Endoscopic Anatomy of the Protympanum

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KEYWORDS

• Endoscopic ear surgery • Protympanum • Surgical anatomy • Tensor tympani
• Carotid artery • Protiniculum

KEY POINTS

- The protympanum, a final common pathway between the tympanic cavity and external environment, is gaining relevance due to the ease and completeness of visualization with angled endoscopes.
- Two primary conformations are described, quadrangular and triangular, and new anatomic structures such as the protiniculum, subtensor recess (SbTR), caroticocochlear recess, and protympanic spine are defined.
- The SbTR, an area of pneumatization inferomedial to the tensor tympani canal (TC) is shown to have 3 conformations: flat TC/absent SbTr (A), raised TC/shallow SbTR (B), and raised TC/deep SbTR (C).
- The protiniculum, a consistent bony ridge from the promontory to the lateral wall demarcating the transition between the hypotympanum and protympanum, is shown to have 3 conformations: ridge (A), bridge (B), and absent (C).
- Surgical relevance of the protympanum is described with respect to ventilation, cholesteatoma, cerebrospinal fluid leak, otic neuralgia, and balloon dilatation of the eustachian tube.

Video content accompanies this article at http://www.oto.theclinics.com.

INTRODUCTION

The protympanum, or bony portion of the eustachian tube (ET), is a middle ear space that lies anterior to the mesotympanum. The space is also confluent with the epitympanum superiorly, hypotympanum inferiorly, and the cartilaginous ET anteriorly.

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The protympanum has been infrequently examined in the past due to its difficulty to view using the operating microscope.[1] However, the area is now gaining relevance with endoscopic ear surgery because it can easily be seen with angled scopes. With surgery moving toward evaluation and restoration of ventilation pathways,[2] the protympanum serves as the final common pathway between the tympanic cavity and external environment, drawing comparisons to the ventilatory function of the larynx in the airway.[3]

EMBRYOLOGY

True ossification of the protympanum only commences at the 18th fetal week because of its dependence on the bone growth of the otic capsule.[4] Earlier studies reported a contribution to protympanum development from the tympanic part of the temporal bone,[5] while more recent studies point to development solely from the petrous part of the temporal bone.[4]

From the 21st fetal week, 2 bony laminae develop around the carotid artery, eventually forming the carotid canal. The superior lamina is better developed, forming 2 prolongations: a superior, which is longer and connects to the tympanic annulus posteriorly, forming the lateral wall of the protympanum; and an inferior prolongation, which is shorter and forms the lateral wall of the carotid canal. Similarly, from the 23rd fetal week, the canal for the tensor tympani muscle forms from superior and inferior laminae. In addition, the tegmen tympani and promontory help to form the superior and medial walls of the protympanum, respectively.[4]

BOUNDARIES

The boundaries of the protympanum had been previously defined as the most anterior extent of horizontal and vertical tangents through the margins of the osseous tympanic ring.[6] The boundaries can now be defined more clearly with angled endoscopes (**Fig. 1**).

- *Superior*: tegmen tympani and entire tensor tympani canal, merging posteriorly with and including the supratubal recess if present, with the boundary defined here by the tensor fold;
- *Inferior*: from the protiniculum (an oblique bony ridge demarcating the transition from hypotympanum) posteriorly, extending anteriorly with the possible presence of protympanic air cells, an anterior extension of the hypotympanic cell complex;
- *Anterior*: confluent with the junctional and then cartilaginous portion of the ET;
- *Posterior*: confluent with the mesotympanum;
- *Medial*: lateral wall of the carotid canal, extending from the caroticocochlear recess anteriorly, with caroticotympanic vessels and nerves including anterior branches from Jacobson's (tympanic branch of glossopharyngeal) nerve. More anteriorly, variations of false passages occur depending on pneumatization patterns.
- *Lateral*: bony wall separating the space from the mandibular fossa and extending to the anterior annulus, from the level of the protiniculum inferiorly to the anterior limit of the notch of Rivinus at the anterior tympanic spine.

Superior Boundary

The predominant feature of the superior boundary is tensor tympani canal. The region superolateral to the tensor canal forms the supratubal recess. The supratubal recess has a variable size or is absent, depending on the orientation of the tensor tympani fold. Önal and colleagues[7] described 2 principal configurations of the anterior epitympanic space: type I (83%) consists of an oblique (and occasionally vertical) tensor

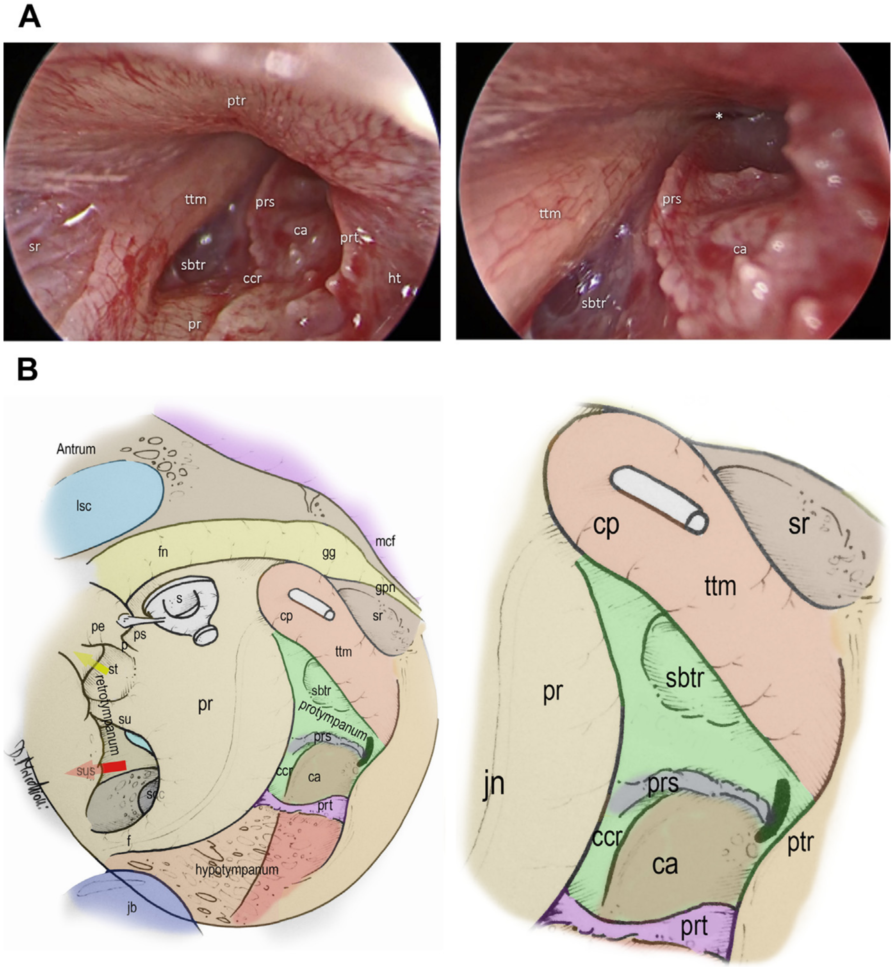

Fig. 1. (*A*) Endoscopic view of protympanum in the right ear with 30° endoscope angled anteriorly. (*Left*) View just after passing beyond the anterior annulus of the tympanic membrane. (*Right*) View obtained by inserting endoscope deeper to visualize the lumen of the ET (*asterisk*). (*B*) Schematic drawing of middle ear (*left*), including the protympanum, its anatomic boundaries, and important structures contained within. Detailed view of protympanum (*right*). ca, carotid artery; ccr, caroticocochlear recess; cp, cochleariform process; f, finiculus; fn, facial nerve; gg, geniculate ganglion; gpn, greater superficial petrosal nerve; ht, hypotympanum; jb, jugular bulb; jn, Jacobson's nerve; lsc, lateral semicircular canal; mcf, middle cranial fossa; p, ponticulus; pe, pyramidal eminence; pr, promontory; prs, protympanic spine; prt, protiniculum; ps, posterior sinus; ptr, pretympanic recess; s, stapes; sbtr, subtensor recess; sr, supratubal recess; st, sinus tympani; su, subiculum; sus, sinus subtympanicus; ttm, tensor tympani muscle.

tympani fold that creates a smaller anterior epitympanic space and the presence of a supratubal recess; type II (17%) consists of a more horizontally placed tensor fold, which does not allow for the presence of a supratubal recess. The superior boundary of the supratubal recess (if present) is the tensor fold, which is occasionally incomplete.

The tubular tensor tympani canal sits either flat or raised on the superior boundary. When an area of pneumatization is inferomedial to the tensor tympani canal, it is called the subtensor recess (SbTR). To keep endoscopic anatomic nomenclature consistent with previous descriptions of the retrotympanum,[8] there are 3 apparent conformations possible based on the depth of the SbTR when present (Fig. 2):

- *Type A*: Flat tensor canal, absent SbTR;
- *Type B*: Raised tensor canal, shallow SbTR, easily visible fundus;
- *Type C*: Raised tensor canal, deep SbTR, difficult to see limits of fundus.

Demarcation between a type B and type C SbTR is when the fundus of the SbTR extends superior to the midpoint of the tensor tympani canal.

Inferior Boundary

A protympanic crest of a variable site, size, direction, and shape was described by Abou-Bieh and colleagues,[9] who found it present in 79% of temporal bones studied either directly or radiologically.

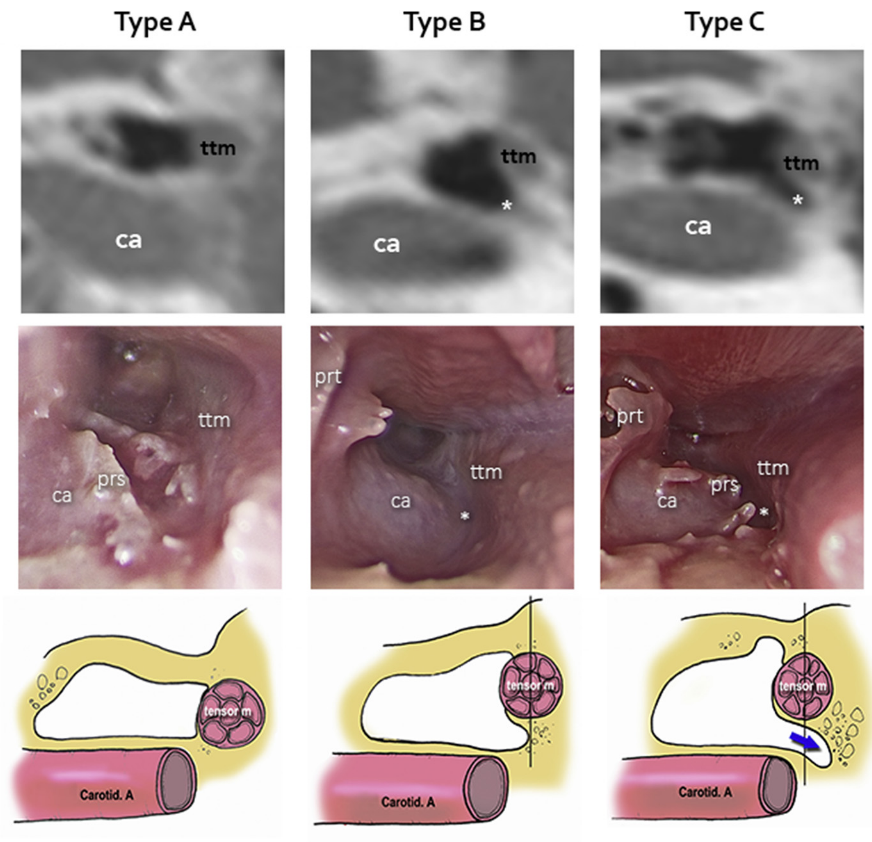

Fig. 2. Demonstration of the possible conformations of the SbTR (*asterisk*), with computed tomographic (*top*) endoscopic (*middle*), and schematic (*bottom*) views of left ears corresponding to the 3 types. Type A: flat tensor canal, absent SbTR; type B: raised tensor canal, shallow SbTR, easily visible fundus; type C: raised tensor canal, deep SbTR, difficult to see limits of fundus.

In temporal bones studied endoscopically by the authors, a bony ridge was commonly found extending from the promontory on the medial wall, across the inferior wall and merging with the lateral wall. The medial aspect of the ridge consistently marked the end of the most anterior hypotympanic air cell, and thus, the start of the protympanum.

This bony ridge has therefore been named the protiniculum (from the Latin *protinus*: forward, farther on), in keeping with previously described nomenclature of promontorial bony ridges in the middle ear.[10] The protiniculum has 3 conformations (**Fig. 3**):

- *Type A*: Ridge, with no air cells passing medially;
- *Type B*: Bridge, with hypotympanic air cells extending inferiorly into the protympanum;
- *Type C*: Absent, no discernible protiniculum, the hypotympanum fusing with the protympanum.

Anterior Boundary

The anterior boundary of the protympanum is a transition point into the junctional and then cartilaginous portions of the ET. It can be reliably found by following the junction of the superior and lateral walls of the epitympanum anteriorly, with the tensor tympani muscle medially, which consistently seems to ensure that false passages are not entered.

The exact point of transition at the anterior boundary however is difficult to define endoscopically. As the protympanum continues toward the anterior boundary, the tensor tympani muscle rotates 90° around the superior wall in a clockwise (right) or counterclockwise (left) fashion, taking it from a medial to a lateral position, consistent with the theory that the tensor veli palatini muscle, which attaches to the entire lateral cartilaginous portion of the ET, forms a functional unit with the tensor tympani.[11]

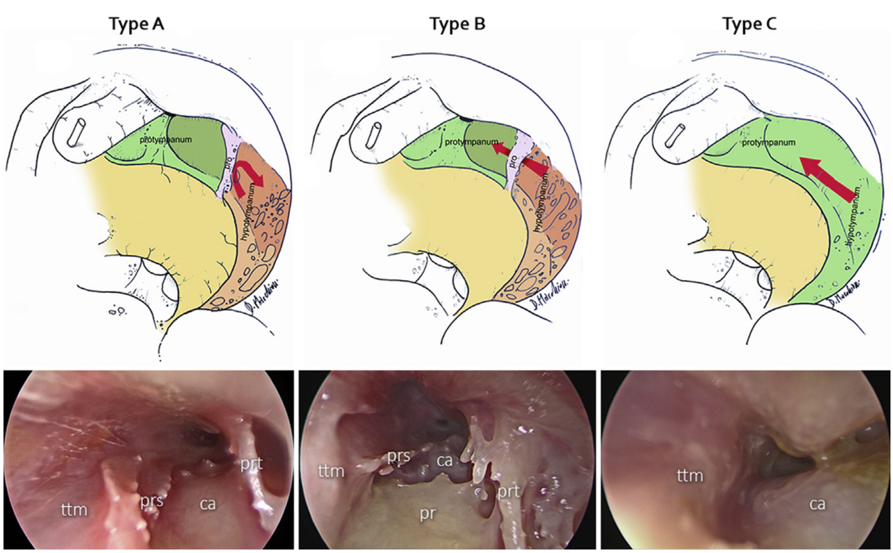

Fig. 3. Demonstration of the possible conformations of the protiniculum with schematic (*top*) and endoscopic (*bottom*) views of right ears corresponding to the 3 types. Type A: ridge, with no air cells passing medially; type B: bridge, with hypotympanic air cells extending inferiorly into the protympanum; type C: absent, no discernible protiniculum, the hypotympanum fusing with the protympanum.

Medial and Posterior Boundary

In a series of 1000 formalin-fixed temporal bones, carotid canal dehiscence on the medial wall of the protympanum has been identified in up to 7.7% of temporal bones and was more common in patients younger than 2 years and older than 40 years.[12] The dehiscence generally arises from failure of the laminae to fuse congenitally,[4] but microdehiscences may be secondary to bony resorption later in life.[12] In a smaller series of 150 temporal bones, the mean thickness of the thinnest bone overlying the carotid artery was 1.5 mm (range 0–3 mm), and bulging of the carotid artery into the protympanum was barely indicated in 31%, moderately noticeable in 56%, and markedly noticeable in 13%.[13]

Jacobson's nerve or the tympanic branch of the glossopharyngeal nerve is a bundle of predominantly secretomotor and sensory fibers. The nerve leaves the inferior ganglion above the jugular foramen and traverses the inferior tympanic canaliculus to enter the middle ear either through or just anterior to the finiculus. The first branches of the tympanic nerve tend to occur above the round window.[14] The nerve traverses anteromedially to form the posterior boundary of the protympanum.

The tympanic nerve is the main contributing nerve to the tympanic plexus, which lies on the promontory. The plexus is usually submucosal; however, the nerves may lie deeper and groove the bone and rarely are embedded in the bone of the promontory.[15] The tympanic nerve provides sensation to the protympanum and ET as well delivers parasympathetic fibers that arise in the inferior salivary nucleus to the same region. The nerve exits the middle ear space, medial to the tensor tympani tendon, and becomes the lesser superficial petrosal nerve carrying the visceral motor parasympathetic fibers from the tympanic plexus to the parotid gland via the otic ganglion. Further parasympathetic supply reaches the tympanic plexus via the nervus intermedius and the facial nerve at the geniculate ganglion.

The caroticotympanic nerves and arteries exit through channels in the bone overlying the carotid canal on the medial aspect of the protympanum. The caroticotympanic nerves carry sympathetic fibers posteriorly and cross the caroticocochlear recess, between the anterior aspect of the promontory and the carotid canal, to reach the tympanic plexus. Postganglionic oculosympathetic palsy (Horner syndrome) has been reported secondary to middle ear infections, likely through an effect on these nerves.[16]

Occasionally, a rough spine composed of either bony ridges or spicules is seen over the carotid artery prominence (see **Fig. 1**). This rough spine has been named the protympanic spine and is likely related to a fusion of the 2 laminae of the carotid canal in embryologic development. If so, it may indicate a decreased likelihood of carotid canal dehiscence in the protympanum.

Lateral Boundary

The lateral lamina separates the protympanum from the mandibular fossa. The lamina is the only boundary of the protympanum that has some contribution from the tympanic part of the temporal bone on the posterior aspect.[4] It is more commonly convex toward the lumen, but may also be concave. A convex conformation appears to result in a narrower lumen and may obstruct view of the anterior boundary, even when using an angled endoscope. In the posterior aspect of the lateral lamina, just medial to the annular sulcus lies a shallow, relatively short and smooth recess, named the pretympanic recess.[17]

Superolaterally is the opening of the petrotympanic (Glaserian) fissure, between the bony annulus of the tympanic and petrous parts of the temporal bone, and containing the anterior malleolar ligament (AML) and discomalleolar ligaments (DML), anterior tympanic artery, and chorda tympani nerve.[18] The AML extends from the neck of the malleus, traverses the fissure, attaches to the capsule of the temporomandibular joint, and is closely associated with the smaller DML.[19] The anterior tympanic artery arises from the first (mandibular) part of the maxillary artery, traverses the fissure, and gives rise to a superior, posterior, and ossicular branch.[20] The chorda tympani nerve exits the middle ear medial to the AML and through the petrotympanic fissure in the separate anterior chordal canal, also known as the iter chordae anterius, Civinini canal, or Huguier canal,[21] traveling superolateral to the ET to reach the lingual nerve.[17] Dehiscence of the anterior chordal canal as well as demonstrated connections between the AML/DML and sphenomandibular ligament may allow for putative anatomic explanation of otomandibular (Costen) syndrome.[18,22]

CONFORMATIONS

The protympanic space has 2 main conformations[5]:

- Quadrangular
- Triangular

The conformational shape is interpreted from the anteriorly facing 30° endoscopic appearance. From this view, a 2-dimensional plane perpendicular to the long axis of ET, passing through the carotid prominence and lateral wall just anterior to the junction with the pretympanic space, is projected.

Demarcation between the 2 types is based on whether the inferior wall is more (quadrangular) or less (triangular) than half the length of the superior wall in equivalent transverse dimension. An irregular shape has also been described, but is likely due to the presence of air cells or taken in a plane that is oblique to that described above. Demarcation between the 2 types also appears to correlate well with computed tomography reconstructions in the same 2-dimensional perpendicular plane (**Fig. 4**).

The quadrangular shape (previously referred to as rectangular) is more common and generally has a carotid artery that is further removed from the tympanic opening of the lumen. A triangular shape forms when the medial and lateral walls merge inferiorly, occasionally obliterating the inferior wall completely. This conformation appears to be less commonly associated with the presence of air cells and potential for false passages.

A video has been included as a supplement to the text and figures of this article, summarizing the anatomic boundaries of the protympanum as well as the conformations of the structures contained therein (Video 1).

NEUROLYMPHOVASCULAR SUPPLY OF THE PROTYMPANUM

The sensory supply of the protympanum is predominantly via the glossopharyngeal nerve (CN IX) and principally Jacobson's nerve.[17] The tubal branch of the tympanic plexus was first described by Ludwig Jacobson in 1818.

Autonomic supply of the area is from the petrosal nerves, Jacobson's nerve, and caroticotympanic branches.[17]

The lymphatics of the region predominantly drain via bony channels and the external auditory canal to the parotid nodes. Accessory drainage occurs via parapharyngeal and retropharyngeal nodes to the upper jugular chain.[17]

Arterial supply to the protympanum is predominantly from anastomoses of the following[20]:

- *The tubal artery*, which branches from the accessory meningeal artery, in turn a branch of the middle meningeal artery from the first (mandibular) portion of the maxillary artery, or more commonly, from the maxillary artery directly;

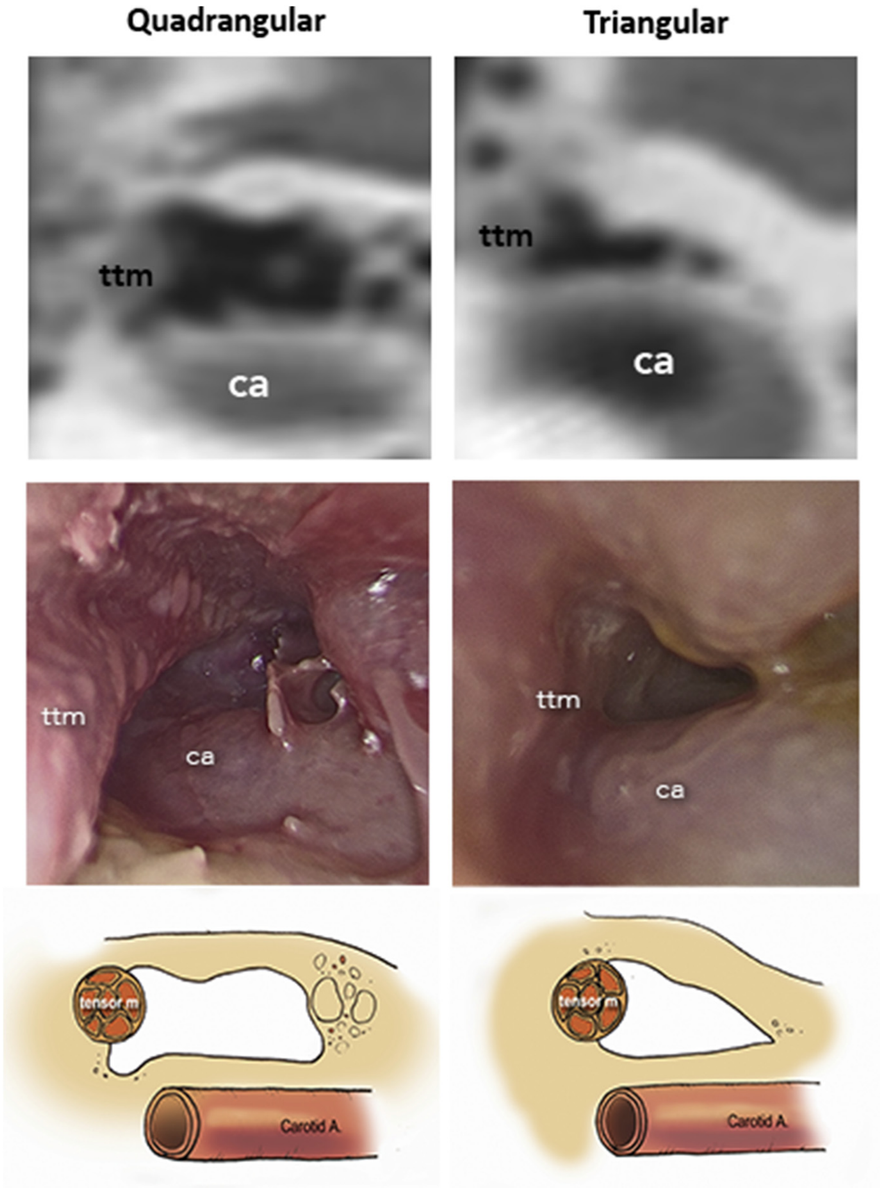

Fig. 4. Demonstration of the 2 possible conformations of the protympanic space, quadrangular and triangular, with computed tomographic (*top*), endoscopic (*middle*), and schematic (*bottom*) views of right ears.

- *Caroticotympanic arteries* (usually a total of 2), which arise from the internal carotid artery and enter the protympanum through bony channels in the caroticocochlear recess;
- *Inferior tympanic artery*, a branch of the ascending pharyngeal artery, in turn a branch of the external carotid artery, enters the middle ear through the inferior

tympanic canaliculus with Jacobson's nerve, then ascends over the promontory in a small groove or canal.

A venous plexus, located along the length of the ET submucosa, drains almost entirely to the pterygoid plexus and via caroticotympanic veins to the paracarotid venous plexus. This plexus may give rise to tubal varices.[17]

MORPHOFUNCTIONAL IMPORTANCE OF THE PROTYMPANUM

Over the promontory and within the protympanum, the mucosa is pseudostratified epithelium. Numerous mucous-secreting and ciliated cells are present, resembling nasal mucosa. The connective tissue here is thicker and denser, and its physiologic function is predominantly mucociliary clearance toward the ET. In contrast, in the posterior mesotympanum and epitympanum, the epithelium is flat with thin, loose connective tissue and no mucous or ciliated cells. This area is devoted to gas exchange, similar to the mastoid mucosa.[23]

When inflamed, protympanic epithelium thickens and may become polypoid. Electron microscopy has demonstrated a decrease in ciliated cells, with collapse of residual cilia and evidence of stagnation with mucous secretion. Mucosal cells contain numerous secretory granules, and there was evidence of polymorphonuclear cells submucousally and bacteria at the mucosal surface.[24]

There appears to be a high prevalence of biofilm formation in both the middle ear and the adenoid bed in chronic otitis media.[25,26] Given its anatomic location, biofilms are likely to be present in the protympanum.

These factors may lead to sequelae such as otitis media with effusion or perforation of the tympanic membrane in the acute setting. In the chronic setting, obstruction leads to a negative pressure in the mesotympanum, facilitating processes such as tympanic membrane retraction and chronic otitis media.[23]

SURGICAL IMPORTANCE OF THE PROTYMPANUM

Final Common Pathway of Ventilation

Considering the morphofunctional importance of the protympanum in the ventilation of the middle ear and mastoid system as well as the development of chronic otitis media, more attention is being paid to disease clearance in this region. The use of 30° and 45° scopes along with angled instruments allows easy access to the boundaries of the protympanum, including the lateral wall for removal of granulation and inflamed mucosa.

Future therapies may investigate the locally targeted application of steroids or other anti-inflammatory mediators to reduce inflammation in this region. Reducing inflammation in this region may in turn lead to a reduction of chronic otitis media or retraction, in an attempt to reduce long-term sequelae.

Cholesteatoma in the Protympanum

The protympanum is a region where cholesteatoma is seldom found, but when present, is often difficult to completely visualize and access. Cholesteatoma in the protympanum is more likely to occur with the following:

- The congenital form of the disease;
- Extensive anterior epitympanic disease with an incomplete tensor fold; or
- Aggressive mesotympanic disease.

Adjunct inspection of the protympanum with a mirror or after drilling of relevant bony landmarks for direct visualization has been recommended in cholesteatoma surgery for many years. The introduction of endoscopes initially allowed adjunct inspection to check for residual disease.[27] More recently, angled endoscopes have been used exclusively to perform surgery in difficult to access areas.[28] In the protympanum, this will allow full and direct visualization to safely remove disease as well as identify previously hidden regions such as false passages, air cells, and the SbTR. An example of protympanic cholesteatoma being fully visualized and completely removed is shown in **Fig. 5**.

With aggressive disease in this region, and with experienced hands, consideration can be given to anterior mobilization of the tensor tympani muscle to reach aggressive disease in the superior and medial walls of the protympanum. Specifically designed instruments, with an appropriate length and angulation, or with a malleable tip, may help to ensure safe and complete disease removal from the protympanum.

Cerebrospinal Fluid Leak

Although the incidence of cerebrospinal fluid leak following lateral skull base surgery has decreased, it remains a reported complication in at least 5% of operative cases.[29] The final common pathway of a transnasal leak is via the protympanum into the nasopharynx. In recalcitrant cases, closure of the ET using transnasal endoscopes to seal the pharyngeal orifice has been reported.[30]

Knowledge of the protympanic spaces and full visualization with an angled endoscope can help the surgeon have confidence in identifying the true ET for safely packing the region. Identifying false passages and pneumatization patterns in the area may help explain leaks that persist after apparent treatment.

Otic Neuralgia

Neurovascular compression of the glossopharyngeal nerve at the route entry zone or variably along its pathway has been postulated to contribute to otic neuralgia. Division

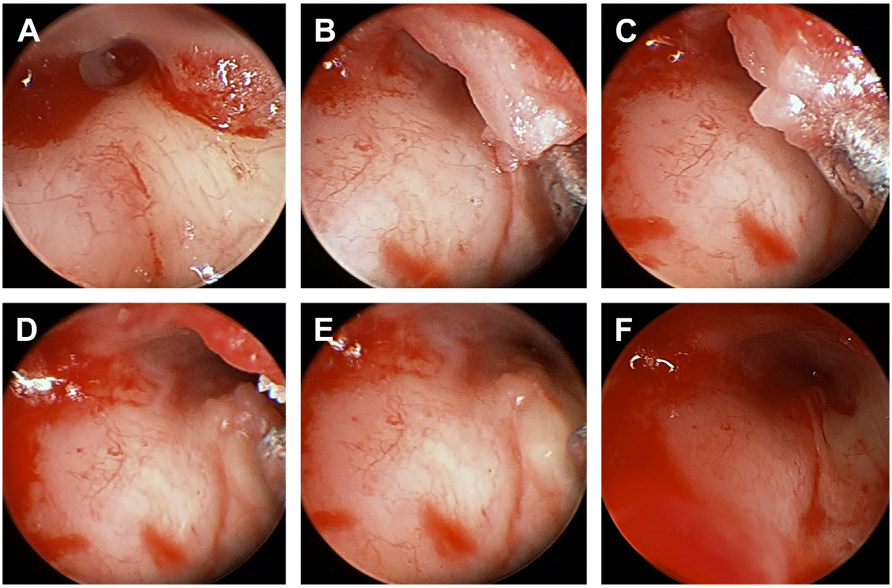

Fig. 5. Protympanic cholesteatoma (*A*), showing time lapse images of careful dissection and removal of disease (*B–E*), with successful clearance of disease (*F*).

of Jacobson's nerve or tympanic neurectomy has been used as a successful treatment of otic neuralgia.[31] A noted additional effect of this procedure is reduction in parasympathetic stimulation on the parotid gland from fibers that travel via the lesser petrosal nerve and synapse in the otic ganglion to supply the parotid through the auriculotemporal nerve. Tympanic neurectomy has therefore been used to ameliorate sequelae of parotid overstimulation such as Frey syndrome, recurrent parotitis, and sialorrhea.[32,33]

When performing the procedure of tympanic neurectomy, attention should be paid to correctly identifying the main trunk of Jacobson's nerve as well as all the branches of the tympanic plexus on the medial wall of the protympanum. It often can groove a channel over the promontory and in up to 20% of cases lies completely encased in a bony canal.[32] Endoscopic visualization of the protympanum and hypotympanum should significantly increase certainty in identification and completeness of division of the main trunk and branches in select cases when this procedure is undertaken.

Surgical Access to the Eustachian Tube

Transtympanic balloon dilatation is being examined as a possible treatment approach in ET dysfunction in failures of transnasal balloon dilatation. Furthermore, this approach to dilatation of the ET may be appropriate in patients who are already undergoing ear surgery for sequelae of ET dysfunction.

Cadaveric work by the authors has demonstrated the feasibility of a balloon dilatation technique using dual endoscopic visualization. No carotid canal fractures were seen in the cohort of 10 heads, and this was verified by 2 surgeons and a board-certified neuroradiologist. Furthermore, efficacy of the dilatation was shown radiologically and via manometry.[34] The use of the endoscope in this technique has fundamentally improved the feasibility and safety in comparison with a previous study, which attempted the same approach with microscopic visualization.[35] Ongoing study is required to clarify the safety of the technique and identify the ideal patient population for treatment.

Further applications of endoscopic protympanic visualisation have been described for managing ET dysfunction. Catheters may be used to gently probe the ET to confirm patency, flush with saline and even instill medical therapy such as topical steroids. Additionally, in cases of patulous ET, a modified catheter inserted transtympanically has been described to shim the ET and reduce severity of symptoms such as autophony.[36]

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.otc.2016.05.009.

REFERENCES

1. Thomassin JM, Inedjian JM, Rud C, et al. Otoendoscopy: application in the middle ear surgery. Rev Laryngol Otol Rhinol (Bord) 1990;111(5):475–7 [in French].
2. Marchioni D, Mattioli F, Alicandri-Ciufelli M, et al. Endoscopic evaluation of middle ear ventilation route blockage. Am J Otolaryngol 2010;31(6):453–66.
3. Bluestone CD, Bluestone MB. Eustachian tube. Structure, function, role in otitis media. Shelton (CT): PMPH-USA; 2005. p. 62.
4. Tóth M, Medvegy T, Moser G, et al. Development of the protympanum. Ann Anat 2006;188(3):267–73.

5. Djerić D, Savić D. Anatomical variations and relations of the bony portion of the eustachian tube. Acta Otolaryngol 1985;99(5–6):543–50.
6. Nadol JB, McKenna MJ. Surgery of the ear and temporal bone. Philadelphia (PA): Lippincott Williams & Wilkins; 2005. p. 125.
7. Önal K, van Haastert RM, Grote JJ. Structural variations of the supratubal recess: the anterior epitympanic space. Otol Neurotol 1997;18(3):317.
8. Marchioni D, Mattioli F, Alicandri-Ciufelli M, et al. Transcanal endoscopic approach to the sinus tympani: a clinical report. Otol Neurotol 2009;30(6):758–65.
9. Abou-Bieh AA, Al-Abdulhadi K, Al-Tubaikh J, et al. The protympanic crest. Otolaryngol Head Neck Surg 2009;141(3):92.
10. Marchioni D, Alicandri-Ciufelli M, Piccinini A, et al. Inferior retrotympanum revisited: an endoscopic anatomic study. Laryngoscope 2010;120(9):1880–6.
11. Kierner AC, Mayer R, Kirschhofer von K. Do the tensor tympani and tensor veli palatini muscles of man form a functional unit? A histochemical investigation of their putative connections. Hear Res 2002;165(1–2):48–52.
12. Moreano EH, Paparella MM, Zelterman D, et al. Prevalence of carotid canal dehiscence in the human middle ear: a report of 1000 temporal bones. Laryngoscope 1994;104(5 Pt 1):612–8.
13. Savić D, Djerić D. Anatomical variations and relations in the medial wall of the bony portion of the eustachian tube. Acta Otolaryngol 1985;99(5–6):551–6.
14. Donaldson I. Surgical anatomy of the tympanic nerve. J Laryngol Otol 1980;94(2):163–8.
15. Rosen S. The tympanic plexus: an anatomic study. Arch Otolaryngol 1950;52(1):15–8.
16. Spector RH. Postganglionic horner syndrome in three patients with coincident middle ear infection. J Neuroophthalmol 2008;28(3):182–5.
17. Proctor B. Embryology and anatomy of the eustachian tube. Arch Otolaryngol 1967;86(5):503–14.
18. Tóth M, Moser G, Patonay L, et al. Development of the anterior chordal canal. Ann Anat 2006;188(1):7–11.
19. Rodríguez-Vázquez JF, Mérida-Velasco JR, Mérida-Velasco JA, et al. Anatomical considerations on the discomalleolar ligament. J Anat 1998;192(Pt 4):617–21.
20. Merchant SN, Nadol JB. Schuknecht's pathology of the ear. Shelton (CT): PMPH-USA; 2010. p. 61.
21. Mudry A. Glaser fissure, Huguier canal, and Civinini canal: a confused eponymical imbroglio. Otol Neurotol 2015;36(6):1115–20.
22. Eckerdal O. The petrotympanic fissure: a link connecting the tympanic cavity and the temporomandibular joint. Cranio 1991;9(1):15–22.
23. Ars B, Ars-Piret NM. Morphofunctional partition of the middle ear cleft. Mediterr J Otol 2007;3:31–9.
24. Chao W-Y, Chang S-J. Ultrastructure of eustachian tube mucosa in chronic otitis media with cholesteatoma. Am J Otolaryngol 1996;17(3):161–6.
25. Saafan ME, Ibrahim WS, Tomoum MO. Role of adenoid biofilm in chronic otitis media with effusion in children. Eur Arch Otorhinolaryngol 2013;270(9):2417–25.
26. Homøe P, Bjarnsholt T, Wessman M, et al. Morphological evidence of biofilm formation in Greenlanders with chronic suppurative otitis media. Eur Arch Otorhinolaryngol 2009;266(10):1533–8.
27. Thomassin JM, Korchia D, Doris JMD. Endoscopic-guided otosurgery in the prevention of residual cholesteatomas. Laryngoscope 1993;103(8):939–43.

28. Presutti L, Gioacchini FM, Alicandri-Ciufelli M, et al. Results of endoscopic middle ear surgery for cholesteatoma treatment: a systematic review. Acta Otorhinolaryngol Ital 2014;34(3):153–7.
29. Fishman AJ, Marrinan MS, Golfinos JG, et al. Prevention and management of cerebrospinal fluid leak following vestibular schwannoma surgery. Laryngoscope 2004;114(3):501–5.
30. Kwartler JA, Schulder M, Baredes S, et al. Endoscopic closure of the eustachian tube for repair of cerebrospinal fluid leak. Otol Neurotol 1996;17(3):470.
31. Cook JA, Irving RM. Role of tympanic neurectomy in otalgia. J Laryngol Otol 1990;104(02):114–7.
32. Golding-Wood PH. Tympanic neurectomy. J Laryngol Otol 1962;76(09):683–93.
33. Friedman WH, Swerdlow RS, Pomarico JM. Tympanic neurectomy: a review and an additional indication for this procedure. Laryngoscope 1974;84(4):568–77.
34. Jufas N, Treble A, Newey A, et al. Endoscopically guided transtympanic balloon catheter dilatation of the eustachian tube: a cadaveric pilot study. Otol Neurotol 2016;37(4):350–5.
35. Kepchar J, Acevedo J, Schroeder J, et al. Transtympanic balloon dilatation of eustachian tube: a human cadaver pilot study. J Laryngol Otol 2012;126(11):1102–7.
36. Oh S-J, Lee I-W, Goh E-K, et al. Trans-tympanic catheter insertion for treatment of patulous eustachian tube. Am J Otolaryngol 2015;36(6):748–52.