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Original Article

A morphometric study of human middle ear ossicles in cadaveric temporal bones of Indian population and a comparative analysis

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ABSTRACT

Introduction: Malleus, Incus and Stapes are the three middle ear ossicles which form an articulated chain and help in conduction of sound from external ear to inner ear. Morphometric study of these ossicles has been going since the early 60s. Although the methods of been changing due to advent of newer technologies and treatments.

Methods: We studied ossicles of 60 temporal bones. The ossicles have been obtained by 'canal-wall down' mastoidectomy technique. They have been measured by an open software, Fiji (https://imagej.nih.gov) where the scale was standardized and set to mm (millimeter).

Results: The mean total length of the malleus is 8.23 mm; a mean angle of 128.76°, mean width of the head 2.56 mm, and mean length of manubrium is 4.17 mm. The mean total length of incus is 7.04 mm, mean angle of 97.23°, mean total width of 5.31 mm, and mean length of long process is 3.27 mm. The mean total height of stapes is 3.44 mm; mean width of the footplate is 1.10 mm and a mean angle of 51.01°.

Discussion: Morphometric data obtained in the present study can be useful for the reconstructive procedures. Preoperative radiological assessment is advised for these small bones. The present study also emphasizes on the future directions where in reconstructive procedures can be improved with the artistic renderings of the blueprints provided, for new prosthetic designs which can be manufactured by using Teflon materials.

1. Introduction

Jaw components of vertebrates and columella auris of reptiles have rendered themselves to become Malleus, Incus and Stapes respectively in evolutionary process. These 3 small bones are one of the contents of tympanic cavity, which are irregular, and laterally placed in the middle ear.[1,2] They are an articulated chain (Fig. 1) connecting laterally with the tympanic membrane and medially with medial wall of the tympanic cavity which conducts the sound from tympanic membrane to cochlea through oval window.

Knowing the morphometric anatomy of ossicles has become very important in otologic surgeries. In any ear pathology the disease can erode the ossicles causing hearing loss. The aim of the present study is to analyse and establish a morphometric data of ossicles in cadaveric temporal bones of Indian origin and data comparison with ossicles of other origins.

2. Materials and methods

The present study has been carried out on 60 sets of ossicles collected during temporal bone dissection by 'canal wall-down mastoidectomy' technique. Eroded and broken ossicles were excluded from study.

The collected ossicles were cleaned, and photographed, under 6.4 x magnifications using a LEICA microscope 320, with a resolution of 2048 × 1098 pixels. Every photograph has been standardized to 900 × 900 pixels in both width and length.

All the photographs were measured using a software, Fiji (https://imagej.nih.gov) where the scale was standardized and set to mm(millimeter). The analysis has been made accordingly from morphometric data of ossicles.

The parameters taken into consideration are as follows:

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Fig. 1. Middle ear ossicles. M-malleus, I-Incus, S-Stapes.

2.1. Malleus (Fig. 2)

- Total length(A–B): Maximum distance between the top of the head and distal part of the manubrium.
- Length of manubrium(C–A): Maximum distance from the superior edge of the lateral process to the distal end of the manubrium.
- Angle(MlA)(D–E): Measured between the long axis of the neck and manubrium.
- Total Width of head(F–G): Maximum width of the head.

2.2. Incus (Fig. 3)

- Total length(A–B): Maximum distance between the superior edge of the body and the distal end of the long process.
- Total Width(C–D): Maximum distance between the tip of the short process to the most protruding part of the articular facet.
- Total length of the long process(E–F): Maximum distance between the superior edge and the distal end of the long process measured in long axis.
- Angle(InA): Measured between the inferior edge of the short process and posterior edge of the long process.

2.3. Stapes (Fig. 4)

- Total height(A–B): maximum distance between the top of the head to the footplate.

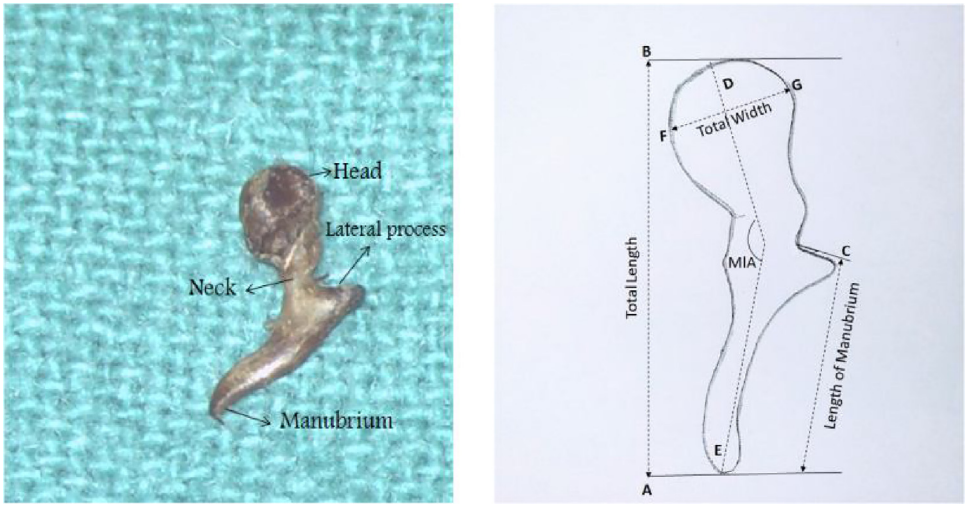

Fig. 2. Malleus and its measurements, MlA-Malleus angle.

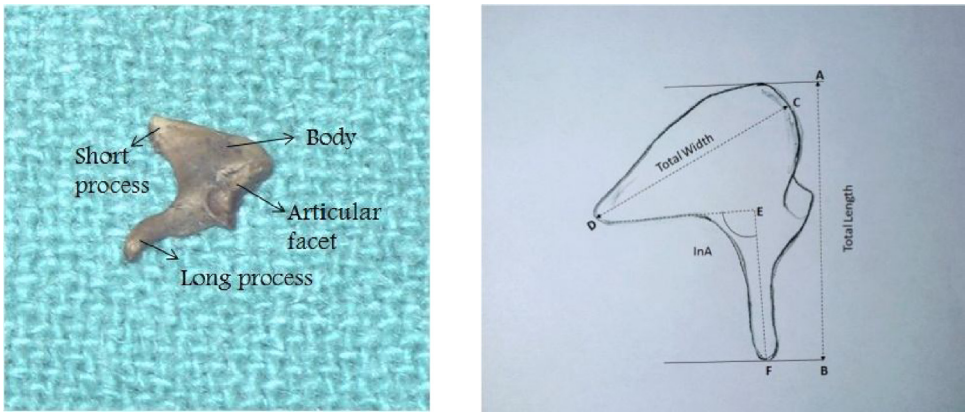

Fig. 3. Incus and its measurements, InA-Angle of the incus.

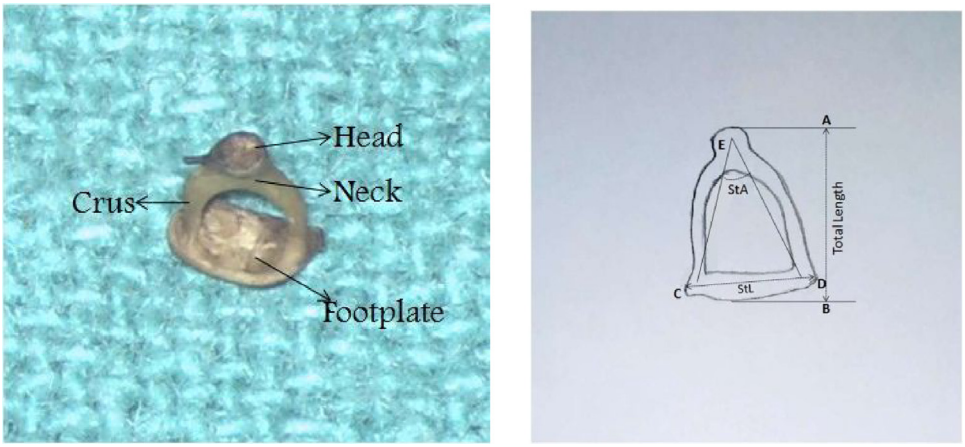

Fig. 4. Stapes and its measurements, StA-angle between the crura, StL-Length of Footplate.

- Total length of the footplate StL(C–D): maximum distance of the long axis of the footplate
- Width of the footplate: maximum distance of the inner aspect of footplate in short axis.
- Angle(StA)(E): measured between the two crura of the stapes (i.e., Line drawn by connecting points at the junction of crura i.e., neck of stapes(E) and footplate on either side(C–D)).

3. Results

Following are the results of our study which includes 53 mallei, 57 incus and 52 stapes obtained after applying the exclusion criteria.

In our observations the malleus average length was around 8 mm with a mean of 8.23 ± 0.36 mm, mean length of handle/manubrium 4.17 mm, mean width of head 2.56 mm and mean angle(MlA) of 128.76° between the long axis of the neck and manubrium (Table 1).

The incus had a mean total length of 7.04 mm, total width of 5.31 mm, length of long process 3.27 mm, and a mean angle of 97.23° between the long and short processes (Table 2).

The stapes had a mean total height of 3.44 mm, footplate length of 3.04 mm, footplate width of 1.10 mm and angle between the two crura 51.01° (Table 3).

4. Discussion

Hearing is a special sense being done by ear, which is divided into external ear, middle ear and inner ear.[1,11] The sounds are collected by external ear, conducted to inner ear by middle ear. This conduction system is formed by ossicles in the middle ear. Any ear disease affecting the ossicles will lead to conductive hearing loss. Although there has been significant research going on ossicles since the 1960s, however we still lag behind in the reconstructive procedures.[5,11]

Malleus(Latin *mallei* = hammer), is the lateral most ossicle which is attached to the tympanic membrane and the first to receive sound waves.[7] It is derived from Meckel's cartilage of the first pharyngeal arch.[2] The normal length defined in literature is around 8 mm.[1] In the present study the mean total length is 8.23 ± 0.36 mm which is more or less equal to the values obtained in the studies done by Unur et al [6]Arsenburg et al in roman population [3,4], Quam, Rak et al [10] (Table 4). Length of the handle of malleus as 4.17 ± 0.31 while in studies done by Unur et al mean length of the manubrium 4.762 ± 0.45, Arsenburg et al 4.6 ± 0.30, Quam, Rak et al 4.94 ± 0.31. The angle which is taken into consideration of parameters was only defined in two other studies Arsenburg et al, Quam, Rak et al is 140° ± 5.61, 132.1° ± 61 respectively while the present study reports a mean angle of 128.76° ± 8.89 (Table 4). Any disruption in the structure by congenital anamoly, erosion or diseases causes hearing impairment particularly conductive hearing loss.

Incus(Latin *Incus* = anvil), credit of discovering this bone is given to Alessandro achillini. It is medial to malleus, acting as a bridge between malleus and stapes, helping in transmission of sound by receiving it from malleus and conducting it to stapes.[8] It is derived from Meckel's cartilage of the first pharyngeal arch.[2] The total length obtained by Unur et al is 6.47 mm ± 0.55, Arsenburg et al is 6.6mm ± 0.17 while the value in the present study is 7.04 mm ± 0.41 which is more or less equal to the previous studies. There is quite a similarity in the angle between the axis of the long and short process obtained in the study by Arsenburg et al with a mean value of 95° ± 8.14 and the present study with a mean angle of 97.23° ± 9.5 (Table 4).

Stapes(Latin *stapes* = stirrup), medial most ossicle, which closes the oval window. It receives the sound waves from incus and transmits them to inner ear.[9] It is derived from the Reichert's cartilage of the second pharyngeal arch.[2] There have been a lot of studies reporting the normal anatomy and variations of this bone, since clinically it is involved in a number of diseases.[13,14] The mean total height reported by Unur et al is 3.22 mm ± 0.31 and Arsenburg et al is 3.3 mm ± 0.14, present study reports a mean total height of

Table 1
Results of the Measurements of Malleus.

Malleus						
Parameters	Number of ossicles	Mean	Standard Deviation	Max	Min	Range
Total length(mm)	53	8.23	0.36	9.17	7.48	1.69
Length of handle(mm)	53	4.17	0.37	5.42	3.56	1.85
Angle(MlA)	53	128.76°	8.89°	149.57°	105.58°	43.99°
Width of head(mm)	53	2.56	0.28	3.33	1.64	1.69

Table 2
Results of the Measurements of Incus.

Incus						
Parameters	No. of ossicles	Mean	Standard Deviation	Max	Min	Range
Total length(mm)	57	7.04	0.41	7.96	6.22	1.73
Total Width(mm)	57	5.31	0.46	6.23	3.29	2.94
Length of long process(mm)	57	3.27	0.32	3.95	2.64	1.31
Angle between long and short processes(Ina)	57	97.23°	9.57°	124.94°	75.42°	49.51°

Table 3
Results of the Measurements of Stapes.

Stapes						
Parameters	No. of ossicles	Mean	Standard Deviation	Max	Min	Range
Angle(StA)	52	51.01°	6.55°	70.41°	40.87°	29.54°
Footplate length(basis stapedis)(mm)	52	3.042	0.28	3.56	1.85	1.71
Total height(mm)	52	3.44	0.38	4.17	2.30	1.87
Footplate width(basis stapedis)(mm)	52	1.10	0.19	1.63	0.72	0.91

Table 4
Comparative analysis of parameters with different studies.

Study & Parameters	Unur et al [6]	Mogra et al[15,16]	Quam, Rak et al [10]	Arensburg et al [3]	Present study
Malleus					
Total length(mm)	7.69 ± 0.60	8.53 ± 0.58	8.25 ± 0.41	8. 8.1 ± 0.31	8.23 ± 0.36
Length of handle(mm)	4.76 ± 0.45	5.20 ± 0.48	4.94 ± 0.31	4.6 ± 0.30	4.17 ± 0.31
MlA-angle			132.1° ± 61.	140° ± 5.61	128.76° ± 8.89
Width of head(mm)			2.43 ± 0.17		2.56 ± 0.28
Incus					
Total length(mm)	6.47 ± 0.55			6.6 ± 0.17	7.04 ± 0.41
Total Width(mm)	4.88 ± 0.47		5.07 ± 0.37	5.3 ± 0.25	5.31 ± 0.46
Ina-angle between long and short processes			64° ± 4.7	95° ± 8.14	97.23° ± 9.51
Stapes					
Total height(mm)	3.22 ± 0.31			3.3 ± 0.14	3.44 ± 0.38
Footplate length(basis stapedis)(mm)	2.57 ± 0.33			2.8 ± 0.12	3.04 ± 0.28
Footplate width(basis stapedis)(mm)	1.29 ± 0.22			1.3 ± 0.13	1.10 ± 0.19
StA-angle					51.01° ± 6.55

3.44 mm ± 0.38. The mean length of the basis stapedis by Unur et al is 2.57 ± 0.33, Arsenburg et al 2.8 mm ± 0.12, present study is 3.04 mm ± 0.28 (Table 4). In the present study additional parameters we considered are the angle (StA) between the two crura of the stapes and width of the footplate, measured on the inner aspect. These can be useful for future stapedial prosthesis development (Fig. 7b).

Otosclerosis is the most common disease which affects the footplate of stapes and it causes fixity of the structure leading to conductive hearing loss.[1,11,12] The morphology and morphometry of the middle ear ossicles has become much more important due to increase in the number of surgeries of CSOM(Chronic suppurative otitis media), ankylosis of stapes, TORP(Total ossicular replacement prosthesis), PORP(Partial ossicular replacement prosthesis) and so on.[11] Present study helps in establishment of the above parameters and census for Indian population where such extensive data is not available to the best of our knowledge.

4.1. Future directions

Any space occupying or ear disease can erode the ossicles. In these conditions existing processes of the ossicles need to be updated, here we are providing a photo design with our knowledge which can help in the reconstruction of the ossicular chain and restore hearing.

1. Malleostapedopexy (for Intact malleus and stapes without incus): Here the prosthesis has base, ventral surface and a hanger (Fig. 5a). The base has a socket or opening which accommodates the head of stapes. Ventral portion has pores for new tissue expansion. The hanger has two parts a shaft and hook. Shaft, which is adjustable in terms of length and is fixed on the margin of the ventral portion horizontally. Hook, which can be fixed to handle of malleus. This bridging connection between Malleus and stapes conducts sound to inner ear (Fig. 5c).
2. Incudostapedopexy(for Intact malleus, stapes and eroded incus): Here the prosthesis has base, ventral surface and a clipper (Fig. 6a). The base has a socket or opening which accommodates the head of stapes. Ventral portion has pores for new tissue expansion. The clipper has a shaft and socket. Shaft, sits on the ventral portion vertically with adjustable length. The socket, accommodates the long process of incus. This bridging between stapes and incus conducts sound to inner ear (Fig. 6b).
3. Stapedopexy (for Intact stapes, eroded malleus and incus): Here the prosthesis is parachute shaped, has a base and ventral surface (Fig. 7a). The base sits onto the footplate of stapes

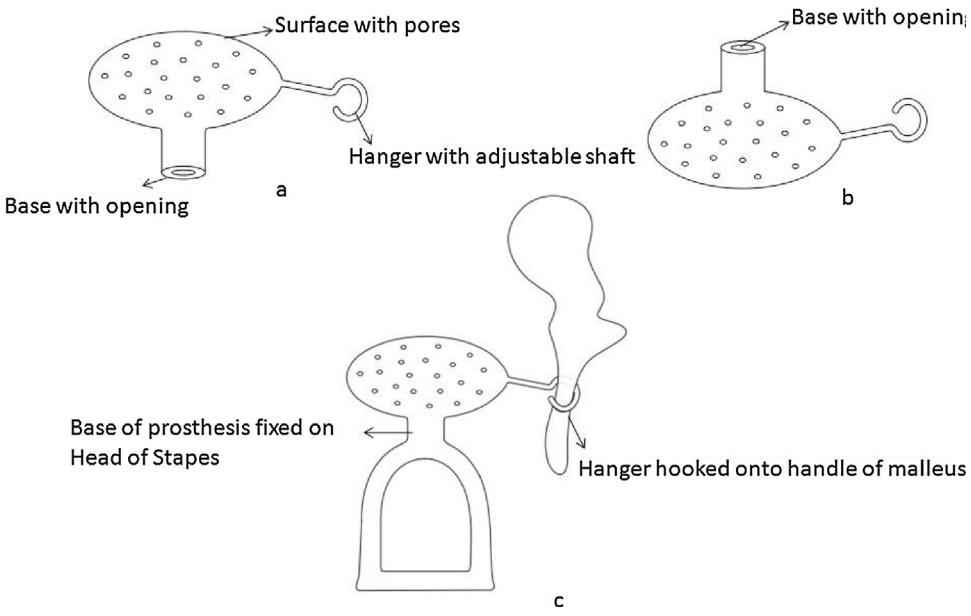

Fig. 5. Prosthesis for Malleo-stapedopexy with adjustable hanger a. Ventral surface b. Dorsal surface c. Prosthesis bridging between Stapes head and handle of malleus.

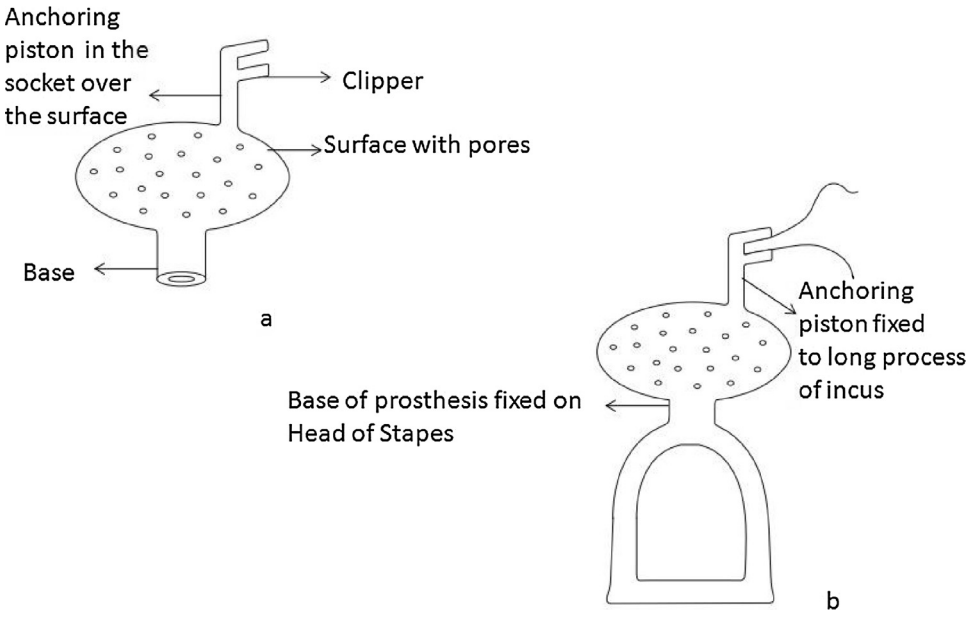

Fig. 6. Prosthesis for Incudo-stapedopexy a. Piston sits on the ventral surface socket b. Prosthesis bridging between Stapes and Long process of Incus.

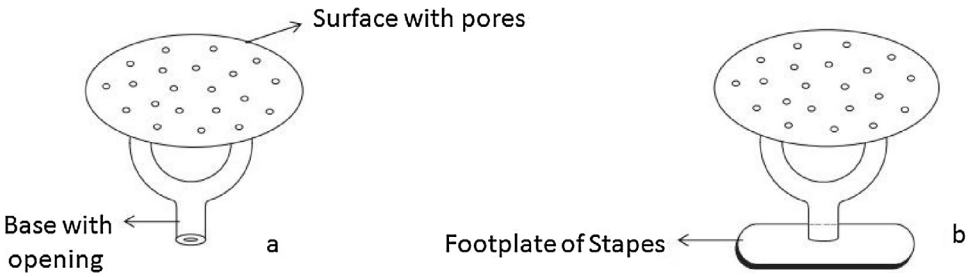

Fig. 7. Prosthesis for footplate of Stapes a. Ventral surface b. Prosthesis directly Bridging the neo-tympanic membrane and footplate of stapes.

(Fig. 7b) and neo-tympanic membrane directly sits onto the ventral surface. This helps in direct conduction of sounds to inner ear.

The proposed designs can be manufactured using Teflon (Polytetrafluoroethylene)[17] biomaterial according to the standard weight which can be sustained by the annulus of footplate.

5. Conclusion

Knowing the anatomy and morphometry of middle ear ossicles is very important. Preoperative radiological assessment is advised for these small bones. Puretone audiometry is the investigation of choice to assess the hearing status and also can be used to assess the ossicular discontinuity. The advantage of radiological and audiometric evaluation can give preoperative assessment of hearing and status of ossicles, it provides better counseling of the patient about ossicular reconstruction by autografts and middle ear implants (TORP and PORP). This study can be a basis for innovation of new prosthetic designs for future use and needs.

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