Moneir *et al.*
*The Egyptian Journal of Otolaryngology* (2023) 39:174
https://doi.org/10.1186/s43163-023-00545-6

The Egyptian Journal of Otolaryngology

ORIGINAL ARTICLE Open Access

# In vivo endoscopic study of the variations of anatomical structures in the hidden spaces of the middle ear during endoscopic ear surgery

Waleed Moneir[1,2], Fatema Alzahraa Ibraheem[2], Hesham Mohamed Eladl[1], Mohamed Elshaer[1], Yasser Khafagy[1] and Mohamed Elkahwagi[1*]

## Abstract

**Objective** The middle ear has compartments with the presence of anatomic variations. Transcanal endoscopic middle ear surgery facilitates the exploration of every single compartment with the least possible tissue dissection.

**Methods** This study was conducted on 250 middle ears of patients who had endoscopic ear surgery (tympanoplasty and stapedotomy) at the period of the study with endoscopic recording of the data. Intraoperative examination of the pro, retro, and hypotympanum was performed with 0, 30, and 45° endoscopes and data was collected, processed, and analyzed with Statistical Package for Social Sciences (SPSS).

**Results** Quadrangular conformation (64%), type B (shallow subtensor recess) (64.8%), and type A protinuculum (ridge) were the commonest in the protympanum. Type A jugular bulb which lies below the level of the bony annulus was the commonest finding (75.6%) in the hypotympanum. Type A (ridge) variant was the commonest finding of ponticulus, subiculum, and finiculus 88.4%, 64.8%, and 72.8% respectively in the retrotympanum. Type B (deep) ST 53.6% was the commonest regarding sinus tympani. Type A (present) subcochlear canaliculus, type B (oblique) fustis and type B (absent) RW membrane were the most common regarding the round window region.

**Conclusion** Good knowledge of the anatomical variations of the middle ear has great surgical importance. The study showed variations of the known structures from other studies that can be attributed to being an in vivo study, racial differences, and a larger sample size.

**Keywords** Middle ear, Endoscopic ear surgery, Retrotympanum, Hypotympanum, Protympanum, Hidden spaces

## Background

Endoscopic ear surgery (EES) had a great development performance curve in the last two decades [1]. The application of EES caused a revolution in the field of otology changing many physiological and management concepts, especially regarding the middle ear which is the focus of wide-spectrum pathology [2]. The application of the endoscope offers many diagnostic and therapeutic advantages in the field of otology due to superior visualization abilities [3].

The retrotympanum and hypotympanum are critical areas that are liable for affection by diseases, especially cholesteatoma [4]. They are distinguished as they are difficult to view during surgical treatment because of their limited direct access and hidden position behind and below the bony annulus and between the important anatomical structures such as the facial nerve, oval and round windows, and the jugular bulb [5]. Detailed anatomy of these regions was described owing to the

*Correspondence:
Mohamed Elkahwagi
Mohamedelkahwagi@mans.edu.eg
[1] Mansoura University, Otorhinolaryngology department, Mansoura, Egypt
[2] Mansoura general hospital, Mansoura, Egypt

endoscopic utility in middle ear surgery [6]. However, many anatomical variations have been identified by further endoscopic anatomical studies which can affect the extension of the disease in these regions [7].

The protympanum is a middle-ear space that lies anterior to the mesotympanum and was difficult to describe intensively before the EES era [8]. Cholesteatoma rarely affects protympanum [9]. However, when found it can be an extensive form of the mesotympanic disease reaching anteriorly, extensive epitympanic cholesteatoma with incomplete tensor fold, or the congenital form of the disease [10]. In addition, this space has gained more endoscopic focus and importance during the transtympanic eustachian tube (ET) ballooning and dilatation [10].

The round window niche is another important compartment that has a special focus due to surgical importance in cochlear implantation and cholesteatoma affection [11]. The round window niche is an anatomical bony structure that forms the entrance of the cochlear membrane and closes the scala tympani, it has a triangular shape that is made by the posterior pillar, tegmen, and anterior pillar and is confluent to the retrotympanum inferiorly and lies between the subiculum posteriorly and the finiculus anteriorly [12].

The study aims to evaluate the anatomical variations of the middle ear compartments utilizing transcanal endoscopy with special emphasis on the retr-, hpo-, and protympanum. We hypothesized that the middle ear in general and these compartments especially are liable to more anatomical variations than thought. In addition, these variations have a direct impact on middle ear pathologies and their extensions with further surgical importance.

## Methods

To address the research purposes, the authors conducted an observational descriptive study. Institutional review board approval for prospective evaluation and data collection was obtained before the initiation of the study. This study was conducted on 250 middle ears of patients admitted to the Otorhinolaryngology Department in Mansoura University for stapedotomy and simple tympanoplasty for inactive chronic suppurative otitis media from August 2017 to December 2021. To be included in the study sample, patients had to be more than 16 years old, cases with Chronic suppurative otitis media (COSM) safe type, cases that are candidates for tympanoplasty, and cases with otosclerosis were included. Exclusion criteria were cases with cholesteatoma, middle ear tumors, and temporal bone fracture as these diseases can disturb the normal middle ear anatomy. Intraoperative endoscopic examination was performed either the operation was endoscopic or microscopic ear surgery. Intraoperative endoscopic ear examination using 4 mm diameter, 17 cm length Storz endoscopes with angles of 0°, 30°, and 45° for middle ear variations were performed and the percentage of each one was reported. Storz camera and monitor system were used for recording. Slight lateralization of the handle of the malleus by angled hook especially during stapedectomy was performed to visualize the protympanum with a 45° endoscope.

## Anatomical structures and classifications

### The protympanum

Protiniculum: A structure that goes from promontory to anterior annulus 8 and was classified as type A: ridge, type B: bridge, and type C: absent.

Subtensor recess: A pneumatisation area inferomedial to the tensor canal 8 and was classified as type A: flat, type B: shallow, and type C: deep.

Conformation: it has 2 conformation 8 and was classified as type A: quadrangular and type B: triangular.

### The retrotympanum

The retrotympanum is divided by the facial nerve into 5 spaces: 3 lying medial (sinus tympani, posterior sinus, and sinus subtympanicus), 2 lying lateral (facial recess and lateral sinus) (Fig. 1). The medial spaces are the focus of EES due to possible affection by pathology. The retrotympanum is also further divided by the subiculum into the upper part including the sinus tympani and posterior sinus and the lower part including the sinus

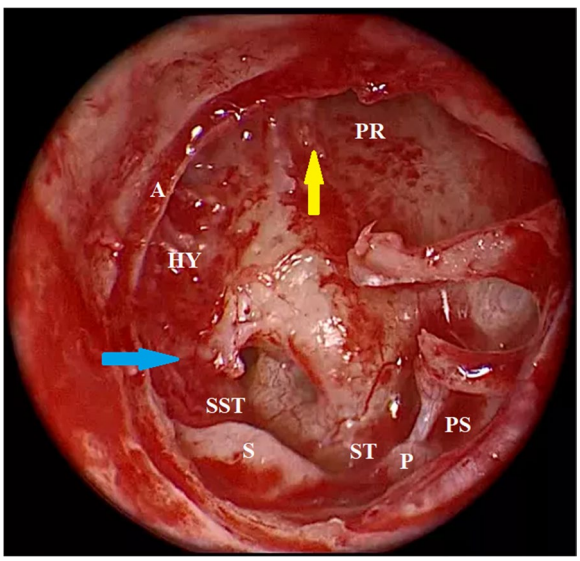


**Fig. 1** 0º endoscopic view of Lt. middle ear. Posterior sinus (PS), pyramidal eminence (P), sinus tympani (ST), styloid eminence (S), sinus subtympanicus (SST), finiculus (blue arrow), hypotympanum (HY), protinuculum (yellow arrow), protympanum (PR) and annular groove (A)

subtympanicus, round window niche, and area concamerata [4, 13].

#### Bony ridges

Ponticulus: bony ridge extending from the pyramidal eminence to the promontory and was classified as type A: ridge, type B: bridge, and type C: incomplete [14].

Subiculum: bony structure connecting the posterior pillar of RW niche with the styloid eminence and was classified as type A: ridge, type B: bridge, and type C: incomplete [5].

Finiculus: a bony structure that connects the anterior pillar of the RW niche with the jugular bulb and was classified as type A: ridge, type B: bridge, and type C: incomplete [6].

#### Retrotympanic sinuses

Sinus tympani: the medial sinus that is located between the ponticulus and subiculum, medial to the facial nerve and pyramidal eminence, and lateral to the posterior semicircular canal. The sinus tympani was classified as follows type A: shallow, type B: deep or starts to develop medial to('under') facial nerve, and type C: extends significantly posteromedial to facial nerve [6].

Sinus subtympanicus: a sinus that is present between the subiculum superiorly and finiculus inferiorly that develops medially and posteriorly about the styloid prominence [5].

#### Round window area

Fustis: is a bony structure that connects the basal turn of the cochlea with the styloid prominence. It indicates the entrance to the RW membrane. It was classified as type A: transverse and type B: oblique [15].

Round window false membrane: a membrane that covers the RW niche and was classified as A: present and B. absent [16].

Subcochlear canaliculus: it is a pneumatized bony channel that connects the round window chamber with the petrous apex and lies inferior to the cochlea. It was classified as type A: present and type B: absent [11].

Jugular bulb: exists in the floor of the hypotympanum with absent or thin bony septum17. It was classified as type A: which lies below the tympanic annulus, type B: which lies at the level of the tympanic annulus and type C: which extends superior to the level of the tympanic annulus named as high riding jugular bulb (HRJB).

The retro and hypotympanum were classified according to Bonali classification 7 into 4 types:

> Type 1: the retro- and hypotympanum is composed of one large chamber that extends from the stapes footplate to the carotid.
>
> Type II: only one bony crest is present, and this creates two chambers of different sizes and shapes. There are 3 subtypes for this: (A) in which the ponticulus is present and this forms the PS and one large anterior sinus; (B) in which the subiculum separates the superior retrotympanum from a confluent SST and HT; (C) present finiculus divides a confluent retrotympanum from the HT.
>
> Type III: two bony crests are present, and this creates three variable sinuses. Three subtypes may be applied: (A) ponticulus is absent with confluent PS and ST; (B) subiculum is absent with one large confluent ST and SST; (C) missing finiculus with confluent SST and HT.
>
> Type IV: all three bony crests are present and this forms four sinuses.

Data was collected, processed, and analyzed with Statistical Package for Social Sciences (SPSS) for Windows (version 20) computer program. Quantitative variables are described according to type, and data, and categorical variables are described as number (percentage).

## Results

A total of 250 middle ears were examined and analyzed for different anatomical variations. The study included 187 females and 63 males with a mean age of 34.12 ± 8.23 years. The study included 153 left ears and 98 right ears. Protympanum, hypotympanum, and retrotympanum anatomical variations were well identified in all cases using a transcanal endoscopic approach even in cases that had microscopic surgeries (Fig. 1). No major complications were detected in the postoperative follow-up. Table 1 summarizes the data identified by the study.

As regards the protympanum, we noted a high prevalence of the quadrangular conformation (64%) while the triangular conformation accounted for 36% of cases (Fig. 2). In addition, type B (shallow subtensor recess) represented most cases (64.8%) while type A (flat STR) accounted for 31.2% of cases and type C (deep STR) was the least finding (4%) (Fig. 3). On the other hand, type A protinuculum (ridge) was the commonest (80%), type C (absent) came next with a percent of 17.6%, and type B bridge was the least (2.4%).

The retrotympanum showed many findings on examination. Type A (ridge) variant was the commonest finding of ponticulus, subiculum, and finiculus with percents of 88.4%, 64.8%, and 72.8% respectively. Type C (incomplete) variants came next with percentages of 8%, 5.2%, and 22.4% respectively. Type B (bridge) variant was the least common in the 3 crests 3.2%, 5.2%, and 3.6% respectively (Fig. 4).

**Table 1** Variations of the study

| Type | No. of cases | Percent |
|---|---|---|
| ET orifice conformation | | |
| Type A: Quadrangular | 160 | 64% |
| Type B: Triangular | 90 | 36% |
| Subtensor recess | | |
| Type A: Flat | 78 | 31.2% |
| Type B: Shallow | 162 | 64.8% |
| Type C: Deep | 10 | 4% |
| Protiniculum | | |
| Type A: Ridge | 200 | 80% |
| Type B: Bridge | 6 | 2.4% |
| Type C: Absent | 44 | 17.6% |
| Jugular bulb | | |
| Type A: Below the level of bony annulus | 189 | 75.6% |
| Type B: At the level of bony annulus | 56 | 22.4% |
| Type C: Above the level of bony annulus | 5 | 2% |
| Ponticulus | | |
| Type A: Ridge | 221 | 88.4% |
| Type B: Bridge | 9 | 3.6% |
| Type C: Incomplete | 20 | 8% |
| Subiculum | | |
| Type A: Ridge | 162 | 64.8% |
| Type B: Bridge | 13 | 5.2% |
| Type C: Incomplete | 75 | 30% |
| Finiculus | | |
| Type A: Ridge | 182 | 72.8% |
| Type B: Bridge | 9 | 3.6% |
| Type C: Incomplete | 59 | 23.6% |
| Sinus Tympani | | |
| Type A: Shallow | 86 | 34.4% |
| Type B: Deep | 134 | 53.6% |
| Type C: Extends significantly postero- medial to facial nerve | 30 | 12% |
| Fustis direction/subcochlear canaliculus | | |
| Type A: Oblique fustis with existing canaliculus | 203 | 81.2% |
| Type B: Transverse fustis with absent canaliculus | 47 | 18.8% |
| Round window false membrane | | |
| Type A: Present | 64 | 25.6% |
| Type B: Absent | 186 | 74.4% |

Sinus tympani endoscopic evaluation revealed a predominance of type B (deep) ST with a percentage of 53.6%. Type A (shallow ST) came next with a percentage of 34.4%, while type C which extends medial and posterior to the facial nerve was the lowest finding (12%).

On examination of the round window region, we encountered a predominance of type A (present) subcochlear canaliculus, type B (oblique) fustis, and type B (absent) RW membrane with percentages of 79.2%, 79.2%, and 70.2% respectively.

Regarding the hypotympanum, type A jugular bulb which lies below the level of bony annulus was the commonest finding (75.6%), type B which lies at the level of bony annulus) came next with a percentage of 22%and type C which lies above the level of the bony annulus was the least in frequency 2% (Fig. 5).

On the classification of the retro and hypotympanum according to Bonali et al. classification in 2017, we encountered a predominance of type IV (60%) with the

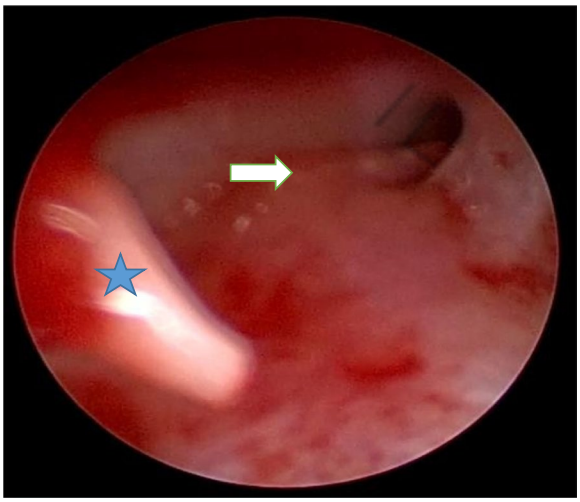

**Fig. 2** 30º endoscopic view of Rt. ear protympanum: quadrangular conformation of the ET orifice, handle of malleus (star), and carotid ridge (white arrow)

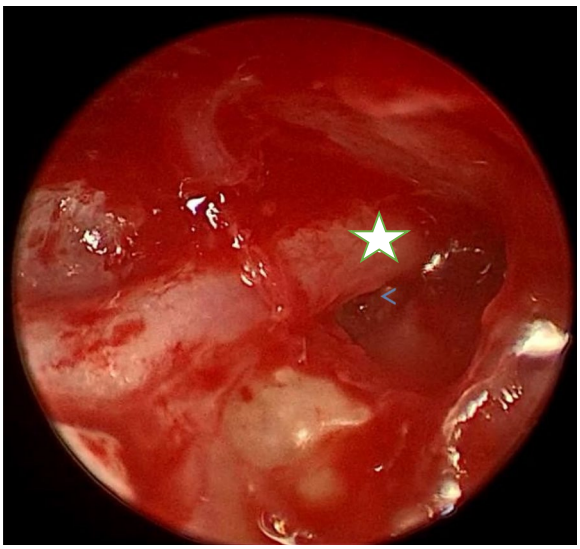

**Fig. 3** 30º endoscopic view of Rt. ear protympanum: Triangular conformation of ET orifice, type B subtensor recess (arrow) and canal of tensor tympani muscle (star)

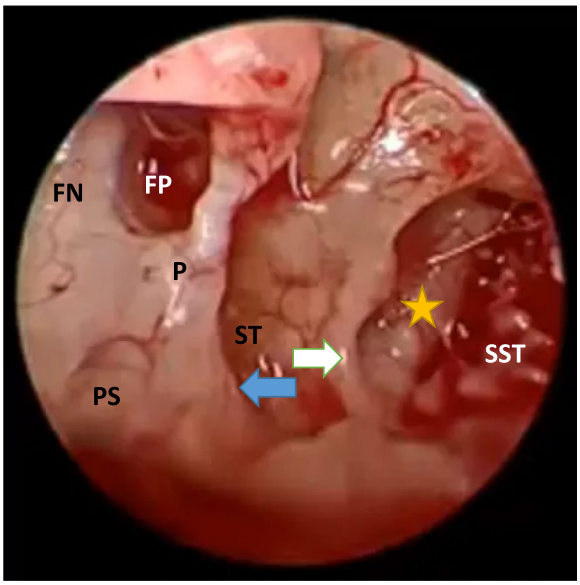


**Fig. 4** 30º endoscopic view of Rt. ear retrotympanum: Ponticulus (blue arrow) and subiculum (white arrow) of type A, footplate (FP), facial nerve (FN), pyramid (P), posterior sinus (PS): pyramid PO, ponticulus, ST: sinus tympani (ST), sinus subtympanicus (SST) and oblique fustis (star)

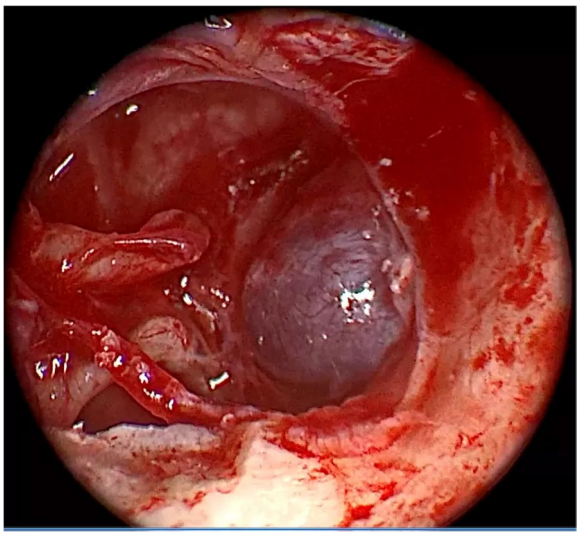

**Fig. 5** 0º endoscopic view of Rt.ear: High riding jugular bulb with dehiscent floor of the middle ear

presence of all bony crests and sinus forms followed by type III C (11.2%) with just absent finiculus.

Endoscopic middle ear examination resulted in some strange and rare findings. A carotid prominence spicule was present in one case (Fig. 2). The RW false membrane was obscured by a very high jugular bulb in three cases, and one case was obscured by a high posterior part of jugular bulb (Fig. 5).

## Discussion

Good knowledge of middle ear structures and anatomical variability is a must for otologists [6]. The wide spread of middle ear disease and surgical procedures can be affected by the presence of bony crests, bridges, and sinuses [13]. The first clinical importance is regarding the cholesteatoma that can spread under the bridges

from one region to another [14]. This could happen even without bone erosion [7]. In addition, small pieces of cholesteatoma may easily be hidden behind a bony crest or under a bridge and therefore escape the surgeon's eyes [7]. Moreover, the round window region and subcochlear canaliculus have great clinical importance in many approaches like cochlear implant surgery, trans tympanic drug delivery to the inner ear, and approaches to the petrous apex [15, 16]. The protympanum is another less well-studied partition of the middle ear despite having many landmarks for different procedures and applications [8, 18]. Therefore, we conducted this study on 250 cases to describe the variations of the different anatomical landmarks of the middle ear, especially the retro, hypo, and protympanic spaces.

Jufas et al. in 2018, conducted a study on the endoscopic anatomy of protympanum which included a total of 97 ears used for analysis: 73 human cadavers and 24 live humans [10]. Bonali and others in 2017, conducted an endoscopic study of anatomical variants of hypo- and retrotympanum [7]. This study included cadaveric dissection on 83 human specimens [7]. Marchioni et al. in 2010, conducted a retrospective endoscopic study of inferior retrotympanum on videos from endoscopic middle ear procedures stored in their database [5]. Our study included 250 middle ears of living humans with endoscopic examination of anatomical variants of protympanum, hypotympanum, and retrotympanum.

Jufas et al. in 2018 described and classified two conformations of protympanum, they encountered a predominance of a quadrangular conformation with a percentage of 59.8% and less triangular conformation with a percentage of 40.2% [10]. In the assessment of the protiniculum, 57.7% were classified as type A (ridge), 22.7% were classified as type B (bridge) and 19.6% were classified as type C (absent) [10]. Regarding the prevalence of subtensor recess conformation in the study group, 29.9% had type A (absent), 48.5% had type B (shallow) and 21.6% had type C (deep) [10]. In our study, we encountered near results with a predominance of quadrangular conformation (64%), type A protinuculum (80%), and type B shallow STR (64.8%). These findings about the protympanum are surgically valuable as the protympanum can be affected by cholesteatoma [8]. The presence of deep STR or bridge-type protinuculum can hide the presence of cholesteatoma [10]. In addition, the protympanum is a focus of study during transtympanic Eustachian tube balloon dilatation or stenting [10]. The conformation of the protympanum and the position of the carotid affect the procedure [10].

The retrotympanum was the focus of many studies owing to its surgical importance, especially in cholesteatoma persistence or recurrence after primary surgery [19]. Bonali et al. in 2017 analyzed a total of 125 middle ears. They identified the retrotympanic structures using the transcanal endoscopic approach [7]. Ponticulus was observed as a ridge in 38%, a bridge in 35% of middle ears, and an incomplete type in 27% of the cases. They encountered the Subiculum mainly as a ridge shape in 73, 58%, and only in 8% of cases the subiculum was observed as a bridge [7]. Marchioni et al. described in a cohort of 25 surgically treated subjects a distribution of 19 ridges, two bridges, and a lack of subiculum in four patients [5]. In our study, we had quite different results. The ridge ponticulus (type A) was the most common finding with 88%. Regarding the subiculum, we had a predominance of ridge type A (64.8%) with less percent than that of Bonali et al. In addition, we got a predominance of type A ridge finiculus with a percentage of 72.8%.

Sinus tympani has a great potential for affection by cholesteatoma and its affection by the disease is blamed for persistence and recurrence after primary surgery [4]. Marchioni et al. classified sinus tympani according to its depth into shallow, deep, and deep with medial and posterior extension to the facial nerve [6]. This classification bears extreme surgical importance, especially in cases affected by cholesteatoma [6]. Endoscopic examination of the sinus tympani during cholesteatoma surgery enables the surgeon to assess the depth and remove every piece of disease [7]. On the other hand, the microscopic approach to the sinus tympani has some difficulties and morbidity as the approach needs to be a retrofacial approach in cases of type C ST [20]. Variations of sinus tympani in our study were presented as follows: 34.4% of subjects presented type A (shallow), 53.6% of subjects presented type B (deep) sinus tympani, and 12% of subjects presented type C (extended significantly posteromedial to facial nerve) sinus tympani.

The round window region has a special interest in the middle ear due to its extreme surgical importance [11]. Yoda et al. in 2011 showed that 4.9% of normal temporal bones had a false RW membrane in their study on 12 cadavers [21]. False RW membrane is a significant morphologic variation in the human RW [11]. False RW membrane may block the drug from coming into contact with the round window membrane [21]. In our study, we had more present false RWM with a percentage of 28%. However, Sahin et al. had more predominance of false RWM with a percentage of 41.6% in their study [22]. In Bonali et al.'s study, subcochlear canaliculus was present in 62.5% more type A present subcochlear canaliculus with a percentage of 79.2% [7]. These data are quite different from that of Marchioni et al. described three types of subcochlear canaliculus based on the depth and extension towards the petrous apex [12]. The accurate evaluation of the depth of the tunnel is based on

both endoscopic and radiologic evaluation [15]. In this study, we limited the assessment to the pure endoscopic view. Cholesteatoma can extend through deep SC to the petrous apex, and this may require an infracochlear approach to eradicate the disease [23]. Moreover, wide SC can be mistaken for the RW niche during cochlear implant surgery [15]. Therefore, we studied the SC to show the presence of variations.

The high jugular bulb is an important vascular malformation of the middle ear [22]. Different descriptions of the HJB have been postulated [22]. Atmaca et al. reported the incidence of HJB frequency as 15.3% [17]. Sayit et al. described the incidence of the HJB frequency as 22% and Satin et al. encountered HJB frequency as 8.3% [22, 24]. In our study, we used the description that the dome of the jugular bulb should be present above the inferior tympanic annulus to describe as HJB. We encountered HJB in 2% of our cases. However, we encountered the dome of the bulb at the level of the annulus at 22%. In addition, we encountered 2 rare findings. The jugular bulb in hypotympanum was below the level of the bony annulus (type A) in the anterior part, and the posterior part was above the level of the bony annulus (type C) in one case. In another case of type C, the jugular bulb was very high obscuring the round window niche and the structures at this site (Fig. 5).

The surgical anatomy of the middle ear has been studied in the past years, especially with endoscopic studies. Most of these studies describe and assess single middle ear compartment like sinus tympani, ponticulus, protympanum, or round window niche [4, 14]. This study can be considered one of the largest that describe the anatomical variations of different compartments of the middle ear focusing on the surgical and clinical importance of these variations. The study included the largest sample size among studies discussing the middle ear anatomical variations. In addition, it is the first to be performed totally on surgical cases, not on cadaveric studies. Moreover, it is the first to describe these anatomical variations in Egyptians.

## Conclusion

Middle ear anatomy is a subject of great variability especially regarding the hidden spaces like the protympanum, retrotympanum, and hypotympanum. The endoscope facilitates the approach to these spaces and aids greatly in the identification of the important structures. The endoscope allows minimal manipulation of the delicate structures of the middle ear. Therefore, it could help in decreasing the morbidity and time of operations. Our results showed slight differences from previous studies which could be attributed to the larger sample size and the racial differences.

**Acknowledgements**
Not applicable.

**Authors' contributions**
HE, ME: conceptualization, methodology, validation. FI: resources, formal analysis, data curation. ME: writing—original draft, writing—review, and editing. WM: investigation, resources. YK: validation. All authors read and approved the final manuscript.

**Funding**
The authors declared that this study has received no financial support.

**Availability of data and materials**
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate**
The study performance was in accordance with the ethical standards of the institutional and/or national research committee of Mansoura University with a number of MS/17.07.77 and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent should have been taken from the patients.

**Consent for publication**
Not applicable.

**Competing interests**
Dr Yasser Khafagy is a co-author of this study and an Associate Editor of the journal. He was not involved in handling this manuscript during the submission and review processes. The rest of the authors have no conflict of interest to declare.

Received: 28 July 2023 Accepted: 10 November 2023
Published online: 21 November 2023

**References**

1. Marchioni D, Alicandri-Ciufelli M, Mattioli F, Nogeira JF, Tarabichi M, Villari D, Presutti L (2013) From external to internal auditory canal: surgical anatomy by an exclusive endoscopic approach. Eur Arch Otorhinolaryngol 270(4):1267–1275. https://doi.org/10.1007/s00405-012-2137-x
2. Tarabichi M, Marchioni D, Kapadia M (2016) The epitympanum revisited: endoscopic anatomy. Indian J Otolaryngol Head Neck Surg 68:490–495. https://doi.org/10.1007/s12070-016-1000-6
3. Nogueira JF, Mattioli F, Presutti L, Marchioni D (2013) Endoscopic anatomy of the retrotympanum. Otolaryngol Clin North Am 46(2):179–188. https://doi.org/10.1016/j.otc.2012.10.003
4. Burd C, Pai I, Connor S (2020) Imaging anatomy of the retrotympanum: variants and their surgical implications. Br J Radiol 93(1105):20190677. https://doi.org/10.1259/bjr.20190677
5. Marchioni D, Alicandri-Ciufelli M, Piccinini A, Genovese E, Presutti L (2010) Inferior retrotympanum revisited: an endoscopic anatomic study. Laryngoscope 120(9):1880–1886. https://doi.org/10.1002/lary.20995
6. Marchioni D, Molteni G, Presutti L (2011) Endoscopic anatomy of the middle ear. Indian J Otolaryngol Head Neck Surg 63(2):101–113
7. Bonali M, Anschuetz L, Fermi M, Villari D, Mariani GA, Manzoli L, Caversaccio M, Presutti L (2017) The variants of the retro- and hypotympanum: an endoscopic anatomical study. Eur Arch Otorhinolaryngol 274(5):2141–2148. https://doi.org/10.1007/s00405-017-4492-0
8. Jufas N, Marchioni D, Tarabichi M, Patel N (2016) Endoscopic anatomy of the protympanum. Otolaryngol Clin North Am 49(5):1107–1119. https://doi.org/10.1016/j.otc.2016.05.009
9. Marchioni D, Piccinini A, Alicandri-Ciufelli M, Presutti L (2013) Endoscopic anatomy and ventilation of the epitympanum. Otolaryngol Clin North Am 46(2):165–178. https://doi.org/10.1016/j.otc.2012.10.002

10. Jufas N, Rubini A, Soloperto D, Alnoury M, Tarabichi M, Marchioni D, Patel N (2018) The protympanum, protiniculum and subtensor recess: an endoscopic morphological anatomy study. J Laryngol Otol 132(6):489–492. https://doi.org/10.1017/S0022215118000464
11. Pringle MB, Konieczny KM (2020) Anatomy of the round window region with relation to selection of entry site into the scala tympani. Laryngoscope 598–604. https://doi.org/10.1002/lary.28738.
12. Marchioni D, Alicandri-Ciufelli M, Pothier DD, Rubini A, Presutti L (2015) The round window region and contiguous areas: endoscopic anatomy and surgical implications. Eur Arch Otorhinolaryngol 272(5):1103–1112. https://doi.org/10.1007/s00405-014-2923-8
13. Anschuetz L, Presutti L, Marchioni D, Bonali M, Wimmer W, Villari D, Caversaccio M (2018) Discovering middle ear anatomy by transcanal endoscopic ear surgery: a dissection manual. J Vis Exp 131:56390. https://doi.org/10.3791/56390
14. Marchioni D, Alicandri-Ciufelli M, Grammatica A, Mattioli F, Presutti L (2010) Pyramidal eminence and subpyramidal space: an endoscopic anatomical study. Laryngoscope 120(3):557–564. https://doi.org/10.1002/lary.20748
15. Marchioni D, Soloperto D, Colleselli E, Tatti MF, Patel N, Jufas N (2016) Round window chamber and fustis: endoscopic anatomy and surgical implications. Surg Radiol Anat 38(9):1013–1019. https://doi.org/10.1007/s00276-016-1662-5
16. Canzi P, Avato I, Manfrin M, Simoncelli AM, Magnetto M, Rebecchi E, Tinelli C, Neri M, Beltrame MA, Benazzo M (2019) Anatomic variations of the round window niche: radiological study and related endoscopic anatomy. Surg Radiol Anat 41(7):853–857. https://doi.org/10.1007/s00276-019-02225-8
17. Atmaca S, Elmali M, Kucuk H (2014) High and dehiscent jugular bulb: clear and present danger during middle ear surgery. Surg Radiol Anat 36:369–374. https://doi.org/10.1007/s00276-013-1196-z
18. Pauna HF, Monsanto RC, Schachern P, Paparella MM, Cureoglu S (2017) A 3-D analysis of the protympanum in human temporal bones with chronic ear disease. Eur Arch Otorhinolaryngol 274(3):1357–1364. https://doi.org/10.1007/s00405-016-4396-4
19. Baklaci D, Kuzucu I, Guler I, Akbal S, Yurtsever N (2019) Effect of mastoid bone pneumatization on the conformation and depth of the sinus tympani, a high - resolution computed tomography study. Surg Radiol Anat. 41:921–926. https://doi.org/10.1007/s00276-019-02246-3
20. Marchioni D, Mattioli F, Alicandri-Ciufelli M, Presutti L (2009) Transcanal endoscopic approach to the sinus tympani: a clinical report. Otol Neurotol 30(6):758–765. https://doi.org/10.1097/MAO.0b013e3181b0503e
21. Yoda S, Cureoglu S, Shimizu S, Morita N, Fukushima H, Sato T, Harada T, Paparella MM (2011) Round window membrane in Ménière's disease: a human temporal bone study. Otol Neurotol 32(1):147–151. https://doi.org/10.1097/MAO.0b013e318200a0e0
22. Şahin B, Orhan KS, Aslıyüksek H, Kara E, Büyük Y, Güldiken Y (2020) Endoscopic evaluation of middle ear anatomic variations in autopsy series: analyses of 204 ears. Braz J Otorhinolaryngol 86(1):74–82. https://doi.org/10.1016/j.bjorl.2018.10.002
23. Wick CC, Hansen AR, Kutz JW Jr, Isaacson B (2017) Endoscopic infracochlear approach for drainage of petrous apex cholesterol granulomas: a case series. Otol Neurotol 38(6):876–881. https://doi.org/10.1097/MAO.0000000000001422
24. Sayit AT, Gunbey HP, Fethallah B, Gunbey E, Karabulut E (2016) Radiological and audiometric evaluation of high jugular bulb and dehiscent high jugular bulb. J Laryngol Otol 130(11):1059–1063. https://doi.org/10.1017/S0022215116009166
25. Boddepalli R, Murthy S (2018) Endoscopic anatomy of hypotympanum surgical implications. Ann Otol Neurotol 1:58–67. https://doi.org/10.1097/MAO.0000000000002787


## Publisher's Note