Novel Surgical and Radiological Classification of the Subtympanic Sinus: Implications for Endoscopic Ear Surgery

Lukas Anschuetz[1], MD; Matteo Alicandri-Ciufelli[2,3], MD, FEBORL-HNS; Marco Bonali[2], MD; Matteo Fermi[2], MD; Marco Caversaccio[1], MD; Livio Presutti[2], MD; Daniele Marchioni[4], MD

[1] Department of Otorhinolaryngology, Head & Neck Surgery, Inselspital, University Hospital and University of Bern, Bern, Switzerland

[2] Department of Otorhinolaryngology, Head & Neck Surgery, University Hospital Modena, Italy

[3] Neurosurgery department, New civil hospital Sant'Agostino Estense, Baggiovara (MO), Italy

[4] Department of Otorhinolaryngology, Head & Neck Surgery, University Hospital Verona, Italy

Conflict of Interest: The authors declare no conflict of interest.

Corresponding Author

Lukas Anschuetz, MD,

Department of Otorhinolaryngology, Head & Neck Surgery, Inselspital University Hospital of Bern, Freiburgstrasse, CH-3010 Bern, Switzerland

Email: anschuetz.lukas@gmail.com, Tel: +41316322654; Fax: +41316324872

Key words: Endoscopic ear surgery; anatomy, retrotympanum, subtympanic sinus, styloid prominence

Abstract

Objective: The aim of this study is to describe the endoscopic anatomy of the subtympanic sinus (STS), establish a classification according to its extension regarding the level of the facial nerve (FN) and assess the feasibility of the transcanal endoscopic approach to the STS.

Study Design: Experimental anatomical research

Setting: Temporal bone laboratory

Methods: We performed endoscopic dissection of 34 human whole head and ear block specimens. Of those, 29 underwent high resolution computed tomography. The STS was classified according to its extension regarding the FN into type A: no extension medial to the FN; type B: extension to the medial limit of the FN; type C: extension of the sinus medial and posterior of the FN into the mastoid cavity.

Results*:* The majority (n=21, 72%) of the cases showed a shallow type A STS. In 6 cases (21%) we observed a deep type B and in two cases (7%) a type C configuration. The STS was completely exposable using a 0° endoscope in 44% of the specimens. Using a 45° endoscope we gained complete insight in 79%. However, in 21% of the cases the postero-medial extension of the STS was too deep to be completely explored by an endoscopic transcanal approach.

Conclusion*:* The majority of the STS is shallow and not extending medially regarding the FN. This morphological variant allows the complete transcanal endoscopic visualization. In more excavated STS a complete endoscopic exploration is not achievable, and a retrofacial approach may be adopted to completely access the STS.

Introduction

The growing implementation of the endoscopic technique in ear surgery during the last two decades raised several questions on the feasibility and suitability of the approach to treat different pathologies. Regarding the posterior wall of the tympanic cavity, the endoscope allows its visualization from a transcanal perspective due to the use of angled endoscopes. Therefore, a detailed description and surgical classification of the anatomy as well as an assessment of the feasibility of the approach is required to optimize the surgical treatment, especially in cholesteatoma surgery.

From the initial description by Proctor using microscopically dissected temporal bones,[1] several endoscopic studies have been performed to further refine and classify the hidden anatomy of the retrotympanum.[2-6] The particular interest from a surgical point of view is the high rate of residual cholesteatoma encountered in the bony bays of the posterior tympanic wall, especially in the sinus tympani (ST).[7] Inferiorly to the ST is situated the subtympanic sinus (STS). Its superior border is represented by the subiculum. This bony structure connects the posterior pillar of the promontory bone to the posterior wall of the tympanum at the level of the styloid prominence. The inferior limit is represented by the finiculus emerging from the anterior pillar of the promontory bone and running towards the region of the jugular bulb (JB). Anteriorly, the STS is interconnected to the round window niche, which has been recently described from an endoscopic point of view.[4]

The STS is in close relationship to the mastoid portion of the facial nerve (FN) with regularly encountered extensions of the sinus inferior and/or medial to the level of the nerve. This anatomic detail has an important impact on the preoperative planning of the surgical approach, in particular during cholesteatoma surgery. Therefore, the exact knowledge of the anatomy as well as the identifiability of these small bony

structures on preoperative high resolution computed tomography (HRCT) is of uppermost importance. However, a detailed description of the posterior aspects of the inferior retrotympanum and especially a surgical classification of the STS is still lacking in literature.

The aim of this study is to describe the endoscopic anatomy of the STS, its variability and to compare these findings to its presentation on HRCT. Moreover, we aim to classify the STS according to its extension regarding the level of the facial nerve and assess the feasibility of the transcanal endoscopic approach to the STS.

Material and Methods

Cadaveric dissection study

The present study dissection study was approved by our institutional review board (KEK-BE 2016-00887). We performed transcanal endoscopic dissection of whole head and ear block specimens (n=34). The anatomical specimens did not present any pathologies and all specimens had tragus and pinna in situ. We used 0° and 45°, 3mm diameter and 14cm length endoscopes, coupled to high-resolution camera system (Karl Storz, Tuttlingen, Germany).[8]

After elevation of a standard tympano-meatal flap, the middle ear was entered with the 0° optic. The inferior retrotympanum was explored, possibly present adhesions or mucosal folds removed with a hook and the anatomy photo-documented. Afterwards, the region was explored using a 45° endoscope, using appropriate bent instruments and aspirators to clean the bony bays from mucosal folds, followed by photo-documentation. The dissection using the angled scope was repeated, whilst standing on the contralateral side of the specimen.

The STS is defined as the bony bay lying between the subiculum superiorly and the finiculus inferiorly. Anteriorly lies the round window niche with the entrance to the

subcochlear canaliculus.[4] The floor of the subtympanic sinus consists of the fustis, the area concamerata and inferiorly the JB. Posteriorly the sinus extends towards the level of the FN and may be in close relations to the subfacial mastoid cells. The visualization of the STS, especially its posterior and medial wall was assessed using 0° and 45° endoscopes. The anatomic variability according to its pneumatization, due to obstruction (high JB) or due to restriction (additional bony crests) was assessed. The styloid prominence marks the posterior and superior border of the STS and represents similar to the pyramidal eminence for the ST an important surgical landmark. According to its presentation and size we classified the endoscopic appearance as following:

- Absent: no bony prominence identifiable
- Short: the styloid prominence is smaller and shorter than the pyramidal process and of restricted appearance
- Levelled: the styloid prominence is of the same overhang and size as the pyramidal process
- Protruding: the styloid prominence is of prominent shape and size partially obstructing the visualization of the ST and STS.

Radiologic analysis

Out of the 34 sides investigated by endoscope, we performed HRCT of 29 anatomical specimens to correlate the endoscopic to the radiologic findings. A 3-dimensional reformation was done in all cases. The anatomical configuration of the STS and its topographical relationships to the surrounding structures, especially the FN were assessed and documented. We classified three types of STS:

- Type A: The excavation of the sinus corresponds to the medial border of the third portion of the FN in the mastoid.

- Type B: The STS extends to the medial limit of the FN, but without posterior extension.
- Type C: Medial and posterior expansion of the sinus regarding the FN. In these cases, the STS extends into the mastoid cavity.

Statistical analysis

Data was analyzed using GraphPad Prism 7. Comparisons were calculated using Chi-Squared Tests with alpha set at 0.05.

Results

Endoscopic dissection

A total of 34 sides in temporal bone and whole head specimens without apparent disease underwent dissection. During endoscopic exploration of the inferior retrotympanum a pneumatization of the STS was observed in 23 cases (68%), whereas 11 specimens (32%) did not show a relevant a relevant posterior and medial extension of the STS. Accordingly, the posterior wall of the STS was completely exposable using a 0° endoscope in 15 cases (44%). Using a 45° endoscope we gained complete insight of the medial wall of the STS in 79% of the cases (n=27). However, in 7 cases (21%) the postero-medial extension of the STS was too deep to be completely explored by an endoscopic transcanal approach (Figure 1).

A total of 3 (9%) restricted configurations of the STS were observed, due to a high JB as shown in Figure 2A. Moreover, we observed 4 cases (12%) with additional bony crests inside the STS. This appearance was classified as partitioned STS as exemplarily illustrated in Figure 2B.

Radiologic evaluation

A total of 29 specimens underwent HRCT. Based on the above introduced classification according to the STS extension regarding the facial nerve, we observed, that the majority (n=21, 72%) of cases showed a shallow type A STS, where the excavation of the sinus corresponded to the anterior medial border of the mastoid segment of the FN. In 6 cases (21%) we observed a deep type B, where the STS extends the medial limit of the FN, but without posterior extension. Two cases (7%) of type C STS showed a medial and posterior expansion of the sinus into the mastoid cavity (Figure 3). The endoscopic pictures of each type of STS are represented in Figure 4. We observed a statistically significant correlation between the introduced radiologic classification according to the depth of the STS regarding the FN and its visualization during the endoscopic exploration ($p < 0.0001$). Actually, only type A STS qualify for complete transcanal endoscopic exposure as illustrated in Figure 5.

Morphology of the styloid prominence

According to the endoscopic presentation and size, the styloid prominence was classified into absent (n=5, 15%), short (n=17, 50%), levelled with pyramidal eminence (n=5, 15%) and protruding (n=7, 20%,). This classification is illustrated in Figure 6. The morphology of the styloid prominence was not correlated to the complete visibility of the posterior STS wall ($p = 0.160$).

Discussion

This study describes the anatomical variability of the STS. The proposed classification system is targeted to detect the topographical relationships of this anatomical region regarding the FN. Actually, the STS has been quite neglected

during the investigations of the past years and a classification is to our knowledge lacking in the literature.

In this study, the majority of the cases presented with a shallow STS not exceeding the level of the FN posteriorly. However, we observed extensions of the STS medial and posterior to the FN in 28% of the specimens. Therefore, we propose a surgical classification system of the STS into Type A to C, similar to the one previously proposed for the ST.[3] Together with the classification of the retro- and hypotympanum proposed by the present authors[2] a reproducible surgical classification of the complete region regarding its morphological variability and its relationship to the FN is now available. As previously suggested, the exact knowledge and classification of the anatomy is of high interest, especially during cholesteatoma surgery. The retrotympanum is considered the most susceptible part of the middle ear for residual cholesteatoma postoperatively.[7] Therefore the preoperative assessment from HRCT of the posterior wall of the tympanic cavity and the extension of disease into this hidden area is useful for the planning of the operation. During the surgery, the knowledge of the endoscopic anatomy allows the efficient exploration of these hidden areas. However, we have to remain alert to possible extensions of the sinus beyond the reachability of the endoscope.

As assessed in the present study, in cases of limited posterior extension of the STS, the complete exploration of the region using 0° and 45° endoscopes is possible without removing any bone for access purposes. However, in cases of a deep excavation of the sinus or even an extension posteriorly and medially regarding the FN, the complete exploration of the STS using a transcanal endoscopic approach is in most cases not achievable. This observation represents in fact a limitation of the feasibility of the transcanal endoscopic approach to the retrotympanum.

To solve this problem, the surgeon may use optical lenses with higher angulation (e.g. 70°) to explore the medial wall of the STS. However, no corresponding instruments are available to remove for instants a cholesteatoma from a type C STS using an extremely angulated optical lens. The instruments would require to be angulated and very long. This treatment option has not been described in the literature and would require a dedicated investigation. We do not know, if the use of higher angulated endoscopes would allow the complete visualization of the different anatomical regions of the middle ear. The other option would be to adopt a transmastoid, retrofacial approach to completely explore the STS and remove the pathology. This approach has been described for the ST by Picket et al.[9] They identified some limitations of the approach such as a limited space between the posterior semicircular canal and the facial nerve as well as the presence of a high JB.[9] Similarly, the retrofacial approach has been proposed to access the hypotympanum.[10]

The feasibility assessment of the exclusive transcanal endoscopic approach to the ST by Marchioni et al. (2009), revealed complete removal of cholesteatoma from the ST in 93.5% of the cases.[3] In this study, the limitations of the transcanal approach were: very deeply excavated ST (Type C) and extensive bleeding. According to our results, the limitation of the endoscopic approach regarding the treatment of a deeply excavated ST can be assigned to the STS as well. Fortunately, the type C configuration of the STS is quite rare. However, a careful analysis and classification of the STS from preoperative HRCT is advisable to appropriately plan the surgical technique required for each patient.

Garcia et al. described a high variability of the styloid prominence in 70 human temporal bones.[11] Hereby, we present a novel endoscopic classification. However, the styloid prominence does not impede statistically significant with the transcanal

access to the retrotympanum. Moreover, it may be removed intraoperatively if necessary. In this case its proximity to the FN has to be kept in mind.

Conclusion

The majority of the STS is shallow and not extending medially regarding the FN (type A). This morphological variant allows the complete transcanal endoscopic visualization. In more excavated STS (Type B or C) a complete endoscopic exploration is not achievable, in these cases, a retrofacial approach may be adopted to completely explore the STS.

Acknowledgements

The authors wish to thank the Institute of Anatomy Bern, Switzerland, especially Mrs. Susanne Bömke for providing the anatomical specimens.

References

1. Proctor B. Surgical anatomy of the posterior tympanum. Ann Otol Rhinol Laryngol 1969; 78:1026–1040
2. Bonali M, Anschuetz L, Fermi M, Villari D, Mariani GA, Manzoli L, Caversaccio M, Presutti L. The variants of the retro- and hypotympanum: an endoscopic anatomical study. Eur Arch Otorhinolaryngol. 2017 May;274(5):2141-2148.
3. Marchioni D, Mattioli F, Alicandri-Ciufelli M, Presutti L. Transcanal endoscopic approach to the sinus tympani: a clinical report. Otol Neurotol 2009; 30:758–765
4. Marchioni D, Alicandri-Ciufelli M, Pothier DD, Rubini A, Presutti L. The round window region and contiguous areas: endoscopic anatomy and surgical implications. Eur Arch Otorhinolaryngol 2015; 272(5):1103–1112
5. Marchioni D, Alicandri-Ciufelli M, Piccinini A, Genovese E, Presutti L. Inferior retrotympanum revisited: an endoscopic anatomic study. Laryngoscope 2010; 120(9):1880–1886
6. Baki FA, El Dine MB, El Said L et al. Sinus tympani endoscopic anatomy. Otolaryngol Head Neck Surg 2002; 127:158–162
7. Weiss MH, Parisier SC, Han JC et al. Surgery for recurrent and residual cholesteatoma. Laryngoscope 1992; 102:145-51
8. Anschuetz L, Presutti L, Marchioni D, Bonali M, Wimmer W, Villari D, Caversaccio M. Discovering Middle Ear Anatomy by Transcanal Endoscopic Ear Surgery: A Dissection Manual. J Vis Exp. 2018 Jan 11;(131).

9. Pickett BP, Cail WS, Lambert PR. Sinus tympani: anatomic considerations, computed tomography, and a discussion of the retrofacial approach for removal of disease. Am J Otol. 1995 Nov;16(6):741-50.

10. Roland JT Jr, Hoffman RA, Miller PJ, Cohen NL. Retrofacial approach to the hypotympanum. Arch Otolaryngol Head Neck Surg. 1995 Feb;121(2):233-6.

11. Garcia PJ, Tamega OJ, Soares JC, Piffer CR, Zorzetto NL. Contribution to the study of the styloid prominence in the posterior tympanic cavity. Anat Anz 1982;151:247–254.

Figure Legends

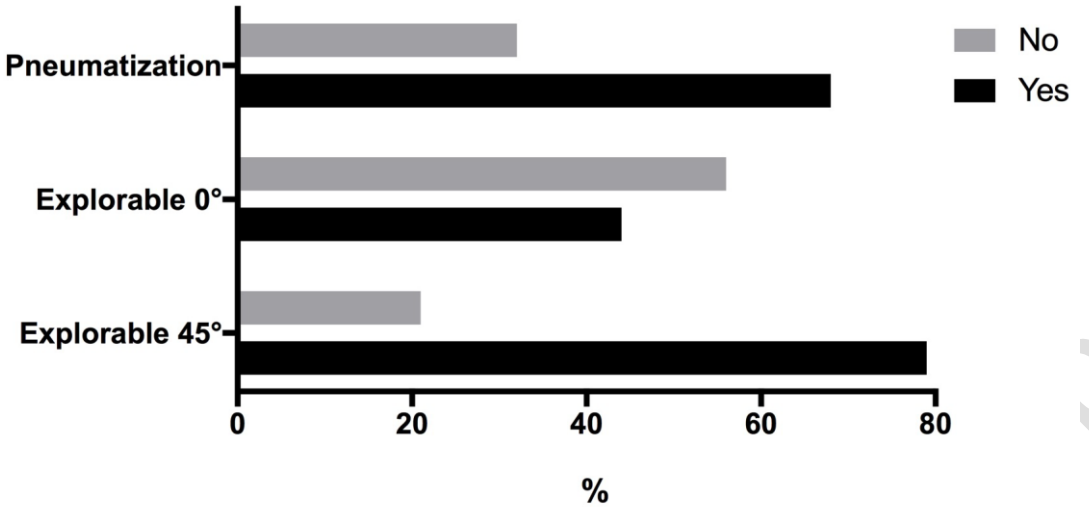

Figure 1: Pneumatization and visualization of the subtympanic sinus using 0° and 45° angled endoscopes by an exclusive transcanal approach without bone removal.

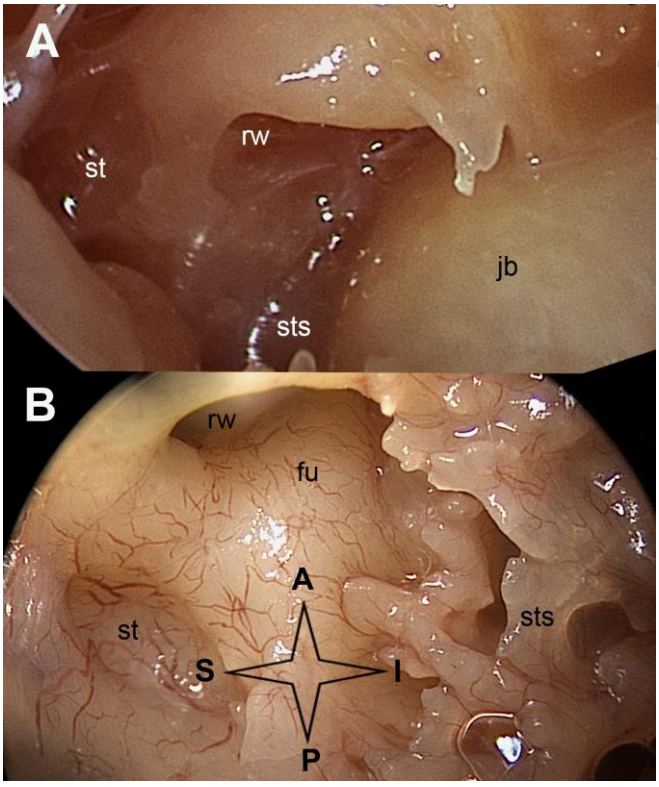

Figure 2: Panel A: Right ear, 45° endoscope; restricted configuration due to a high jugular bulb. Panel B: Right ear, 45° endoscope; partitioned configuration due to additional bony crests partially obstructing the entrance to the sinus.

st: sinus tympani, rw: round window niche, fu: fustis bone, sts: subtympanic sinus, jb: jugular bulb; Orientation valid for all panels: A: anterior, P: posterior, I: inferior, S: superior

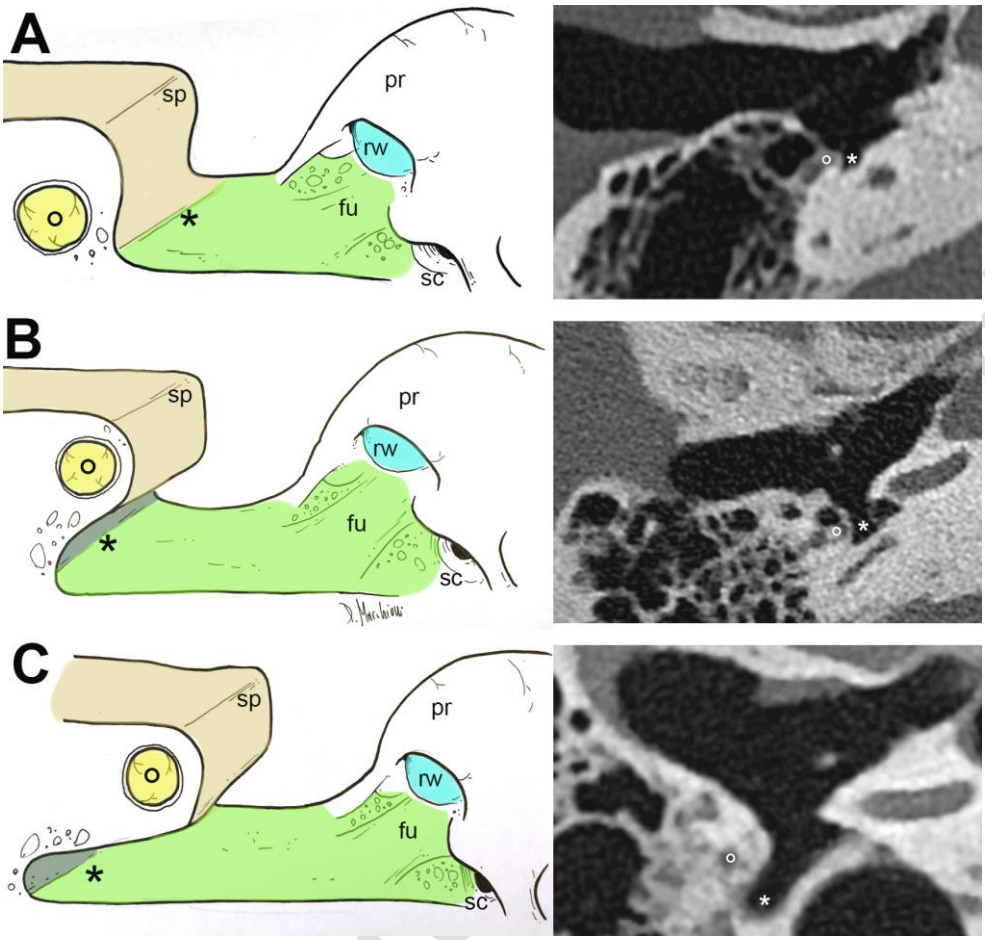

Figure 3: Novel surgical classification of subtympanic sinus (STS, green) with graphical illustrations (left) and axial high-resolution computed tomography scans (right). Panel A: Type A STS. B: Type B STS. Panel C: Type C STS.
rw: round window niche, fu: fustis bone, pr: promontory sp: styloid prominence, sc: subcochlear canaliculus, °: facial nerve, *: subtympanic sinus

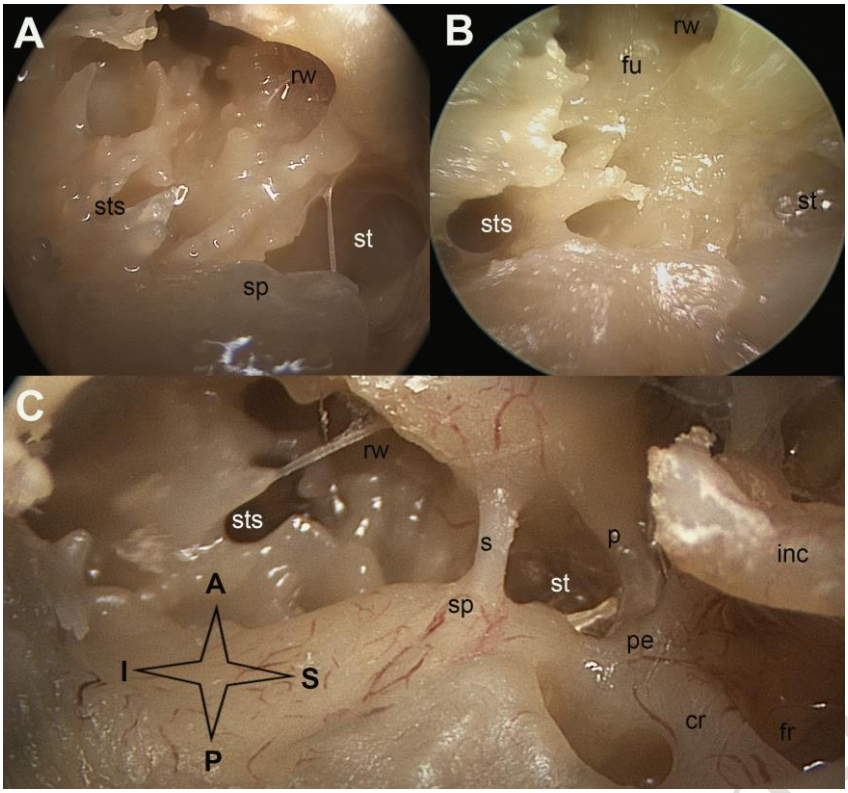

Figure 4: Endoscopic presentation of the subtympanic sinus (STS), left ears, 45° endoscope. Panel A: Type A STS. B: Type B STS. C: Type C STS, Note the bridge configuration of the subiculum.

st: sinus tympani, sp: styloid prominence, rw: round window niche, sts: subtympanic sinus, fu: fustis bone, fr: facial recess, pe: pyramidal eminence, cr: chordal ridge, p: ponticulus, s: subiculum, sp: styloid prominence, inc: incus; Orientation valid for all panels: A: anterior, P: posterior, I: inferior, S: superior

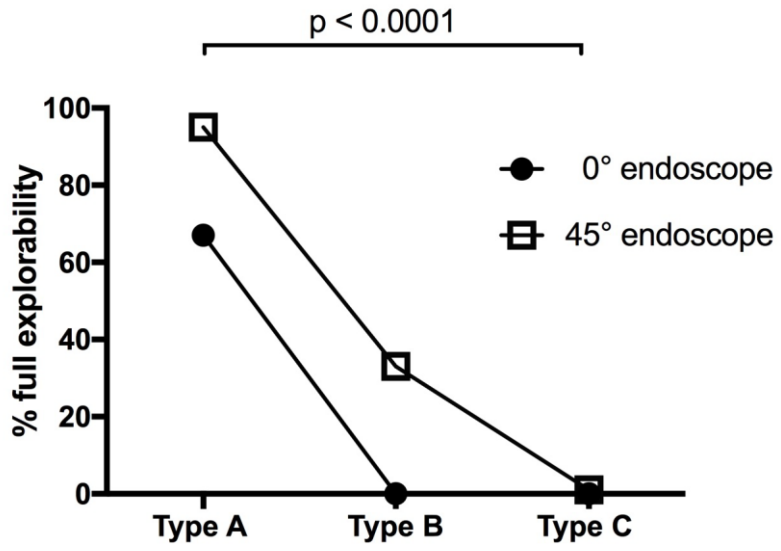

Figure 5: Correlation between the type of subtympanic sinus and the visibility using 0° or 45° endoscopes in the same anatomical specimens (n=29). The classification is statistically significantly correlated to the full endoscopic exploration of the sinus.

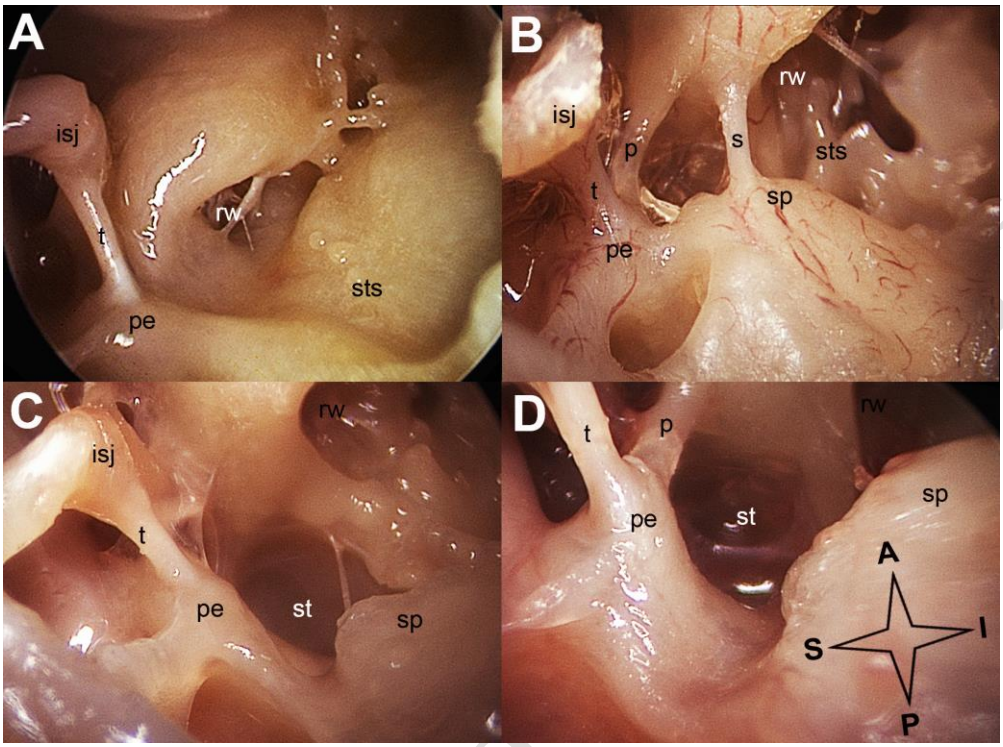

Figure 6: Classification of the styloid prominence (SP) according to its endoscopic presentation. Right ears, endoscopic 45° view. Panel A: absent SP. Panel B: protruding configuration. Panel C: short SP. Panel D: SP levelled with pyramidal eminence.

st: sinus tympani, sp: styloid prominence, rw: round window niche, sts: subtympanic sinus, pe: pyramidal eminence, p: ponticulus, s: subiculum, sp: styloid prominence, t: tendon of stapedial muscle, isj: incudo-stapedial joint; Orientation valid for all panels: A: anterior, P: posterior, I: inferior, S: superior