5.53	0.39
Rt cochlea height	Male	3.57	0.36
	Female	3.47	0.34
Rt cochlea nerve canal width	Male	1.95	0.21
	Female	1.89	0.19
Rt basal turn width	Male	1.88	0.19
	Female	1.87	0.16
Rt mean of CT number of the cochlea nerve	Male	322..26	394.61
	Female	273.30	145.83
Cranium transverse diameter	Male	121.11	9.15
	Female	122.03	4.25

Table (4.1.4) T test for equality of means between male and female

Independent Samples Test

Variables	t	Sig. (2-tailed
age	1.66	0.10
Lt cochlea width	0.64	0.52
Lt cochlea height	1.35	0.18
Lt cochlea nerve canal width	1.04	0.30
Lt basal turn diameter	0.81	0.42
Lt mean of CT number of the cochlea nerve	0.21	0.83
Rt cochlea width	1.73	0.09
Rt cochlea height	1.90	0.06
Rt cochlea nerve canal width	1.77	0.08
Rt basal turn diameter	0.40	0.69
Rt mean of CT number of the cochlea nerve	0.95	0.34
Cranium transverse diameter	0.76	0.45

Using T test there is no differences between male and female measurement at p=0.05 with p>0. 06

Table (4.1.5) Measurements between Lt and RT cochlea means and Standard deviation

Variables	Mean	Std. Deviation
Lt cochlea width	5.59	0.58
Rt cochlea width	5.61	0.40
Lt cochlea height	3.56	0.63
Rt cochlea height	3.54	0.36
Lt Cochlea nerve canal width	2.02	0.20
Rt Cochlea nerve canal width	1.93	0.20
Lt basal turn diameter	1.87	0.183
Rt basal turn diameter	1.88	0.18
Lt mean of CT number of the cochlea nerve	279.41	159.02
Rt mean of CT number of the cochlea nerve	306.84	336.99

Table (4.1.6) Comparative normal Lt and RT Sudanese cochlea measurements

Variables	Lt cochlea	RT cochlea
Cochlea width	5.59±.0.58	5.60± 0.40
Cochlea height	3.56± 1.23	3.54± 0.36
Cochlea nerve canal width	2.02±1.20	1.93± 0.20
Basal turn width	1.87 ± 0.18	1.88 ± 0.18
Cochlea nerve CT number	279.41 ±159.02	306.84 ± 336.99

Table (4.1.7): Cochlea measurements (mm) and cranium transverse diameter according to the age center

Age center	lt CW	Lt CH	Lt CNCW	LT BTD	LT CN CT- N	RT CW	Rt CH	RT CNCW	Rt BTD	Rt CN C T -N	Cranium T D
6.50	5.52	3.60	1.90	1.90	311.72	5.46	3.48	1.85	1.79	618.48	101.98
17.50	5.45	3.54	1.88	1.81	267.92	5.43	3.52	1.89	1.85	308.49	122.17
28.50	5.66	3.58	1.99	1.91	280.20	5.67	3.55	1.96	1.89	292.00	123.20
39.50	5.70	3.58	1.94	1.93	264.21	5.68	3.51	1.96	1.91	244.78	123.47
50.50	5.41	3.48	1.91	1.81	295.92	5.64	3.50	1.93	1.87	298.96	121.87
72.50	5.48	3.61	1.94	1.88	255.43	5.63	3.68	1.93	1.87	290.03	122.20
83.50	5.70	3.62	1.98	1.90	289.42	5.69	3.56	1.94	1.92	231.95	124.12

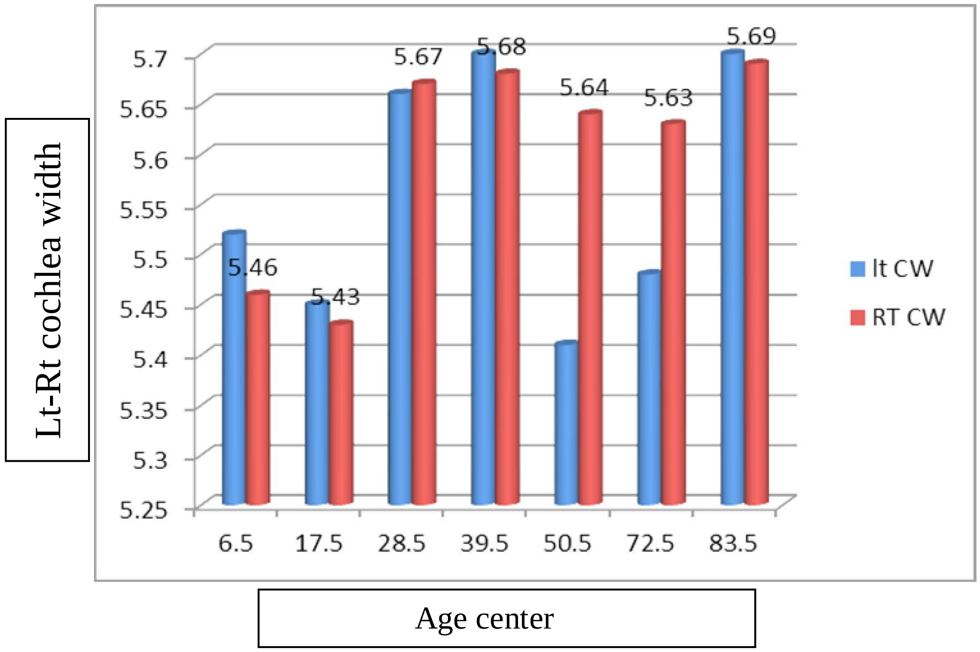


Figure 4.1.3 Age group center relation to Rt and lt CW measurements(mm)

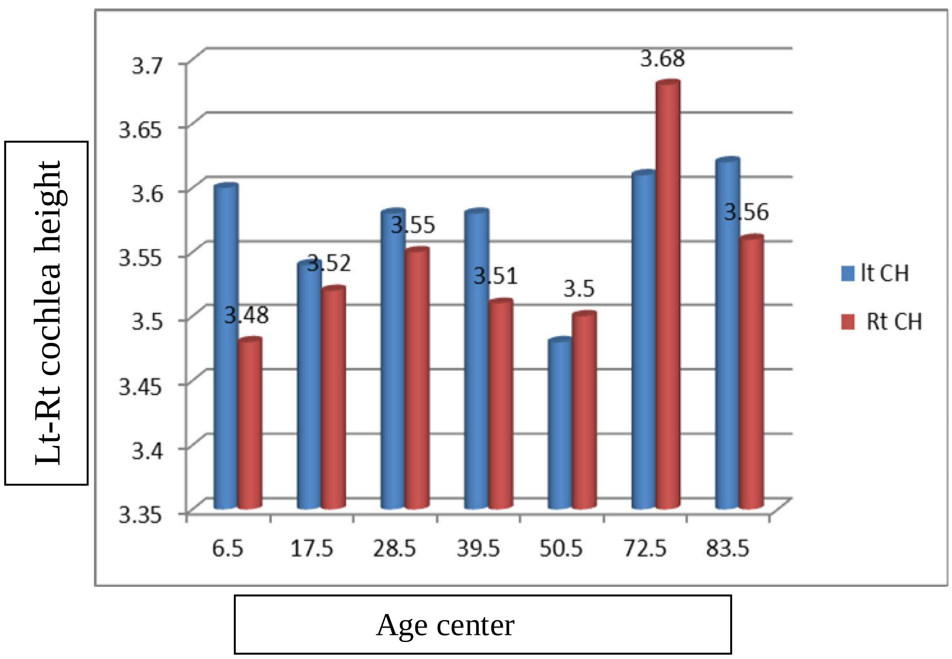


Figure 4.1.4 Age group center relation to Rt and lt CH measurements(mm)

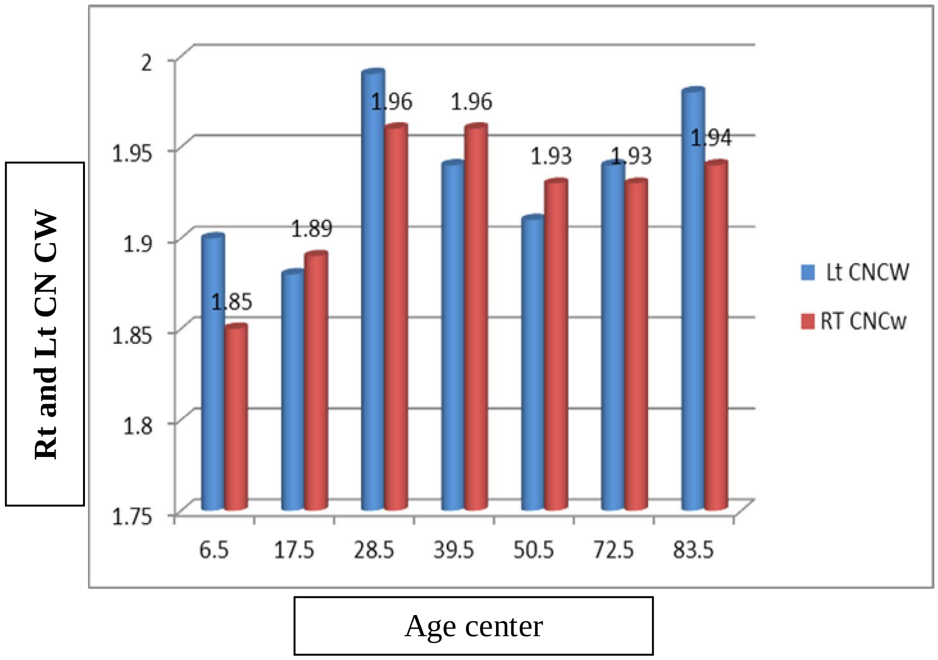


Figure 4.1.5 Age group center relation to Rt and Lt Rt and Lt cochlea nerve canal width CN CW measurements (mm)

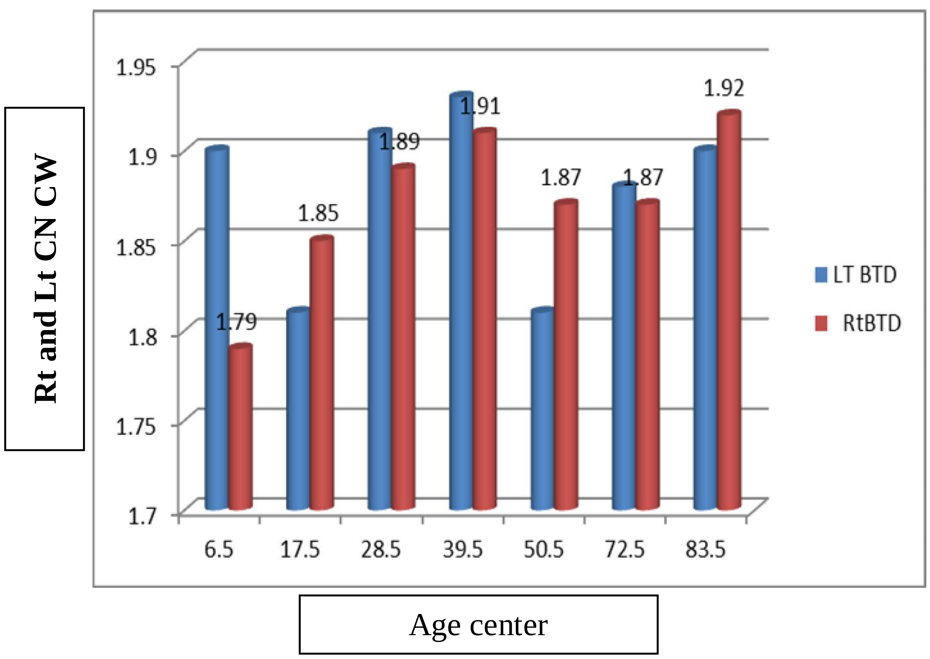


Figure 4.1.6 Age group center relation to Rt and lt Basal turn width measurements (mm)

Table (4.1.8) T test for the differences between lt and Rt measurements

Variables	T	Sig. (2-tailed)
Lt cochlea width **Rt cochlea width**	1.51	0.13
Lt cochlea height **Rt cochlea height**	1.29	0.20
Lt cochlea nerve canal width **Rt cochlea nerve canal width**	1.03	0.31
Lt basal turn width **Rt basal turn width**	0.22	0.83
Lt mean of cochlea nerve CT number **Rt mean of cochlea nerve CT number**	1.23	.22

Using T test there is no differences between lt and Rt measurement at $p=0.05$ with $p>0.1$

Table 4.1.9 The Co efficient value of age as dependent variable- predictors

Co efficient [a]					
Variables	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std.Error	Beta		
(Constant)	3.55	1.681		2.11	.036
Transverse Cranium width	0 .06	0.01	0.29	4.33	0.00
(Constant)	7.19	2.26		3.19	0.00
brain_diameter	.060	0.01	0.30	4.40	0.00
Tans- cochla width Rt cochlea width	0.64	0.27	0.16	2.38	0.02
(Constant)	7.33	2.23		3.29	0.00
brain_diameter	0.06	0.01	0.31	4.60	0.00
cochlea_widith_ Rt	0.67	0.27	0.17	2.51	0.01
mean_Rt	0.00	0.00	0.16	2.47	0.01

a. Dependent Variable: Age

Table 4.1.10 ANOVA test for the entered variables (Transverse cranium width- Rt cochlea width – Rt mean cochlea nerve CT number)

Variables	Model	Sum of Squares	df	Mean^2	F	Sig.
Transverse cranium width	Regression	44.87	1	44.87	18.73	.000[b]
	Residual	474.31	198	2.40		
	Total	519.18	199			
Rt cochlea width	Regression	58.17	2	29.08	12.43	.000[c]
	Residual	461.01	197	2.34		
	Total	519.18	199			
Rt mean cochlea nerve CT number	Regression	72.08	3	24.03	10.53	.000[d]
	Residual	447.10	196	2.281		
	Total	519.18	199			

a. Dependent Variable : Age

b. Predictors: (Constant), Transverse cranium width

c. Predictors: (Constant), Transverse cranium width, Rt cochlea width

d. Predictors: (Constant), Transverse cranium width ,Rt mean of cochlea nerve CT number

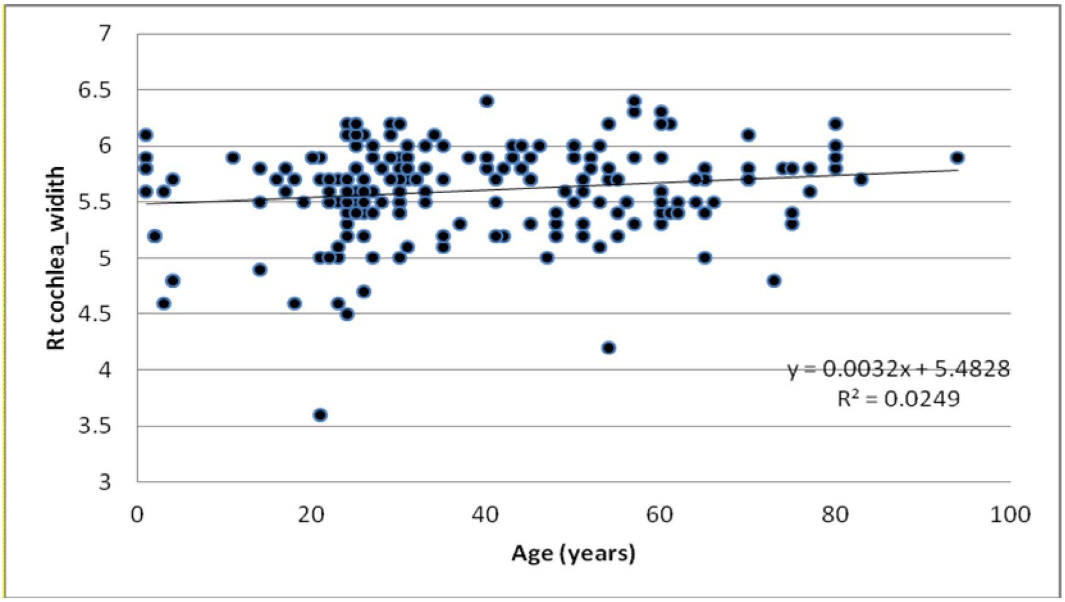


Figure 4.1.7: Rt Cochlea Nerve canal width to Age correlation

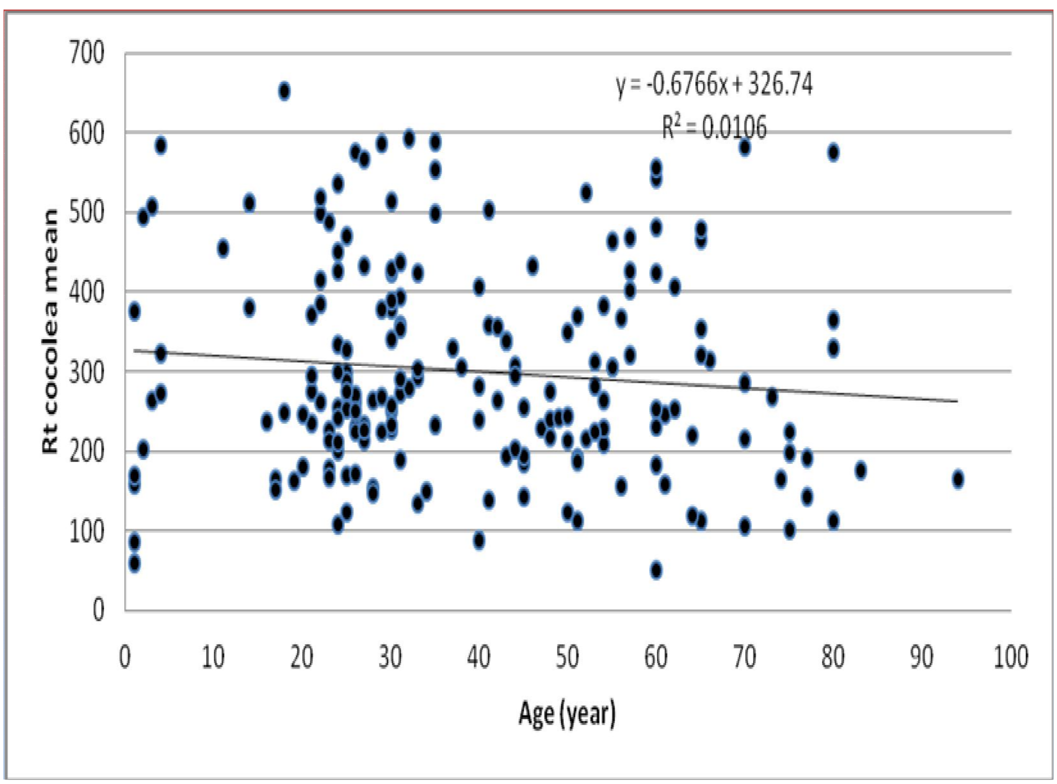
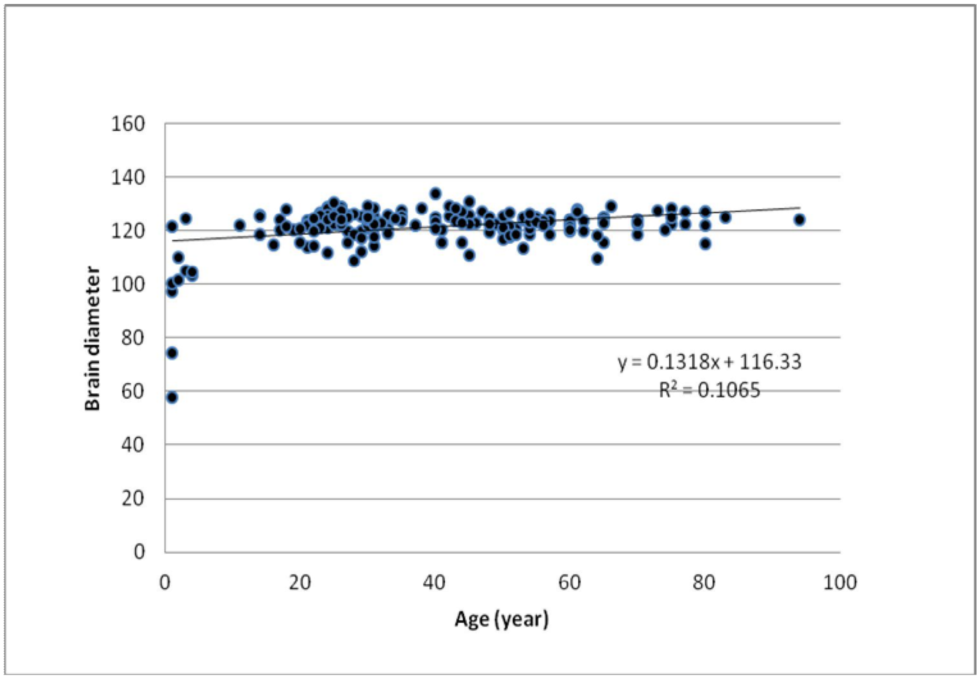


Figure 4.1.8 Rt Cochlea Nerve CT number to Age correlation



Age = (0.838*Brain Diameter)+(7.799* cochlea N canal Width Rt)+
(0.028*CN CT number lt) – 106.43

Figure 4.1.9 Cranium transverse width- Age correlation

4.2 General characteristics of the hearing loss sample (Group B):

Table 4.2.1 Gender distribution frequency and percentage

Variables	Frequency	Percentage%
Male	12	40
Female	18	60
Total	30	100

Table 4.2.2 Age - gender descriptive statistics

			Age		
Variable	**Frequency**	**Min**	**Max**	**Mean**	**Std.**
Male	12	10	30	17.85	6.60
Female	18	11	27	19.83	0.00
Total	30	10	30	18.93	5.94

4.2.3. Statistical analysis of other variables measurements

Table 4.2.3 Cranium Transverse Width descriptive statistics

Variable	Frequency	Min	Max	Mean	Std.
T-Cranium Width	30	111.0	125.0	120.57	3.10

Table 4.2.4 Left cochlea measurements descriptive statistics

Descriptive Statistics

Left Variables	Min	Max	Mean	Std.
cochlea width	4.4	5.9	5.35	0.30
Cochlea height	3.1	4.0	3.54	0.25
Cochlea nerve canal width	1.3	2.0	1.76	0.19
Basal turn width	1.5	2.0	1.77	0.14
Mean CN CT number	443.8	875.5	232.84	316.82

Table 4.2.5 Right cochlea measurements descriptive statistics

Descriptive Statistics

Right Variables	Min	Max	Mean	Std.
Cochlea width	3.9	6.3	5.38	0.46
Cochlea height	3.0	4.2	3.49	0.28
Cochlea nerve canal width	1.3	2.0	1.74	0.18
Basal turn width	1.6	2.0	1.79	0.14
Mean CN CT number	267.9	667.3	196.58	230.06

Table (4.2.6) Comparative Lt and RT SNHL cochlea measurements

Variables	Lt cochlea	RT cochlea
Cochlea width	5.34 ±.0.30	5.38± 0.46
Cochlea hight	3.53 ± 0.25	3.49± 0.28
Cochlea nerve canal width	1.75 ± 0.18	1.73± 0.18
Basal turn diameter	1.76 ± 0.13	1.79 ± 0.13
Mean of CT number of CN	232.84± 316.82	196.58± 230.05

Table (4.2.7) Compare Left cochlea width and Right cochlea width

Variable	Correlation	Sig.
Left cochlea width and Right cochlea width	0.80	0.00

There is a significant difference between left and right Cochlea width at 0.05 significant levels and there is a medium positive correlation between Left cochlea width and Right cochlea width.

Table (4.2.8) Left cochlea height Left and Right cochlea height

variable	Correlation	Sig.
Left cochlea height and Right cochlea height	0.31	0.11

There is no significant difference between left and right Cochlea height at 0.05 significant levels. And there is a weak positive correlation between Left cochlea height and Right cochlea height

Table (4.2.9) Left cochlea nerve canal width and Right cochlea nerve canal width

Variable	Correlation	Sig.
Left cochlea nerve canal width and Right cochlea nerve canal width	0.49	0.01

There is a significant difference between left and right Cochlea nerve canal width at 0.05 significant levels. And there is a weak positive correlation between Left cochlea nerve canal width and Right cochlea nerve canal width.

Table (4.2.10) Paired Samples Correlations Left basal turn width and Right basal turn width

Variable	Correlation	Sig.
Left basal turn width and Right basal turn	0.66	0.00

There is a significant difference between left and right Basle turn diameter at 0.05 significant levels. And there is a medium positive correlation between them.

Table (4.2.11) Paired Samples Correlations of Left mean of cochlear nerve CT number and Right mean of cochlear nerve CT number

Variable	Correlation	Sig.
Left Mean CN CT number and Right Mean CN CT number	0.50	0.01

There is a significant difference between left and right Mean CT number at 0.05 significant levels. And there is a weak positive correlation between them.

Table (4.2.12) Paired Samples Correlations Age & Cranium Width

Variables	Correlation	Sig.
Age and Transverse Cranium width	0.23	0.23

There is no significant difference between age and Cranium Diameter at 0.05 significant levels. And there is a weak negative correlation between them.

Table (4.2.13): Compare Means (Left & Right Sides With Age):

	Left Side		
Variable Age	Correlation	Sig.	Result
Cochlea width	0.08	0.69	Weak positive correlation No significant difference
Cochlea height	0.02	0.93	Weak positive correlation No significant difference
Cochlea nerve canal width	0.44	0.02	Weak negative correlation There is a significant difference
Basle turn width	0.38	0.05	Weak positive correlation There is a significant difference
Mean of CN CT number	0.51	0.01	Weak negative correlation No significant difference
	Right Side		
Cochlea width	0.03	0.90	Weak positive correlation No significant difference
Cochlea height	0.06	0.75	Weak positive correlation No significant difference
Cochlea nerve canal width	0.30	0.11	Weak negative correlation There is a significant difference
Basle turn width	0.21	0.27	Weak positive correlation No significant difference
Mean CN CT number	0.44	0.02	Weak negative correlation There is a significant difference

- Significant levels = 0.05
- Use Pearson correlation.

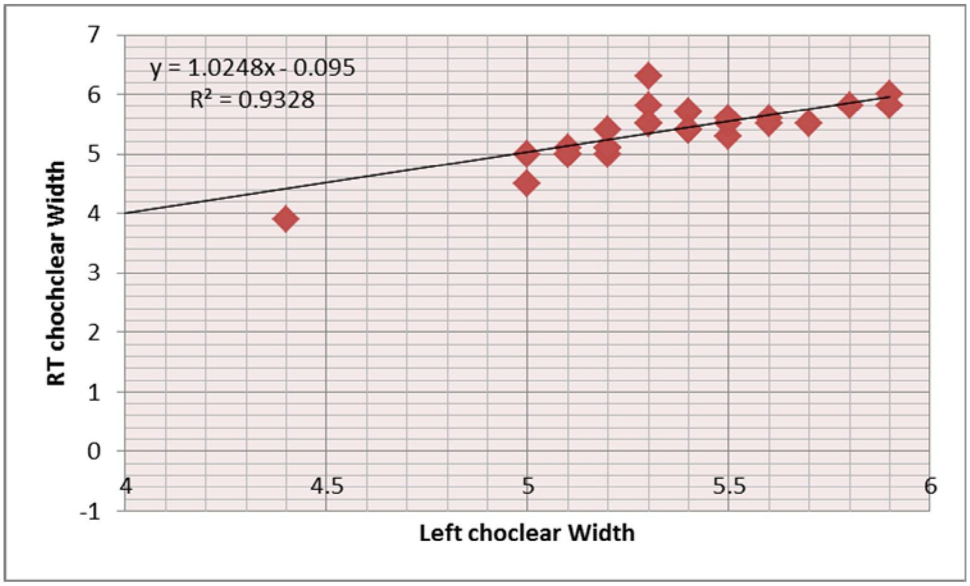


Figure 4.2.1 Left cochlea width and Right cochlea width correlation

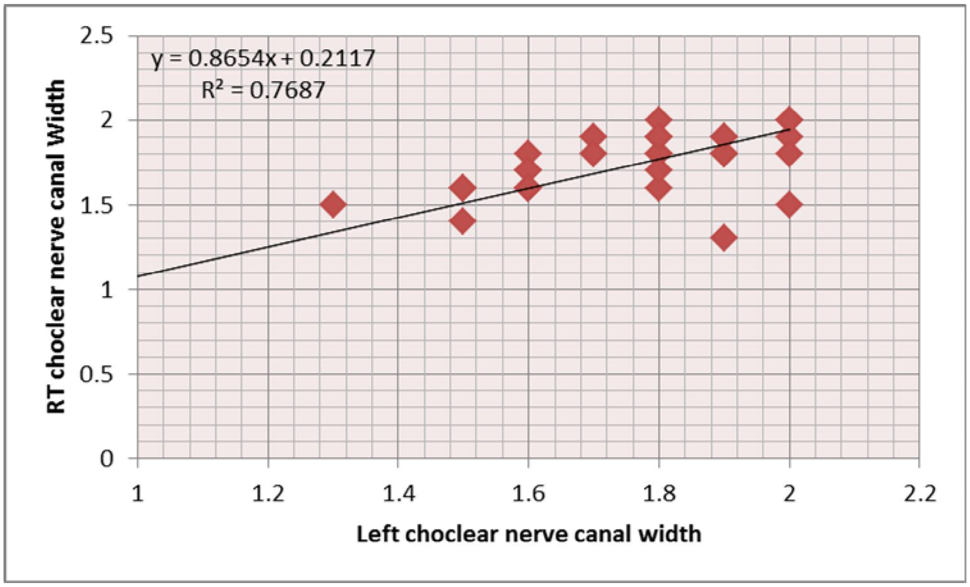


Figure 4.2.2 Left cochlea nerve canal width and Right cochlea nerve canal width correlation

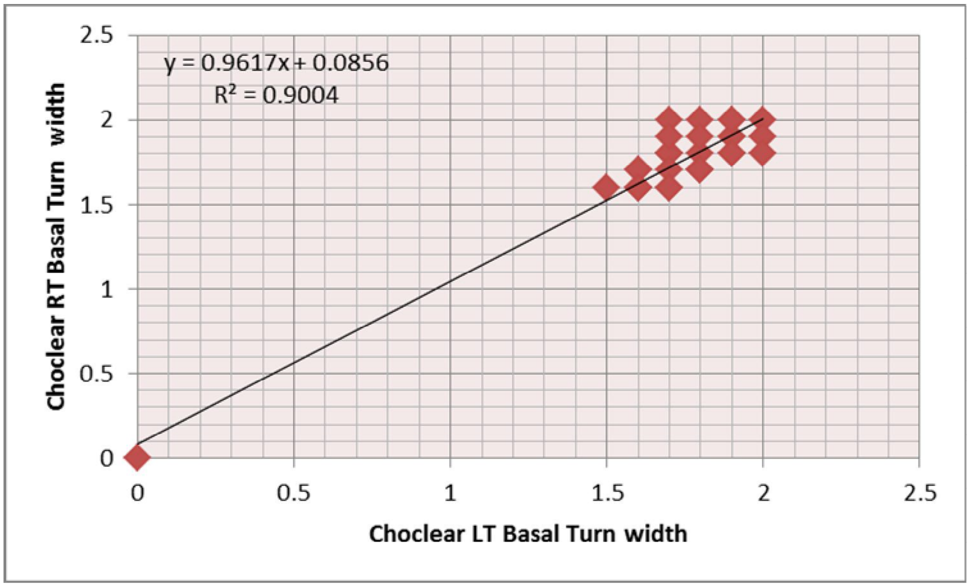


Figure 4.2.3 Left basal turn width and Right basal turn width correlation

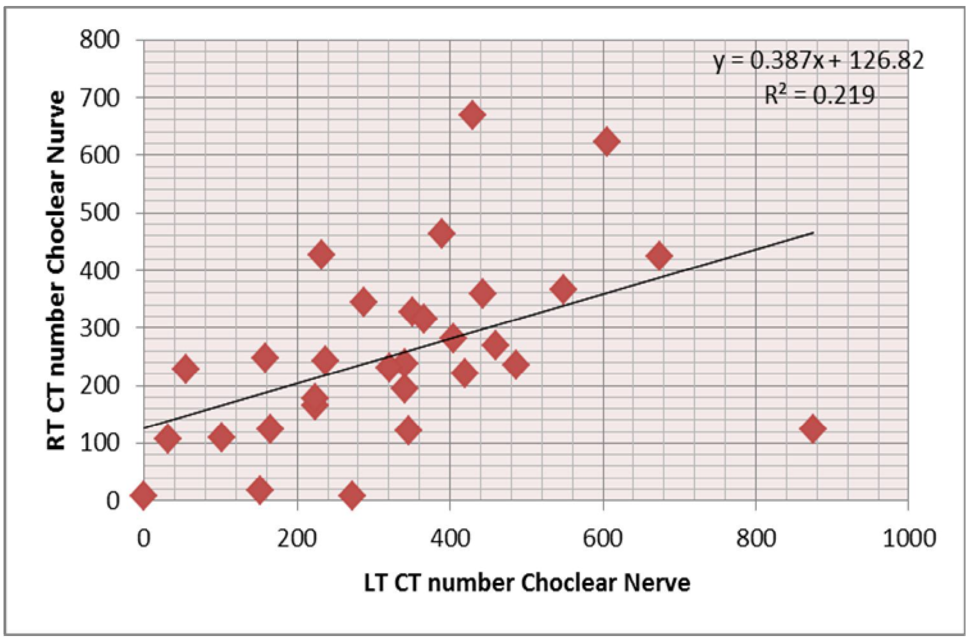


Figure 4.2.4 Left Mean CN CT number and Right Mean CN CT number correlation

Table 4.2.14 Cochlea's measurements for both hearing loss (deaf) and normal Hearing subjects, means and standard deviation.

Group Statistics

Variables		Mean	Std. Deviation
Lt CW	Deaf	5.34	0.30
	Normal	5.59	0.58
Lt CH	Deaf	3.53	0.25
	Normal	3.56	1.23
Lt CNW	Deaf	1.75	0.18
	Normal	2.02	1.20
Lt BTW	Deaf	1.76	0.13
	Normal	1.87	0.18
Rt CW	Deaf	5.38	0.46
	Normal	5.60	0.40
Rt CH	Deaf	3.49	0.28
	Normal	3.54	0.36
Rt CNW	Deaf	1.73	0.18
	Normal	1.93	0.20
Rt BTW	Deaf	1.79	0.13
	Normal	1.88	0.18

Chapter Five

Discussion, Conclusion and Recommendation

5.1 Discussion

Knowledge of the anatomy of the human cochlea is scanty than other sensory systems because of technical difficulties in examining inner ear structures (Adrian F et al, 2011). The mean length of the cochlea is about 33.01 mm (S.D 2.31 mm) and is normally known to demonstrate 2 ½ to 2 ¾ turns to allow its full dimensions to be accommodated in the temporal bone. (Nemzek et al, 1996)

The measuring of cochlea dimensions using High resolutions computed tomography was done available within the literature.

In this study cochlea's dimension of normal Sudanese in different ages using High resolutions computed tomography was measured.

The study had done over two groups A and B, the study of Group A which concerning normative Sudanese Cochlea measurements in (mm) using HRCT, included both genders with mean ages of 37.26±20.48 and 42.24±17.85 years for both males and females respectively (table 4.1.1). their ages were classified with an interval of 11years as descriptive graph showed in figure (4.1.2).

The variables were the mean left and right Cochlear width measured 5.56±0.58 mm, 5.61±0.40 mm and the height measured 3.56±0.36mm, 3.54±0.36mm, the basal turn widths were found to be 1.87±0.19mm, 1.88 ±0.18mm, Cochlea nerve canal widths were 2.02±1.23mm, 1.93±0.20mm, and Cochlea nerve signal intensity (CT number) were 279.41±159.02, 306.84±336.9 Hounsfield respectively, with no significant differences were noted in both sides as mentioned in(table 4.1.6). These were the standard measures of Sudanese normal cochlea found by this study.

This study confirmed that there were no significant difference anatomically between left and right cochlea measured in (mm) (table 4.1.4). Our study also showed that no significant differences were detected between the normal Cochlea characters in both genders (table 4.1.5). On the other hand (Mclay et al. 2002) explained a possible fluctuation of height, width measurements with age. Presented the measured variables according to different age classes, the influence of age was studied on the measurements of the cochlea by establishing a graph of the measurements by age for the variables which have significant relations with the age, this was done by applying the ANOVA test (table 4.1.9) using age center as dependent variable (table 4.1.7), Two of the variables data sets do not vary with age including the cochlea height and width, this was agreed with the study done by (Moria,Changa.2012) that concluded that cochlea height does not change from 1 month of age to adulthood; and it is slightly greater in males than in females and thier results was different from what was found in Sudanese.

The importance of the selection of the Cochlea height, is that the height contributes to the diagnosis of Sensoral hearing loss as in cases of cochlear hypoplasia or hyperplasia. This agreed also with (Purcell DD et al, 2006), for the study done in California, they measured cochlea height on coronal CT scans of the temporal bone, average cochlea height was 5.3 (mm) (normal range, 4.4–6.2 mm). Sudanese cochlea height measured in a xial CT scans was less height, and their analysis showed no statistically significant change in CH across ages from 1 month to 23 years.

Three of these variables had significant relation at p<.05 with age including cranial transverse dimension ,Cochlea nerve signal intensity (CT number), and RT Cochlea nerve canal width (Figure 4.1.3), These findings were different to what was mentioned previously in a study done in children that showed the absence of variability with age (Natasha Teissier et al.2010). Anatomical changes due to aging have been found throughout the auditory system and the hearing problems are caused by changes in the cochlea, eighth nerve, central auditory nervous system due degenerative anatomical changes (Lynn E Marshall etal,1981) ,this justify our study findings and changes which had been detected in the auditory nerve CT number to be reduced by age Figure (4.1.5).

Recent improvements in CT imaging technology facilitate visualization of the inner ear at resolutions sufficient to review the basic structural anatomy of the cochlea providing possibility to confirm existing knowledge on human Cochlear dimensions, turns, variations and pathology (Adrian F. Fernando et al .2011). This is the cause of our selection of HRCT scans.

New equations were established to predict the Cochlea nerve canal width and nerve signal intensity described by measuring the CT number for the normal hearing Sudanese subjects whose ages were known.

RT cochlear nerve canal width =0.0008 x age+1.887-----(1)

RT Cochlear nerve CT number=-3.044 x age+456.2------(2)

Cranium transverse dimension=0.165 x age+112.8-------(3)

Group B concerning congenital hearing loss Sudanese Cochlea measurements Using HRCT, included both genders with mean ages of 18.93±5.93 years for both males and females respectively. This study showed that the mean left and right Cochlear width measured 5.34±0.30mm, 5.38±0.46 mm and height measured 3.53±0.25mm, 3.49±0.28mm, the basal turn widths were found to be 1.76±0.13mm, 1.79±0.13mm, Cochlea nerve canal widths were1.75±0.18mm, 1.73±0.18mm, and Cochlea nerve signal intensity (CT number) were 232.84±316.82, 196.58±230.05Hounsfield respectively.(table 4.2.6).

When comparing normal hearing subjects to the control group we found a significant difference in the size of the measures of the cochlea. This occurs both when the cochlea is considered abnormal at visual inspection and when no major malformation is diagnosed. Therefore, measurement of the hight can be important when trying to establish the congenital origin of hearing loss and should be included in the checklist when interpreting a CT scan in cases of SNHL.

We confirmed that a cochlear width measured > 5.61 mm and < 5.38 and height measured > 3.56 mm and < 3.53, the basal turn widths were found to be > 1.87 mm and < 1.79mm , Cochlea nerve canal widths > 1.93 mm and < 1.75mm and cochlea nerve signal intensity (CT number) > 279.41 Hounsfield and < 232.84 Hounsfield is frequently associated with SNHL.

Our results consigned to what was acknowledged by (Natacha Teissier et al, 2010) , that both normal Cochlea's have the same radiological appearance with no significant difference, and any genetic or embryological defects leading to congenital hearing loss may affect both ears although their size is smaller when compared to normal hearing Cochleas (table 4.2.13).This reflects the necessitate of coming across the normative values in order to discriminate the normal from any pathological conditions. Many authors have tried to define normative measurements of inner ear structures when assessing SNHL by CT. (Fatterpekar et al.2000) found a significantly smaller width and height of the bony canal for the cochlear nerve agree with our study (Table 4.2.13) .

A thorough Knowledge of the normal range of variation of anatomy and topography of the cochlea is necessary for accurate interpretation of the radiographs.

5.2 Conclusion

- Normal cochlea’s have the same radiological appearance with no significant difference in different ages.
- There is no significant differences were detected between the normal Cochlea characters in both genders.
- There is no significant differences were detected between the normal right and left Cochlea measerments.
- New equations were established to predict the Cochlea nerve canal width and nerve signal intensity described by measuring the CT number for the normal Sudanese subjects whose ages were known

  RT cochlear nerve canal width =0.0008 x age+1.887----- (1)

  RT Cochlear nerve CT number=-3.044 x age+456.2 ----- (2)

  Cranium transverse dimension=0.165 x age+112.8 ----- (3)

- Genetic or embryological defects leading to congenital hearing loss may affect both ears although their size is smaller when compared to normal hearing Cochlea’s.
- Measurement of the cochlea height, width and the cochlea nerve canal width can be important to determine the congenital origin of hearing loss and should be included in the checklist when interpreting a CT scan in cases of SNHL.
- High-resolution CT is considered as excellent method to determine normal and pathological cochlea avoids image artifices with an acquisition of submillimetrical slices with optimum resolution.

5.3 Recommendation

- Further studies of the cochlear normal dimensions in specific age groups using HRCT is recommended
- Further studies of the cochlear dimensions in specific age groups Hearing loss subjects using HRCT is recommended
- Further studies of the cochlear dimensions in specific age groups for normal and Hearing loss subjects using HRCT is recommended in different Sudanese tribe.
- The Study cochlear dimensions and its correlation to audiometric status and brain stem changes is recommended to determine other significant physiologic correlations.
- HRCT must be a basic imaging modality for hearing loss diagnosis.
- This new protocol for cochlear (MPR) measurements should be used for evaluated of cochlea and turns .
- Further volumetric measurements (3D) using HRCT can be determine and compare with this study.
- Further study about the use of HRCT compare to MRI in assessment of cochlea anatomy recommended.
- Further study about the use of HRCT compare to MRI in assessment of Hearing loss recommended.
- Further study about the use of HR /US in assessment of intra-cochlear anatomy recommended.
- For the recent introduce of cochlea implantation in Sudan, further study in the use of HTCT,MRI pre and post-surgery for inner ear evaluation is recommended.