"MORPHOLOGICAL AND ANTHROPOMETRICAL FEATURES OF HUMAN EAR OSSICLES" – A ONE YEAR CADAVERIC OBSERVATIONAL STUDY

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LIST OF ABBREVIATIONS

• M	Malleus
• I	Incus
• S	Stapes
• Ha	Handle of malleus
• He	Head of malleus
• G	Ectodermal groove
• mm	Millimeter
• mg	Milligram
• ASL	Anterior suspensory ligament
• LSL	Lateral suspensory ligament
• SSL	Superior suspensory ligament
• AML	Anterior malleal ligament
• PML	Posterior malleal ligament
• PIL	Posterior incudal ligament
• SIL	Superior incudal ligament

ABSTRACT

Background and objectives: The ossicular chain formed by malleus, incus, and stapes, is considered as an essential content of the middle ear and is responsible for transmission of sound-induced vibrations from the tympanic membrane to the oval window. This study aims to evaluate the morphology and anthropometry of malleus, incus, stapes from temporal bones.

Material and methods: This study was conducted in the department of otorhinolaryngology and head and neck Surgery and department of anatomy of KAHER's Jawaharlal Nehru Medical College, Belagavi from January 2019 to December 2019. 20 fresh cadavers (40 sets of ossicles) were dissected to study anthropometry and morphology of each middle ear bone. All measurements and weight were recorded and photographs were documented. Measurements of all 3 bones were taken using an osseous sizer.

Result: Among the 40 sets of ossicles obtained, malleus showed the least morphological variations except the distal ends, which in 13 bones were straight (30%) and 27 bones were curved (70%). Weight of malleus ranged from 12mg–21mg. The length of malleus ranged from 6mm–9 mm. Morphology of incus showed variation in the lenticular process. 70% of the incus bones showed fully developed lenticular process and the remaining 30% bones showed underdeveloped/necrosed lenticular process. Weight of the incus ranged from 12mg–28mg and the length of incus ranged from 4.40 mm–7 mm. In stapes morphology, we found the obturator foramen was triangular shaped in 18 bones (45%) and oval shaped in 22 bones (55%). The weight of stapes ranged from 1.5mg–3mg and the height ranged from 2 mm–3.5 mm.

CONCLUSION: With a rapid rise in the demand of ossiculoplasty in our country, this study assesses the possible morphology and anthropometric variation that can exist in the Indian cadavers with an intention to add up to the present understanding for the middle ear dynamics.

Key words- ossicles, dissection, malleus, incus, stapes, ossiculoplasty

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

LIST OF PHOTOGRAPHS

INTRODUCTION

In the words of Shakespeare, “the earth has music for those who listenand everything becomes different as soon as it is lost”, the sense of hearing is one of the most remarkable possessions of mankind. It is astonishing to know that such a minorbody part like the ear sub serves such a dynamicpurpose of hearing. Awareness to the environment and communicating with it are key elements to survival**.**

A survey carried out by WHOshowed, “thereare 250 million people suffering from hearing loss globally.”[1]Around466 million persons in the world live with disabling hearing loss which is more than 6.1% of the population in the world. 432 million 93% were adults more than 242 million males, 190 million females 34 million were found to be children.The number of people with hearing disability is on the risewhich will further increase over the years and reach up to 630 million by 2030 and by 2050, over 900 million cases might be seen**.**[2]

The process of hearing is carried out by a small organ like ear and it is more amazing that inside this miniaturestructure, there are three minor bones-malleus (hammer), incus(anvil)and stapes(stirrup) tacticallypositioned to form a semi rigid bony cable for transmitting sound in the middle ear i.e., from the ear drum to the fenestra vestibule**.**[3]

The malleus is the 1st bone and is attached to the ear drum and the stirrup or the stapesis attached to the oval window. The incus is bridged between them, and articulates with both the bones.This arrangement, along with the ventilation, is the driving force of middle ear mechanics.

Abnormalities of ossicular chaincan be due to ossicular discontinuity or fixation that may cause conductive hearing lossof up to 60 decibel. [4]The most common causeofossiculardiscontinuity isincudo-stapedial joint erosion, followed byerosion ofincus, or completeabsence of incus and stapes suprastructure.

To restore appropriate sound transmission, ossicular chain reconstruction has to be performed.Reconstructive procedures for ossicular abnormalities have come a long way from being rarely performed in the middle of the 20th century to being performed by almost all ear surgeons presently. [5]It is a great challenge for an otologist to give the patient better hearing aftersurgical intervention in cases of ossicular abnormalities. Hence, precise dimensions and make of an implant isthe key to successful ossicular repair.

To study the morphology and anthropometry of middle ear ossicles during a surgery is difficult. Hence studying them in cadavers gives better understanding about its variations and dimensions. The knowledgeof theseossicledimensions,their variations and their morphometric data will help the otologists during reconstructive surgery and also aid in designing better prosthesis.

OBJECTIVES

To study the morphology and anthropometry of malleus, incus, stapes from temporal bones.

REVIEW OF LITERATURE

According to Arensburg B et al, analysis of ossicular morphology was done since mid-fifteenth century.[6]Additionally, there werestudies done on morphology and dimensions of ossicles in Downs syndrome babies and one such study was done by Balkany et al.[7]In his study, histological findings in five temporal bones was studied and it showed abnormalities in ossicles such as fixation, superstructure deformity of the stapes andfallopian canal dehiscence.[7]

Cousins VC and Milton CM conducted a study on 68 cases with congenitalossicular abnormalities. They observed pathology in 66% ofthe middle ear with absence of any other congenital diseases.[9] The goal of ossicular reconstruction is to, re-institute and establish good hearing.[10]In cases of congenital malformations of middle ear ossicles like absence of incus, long process and stapes capitulum, reconstruction of ossicles can beperformed using incus long process homograft.[8]

In 2015, K Radha et al performed a study on 25 dry temporal bones andit was observed that, themalleus length was ranged between 6.7 mm-7.94 mm, mean length of manubrium was around 4.2 mm and that of the head and neck was 3.5mm. These measurements were measured using digital Vernier calipers.[11]Study by Vijaya Chandra et al measured ossicles using electro cardiogram paper, according to him,the height of the malleus wasfound to be in the range of 6.94 mm-7.78 mm.[12]Ramirez et al has studied 23 sets of ossicles,according to his study,malleuslengthwas found to be 8.18 mm.[13]In the study done by Ajay Kumar et al, it was observed that the malleus length was in the range of about 6.4mm to 9.1mm.[14]In 2002 Unur et al studied ossicles and estimated their measurements with a Mitutoyo micrometer and

themalleus length was found to be 7.7mm, manubrium length was 4.7mm and length of head and neck of malleus was around 4.9mm.[15]

According to Dr. Khushboo Mogra et al,**"**the average of morphometric limitsexhibited that the malleus is around 8.53mm in itsentire length, the manubrium was found to be 5.20mmand thelength of head& neck is around 4.72mm. This was calculatedbyVernier caliper".**[16]**In a study conducted by Jyothi K C in 2011, the malleus length ranged from 6.50 mm–8.36 mm.The manubrium measuredaround 2.91 mm–4.43 mm. The maximum width of head ranged from 1.83 mm – 2.80 mm. The weight ranged from 13.5 mg–25.4 mg.[5]In Quain's "Elements of anatomy", Schafer and Symington have studied the proportions of the three tiny ear ossicles. The malleus length was calculated from the highest point on the head to the terminal point of the manubrium, and was found to be in the range between 8 to 9 mm.[17]Anson and Bast suggested that maximum diameter of head of malleus ranged from 2.13mm-2.8mm.Length of handle the of malleus ranged between 4.33mm–5.67 mm andtotal malleus length is between 7.6–9.11 mm.[18]

According to Ritaban Saha et al**, "**the malleus morphologically showed disparity in the shape and tip ofhandle, lateral process and anterior process". Among the 52 bones he studied, 29 had the free ends of the manubrium of malleus curved anteriorly and 23 had straight free ends of the handle. In few bones, they observed the lateral process of malleus to be long and pointed and few had blunt edge. In few it was not present.[3]Nomura et al., observed unusualresultslike spindle shaped handle of malleus.[19]Unnur et al observed that few bones in his study showed no neck between head (caput) and manubrium.[15]

Incus has minimum morphological variations in the ossicles. According to Unnur et al, incus length is around 6.5mm and its total width was around 4.9mm.[15]In a study conducted by Jyothi K C in 2011, the incus length ranged from 5.46 mm – 6.96 mm. The total width of the body ranged from 3.31 mm – 4.96 mm. The length of long process ranged from 2.63 mm – 4.4mm, the weight of the incus ranged from 11.10 mg – 33.70 mg.[5]

In Quain's Elements of anatomy, Schafer and Symington have studiedthe incus length andcalculated it from the top of the body to the end of long process and they found it to be about 6 mm. The width of the ossicle from the anterior end of the body to the end of the short process was about 5 mm.[17]According toAnson and Bast,maximum width of ossicle was 1.73mm – 2.49 mm,length of long process was 4.27 – 5.55 mm and width of short process – 2.30 – 2.89 mm.[18]

The incus is the largest ossicle among the three and is immediately medial to the malleus.[20]According to Ritaban Saha et al,"disparities in incus were found to be considerably less as compared to other bones". In their study, the short process of 21 incus exhibited a notch in its inferior border.Also, twelveshowed a skyward course whereas nine showed a forward course of the notches.[3]Mogra K et al found thata notch was present in the inferior aspect of the short process.[21]

Shea J J, Orchick D J, Emmett J R reported a case of "congenital absence ofincus in a 3 ½ year old female child who came with hearing loss since birth. Onexamination of the ear, there was fluid in the middle ear. Myringotomy with placement ofventilation tube did not result in significant improvement in the hearing. Onexploratory tympanotomy, they found absence of incus with normal malleus and

stapes. Ossicular chain reconstruction was done using polyethylene sponge prosthesis inserted between malleus handle and stapes capitulum".[22]

According to Unur et al, stapes total height was found to be around 3.2mm, length of foot plate was 2.6mm and width 1.3mm.[15]Wadhwa S et al studied the morphology of stapes and according to their study, the height of bone is calculated from itshead to the undersurface of the footplate was in the range of 3.06 mm to 3.71 mm and the height of bone calculated from its head to upper surface of the footplate was found to be around 3.20mm. The length of the footplate ranged between 2.64 - 3.56 mm. On measuring the length of the head, perpendicular to the footplate, it was found to be in the range between 0.53 mm to 1.21 mm. The length of the posterior crus was 1.65 mm -2.11 mm. The anterior crura measured 1.46 mm -1.96 mm.[1]

According to Jyothi K C**,** the height of the stapes ranged from 2.41 mm – 3.43 mm. The length of the footplate ranged from 2.41 mm – 3.57 mm. The width of footplate ranged from 1.25 mm – 1.80 mm. The length of anterior crus ranged from 1.27 mm – 2.76 and posterior crus ranged from 1.36 mm – 2.76 mm. The width of the head ranged from 0.78 mm – 1.42 mm and the weight ranged from 1.00 mg – 4.80 mg with an average of 2.23 mg.[5]

In Quain's Elements of anatomy, Schafer and Symington have studied the dimensions of stapes The whole stapes measured 3-4 mm in length and about 2.5 mm in breadth.[17]According toAnson and Bast**,** the average height of stapes is 3.26 mm, average width of footplate is 1.41mm,average length of anterior crus is 3.62mm and average length of posterior crus is 3.73 mm.[18]

Measurement of stapes superstructure was conducted by Wengen et al and they concluded thatstapes head measured 0.91-1.49 mm in diameter parallel to the axis of the footplate and 0.65- 1.08 mm perpendicular to it. The distance measured between the stapes head to the shoulder measured 0.81- 1.07 mm, head to foramen measured1.15 – 1.39 mm, and head to lateral aspect of stapes footplate 2.91 -3.45 mm. The width of the neck parallel to footplate measured 0.88-1.47 mm and 0.48-0.88 mm perpendicular to it. Length of the anterior crus measured 0.41-0.74 mm at the shoulder of arch.[23]

According to Ritaban Saha et al,"stapes presentedsupreme morphological differences among the three bones." The disparitiesof stapes were observed in the neck, crura and the obturator foramen. Variety of shapes were seen in obturator foramen.Few shapes that were seen are'oval'in around 17 'circular' in 9,'triangular' in 23, tunnel shaped in 3 bones. The anterior and posterior crura were symmetrical in their shape i.e. were curved equally. In their studythey observed that the anterior crus was more straighter and posterior crus was more curved.[3]

Farahani and Nooranipour, in their studyalso specified "straighter anterior crus than posterior".[24]Unur et alreported that "stapes had maximum morphological variations in the middle ear ossicle". The disparities of stapes were in the neck, the cruses and the obturator foramen. The stapes had no neck, a short or a long neck. The crus of the stapes had symmetry or asymmetry. The hole of stapes was circular, oval, triangular,tunnel shaped or without hole.[15]

Wadhwa S et al in their study, the stapes head displayed a variety of sizes and shapes.The crura showed variations in size and thickness. The obturator foramen

showed a variety of shapes, oval in 2 specimens, circular in 3,triangular in 4 and semicircular in 1.[1]

ANATOMY OF EAR

The ear is asensory organ for hearing and balance and anatomically it can be divided into three parts as shown in Fig 1.[25]

EXTERNAL EAR- It forms the attachment of the lateral aspect of the ear and the canal leads inward. The external ear consists of two parts namely:

- **PINNA**- also called auricle is the large cartilaginous projecting part of external ear.
- **EXTERNAL AUDITORY CANAL**- the canal leading inward is the external auditory canal.

MIDDLE EAR-A space in temporal bone between eardrum and oval windowbounded laterallyby a tympanic membrane and connected internally to the pharynx by eustachian tube.

INTERNAL EAR-also called labyrinth has spaces within the temporal bone between the middle ear laterally and the internal acoustic canal medially.[25]

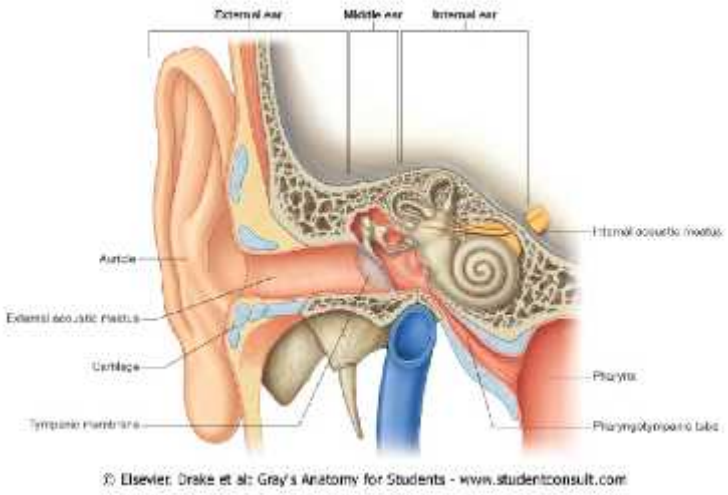


Fig. 1Anatomy of Ear[25]

The tympanic cavity is a slightly oblique space that is bounded by six walls:

Lateral (membranous) wall: bounded by external ear; separated from it by tympanic membrane.

Medial (labyrinthine) wall: formed by the promontory, overlying the cochlear basal turn which separates it from the inner ear.

Inferior (jugular) wall: forms the floor of the middle ear cavity and has prominent bulb of the jugular vein.

Posterior (mastoid) wall:separates middle ear from the mastoid cavity, has communication in the attic area via aditus (inlet) to the mastoid antrum.

Superior (tegmental) wall: forms the roof of the tympanic cavity.

Anterior (carotid) wall: includes the opening of theeustachian tube and is related to the carotid canal.[26]

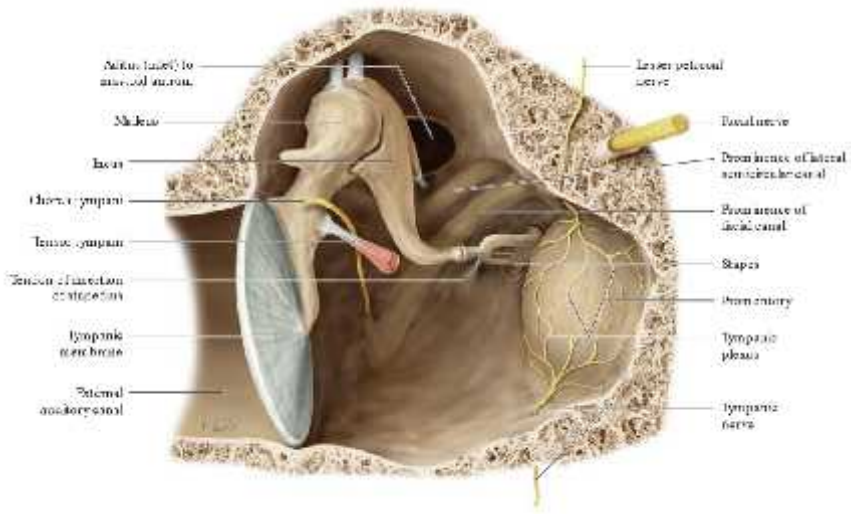


Fig. 2CONTENTS OF MIDDLE EAR[26]

It is more interesting to know that inside this tiny organ, there are 3 small bones– malleus (hammer), incus (anvil)and stapes(stirrup) which aid in conduction of sound waves and they are placed strategically to form a bony cable for transmitting signal inwards as shown in Fig 2.

EMBRYOLOGY OF OSSICLES - The mesenchyme in the middle ear area leads to the formation of ossicles, muscles, and tendons and the lining epithelium is from the first pharyngeal pouch. Meckel's cartilage of first arch and Reichert's cartilage of second arch form the ossicles.[27]Ossicles start developing at four weeks of gestation and reach adult size and shape by 25 weeks.

Meckel's cartilage forms malleus head and incus body.[27]

Reichert's cartilage forms manubrium or the handle of the malleus and the long process of the incus and the stapes crurae.[27]

The foot plate of stapes develops from otic capsule and periotic endosteum.[27]

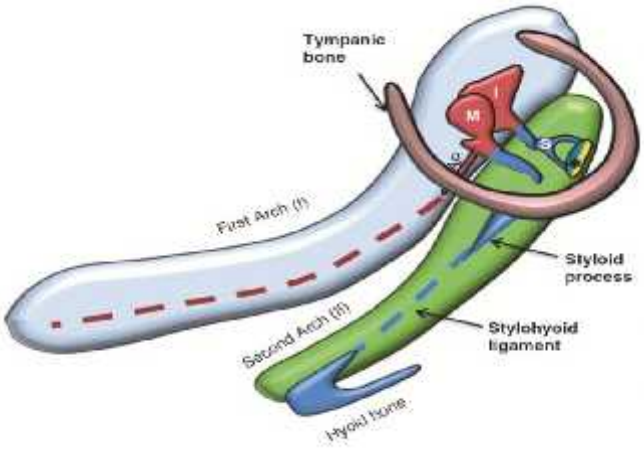


Fig. 3-DESTINATION OF FIRST & SECOND BRANCHIAL ARCHES[27]

DEVELOPMENT OF MALLEUS

The malleus head develops as a small formwhich is linked to the cranial extremity of the Meckel's cartilage.[27] This assembly disappears and issubstituted by the anterior malleal ligament and anterior process of the malleus in later stages.[27] This anterior process is 10 mm in neonates and this remains as a small prominence in the adult.[27]

In blastema, malleus handle has relationships with the long process of the incus and is connected to the Reichert's cartilage, a bony bardevelops, if there is failure of resorption of this assembly with Reichert's cartilage.[27]

By the end of 6thweek of intrauterine life malleus ossification ends. Fig4[27]shows 6-week old human embryo of 19 mm size, showing the "development of the handle of malleus (Ha) and the head of malleus (He). The handle projects between

the first ectodermal groove (G) and the first endodermal pouch (TR)". Ossicles are cartilaginousin this stage.[27]

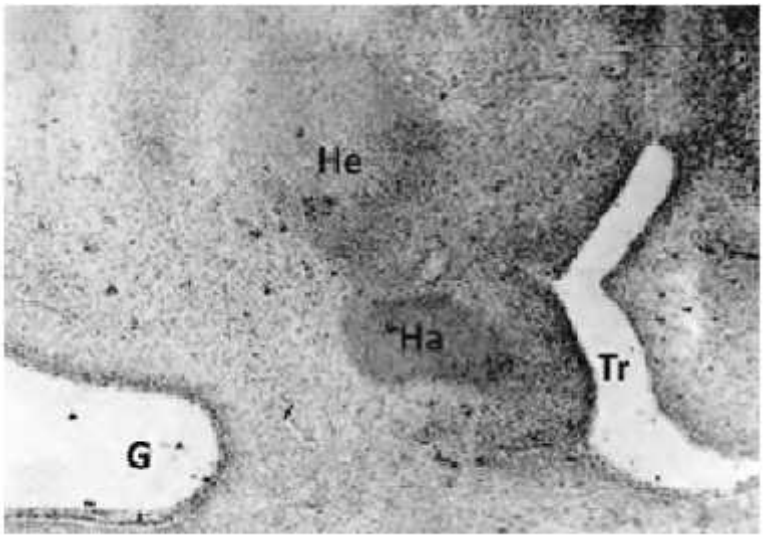


Fig. 4: SECTION OF MIDDLE EAR OF 6 WEEK HUMAN EMBRYO[27]

INCUS DEVELOPMENT

The incus body is a derivative of the cranial part of the Meckel's cartilage and the Reichert's cartilage is also attributed as the source of incus development. It is the second bone to develop but 1st to ossify,incus ossification starts at the beginning of the 16th week of intrauterine life and reaches adult size by the 24th week.[27]Based upon the morphological observations done in 2016, it was concluded that the early anlagen of the malleus handle and the incus long process are very difficult to identify on very young embryos.[27]

STAPES DEVELOPMENT

The 1st ossicle to appear is stapes, which develops from second branchial arch from its cranial end.[27]

Footplate development

It is developed mainly by mesenchymal cells and there are 2 theories with several differences which tell us the development of the footplate. The two theories are -

'The classical theory of footplate origin'

The classical theory tells us that the footplate develops from 2 derivative-stapedial ring forms the tympanic surface of foot plate and a part of the oticcapsule forms the vestibular surface of footplate.[27]

'Alternative theory of footplate origin':This theory explains that the entire stapes is derived from the Reichert's cartilage which is a stapedial anlage and there is no evidence of involvement of the otic capsule.[27]

Annular Ligament

In the beginning of the development of thefootplate, there is a band of mesenchyme attached to the otic capsule which later transforms into the annular ligament[27].

Stapes Ossification

The footplate is hypothesized to be having a single ossification center. Around the 4th month of intra-uterine life, enchondral ossifications start which later extends to the 2 crura and then to the capitlum of stapes.[27]

Embryology of Ossicular Articulations

Around the 7th week of intrauterine life, the contour of the lenticular process of the incus and stapes head are spilt by a condensed mesenchyme interzone.[27] Around the 12th week of intrauterine life, cavitation commences in the interzone, the cavitationconsolidateslater to arrange as the incudo-stapedial joint around the 16th week of gestation.[27]

The Incudo-malleal joint- the incus and malleus, formerly one assembly of mesenchyme, separate with construction of the incudo-malleal joint at the eighth to ninth week of intrauterine life by the similar mechanism as the incudo-stapedial joint.[27]

OSSICULAR CHAIN

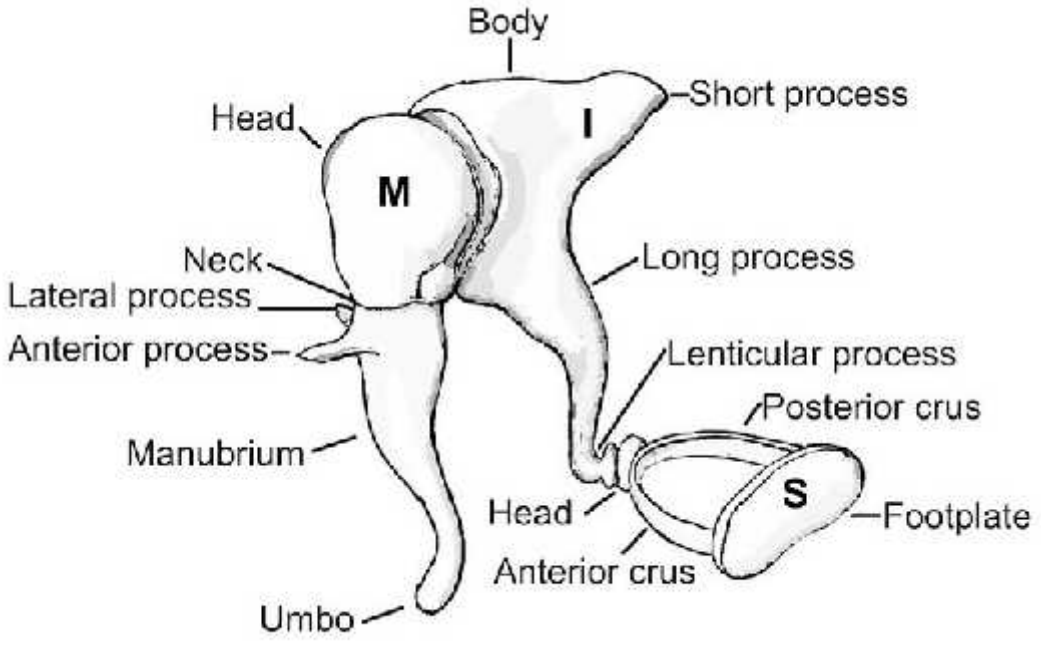


Fig. 5 OSSICULAR CHAIN AND ITS ARTICULATION[21]

ANATOMY OF MALLEUS

Malleus is also called hammer because it is designed like a hammer and it is the chief bone among the 3 ossicles.[27] It measures around 8-9mm long and weighs around 20-25mg.Anatomically, malleus is divided into head, neck, handle or manubrium and 2 processes i.e., anterior and lateral as shown in Fig 6.

Head of malleus- It is globular in shape, measuring around 2mm in size and resides in attic area. It has a facet for articulation with incus in its posteromedial aspectand is covered by cartilage.[27]

Neck of malleus- is a narrow portion between head and handle. On its medial surface there is an attachment of the tensor tympani muscle, on the medial surface,the chorda tympani nerve passes. Additionally, it also forms the medial wall of Prussak's space.[27]

Handle of malleus- also called the manubrium, is angulated with around 140° with the head of malleus, it runs inferiorly between the fibrous and mucous layer of the membrane, and at a point gets decisivelyinvolved to the membrane forming 'umbo'.[27]

The 2 processes of malleus -

The lateral process: It is a tiny conical projectionof around 1 mm size. It projects laterally. The anterior and posterior malleal ligaments get attached to lateral the process.[27]

The anterior process- also called processus gracilis is thin projection from the neck of malleus, and measures around 5 mm and extends till the glaserian fissure. Chorda tympani nerve passes on its medial side and enters anteriorly to the petrotympanic fissure. Anterior malleal ligament origins at this site.[27]

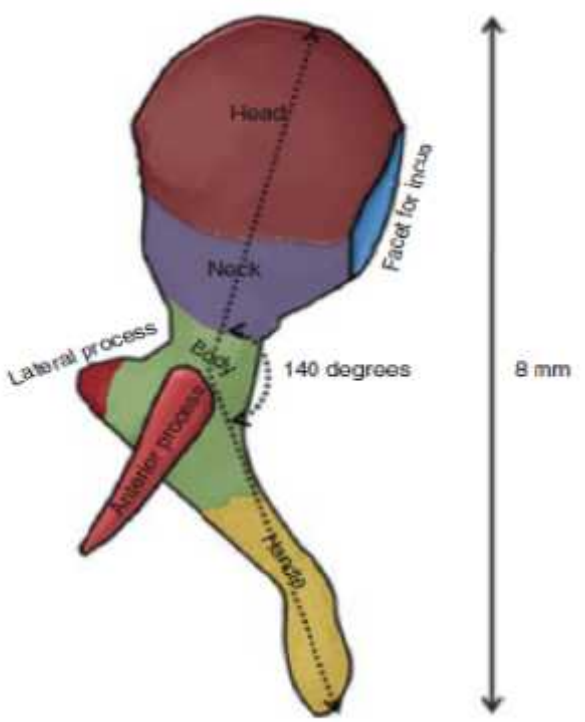


Fig.6 -SCHEMATIC DIAGRAM OF MALLEUS[27]

Image 1- CADAVERIC MALLEUS BONE

Malleus Ligaments-

Stability of the malleus is maintained by 5 main ligaments in the middle ear as shown in figure 7 They are-

1. Anterior suspensory ligament (ASL)- It is situated above the anterior malleal ligament and gets attached to the malleus head.[27]
2. Lateral suspensory ligament (LSL) – It lies between the notch of Rivinus and malleus neck and also forms the superior wall of the Prussak's space .[27]
3. Superior suspensory ligament- It lies between the malleus head and the tegmen and carries a vessel i.e. superior tympanic artery which is a branch of middle meningeal artery. [27]

The above three ligaments near its attachment to the bone causes minimal movements, hence they don't play a significant role in sound transmission and middle ear mechanics.[27]

- Anterior malleal ligament (AML)- mainly helps in the axis of rotation by working along with the posterior incudal ligament. The anterior malleal ligament attaches atthe angular spine of the sphenoid boneand inserts on the malleus neck at the base of the anterior process of the malleus and is accompanied by the anterior tympanic artery. [27]
- The posterior malleal ligament (PML)-lies between the neck of the malleus and the posterior tympanic spine.[27]

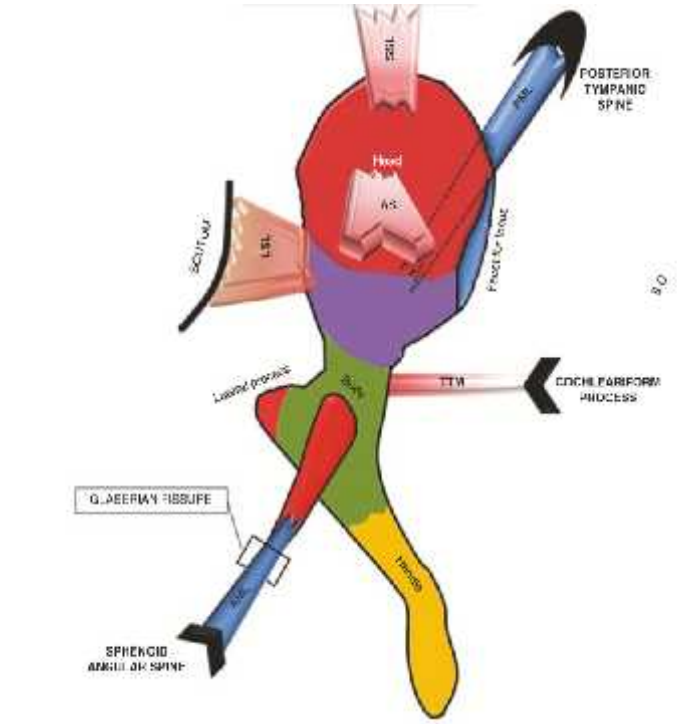


Fig. 7- MALLEAL LIGAMENTS[27]

The malleus is a vital bone in ossiculoplasty as it aidsinreestablishing the purpose of ossicular lever and acts as a prosthesis stabilizer.Malleus head fixation is not an unusual pathology and it may be an inborn anomaly or could be as a result of tympanosclerosis. Clinically, it establishes as a 15–25 dB conductive hearing loss.[27]

ANATOMY OF INCUS

Incus also called 'anvil' is the 2nd bone in the middle ear which bridges between the malleus and stapes and it weighs about 30 mg. The average lengthis 5-7 mm.[27] It is trapezoid in shape and is anatomically divided into body, long process, short process and lenticular process.[27]

Body of the incus- It is a flat bone, resides in the attic area along with head of the malleus. In its anterior aspect, it has an articular surface for articulation with the

head of the malleus.[27] Both long and short processes of incus arise in the lower part of the body in its posterior aspect. The two processes are at right angles to each other.[27]

Short process of the incus -It is an extension from the posterior aspect of the body and is thick and triangular in shape, placed in the horizontal axis. In the floor of the aditus there is a fossa which lodges the short process and is called the incudal fossa.[27]

Long process of the incus–is also called vertical process. It extends downwards along with the manubrium of malleus, but lies more posteriorly. Long process has very poor blood supply and undergoes osteitic resorption. The caudal end of this process forms the lenticular process which is at right angles to the long process.[27]

Lenticular Process – is a small bony pedicle and is a flattened bone which forms a communication between the incus and stapes head and is surrounded by joint capsule.[27]

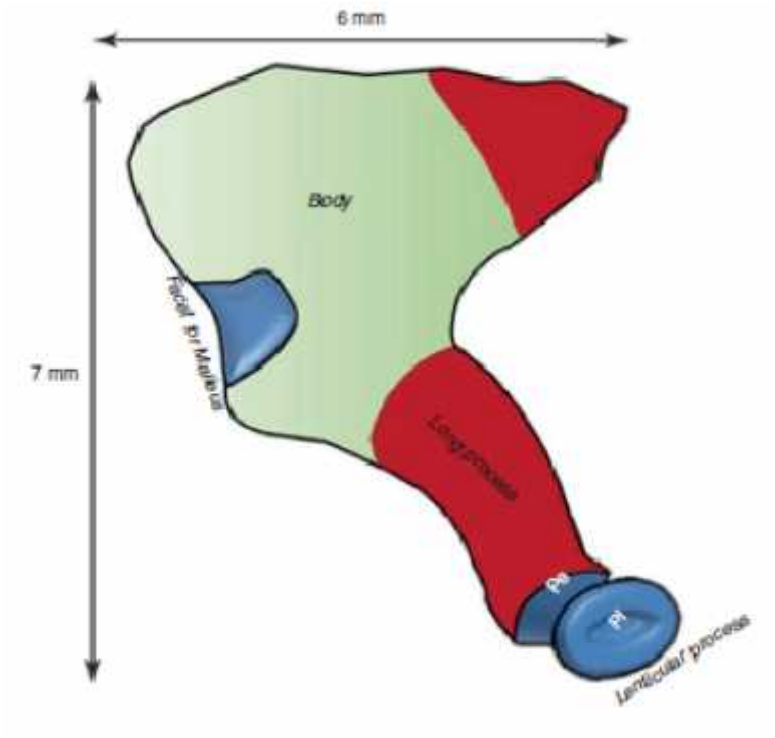


Fig. 8 SCHEMATIC DIAGRAM OF INCUS[27]

Image 2- **CADAVERIC INCUS BONE**

Ligaments of the Incus

The incus has the minimum ligaments and is thus more vulnerable to traumatic dislocation compared to other ossicles.[27] Two ligaments keep the incus in position:

1. Superior incudal ligament(SIL)-It arises from the tegmen and attaches to the incus body.Upper lateral attic is separated from upper medial attic by this ligament.[27]
2. Posterior incudal ligament(PIL) -safeguards the short process in the incudal fossa. It is in the axis of rotation of the ossicular chain.[27]

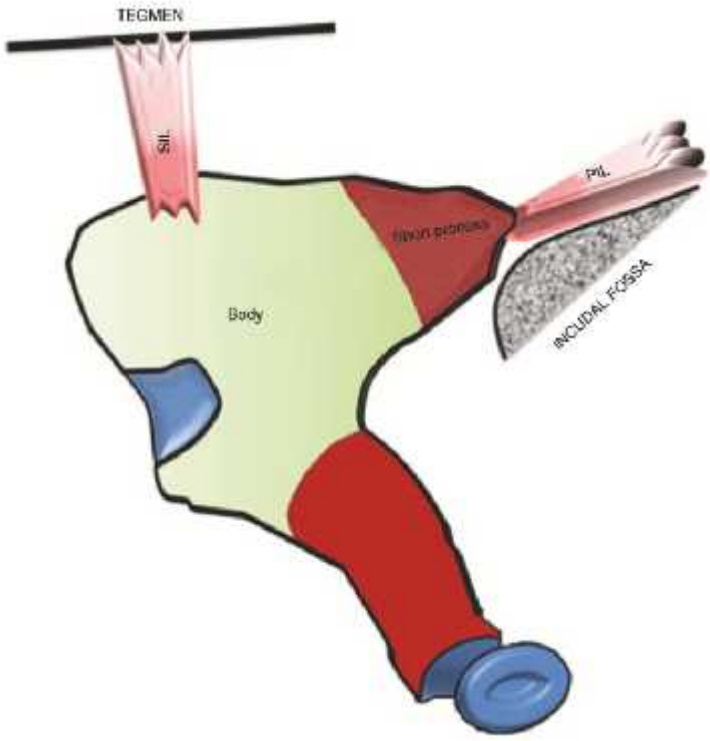


Fig. 9 INCUDAL LIGAMENTS[27]

ANATOMY OF STAPES

The stapes also called 'stirrup'is a miniature bone in our body and measures 3.25mm in height, 1.4mm wide and weighs around 3-4mg. It acts as a bridge between the lenticular process of the incus and the oval window and is placed below the facial nerve.[27]Anatomically, it can be divided into head, neck and crura i.e. anterior and a posterior and footplate as shown in figure 10.[27]

Head- is small discoid shaped bone and has an articular surface on its lateral aspect, leading medially to form a neck. On its posterior part we can see the attachment of stapedial tendon.[27]

Crura- Two crura of different size are seen in the stapes i.e. the anterior and posterior crura. The anterior crura is shorter, thinner and less curved than the posterior crura.[27] Obturator foramen is the area between the two crura and has mucous membrane covering it at times.[27]

Footplate- It is an oval, thin, flat bone measuring around 3mm long and 1.5mm wide and 0.25mm thick.[27]The saccule is situated 1 mm deep from the anterior part of the vestibular surface of the footplateand the utricle is situated 1.5 mm deep from its posterior part.[27]

Image 3**CADAVERIC STAPES BONE**

Annular ligament -is a ring of elastic fibers that confers the cartilaginous margin of the footplate to the boundary of the oval window.

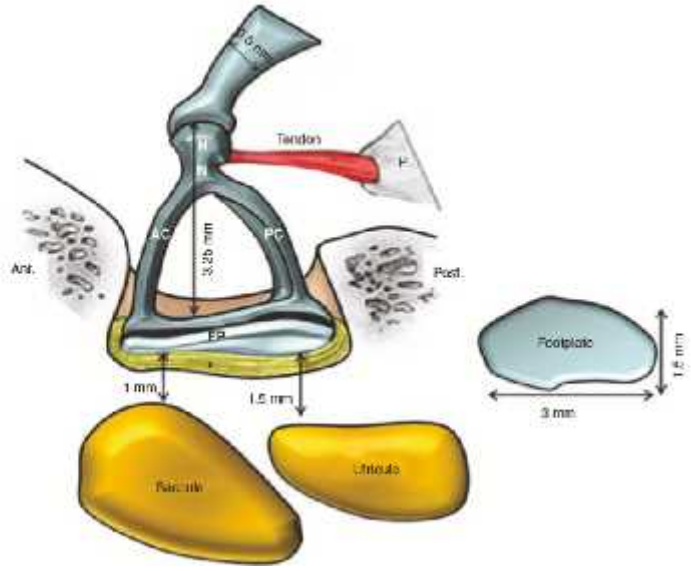


Fig. 10RELATIONSHIP OF STAPES AND OVAL WINDOW[27]

Discontinuity or fixity of ossicular chain leads to conductive hearing loss. An eroded incudo-stapedial joint, an absence incus or an absent incus and stapes superstructure leads to ossicular discontinuity in increasing order of frequency.[27]To restore appropriate sound transmission, ossicular chain reconstruction has to be performed. Several factors have to be considered when selecting a material to use for ossicular reconstruction. This includes ease of availability, stiffness, stability, biocompatibility and cost effectiveness.

One of the main aims in modern ear surgery is reconstruction of theossicular chain. They may be divided in to groups, depending on the material that is used for reconstruction of the ossicular chain, ossicular tissue and bone or cartilage as autografts. Prosthetic devices have become popular because of the relative simplicity of the procedure and availability.However, some drawbacks of introducing a foreign material in the middle ear like chronic inflammatory changes have beenrecognized.

According to R S Mudhol et al, autograftswerepreferred for ossicular reconstructionbecause they hadvery low extrusion rate. But, with the development of newer bioactive synthetic prosthesis and moldable materials, extrusion rate has become low. Hence, we can expect bio-synthetic materials to be more popular.[28]

MATERIALS AND METHODS

Study design: Cross sectional study

Study period: One year - 01 (January 2019 to December 2019)

Source of data: Temporal bones subjected for dissection during the study period in Department of Anatomy, J. N. Medical college, Belagavi.

Sample size: 40 formalin fixed temporal bone

Ethical clearance: Ethical clearance was obtained from the Institution's EthicsCommittee (IEC)

[Ref: dated: 24/11/18 - MDC/DOME/51]

Inclusion criteria: Temporal bones from cadavers subjected for dissections

Exclusion criteria:

1. Temporal bones with any evidence of previous surgeries
2. Temporal bones with history or any evidence of trauma.

Methodology:

- Each cadaver was numbered categorically and the incision was marked.
- Post auricular (Wilde's) incision was taken
- Using the instruments showed in the picture below (Image-1), dissection was carried out

Image 4 – Instruments

- Skin, subcutaneous tissue up till periosteal layer was dissected.
- Entry into external auditory canal was made
- Tympanic membrane was meticulously dissected.
- All 3 ossicleswere visualized using a zero-degree endoscope
- Muscle attachments from the bone were separated.
- With gentle manipulation,ossicles were removed.
- All three ossicles were washed with hydrogen peroxide solution and each set of ossicles was stored in a clean box after labelling it.
- Each ossiclewas weighed using electronic weighing machine.
- Measurementof each ossicles was done using osseous sizer
- Photographs were taken from a fixed distance using NIKON^{TM} D3500 DSLR camera.
- Later, ossicles were plastinated and preserved for further studies.

All measurements were noted and analyzed based on their distribution amongst the gender and their mean, median and standard deviation were calculated. Statistical analysis was done by Chi-square test, Paired t test, Independent t test and Karl Pearson's correlation coefficient method using statistical package for social sciences version 20 (SPSS™ 20).

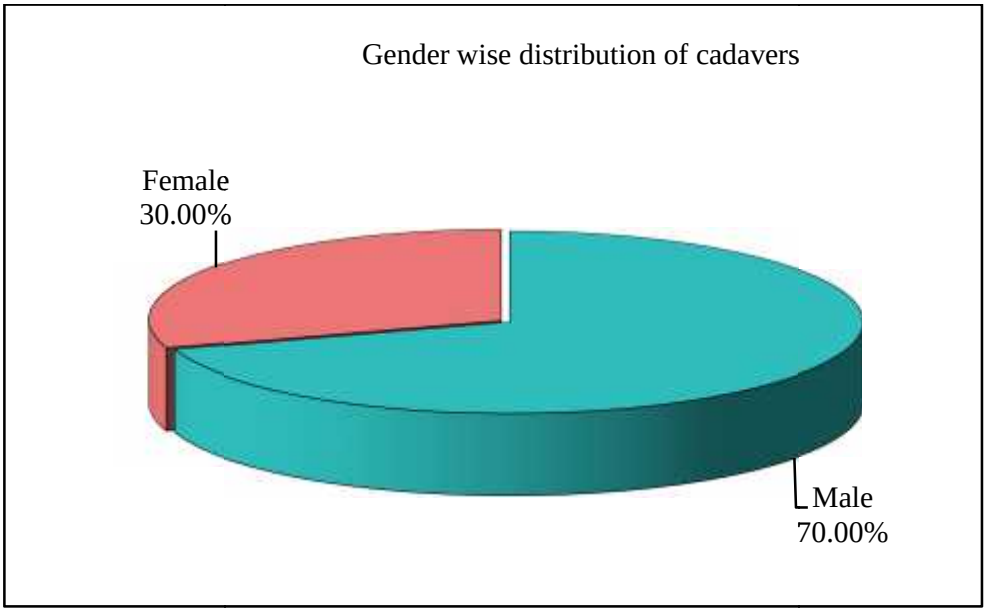
RESULTS

Image-5 Photographs of 40 sets of Ear ossicles

A total of 20 cadavers (40 sets of ossicles) were evaluated. The gender distribution of the sample was as follows (Table 1, Graph 1)

Gender	No of cadavers	% of cadavers
Male	14	70.00
Female	6	30.00
Total	20	100.00

Table 1: Gender distribution of cadavers used in the study



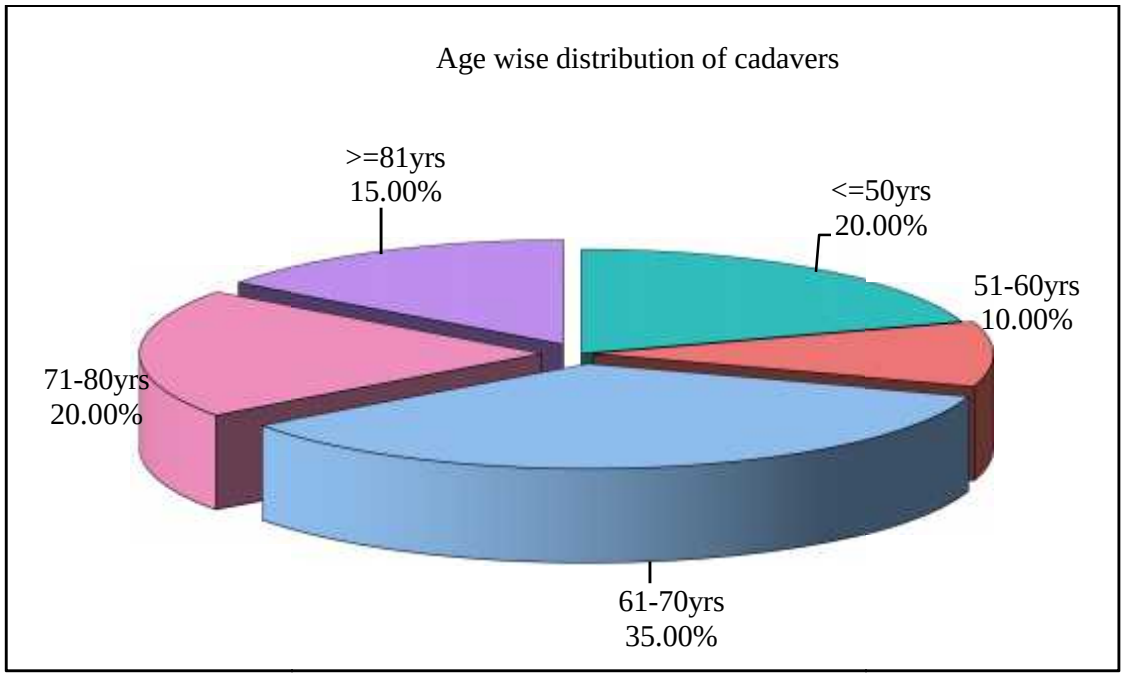
Graph 1- Pie chart showing gender distribution of cadavers used in the study

70% were males and 30% were females.

The age distribution of the sample is as follows (Table 2, Graph 2)

Age groups	No of cadavers	% of cadavers
<=50yrs	4	20.0
51-60yrs	2	10.0
61-70yrs	7	35.0
71-80yrs	4	20.0
>=81yrs	3	15.0
Total	20	100.0

Table 2: Age wise distribution of cadavers



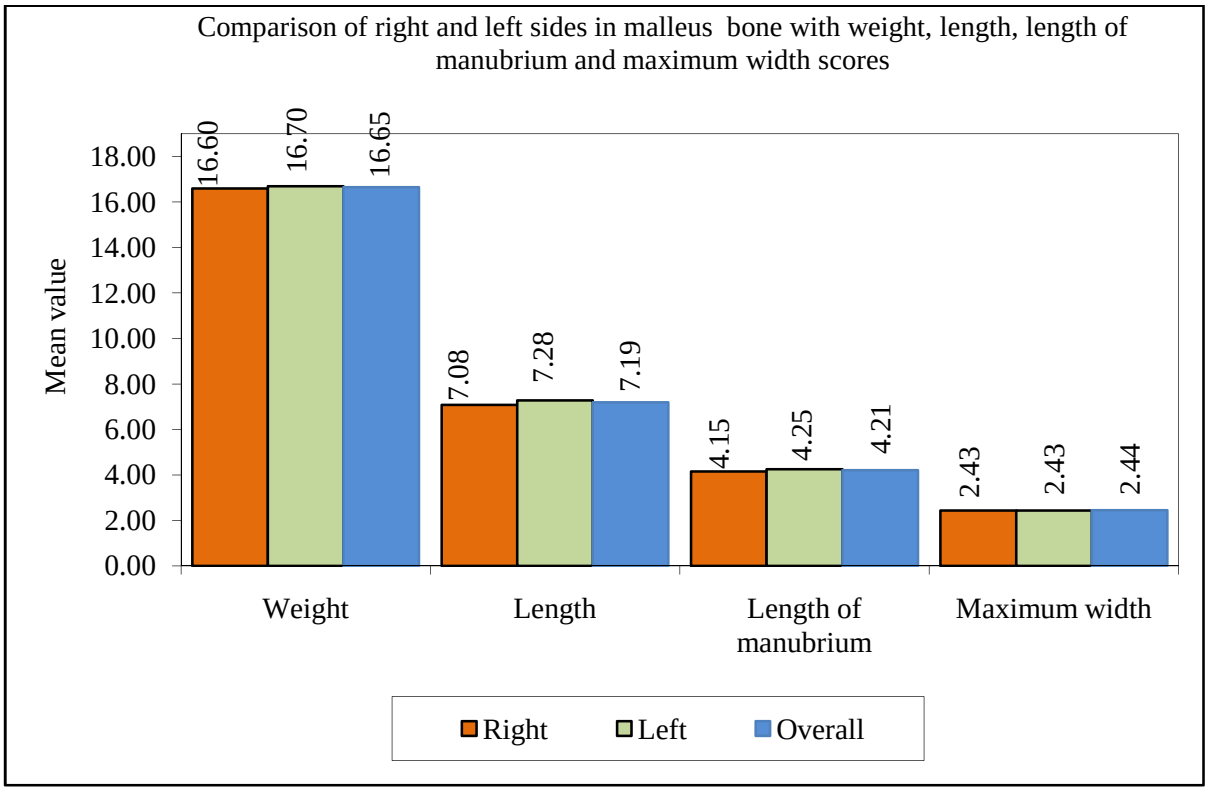
Graph 2: Pie chart showing age wise distribution of cadavers

The youngest cadaver was 23 years old and oldest cadaver was 92 years old.

MALLEUS

Summary of weight, length, length of manubrium and maximum width in right and left sides of the malleus bonewas done as shown below **(**Table 3, Graph 3)

Parameters	Sides	N	Min	Max	Range	Mean	SD
Weight	Right	20	12.00	21.00	9.00	16.60	2.66
	Left	20	13.00	20.00	7.00	16.70	2.60
	Overall	20	12.50	20.50	8.00	16.65	2.52
Length	Right	20	6.00	8.50	2.50	7.08	0.99
	Left	20	6.00	9.00	3.00	7.28	1.03
	Overall	20	6.00	8.80	2.80	7.19	1.00
Length of manubrium	Right	20	2.50	5.00	2.50	4.15	0.76
	Left	20	2.50	5.00	2.50	4.25	0.75
	Overall	20	2.50	5.00	2.50	4.21	0.75
Maximum width	Right	20	1.50	4.50	3.00	2.43	0.83
	Left	20	1.50	4.50	3.00	2.43	0.83
	Overall	20	1.50	4.50	3.00	2.44	0.82



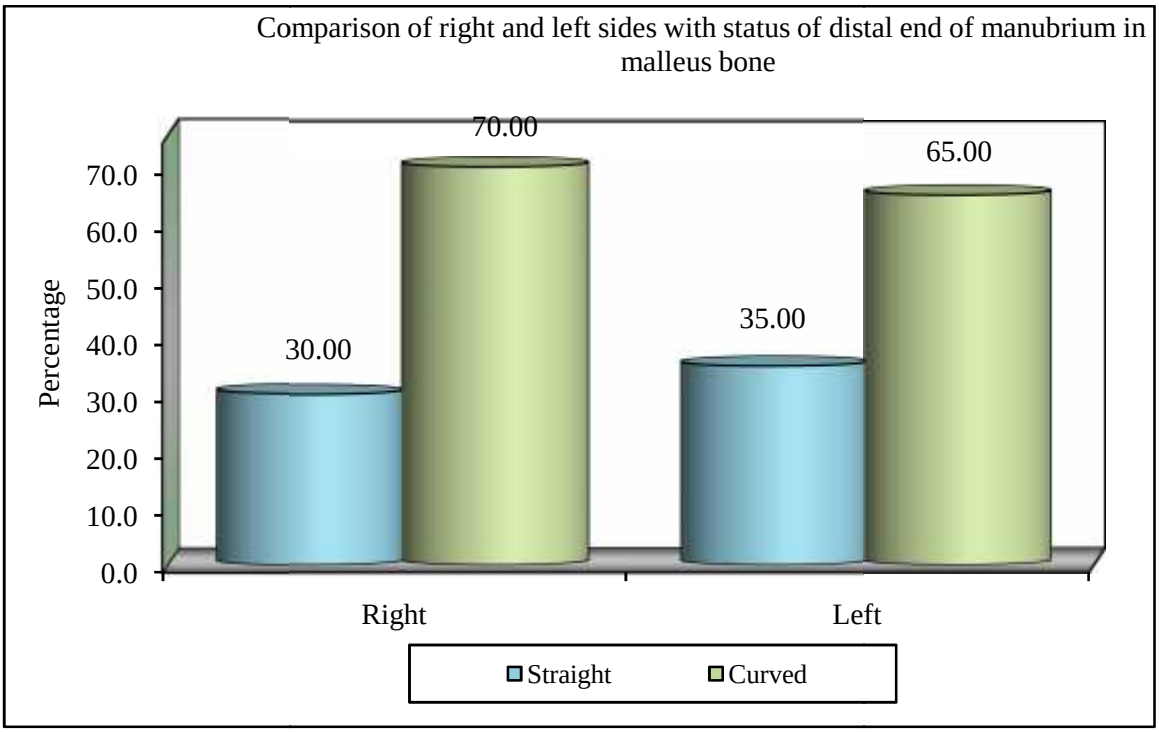
Graph 3- showing comparison of right and left side malleus

- The weight ranged from 12mg – 21 mg, an average of 16.65 mg. Average on the right side was 16.60 mg and 16.70 mg on left side.
- The total length of the malleus ranged from 6mm – 9 mm with an average of 7.19 mm. Average on the right side was 7.08 mm and 7.28 mm on the left side.
- The length of the manubrium ranged from 2.5 mm – 5 mm with an average of 4.21 mm. Average on right side was 4.15 mm and 4.25 mm on the left side.
- The maximum width of the head ranged from 1.5 mm – 4.5mm and an averageof 2.44mm. Average on the right side was 2.43 mm and 2.43 mm on the left side.

Comparison of right and left sides with status of distal end of manubrium in the malleus bone (Table 4, Graph 4) was done as follows-

Distal end of manubrium	Right	%	Left	%	Total	%
Straight	6	30.00	7	35.00	13	32.50
Curved	14	70.00	13	65.00	27	67.50
Total	20	100.00	20	100.00	40	100.00
Chi-square= 0.1142 P = 0.7363						

Table 4- Comparison of Distal end of manubrium of right and left malleus



Graph 4- Bar diagram showing right and left sides with status of distal end of manubrium in malleus bone

Out of 40 sets of ossicles, morphologically malleus showed very less variations except that distal end of 13 bones were straight (30%) and 27 bones were curved (70%) as seen in Image 6.There is no statistical difference between right and left side.

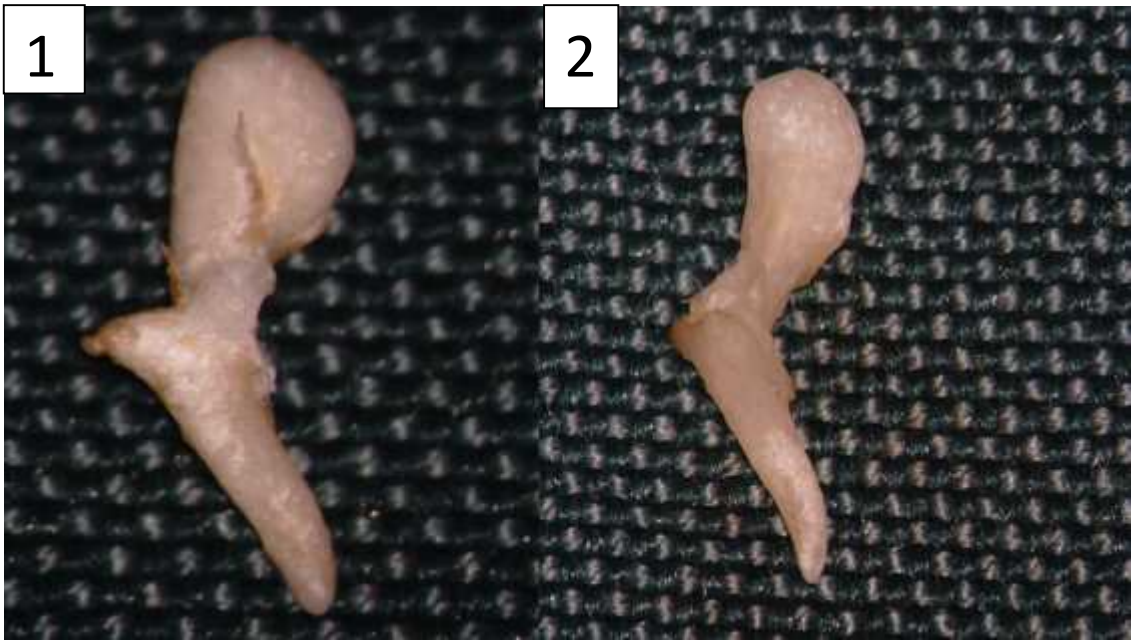


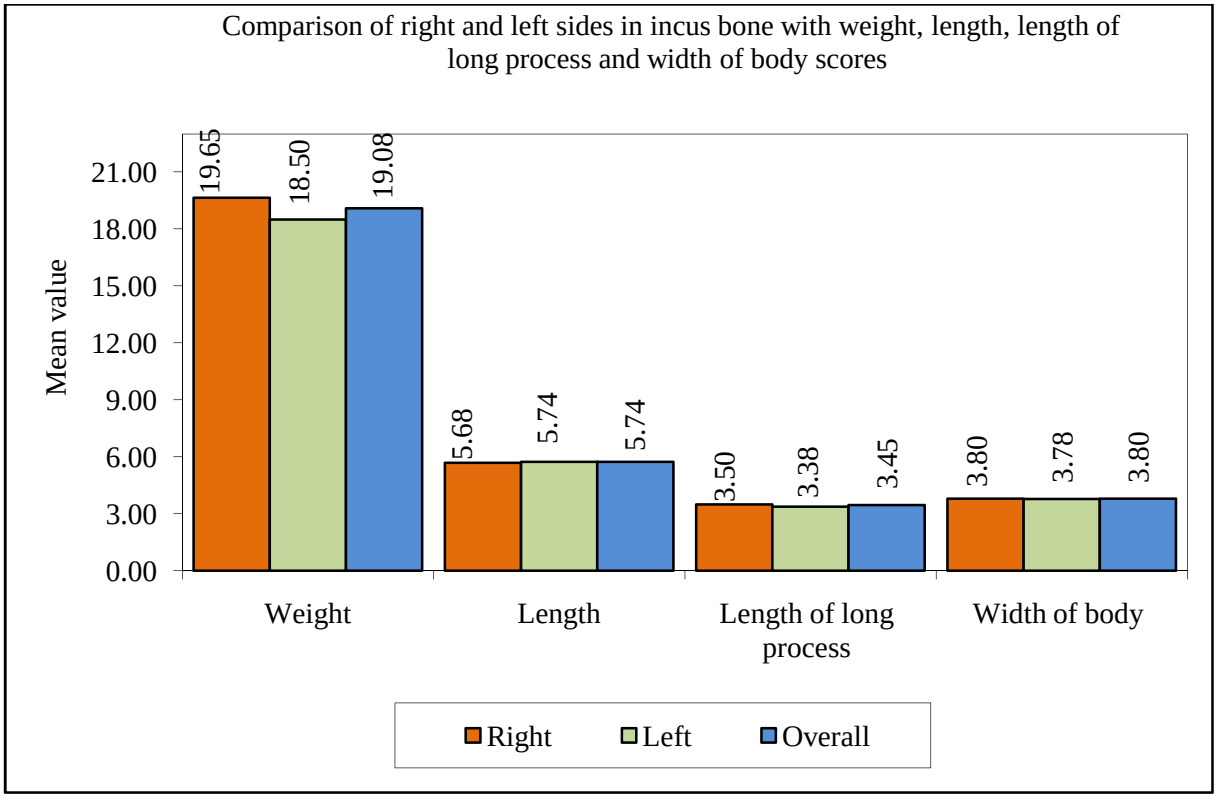
IMAGE 6 1st Showing straight and 2nd image showing curved distal endof manubrium

2)INCUS

Summary of weight, length, length of long process and width of body in the right and left sides in of the incus bone **(**Table 5, Graph 5) was done as shown below.

Parameters	Sides	N	Min	Max	Range	Mean	SD
Weight	Right	20	13.00	26.00	13.00	19.65	3.75
	Left	20	12.00	28.00	16.00	18.50	4.48
	Overall	20	12.50	27.00	14.50	19.08	4.04
Length	Right	20	4.50	7.00	2.50	5.68	0.86
	Left	20	4.40	7.00	2.60	5.74	0.93
	Overall	20	4.50	7.00	2.50	5.74	0.87
Length of long process	Right	20	2.50	4.50	2.00	3.50	0.51
	Left	20	2.50	4.50	2.00	3.38	0.56
	Overall	20	2.50	4.50	2.00	3.45	0.50
Width of body	Right	20	3.00	5.50	2.50	3.80	0.85
	Left	20	3.00	5.00	2.00	3.78	0.68
	Overall	20	3.00	5.30	2.30	3.80	0.77

Table 5- Summary of weight, length, length of long process and width of body in theright and left sides in of the incus bone.



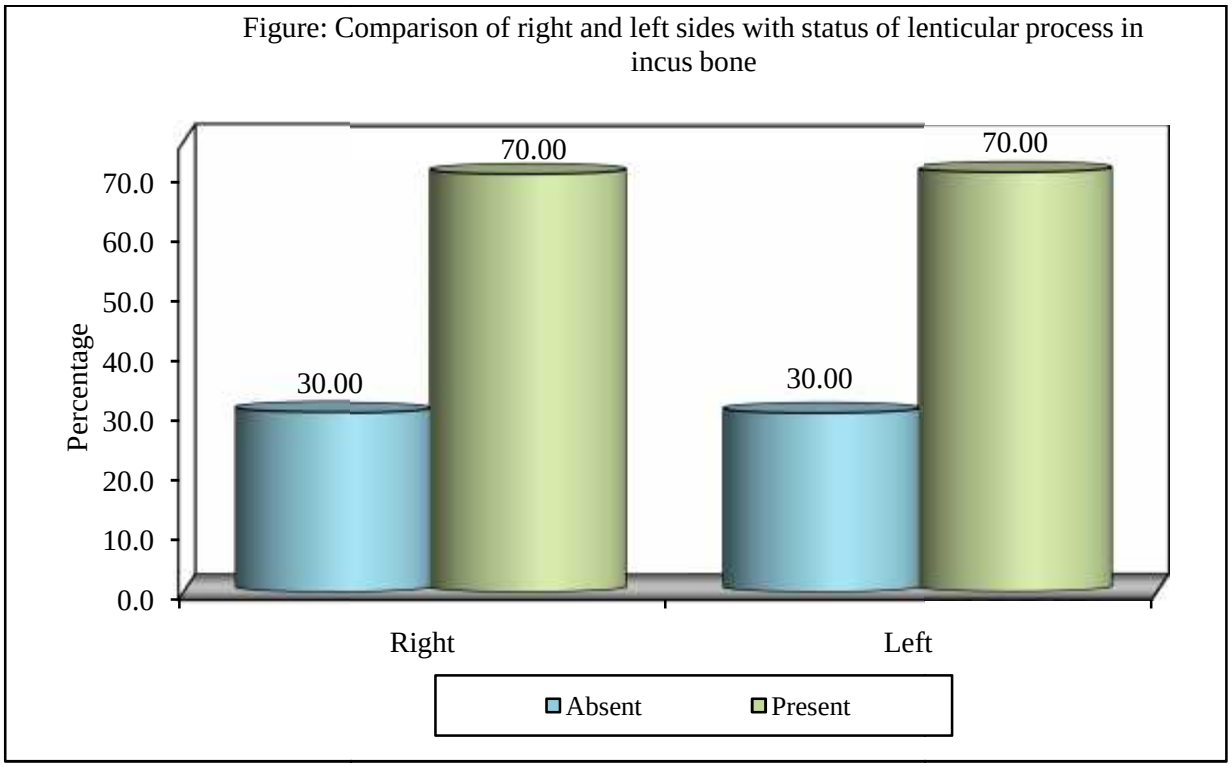
Graph 5: Bar diagram summarizingweight, length, length of long process and width of body of incus

- The weight of the incus ranged from 12mg – 28 mg with an average of 19.8 mg. Average on the right side was 19.65 mg and 18.50 mg on the left side.
- The total length of the incus ranged from 4.40 mm – 7 mm with an averageof 6.74mm. Average on the right side was 5.68 mm and 5.74 mm on the left side.
- The total width of the body ranged from 3 mm – 5.50 mm with an average of 3.80 mm. Average on the right side was 3.80 mm and 3.78mm on left side.
- The length of the long process ranged from 2.50 mm – 4.50 mm with an average of 3.80 mm. Average on the right side was 3.80 mm and 3.78 mm on the left side.

Comparison of the right and left sides with status of lenticular process ofincus bone was done as shown in (Table 6, Graph-,6)

Lenticular process	Right	%	Left	%	Total	%
Absent	6	30.00	6	30.00	12	30.00
Present	14	70.00	14	70.00	28	70.00
Total	20	100.00	20	100.00	40	100.00
Chi-square=0.0000, p=1.0000						

Table 6: Comparison of right and left sides with status of lenticular process of incus



Graph 6: Comparison of right and left sides with status of lenticular process of incus

Out of 40 sets of ossicles, morphology of the incus showed variation which could be developmental or necrosis of lenticular process. In 28(70%) bones, showed fully developedlenticular process was seen and in 12 (30%) bones showed underdeveloped/necrosedlenticular process was seen as seen in Image 7.There is no statistical difference between right and left side.

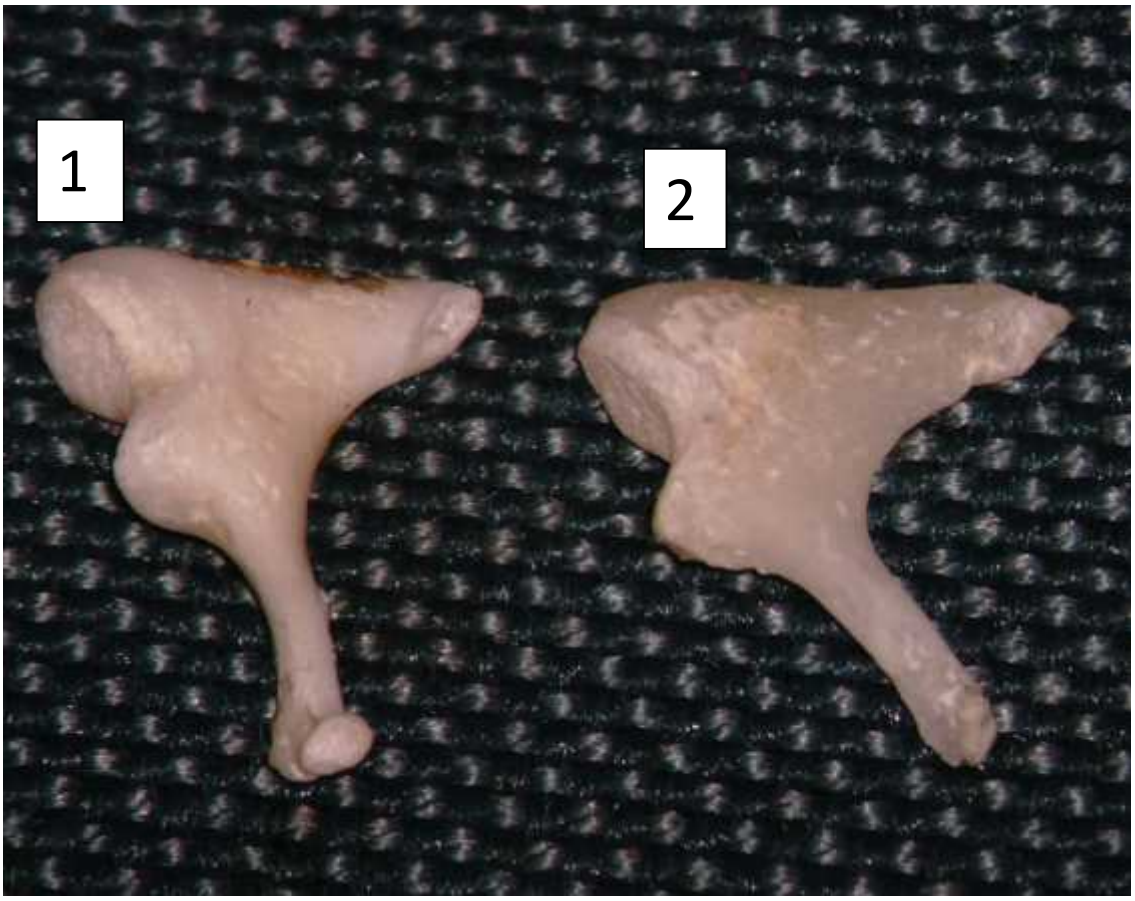


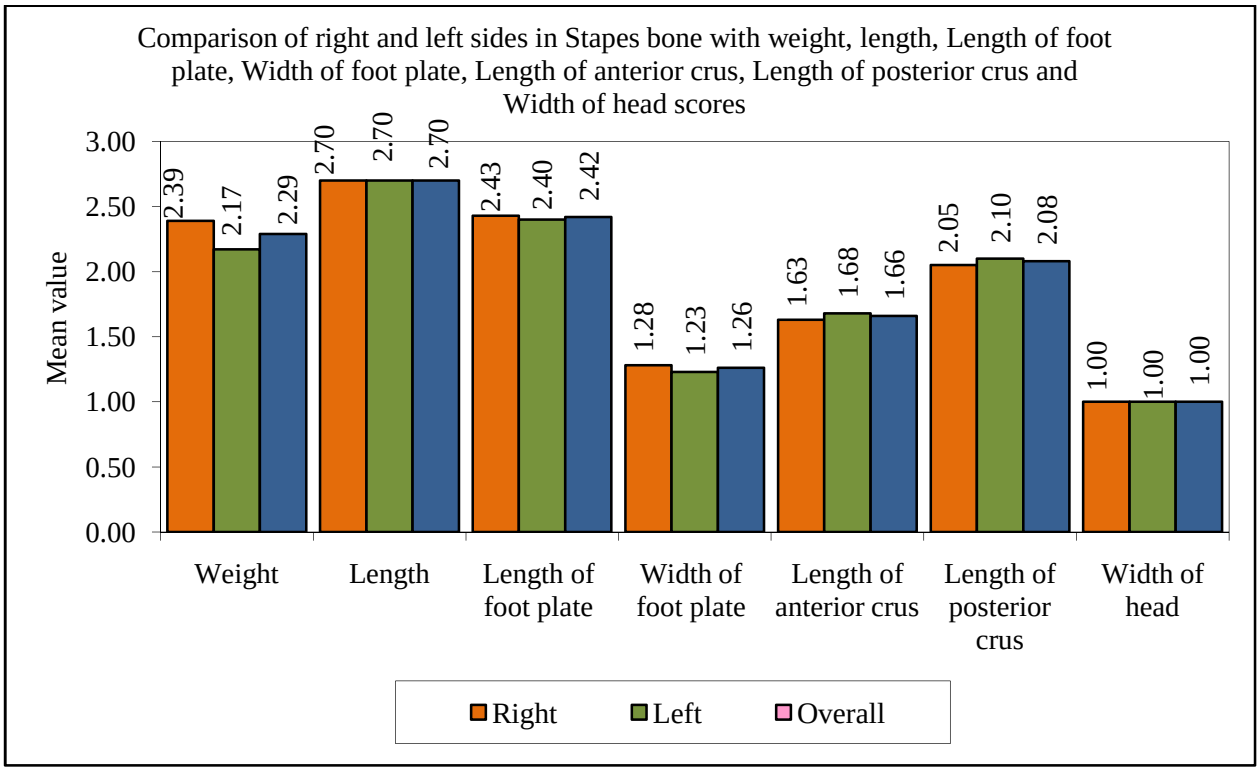
IMAGE 7- 1st Showing fully developed lenticular process and 2nd image showing underdeveloped/necrosedlenticular process

3) STAPES–

Summary of weight, length, length of foot plate, width of foot plate, length of anterior crus, length of posterior crus and width of head in right and left sides in stapes bonewas done as shown in**(**Table 7, Graph 7)

Parameters	Sides	N	Min	Max	Range	Mean	SD
Weight	Right	20	1.80	3.00	1.20	2.39	0.47
	Left	20	1.50	3.00	1.50	2.17	0.46
	Overall	20	1.70	3.00	1.30	2.29	0.43
Length	Right	20	2.00	3.50	1.50	2.70	0.38
	Left	20	2.00	3.50	1.50	2.70	0.38
	Overall	20	2.00	3.50	1.50	2.70	0.38
Length of foot plate	Right	20	2.00	3.00	1.00	2.43	0.37
	Left	20	2.00	3.00	1.00	2.40	0.38
	Overall	20	2.00	3.00	1.00	2.42	0.37
Width of foot plate	Right	20	1.00	2.00	1.00	1.28	0.38
	Left	20	1.00	2.00	1.00	1.23	0.38
	Overall	20	1.00	2.00	1.00	1.26	0.37
Length of anterior crus	Right	20	1.00	2.50	1.50	1.63	0.46
	Left	20	1.00	2.50	1.50	1.68	0.41
	Overall	20	1.00	2.50	1.50	1.66	0.42
Length of posterior crus	Right	20	1.50	2.50	1.00	2.05	0.36
	Left	20	1.50	2.50	1.00	2.10	0.31
	Overall	20	1.50	2.50	1.00	2.08	0.32
Width of head	Right	20	0.50	1.50	1.00	1.00	0.28
	Left	20	0.50	1.50	1.00	1.00	0.28
	Overall	20	0.50	1.50	1.00	1.00	0.28

Table 7- Summarising of weight, length, length of foot plate, width of foot plate, length of anterior crus, length of posterior crus and width of head in right and left sides in stapes bone.



Graph 7- Comparison of right and left sides in Stapes bone with weight, length, Length of foot plate, Width of foot plate, Length of anterior crus, Length of posterior crus and Width of head

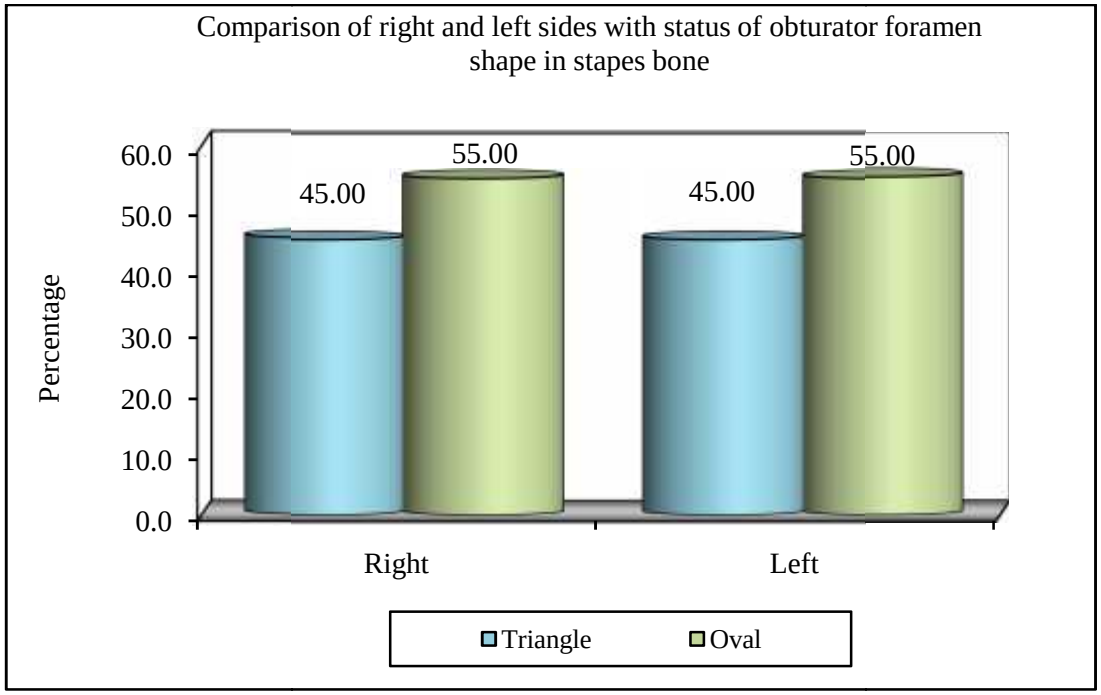
- The weight ranged from 1.50 mg – 3mg with an average of 2.29 mg. Average on the right side was 2.39 mg and 2.17mg on the left side.
- The total height of the stapes ranged from 2 mm – 3.5 mm with an average of 2.7 mm. Average on the right side was 2.7 mm and 2.7 mm on the left side.
- The length of the footplate ranged from 2 mm – 3 mm with an average of 2.42 mm. Average on the right side was 2.43 mm and 2.40 mm on the left side.
- The width of footplate ranged from 1 mm – 2 mm with an average of 1.26 mm. Average on the right side was 1.28 mm and 1.23 mm on the left side.

- The length of the anterior crus ranged from 1 mm – 2.5 mm with an average of 1.66 mm. Average on the right side was 1.63 mm and 1.68 mm on the left side.
- The length of the posterior crus ranged from 1.5 mm – 2.5 mm with an averageof 2.08 mm. Average on the right side was 2.05 mm and 2.10 mm on the left side.
- The width of the head ranged from 0.5 mm – 1.5 mm and an average of 1 mm. Average on the right side was of 1 mm and 1 mm on the left side.

Comparison of right and left sides with status of obturator foramen shape in stapes bone (Table-8, Graph-8)

Obturator foramen shape	Right	%	Left	%	Total	%
Triangle	9	45.00	9	45.00	18	45.00
Oval	11	55.00	11	55.00	22	55.00
Total	20	100.00	20	100.00	40	100.00
Chi-square=0.0000, p=1.0000						

Table 8: Comparison of right and left sides with status of obturator foramen shape in stapes bone



Graph 8: Comparison of right and left sides with status of obturator foramen shape in stapes bone

Out of 40 sets of ossicles, with respect to stapes morphology, we found 18 (45%) bones had triangular shaped and around 22 (55%) bones had ovalshaped obturatorforamen as seen in Image 8.

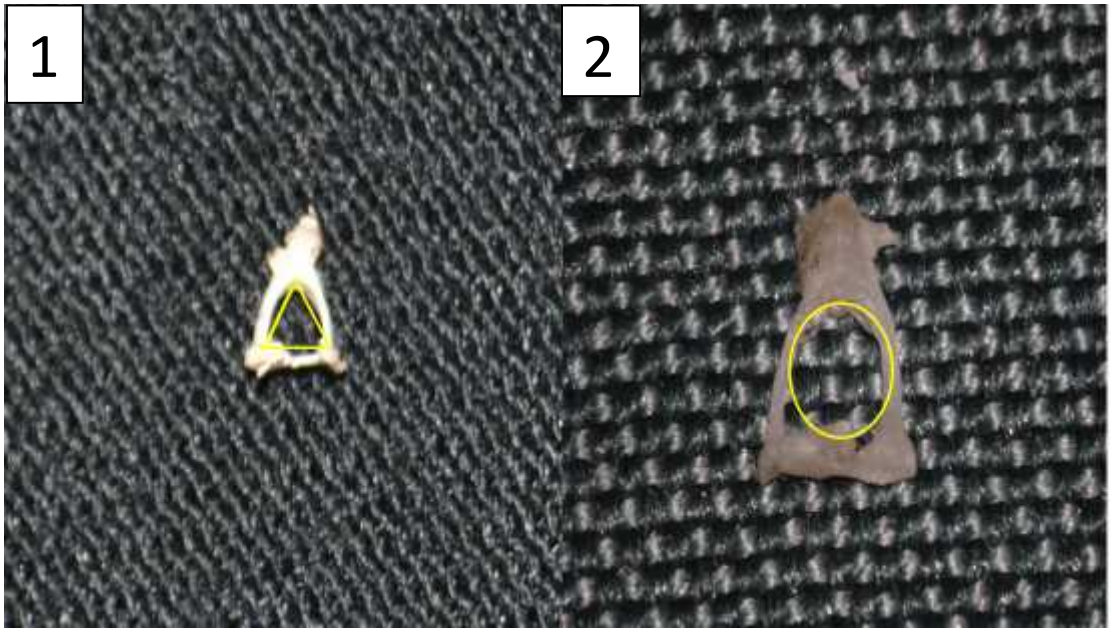
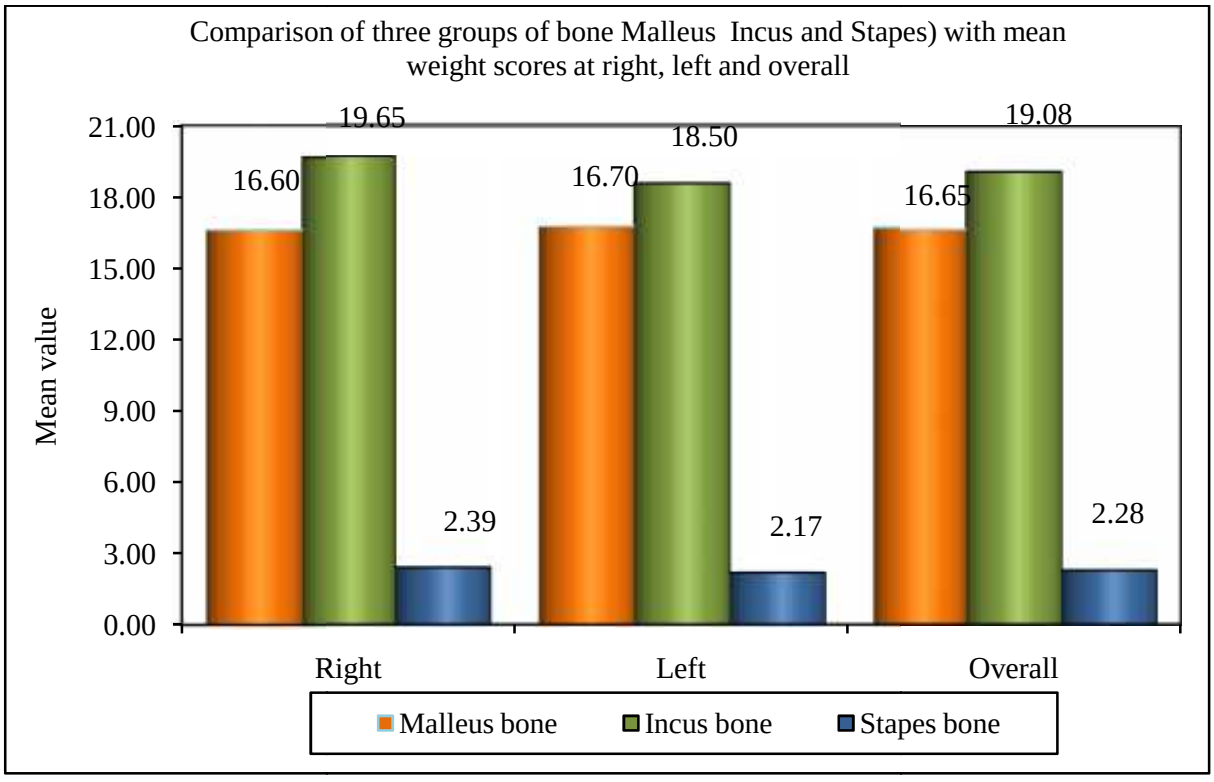


IMAGE 8 - 1st showing triangular shaped and 2nd image showing oval shaped obturator foramen

Comparison of the three groups of ossicles (malleus, incus and stapes) with mean weight scores of right and left and overall,by oneway analysis of variance or ANOVA (Table-9, Graph-9)

Bones	Right		Left		Overall	
	Mean	SD	Mean	SD	Mean	SD
Malleus bone	16.60	2.66	16.70	2.60	16.65	2.52
Incus bone	19.65	3.75	18.50	4.48	19.08	4.04
Stapes bone	2.39	0.47	2.17	0.46	2.28	0.44
Total	12.88	8.03	12.46	7.94	12.67	7.95
F-value	238.6616		178.0891		216.1340	
p-value	0.0001*		0.0001*		0.0001*	

*p<0.05**Table 9: Comparison of the mean weight of all 3 ossicles.**



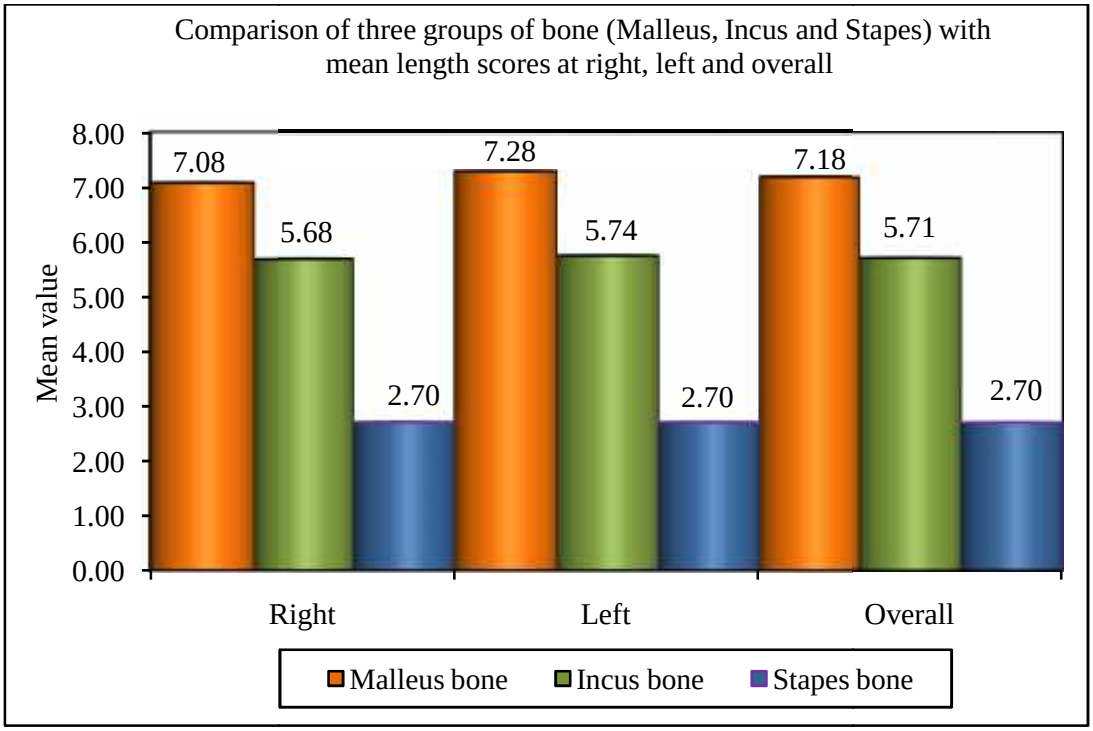
Graph 9: Comparison of the mean weight of all 3 ossicles.

Among all 3 bones heaviest bone wasincus(19.08mg) followed by malleus (16.65mg) and least being stapes (2.28mg).There is no statistical difference between the right and left side.

Comparison of the three groups of bone (malleus, incus and stapes) with mean length scores at right, left and overall (Table 10,Graph 10)

Bones	Right		Left		Overall	
	Mean	SD	Mean	SD	Mean	SD
Malleus bone	7.08	0.99	7.28	1.03	7.18	1.00
Incus bone	5.68	0.86	5.74	0.93	5.71	0.88
Stapes bone	2.70	0.38	2.70	0.38	2.70	0.38
Total	5.15	2.00	5.24	2.08	5.20	2.04
F-value	160.4154		158.5260		164.1365	
p-value	0.0001*		0.0001*		0.0001*	

Table 10: Comparison of the three groups of bone with their mean length



Graph 10: Comparison of the three groups of bone with their mean length.

Malleus(7.18mm)is the longest bone followed by incus (5.71mm) and stapes(2.70mm) being the shortest.

There is no statistical difference between right and left side.

DISCUSSION

Our existing knowledge of sound transmission is ongoingsince the sixth century B.C. when Pythagoras, the Greek mathematician, familiarized the concept that soundwas a vibration in air. Seven centuries later, in 175 AD,Galen, the Greek physician,recognized that the sensation of sound was transmitted to the brain via nerves. Thebreach in knowledge between Pythagoras's theory of sound as air vibration and Galen's theory of nervestransmitting sound to the brain was filled in 1543 by the Belgian anatomist AndreasVesalius, who discovered the malleus and incus. Seven years later in 1546, Ingrassiasdiscovered the third ossicle, the stapes.[29]

The human auditory system is a remarkable engineering design that is madeup of complex geometries. Sound is transmitted from external auditory canal to the cochlea via two mechanisms: the tympano-ossicular systemand direct acoustic stimulation of the oval and round windows (acoustic coupling)[30].

It has been valued that large section of the deaf in evolving countries require 32 million hearing aids per year.[31]In order of frequency, ossicular break usuallyoccurs due to an eroded incudo-stapedial joint, an absent incus, or an absent incus and stapes suprastructure. To restore appropriate sound transmission, ossicular chain reconstruction has to be performed.[32]

Although the knowledge of ossicular chain has been there for around 500 years, there are only a small number of morphometrical studies on ear ossicles.[33]Quam and Rak[34]provided the foremost set of well-defined measurements. By determining the X and Y axis of the bone following which all the distances and angles were calculated. However,Hallgrimssonet al[35]gave one of the most efficient and accurate method,computerized tomography whichprovided the measurements of

ossicles**.**Other competent methodswere,projection of the ossicle on a printedphotograph or digitally on a screen from a microscope followed bycalculation of the dimensions. The latter method is more easily performed, but entails errors regarding the projection of such small objects onto a screen thuscausing parallax error.

A study by Flohr et alprovided measurements from two different technicians and showed an inter-observer error ranging from 2% to 2.63%. Hence there must be a minimum of at least two measurements of equivalent value for every separate ossicle.[36]Noussiosat etconcluded from their review that despite measuring common dimensions andthe mean weight, other dimensions cannot be sufficiently interpreted as large differences exist between different authors and amongst races.[33]

In our present study under endoscopic guidance all 3 ossicles were carefully removed in toto and measured using anosseous sizer and weighed using electronic weighing machine. Photographs were documented for evaluation of morphological features

MALLEUS

In our study, we compared 40 sets of ossicles from 20 cadavers.The length of malleus in our study ranged from 6mm–9mm with an average of 7.19mm which is almost similar to other studies.Shafer, Symington and Bryce have observed that the malleus is 8–9mm in length.[17]Comparison of measurements with other studies is shown in Table 11.

In the present study, the maximum width of head ranged from 1.5mm–4.5mm with an averageof 2.44mm. Jyoti et alreported similar values ranging from 1.83mm–

2.80mm with a mean of 2.37mm[5].The weight in our study ranged from 12mg – 21 mg with an average of 16.65 mg which was slightly low compared to other studies.

Out of 40 sets of ossicles, morphologically malleus showed very less variations. Todd and Creighton studied 82 malleusand found that there was an absence of the lateral process in one case.[37] In a study done by RitabanSaha et al, they reported that the distal end was curved in 55.8% of the bones and straight in 44.2%.[3]In the present study distal end of 13 bones were straight (30%) and 27 bones were curved (70%). There is no statistically significant difference between right and left side.A Comparison of morphometry of malleus in our study with other studies is shown in Table 11.

Author	Length of malleus	Length of manubrium
Present study	7.19 mm	4.21mm
K. Radha et al[11]	7.4mm	4.2mm
Unur, Ulger& Ekinki[15]	7.7 mm	4.7mm
Jyoti et al[5]	7.65mm	3.52mm
Harneja NK[38]	7.15mm	4.22mm
D.V. Kumar et al[10]	8mm	4.17mm
Singh K[39]	7.9mm	4.76mm

Table 11: A Comparison of morphometry of malleus with other studies

INCUS

In our study, the length of the incus ranged from 4.4mm–7mm with an averageof 6.74mm. The width of the body ranged from 3mm–5.5mm withan average

of 3.8mm. The weight of incus ranged from 12mg–28mg with an average of 19.8mg. A comparison of morphometry of incus with other studies is shown in Table 12.

Author	Length of Incus	Width
Present study	6.47mm	3.80mm
Arrensburg et al[6]	6.4mm	5.1mm
Unur, Ulger&Ekinki[15]	6.5mm	4.9mm
Jyoti et al[5]	6.3mm	4.4mm
Harneja NK[33,38]	3.14mm	1.82mm
D.V. Kumar et al[10]	7.04mm	5.31mm
Harada[5]	8.0mm	4.2mm

Table 12: Comparison of morphometry of incus with other studies

The length of incus in the present study is almost similar to other studies shown in the above comparison table. The width of incus islesser compared to other studies.The mean weight of incus in ourstudy was found to be 19.8mg which was lesser than that inthe study done by Jyoti et al (23.8mg).[5]The mean length of long process of incus inour study is 3.80mmwhich is lower as compared to 4.27mm-5.55mm reported by Wolff et al.[40]

According to Lanningan FJ et al, the morphometric study done on seventeen incus specimens using scanningelectron microscope demonstrated the progressive symmetric resorption of thelenticular process of the incus with advancing age.[41]In our study, we could not quantify the resorption due to lack of appropriate apparatus, however, there was no such trend observed overall.

STAPES

The stapes is the smallest bone in the human body. It measures around 3.25mm high and 1.4mm wide and has a weight of 3–4 mg (Wengen et al).[23]Horiuchi et al used computerized tomography for viewing stapes supra structure but only around 70% of theossicle was visualized as it was dependent on the air present in the surrounding and it was also difficult to visualizeon computed tomography because of its low bone density and volume.[42]In the present study, the morphometric data of stapes showed thatthe height of stapes ranged from 2mm–3.5mm with an average of 2.7mm. A comparison of morphometry of Stapes with other studies is shown in Table 13.

Author	Height of stapes	Length of foot plate	Widthof foot plate
Present study	2.7 mm	2.42 mm	1.26mm
Arrensburg et al 1981[6]	3.20 ± 0.21	2.8 ± 0.15	1.3 ± 0.07
Unur, Ulger&Ekinki 2002[15]	3.22 ± 0.31	2.57 ± 0.33	1.29 ± 0.22
Jyoti et al[5]	3.1mm	1.5mm	1.5mm
Harneja NK[33,38]	3.12 ± 0.21	2.68 ± 0.27	1.26 ± 0.08
Wadha et al, 2005[1]	3.41 ± 0.20	2.97 ± 0.31	0.39 ± 0.10
Rathava et al, 2013[43]	3.33 ± 0.25	2.78 ± 0.15	1.34 ± 0.13

Table 13: Comparison of morphometry of Stapes with other studies

From the above table we know that the height of the stapes in our study is lesser compared to other studies, length and width of footplate is similar in measurements compared to other studies. A comparison of length of anterior crus and posterior crus of stapes with other studies is shown in Table 14.

Author	Length of Anterior crus	Length of Posterior crus
Present study	1.66mm	2.08mm
Wadhwa S, kaul J M, & Agarwal A K [1]	1.76mm	1.97mm
Jyoti et al[5]	1.93mm	2.04mm
Dass, Grewal& Thaper[31]	1.98mm	2.03mm

Table14- Comparison of morphometry of stapes (length of anterior crus and posterior crus) with other studies

In the present study, out of the 40 stapes specimens, the length of the anterior andposterior crus were equal in 5 specimens and in all other specimens, the posterior crus was longer than the anterior crus. Wadhwa S, Kaul J M, and Agarwal A K in their study on 10 stapes reported that in all the bones, the anterior crus of stapes was shorter than the posterior crus.[5,44]

Differences in the shape of foramen obturatumranging from circular, oval, triangular to even tunnel shaped were mentioned in different studies.[31,38]Sarrat, Guzman, Toressdistinguished numerous shapes of obturator foramen of stapes,which were round, oval, or angled.[46]In our study, we observed triangular shaped foramen in 45% of the bones and oval shaped in 55%.

Prabhu L, Saralya V, Kumar A have reported that stapes exhibited a high number of anomalous features in the head, crural regionand in the footplate area.[45]No such anomalies were observed in our study. Sarrat, Guzman, Toress noted that in 65% of the cases, the neck ofstapes was absent.[46]

In 1992, Sarrat et alanalysed the histologic design ofthe bone in human ossicles.[46]They reported that cartilaginous nodules were found in the crura, as well as in the footplate.

Ossiculoplastyis performed by a large number of surgeons using a wide variety of prosthesis materials. According to a study done by Mudhol RS and colleagues, there was significant betterment in hearing in people with ossiculoplastydone using autologous incus as compared to titanium prosthesis.[47]They also observed thathearing results and graft uptake after ossiculoplasty are significantly better when using an autologous incus rather than a titanium prosthesis for reconstructing Austin type A ossicular defects.[48]

The value of ear surgery encompassesdrive from one recognizedmilestone to another, letting the otologic surgeon to navigate through the maze of the vital structures without damaging them.[49]Some disparities in morphometric values andmorphological observations of earossicles in different studies can be explained

either by difference in the number ofspecimens studied, by the definition adopted for anatomical variants or by themethodology of analysis.[50]

CONCLUSION

Surgeons operating in themiddle ear should be aware of the possible dimensions and the considerable variations that can be present in the region to perform the needed andanticipated corrections without causing any instability tothe structural integrity. Reckoning this, ossicles are of significant importance in reconstructive efforts and a careful assessment of this region should be carried out during ossiculoplasty.

Since it is not practical to assess all the finer details of these structures in live patients, itbecomes essentialto assess, interpret and analyze with an alternative, the only feasible possibilitybeing cadaveric studies.

Till date, very few Indian studies have been done on ossicles. Most of them were done using various digitalsoftware, graph sheets or Verniercalipers for measuring ossicles. These measurementsmay be associated with errors.In this study, an attempt has been madefor the first time using anosseous sizer, a more accurate tool for the assessment of ossicular morphometry.

With a rapid rise in demand forossiculoplasty in our country, this study assesses the possible morphology and anthropometric variation that can exist in Indian cadavers with an intention to add up to the present understanding of middle ear dynamics.

We also expect that the effortof this study will also motivateseveral others to carry out temporal bone dissections with anunderstanding to gather additionalinformation on ossicles which might be conserved in ossicular banks by practicingappropriatesafeguarding and sterilization approachesfor forthcoming use as homografts in ossiculoplasty. These collected ossicles may be used to substitute eroded middle ear ossicles as an alternativeto commercially available prosthesis.

SUMMARY

This study was conducted in a span of 1 year.The objective was to studythe morphology and anthropometry of malleus, incus, stapes from temporal bonesin Indian cadavers.

40 formalin fixed temporal bonesi.e., 20 cadavers were dissected, the morphological patterns of distal end of malleus, variations in lenticular process of incus and variation in obturator foramen of stapes was studied.The anthropometric variationsinall three bones werestudied.

We obtained different measurements and patterns of ossicles and after analyzing the results were as follows–

- Among all 3 bones, the heaviest bone was incus(mean weight-19.08mg) followed by malleus (mean weight-16.65mg) and the lightest bonewas stapes (mean weight-2.28mg)
- Malleus(mean length-7.18mm)was found to be the longest bone among the three, followed by incus (mean length-5.71mm) and stapes(mean length-2.70mm).
- Malleus showed the leastmorphological variations except the distal ends, whichin 13 bones were straight (30%) and 27 bones were curved (70%).
- Morphology of incus showed variation in thelenticular process. 70% of the incus bones showed fully developed lenticular process and the remaining 30% bones showed underdeveloped/necrosed lenticular process.
- In stapes morphology, we found the obturator foramen wastriangular shaped in 18 bones(45%) and ovalshaped in 22 bones(55%).

These differences in dimensions of ossicles inpeople of different ethnicities have surgical implicationsin reconstructive middle ear surgeries and affect the design and proportions of indigenously manufactured prosthesis to suit the Indian population.

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ANNEXURE I

ETHICAL CLEARANCE CERTIFICATE

K.L.E. ACADEMY OF HIGHER EDUCATION AND RESEARCH
(Deemed - to- be- University)
Accredited 'A' Grade by NAAC (2nd Cycle) Placed in Category 'A' by MHRD (GoI)
JAWAHARLAL NEHRU MEDICAL COLLEGE,
NEHRU NAGAR, BELAGAVI-590010 (KARNATAKA-INDIA)
Website: http://www.jnmc.edu
E-Mail : dome@jnmc.edu
Phone: (+ 91-(0)831 Office : 2472550
Principal: 2471701
Fax No. +91 (0)831 – 2470759

Ref: MDC/DOME/ 5 1 Date: 24/11/2018

To,

REG. NO: BE0118004

PG student in Otorhinolaryngology & Head and Neck Surgery,
J.N.Medical College,
BELAGAVI.

Sub: Institutional Ethical Clearance for the study.

With reference to the above, we wish to inform you that your proposed research project titled **"A STUDY ABOUT MORPHOLOGICAL AND ANTROPOMETRICAL FEATURES OF HUMAN EAR OSSICLES – A CADAVERIC STUDY"**, is ethical and justifiable. The proposed research project has been cleared by the JNMC Institutional Ethics Committee on Human Subjects Research.

(Dr. Arathi Darshan)
Member Secretary
JNMC Institutional Ethics Committee
on Human Subjects Research,
J.N.Medical College, Belagavi.

(Dr. Roopa M Bellad)
Chairman,
JNMC Institutional Ethics Committee
on Human Subjects Research,
J.N.Medical College, Belagavi.

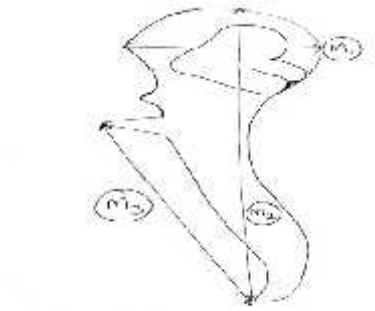
ANNEXURE II

PROFORMA FOR DATA COLLECTION

Sr. no:

CADAVER NO: GENDER: APPROXIMATE AGE:

MALLEUS



M1:Width of head- maximum distance between the two lateral margins of the head

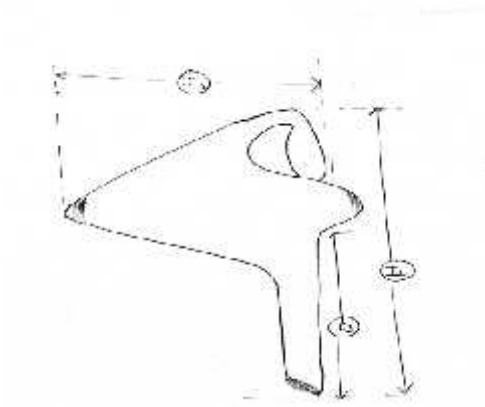
M2:Total length – from the top of the head to lower end of handle

M3: Length of manubrium or handle- from the end of lateral process to end of handle.

SIDE	WEIGHT	TOTAL LENGTH	LENGTH OF MANUBRIUM	MAXIMUM WIDTH
LEFT				
RIGHT				

MORPHOLOGICAL VARIATION:

INCUS

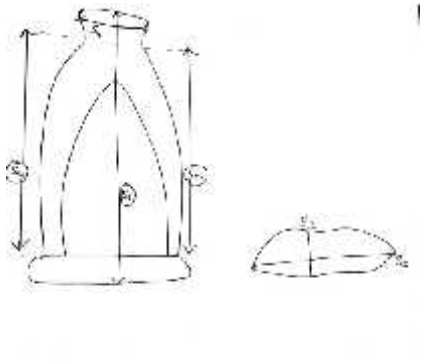


I_1 : Width of the body- distance between the anterior end of the body and the end of short process
I_2 : Total length –distance between upper edge of the body and the end of the long process
I_3 : Length of the long process- distance between the lower edge of the body and the end of long process

SIDE	WEIGHT	TOTAL LENGTH	LENGTH OF LONG PROCESS	WIDTH OF BODY
LEFT				
RIGHT				

MORPHOLOGICAL VARIATION:

STAPES



S_1 : Total height –distance between top of the head to the undersurface of stapes footplate
S_2 : Length of footplate – maximum length of long axis of footplate
S_3 : Width of footplate – maximum width of the footplate
S_4 : Length of anterior crus – from shoulder to the upper surface of footplate
S_5 : Length of posterior crus – from shoulder to the upper surface of footplate
S_6 : Width of head – maximum width of the head

STAPES

SIDE	WEIGHT	TOTAL HEIGHT	LENGTH OF FOOT PLATE	WIDTH OF FOOT PLATE	LENGTH OF ANTERIOR CRUS	LENGTH OF POSTERIOR CRUS	WIDTH OF HEAD
LEFT							
RIGHT							

MORPHOLOGICAL VARIATIONS :

ANNEXURE - III-PHOTOGRAPHS

Image-1 Malleus

Image 2 Incus

Image 3- Stapes

Image 4- Instruments

Image 5-Photographs of 40 sets of Ear ossicles

IMAGE 61st Showing straight and 2nd image showing curved distal end of manubrium

IMAGE 7- 1st Showing fully developed lenticular process and 2nd image showing underdeveloped/Necrosed Lenticular process

IMAGE 8 - 1st Showing Triangular shaped and 2nd image showing Oval shaped obturator foramen

ANNEXURE IV

KEY TO MASTER CHART

Cadaver no

Age- In years

SEX

Male – 1

Female – 2

DISTAL END OF MANUBRIUM STRAIGHT- 0

CURVED -1

LENTICULAR PROCESS PRESENT-1

ABSENT -0

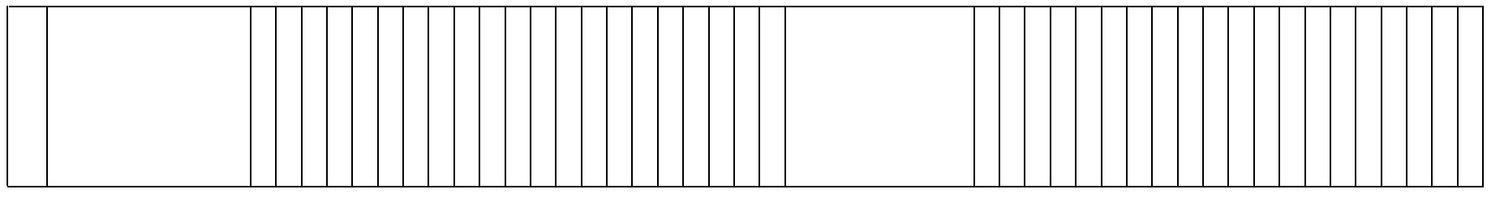
OBTURATOR FORAMEN SHAPETRIANGLE -0

OVAL -1

MALLEUS			RIGHT					LEFT										
CAD NO	Approximate age	SEX	WEIGHT	TOTAL LENGTH	LENGTH OF MANUBRIUM	MAXIMUM WIDTH	DISTAL END OF MANUBRIUM (STRAIGHT- 0 CURVED -1	WEIGHT	TOTAL LENGTH	LENGTH OF MANUBRIUM	MAXIMUM WIDTH	DISTAL END OF MANUBRIUM (STRAIGHT- 0 CURVED -1					
1	75	1	16mg	6.5mm	4mm	2.5mm	1	14mg	7.5mm	4mm	2mm	1					
2	68	1	16mg	6.5mm	4mm	2mm	0	18mg	6.5mm	4mm	2mm	0					
3	77	1	19mg	8.5mm	5mm	4.5mm	1	18mg	8.5mm	5mm	4.5mm	1					
4	65	1	21mg	8.5mm	5mm	2.5mm	1	20mg	9mm	5mm	2.5mm	1					
5	80	1	18mg	8.5mm	4mm	2mm	1	20mg	8.5mm	4.5mm	2.5mm	1					
6	69	2	12mg	6.5mm	4mm	1.5mm	0	13mg	6.5mm	4mm	1.5mm	0					
7	70	2	12mg	6mm	2.5mm	1.5mm	0	13mg	6mm	2.5mm	1.5mm	0					
8	63	1	18mg	6.5mm	5mm	3mm	1	16mg	6.5mm	5mm	3mm	1					
9	89	1	14mg	6.5mm	3mm	2mm	1	14mg	6.5mm	3mm	2mm	1					
10	55	1	18mg	7mm	5mm	3mm	0	20mg	7.5mm	5mm	3mm	0					
11	60	2	12mg	6mm	4mm	1.5mm	1	13mg	6mm	4mm	1.5mm	1					
12	90	1	17mg	6.5mm	4mm	2mm	0	17mg	6.5mm	4.5mm	2mm	0					
13	50	1	16mg	6mm	3.5mm	2.5mm	1	17mg	6.5mm	4mm	2.5mm	1					
14	75	1	15mg	6.5mm	3mm	2mm	1	15mg	6.6mm	3mm	2mm	1					
15	25	1	18mg	7mm	5mm	2.5mm	1	16mg	7mm	5mm	2.5mm	1					
16	70	2	16mg	6.5mm	4mm	2.5mm	1	14mg	7.5mm	4mm	2mm	0					
17	50	1	16mg	6.5mm	4mm	2mm	0	18mg	6.5mm	4mm	2mm	0					
18	65	2	19mg	8.5mm	5mm	4.5mm	1	18mg	8.5mm	5mm	4.5mm	1					
19	88	2	21mg	8.5mm	5mm	2.5mm	1	20mg	9mm	5mm	2.5mm	1					
20	50	1	18mg	8.5mm	4mm	2mm	1	20mg	8.5mm	4.5mm	2.5mm	1					

INCUS			RIGHT					LEFT										
CAD NO	Approximate age	SEX	WEIGHT	TOTAL LENGTH	LENGTH OF LONG PROCESS	WIDTH OF BODY	LENTICULAR PROCESS (PRESENT-1 ABSENT -0	WEIGHT	TOTAL LENGTH	LENGTH OF LONG PROCESS	WIDTH OF BODY	LENTICULAR PROCESS (PRESENT-1 ABSENT -0					
1	75	1	21mg	6.5mm	4mm	3.5mm	0	18mg	6.5mm	3mm	3.5mm	0					
2	68	1	23mg	5.5mm	3.5mm	4mm	1	22mg	5mm	3mm	4mm	1					
3	77	1	19mg	4.5mm	3.5mm	5.5mm	1	18mg	5mm	4mm	5mm	1					
4	65	1	26mg	5.5mm	4mm	4mm	0	28mg	6mm	4mm	4mm	0					
5	80	1	16mg	4.5mm	3mm	3mm	1	13mg	4.4mm	3mm	3mm	1					
6	69	2	18mg	5.5mm	3.5mm	3mm	1	15mg	5mm	3mm	3mm	1					
7	70	2	13mg	5.5mm	3.5mm	4mm	1	13mg	5.5mm	3.5mm	4mm	1					
8	63	1	18mg	6mm	3mm	3.5mm	1	20mg	6mm	3mm	3.5mm	1					
9	89	1	22mg	6.5mm	4mm	3mm	1	20mg	7mm	4mm	3mm	1					
10	55	1	24mg	7mm	4mm	5mm	0	22mg	7mm	4mm	4.5mm	0					
11	60	2	13mg	4.5mm	2.5mm	3.5mm	1	12mg	4.5mm	2.5mm	3.5mm	1					
12	90	1	16mg	5.5mm	3mm	3mm	1	15mg	5.5mm	3mm	3mm	1					
13	50	1	19mg	7mm	4.5mm	5mm	1	19mg	7mm	4.5mm	5mm	1					
14	75	1	20mg	6.5mm	3mm	3mm	0	18mg	6.5mm	3mm	3.5mm	0					
15	25	1	20mg	6.5mm	3mm	3mm	1	18mg	7mm	3mm	3.5mm	1					
16	70	2	21mg	6.5mm	4mm	3.5mm	0	18mg	6.5mm	3mm	3.5mm	0					
17	50	1	23mg	5.5mm	3.5mm	4mm	1	22mg	5mm	3mm	4mm	1					
18	65	2	19mg	4.5mm	3.5mm	5.5mm	1	18mg	5mm	4mm	5mm	1					
19	88	2	26mg	5.5mm	4mm	4mm	0	28mg	6mm	4mm	4mm	0					

STAPES			RIGHT								LEFT						
CAD NO	Approximate age	SEX	WEIGHT	TOTAL LENGTH	LENGTH OF FOOT PLATE	WIDTH OF FOOT PLATE	LENGTH OF ANTERIOR CRUS	LENGTH OF POSTERIOR CRUS	WIDTH OF HEAD	OBTURATOR FORAMEN SHAPE TRIANGLE -0 OVAL -1	WIEIGHT	TOTAL HEIGHT	LENGTH OF FOOT PLATE	WIDTH OF FOOT PLATE	LENGTH OF ANTERIOR CRUS	LENGTH OF POSTERIOR CRUS	WIDTH OF HEAD
1	75	1	2.6mg	2.5mm	2mm	1mm	1.5mm	2mm	1mm	0	2.2mg	2.5mm	2mm	1mm	1.5mm	2mm	1mm
2	68	1	1.8mg	2.5mm	2.5mm	1mm	1mm	1.5mm	1mm	1	1.5mg	2.5mm	2.5mm	1mm	1.5mm	2mm	1mm
3	77	1	2.5mg	3mm	2.5mm	1mm	2.5mm	2.5mm	1mm	1	2mg	3mm	2.5mm	1mm	2.5mm	2.5mm	1mm
4	65	1	3mg	3mm	2.5mm	1.5mm	1.5mm	2mm	1mm	0	2mg	3mm	2.5mm	1,,	1.5mm	2mm	1mm
5	80	1	2mg	2.5mm	2mm	1mm	1.5mm	2mm	0.5mm	1	2mg	2.5mm	2mm	1mm	1.5mm	2mm	0.5mm
6	69	2	2mg	2.5mm	2mm	1.5mm	2mm	2.5mm	1mm	0	2mg	2.5mm	2mm	1.5mm	2mm	2.5mm	1mm
7	70	2	2mg	3mm	2.5mm	1mm	1mm	1.5mm	1mm	1	2mg	3mm	2.5mm	1mm	1mm	1.5mm	1mm
8	63	1	2mg	3mm	3mm	1.5mm	1.5mmm	2mm	1.5mm	1	2mg	3mm	3mm	1.5mm	1.5mm	2mm	1.5mm
9	89	1	3mg	3mm	2.5mm	2mm	2mm	2.5mm	1mm	0	3mg	3mm	2.5mm	2mm	2mm	2.5mm	1mm
10	55	1	3mg	3.5mm	3mm	1.5mm	2mm	2.5mm	1.5mm	0	3mg	3.5mm	3mm	1.5mm	2mm	2.5mm	1.5mm
11	60	2	2mg	2.5mm	3mm	2mm	2mm	2.5mm	1mm	0	2mg	2.5mm	3mm	2mm	2mm	2.5mm	1mm
12	90	1	3mg	2mm	2mm	1mm	1mm	1.5mm	0.5mm	1	3mg	2mm	2mm	1mm	1mm	1.5mm	0.5mm
13	50	1	3mg	3mm	3mm	2mm	2mm	2mm	1.5mm	0	3mg	3mm	3mm	2mm	2mm	2mm	1.5mm
14	75	1	2mg	2mm	2mm	1mm	1.5mm	2mm	1mm	1	2mg	2mm	2mm	1mm	1.5mm	2mm	1mm
15	25	1	2mg	2.5mm	2.5mm	1mm	1.5mm	2mm	1mm	1	2mg	2.5mm	2mm	1mm	1.5mm	2mm	1mm
16	70	2	2.5mg	2.5mm	2mm	1mm	1.5mm	2mm	1mm	0	2.2mg	2.5mm	2mm	1mm	1.5mm	2mm	1mm
17	50	1	1.8mg	2.5mm	2.5mm	1mm	1mm	1.5mm	1mm	1	1.5mg	2.5mm	2.5mm	1mm	1.5mm	2mm	1mm
18	65	2	2.5mg	3mm	2.5mm	1mm	2.5mm	2.5mm	1mm	1	2mg	3mm	2.5mm	1mm	2.5mm	2.5mm	1mm
19	88	2	3mg	3mm	2.5mm	1.5mm	1.5mm	2mm	1mm	0	2mg	3mm	2.5mm	1,,	1.5mm	2mm	1mm
20	50	1	2mg	2.5mm	2mm	1mm	1.5mm	2mm	0.5mm	1	2mg	2.5mm	2mm	1mm	1.5mm	2mm	0.5mm



1	0	1	1	0	1	1	0	1	0	0	0	1	1	0	1	0	1	1	0	OBTURATOR FORAMEN SHAPE TRIANGLE -0 OVAL -1	