بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Graduate Studies

Study of Chronic Suppurative Otitis MediaUsingComputed Tomography

دراسة إلتهاب الأذن الوسطي المزمن المتقيح بإستخدام التصوير بالأشعة المقطعية

Thesis Submitted for the Award of PhD Degree in Diagnostic Radiologic Technology

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الآية

قال تعالى:

{وَيَسْأَلُونَكَ عَنِ الرُّوحِ قُلِ الرُّوحُ مِنْ أَمْرِرَبِّي وَمَاأُوتِيتُم مِّنَ الْعِلْمِ إِلَّا قَلِيلًا}

صدق الله العظيم

سورة الإسراء الآية {85}

DeDication

To our loved ones, soul of my parents,,,,,

To my Husband for his continues inspiration and support,,,,

To my sons,,,

To my sisters and brothers,.

And we dedicate this humble effort, to all those who appreciate science

Acknowledge

First thanks to Allah,the almighty for providing me this opportunity to proceed successfully,and the prayers & peace be upon the merciful Prophet Mohammed .

I would like to express our great appreciation,

Indebtedness and gratitude to: **Dr.Caroline Edward**

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Abstract

Chronic Suppurative Otitis Media (CSOM) is one of the leading causes of hearing impairment in developing countries. The study aim are to highlight the high resolution computerized tomography (HRCT) temporal bone findings in chronic middle ear infections with reference to its extent and complications, as well, the presented common signs, symptoms and the duration impact on the anatomical structures and pathologicalchanges in each part and for both sides.

Preliminary clinical assessment was obtained for 114 patients diagnosed with CSOM, and then they were referred for a HRCT of temporal bone which was done using multi-detector CT scanner.

The resultsshowed Of the 114 patients; 63(55.3%) were males and 51(44.7%) were females: Otorrhoea is the most common symptom, and was found in 113 patients constituting (99.1%) followed by Otolegia 69(60.5%) and headache affected 53(46.5%) of the cases. CSOM is more common in low socio-economic status .In ears affected with CSOM, the maximum CT number (Hounsfield) was found to be changed and was significantly affected with increasing patients' age. Sclerotic changes and soft tissue density increased as the duration of CSOM increased in right and left middle ears significantly (F=5.802, Sig at 0.000), and (F=23.182, Sig at .015) respectively. Partial and complete erosion were detected in both right and left ossicle in the advanced phase of disease, where the ossicle still intact in the early stage , and the correlation is found to be significant withincreasing of CSOM duration (F=16.959, Sig 0.000) and (F= 3.673, Sig =0.036)for right and left ossiclesrespectively. Changes including total and partial opacification, sclerotic changes, soft tissue

density, mucosal thickening were the findings detected in both right and left mastoid in HRCT for temporal bone scanning.

HRCT of temporal bone is useful in identifying various findings related to the location and extent of disease.

AlsoThis study concern to characterize the Temporal bone were defining to Fluid, Mucosal, Sclerotic and Soft tissues density using texture feature extraction and extract classification features from CT images. The texture analysis technique used to find the gray level variation in CT images. analyzing the image with Interactive Data Language IDL software to measure the grey level variation of images. The results show that texture analysis give classification accuracy of temporal bone to fluid 86.3%, mucosal 98.2%, sclerotic 99%, While the soft tissue density showed a classification accuracy 92.2%. the overall classification accuracy of temporal bone area 93.6%.

These relationships are stored in a Texture Dictionary that can be later used to automatically annotate new CT images with the appropriate temporal bone area names

مستخلص الدراسة

التهاب الاذن الوسطي المُزمن المتقيح أحد الأسباب المؤديةلضعف السمع في الدول النامية .
هدفت هَذه الدراسة َأن تُبرز َ درجة الوضوح العالية لنتائج تصوير العظم الصدغي في المرضي المصابين بالتهاب الأذن الوسطى المُزمن المتقيح وذلك بالرجوع إلى مدى انتشارها والمضاعفات ، أيضاً، العلامات المشتركةُقَدَّمة، أعراض وتأثير المدّة َ على التراكيب التشريحية و التغيرات المرضيةفي كُلّ جزء ولكلا الجانبين.

اجري التقييم السريري التمهيدي ل 114مريضشخّص َ بالتهاب الاذن الوسطي المتقيح وبعدئذٍ ُم ْ أُحيلوا لفحص العظم الصدغي الذيُم ِل َبإستعمال جهاز اشعة مقطعية متعدّد الكواشف َ رات نتائج المرضى ال114؛ 63 (55.3 %)كَانت ْ ذكور َ و51 (44.7 %)كَانوا إناث

سيلان الاذن العلامةُ الأكثر شيوعاً، ُجِد َ في113مريضيُشكّلون َ (99.1) تليها الم الاذن 69( )والصداع اصاب 53 من الحالات.التهاب الاذن الوسطي المتقيح اكثر شيوعا لذوي الدخل المنخفض في الآذان المصابة وجد العدد الاقصي لسيوتُجِد َ لكيُغ ِرَوكَان َ بشكل ملحوظ متأثّر بزيادة بعُمر المرضى.التغييرات الصلبية وكثافة النسيج الناعمةزادت ْ بزيادة مدّة الاصابة بالتهاب الاذن الوسطي زاد َ في الاذن الوسطي اليمين واليسار بشكل ملحوظ التآكل الجزئي والكاملإكتشف َ في العظيمة اليمين واليسار فيالمراحل المتقدّمة للمرض حيث العُظيمةازالَت ْ سليمة َ فيالمرحلة المبكّرة. والإرتباط َبَيَّن بأنه كَانواضح مَع زيادة مدة الاصابة بالمرض (إف =16.959،سيج 0.000) و(إف = 3.673،سيج =0.036)لعُظيمات اليمين واليسار على التوالي. التغيرات التي تشتمل علي العتمة الجزئية والكلية ,تغييرات صلبية، كثافة نسيج ناعمة وتخثن مخاطي نتائجهم اكتشفت في الجانب اليمين واليسار للعظم الخشائ عند تصوير العظم الصدغي باستخدام الاشعة المقطعية

ايضا هذه الدراسة اهتمت بتوصيف العظم الصدغي بالتعرف علي كثافة السوائل ,مخاطي , أنسجة متصلبة وناعمة باستخدام كثافة النسيج واستخلاص ملامح التصنيف من صور الاشعة المقطعية تقنية تحليل انسيج تُستَعمل ُلإيجادإختلاف المستوي الرمادي في الصور الاشعة المقطعية .حللت الصور باستخدام لغة بيانات التفاعلية (آي دي إل)برامج يستخدم لقيَاْس إختلاف المستوي الرماديصور الذَتائج َ اظهرت بأنّ تحليل النسيج يَعطي دقةتَصنيف العظم

الصدغي إلىسائلِ ,مخاطي ونسيج متصلب بينما كثافة النسيجِ الناعم اظهرت دقة تصنيف دقةالتصنيفالعامّةِ لمنطقةِ العظم الصدغي هللهِ لاقاتِ خْزُونة في قاموس النسيج الذي يُمكنُ أَن تستخدم اليا لاحقاًلتَذْييل الصورِ الاشعة المقطعية الجديدةِ بأسماءِ منطقةِ العظم الصدغيالملائمةِ .

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List of abbreviation

CT	Computed Tomography
CN	Cranial nerve
CBCT	Cone Beam Computed Tomography
CSOM	Chronic Suppurative Otitis Media
cm	Centimeter
EE	External ear
ENT	Ear Nose Throat
FOS	First Order Statistics
FOV	Field of view
HRCT	High Resolution Computed Tomography
HU	Hounfield unit
IE	Internal ear
IAC	Internal Auditory Canal
IAM	Internal Auditory Meatus
IDL	Interactive Data Language
KHz	Kilo hertiz
KHU	Kilo Heat Unit
Kv	Kilo volt
MRI	Magnetic Resonance Imaging
MSCT	Multi Slice Computed Tomography
MDCT	Multi Detector Computed Tomography
MHU	Mega Heat Unit
mAs	Milli ampere second
mm	Milli meter
SPSS	statistical package of social science
s	Second
WHO	World Health Organization

Chapter one

Introduction

1.1 Introduction:

Chronic suppurative otitis media (CSOM) is a major cause of acquired hearing impairment in children.[1] CSOM remains a significant health problem in terms of prevalence, economics and sequelae. It can be avoided if diagnosed early and properly treated. [2]

Studies showed that CSOM affect millions of children around the world annually with attendant complications presented in more than half of the cases. [3,4].

Long duration lead to severity of the cases compared with acute otitis media. [5]The importance of taking care about CSOM in children because it is likely inhibits language and development. Several studies have linked persistent and significant hearing loss from otitis media during the first two years of life with learning disabilities [6, 7]. Other studies have shown no effect. [8, 9]

At a recent World Health Organization (WHO) meeting of experts from 15 African countries, CSOM was considered most common cause of persistent mild to moderate hearing problems in developing countries. [10]

The disease and its sequelae produce financial and public costs. A prevalence of CSOM greater than 1% in children in a defined community indicates that there is an avoidable burden of the disease. A prevalence of 4% or greater indicates a public health problem that needs critical consideration. [11]

The burden of CSOM varies.Global prevalence rates estimates a range between 1% and 46%; it has been estimated that 65–330 million individuals have discharging ears, 60% of whom suffer from significant hearing impairment. [1]According to the WHO, Western Pacific countries have the highest prevalence, followed by South East Asia, Africa, South and Central America, the Eastern Mediterranean, and finally Europe. [12]

Imaging plays an important role in providing key information to the surgeon in this regard. Many imaging modalities are available for the evaluation of the temporal bone, including conventional radiographs, computed tomography (CT), and magnetic resonance imaging (MRI) which are currently the most widely used techniques and have largely replaced other modalities. CT scanning has an excellent role in the evaluation of bone and air space anatomy and disorders. Because CT scans are more accurate in identifying many soft tissue abnormalities and are much less prone to artifacts, CT has the advantage of producing images with higher contrast and a better spatial resolution.[13]This represent the status of the structure of the temporal bone represents a major advance in delineating pathology prior to surgical treatments.[14]

Sudan is a country in Africa. To the best of our knowledge, there are no previous studies of CSOM wasdone in Sudan, however a recent hospital-based case-control studies had reported results in children with CSOM in Khartoum-Sudan. [15, 16]

The proposes of this highlighting study are to provide an overview of current knowledge and scientific basis about CSOM in Sudan as one of the developing countries as well to highlight the HRCT temporal bone findings in chronic middle ear infections with reference to its extent and complications, the common sign, symptoms and the duration impact on the anatomical structures and pathological changes in each part and for both sides. Since the high index of cases referred to CT scanning, it will ensure rapid diagnosis and treatment and considerably reduces the incidence of complications in Sudanese.

1.2 Texture Analysis

Texture can be defined as the relationship between the pixels; therefore it can pick up the microscopic structures and hence it is superior to visual perception which is solely subjective.

Texture can be calculateusing a window of appropriate size that depict the underlined textures using features vector that correlated with the classes of interest for successful classification and segmentation of the underline textures through a suitable classifier (e.g. k-means, linear discriminant analysis, neural net work etc…)

Texture is an important characteristic for the analysis of many types of images. It can be seen in all images from multi spectral scanner images obtained from aircraft or satellite platforms (which the remote sensing community analyzes) to microscopic images of cell cultures or tissue samples (which the biomedical community analyzes).

Despite its importance and ubiquity in image data, a formal approach or precise definition of texture does not exist. (Haralick, 1979) The texture discrimination techniques are, for the most part, ad hoc.

Image texture, defined as a function of the spatial variation in pixel intensities (gray values), is useful in a variety of applications and has been a subject of intense study by many researchers. One immediate application of image texture is the recognition of image regions using texture properties. Texture is the most important visual cue in identifying these types of homogeneous regions. This is called texture classification. (Haralick, 1979)

Image analysis techniques have played an important role in several medical applications. In general, the applications involve the automatic extraction of features from the image which is then used for a variety of classification tasks, such as distinguishing normal tissue from abnormal tissue.

Depending upon the particular classification task, the extracted features capture morphological properties, color properties, or certain textural properties of the image.(Clausi et. al., 2002)

Texture is a combination of repeated patterns with a regular frequency. In visual interpretation texture has several types, for example, smooth, fine, coarse etc., which are often used in the classification of forest types. Texture analysis is defined as the classification or segmentation of textural features with respect to the shape of a small element, density and direction of regularity. In the case of digital image, it is difficult to 24 treat the texture mathematically because texture cannot be standardized quantitatively and the data volume is so huge. (Clausi et. al., 2002)

1.2.1 Texture Analysis Types

Approaches to texture analysis are usually categorized into:

1. Structural,
2. Statistical,
3. Model-based and
4. Transform

1.3 Justification

The limitations concerning the visual perception interpretation of the images necessitate development of new analysis techniques that will improve diagnostic ability. One promising technique is texture analysis, which characterizes tissues by determine internal changes or characteristics of organs at the onset of disease.

1.4 Problem of the Study

The examination of the ear traditionally carried out by otoscope ,otoscope does not show the site infection as well as the degree of infection.,as the condition of mastoid ,the application of CT can solve most of these problem ,but there is difficulties between the soft tissues and sclerotic lesion using texture analysis can solve this problem as well as it can build a model that can be used to differentiate between the normal ,fluid content or lesion objectively.

1.5 Objectives

1.5.1 General objectives:

The general aim of this study to characterized the chronicsuppurative otitis media by the CT temporal bone findings.

1.5.2 Specific objectives:

- To correlate the finding with age and gender .

- To correlate the duration of CSOM andossicles erosion .

- To correlate and classify the diagnosis with the CT number of the middle ear cavity contents.

- To correlate the duration of CSOM and CT findings.

- To evaluate clinical finding with the mastoid ,EE ,IE, Scutum and tegmen tympani.

-To correlate the patients socioeconomic status correlated with duration of (CSOM)

-To use an algorithm and function that can extract textural feature from CT images

-To extract texture feature from middle ear in CSOM patients

-To choose the discriminant subset of texture feature for classification

-To classify the textures features of the CSOM patients .

1.6 Overviewof the study

This study is concerned with characterization of chronic suppurative otitis media(CSOM) in CT images using texture analysis, it falls into five chapters. Chapter one is an introduction, which include preparation of the problem of study and texture analysis and CSOM as well as statement of the problem and study objectives. While Chapter two will include a comprehensive scholarly literature reviews concerning the previous studies. Chapter three deals with the methodology, where it provides an outline of material and methods used to acquire the data in this study as well as the method of analysis approach. While the results were presented in chapter four,and finally Chapter five include discussion of results, conclusion and

Chapter two

Theoretical background and Literature Review

2. Anatomy:

2.1 The ear

Theorgan of hearing and equilibrium (balance)is divided into the external, middle, and internal ear .The external ear and middle ear are mainly concerned with the transfer of sound to the internal ear, which contains the organ for equilibrium as well as for hearing. The tympanic membrane separates the external ear from the middle ear.

The pharyngotympanic tube joins the middle ear to the nasopharynx.

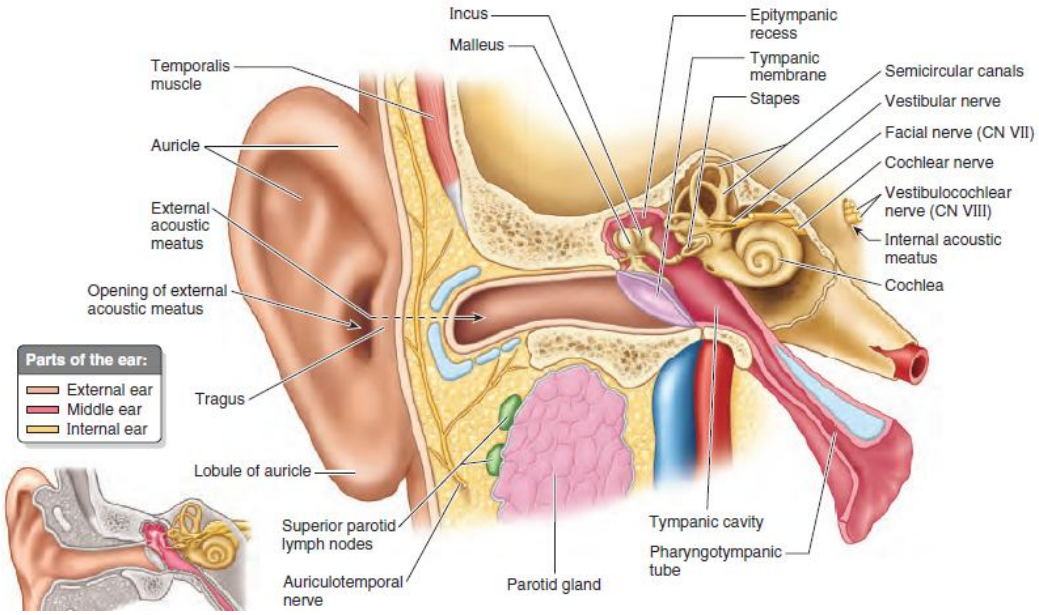


Figure 2.1 Parts of ear. A coronal section of the ear

2.1.1 External Ear

The external ear is composed of the shell-like auricle(pinna), which collects sound, and the external acoustic meatus (ear canal), which conducts sound to the tympanic membrane.

2.1.1.1 AURICLE

The auricle (L. auris, ear) is composed of an irregularly shaped plate of elastic cartilage that is covered by thin skin .The auricle has several depressions and elevations. The concha of the auricle is the deepest depression. The elevated margin of the auricle is the helix. The other depressions and elevations are identified in. The non-cartilaginous lobule (lobe) consists of fibrous tissue, fat, and blood vessels. It is easily pierced for taking small blood samples and inserting earrings. The tragus (G. tragos, goat; alluding to the hairs that tend to grow from this formation, like a goat's beard) is a tongue-like projection overlapping the opening of the external acoustic meatus.

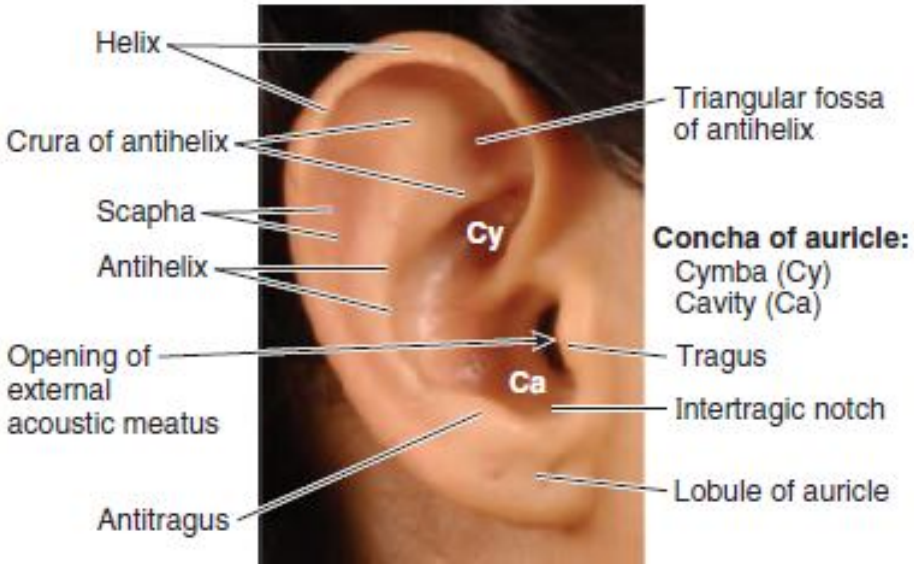


Figure2.2 show External ear. The parts of the auricle

The arterial supply to the auricle is derived mainly from the posterior auricular and superficial temporal arteries .The main nerves to the skin of the auricle are the great auricular and auriculotemporal nerves. The great auricular nerve supplies the cranial (medial) surface (commonly called the "back of the ear") and the posterior part (helix, antihelix, and lobule) of the lateral surface ("front"). The auriculo temporal

nerve, a branch of CN V3, supplies the skin of the auricle anterior to the external acoustic meatus. Minor contributions of embryological significance are made to the skin of the concha and its eminence by the vagus and facial nerves.

The lymphatic drainage of the auricle is as follows: the lateral surface of the superior half of the auricle drains to the superficial parotid lymph nodes the cranial surface of the superior half of the auricle drains to the mastoid lymph nodes and deep cervical lymph nodes; and the remainder of the auricle, including the lobule, drains into the superficial cervical lymph nodes.

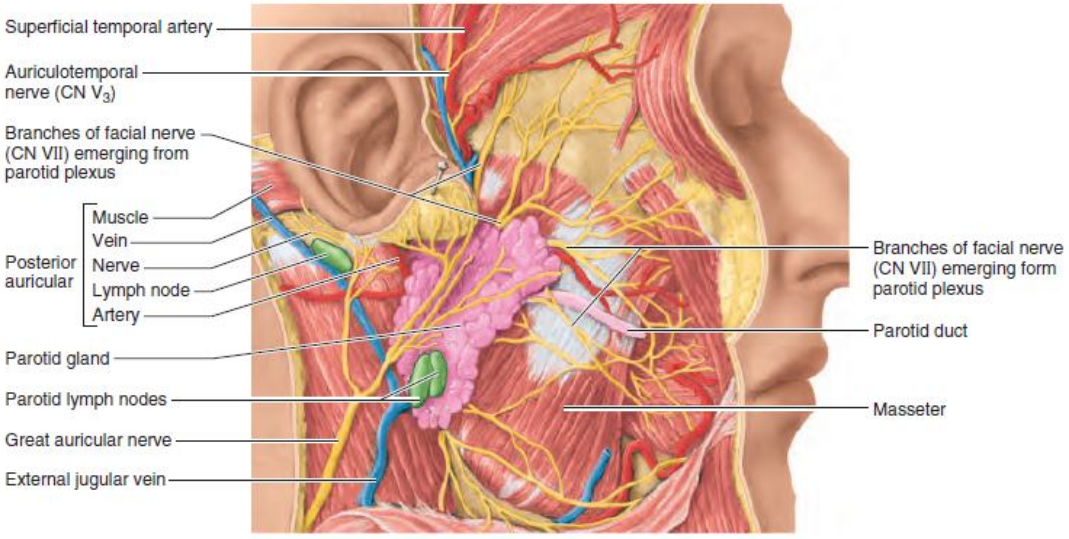


Figure.2.3 Show Dissection of face and lymphatic drainage of head

2.1.1.2 External Acoustic Meatus

The external acoustic meatus is an ear canal that leads inward through the tympanic part of the temporal bone from the auricle to the tympanic

membrane, a distance of 2–3 cm in adults .
The lateral third of this slightly S-shaped canal is cartilaginous and is lined with skin that is continuous with the auricular skin. The medial two thirds of the meatus is bony and lined with thin skin that is continuous with the external layer of the tympanic membrane. The ceruminous and sebaceous glands in the subcutaneous tissue of the cartilaginous part of the meatus produce cerumen (earwax).

2.1.1.3The tympanic membrane

approximately 1 cm in diameter, is a thin, oval semitransparent membrane at the medial end of the external acoustic meatus. This membrane forms a partition between the external acoustic meatus and the tympanic cavity of the middle ear. The tympanic membraneis covered with thin skin externally and mucous membrane of the middle ear internally. Viewed through an otoscope, the tympanic membrane has a concavity toward the external acoustic meatus with a shallow, cone-like central depression, the peak of which is the umbo .
The central axis of the tympanic membrane passes perpendicularly through the umbo like the handle of an umbrella, running anteriorly and inferiorly as it runs laterally. Thus, the tympanic membrane is oriented like a mini radar or satellite dish positioned to receive signals coming from the ground in front and to the side of the head. Superior to the lateral process of the malleus (one of the small ear bones, or auditory ossicles, of the middle ear), the membrane is thin and is called the pars flaccida (flacid part. It lacks the radial and circular fibers present in the remainder of the membrane, called the pars tensa (tense part). The flaccid part forms the lateral wall of the superior recess of the tympanic cavity.

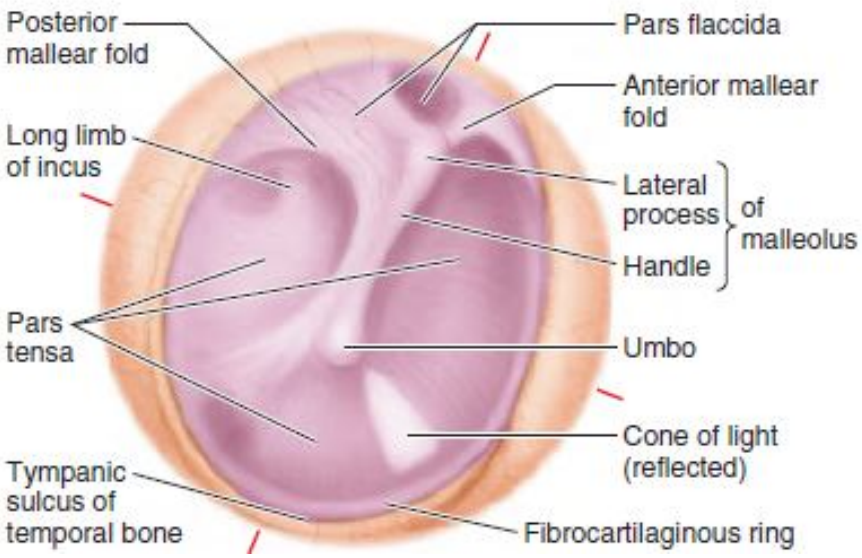


figure 2.4 show An otoscopic view of the right tympanic membrane is demonstrated.

The tympanic membrane moves in response to air vibrations that pass to itthrough the external acoustic meatus. Movements of the membrane are transmitted by the auditory ossicles through the middle ear to the internal ear .The external surface of the tympanic membrane is supplied mainly by the auriculotemporalnerve,a branch of CN V3. Some innervation is supplied by a small auricular branch of the vagus (CN X). The internal surface of the tympanic membrane is supplied by the glossopharyngeal nerve (CN IX).

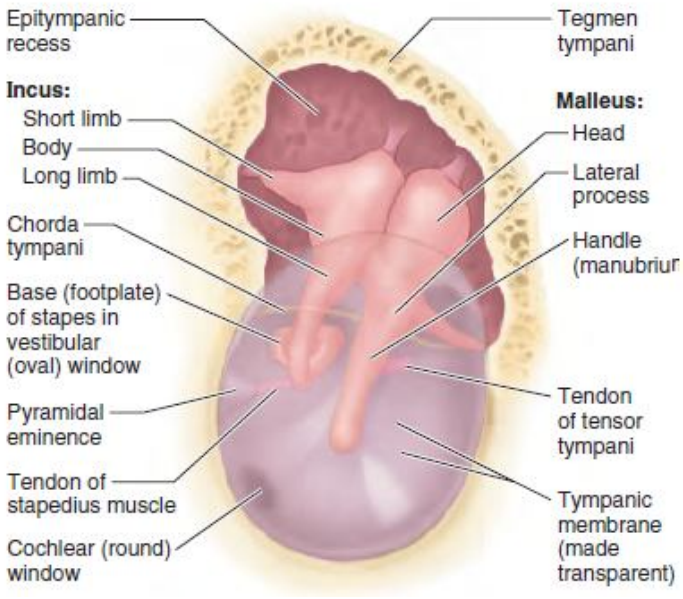


Figure2.5 show The tympanic membrane

2.1.2 Middle Ear

The tympanic cavity or cavity of the middle ear is the narrow air-filled chamber in the petrous part of the temporal bone .

The cavity has two parts: the tympanic cavity proper, the space directly internal to the tympanic membrane, and the epitympanic recess, the space superior to the membrane. The tympanic cavity is connected anteromedially with the nasopharynx by the pharyngotympanic tube and posterosuperiorly with the mastoid cells through the mastoid antrum .

The tympanic cavity is lined with mucous membrane that is continuous with the lining of the pharyngotympanic tube, mastoid cells, and mastoid antrum. The contents of the middle ear are the:

• Auditoryossicles (malleus, incus, and stapes).

• Stapedius and tensor tympani muscles.

• Chorda tympani nerve, a branch of CN VII.

• Tympanic plexus of nerves.

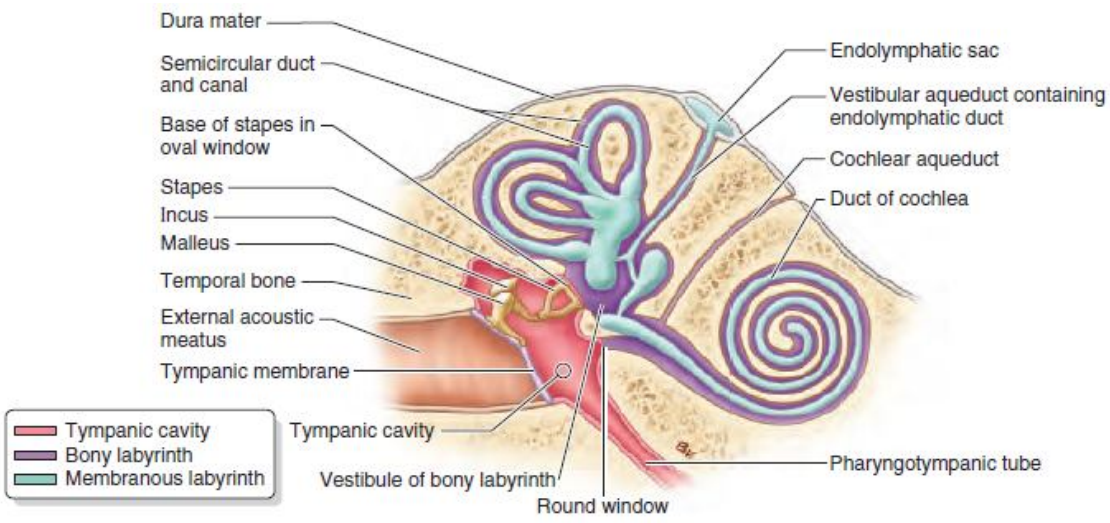


Figure 2.6show .the middle and internal parts of the ear

2.1.2.1 Walls of tympanic cavity

The middle ear is shaped like a lozenge or narrow box with concaveides. It has six walls .

1. The tegmental wall (roof) is formed by a thin plate of bone, the tegmen tympani, which separates the tympanic cavity from the dura mater on thefloor of the middle cranial fossa.

2. The jugular wall (floor) is formed by a layer of bone that separates the tympanic cavity from the superior bulb of the internal jugular vein.

3. The membranous (lateral) wall is formed almost entirely by the peaked convexity of the tympanic membrane; superiorly it is formed by the ateral bony wall of the epitympanic recess. The handle of the malleus is ttached to the tympanic membrane, and its head extends into the epitympanic recess.

4. The labyrinthine (medial) wall (medial wall) separates the tympanic cavity from the internal ear. It also features the promontory of thelabyrinthine wall, formed by the initial part (basal turn) of the cochlea,

and the oval and round windows, which, in a dry cranium, communicate with the internal ear.

5. The mastoid wall (posterior wall) features an opening in its superior part, the aditus (L. access) to the mastoid antrum, connecting the tympanic cavity to the mastoid cells; the canal for the facial nerve descends between the posterior wall and the antrum, medial to the aditus.
6. The anterior carotid wall separates the tympanic cavity from the carotid canal; superiorly, it has the opening of the pharyngotympanic tube and the canal for the tensor tympani.

The mastoid antrum is a cavity in the mastoid process of the temporal bone The antrum (L. from G., cave), like the tympanic cavity, is separated from the middle cranial fossa by a thin plate of the temporal bone, called the tegmen tympani. This structure forms the tegmental wall (roof) for the ear cavities and is also part of the floor of the lateral part of the middle cranial fossa. The mastoid antrum is the common cavity into which the mastoid cells open. The antrum and mastoid cells are lined by mucous membrane that is continuous with the lining of the middle ear. Antero - inferiorly, the antrum is related to the canal for the facial nerve.

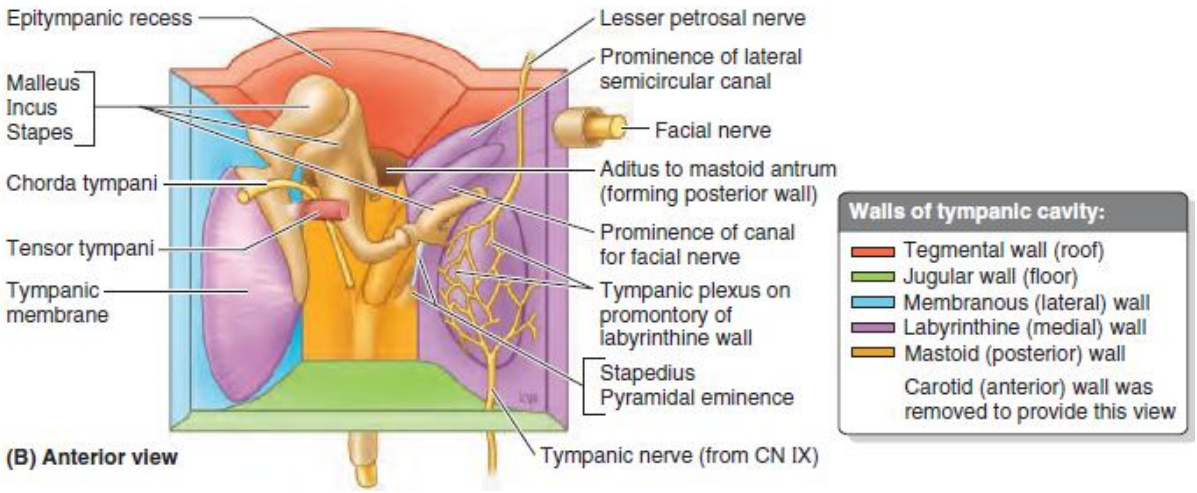


Figure 2.7show Walls of tympanic cavity.

2.1.2.2Pharyngotympanic Tube

The pharyngotympanic tube (auditory tube) connects the tympanic cavity to the nasopharynx, where it opens posterior to the inferior nasal meatus. The posterolateral third of the tube is bony, and the remainder is cartilaginous.

The pharyngotympanic tube is lined by mucous membrane that is continuous posteriorly with that of the tympanic cavity and anteriorly with that of the nasopharynx.

The function of the pharyngotympanic tube is to equalize pressure in the middle ear with the atmospheric pressure, thereby allowing free movement of the tympanic membrane.

By allowing air to enter and leave the tympanic cavity, this tube balances the pressure on both sides of the membrane.

Because the walls of the cartilaginous part of the tube are normally in apposition, the tube must be actively opened. The tube is opened by theexpanding girth of the belly of the levatorvelipalatini as it contracts longitudinally, pushing against one wall while the tensor velipalatinipulls

on theother. Because these are muscles of the soft palate, equalizing pressure (“popping the eardrums”) is commonly associated with activities such as yawning and swallowing.

The arteries of the pharyngotympanic tube are derived from the ascending pharyngeal artery, a branch of the external carotid artery, and the middle meningeal artery and artery of the pterygoid canal, branches of the maxillary artery .

The veins of the pharyngotympanic tube drain into the pterygoid venous plexus.

Lymphatic drainage of the tube is to the deep cervical lymph nodes. The nerves of the pharyngotympanic tube arise from the tympanic plexus, which is formed by fibers of the glossopharyngeal nerve (CN IX). Anteriorly, the tube also receives fi bers from the pterygopalatineganglion .

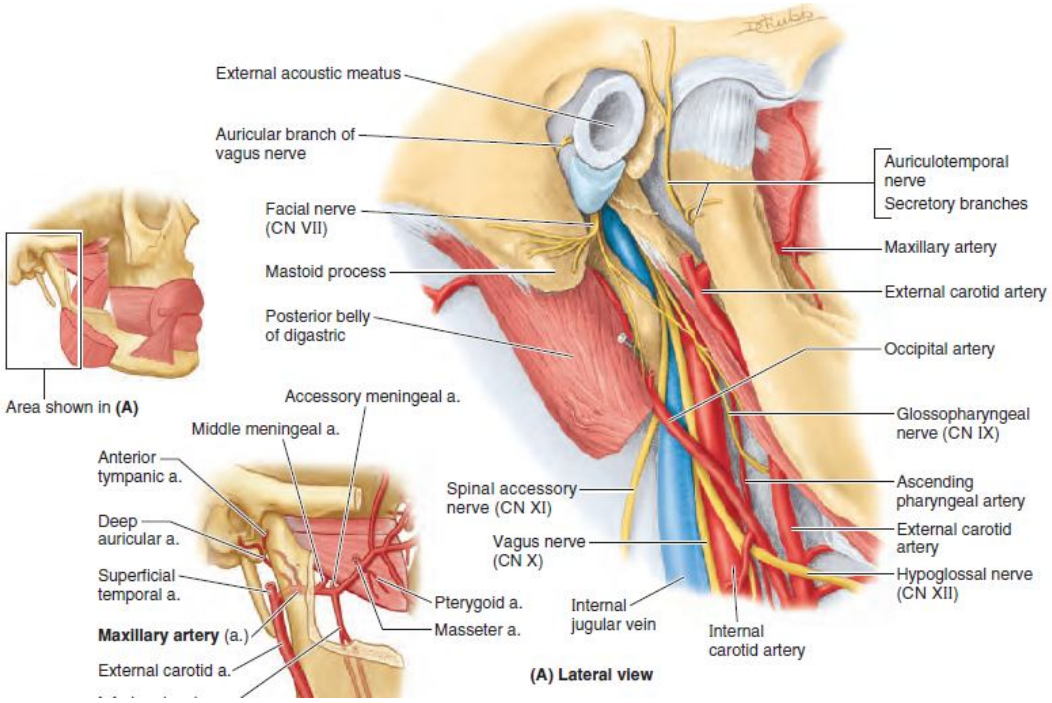


Figure 2.8 show Neurovascular structures in vicinity of external and middle ear.

2.1.2.3 Auditory Ossicles

The auditory ossicles form a mobile chain of small bones across the tympanic cavity from the tympanic membrane to the oval window (L. fenestra vestibuli), an oval opening on the labyrinthine wall of the tympanic cavity leading to the vestibule of the bony labyrinth . These ossicles are the first bones to be fully ossified duringdevelopment and are essentially mature at birth. The bonefrom which they are formed is exceptionally dense (hard).

The ossicles are covered with the mucous membrane lining the tympanic cavity; but unlike other bones, they lack a surrounding layer of osteogenicperiosteum.

2.1.2.3.1**Malleus**.

The malleus (L. a hammer) attaches to the tympanic membrane. The rounded superior head of the malleus lies in the epitympanic recess .The neck of the malleus lies against the flaccid part of the tympanicmembrane, and the handle of the malleusis embedded in the tympanic membrane, with its tip at the umbo; thus themalleus moves with the membrane. The head of the malleus articulates with the incus; the tendon of the tensor tympani inserts into its handle near the neck. The *chorda tympani*crosses the medial surface of the neck of the malleus. The malleus functions as a lever, with the longer of its two processes and its handle attached to the tympanic membrane.

2.1.2.3.2**Incus.**

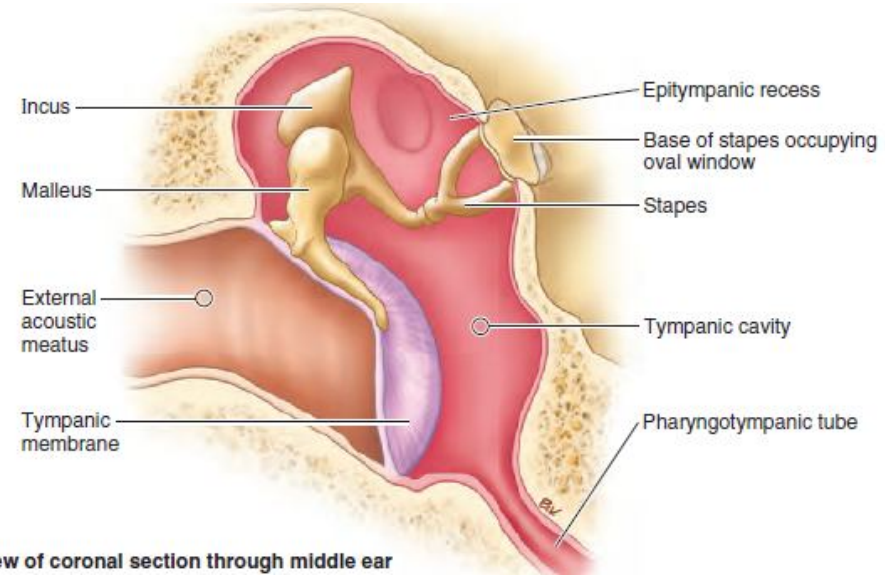
The**incus** (L. an anvil) is located between the malleus and the stapes and articulates with them. It has a body and two limbs. Its large bodylies in the epitympanicrecess ,where it articulates with the head of the malleus. The long limblies parallel to the handle of the malleus, and its interior end

articulates with the stapes by way of the lenticular process, a medially directed projection.

The short limb is connected by a ligament to the posterior wall of the tympanic cavity.

2.1.2.3.3 Stapes.

The **stapes** (L. stirrup) is the smallest ossicle. It has a head, two limbs, and a base Its head, directed laterally, articulates with the incus . The **base** (foot plate) of the stapes fits into the oval windowon the medial wall of the tympanic cavity. The oval base is attached to the margins of the oval window. The base of the stapes is considerably smaller than the tympanic membrane; as a result, the vibratory force of the stapes is increased approximately 10 times over that of the tympanic membrane. Consequently, the auditory ossicles increase the force but decrease the amplitude of the vibrations transmitted from the tympanic membrane through the ossicles to the internal ear .



(A) Anterior view of coronal section through middle ear

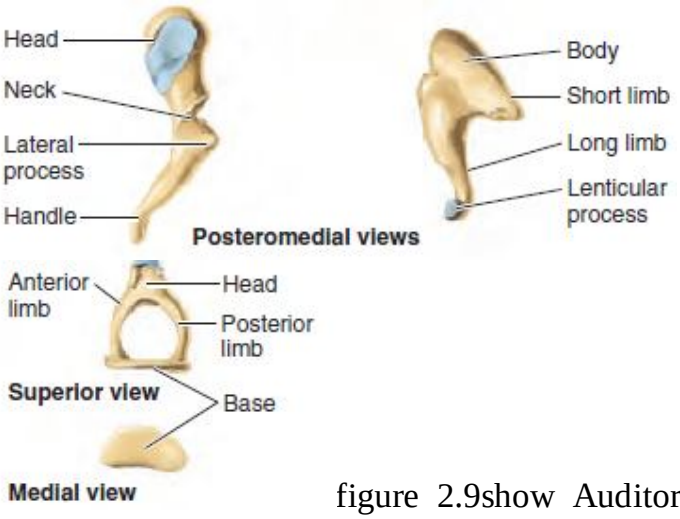


figure 2.9show Auditory ossicles.

2.1.2.4 Muscles Associated with Auditory Ossicles.

Two muscles dampen or resist movements of the auditory ossicles; one also dampens movements (vibration) of the tympanic membrane. The **tensor tympani** is a short muscle that arises from the superior surface of the cartilaginous part of the pharyngotympanic tube, the greater wing of the sphenoid, and the petrous part of the temporal bone . The muscle inserts into the handle of the malleus. The tensor tympani pulls the handle medially, tensing the tympanic membrane and reducing the amplitude of its oscillations. This action tends to prevent damage to the internal ear when one is exposed to loud sounds. The tensor tympani is supplied by the mandibular nerve (CN V3). The **stapedius**is a tiny muscle inside the **pyramidaleminence** (pyramid), a hollow, cone-shaped prominence on the posterior wall of the tympanic cavity . Its tendon enters the tympanic cavity by emerging from a pinpoint foramen in the apex of the eminence and inserts on the neck of the stapes. The stapedius pulls the stapes posteriorly and tilts its base in the oval

window,thereby tightening the anular ligament and reducing the oscillatory range. It also prevents excessive movement of the stapes. The nerve to the stapedius arises from the facial nerve (CN VII).

2.1.3 Internal Ear

The **internal ear** contains the **vestibulocochlear organ** concerned with the reception of sound and the maintenanceof balance. Buried in the petrous part of the temporal bonethe internal ear consists of the sacsand ducts of the membranous labyrinth. The membranous labyrinth, containing endolymph, is suspended within the perilymph-filled bony labyrinth, either by delicate filaments similar to the fi laments of arachnoid mater that traverse the subarachnoid space or by the substantial spiral ligament. It does not float. These fluids are involved in stimulating the end organs for balance and hearing, respectively.

2.1.3.1 Bony Labyrinth

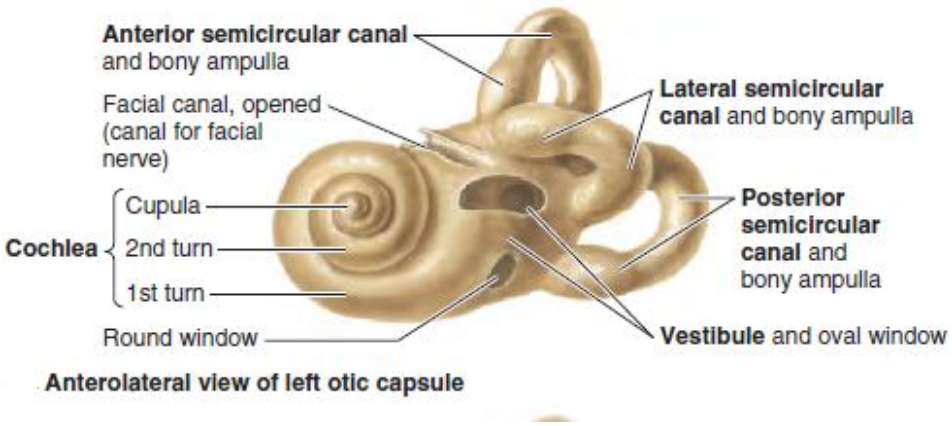
The **bony labyrinth** is a series of cavities (cochlea, vestibule, and semicircular canals) contained within the otic capsule of the petrous part of the temporal bone .

The **otic capsule** is made of bone that is denser than the remainder of the petrous temporal bone and can be isolated (carved) from it using a dental drill. The otic capsule is often erroneously illustrated and identified as being the bony labyrinth. However, the bony labyrinth is the fluid filled space,which is surrounded by the otic capsule, and is most accurately represented by a cast of the otic capsule after removal of the surrounding bone.

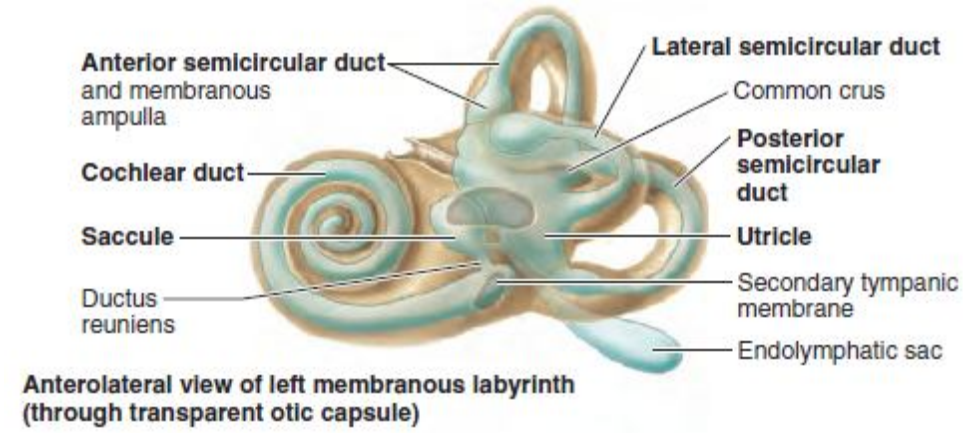
Cochlea.

The **cochlea** is the shell-shaped part of the bony labyrinth that contains the **cochlear duct** .

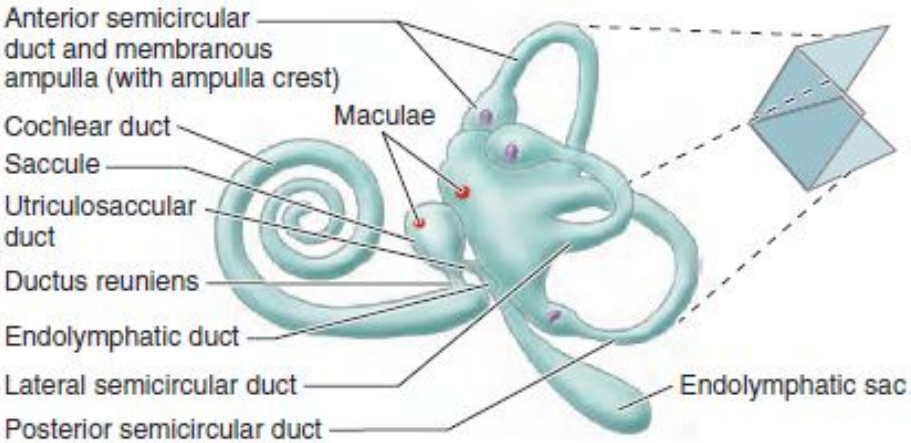
the part of the internal ear concerned with hearing. The **spiralcanal of the cochlea** begins at the vestibule and makes 2.5 turns around a bony core, the **modiolus**, the cone-shaped core of spongy bone about which the spiral canal of the cochlea turns. The modiolus contains canals for blood vessels and for distribution of the branches of the cochlear nerve. The apex of the cone-shaped modiolus, like the axis of the tympanic membrane, is directed laterally, anteriorly, and inferiorly. The large basal turn of the cochlea produces the *promontory of the labyrinthine wall* of the tympanic cavity . At the basal turn, the bony labyrinth communicates with the subarachnoid space superior to the jugular foramen through the **cochlear aqueduct** . It also features the round window (L. fenestra cochleae), closed by the secondary tympanic membrane.



Anterolateral view of left otic capsule



Anterolateral view of left membranous labyrinth (through transparent otic capsule)



Anterolateral view of left membranous labyrinth

Figure 2.10show Bony and membranous labyrinths of internal ear.

2.1.3.1.1 Vestibule of Bony Labyrinth.

The vestibule of the bony labyrinth is a small oval chamber (approximately 5 mm long) that contains the utricle and sacculeand parts of the balancing apparatus (vestibular labyrinth).The vestibule features the *oval window* on its lateral wall,occupied by the base of the stapes. The vestibule is continuouswith the bony cochlea anteriorly, the semicircular canalsposteriorly, and the posterior cranial fossa by the vestibular aqueduct .

The aqueduct extends to theposterior surface of the petrous part of the temporal bone,where it opens posterolateral to the *internal acoustic meatus*The vestibular aqueduct transmits the endolymphatic ductand two smallblood vessels.

2.1.3.1.2 Semicircular Canals.

The semicircular canals (anterior, posterior, and lateral) communicate with the vestibuleof the bony labyrinth .The canals lieposterosuperior to the vestibule into which they open; theyare set at right angles to each other. The canals occupy threeplanes in space. Each semicircular canal forms approximatelytwo thirds of a circle, and is approximately 1.5 mmin diameter, except at one end where there is a swelling, thebony ampulla. The canals have only five openings into thevestibule because the anterior and posterior canals have onelimb common to both. Lodged within the canals are the semicircularducts

2.1.3.2 Membranous Labyrinth

The membranous labyrinth consists of a series of communicating sacs and ducts that are suspended in the bony labyrinth .

The labyrinth contains endolymph**,** a watery fluid similar in composition to intracellular fluid, thus differing in composition from the surrounding perilymph (which is like extracellular fluid) that fills the remainder of thebony labyrinth. The membranous labyrinth—composed of two divisions, the vestibular labyrinth and the cochlear labyrinth—consists of more parts than does the bony labyrinth:

Vestibular labyrinth: utricle and saccule, two smallcommunicating sacs in the vestibule of the bony labyrinth three semicircular ducts in the semicircular canals

Cochlear labyrinth: cochlear duct in the cochlea.

The spiral ligament,a spiral thickening of the periosteal lining of the cochlear canal, secures the *cochlear duct* to the spiral canal of the cochlea The remainder of the membranous labyrinth is suspended by delicate filaments that traverse the perilymph.

The semicircular ductsopen into the utricle through five openings, reflective of the way the surrounding semicircular canals open into the vestibule. The utricle communicates with the saccule through the utriculosaccular duct,from which the endolymphatic duct arises . The sacculeis continuous with the cochlear duct through the ductusreuniens,a uniting duct. The utricle and saccule have specialized areas of sensory epithelium called maculae. The macula of the utricle (L. macula utriculi) is in the floor of the utricle, parallel with the base of the cranium, whereas the macula of the saccule (L. macula sacculi) is vertically placed on the medial wall of the saccule. The hair cells in the maculae are innervated by fi bers of the vestibular division of the vestibulocochlear nerve. The primary sensory neurons are in the vestibular ganglia,which

The endolymphatic duct traverses the vestibular aqueductand emerges through the bone of the posteriorcranial fossa, where it expands into a blind pouch called theendolymphatic sac.

Theendolymphatic sac is located under the dura mater on theposterior surface of the petrous part of the temporal bone.The sac is a storage

reservoir for excess endolymph, formedby the blood capillaries in the membranous labyrinth.

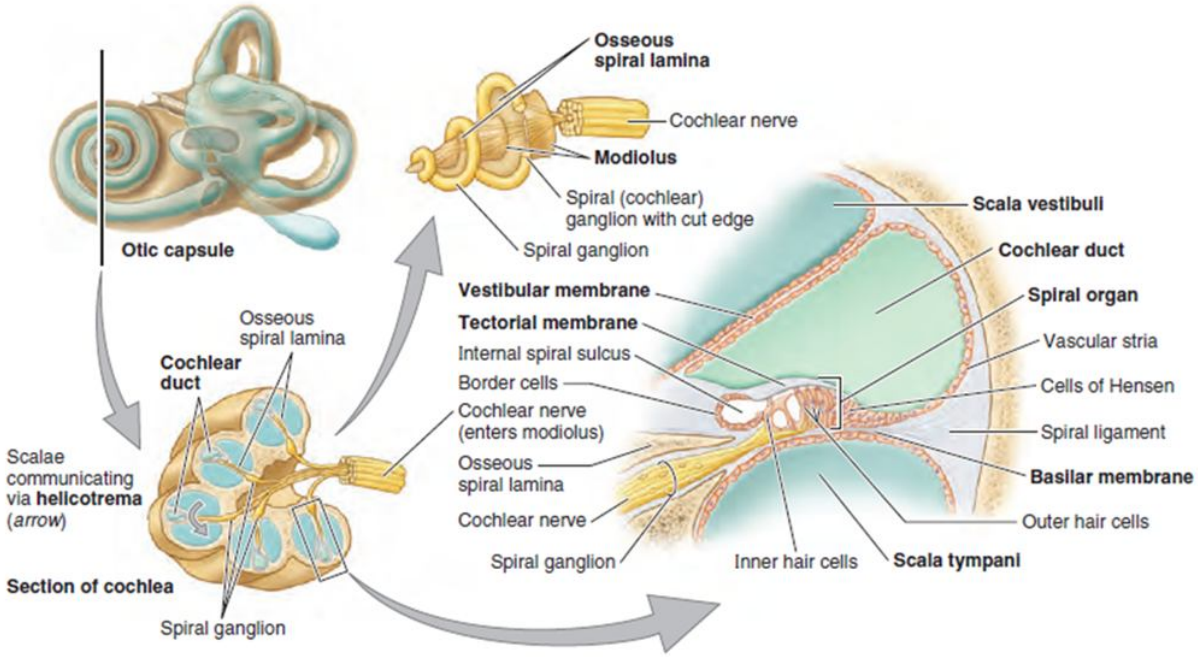


figure 2.11show Structure of cochlea.

2.1.3.3 Semicircular Ducts

Each semicircular duct has an ampulla at one end containing a sensory area, the ampullary crest (L. crista ampullari) .

The crests are sensors for recording movements of the endolymph in the ampulla resulting from rotation of the head in the plane of the duct. The hair cells of the crests, like those of the maculae, stimulate primary sensory neurons, whose cell bodies are in the vestibular ganglia.

The cochlear ductis a spiral tube, closed at one end and triangular in cross section. The duct is firmly suspended across the cochlear canal between the spiral ligamenton the external wall of the cochlear canal and the osseous spiral lamina of the modiolus.

Spanning the spiral canal in this manner, the endolymph-filled cochlear duct divides the perilymph-fi led spiral canal into two channels that are continuous at the apex of the cochlea at the helicotrema, a semilunar communication at the apex of the cochlea.

Waves of hydraulic pressure created in the perilymph of the vestibule by the vibrations of the base of the stapes ascend to the apex of the cochlea by one channel, the scalavestibuli.

The pressure waves then pass through the helicotrema and descend back to the basal turn of the cochlea by the other channel, the scala tympani**.** Here, the pressure waves again become vibrations, this time of the *secondarytympanic membrane* in the round window, and the energy initially received by the (primary) tympanic membrane is finally dissipated into the air of the tympanic cavity.

The roof of the cochlear duct is formed by the vestibular membrane. The floor of the duct is also formed by part of the duct, the basilar membrane,plus the outer edge of the osseousspiral lamina. The receptor of auditory stimuli is the spiral organ (of Corti), situated on the basilar membrane. .It is overlaid by the gelatinous tectorial membrane.The spiral organ contains hair cells, the tips of whichare embedded in the tectorial membrane. The organ isstimulated to respond by deformation of the cochlear ductinduced by the hydraulic pressure waves in the perilymph, which ascend and descend in the surrounding scalae vestibule and tympani.

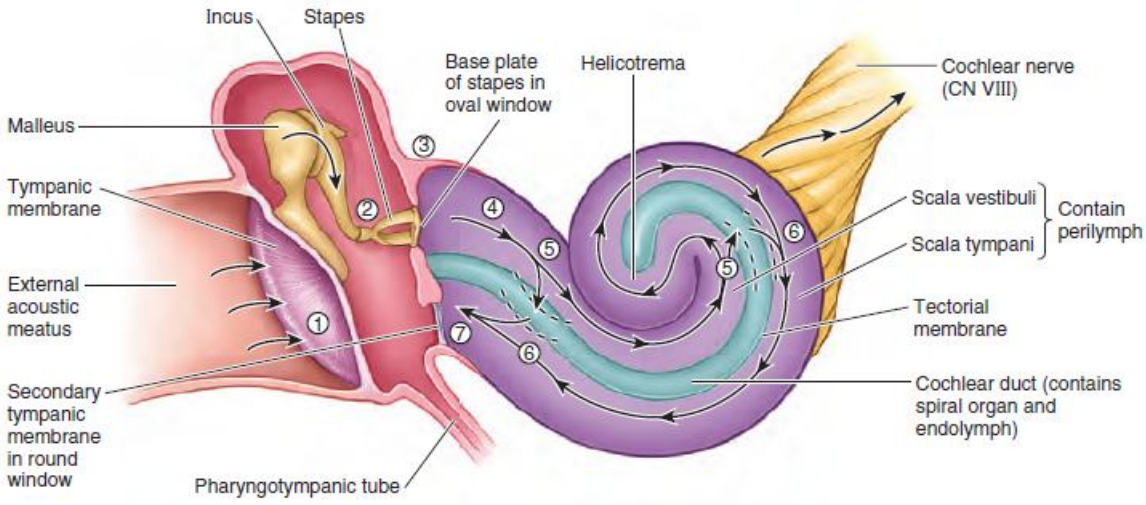


Figure 2.12show Sound transmission through the ear.

2.1.3.5 Internal acoustic meatus

The internal acoustic meatusis a narrow canal that runs laterally for approximately 1 cm within the petrous part of the temporal bone. The internal acoustic meatus openingis in the posteromedial part of this bone, in line with the external acoustic meatus. The internal acoustic meatus is closed laterally by a thin, perforated plate of bone that separates it from the internal ear. Through this plate pass the facial nerve (CN VII), the vestibulocochlear nerve (CN VIII) and its divisions, and blood vessels. The vestibulocochlear nerve divides near the lateral end of the internal acoustic meatus into two parts: a cochlear nerve and a vestibular nerve .

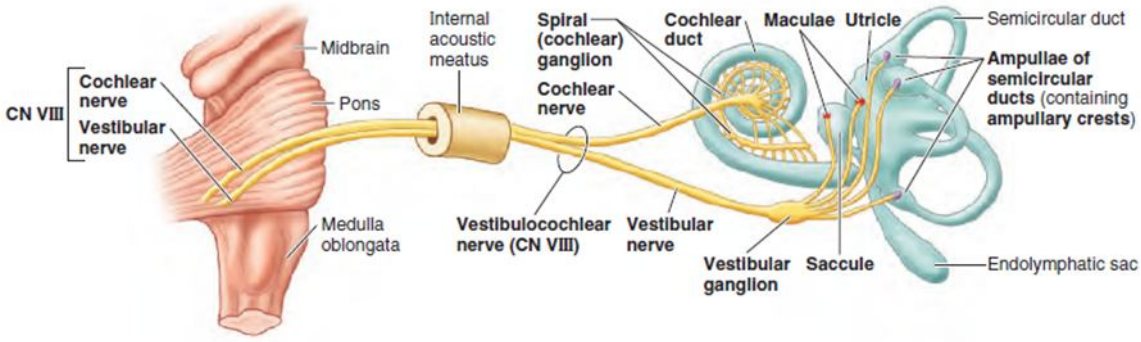


figure 2.13show Vestibulocochlear nerve.

2.2. Physiology of ear

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 mechanism to achieve this is complex. This chapter will deal mainly with the ear, first its structure and then its function, for it is the ear that is mainly at risk from hazardous sounds.

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. Because they are living, they are bathed in body fluid which provides them with energy, nutrients and

oxygen. Most sound is transmitted by a vibration of air. Vibration is poorly transmitted at the interface between two media which differ greatly in characteristic impedance (product of density of the medium and speed of sound within it, c), as for example air and water. The ear has evolved a complex mechanism to overcome this impedance mis-match, known as the sound conducting mechanism. The sound conducting mechanism is divided into two parts, an external and the middle ear, an external part which catches sound and the middle ear which is an impedance matching device.

2.2. 1 Sound conducting mechanisms

2.2.1. 1 The external Ear

The external 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 into 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 centimetres 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.

In life, skin sheds and is continuously renewing. Ear canal skin grows like a fingernail from the depths to the exterior so that the skin is shed into the waxy secretions in the outer part and falls out. This is the reason for not using cotton buds to clean the ear canal because very frequently they merely push the shed skin and wax deep into the canal, impacting it and obstructing hearing. 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.

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 millimetre thick. It covers a round opening about 1 centimetre 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.

2.2.1.2 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 inthe 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.

2.2. 2THE SOUND TRANSDUCING MECHANISM

2.2.2.1 The Inner Ear

2.2.2.1.1 Structure

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 millilitre. In this space lie up to 30,000 hair cells which transduce vibration into nervous impulses and about 19,000 nerve fibres 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.

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 scalavestibuli by Reissner's membrane, and on the opposite side from the scala tympani by the basilar membrane (see Figure 2.3). The basilar membrane is composed of a great number of taut, radially parallel fibres sealed between a gelatinous material of very weak shear strength. These fibres are resonant at progressively lower frequencies as one progresses 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. In summary then, 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. 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.

2.2.2.1.2 Function

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. As mentioned earlier, 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. 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. The copious nerve supply to the outer hair cells is overwhelmingly efferent, although the full function of the efferent pathways is not yet fully understood. It has been suggested that the purpose of the active feedback system which has been described is to maintain the lateral displacement of the stereocilia in the sub tectorial space within some acceptable limits.

2.2.3 THE PHYSIOLOGY OF HEARING

2.2.3.1 The Outer and Middle Ears

Let us deal first with the sound conducting mechanism. 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 one side 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. The head in humans is large in comparison to the size of the pinna so the role of the pinna is less than in some other mammals. Nonetheless, its 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. 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. Anyone who has their ear blocked even by the small pressure change of a rapid elevator ride knows the truth of this. 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.

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.

2.2.3.1 The Inner Ear

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.

As mentioned above 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. An explanation is thus provided for the observation that low frequency sounds, for example traffic noise, are very effective in masking high frequency sounds, for example the fricatives of speech, making telephones near busy streets difficult to use. How does the brain cope with intensity? The physiological range of intensity of the normal ear is huge. As a matter of interest it is the same as that of the eye when the responses of the cones and rods are considered together; thus the visual analogue is appropriate. It is as wide as seeing a candle flicker on a dark night at a hundred meters to looking indirectly into a bright sun. The range is so great that only the logarithmic response characteristic of variable rate processes and thus favored 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.

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, how do the inner hair cells respond to slight or moderate amounts of stimulation? Here the outer hair cells play a major 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 haircell 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. Thus, the most intense stimulus is produced at these frequencies and the outer hair cells which respond to these frequencies are most at risk from damage. 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.

2.2. 4CENTRAL AUDITORY PROCESSING

The nervous impulses are carried along the 8th (statico-acoustic nerve) from the cochlea to the brain stem. Here the nerve fibres reach nuclei where they relay with other nerve fibres. The fibres 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 fibres pass up the hind brain to the mid brain and the cerebral cortex. There are many central functions, some of which will be examined but most of which lie outside the scope of this chapter.

2..1. The Ability to Block Out Unwanted Sounds.

In a crowded noisy room a young person with normal hearing can tune in and out conversations at will. This is known technically as the cocktail party effect. The brain quite automatically adjusts time of arrival and intensity differences of sound from different signal sources so that the one which is wanted passes to the cortex and all others which do not meet these criteria are suppressed by feedback loops. This requires both good high frequency peripheral hearing, two ears and an additional central mechanism. Even in the presence of normal bilateral peripheral hearing, the elderly lose part of the central mechanism and find it difficult to listen in crowded rooms. This is compounded if there is some hearing loss.

2.5.2. Spatial Localization.

A normal human can localize quite accurately the source of the sound. One knows from what direction the sound is coming; one knows where to turn one's head to look for a speaker; as one knows where to look for an aeroplane or a bird. There are specific neurones which deal with this in the mid brain.

2.5.3. On and Off Sounds

Hearing has an alerting function especially to warning signals of all kinds. There are brain cells which respond only to the onset of a sound and others which respond only to the switching off of the sound, i.e. a change. Think only of being in an air conditioned room when the air conditioner turns on, one notices it. After a while it blends into the background and is ignored. When it switches off, again one notices it for a short time and then too the absence of sound blends into the background. These cells allow the ear to respond to acoustic change - one

adjusts to constant sound - change is immediately noticeable. This is true too with machinery and a trained ear notices change.

2.5.4. Interaction of Sound Stimuli with Other Parts of the Brain

Sound stimuli produce interaction with other parts of the brain to provide appropriate responses. Thus, a warning signal will produce an immediate general reaction leading to escape, a quickening of the heart rate, a tensing of the muscle and a readiness to move. A baby's cry will alert the mother in a way it does not alert others. The sound of martial music may lead to bracing movement of those to whom it is being played and induce fear and cowering in the hearts and minds of those at whom it is being played. Certain sounds can evoke anger, others pleasure. The point is that the sensations produced by hearing are blended into the body mechanism in the central nervous system to make them part of the whole milieu in which we live.

2.3.1 THE EXTERNAL EAR

2.3.1.1.EAC atresia.

The external canal starts to hollow out (recanalize) during the 6th month and progresses from medial to lateral Arrest of recanalization process leads to the various deformities seen in atresia Formed tympanic membrane and bony canal with a stenotic membranous canal leads to canal cholesteatoma

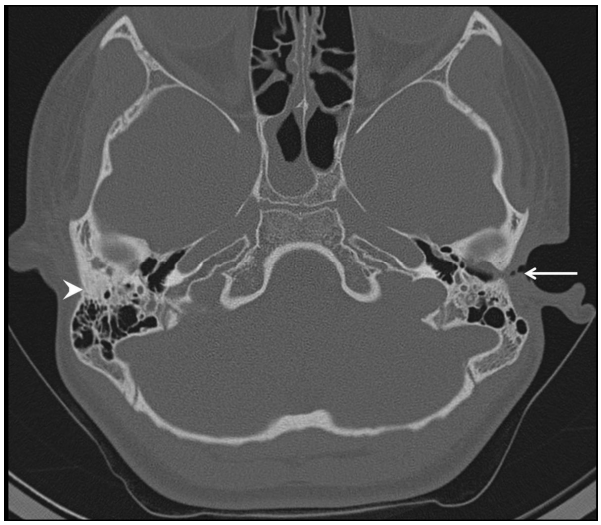


Figure 2.3.1 Axial HRCT image showing partial EAC atresia on left side (white arrow) andcomplete atresia on right side (white arrowhead)

2.3.1.2 Malignant external otitis

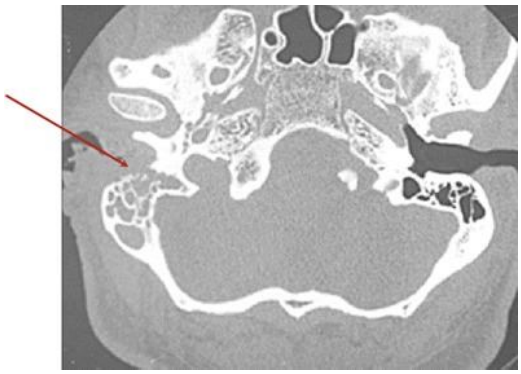


Figure 2.3.2Axial HRCT image showing Malignant external otitis. Axial CT scan in bone window demonstrates destruction of mastoid segment of petrous bone. There were also subtle cortical destructions visible in tympanic bone.

2.3.1.3 EAC Exostoses

Benign-appearing bony protuberances, arising from the osseous portions of EAC. They are found commonly in people with prolonged, repetitive exposure to cold water (“surfer’s ear”)HRCT of the temporal bone is the

examination of choice; intravenous contrast is not required to make the diagnosis

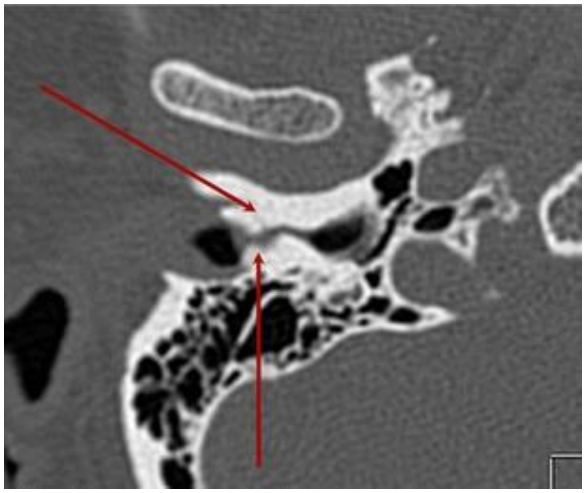


Figure 2.3.3 show Surfer's ear. Axial CT scan demonstrates broad-based overgrowth of osseous EAC (arrows)

2.3.1.4 EAC medial canal fibrosis

Post-inflammatory, acquired atresia of EAC. The disease is characterised by formation of fibrous tissue, overlying lateral surface of tympanic membrane. In many cases (~60%) it occurs bilaterally [4, 6]. Clinically the disease may be discrete, with conductive hearing loss, otorrhea and history of chronic otitis.Preferable imaging method Temporal bone HRCT is the examination of choice.Clinically relevant imaging findings

medial canal fibrosis typically is seen as a homogenous soft tissue against the tympanic membrane (Fig. 8a, b), there are no EAC bone changes

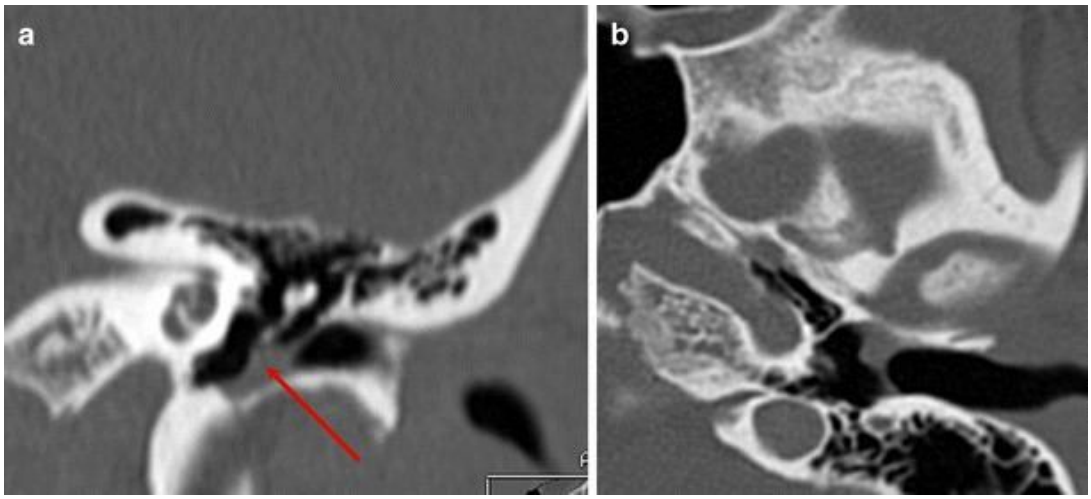


figure2.3.4show EAC medial canal fibrosis. a Coronal CT demonstrates soft tissue crescent abutting tympanic membrane (arrow)—classic CT findings. b On axial CT, soft tissue is visible, filling EAC and sparing middle ear cavity

2.3.1 EAC squamous cell carcinoma

Neoplasm in the EAC. This tumour has an aggressive nature and spreads along vascular and neural pathways, invading adjacent structures [15]. Most squamous cell carcinomas of the temporal bone occur in the 5th and 6th decades of life.

Symptoms these include otorrhea, otalgia, hearing loss and bleeding. Diagnosis is usually delayed because symptoms are similar to other benign otological conditions such as chronic suppurative otitis media or EAC cholesteatoma [15, 16] .

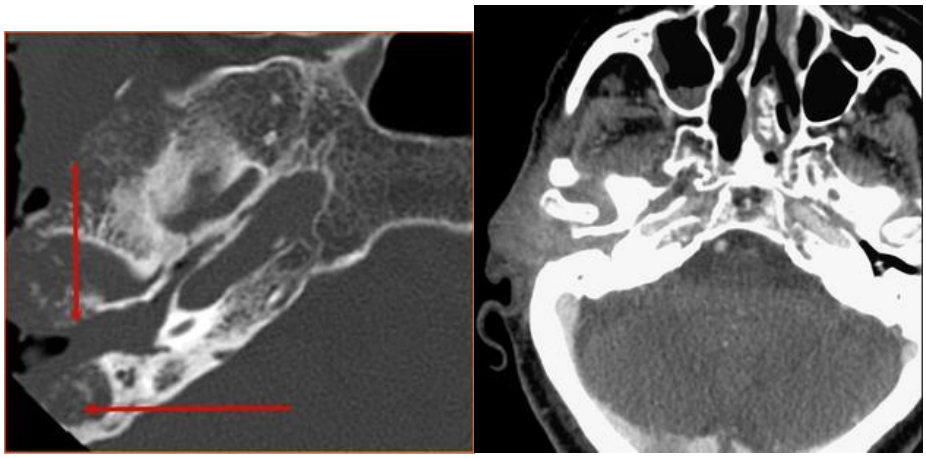


Figure 2.3.5show Squamous cell cancer of EAC. Axial contrast-enhanced CT demonstrates heterogenously enhancing soft tissue mass infiltrating auricle, parotid gland and EAC

2.3.2 THE MIDDLE EAR

2.3.2.1 Traumatic opacified middle ear

Trauma to the temporal bone is usually the result of a blunt head injury. Patients with temporal bone fracture may present at the time of trauma with evidence of basilar skull fracture, such as battle sign, raccoon eyes, or hemotympanum. In addition, they may complain of hearing loss or dizziness [18, 19]. If a temporal bone fracture initially goes unrecognized, delayed presentation may involve cerebrospinal fluid (CSF) otorrhea, hearing loss, or symptoms related to cranial nerve VII dysfunction.

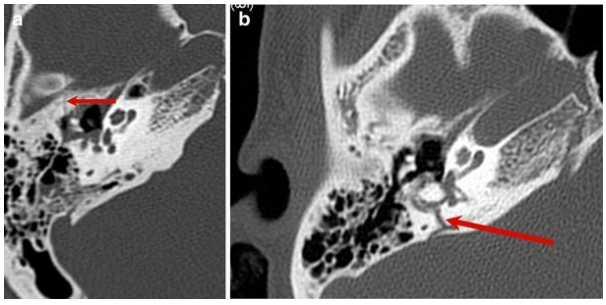


Figure 2.3.6show Temporal bone trauma. a Axial bone-window CT scan demonstrates fracture line limited to mastoid (arrow) and not affecting otic capsule structures. b Axial bone-window CT scan shows fracture with involvement of lateral semicircular canal (arrow) and vestibule.

2.3.2.2 Eustachian tube dysfunction (secretory otitis)

Persistent mucoid or serous middle ear effusion, in the absence of acute inflammation [21]. Eustachian tube dysfunction is well known to be related in the pathogenesis of secretory otitis. Secretory otitis is the most common disease in children, sometime it can be seen in adults. In children, this can occur purely from enlarged adenoids, with no pain or bacterial infection. In adults, secretory otitis may be found when a growing tumour in the nasopharynx blocks Eustachian tube opening [22]

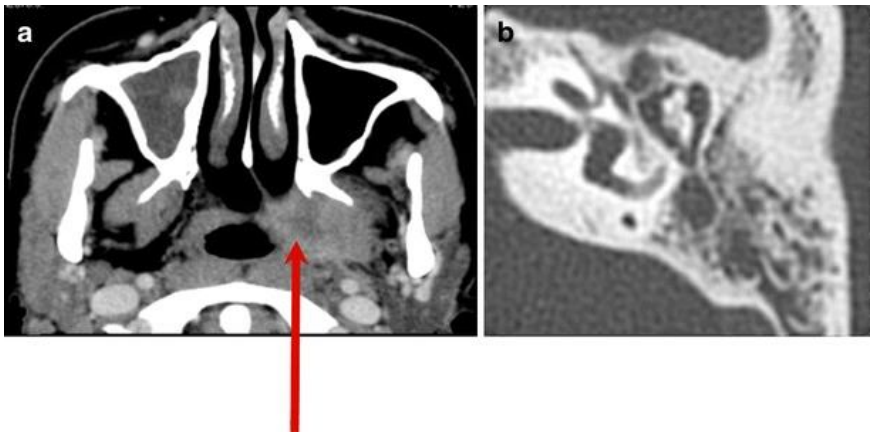


Figure 2.3.7show Middle ear secretory otitis. a Axial contrast-enhanced CT shows a mass filling left nasopharynx and compromising Eustachian tube patency. b Axial CT scan shows that left middle ear cavity and mastoid air cells are completely opacified

2.3.2.3 Chronic otitis media without cholesteatoma

In the setting of chronic middle ear inflammation, if there is no clinical suspicion of cholesteatoma, imaging studies are performed to evaluate: Reasons for conductive hearing loss (possible ossicular chain fixation or erosion)Tympanic cavity walls Semicircular canals, Facial nerve canal

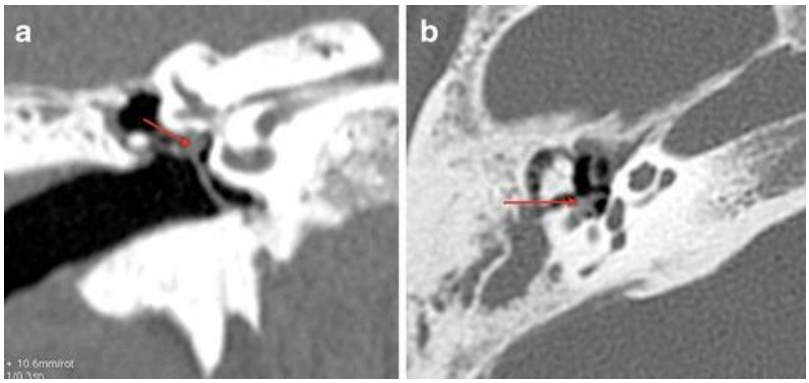


Figure 2.3.8show Chronic middle ear inflammation.(a) Coronal CT in bone window shows opacification around oval window niche, encasing stapes superstructure (arrow). (b) Soft tissue around stapes crura is visible on axial slice at the level of oval window.

2.3.2.4 Tympanosclerosis

Which reflects deposits of hyalinised collagen in the tympanic cavity. If it occurs in tympanic membrane, it is called myringosclerosis In the tympanic cavity, it may be present in any location, visible as focal calcified densities in the middle ear cavity, along tendons, also in direct apposition to the ossicularchain .

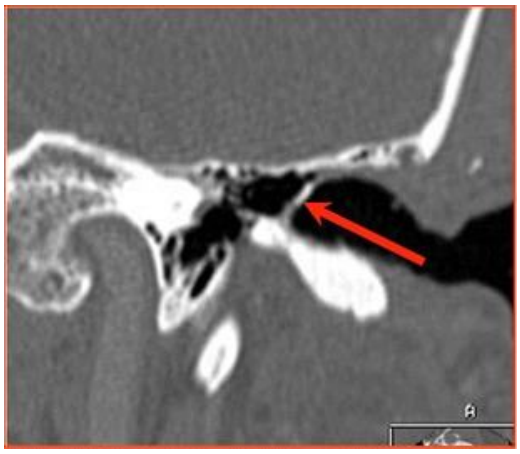


Figure 2.3.9 show Chronic middle ear inflammation. Axial CT scan demonstrates focal calcifications in thickened tympanic membrane (arrow). This is called myringosclerosis.

2.3.2.5 GlomusTympanicumParaganglioma(GTP)

Paraganglioma that arises in glomus bodies situated in the cochlear promontory. It is the most common primary neoplasm of the middle ear [29].

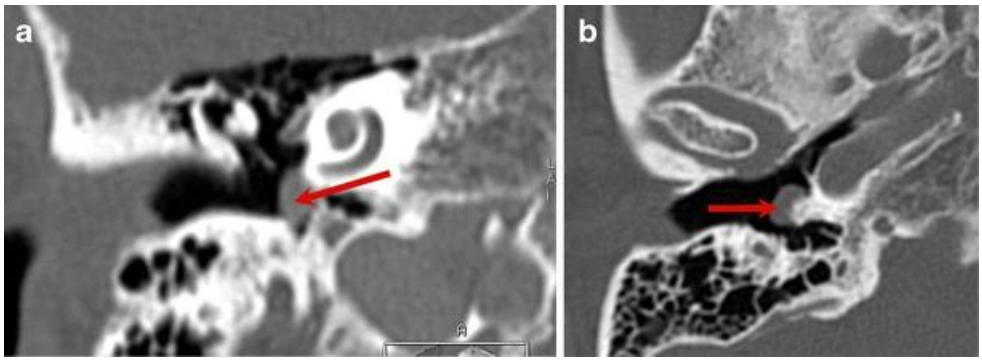


Figure2.3.10 showGlomustympanicumparaganglioma. a Coronal CT scan with no contrast enhancement demonstrates a small oval soft tissue mass (arrow) on cochlear promontory. b Axial CT scan shows small glomustympanicum in typical location (arrow)

2.3.2.6 Middle Ear Schwannomas

Tumourarising within middle ear cavity, originating from the facial nerve, chorda tympani nerve (7th branch), Jacobson nerve (9th branch), or Arnold nerve (10th branch), with the facial nerve being the most common nerve of origin.Schwannomas have been identified along the entire course of the facial nerve, although intratemporaltumours appear to be much more common than intracranial tumours. Within the temporal bone, the most common sites of involvement, in descending order, are the geniculate ganglion, labyrinthine segment, tympanic and vertical segments, and theinternal auditory canal [32}

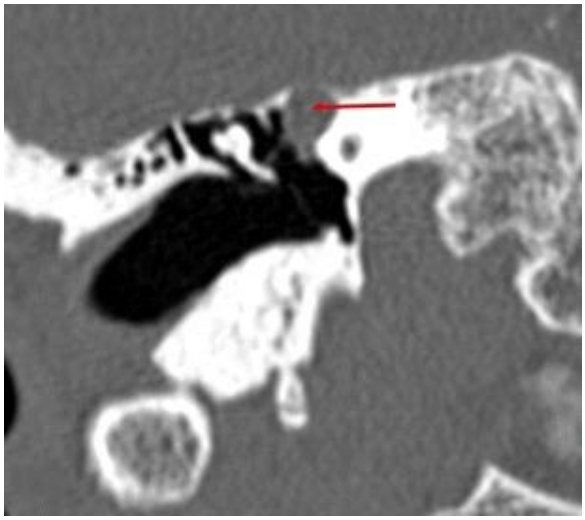


Figure2.3.11 showFacial nerve schwannoma. Axial CT image, bone window, demonstrates widening of geniculate ganglion, where homogenous, soft tissue mass is present, representing schwannoma of the 7th nerve (arrow

2.3.2.7 Acute Otitis Media

The most common causes of disease of the middle ear are respiratory infections producing acute or chronic otitis media. The middle ear, being part of the respiratory tract, is subjected to the same infections as the nose

and sinuses and is frequently involved when they become inflamed. The most common is acute otitis media, inflammation of the lining membrane of the middle ear, including the tympanic membrane. If the infection is severe, the middle ear lining, including the tympanic membrane, swells.

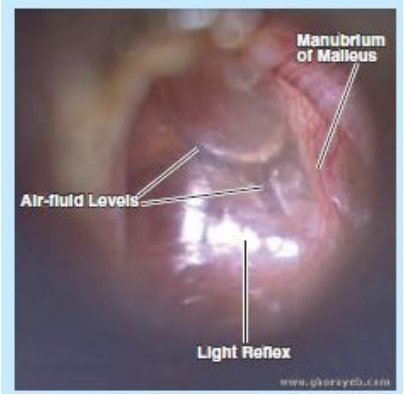
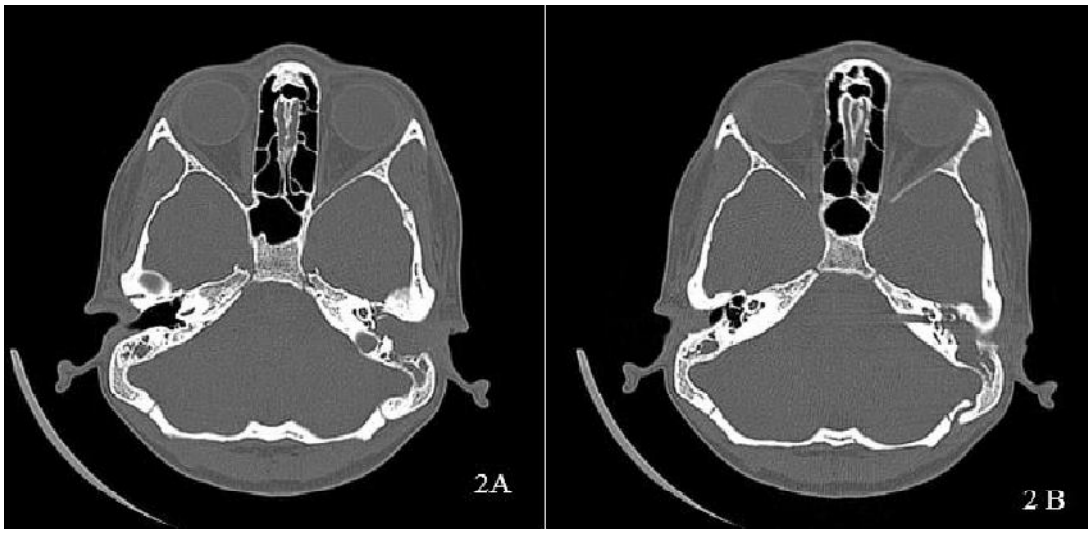


Figure 2.3.12 show Acute Otitis Media

2.3.2.8 Chronic Otitis Media

Sometimes the infection does not settle down and a chronic perforation occurs. This may produce a conductive hearing loss because there is not enough area of the tympanic membrane to catch sound. This type of perforation is usually central, and the middle ear lining becomes thickened and chronically inflamed. The ear is at risk for further acute infections, particularly if dirty water enters the ear. The hearing is also reduced, with a conductive loss of about 20 to 50 dB. The perforation usually happens in childhood and is often associated with a malfunction of the Eustachian tube.



Figures 2.3.13 show Axial sections (2A & B) show soft tissue opacification of left middle ear cavity and mastoid with erosion of ear ossicles

2.3.2.9Chronic Otitis Media with Cholesteatoma

In the presence of marginal perforations skin from the ear canal can migrate into the middle ear and space and into the attic surrounding the ossicles and into the mastoid. This skin sheds its surface cells which remain in the middle ear space, looking like white pearly material. If this gets wet or infected it swells and can produce a great deal of damage in the ear and surrounding structures such as the brain and the facial nerve, the nerve that supplies the muscles of the face, because it runs through the ear. Its diagnosis and management are outside the scope of this document.

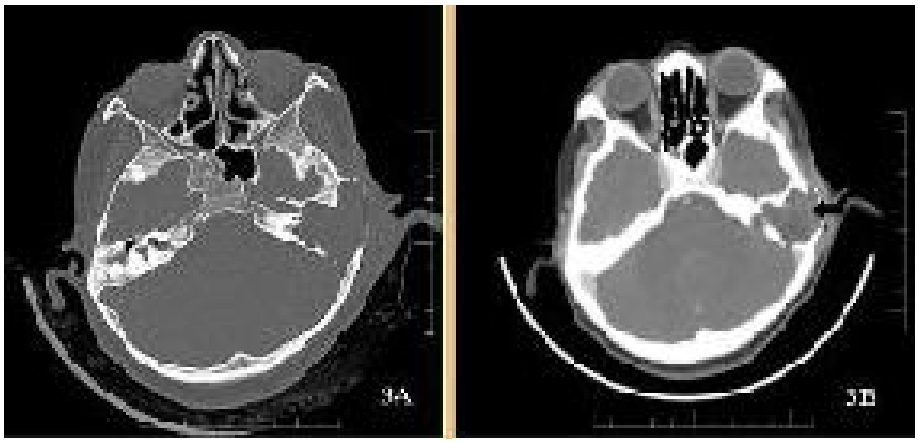


Figure 2.3.14 (A & B) show Axial CT temporal with Cholesteatoma

3.4.4. Chronic Suppurative Otitis Media

The persistent discharge of pus through a perforated tympanic membrane for more than two weeks.

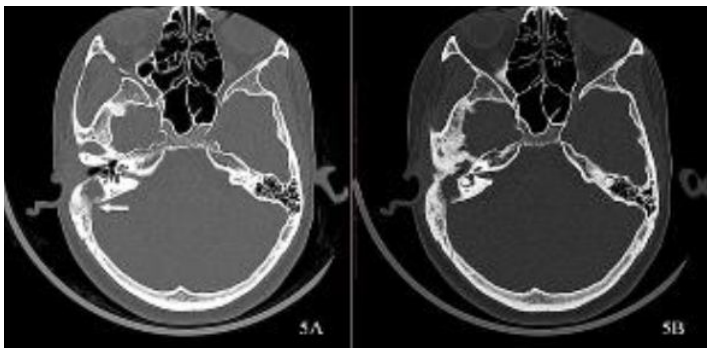


Figure2.3.15 show temporal bone CT, axial view,Chronic Suppurative Otitis Media(CSOM)

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2.3.3 THE INNER EAR

2.3.3 .1 Complete Labyrinthine Aplasia Complete labyrinthine aplasia, also known as Michel aplasia (because it was first described by Michel in 1863), is the most severe form of inner ear deformity; it is caused by developmental arrest of the oticplacodeduring the 3rd gestational week

(7–9,12,14,15).

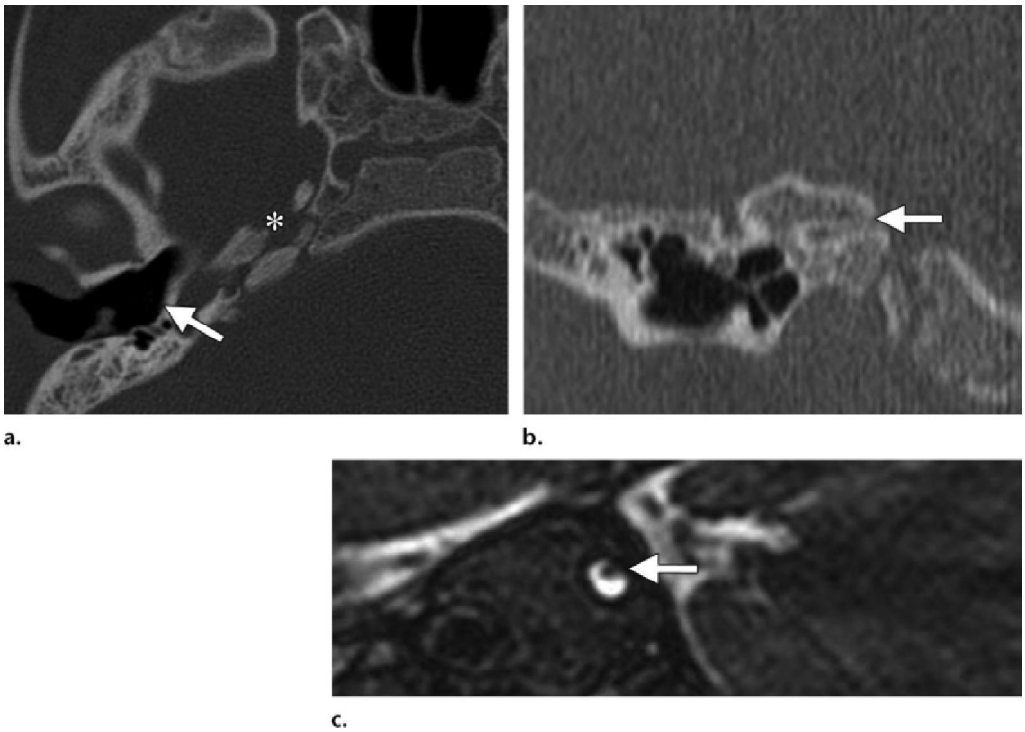
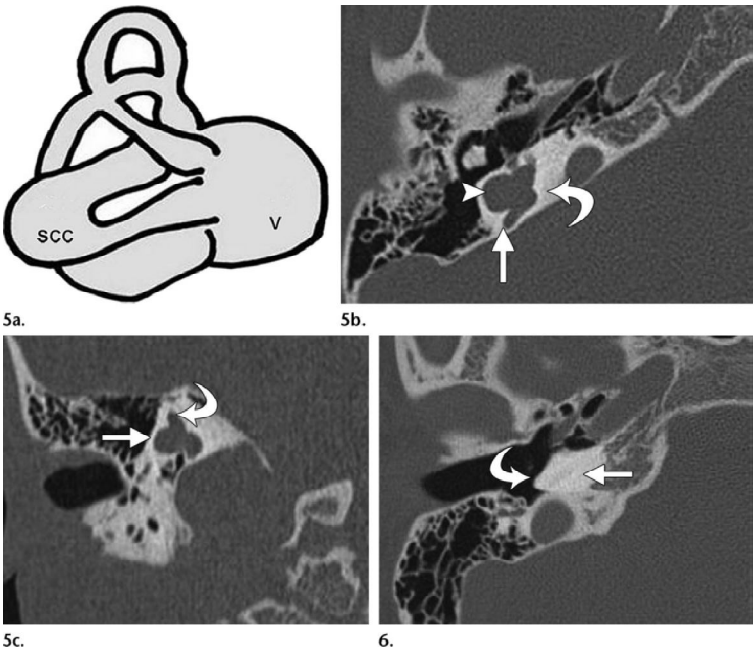


Figure 2.3.16Complete labyrinthine aplasia.

2.3.2 Cochlear Aplasia Cochlear aplasia, or complete absence of the cochlea, is most likely due toarrested development of the inner ear in the latter part of the 3rd week of gestation as described by some, in the 5th week (6).



.Figure2.3.17show axial CT show Cochlear aplasia.

2.3.3 A narrow IAC

May indicate a failure of eighth cranial nerve development. When a patienthas normal facial function and an IAC less than 3 mm in diameter, it is likely that thebony canal transmits only the facial nerve

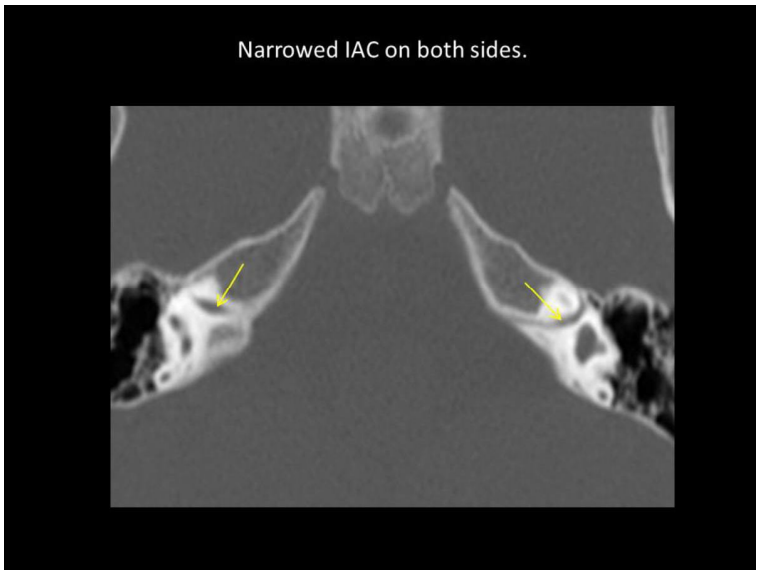


Figure 2.3.18 show Axial CT scan showing narrowed internal auditory canal (IAC) on both sides (yellow arrows)

(Department of Radiology, B J Medical College and Civil Hospital/Gujarat University, Ahmedabad 2012)

2.3.4 Acoustic Neuroma Benign tumor that develops from the eighth cranial (vestibulocochlear) nerve and grows within the auditory canal. Depending on the location and size of the tumor, progressive hearing loss, headache, facial numbness, dizziness, and an unsteady gait may result.

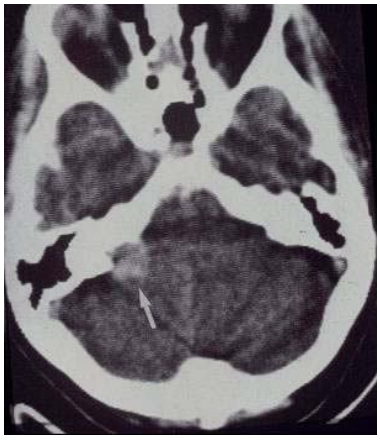


Figure 2.3.19show temporal bone CT, axial view, the arrow shows acoustic neuroma

2.3.5 Fistula lateral Semicircular Canal

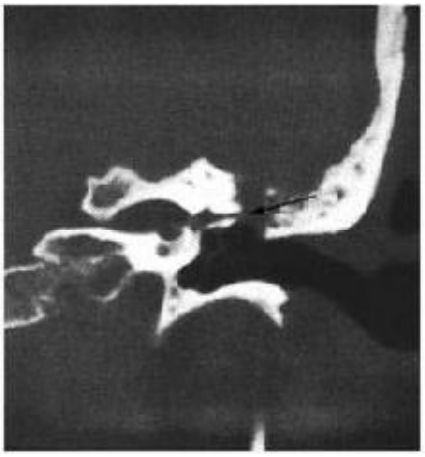


Figure 2.3.20show temporal bone CT, axial view ,arrow showFistula lateral Semicircular Canal(Department of Radiology, B J Medical College and Civil Hospital/Gujarat University, Ahmedabad 2012)

2.3.6 Mastoid Abscess

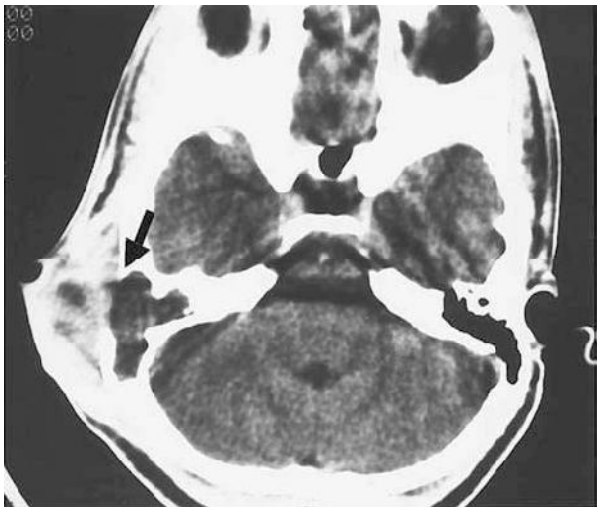


Figure2.3.21 show temporal bone CT, axial view ,arrow show mastoid abscess(Department of Radiology, B J Medical College and Civil Hospital/Gujarat University, Ahmedabad 2012)

2.3.7 Acutemastoiditis

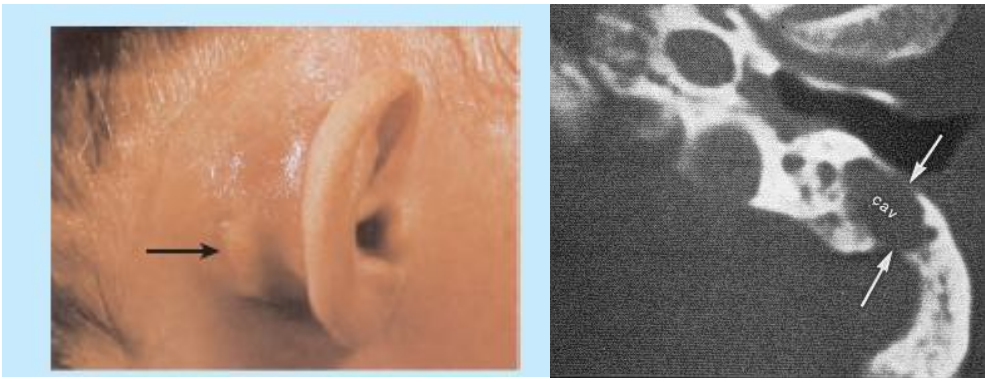


Figure2.3.22 show temporal bone CT, axial view ,arrows show acute mastoditis(Department of Radiology, B J Medical College and Civil Hospital/Gujarat University, Ahmedabad 2012)

2.3.8 Otosclerosis

Progressive deafness due to ossification in the bony labyrinth of the inner ear. Treatment for otosclerosis includes stapedectomy or stapedotomy, which is usually successful inrestoring hearing.

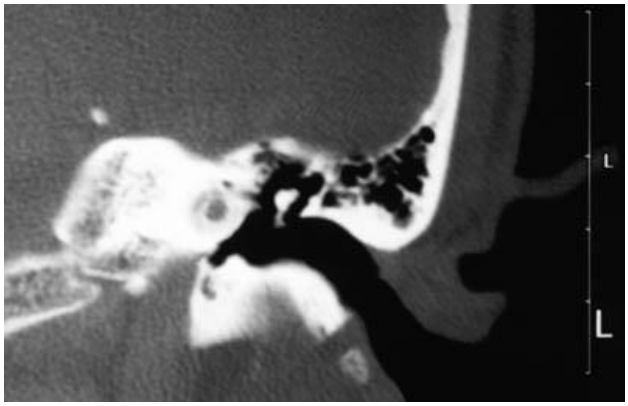


Figure 2.3.23show temporal bone CT, axial view , show otoscleorsis

2.3. 9Wide IAM

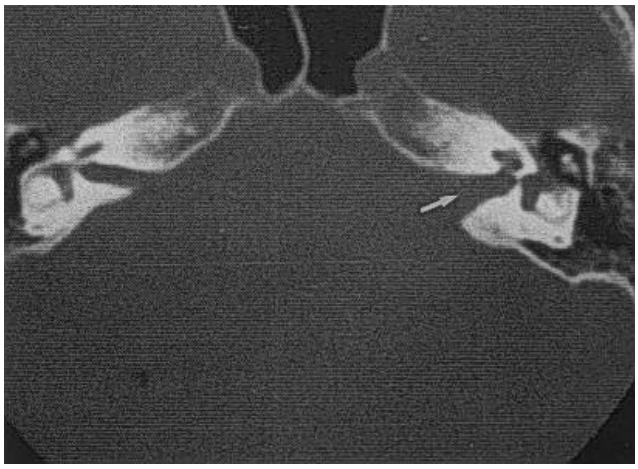


Figure 2.3.24show temporal bone CT, axial view ,Wide IAM(Department of Radiology, B J Medical College and Civil Hospital/Gujarat University, Ahmedabad 2012)

Tegmen erosion

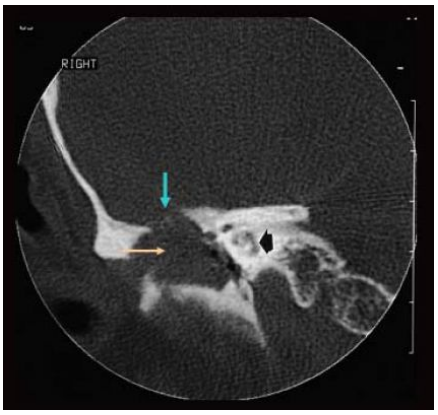


Figure2.3.25show temporal bone CT, axial view ,Tegmen erosion(Department of Radiology, B J Medical College and Civil Hospital/Gujarat University, Ahmedabad 2012)

2.3.4 Disorders Related To CSOM

2.3.4.1 Lateral sinus thrombophlebitis (sigmoid sinus thrombosis) Is an inflammation of the inner wall of the lateral venous sinus with formation of a thrombus and occurs as a complication of acute coalescent mastoiditis, masked mastoiditis or chronic suppuration of middle ear and cholesteatoma.

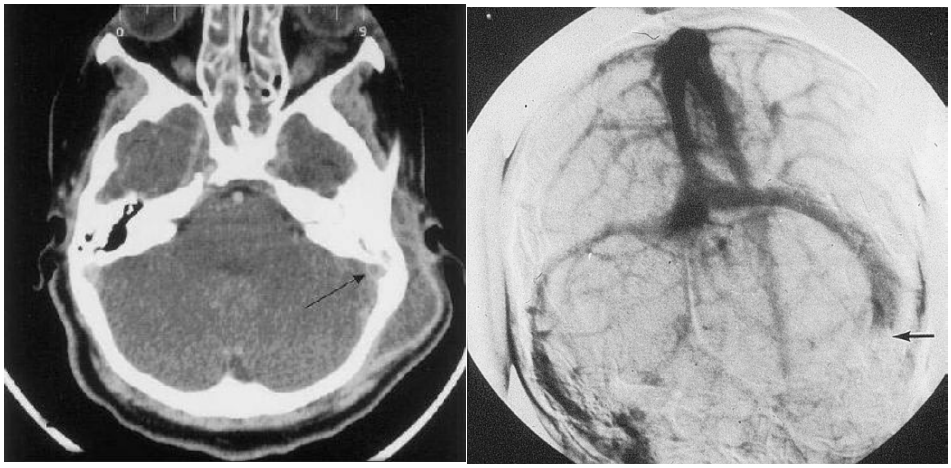


Figure2.3.26 show temporal bone CT, axial view ,Lateral sinus thrombophlebitis

2.3.4.2 Extradural Abscess.

Collection of pus between the bone and dura may occur both in acute and chronic infections of the middle ear giving rise to extradural abscess**.**

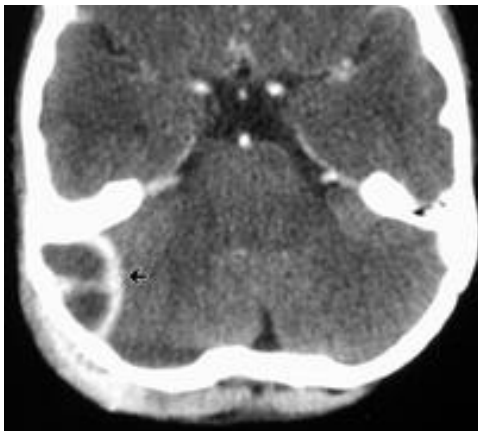


Figure 2.3.27show temporal bone CT, axial view showing Extradural Abscess.

2.3.4.3 Subdural Abscess.

Pus can also collect between the dura and arachnoid leading to subdural abscess.

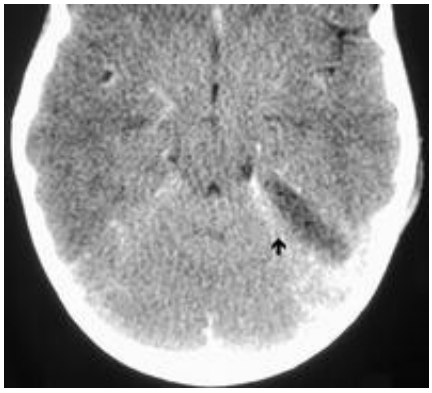


Figure2.3.28 show temporal bone CT, axial view Subdural Abscess.

2.3.4.4 Cerebral abscess

Is another serious complication of acute otitis media in children. It is often

associated with extradural abscess. Cerebellar abscessis a direct extension through the Trautmann's triangle or by retrograde thrombophlebitis. Generally, brain abscess is often associated with other complications, such as extradural abscess, peri-sinus abscess, meningitis, sinus thrombosis and labyrinthitis. Thus, the clinical picture may be overlapping.

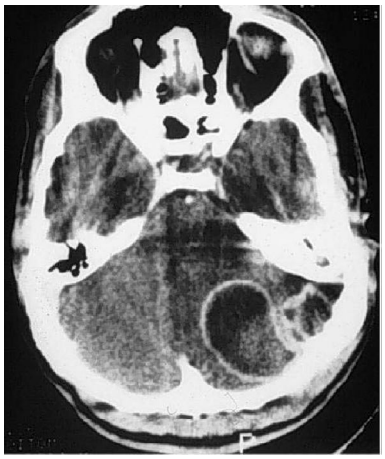


Figure 2.3.29show temporal bone CT, axial view showingCerebral abscess

2.3.4 .5 Otitis hydrocephalus

is characterized by raised intracranial pressure with normal cerebrospinal fluid findings [14] [37]. Its pathogenesis is thought to result from thrombosis from the lateral sinus extending to the superior sagittal sinus.

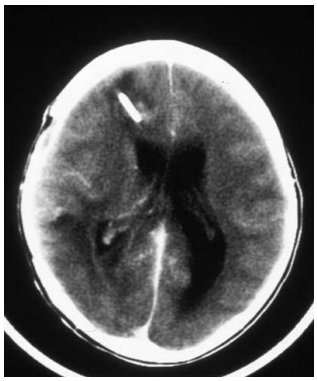


Figure 2.3.30show temporal bone CT, axial view showing Otitis hydrocephalus

2.4 CT Techniques for Temporal Bone Imaging

Multi-slice CT (MSCT) has been used for many years to image the temporal bone. However, the last couple of years Cone Beam CT (CBCT) is taking over that role.

2.4.1 CBCT of the Temporal Bone

CBCT uses a rotating gantry on which an X-ray tube and detector is attached. A cone-shaped X-ray beam is directed through the middle of the temporal bone onto a twodimensional X-ray detector. Because CBCT uses the entire FOV of the two-dimensional X-ray detector, only a single 360gantry rotation is necessary to acquire a 3D-volumetric data set. Of this data reconstructions can be made in any desired plane.

The advantages of CBCT over MSCT are the shorter examination time, high spatial resolution, and low radiation dose. It is also less sensitive for metallic and beam hardening artifacts because image acquisition is based on conventional radiographic images. The most important disadvantage ofCBCT is its high sensitivity for motion artifacts because the patient has to hold the head perfectly still during the acquisition time of

approximately 40s.

Many manufacturers construct cone beam scanners, and their parameters will differ. In some scanners the patients are in a sitting position. We chose a scanner with supine patient position. Fixation of the patient's head is done to prevent motion artifacts. We use the following parameters (only suggestive because scanner specific):

• 110 kV
• ±140 mAs
• Field of view 15 9 5 cm High Resolution
• Slice thickness 0.15 mm
• Scan time 40 s

Reconstructions in the axial and coronal planes are made of the axial raw data images with a slice thickness of respectively 0.3 and 1 mm using special software.

The technicians are instructed to make this reconstruction in a plane parallel to the lateral semicircular canal. This is the axial imaging set. The coronal imaging set is reconstructed exactly perpendicular to this axial set of images. On the most cranial axial image the superior semicircular canal is shown. The most anterior coronal image is made just anterior to the geniculate ganglion of the facial nerve. This procedure is repeated for both the right and left temporal bones separately, and images are viewed using a window width of 3050 HU and a window level of 525 HU. These parameters for windowing only have an indicative value, as each radiologist has to make his/her own choice. Systematic visualization of both stapes crura and of the suspensory ligaments in the middle ear cavity can be a helpful indicator when choosing the windowing parameters.(http://www.springer.com/978-3-642-17895-5)

2.4.2 MSCT of the Temporal Bone

The images are acquired in a single imaging plane using a multi-slice detector scanner. The patient is lying on his/herback and the gantry of the scanner is not tilted. We use thefollowing imaging parameters (only indicative becausescanner and user-specific):• 120 kV• 250 mAs• Collimation 0.5 mm or 0.625 mm• Scan time 1.0 s

Figure 2.4.1 show CT machine

Postprocessing is done in a similar way as data acquiredwith CBCT. After acquiring the raw dataset images arereconstructed with a slice thickness of 1 mm and by usingan ultra high resolution reconstruction mode. The techniciansare instructed to make this reconstruction in a planeparallel to the lateral semicircular canal. This is the axialimaging set. The coronal imaging set is reconstructedexactly perpendicular to this axial set of images. On themost cranial axial image the superior semicircular canal isshown. The most anterior coronal image is made justanterior to the geniculate ganglion of the facial nerve. Thisprocedure is repeated for both the right and left temporalbones separately, and the

images are viewed using a windowwidth of 4000 HU and a window level of 200 HU.

These parameters for windowing only have an indicative value, as each radiologist has to make his/her own choice.

Systematic visualization of both stapes crura and of the suspensory ligaments in the middle ear cavity can be a helpful indicator when choosing the windowing parameters. (http://www.springer.com/978-3-642-17895-5)

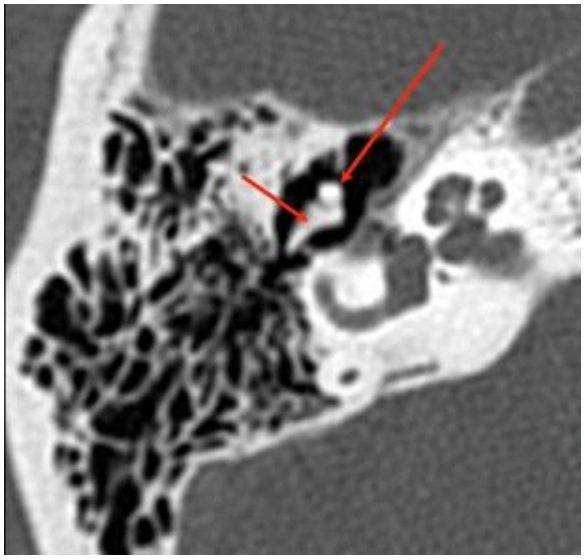


Figure 2.4.2show ,Normal anatomy of middle ear. Axial CT, bone window. Malleus head (long arrow) and incus body (short arrow) with short process are visible in epitympanum, forming a so-called “ice cream cone

2.5 texture analysis (prof)

2.5 Previous Study

Chakenahalli P. Nanjaraj1,etal ,2013done study aim to correlate the sensitivity and specificity of High Resolution Computed Tomography (HRCT) findings of temporal bone in chronic otitis media with surgical findings.HRCT of temporal bone of fifty patients with chronic otitis media were evaluated prospectively between July 2012 and December 2013. The various pathological findings, complications and important anatomical variations were evaluated ,these findings were compared with intraoperative findings .the study concluded HRCT temporal bone is a reliable investigation in preoperative evaluation of chronic otitis media and its complications, but unreliable for tegmen tympani and posterior fossa dural plate erosion.

Salem Muftah, Ian Mackenzie,etal ,2015, We conducted a community-based descriptive cross-sectional prevalence survey in the schools of Socotra Island, Yemen, over a period of two months extending from 20th April to 20th June 2011. Socotra Island lies in the north-western part of the Indian Ocean and forms part of the Republic of Yemen.The study abstractedthe burden of CSOM in the children studied indicates a high level of DHI in these communities within Yemen. A history of ear discharge, swimming in local pools, recurrent respiratory infections, and overcrowded housing were the strongest predictors for CSOM. There is a need for better ear care and screening programs for early detection and management of this disease

Teele DW1, Klein JO,1984 done study aim to determine intellectual and linguistic sequelae of middle ear disease, 207 children were randomly selected from a cohort of 498 followed prospectively from birth until age 7 years.Each child had been followed prospectively from birth to record the number of episodes of middle ear disease and to document time spent with middle ear effusion. Standardized tests of speech and language were

administered at age 3 years to children who had spent much time with middle ear effusion and to children who had spent little or no time with middle ear effusion. Children who had spent prolonged periods of time with middle ear effusion had significantly lower scores when compared with those who had spent little time with middle ear disease. The correlation was strongest in children from higher socioeconomic strata. Time spent with middle ear effusion in the first 6 to 12 months of life was most strongly associated with poor scores.

RohitVallabhaneni, etal 2016, To study the HRCT temporal bone findings in chronic middle ear infections with reference to its extent and complications.In this study CSOM was slightly more common in males (52%) than females(48%). He concluded CSOM is a common disease that can have serious, life threatening complications. As such early diagnosis and treatment is of importance for a good patient prognosis. HRCT of temporal bone is of great value in the diagnosis and preoperative assessment of a case of CSOM. CSOM is more common in the younger age group with a slight male preponderance. Patients usually present with otorrhea. Other symptoms include hearing loss, otalgia, vertigo, tinnitus, fever with chills and rigors, headache, nausea, vomiting, swelling behind the ear and facial weakness .Scutum and ossicular erosion is often present in a case of CSOM with cholesteatoma. Incus is the most commonly involved ossicle, followed by stapes and malleus. Mastoiditis and mastoid abscess is the most common complication, followed by sinus plate erosion, mastoid cortex erosion, intracranial complications, facial canal dehiscence, tegmen tympani erosion, cochlearerosion and LSCC erosion. Epitympanum is the most commonly involved site followed by posterior tympanum.

EatmadAbd Allah Babeker ,Wafa Ibrahim Elhag 2016 donecross – sectional study included 100 ear swabs collected from patients who clinically diagnosed with otitis media aged between 3 months to 60 years with mean (16.02)years old conducted in Khartoum Ear, Nose and Throat hospital, Khartoum state, Sudan, during August to October 2015.This study was done to determine the bacterial etiology and their antimicrobial susceptibility pattern of otitis media the study abstracted otitis media is major health problem of children and adults in low income countries.

BijanBasak, Ganesh Chandra Gayen 2014 done prospective observational study over a period of 6 years (January, 2007 to December, 2013), this study aim to analyze the demographic and clinical aspects of chronic suppurative otitis media (CSOM) ,1717 patients with CSOM have been cared for in the department of ENT , Burdwan Medical College & Hospital, Burdwan.Thestudy abstractedCSOM is a common public health problem that is often wrongly trivialized by people.Health awareness campaign, improved health education and easy accessibility to health care facilities can reduce the morbidity and mortality of this disease and therefore can reduce the incidence of this disease.

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Chapter three Methodology

3. Materials And Methods

3.1 Methods

This is a prospective, analytical study which included 114 patients with chronic suppurative otitismedia. The data of this study were conducted during the period from 2014 -2017, in Khartoum state. Patientscame to ENT hospital and clinically diagnosed with CSOM and refereed to Antalya Medical Centre for CT scanof the temporal bones. Patients gender, age, residence, occuppation, education, socio economic status, duration ofdisease, signs and symptoms were recorded .The sample of this study were selected from CT temporalexamination cases .Patients that have undergone previous temporal bone surgeries and traumatic patients to thetemporal bone were excluded from this study. In the study sample the total of the 114 participants were fromKhartoum state, 51(44.7%) were females and 63(55.3%) were males. the participant's Occupation were: 15without job constituting (13.2%), students were 17 (14.9%), workers were 32(28.1%) and house wives were50(43.9%). Participant’s education was: 62 (54.4%) were not educated, patients who had primary educationwere 36(31.6%) and secondary education were 16 and constituting (14.0%).

3.2Materials:

3.2.1 CT scanner machine:

GE 8 slice MDCT scan .Scanning parameters: 120-140 kV, 200 -220 mAs. X-ray tubespecification: focal spot 0.6mm *0.6mm and anode heat dissipation 400kuH/min, anode heat storage capacity4.0 MHU.

Gantry specification :Rotation speed 360º in 0.30,1,1.5 second ,tilt +/-30 º and aperture 70 cm

.Detector specification :Scan type eight (option) ,spiral or axial, slice thickness 0.5,1.0,1.5, 3.0,5.0and 10 mm,scan mode 0.50:1 /1.5:1.Algorithm (option)standard ,soft tissue ,bone and edge enhancement , matrix 512*512
and 20 cm field of view.

3.2.2 Technique and protocol:

Scan to evaluate the organ of hearing and balance was obtained. Thin slices without overlapping wereused to ensure optimal resolution, the whole skull was not imaged, and just the required part of the temporalbone was included. The two temporal bones images are magnified and imaged separately .This to make possibledifferentiation between small structures like the ossicles, cochlea and semicircular canals. CT scans wereperformed including protocol of axial images from the area of temporal bone with patient in supine position,head first. Reconstruction used to obtain coronal views of temporal bone. No preparation for patient who'sundergone CT temporal bone was done.

3.3 Image interpretation:

For evaluation of images and to measure the CT number of middle ear contents the bone windowsetting from axial cuts was used .Each middle ear was identified and it's ossicles was observed and evaluated as(intact, partially eroded or totally eroded) ,mastoid were also been evaluated.

3.4Data Analysis

-The data were collected by using data sheet which included medical reports and were analyzed byusing SPSS (statistical package of social science) version 16.

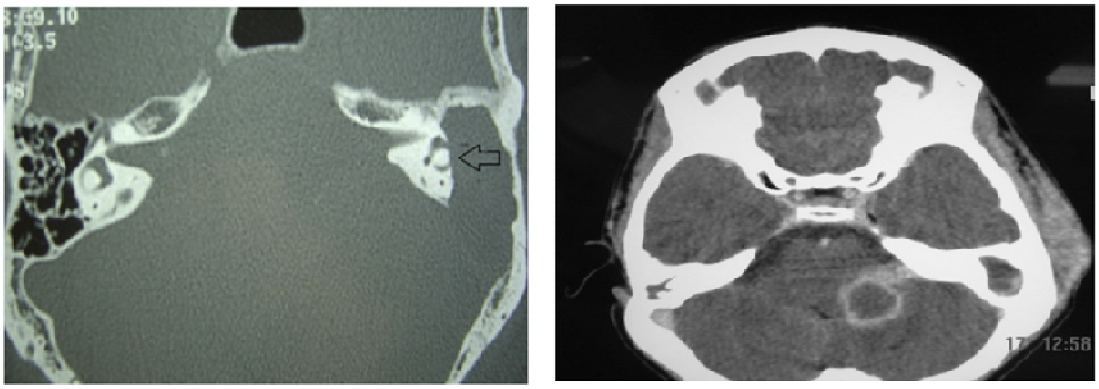
-Frequency distribution of the variable used in the study will be obtained

-Linear discriminant analysis using stepwise will be applied to select the optimum subset of the textural feature.

-Using linear discrimination analysis and k-means for classification of CSOM findings.

3.5 Texture analysis:

Analyzing the images with Interactive Data Language IDL software to measure the grey level variation of CT images, classify the CT temporal bone to Fluid, Mucosal, Sclerotic and Soft tissues density the features of the classified regions of the whole images (as raw data) were classified furthers using linear discriminate analysis.



(A)

(B)

Fig. (A) show temporal bone CT, axial view, the arrow shows erosion of the lateral semicircular canal on the left. (B) brain CT with contrast, axial view and soft tissue window, show cerebellar abscess on the left

Statistical Methods

First Order Statistics: FOS can be used as the most basic texture feature extraction methods, which are based on the probability of pixel intensity values occurring in digital images. The parameters in the following statistical formulas are xi, the intensity value of pixel i, N, the total number of pixels, maxV , the maximum intensity value within a patch and Hi, the histogram of an image patch.

Mean:

Calculates the mean intensity value of all pixels. In Matlab the function μ= mean2(IP) can be used to compute this feature.

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$$

Standard Deviation

The standard deviation of all the intensity values of a patch is used as a texture feature. The corresponding Matlab function is σ= std2(IP).

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

Coefficient of variation

The coefficient of variation can be seen as the relative standard deviation. It is calculated by dividing the standard deviation with the mean value.

$$c_v = \frac{\sigma}{\mu}$$

Skewness

Another statistical measure which is used for texture analysis is skewness. It measures the symmetry of a distribution curve of pixel intensity occurrences as seen in a histogram. The function .

ϒ1= skewness(IP) can be used to compute the skewness in Matlab

$$\gamma_1 = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^3}{(\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2)^{\frac{3}{2}}}$$

Kurtosis

The kurtosis measures the atness of a histogram relative to a normal distribution. A curve has a high kurtosis when it has a clear peak close to the mean value. The Matlab function for the kurtosis is ϒ2= kurtosis(IP).

$$\gamma_2 = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^4}{(\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2)^2} - 3$$

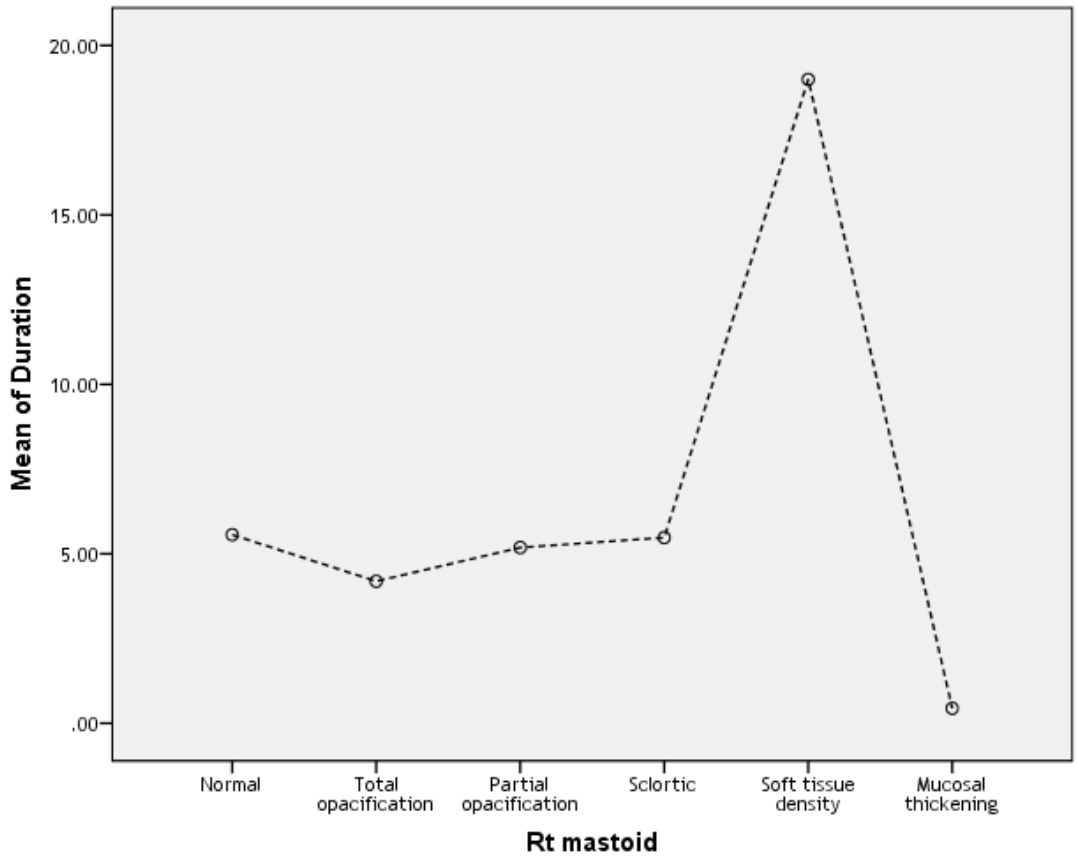
Entropy

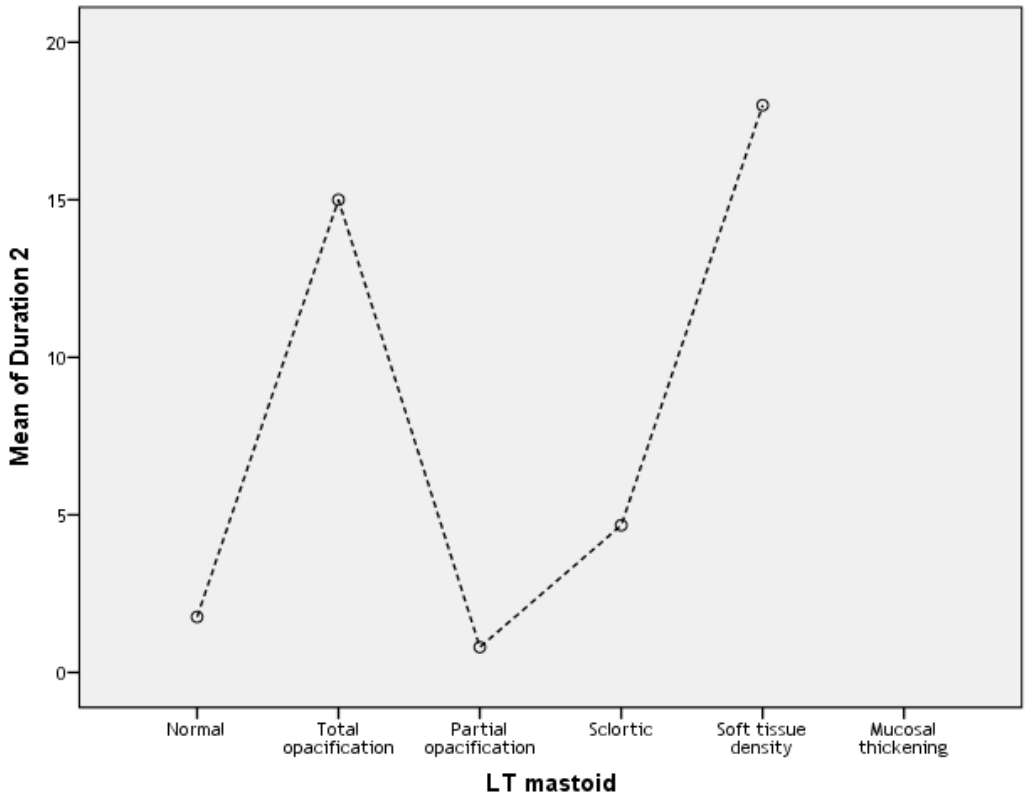
The entropy of a gray-scale image is a measure of intensity value randomness. It is calculated from the histogram counts of an image giving a probability p of certain pixel values occurring in the image

$$s = -\sum(p. * log2(p))$$

Chapter four

Results





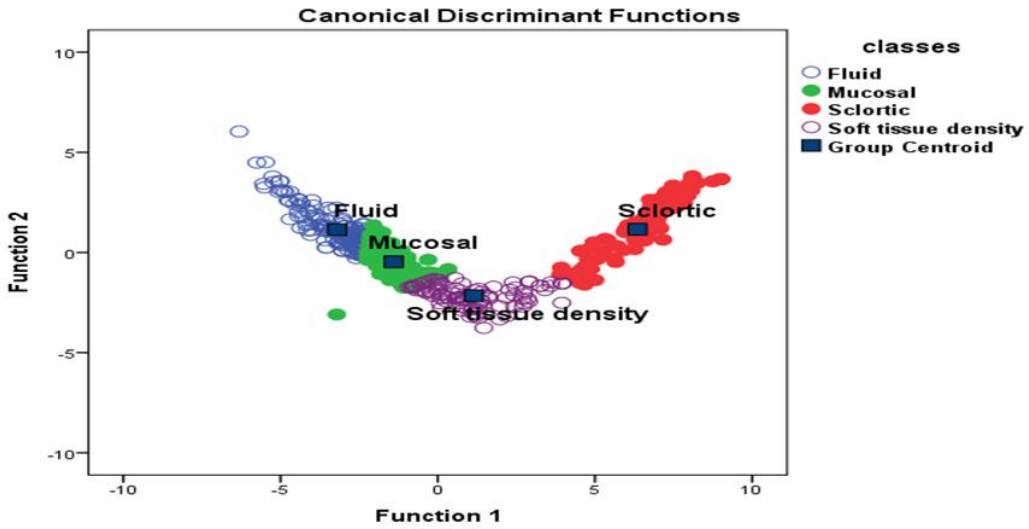


Fig 1.scatter plot demonstrates the distribution of four Classes according to their textural feature using linear discriminate analysis functions

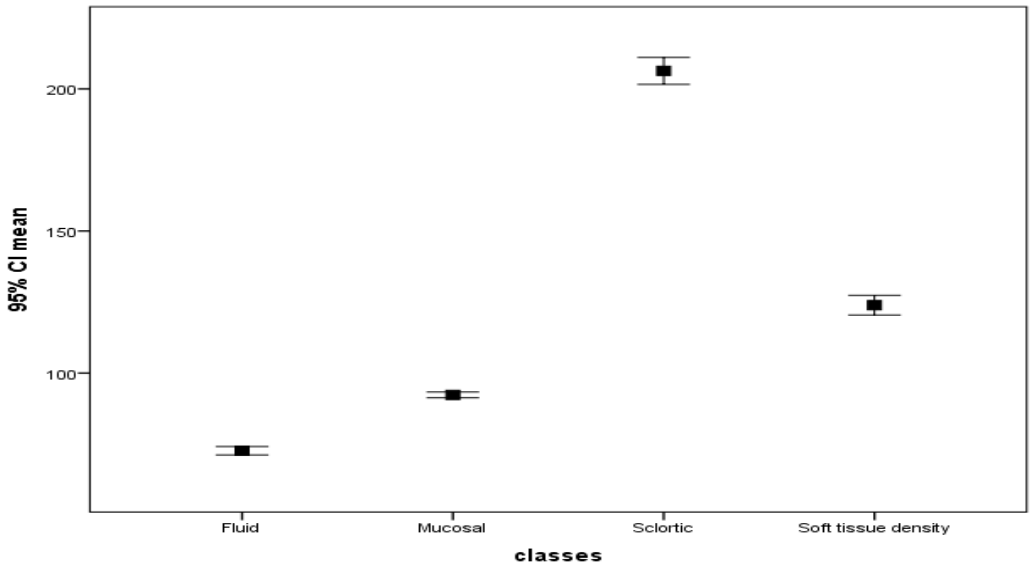
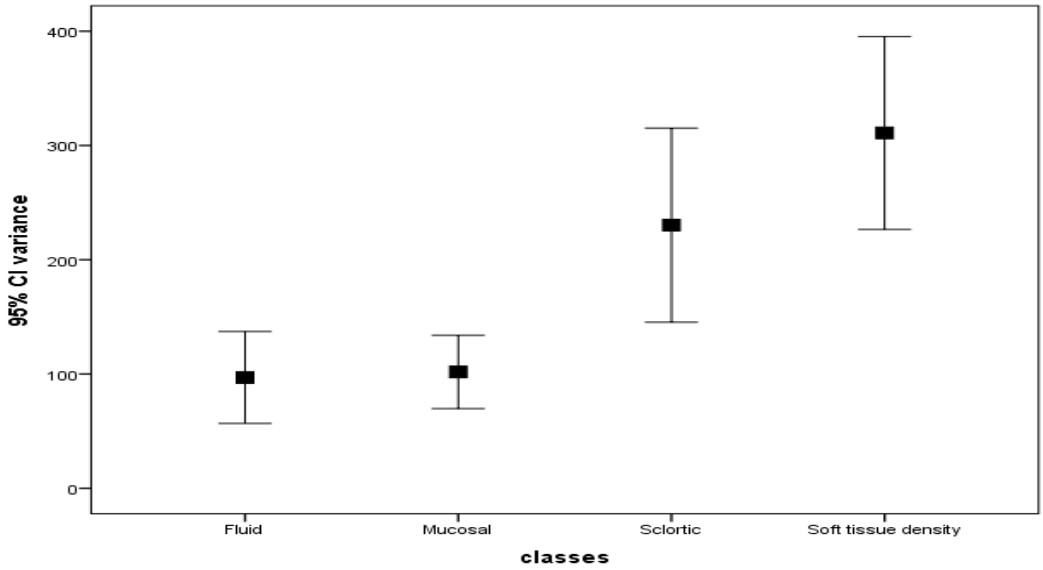


Fig .2 show error bar plot for the CI mean textural features that selected by the linear stepwise discriminate function as a discriminate feature where it discriminates between all features.



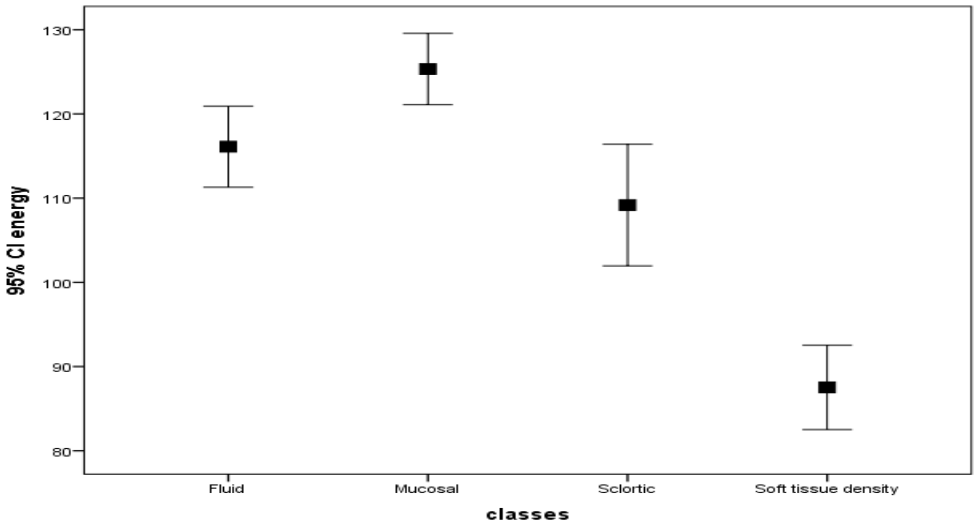


Fig .4 show error bar plot for the CI energy textural features that selected by the linear stepwise discriminate function as a discriminate feature where it discriminates between all features.

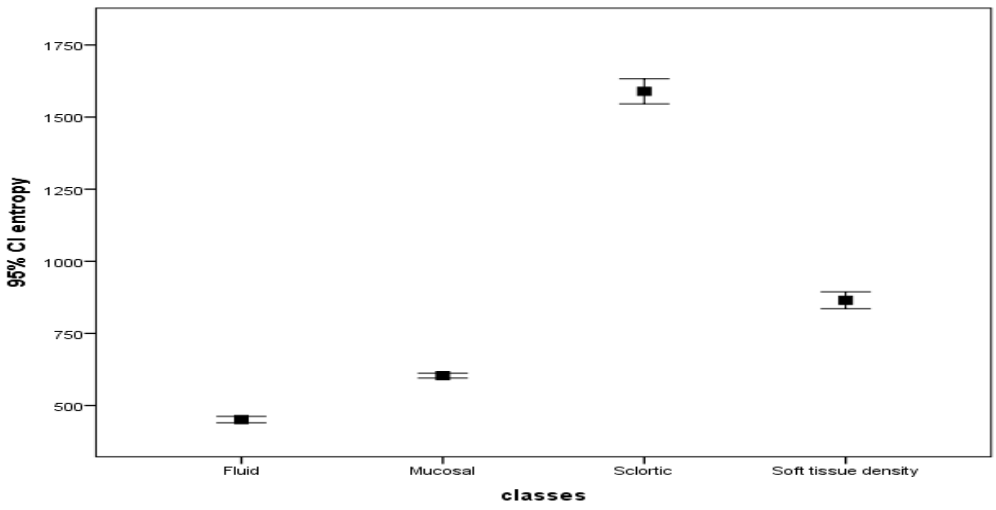


Fig .5 show error bar plot for the CI entropy textural features that selected by the linear stepwise discriminate function as a discriminate feature where it discriminates between all features

	Frequency	Percentage %
<10	13	11.4
11-20	11	9.6
21-30	17	14.9
31-40	13	11.4
41-50	28	24.6
51-60	24	17.5
>61	12	10.5
Total	114	100.0 (%)

Table No (1) Distribution of study sample according to Participant's Age

Table 4-1.a confusion matrix shows the classification accuracy of the original classes versus the predicted membership according to linear discriminant functions (multiple linear regression equation)

Classes		***Predicted Group Membership***				***Total***
	Original groups	***Fluid***	***Mucosal***	***Sclortic***	***Soft tissue density***	
%	*Fluid*	***86.3%***	*13.8%*	*0.0%*	*0.0%*	*100.0%*
	Mucosal	*0.0%*	***98.2%***	*0.0%*	*1.8%*	*100.0%*
	Sclortic	*0.0%*	*0.0%*	***99.0%***	*1.0%*	*100.0%*
	Soft tissue density	*0.0%*	*7.8%*	*0.0%*	***92.2%***	*100.0%*

Chapter five

Discussion

IV. Discussion

This study is an attempt to characterize the HRCT imaging findings of temporal bones in CSOM diagnosed for Sudanese patients. A total number of 114 patients were studied. Of the 114 patients, the age at presentation ranged from <10years to >65years. The mean age was 39.16 years± 20.3(max=86 years, min=1year) and the maximum numbers of patients affected in the age group of 41 to 50 years were 28 constituting (24.6%) table (1). This age group which was affected by CSOM is similar to study bone by Paperella and Kim, 1977 [17].In this Sudanese study; CSOM was slightly more common in males (55.3%) thanfemales (44.7%), similar findings highlighted by Rohit et al, 2016 in Indian population -India as one of thedeveloping countries.[2]

CSOM is a major health problem in developing countries like Sudan despite the advances in healthcarefacilities. It is one of the common diseases in ENT practice. In our country burden of the disease is too high.CSOM is more common in low socio-economic status groups tables (2, 12). A significant relation was found inpatients with low socioeconomic status and duration of CSOM. We referred these findings in Sudanese comingto our ENT and CT departments to the overcrowding, frequent upper respiratory tract infection, unavailablehealth care

knowledge, as the patients are of primary or uneducated groups; this was similarly found and jutostified by Bijan [18] previously.Otorrhoea was found in 113(99.1%) of the cases, acting the most common symptom, followed byotalgia 69 (60.5%), and headache that was found in 53 (46.5%), table (3) .These findings are consistent with thestudy done in India where the complication as hearing loss was also been presented in their population, wewould like to highlight that the CSOM which usually presents with otorrhoea, otalgia and other symptomscausing psychological disturbance and financial burden to the society as mentioned by Bijan.[18] The mean ofmaximum CT numbers varies in both sides of ears, this because there are many changes were happened in earsaffected with CSOM ranged between 1066.00±153.14 and 190±66.87 Hounsfield for right and left siderespectively as presented in table (4) and significantly affected with the patients' age, table (8).

The justification to have changes in CT number; is that the Otitis media presents in acute phase, doreversible mucosal and bony pathological changes, which continues to a late chronic phase with intractable mucoperiosteal disease. [19].The recurrent occurrence of otorrhoea and different signs and symptoms with longduration of disease extended to years lead to mucosal changes which are characterized by osteoneogenesis, bonyerosions, and osteitis that include the temporal bone, ossicles and mastoid that lead to destruction, total or

partialopacification, sclerotic changes, presence of soft tissue density and mucosal thickening which is probably leadto change the CT (HU). Similar studies had mentioned that tympanic perforation may also been found due tolong stage of CSOM, contributing to the hearing loss [20,21].However our sample didn't affected with suchcomplications .Changes in right and left middle ear, ossicles and mastoid were presented in tables (5,6,7)

Duration of CSOM and the changes detected in right and left middle ear were significantly presentedin table (9) and figure (1), (F=5.802, Sig at 0.000), and (F=23.182,Sig at .015) respectively .Sclerotic changeswas found to be the commonest result due to increasing duration in the right middle ear, where the soft tissuedensity increased as the duration increased significantly in the left middle ear .Right and left Ossicles were alsoaffected significantly with increasing of CSOM duration (F=16.959, Sig at 0.000) and (F= 3.673 ,Sig at 0.036)

.Partial and complete erosion were detected in both right and left ossicle in the advanced period of disease,where the ossicle still intact in the early stage ,these were noticed in table(10) and figure (2).The changes of

soft tissues density was the commonest findings detected in both right and left mastoid in HRCT for temporalbone scanning.Significant changes were detected in the left mastoid (F=2.832 ,Sig at0.041) as seen in table (11)

and figure(3).

Many findings have been found in Sudanese with long standing CSOM, on the other hand; studieshave mentioned that long duration, lead to severity of the cases compared with acute otitis media [5].Theimportance of taking care about CSOM in children because it is likely inhibit language and development.

Several studies have linked persistent and significant hearing loss from otitis media during the first two years oflife with learning disabilities [6,7]. Other studies have shown no effect [8,9].

V. CONCLUSION

Regarding the results, the study showed that HRCT of temporal bone is useful in identifying various findings related to the location and extent of disease which are clinically obscured and is of significance in guiding the surgeon in planning the surgical approach, similarly the literature have

mentioned that the ability of the high resolution computed tomogram to depict the status of the structure of the temporal bone represents a major advance in delineating pathology [22], as well, HRCT scan for temporal bone is valuable in diagnosis of soft tissue density and when the disease is restricted to anatomical structures, beyond otoscopic view.

The ability of HRCT in the evaluation of the acquired changes based on the detection of soft tissue mass and areas of bone destruction and measuring the CT(Hounsfield) make it of an acknowledged and excellent results in the detection of changes and reduce complications in Sudanese.

The classification processes of CT Temporal bone were defining the otitis media to Fluid, Mucosal, Sclerotic and Soft tissues density and carried out using Interactive Data Language (IDL) program as platform for the generated codes.The result of the classification showed that the temporal bone areas were classified well from the rest of the tissues although it has characteristics mostly similar to surrounding tissue.

Several texture features are introduced from ***FOS*** and the classification score matrix generated by linear discriminate analysis and the overall classification accuracy of temporal bone area classify to fluid 86.3%, mucosal 98.2%, sclerotic 99%, While the soft tissue density showed a classification accuracy 92.2%. The overall classification accuracy of temporal bone area 93.6%.

Using Linear discrimination analysis generated a classification function which can be used to classify other image into the mention classes as using the following multi regression equation;

Fluid, Mucosal, Sclerotic and Soft tissues density

Fluid = (mean × 23.7) + (variance × 0.006) + (energy × -0.099) + (entropy × -2.703) -247.54

Mucosal = (mean × 26.1) + (variance × 0.006) + (energy × -0.109) + (entropy × -2.97) -303.93

Sclerotic = (mean × 26.7) + (variance × 0.007) + (energy × -0.104) + (entropy × -2.97) -387.66

Soft tissues density = (mean × 28.4) + (variance × 0.009) + (energy × -0.17) + (entropy × -3.22) -362.83

Recommendation :

-MRI studies can also be extremely useful in the evaluation of blood vessel related disorders of the temporal bone.

-MRI has expanded the range of pathology that can be accurately evaluated because it can image many soft tissue entities not visible by other techniques.

As such HRCT apart from diagnosis, is mainly useful in the preoperative evaluation of the type, location and extent of disease process to help the surgeon in planning further management.

Appendices

Data collection sheet

no	gender	age	residence	occupation	education	Social economic status	Signs and symptoms	Duration	Other comment

CT number of middle ear	Middle ear cavity(air – fluid-soft)	Ossicles (intact - partially- totally)	Tegmen tympani	Internal ear	External ear	IAM	Mastoid	Scutum	Remarks

Appendices

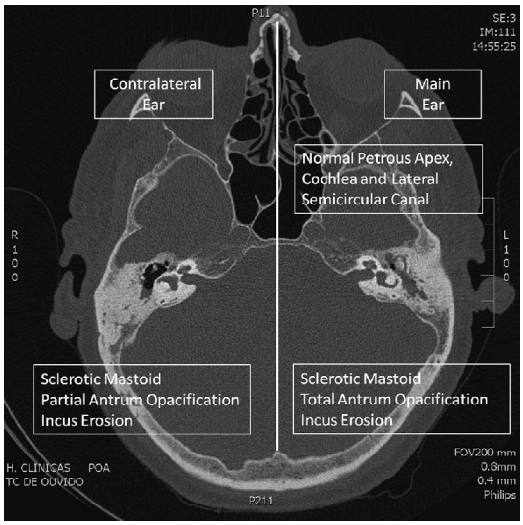


Figure show Axial CT Scan. Comparison of abnormalities in the main (left)and contralateral (right) ear.

Figure showA 62-year-old woman with missed old trauma and hearing loss in the left ear. A, 3D reconstructed volume rendered (VR) CT image. Destruction and erosion in the malleolus and mildstapoincus dislocation that is best shown in 3D VR in comparison with 2D images;

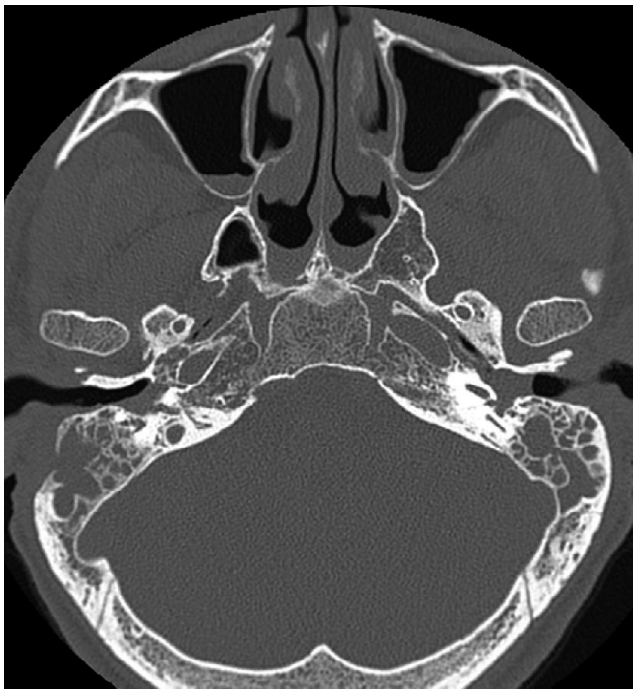


Figure show 33-year-old man with persistent otorrhea.

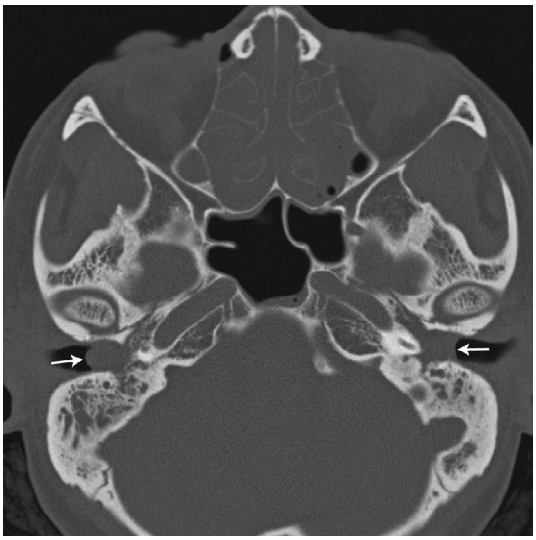


Figure show37-year-old woman with progressive, bilateral hearing disturbance.

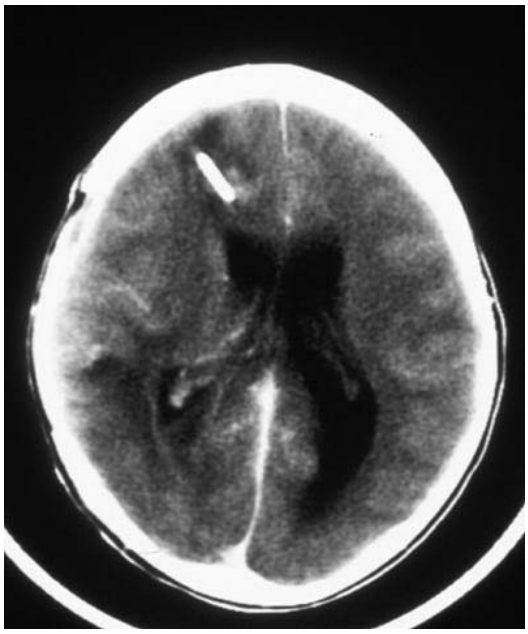


Figure show CT temporal axial cut showing Otitic hydrocephalus

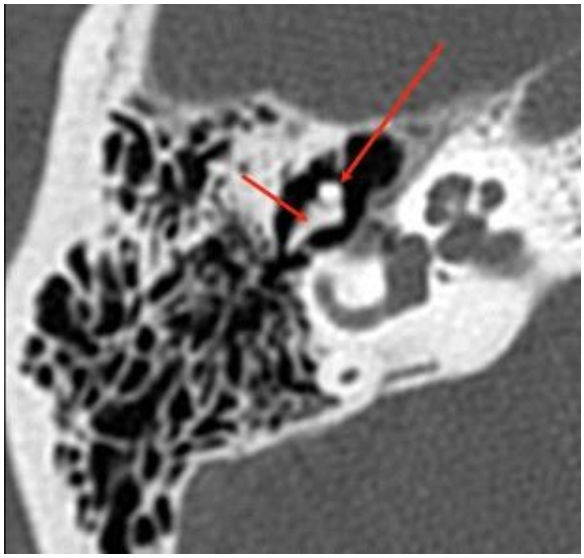


Figure show ,Normal anatomy of middle ear. Axial CT, bone window. Malleus head (long arrow) and incus body (short arrow) with short process are visible in epitympanum, forming a so-called “ice cream cone

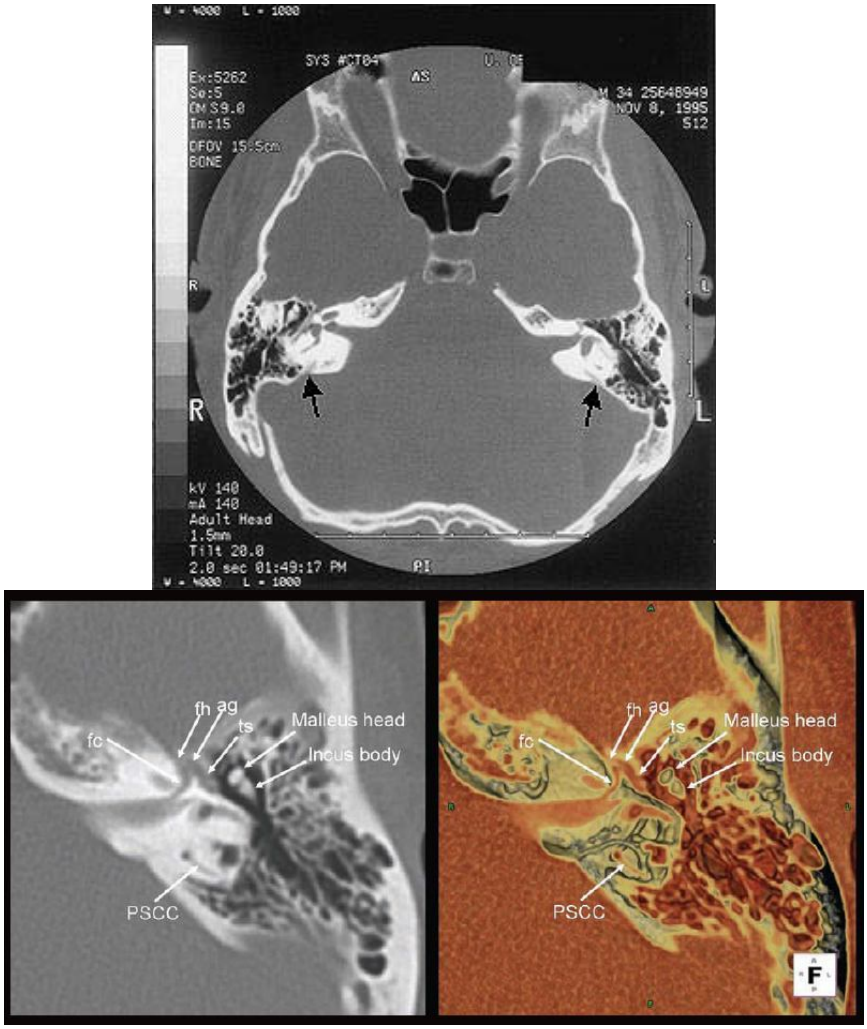


Figure show HRCT Temporal Bone,axial view , show ear structures

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