The Endoscopic Relationship of the Stapedius Muscle to the Facial Nerve: Implications for Retrotympanic Surgery

†‡Alessia Rubini, *†||¶**Nicholas Jufas, ‡Daniele Marchioni, †§||**Alexander J. Saxby, †Jonathan H. K. Kong, and *†||¶**Nirmal P. Patel

*Department of Otolaryngology and Head and Neck Surgery, Royal North Shore Hospital, St Leonards; †Kolling Deafness Research Centre, Macquarie University and University of Sydney, NSW; ‡Department of Otolaryngology Head and Neck Surgery, University of Verona, Verona; §Department of Otolaryngology Head and Neck Surgery, Royal Prince Alfred Hospital, University of Sydney; ||Sydney Endoscopic Ear Surgery ('SEES') Research Group; ¶Department of Otolaryngology–Head & Neck Surgery, Faculty of Medicine and Health Sciences, Macquarie University; and **Discipline of Surgery, Sydney Medical School, University of Sydney, Sydney, Australia

Objectives: The stapedius muscle, tendon, and pyramidal eminence are structures within the retrotympanum. In cholesteatoma surgery, the retrotympanum is a common site of residual disease. The removal of the pyramidal eminence during surgery is sometimes necessary to obtain better visualization of the superior retrotympanum during surgery. Understanding the relational anatomy of structures in the region to the facial nerve allows the surgeon to safely access regional disease. This study aims to better understand the anatomical relationship between the mastoid portion of the facial nerve, the pyramidal eminence, and the stapedius muscle. A secondary aim is to demonstrate that removal of the stapedius muscle in the cadaver model, can increase exposure to the retrotympanic space.

Study Design: Anatomical cadaveric observation study.

Methods: Endoscopic dissection of cadaveric heads was undertaken. Classification of the superior and inferior retrotympanic area was performed. The anatomy of the stapedius muscle was described including relationships, depth, course, and angle with respect to the facial nerve. The pyramidal eminence and stapedius muscle were removed in all specimens and the exposure of the retrotympanum re-evaluated to determine if exposure of the region was increased.

Results: In all cases (11 ears), the stapedius muscle was located medial and anterior to the mastoid portion of the facial nerve, with the second genu superior. The mean antero-posterior distance from the apex of the pyramidal eminence, which the stapedius tendon enters, to the stapes itself was 4.10 mm (range, 2.92–5.73 mm; standard deviation [SD] 0.90 mm). In all cases, irrespective of sinus tympani conformation, removal of the pyramidal eminence and stapedial bony crest in proximity to the facial nerve allowed exposure of the whole retrotympanic region, using a 0-degree endoscope.

Conclusions: The pyramidal eminence and stapedius muscle have a relatively constant relationship to the facial nerve. Removal of the stapedius muscle in the human cadaver model increases the exposure of the sinus tympani and subpyramidal space. Increased visualization in this region, may reduce risk of residual cholesteatoma in patients. **Key Words:** Cholesteatoma—Endoscopic anatomy—Endoscopic ear surgery—Facial nerve—Pyramidal eminence—Retrotympanum—Stapedius tendon.

Otol Neurotol **40:**xxx–xxx, 2019.

The retrotympanum is located posteriorly in the middle ear space, and divided in two compartments, the superior and inferior retrotympanum, by the subiculum. The subiculum extends posteriorly from the posterior pillar of the round window niche to the styloid eminence. The posterior region of the inferior retrotympanum is called the sinus subtympanicus which is bound superiorly by the subiculum and inferiorly by the finiculus (1). The superior retrotympanum is composed of the posterior sinus (a space bounded by the ponticulus, stapedius tendon, and posterior crus of the stapes bone), the subpyramidal space (medial to the pyramidal eminence), and the sinus tympani (between ponticulus and subiculum). Sinus tympani and sinus subtympanicus are located medial and anterior to the stapedius muscle and facial nerve. Sinus tympani is classified relative to its depth and the anatomical relationship to the facial nerve into, Type A (anterior to the facial nerve), Type B (medial to the facial nerve with a depth no greater than the nerve), and Type C (medial to the nerve, with a depth

Address correspondence and reprint requests to Alessia Rubini, M.D., University Hospital of Verona, Verona, Italy; E-mail: rubinialessia@gmail.com

All of the authors have read and approved the manuscript.
The present authors have no financial relationship to disclose.
The authors disclose no conflicts of interest.
DOI: 10.1097/MAO.0000000000002454

greater than the nerve and an extension posteromedial to the facial nerve).

In cholesteatoma surgery, the superior and inferior retrotympanum are possible sites of residual disease. Maximum exposure of the region is critical to good surgical control, but it can be difficult, due to the relative inaccessibility and the important structures in the region (2).

Sometimes, despite the use of angled endoscopes, removal of the pyramidal eminence is necessary to obtain complete disease removal from the posterior sinus and the subpyramidal space, however, the close proximity of the facial nerve puts it at risk of injury. Knowledge of the anatomy of the region is crucial for safe dissection of disease. The aim of this study is to describe the relationship of the stapedius muscle, the facial nerve, and contiguous structures in the superior retrotympanum.

MATERIALS AND METHODS

Approval was obtained under institutional anatomical licensing for cadaveric research for medical and scientific purposes. During February and March of 2018, endoscopic anatomical dissections were performed in 11 fresh frozen cadaver ears with no history of either ear disease or trauma.

Equipment used during dissection was a 0 and 45 degree, 3-mm diameter, 14-cm endoscope, with a SPIES H3-Z three-chip full HD camera, Image1 Connect Processing Module and full HD monitor (Karl Storz Gmbh & Co., Tüttlingen, Germany).

Dissection Procedure

An anteriorly based tympanomeatal flap was elevated, using a 0-degree endoscope transcanal. Exposure of the stapes, pyramidal eminence, and the entire retrotympanum was achieved by curettage of the scutum posteriorly.

The facial nerve was identified and skeletonized from the mid-tympanic portion to the second genu and the mastoid portion. The stapedius muscle was identified by following the stapedius tendon and removing the pyramidal eminence with curette or diamond burr.

Complete exposure of the stapedius muscle was achieved by removing the bony pyramid and the styloid eminence, dissecting in an anterior to posterior then superior to inferior direction. The appearance of the muscle and its anatomical relationships with the facial nerve were evaluated, then the muscle was removed from its bony shell. The walls of the bony canal in which the stapedius lies were morphologically evaluated, in particular the relation between its anterior limit and the mastoid tract of the facial nerve, at the level of the sinus tympani and the sinus subtympanicus. Using a diamond drill, removal of the medial aspect of the stapedial bony canal allowed access to the retrotympanic regions (sinus tympani, sinus subtympanicus, and posterior sinus).

Endoscopic evaluation and classification of the areas in the retrotympanum were evaluated in each specimen from superior to inferior including: posterior sinus, subpyramidal space, subiculum, sinus tympani, ponticulus, sinus subtympanicus, finiculus, and subcochlear canaliculus (Fig. 1).

Although the aim of this work is the endoscopic study of regional anatomical relationships, measurements were also undertaken of the antero-posterior distance from the posterior aspect of the stapes capitulum along the line of the stapedius tendon to the anterior aspect of the facial nerve in the descending portion. The measurements were obtained by four authors independently and blindly using two representative pictures of each cadaveric middle ear. In each of these, a cut segment of surgical ruler (DeRoyal Industries Inc., Powell, TN) was placed in the two-dimensional plane of the stapedius tendon and descending portion of facial nerve and as close to these structures as possible. Measurements were taken by measuring the pixels between the points of interest on a high resolution image and referencing this to the pixels per millimetre of the ruler. Two measurements were taken on each image and averaged, the measurements from each of the images was then in turn averaged, similar to the method used in Jufas and Bance (3).

The stapedius muscle was then removed and anatomical details of the retrotympanum re-examined to determine if exposure of the region was increased (Fig. 2).

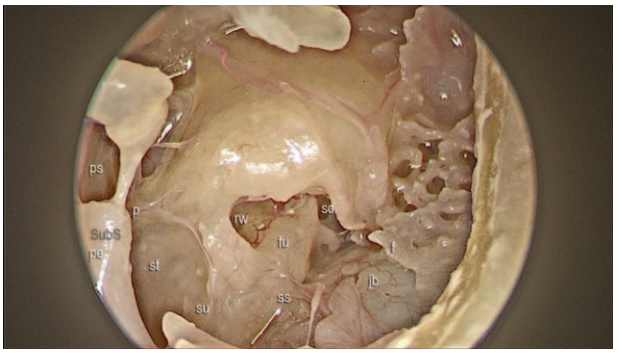

FIG. 1. Right side, endoscopic view with 0-degree endoscope. Endoscopic anatomy of the retrotympanum. f indicates finiculus; fu, fustis; jb, jugular bulb; p, ponticulus; pe, pyramidal eminence; ps, posterior sinus; rw, round window; sc, subcochlear canaliculus; ss, sinus subtympanicus; st, sinus tympani; su, subiculum; SubS, subpyramidal space.

RESULTS

In all specimens, the tympanic and mastoid portions of the facial nerve and the entire stapedius muscle were able to be fully exposed by endoscopic dissection (Fig. 3).

In all cases, at the superior aspect, the stapedius muscle was located anterior to the mastoid (descending) portion and second genu of the facial nerve. The muscle showed an antero-posterior course from the stapedius tendon insertion on the stapes to its bony insertion inferiorly, with a course from superior to inferior and from anterior to posterior. In its inferior portion the muscle runs medial to the facial nerve, contained within a bony grove in a widening of the fallopian canal. Following its course from posterior to anterior, the muscle separates itself from the facial nerve becoming anterior to it, contained in its own bony canal.

The mean antero-posterior distance from the posterior aspect of the stapes capitulum along the line of the stapedius tendon to the anterior aspect of the facial nerve in the descending portion was 3.95 mm (range, 2.92–5.74 mm; standard deviation [SD] 0.75 mm). The inferior part of the stapedius muscle is medial and parallel to the facial nerve without any bony separation.

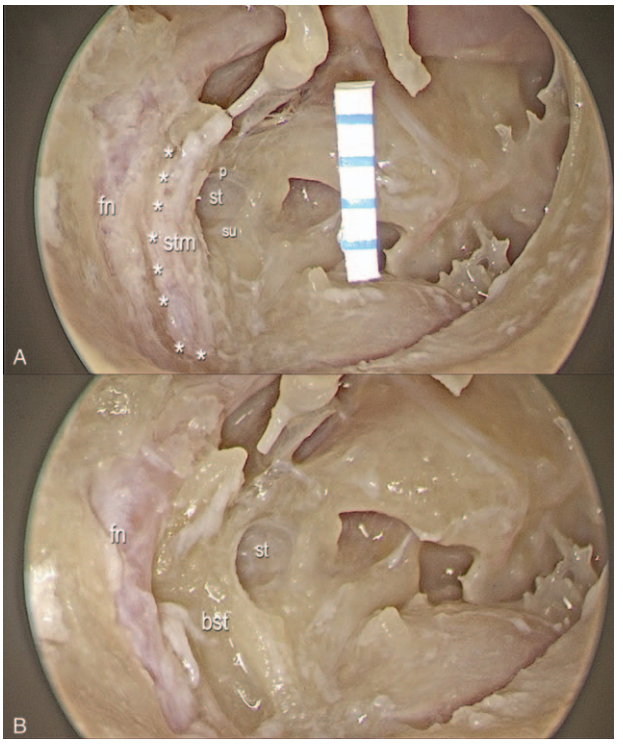

FIG. 2. Right side, endoscopic view with 0-degree endoscope. Panel A: Styloid eminence removed and stapedius tendon divided. Mastoid portion of the facial nerve and the stapedius muscle exposed, preserving the ossicular chain. Ruler showed used to take measurements of exposed mastoid facial nerve and stapedius muscle. Panel B: Stapedius muscle removed. The relationship between the facial nerve, the stapedius muscle, and the retrotympanic areas is appreciated. *bst* indicates bony canal of stapedius muscle; *fn*, facial nerve; *p*, ponticulus; *st*, sinus tympani; *stm*, stapedius muscle; *su*, subiculum.

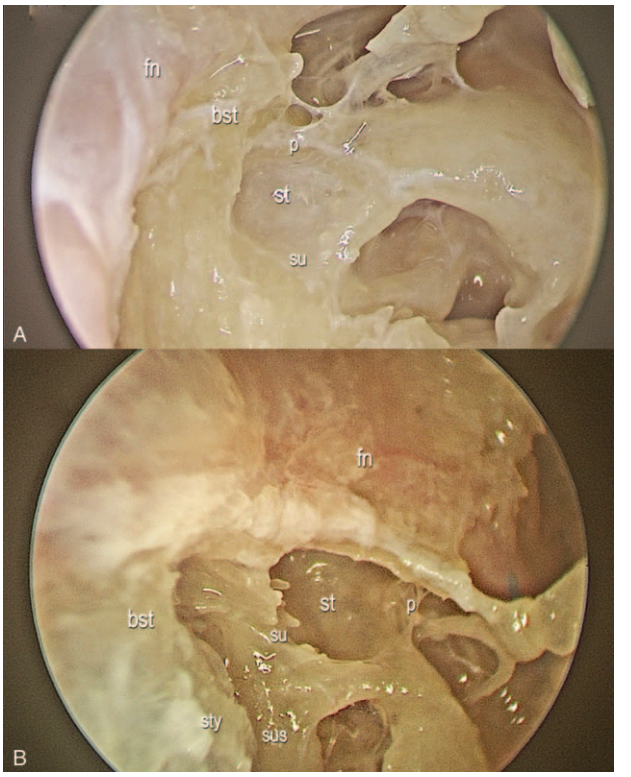

FIG. 3. Right side. Panel A: Endoscopic view with a 0-degree endoscope. Stapedius muscle removed. Panel B: Endoscopic view with a 45-degree endoscope. Note the bony canal of the stapedius muscle covering the sinus tympani and the sinus subtympanicus. *bst* indicates bony canal of stapedius muscle; *fn*, facial nerve; *p*, ponticulus; *st*, sinus tympani; *sty*, styloid eminence; *su*, subiculum; *sus*, sinus subtympanicus.

The stapedius muscle has a direct connection to the facial nerve. The stapedial branch of the facial nerve arises where it merges into the muscle. Complete exposure of the muscle and the facial nerve was achievable endoscopically without causing disturbance to the ossicular chain. In all cases, it was possible to remove the stapedius muscle completely from its bony canal, exposing the medial aspect of the canal without manipulation of the facial nerve. The fallopian canal at this level showed two grooves: one for the facial nerve and one for the stapedius muscle.

Retrotympanic Assessment

Type A sinus tympani was observed in seven ears, while in four ears a type B sinus tympani was present. None of the specimens had a type C sinus tympani.

The morphology of the pyramidal eminence can be classified into three types: 1) independent morphology, if the medial surface is completely formed and recognizable; 2) partial morphology, where the subpyramidal eminence communicated with the sinus tympani or with posterior tympanic sinus; and 3) merged morphology occurred if no space was present under the pyramidal eminence (4).

The subpyramidal eminence, in four out of 11 ears had an independent morphology, in three ears a merged configuration, and in four ears a partial configuration was observed.

In all the dissections, after removal of the stapedial bony crest (medial wall of the stapedius bony canal) complete exposure of the sinus tympani and sinus subtympanicus was achieved using the 0-degree endoscope (Fig. 4).

DISCUSSION

Different controversial theories have been proposed to explain the development of the stapedius muscle. According to Rodriguez-Vazquez (5), the stapedius muscle is formed by two precursors: one for the tendon and another for the belly. The anlage of the tendon is thought to be formed from a portion of the structure called the interhyale. The interhyale is detected in embryos at approximately 37 postovulatory days, in the mesenchyme of the second pharyngeal arch.

The belly anlage of the stapedius muscle appears at approximately 44 to 48 postovulatory days, medial to the facial nerve, and near the interhyale but independent of it.

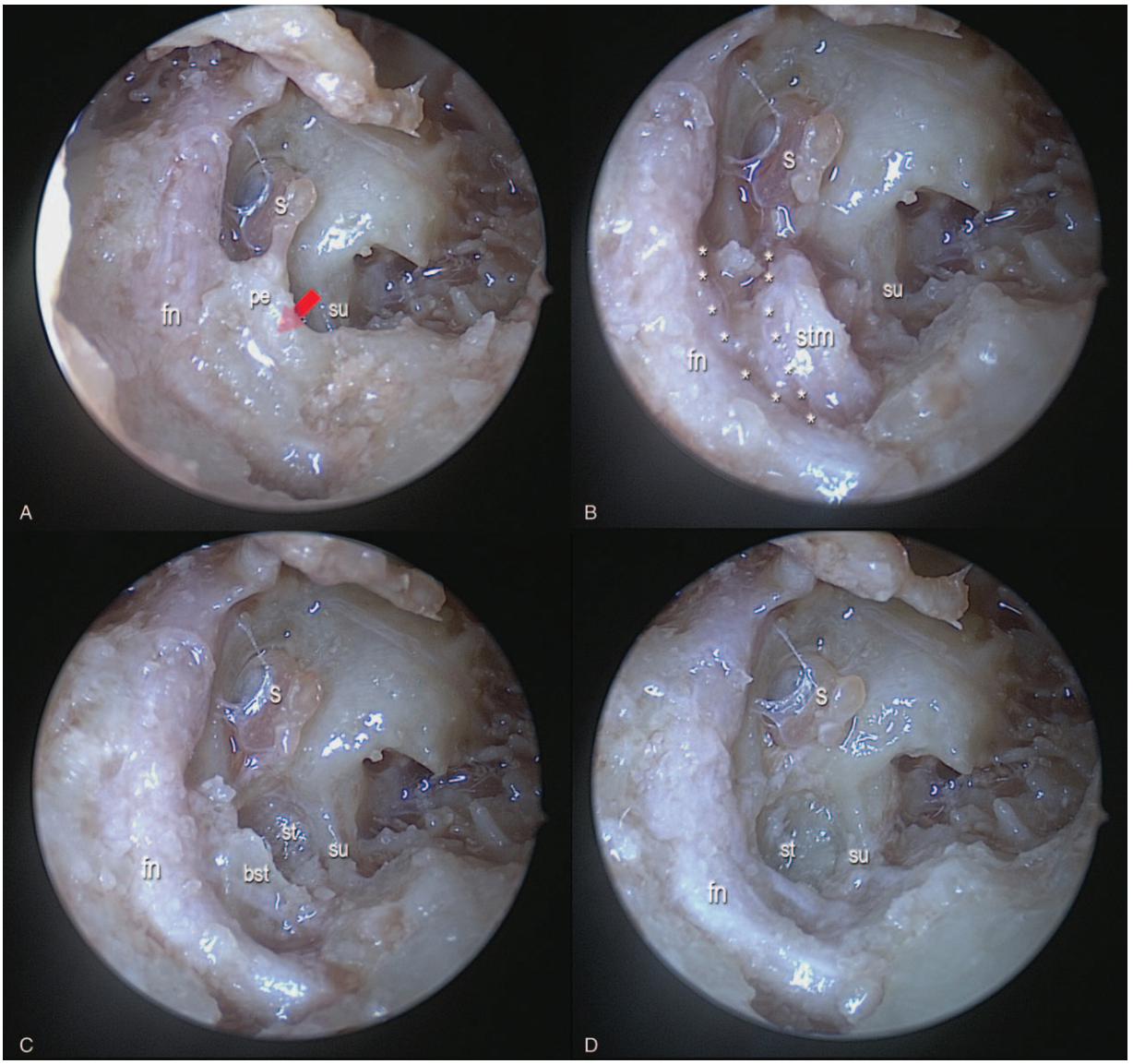

FIG. 4. Right side, endoscopic view with a 0-degree endoscope. In this specimen an incus removal was performed to better appreciate the tympanic and the mastoid facial nerve. Panel A: Styloid eminence removed, mastoid facial nerve, and stapedius muscle exposed. Panel B: Stapedius muscle exposed. Panel C: Stapedius muscle removed from its bony canal. Panel D: Stapedius bony canal was removed, exposing the sinus tympani and the sinus subtympanicus. This allows easy exploration of the whole retrotympanum using a 0-degree endoscope. *bst* indicates bony canal of stapedius muscle; *fn*, facial nerve; *pe*, pyramidal eminence; *s*, stapes; *st*, sinus tympani; *stm*, stapedius muscle; *su*, subiculum.

In the interhyale, two segments are differentiated (internal and external), and form an angle; at the vertex, the belly of the stapedius muscle is attached. The internal segment is connected from the attachment of the belly of the stapedius muscle to the anlage of the stapes, forming the anlage of the tendon of the stapedius muscle (approximately 54 postovulatory days). The external segment completely disappears at the beginning of the fetal period. Angulation between the belly and the tendon of the stapedius muscle (9–11 weeks of postconception development) decreases progressively over the fetal period until its alignment between 15 and 17 weeks postconception development.

The pyramidal eminence is formed by an anlage independent of Reichert's cartilage, from the mesenchymal tissue of the tympanic cavity, which condenses around the belly of the stapedius muscle from 12 weeks of postconception development.

The great variations in the length of the tendon of the stapedius muscle identified in adults could be explained depending on the place of fixation of the belly of the stapedius muscle in the interhyale, which would determine the length of the internal segment (anlage of the tendon) and consequently the length of the tendon of the stapedius muscle. In addition, the persistence of a greater or lesser degree of angulation observed between the

tendon and the belly of the stapedius muscle may explain the variations in the direction of the insertion and the different positions in which the tendon can be presented (5).

Anatomy

There has been surprisingly little written about the anatomy of the stapedius muscle and its surrounds. Platzer (6) in 1961 studied the pyramidal eminence and named the space containing the terminal muscle and stapedius tendon, the ''cavum eminentiae.'' He found that in 19 out of 25 specimens the space opened directly into the facial canal, and in 6 out of 25 specimens it opened into an independent cavity which was anterior to the facial canal. Marchioni classified the morphology of the pyramidal eminence into three types: independent, partial, and merged morphology (4). The region medial to the pyramidal eminence is called the subpyramidal space. Posteriorly, this space is separated from the vertical tract of the bony canal of the facial nerve by a thin bony layer.

In 1967, Anson et al. (7) dissected temporal bones and described the anatomy of the facial nerve and stapedius muscle. He described the vertical part of the facial canal (mastoid portion) as partly divided into two compartments: the one for the facial nerve, the other for the stapedius muscle. The stapedius muscle matched the vertical course of the facial nerve and ended at the pyramidal eminence. In some specimens, the two channels were confluent for a short distance. In others, larger blood vessels occupied a separate third compartment in the facial canal, dividing the region into three compartments.

Discussion of Findings and Surgical Implications

This work demonstrates the relatively constant relationship of the pyramidal eminence and stapedius muscle to the facial nerve. The muscle runs medial to the facial nerve, contained within a bony grove in the fallopian canal. Following its course from posterior to anterior, the muscle separates itself from the facial nerve becoming anterior to it, contained in its own bony canal. From inferior to superior the stapedius muscle was medial then anterior to the facial nerve. These findings are consistent with that of the literature. Removal of the muscle and surrounding bone can be consistently performed in the cadaver model and demonstrates that the exposure of the retrotympanum can be widened considerably. The posterior and lateral walls of the sinus tympani and sinus subtympanicus can be confidently removed to further expose a type B conformation of this region.

The surgical implications of this work are most relevant to cholesteatoma removal in the region of the retrotympanum. This work highlights how the whole stapedius medial bony ridge participates in making the retrotympanum recesses hidden and how the exposure of the stapedius can be performed without injury to the facial nerve. Typically, the retrotympanum is endoscopically accessed with a 30- or 45-degree scope. Previous papers have highlighted both the ipsilateral and contralateral approach to the retrotympanum using angled scopes (2,8–10). The findings from this study open the potential for an endoscopic transcanal approach to directly expose the retrotympanic spaces using a 0-degree endoscope. If there was a need to expose the full extent of the retrotympanum, extensive and maximal dissection in the region would begin with identification of the mastoid portion of the facial nerve, division of the stapedial tendon with the removal of the pyramidal eminence, the subsequent exposure of the (superior part of) stapedius entirely and its removal from the stapedial bony groove, and the subsequent removal of the stapedial bony crest by curette, microdrill or piezosurgery close to the mastoid facial nerve. This should then provide a direct exposure of the whole retrotympanic area from the posterior sinus with the subpyramidal space, sinus tympani and sinus subtympanicus. (Fig. 5). A careful understanding of the anatomical relationships can allow the surgeon to confidently and safely remove structures to expose the disease, allowing the endoscopic surgeon to remove deep type B or even type C disease.

Limitations of this study include a small sample size and an absence of any specimens with a type C sinus tympani. Access to the full depth of a deep type C sinus tympani would remain very challenging even with the above described maximal methods of removal. It is likely in such cases that a post auricular, transmastoid, retrofacial approach would be required, due to the limitation provided by the facial nerve. Another limitation of this study is the poor reproducibility of distance measurements with the method used. Within the constraints of measuring endoscopically, the aim was to ascertain an approximate/typical distance and range which is useful knowledge when operating in the area.

There are inherent hazards in dissection of this area in patients. Care would be required in pyramidal eminence removal to avoid injury to the ossicles. Superior to inferior dissection would be considered safer as the dissection moves away from the ossicles and second genu of the facial nerve. This direction is also favorable as it removes stapedius muscle from known regions to unknown. Any bleeding encountered with removal of the stapedius muscle would impair visualization and attaining haemostasis presents an avenue for direct damage to the facial nerve or indirectly through compromise of the blood supply. Lastly, removal of the stapedius muscle could potentially expose the patient to hyperacusis and sensitivity to loud sounds and this would need to be considered in preoperative discussions. Often in circumstances where this is needed, it would be very rare to have a completely intact ossicular chain, so the risk of hyperacusis would be reduced by the ossicular damage associated with the disease and subsequent reconstruction.

CONCLUSIONS

The pyramidal eminence and stapedius muscle have a relatively constant relationship to the facial nerve. Removal of the stapedius muscle in the human cadaver model increases the exposure and visualisation of the

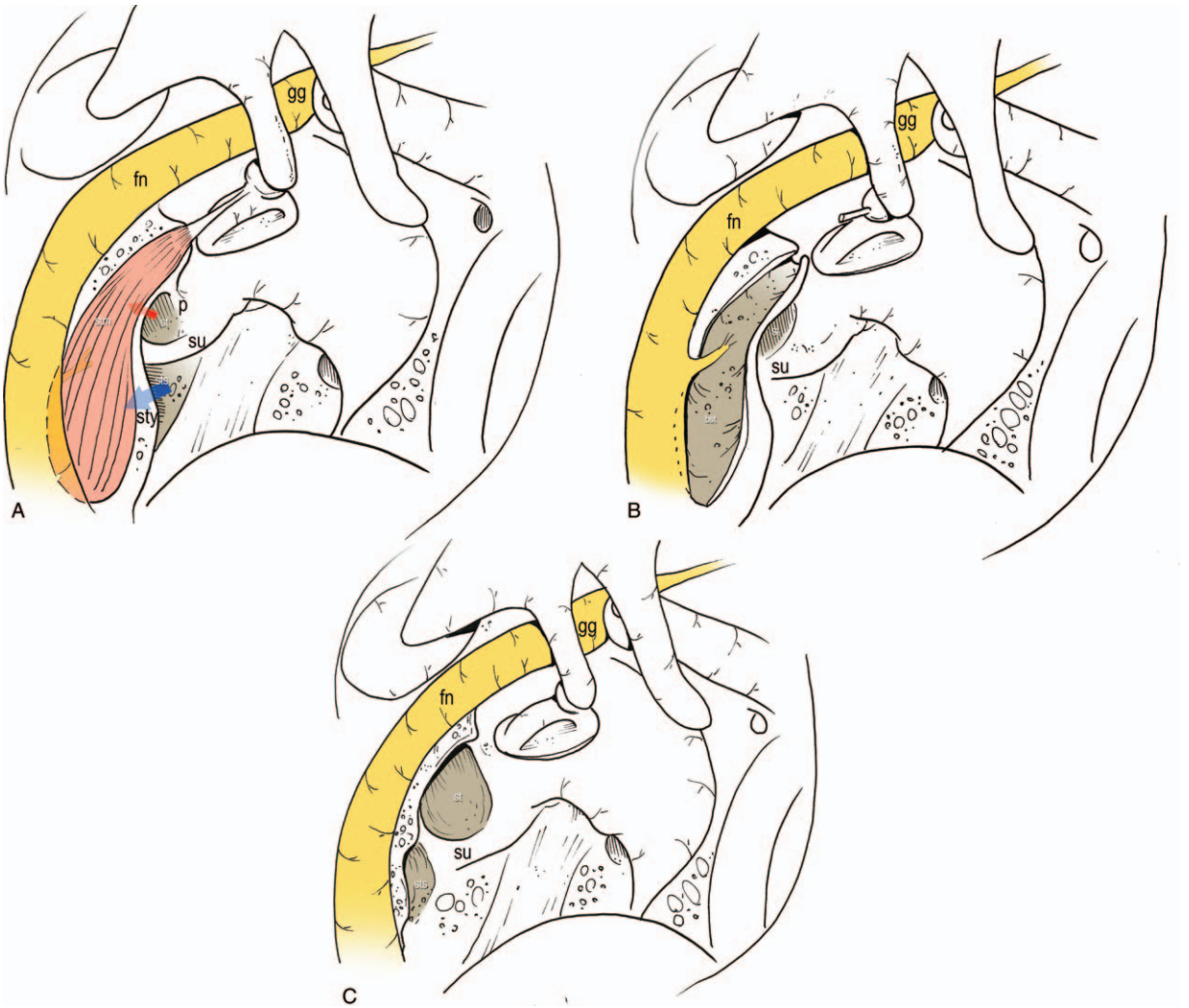

FIG. 5. Schematic drawings, right side. Panel A: Exposure of the mastoid facial nerve and stapedius muscle. Panel B: Stapedius muscle removed from its bony canal. Panel C: Stapedius bony canal removed, exposing the whole retrotympanum.

sinus tympani and sinus subtympanicus. These findings may have favorable implications during surgery for increasing exposure of the retrotympanum, which may translate to reduced residual cholesteatoma in the region.

REFERENCES

1. Marchioni D, Alicandri-Ciufelli M, Piccinini A, Genovese E, Presutti L. Inferior retrotympanum revisited: an endoscopic anatomic study. *Laryngoscope* 2010;120:1880–6.
2. Marchioni D, Mattioli F, Alicandri-Ciufelli M, Presutti L. Transcanal endoscopic approach to the sinus tympani: a clinical report. *Otol Neurotol* 2009;30:758–65.
3. Jufas N, Bance M. Endoscopically-assisted transmastoid approach to the geniculate ganglion and labyrinthine facial nerve. *J Otolaryngol Head Neck Surg* 2017;46:53.
4. Marchioni D, Alicandri-Ciufelli M, Grammatica A, Mattioli F, Presutti L. Pyramidal eminence and subpyramidal space: an endoscopic anatomical study. *Laryngoscope* 2010;120:557–64.
5. Rodriguez-Vazquez JF. Development of the stapedius muscle and pyramidal eminence in humans. *J Anat* 2009;215:292–9.
6. Platzer W. [On the anatomy of the eminentia pyramidalis and the stapedius muscle]. *Monatsschr Ohrenheilkd Laryngorhinol* 1961; 95:553–64.
7. Anson BJ, Donaldson JA, Warpeha RL, Winch TR. The surgical anatomy of the ossicular muscles and the facial nerve. *Laryngoscope* 1967;77:1269–94.
8. Thomassin JM, Korchia D, Doris JM. Endoscopic-guided otosurgery in the prevention of residual cholesteatomas. *Laryngoscope* 1993;103:939–43.
9. Badr-el-Dine M. Value of ear endoscopy in cholesteatoma surgery. *Otol Neurotol* 2002;23:631–5.
10. Abdel Baki F, El Dine MB, El Saiid I, Bakry M. Sinus tympani endoscopic anatomy. *Otolaryngol Head Neck Surg* 2002;127:158–62.