

Study of morphologic variability of incudostapedial angle and its relation with temporal bone pneumatization

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ABSTRACT

Introduction: Optimal sound transmission across the ossicular chain is dependent on the appropriate alignment of the middle ear ossicles. Incudostapedial joint (ISJ) is conventionally considered to be at right angle.

Objective: We intended to study the ISJ anatomy and the impact of temporal bone pneumatization on the same.

Methods: In a cadaveric study comprising of 47 human temporal bones, canal wall down mastoidectomy was carried out under microscopic guidance keeping the ossicular chain intact. The morphology of ISJ was recorded and analysed with respect to the pneumatization status of the temporal bone. The data analysis was performed using statistical software Stata version 12.0.

Results: The mean ISJ angle for the 47 bones was 90.5° (SD-15°; range:54°-122°). The mean angle in well pneumatized bones was 93.7° (SD-16.5; Range:54°-122°) and in sclerotic mastoids was 88.7° (SD-14; Range:68°-118°). The difference in the ISJ angle in these two conditions was not statistically significant ($p = 0.27$). The mean angle was found to be significantly more obtuse in the cases with partially eroded ISJ (111.4° {SD-8.8; range:100.3°-121.9°}; $p = 0.0001$) and in the cases with an 'adherent/tilted morphology' of the stapes suprastructure with the promontory (mean-95.8°{SD-13.8; range:70.7°-120.4°}; $p < 0.00001$).

Conclusion: The ISJ angle shows considerable variations. This variability needs to be taken into account when undertaking middle ear reconstructive procedures, specifically the ones involving the stapes footplate. The mastoid pneumatization does not appear to have an impact on the ISJ angle.

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1. Introduction

There is scarcity of data in literature regarding the angulation between long process of incus and stapes supra structure (ISJ angle). The two structures are conventionally believed to be at right angle. A loss of this perpendicular relation may affect the surgical outcomes in reconstructed ears by causing an unstable positioning or restricted movement of the ossicular reconstruction prosthesis

in relation to a non-coplanar stapes footplate (Merchant et al., 1997). We examined the ISJ angle in human cadaveric temporal bones with special emphasis on the cases with a tilted stapes morphology towards promontory.

2. Materials and methods

The study was done in cadaveric human temporal bones obtained from unclaimed human cadavers from the Department of Forensic Medicine at our institute after obtaining approval from institutional Ethical committee (F.8-522/A-522/2017/RS). The temporal bones were stored in 10% formalin and soft tissue was removed before the bones were mounted on a House Urban temporal bone holder. A cortical mastoidectomy was carried out using

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standard otologic instruments and drill. Next, the canal wall was taken down keeping the ossicular chain intact. The dissection was performed under microscopic guidance using Leica M320 F12 microscope with LED with inbuilt 3-mega pixel camera and HD video system (Wetzlar, Germany) and the pictures of ISJ angle were taken in a posterior to anterior direction, in exact alignment to the anterior-posterior direction of crura, following the direction of stapedia tendon, co-planar with the Stapes footplate, at a magnification of $25\times$ (Fig. 1).

Based on subjective assessment of the temporal bone pneumatization pattern by the dissector, the bones were categorized into well-pneumatized and under-pneumatized (sclerotic) mastoid. The observations were made regarding morphology of incus and stapes suprastructure (SSS). A particular note was made of the 'adherent morphology' of SSS in which the stapes was tilted/curved inferiorly to come in contact with the promontory and the 'eroded morphology' of the ISJ with a partially eroded lenticular process (Fig. 2). The following measurements were taken using digital software (Digimizer, a product of MedCalc Software, a developer of medical and statistical software solutions {MedCalc Software bvba, Acaciaaan-22, 8400-Ostend, Belgium}) after the completion of the dissection:

- Angle between short process of incus and LPI.
- Angle between LPI and stapes supra structure (SSS)

The data was transferred to Microsoft excel version 2007. The subgroup analysis of the ISJ angle was performed between various morphologies of LPI/SSS/ISJ complex (normal versus 'adherent' and 'eroded' morphologies). The data analysis was performed using chi-square test for nominal independent data and *t*-test for continuous parametric data using statistical software Stata version 12.0.

3. Results

A total of 47 temporal bones were harvested. Twenty-three bones were right sided while 24 were left sided. The long process of incus was partially eroded ('eroded morphology') in four (8.5%) bones. Twenty-three (48.9%) bones were found to have an 'adherent morphology' of SSS. The pneumatization pattern of the bones is tabulated in Table 1. The distribution of the pneumatized and sclerosed bones between the two sides was statistically similar ($p = 0.68$).

The angle between short process of incus and LPI was 90° (range: $55.8\text{--}128.4^\circ$).

The mean ISJ angle for all the bones was calculated to be 90.5° (SD-15.0; range: $54.3^\circ\text{--}121.9^\circ$).

3.1. Impact of morphology of LPI/SSS/ISJ complex on the ISJ angle

In cases with the 'adherent morphology' of stapes, the ISJ angle was 95.8° (SD-13.8; range: $70.7^\circ\text{--}120.4^\circ$). The mean angle in the four cases with eroded incus morphology was 111.4° (SD-8.8; range: $100.3^\circ\text{--}121.9^\circ$). These configurations and the obtuse angulation subtended in these cases is depicted in Fig. 2. The results are tabulated in Table 2. The angle in the 'adherent' and 'eroded' morphologies was found to be significantly obtuse compared to the angle in normal LPI/SSS/ISJ complex morphology ($p\text{-value} = 0.0001$ and <0.00001 , respectively).

3.2. Impact of pneumatization on the ISJ angle

The average ISJ angle in well pneumatized cases was 93.7° (SD-16.5; Range: $54.3\text{--}121.9^\circ$) and in sclerotic mastoids was 88.7° (SD-14.1; range: $68.4\text{--}117.9^\circ$). The difference in the ISJ angle in these two conditions was not statistically significant ($p = 0.27$).

4. Discussion

Transmission of sound pressure waves falling onto tympanic membrane (TM) and across the ossicular chain is a complex process, intricately related to motion across malleus-incus and incus-stapes joint. The motion of this TM-ossicular chain assembly is frequency dependent. The movement of stapes is linear piston like at low frequency and acquires rocking movements along the long and short axis of stapes footplate at higher frequencies (Merchant et al., 1997; Dong et al., 2017). The orientation of stapes angled to the long process of incus transfers the sound energy in the plane of stapes to the footplate. The incus-stapes joint angle and stapes suprastructure-footplate junction angles are traditionally considered to be right angles.

The human ossicular chain shows considerable anatomic variations (Noussios et al., 2016). Surprisingly, there is very limited data in the literature regarding the incus-stapes joint angle. An angled (acute or obtuse) rather than perpendicular orientation of stapes in relation to incus and stapes footplate may affect sound

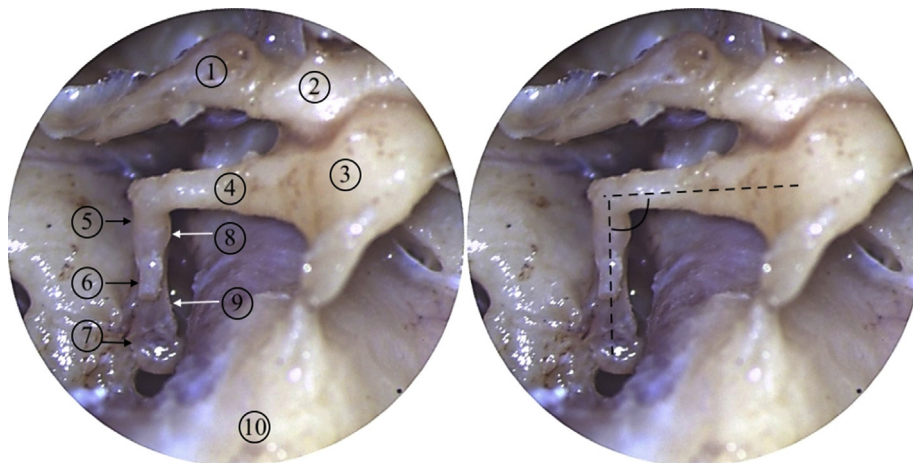


Fig. 1. Left sided cadaveric temporal bone showing the Incudostapedial joint angulation in bones with normal morphology of the LPI/SSS/ISJ complex. (LPI -long process of incus; SSS- stapes suprastructure; ISJ-incudostapedial joint; 1- Handle of malleus; 2-Head of malleus; 3-Short process of incus; 4-Long process of incus; 5- Lenticular process; 6- Stapedioid tendon (cut); 7- Footplate of stapes; 8-Head of Stapes; 9-Crura of stapes; 10- Lateral Semicircular Canal).

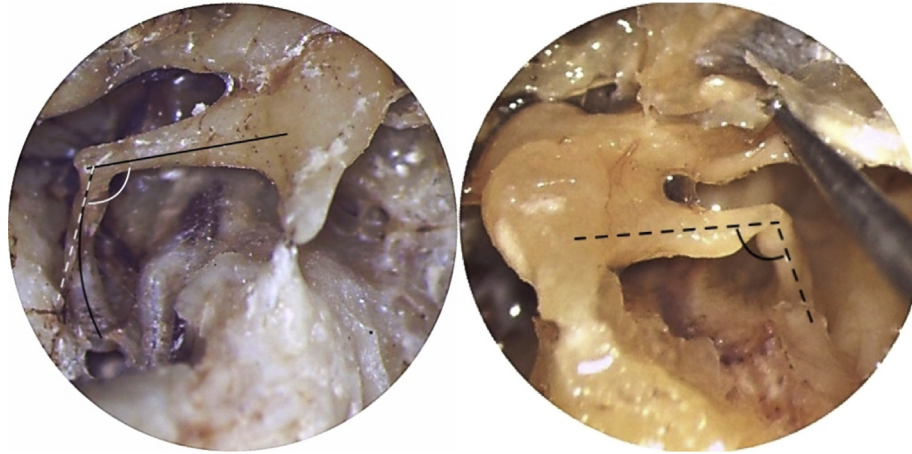


Fig. 2. IS Joint with an obtuse angulation in the dissected bones showing the 'adherent morphology' of the stapes suprastructure in a left sided bone (Left panel), and (B) the 'eroded morphology' in a right sided bone (Right panel) (IS Joint- Incudostapedial joint).

Table 1
Distribution of bones as per the pneumatization pattern.

	Pneumatized	Sclerosed	Total (%)
Right	9	14	23 (48.9%)
Left	8	16	24 (51.1%)
Total (%)	17 (36.2%)	30 (63.8%)	47 (100%)

(*p*-value = 0.68).

Table 2
Impact of morphology of LPI/SSS/IS joint complex on the IS joint angle.

Morphology	IS joint angle		
	Mean	SD	Range
Normal	80.3 ⁰	9	54.3 ⁰ –94.5 ⁰
Adherent	95.8 ⁰	13.8	70.7 ⁰ –120.4 ⁰
Eroded	111.4 ⁰	8.8	100.3 ⁰ –121.9 ⁰

(LPI-Long process of incus; SSS-Stapes suprastructure; IS joint-Incudostapedial joint; SD-standard deviation.

p-value: Normal versus adherent = 0.0001; Normal versus eroded morphology < 0.00001).

transmission in various diseased and reconstructed states of ossicular chain. This angle has been seen to be 'wide' or obtuse in some cases of congenital malformations of middle ear and there is some evidence to support that reconstruction of hearing in such cases with a type II tympanoplasty may give inferior results compared to the ears with a 'narrow' or near right angle configuration (Kim et al., 2011). Another potential implication of the variability of this angle is with crimping of the piston to the LPI during stapes surgery for otosclerosis. A footplate not in plane with the LPI in cases with obtuse LPI- SSS angle may result in faulty crimping since the efforts to align piston perpendicular to footplate may result in obliquity with the LPI, and a resulting imperfect crimping may result in necrosis of incus at the point of attachment (Skinner et al., 2003).

Anand et al. (Anand and Udayabhanu, 2016), studied ten otosclerotic ears and compared them with ten non-otosclerotic controls. They found that the obliquity and downward displacement of the SSS in cases of otosclerosis causes an increase in the distance between the horizontal facial nerve canal and the posterior crus of stapes, providing an increase in the space for instrumentation. The reversal of the torsional effect exerted by the SSS on the incus/malleo-incudal joint after stapedotomy may potentially cause

piston lateralization and loose wire syndrome and may result in recurrent conductive hearing loss after a successful surgery. This obliquity of the SSS in cases of otosclerosis has been termed 'Pisa sign' by the authors indicating its similitude with the leaning tower of Pisa (Anand et al., 2016).

While the mean ISJ angle in bones with normal morphology was 80.3⁰ (range 54.3⁰–94.5⁰), we observed that a peculiar morphology of stapes with slight curvature causing a promontorial tilt or the 'adherent morphology' is associated with a wider ISJ angle (95.8⁰; range 70.7⁰–120.4⁰) compared to normal morphology. As mentioned above, such cases may face unfavorable crimping dynamics during stapedotomy in view of non-planar LPI- footplate relationship. From a practical standpoint, these are the cases in which the piston put during stapedotomy may not be able to maintain a right angle relationship with long process of incus and stapes footplate, and consequently may result in an imperfect crimping or higher risk of displaced piston.

In patients with partial LPI erosion, the ISJ was found to be obtuse (111.4⁰; range: 100.3⁰–121.9⁰). Though this morphology was present in only four bones, a universally obtuse angle in all such bones emphasizes on the possibility of association between the two, and needs to be studied in larger samples. An attempt at correlating the pneumatization pattern of mastoid with ISJ angle revealed no statistically significant correlation between the two.

The results of our study are limited by a small sample size (particularly with respect to the eroded morphology of ISJ). A larger sample size, preferably intraoperative observations in live human beings will likely be more helpful in reaching more definitive conclusions.

5. Conclusion

The ISJ angle shows considerable variation. The average angle in ISJs with normal ossicular morphology was found to be 80⁰. However, this angle is considerably obtuse in cases with an 'adherent stapes' morphology and with partial erosion of long process of incus. The pneumatization pattern of the temporal bone does not have an influence over the ISJ angulation.

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