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

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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 anatomic 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 level of the FN: type A, no extension medial to the FN; type B, extension to the medial limit of the FN; type C, extension of the sinus medially and posteriorly from the FN into the mastoid cavity.

Results. The majority of cases (n = 21, 72%) showed a shallow type A STS. We observed a deep type B configuration in 6 cases (21%) and a type C in 2 cases (7%). The STS was completely exposable with 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 posteromedial 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 does not extend medially from the FN. This morphologic variant allows 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.

Keywords

endoscopic ear surgery, anatomy, retrotympanum, subtympanic sinus, styloid prominence

The growing implementation of the endoscopic technique in ear surgery during the last 2 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 are 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 were 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] Inferior to the ST is the subtympanic sinus (STS), and 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

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promontory bone and running toward the region of the jugular bulb (JB). Anteriorly, the STS is interconnected to the round window niche, which was 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, 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 and 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 FN and to assess the feasibility of the transcanal endoscopic approach to the STS.

Material and Methods

Cadaveric Dissection Study

The present 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 anatomic specimens did not present any pathologies, and all specimens had tragus and pinna in situ. We used 0° and 45° endoscopes (3-mm diameter, 14-cm length) coupled to a high-resolution camera system (Karl Storz, Tuttlingen, Germany).[8]

After elevation of a standard tympanomeatal flap, the middle ear was entered with the 0° optic. The inferior retrotympanum was explored, with any present adhesions or mucosal folds removed with a hook and the anatomy photodocumented. Afterward, the region was explored with a 45° endoscope, with appropriate bent instruments and aspirators to clean the bony bays from mucosal folds, followed by photodocumentation. The dissection with the angled scope was repeated with the researcher 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. The round window niche lies anteriorly with the entrance to the subcochlear canaliculus.[4] The floor of the STS consists of the fustis, the area concamerata, and, inferiorly, the JB. Posteriorly, the sinus extends toward 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 walls, was assessed with 0° and 45° endoscopes. The anatomic variability was assessed according to its pneumatization, due to obstruction (high JB) or restriction (additional bony crests).

The styloid prominence marks the posterior and superior borders of the STS and represents an important surgical landmark, similar to the pyramidal eminence for the ST. We classified the endoscopic appearance according to its presentation and size as follows:

Absent: No bony prominence is identifiable.
Short: The styloid prominence is smaller and shorter than the pyramidal process and of restricted appearance.
Leveled: The styloid prominence is of the same overhang and size as the pyramidal process.

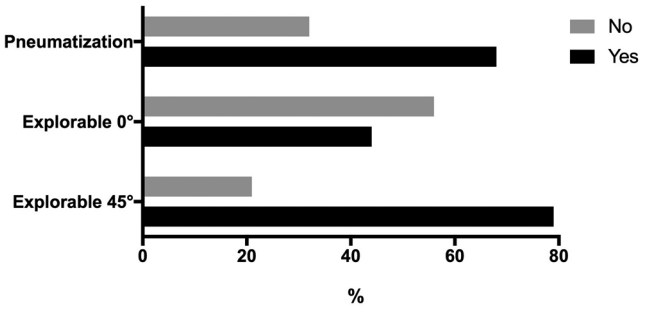

Figure 1. Pneumatization and visualization of the subtympanic sinus with 0° and 45° endoscopes by an exclusive transcanal approach without bone removal.

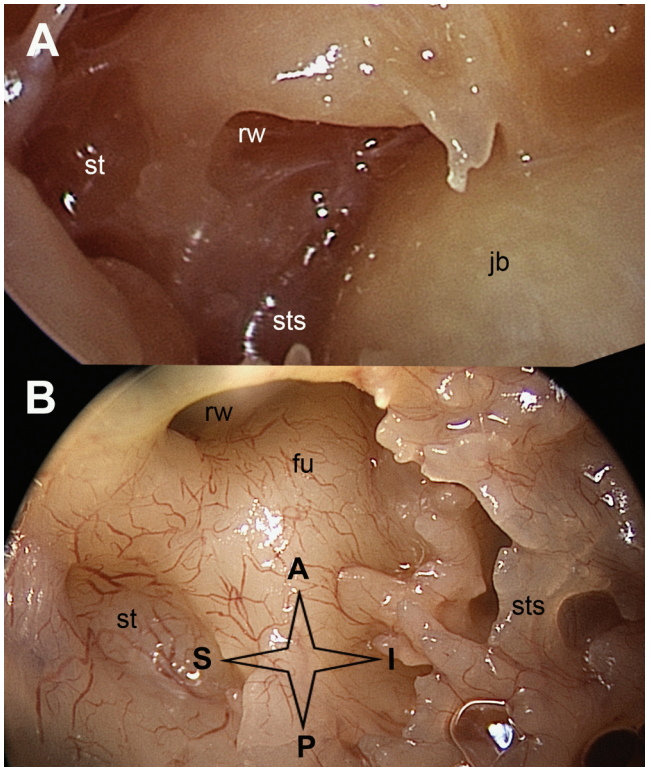

Figure 2. Right ear, 45° endoscope: (A) restricted configuration due to a high jugular bulb; (B) partitioned configuration due to additional bony crests partially obstructing the entrance to the sinus. fu, fustis bone; jb, jugular bulb; rw, round window niche; st, sinus tympani; sts, subtympanic sinus. Orientation valid for all panels: A, anterior; I, inferior; P, posterior; S, superior.

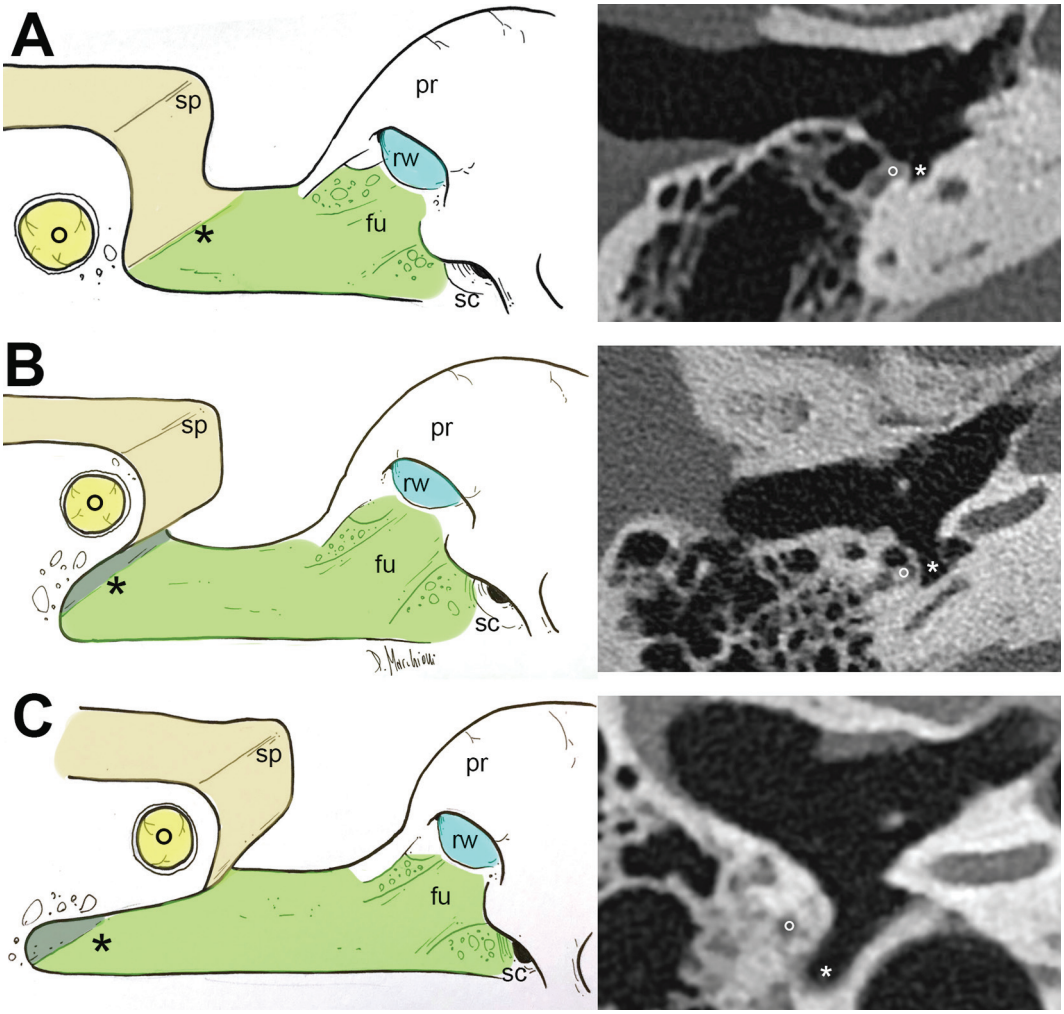

Figure 3. Novel surgical classification of subtympanic sinus (STS; green) with graphical illustrations (left) and axial high-resolution computed tomography scans (right): (A-C) type A, B, and C, respectively. fu, fustis bone; pr, promontory; rw, round window niche; sc, subcochlear canaliculus; sp, styloid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

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 anatomic specimens to correlate the endoscopic findings to the radiologic findings. A 3-dimensional reformation was done in all cases. The anatomic configuration of the STS and its topographic relationships to the surrounding structures, especially the FN, were assessed and documented. We classified 3 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 from the FN. In these cases, the STS extends into the mastoid cavity.

Statistical Analysis

Data were analyzed with GraphPad Prism 7. Comparisons were calculated with chi-square tests with alpha set at 0.05.

Results

Endoscopic Dissection

A total of 34 middle ears 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 posterior and medial extension of the STS. Accordingly, the posterior wall of the STS was completely exposable with 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

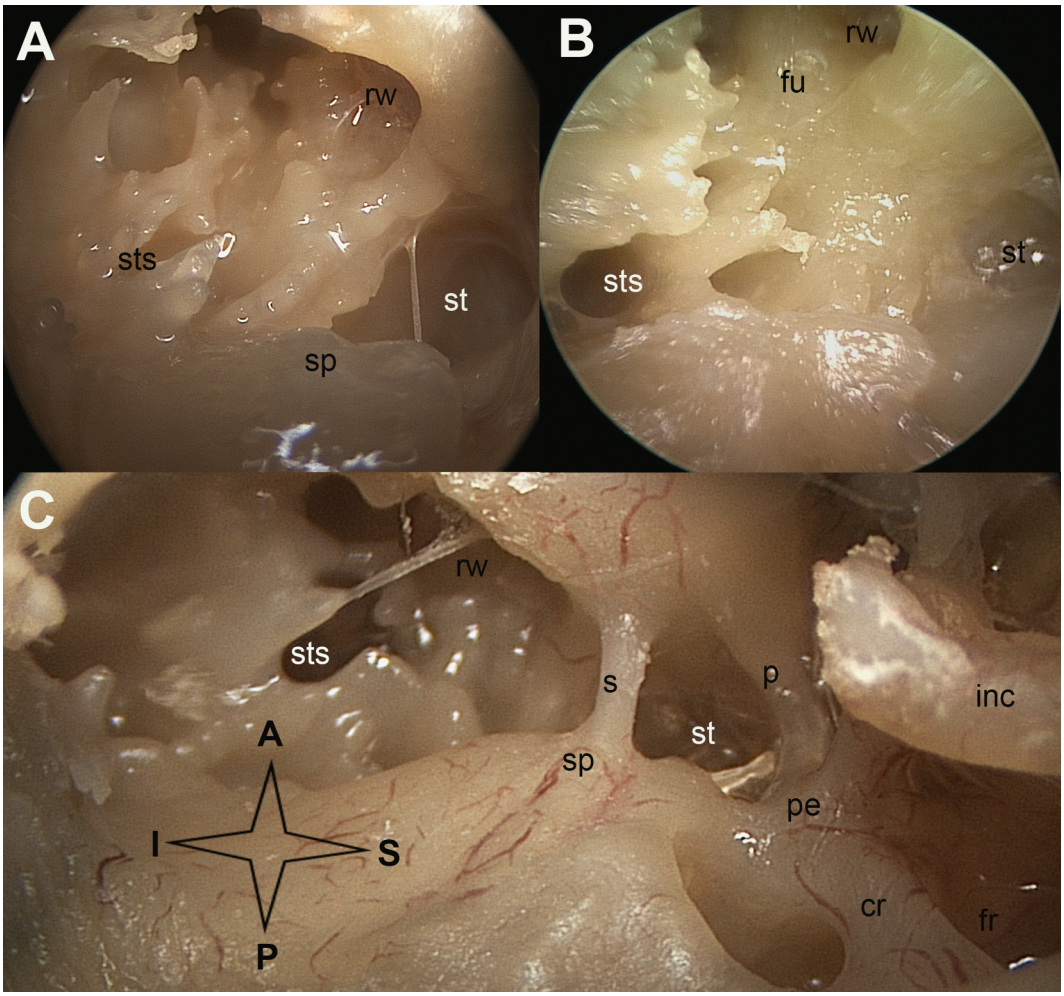

Figure 4. Endoscopic presentation of the subtympanic sinus (STS), left ears, 45° endoscope: (A-C) type A, B, and C, respectively. Note the bridge configuration of the subiculum. cr, chordal ridge; fr, facial recess; fu, fustis bone; inc, incus; p, ponticulus; pe, pyramidal eminence; rw, round window niche; s, subiculum; sp, styloid prominence; st, sinus tympani; sts, subtympanic sinus. Orientation valid for all panels: A, anterior; I, inferior; P, posterior; S, superior.

cases (21%), the posteromedial 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 classification introduced here, according to the STS extension from the FN, 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 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 from the FN and its visualization during the endoscopic exploration ($P < .0001$). Actually, only type A STS qualifies for complete transcanal endoscopic exposure, as illustrated in **Figure 5**.

Morphology of the Styloid Prominence

According to endoscopic presentation and size, the styloid prominence was classified into absent (n = 5, 15%), short (n = 17, 50%), leveled 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 ($P = .160$).

Discussion

This study describes the anatomic variability of the STS. The proposed classification system is targeted to detect the topographic relationships of this anatomic region from the

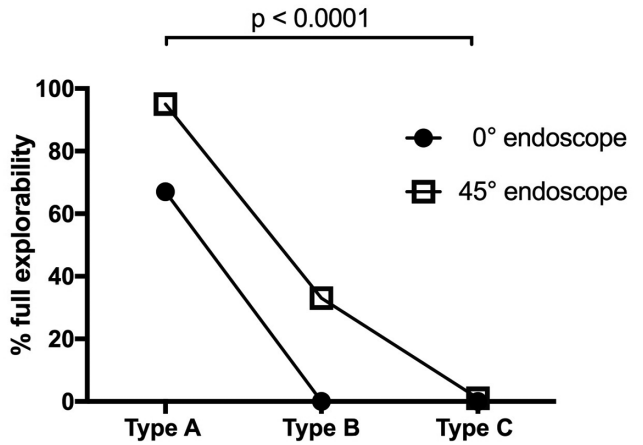

Figure 5. Correlation between the type of subtympanic sinus and the visibility with 0° or 45° endoscope in the same anatomic specimens (n = 29). The classification is significantly correlated to the full endoscopic exploration of the sinus.

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 types A to C, similar to the one previously proposed for the ST.[3] Along with the previous classification of the retro- and hypotympanum,[2] a reproducible surgical classification of the complete region regarding its morphologic 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 postoperative residual cholesteatoma.[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 planning the operation. During surgery, 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 with 0° and 45° endoscopes is possible without removing any bone for access purposes. However, in cases of deep excavation of the sinus or even posterior and medial extension from the FN, complete exploration of the STS with a transcanal endoscopic approach is, in most cases, not achievable. This observation represents in fact a limitation

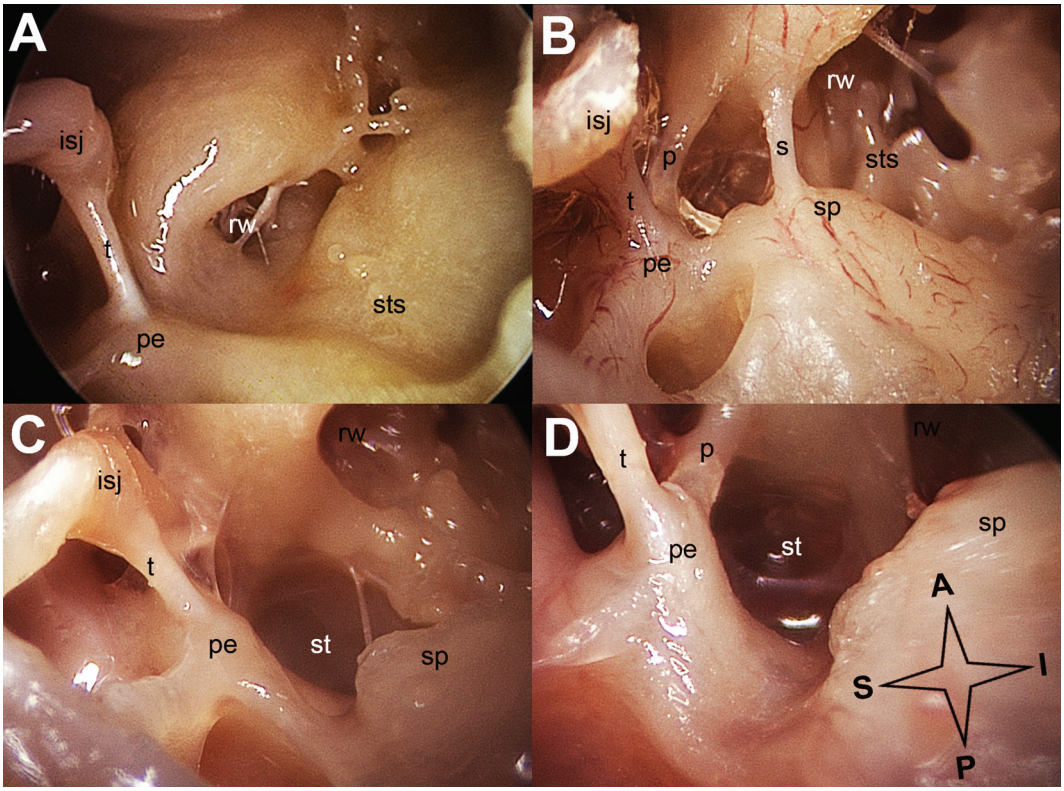

Figure 6. Classification of the styloid prominence (SP) according to its endoscopic presentation. Right ears, endoscopic 45° view: (A) absent SP, (B) protruding configuration, (C) short SP, and (D) SP leveled with pyramidal eminence. isj, incudostapedial joint; p, ponticulus; pe, pyramidal eminence; rw, round window niche; s, subiculum; st, sinus tympani; sts, subtympanic sinus; t, tendon of stapedial muscle. Orientation valid for all panels: A, anterior; I, inferior; P, posterior; S, superior.

of the feasibility of the transcanal endoscopic approach to the retrotympanum.

To solve this problem, the surgeon may use optical lenses with higher angulation (eg, 70°) to explore the medial wall of the STS. However, no corresponding instruments are available to remove, for instance, a cholesteatoma from a type C STS with an extremely angulated optical lens. The instruments would need 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 anatomic 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 was described for the ST by Picket et al,[9] who identified some limitations of the approach, such as a limited space between the posterior semicircular canal and the FN, as well as the presence of a high JB. Similarly, the retrofacial approach was proposed to access the hypotympanum.[10]

The feasibility assessment of the exclusive transcanal endoscopic approach to the ST by Marchioni et al revealed complete removal of cholesteatoma from the ST in 93.5% of the cases.[3] In this study, the limitations of the transcanal approach included 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, careful analysis and classification of the STS from preoperative HRCT are advisable to appropriately plan the surgical technique required for each patient.

Garcia et al described 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 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 does not extend medially from the FN (type A). This morphologic variant allows 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.

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Author Contributions

Lukas Anschuetz, conception and design, dissection, data collection, statistical analysis, manuscript draft and approval of final version; is accountable for all aspects of the work; **Matteo Alicandri-Ciufelli**, conception and design, dissection and data analysis supervision; revision of the manuscript and approval of final version; is accountable for all aspects of the work; **Marco Bonali**, conception and design, dissection, data collection, revision of the manuscript and approval of final version; is accountable for all aspects of the work; **Matteo Fermi**, data collection, dissection; revision of the manuscript and approval of final version; is accountable for all aspects of the work; **Marco Caversaccio**, conception and design, critical senior supervision of the study; revision of the manuscript and approval of final version; is accountable for all aspects of the work; **Livio Presutti**, conception and design, critical senior supervision of the study; revision of the manuscript and approval of final version; is accountable for all aspects of the work; **Daniele Marchioni**, conception and design, critical senior supervision of the study; revision of the manuscript and approval of final version; is accountable for all aspects of the work.

Disclosures

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