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OTOLOGY

The round window region and contiguous areas: endoscopic anatomy and surgical implications

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Abstract The round window region is a critical area of the middle ear; the aim of this paper is to describe its anatomy from an endoscopic perspective, emphasizing some structures, the knowledge of which could have important implications during surgery, as well as to evaluate what involvement cholesteatoma may have with these structures. Retrospective review of video recordings of endoscopic ear surgeries and retrospective database review were conducted in Tertiary university referral center. Videos from endoscopic middle ear procedures carried out between June 2010 and September 2012 and stored in a shared database were reviewed retrospectively. Surgeries in which an endoscopic magnification of the round window region and the inferior retrotympanum area was performed intraoperatively were included in the study. Involvement by cholesteatoma of those regions was also documented based on information obtained from the surgical database. Conformation of the tegmen of the round window niche may influence the surgical view of round window membrane. A structure connecting the round window area to the petrous apex, named the subcochlear canaliculus, is described. Cholesteatoma can invade the round window areas in some patients. Endoscopic approaches can guarantee a very detailed view and allow the exploration of the round window region. Exact anatomical knowledge of this region can have important advantages during surgery, since some pathology can invade inside cavities or tunnels otherwise not seen by instrumentation that produces a straight-line view (e.g. microscope).

Keywords Retrotympanum · Endoscopic ear surgery · Cholesteatoma · Middle ear anatomy · Round window

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Introduction

The surgical management of cholesteatoma is still a controversial issue. Endoscopic instrumentation, techniques and knowledge have improved considerably over the last few years, and we believe that, in the future, endoscopic surgical techniques will gain increasing importance in otologic surgery. From our 7-year experience in endoscopic ear surgery, we believe that most of the spaces considered to be difficult to access with a microscopic technique could be easily accessed by endoscope-assisted surgery; we feel that new anatomical concepts should be introduced for this. Moreover, the new concept of endoscopic ear surgery redirects attention away from the less critical areas (i.e., mastoid) toward the tympanic cavity and its 'hard-to-reach' extensions. The endoscopic technique was developed as a technique for the minimally invasive eradication of limited attic cholesteatoma, preserving the ossicular chain wherever possible, with complete extirpation of disease. From this indication the clinical application of the transcanal endoscopic approach has allowed the extension of the indications for this technique to cholesteatoma of the whole tympanic cavity without mastoid involvement. Indeed, some new anatomical concepts have already been introduced or revisited through the thorough endoscopic

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exploration of middle ear spaces, including retrotympanic area [1], noticing that most of these areas can be involved by cholesteatoma or any other middle ear pathology, whether neoplastic or inflammatory [2]. The round window area is a critical region of the middle ear, and the aim of this paper is to describe the anatomy of the round window area from an endoscopic perspective, possibly underlining, revising and defining structures that could have important implications, in particular (but not only) in cholesteatoma surgery. A further aim is to investigate the possible involvement of those regions by cholesteatoma.

Materials and methods

From May to July 2013, videos from endoscopic middle ear procedures carried out between June 2010 and September 2012 and stored in our database were reviewed. Surgeries during which endoscopic magnification of the round window region and the inferior retrotympanum area was purposefully performed were included in the study, regardless of the aim of the surgery. Endoscopic procedures were carried out according to codified techniques, already described in former articles [3]. Two 3 mm diameter, 15 cm length, endoscopes (Karl Storz, Tuttlingen, Germany) with angles of 0 and 45° were used in all of the surgeries. A three-CCD camera system and a high-resolution monitor (Karl Storz, Tuttlingen, Germany) were used for all of the procedures.

In all patients, after tympanomeatal flap elevation, the endoscopic procedures were performed under endoscopic magnification of the tympanic cavity while the surgeon held the endoscope with the left hand and the operative instrument with the right hand. When an exploration of the round window and inferior retrotympanum was performed (Fig. 1), an accurate description of the anatomic findings of the round window niche, round window chamber and subtympanic sinus was noted in a database for each ear. In particular, the anatomical conformation of the bony wall of the round window niche was noted, with particular attention being paid to the description of the morphology of the tegmen, the anterior and posterior pillars of the round window, and the round window membrane.

All anatomical details of the round window area and inferior retrotympanum were noted as follows (Fig. 1b):

- The round window niche was defined as an anatomical bony structure forming the entrance of the cochlear membrane, having a triangular shape confluent posteriorly and laterally to the inferior retrotympanum and lying between the finiculus (anteriorly, laterally and inferiorly) and subiculum (posteriorly, laterally and slightly superiorly). The round window niche was formed in a triangular shape by the posterior pillar, the tegmen and the anterior pillar. At the apex of this triangular shape was the round window membrane whose internal aspect opened into the tympanic scala of the basal turn of the cochlea.
- The tegmen was defined as the oblique dorsolateral edge of the promontory, forming a convex edge over the round window entrance. The free edge of the tegmen was anatomically described.
- The posterior pillar was defined as a pillar located near the bony edge of the round window niche entrance, in its posterior and superior aspect forming an acute angle with the tegmen.
- The anterior pillar was defined as a pillar located in the anterior and superior aspect of the round window niche, fusing with the anterior portion of the tegmen.
- The round window chamber was defined as the three-dimensional space lying between the round window niche and the round window membrane and it was also evaluated endoscopically along with the presence of the fustis bone and Proctor's area concamerata [4].

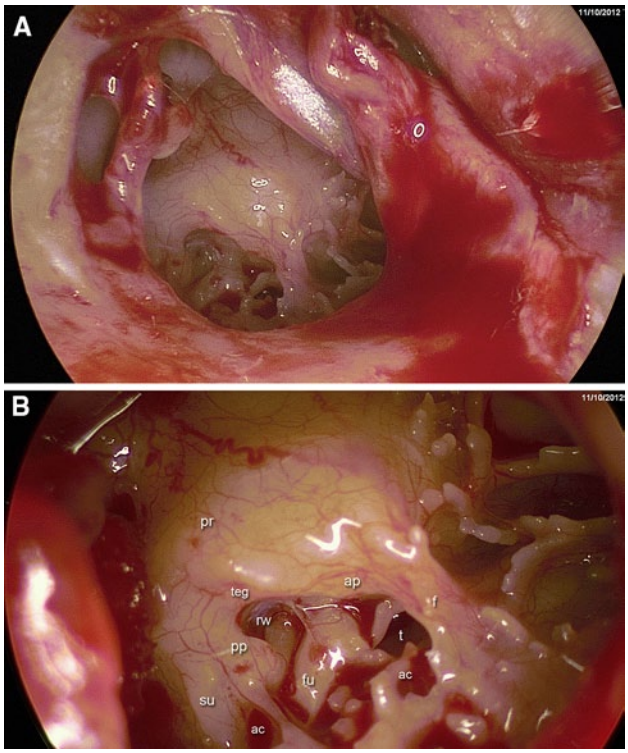

Fig. 1 **a** Endoscopic surgical approach (right ear) the tympanomeatal flap is elevated exposing the tympanic cavity, a 0° endoscope is introduced into the tympanic cavity detecting the round window niche. **b** Endoscopic magnification of the anatomical structures forming the round window area; in this subjects the round window membrane could be explored endoscopically. *pp* posterior pillar, *ap* anterior pillar, *teg* tegmen, *fu* fustis, *f* finiculus, *su* subiculum, *rw* round window, *pr* promontory, *ac* area concamerata, *t* tunnel of subcochlear canaliculus

– The fustis was defined as the thick smooth bone linking the basal turn of the cochlea with the styloid prominence, located within the round window chamber and extending from the styloid complex into round window niche, indicating the entrance to the round window niche [4].
– The Proctor's area concamerata was defined as an anatomical area composed by bony cells developed around the fustis bone [4].

Data regarding the inferior retrotympanum, subiculum, finiculus, styloid complex and sinus subtympanicus were also collected:

– The subiculum was defined as a bony ridge arising from the posterior pillar towards the styloid complex posteriorly.
– The finiculus was defined as a bony ridge arising from the anterior pillar and running towards the floor of the hypotympanum where the jugular dome is located, dividing the inferior retrotympanum from the hypotympanum.
– The sinus subtympanicus was defined as an anatomical space between the subiculum superiorly and the finiculus inferiorly, developing medially and posteriorly with respect to the styloid prominence, forming a deep space into the retrotympanum below the sinus tympani.

From January 2006 a database was created at our clinic, in which all patients operated on for middle ear endoscopic surgery were included. Data regarding the involvement of the sinus subtympanicus with cholesteatoma, and round window region were extracted from that database and analyzed.

Results

Of the 89 subjects who underwent endoscopic procedures of the middle ear 65 patients were included in our study. Of these subjects 10/65 (15.3 %) were pediatric patients, 55/65 (84.61 %) were adults.

Round window niche

From the analysis of the recordings of the 65 subjects we noted three kinds of conformation of the free edge of the round window's tegmen:

– 15/65 (23, 7 %) Subjects presented a well-formed free edge of the tegmen confluent posteriorly with the posterior pillar and anteriorly with the anterior pillar; in these subjects the round window membrane was endoscopically detected and visible (Fig. 2).

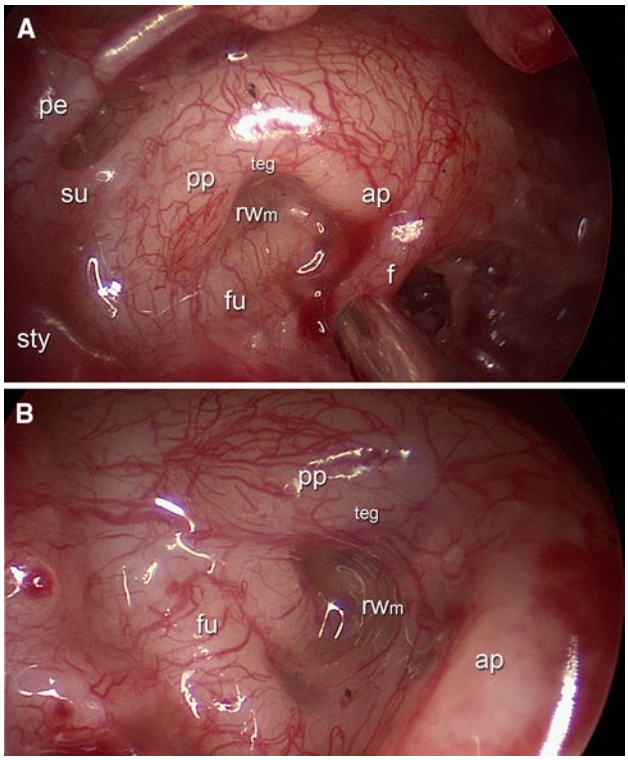

Fig. 2 (Membrane) (right ear) In this subject the tegmen of the round window niche did not obscure the round window membrane and the 0° endoscope allowed us to detect the round window membrane directly. *Pe* pyramidal eminence, *pp* posterior pillar, *ap* anterior pillar, *teg* tegmen, *fu* fustis, *sty* styloid prominence, *f* finiculus, *su* subiculum, *rwm* round window membrane

– 13/65 (20 %) subjects presented a well-formed free edge of the tegmen confluent with the posterior and anterior pillar, but because of the angle of this anatomical structure in all these cases, the membrane of the round window was covered by the tegmen and the endoscope did not allow direct observation of the membrane.
– In 37/65 (56, 9 %) of subjects the free edge of the tegmen of the round window was hypertrophic and protruding medially, obscuring the round window membrane and the round window chamber. In all these cases the round window membrane was not visible endoscopically (Fig. 3).
– In all cases it was possible to observe the anterior and posterior pillar endoscopically; we did not notice any anatomical variations of these structures.

Round window chamber

The conformations of the round window chamber depended on the presence of the fustis and area concamerata.

– In all 65 subjects the fustis was detected endoscopically as a smooth area of bone arising from the styloid promi-

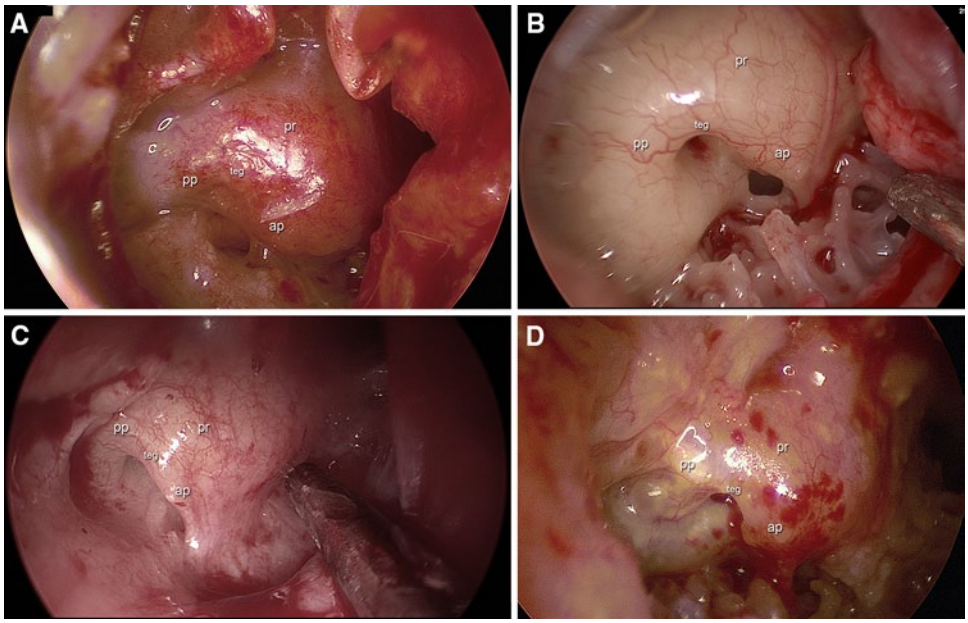

Fig. 3 (Right ears) **a** in this subject an inflammatory web obscured the round window membrane. **b**, **c** subjects with a hypertrophic tegmen obscuring the round window niche. In all of these cases it was not possible to detect the round window membrane *pp* posterior pillar, *ap* anterior pillar, *teg* tegmen, *pr* promontory

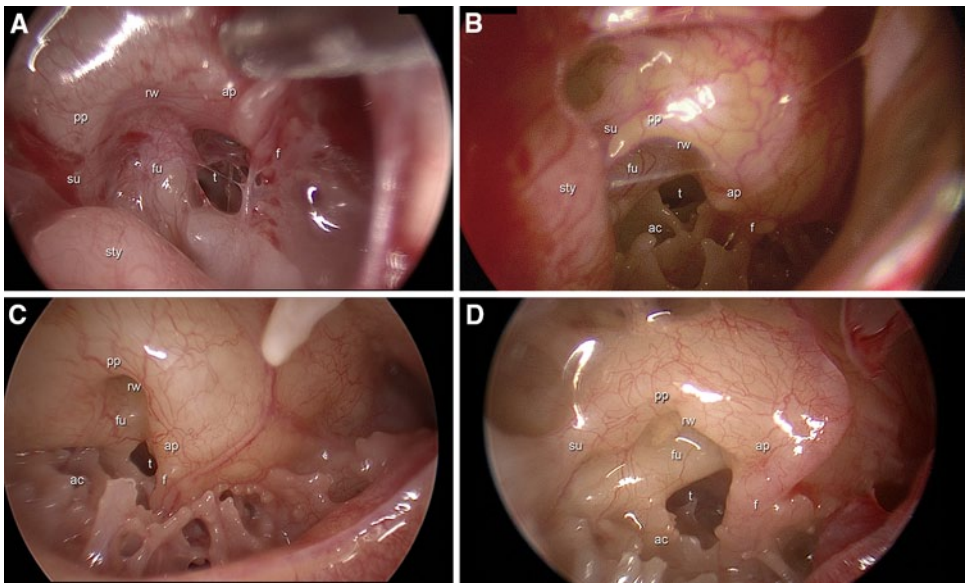

Fig. 4 (Right ears) **a**–**d** in these subjects a deep (Type A) "subcochlear canaliculus" is found between the fustis bone and the finiculus and has different dimensions *pp* posterior pillar, *ap* anterior pillar, *pr* promontory, *rw* round window, *t* tunnel of subcochlear canaliculus, *ac* area concamerata, *f* finiculus, *su* subiculum, *fu* fustis, *su* subiculum, *sty* styloid complex

nence and going from lateral to medial to the round window membrane.

– In 50/65 (76, 9 %) subjects a tunnel/hole between the finiculus bone and the fustis was found from the Proctor's area concamerata, connecting the tympanic cavity to the hypotympanic and petrous bone cells lying below the cochlea (Fig. 4). Three kinds of conformation with respect to the presence or absence of this tunnel were classified:

Type A: 42/65 (64, 6 %) patients presented, just below and medially with respect to the finiculus and anterior pillar, a wide tunnel/hole with a deep extension below the cochlea connecting the tympanic cavity with the petrous apex cells extending under the promontory, which were endoscopically detectable (see Fig. 5a).

Type B: 8/65 (12, 3 %) subjects, a small hole was detected under the finiculus bone, (see Fig. 5b). We called this anatomical area "subcochlear canaliculus" indicating the connection between the tympanic cavity (round window chamber) and the petrous apex cells lying under the cochlea.

Type C: 15/65 (23, 07 %) subjects, we did not find a subcochlear canaliculus and the finiculus bone was merged medially with the concamerata area and fustis (see Fig. 5c).

The distribution of the "subcochlear canaliculus" conformations varied according to age:

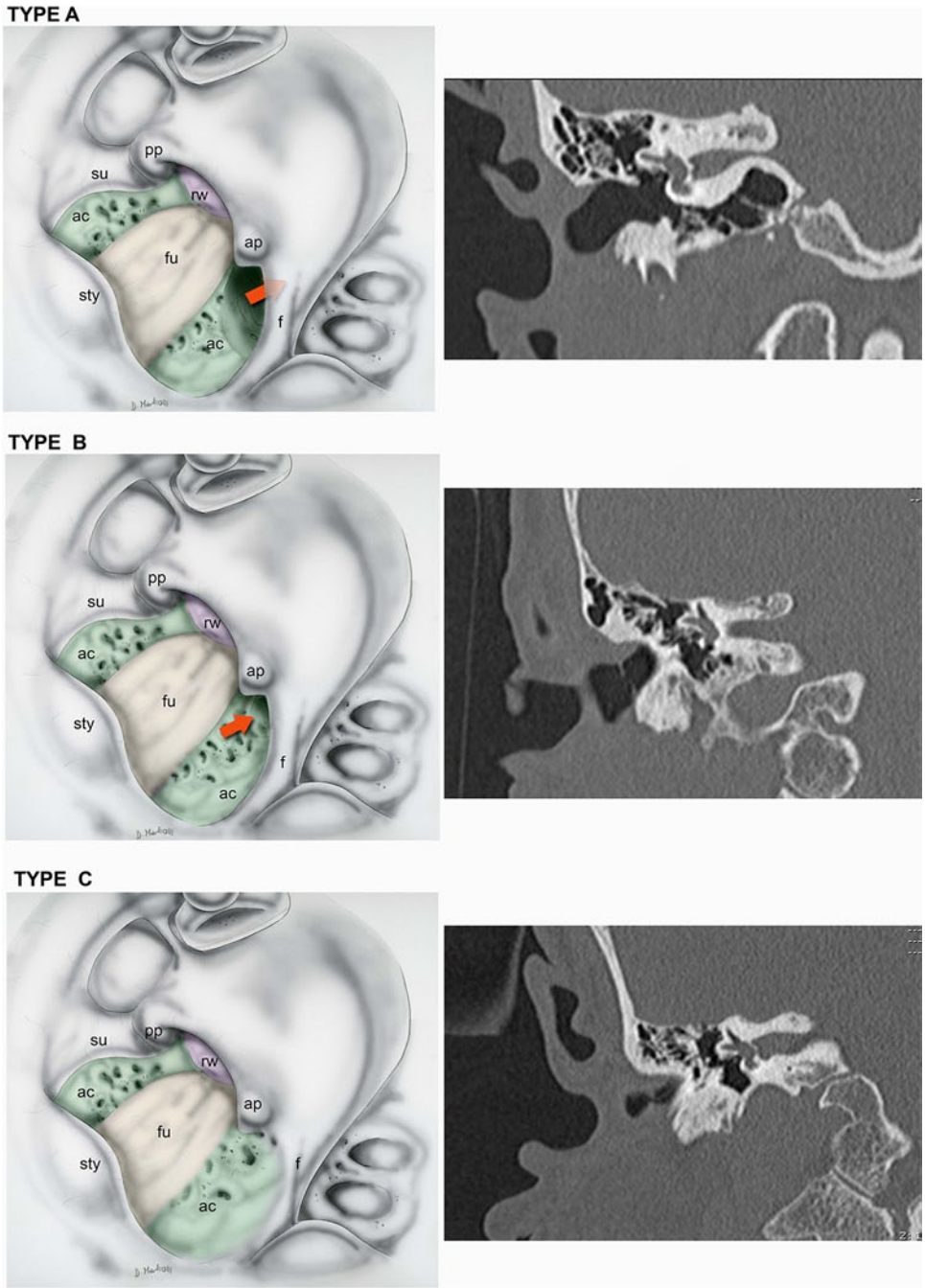

Fig. 5 (Right ears) Three types of conformations of the round window chamber related to the relationship between the fustis, area concamerata and the finiculus bone. Type A between the fustis and the finiculus a deep hole/tunnel is present with deep extension to the petrous apex cells lying below the cochlea; in these cases a CT scan in a sagittal view shows the presence of a well pneumatized temporal bone at the most inferior and medial portion of the petrous apex below the internal auditory canal. Type B between the fustis and the finiculus a small hole is present, the connection between this hole and the apex is not recognizable endoscopically because of the dimensions of this area; in these cases a CT scan in a sagittal view shows the presence of a limited pneumatized bone below the cochlea. Type C the fustis and area concamerata are fused with the finiculus and anterior pillar without any connection between the round window chamber and the petrous apex, in these cases no air cells are present at the most inferior and medial portion of the petrous apex on the CT scan in a sagittal view *pp* posterior pillar, *ap* anterior pillar, *rw* round window, *red arrow* tunnel of subcochlear canaliculus, *ac* area concamerata, *f* finiculus, *su* subiculum, *fu* fustis, *su* subiculum, *sty* styloid complex

– In 9/10 (90 %) children a wide depth conformation (Type A conformation) of subcochlear canaliculus under the finiculus was observed. In one child no subcochlear canaliculus was observed.

In contradistinction in 33/55 (60 %) adults a wide depth conformation of the subcochlear canaliculus was observed (Type A conformation); in 8/55 (14, 5 %) adults a subcochlear canaliculus as a hole medially and under the finiculus was noted (Type B conformation), instead in 14/55 (25, 4 %) adults the presence of this canaliculus was not observed.

Inferior retrotympanum

Some morphologically different conformations of the sinus subtympanicus were found:

– In 46/65 (70, 7 %) patients we found a very well-defined sinus subtympanicus lying inferior to the sinus tympani, forming a delimited space between the subiculum superiorly and posteriorly and the finiculus inferiorly and anteriorly, the styloid prominence posteriorly and laterally, and the otic capsule posteriorly and medially

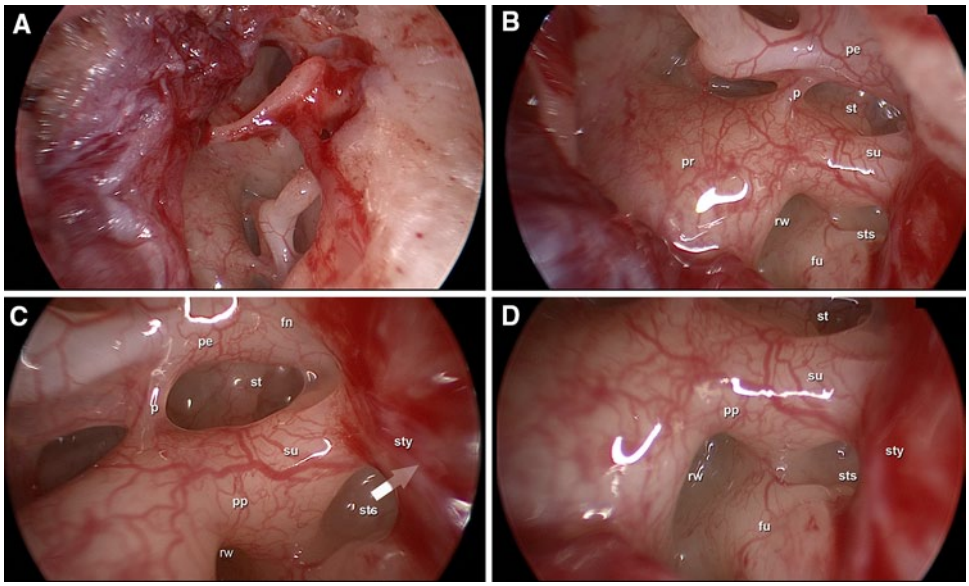

Fig. 6 (Left ear) In this subject the use of a 45° endoscope allowed the detection of a well-formed sinus subtympanicus lying inferiorly to the subiculum and the sinus tympani with a medial and posterior extension with respect to the styloid complex. **a** endoscopic view of the tympanic cavity after elevation of the tympanomeatal flap. **b** endoscopic view of the whole retrotympanum. **c** endoscopic magnification of the sinus subtympanicus and sinus tympani; note the subiculum as a line of separation between the sinus tympani and the sinus subtympanicus. *sts* sinus subtympanicus, *su* subiculum, *st* sinus tympani, *rw* round window, *sty* styloid prominence, *fu* fustis, *pr* promontory, *pe* pyramidal eminence, *p* ponticulus, *fn* facial nerve, *pp* posterior pillar, *white arrow* depth of the sinus subtympanicus under the styloid prominence

(Fig. 6). In all these cases the styloid prominence was evident, and this sinus was open anteriorly and medially toward the round window niche (see Fig. 6d).

- In 7/65 (10.7 %) subjects no finiculus was found and the subtympanic sinus was confluent antero-inferiorly to the hypotympanic cells.
- In 14 subjects we found a prominence of the styloid complex with a deep sinus subtympanicus found below the sinus tympani, extending medially and posteriorly with respect to the styloid complex.
- In 19/65 (29, 2 %) subjects where a poorly developed styloid complex was found, the sinus subtympanicus was not found to be deep, ending just before the styloid eminence.

Surgical consideration in cholesteatoma cases

In the database of our clinic collecting endoscopic surgeries for cholesteatoma, information about 146 subjects was noted and reviewed regarding cholesteatoma involvement of round window area.

- In 6/146 (4, 01 %) the cholesteatoma was infiltrating the round window chamber (3 were children, 3 adults). Of these patients, in 3/6 cases the cholesteatoma was lying within the chamber without deep extension and it was possible to remove the matrix of the cholesteatoma from the round window chamber endoscopically without any drilling of this area. On the contrary, in 3/6 cases the matrix of the cholesteatoma was noticed within the "subcochlear canaliculus" involving the petrous apex cells below the cochlea (Fig. 7), with a medial extension with respect to the internal carotid artery was observed. In all of these cases, it was necessary to perform a endoscopic infracochlear approach to remove the cholesteatoma; the finiculus was removed, the carotid artery and the jugular bulb were detected, and the area concamerata with the "subcochlear canaliculus" was drilled below the promontory until the cholesteatoma was removed from the petrous apex (Fig. 8).
- In 25/146 (17.1 %) subjects the cholesteatoma was infiltrating the retrotympanum of these subjects; in 5/17 subjects the disease was found extending into a deep sinus subtympanicus and was removed by angulated instruments under endoscopic view. In a single case, we had to remove the styloid prominence to reach the deepest part of the sinus subtympanicus, so as to complete removing the residual cholesteatoma.

Discussion

The development of the bony round window niche begins in the 16th fetal week. Anterior, superior and posterior

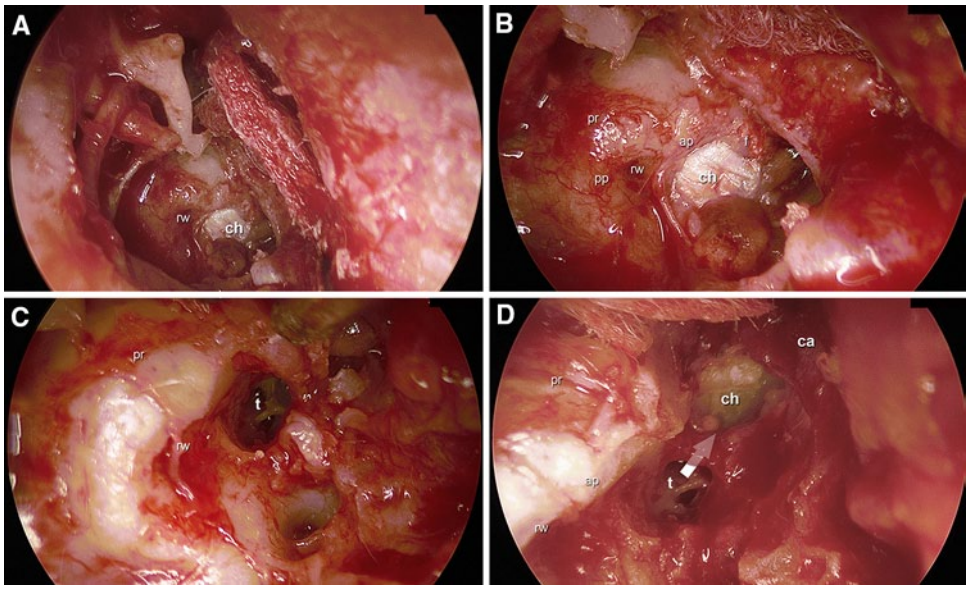

Fig. 7 (Right ear) Subjects affected by tympanic cavity cholesteatoma. **a**, **b** the cholesteatoma matrix was found to extend into the tunnel of the subcochlear canaliculus. **c** endoscopic magnification of the tunnel of the subcochlear canaliculus after cholesteatoma removal. **d** endoscopic view of the subcochlear canaliculus, The cholesteatoma matrix was present in the depth of the canaliculus in close relation to the internal carotid artery. *White arrow* indicating the direction of the tunnel of the subcochlear canaliculus, *ch* cholesteatoma, *rw* round window, *t* tunnel of subcochlear canaliculus, *ap* anterior pillar, *ca* carotid artery, *pp* posterior pillar, *pr* promontory

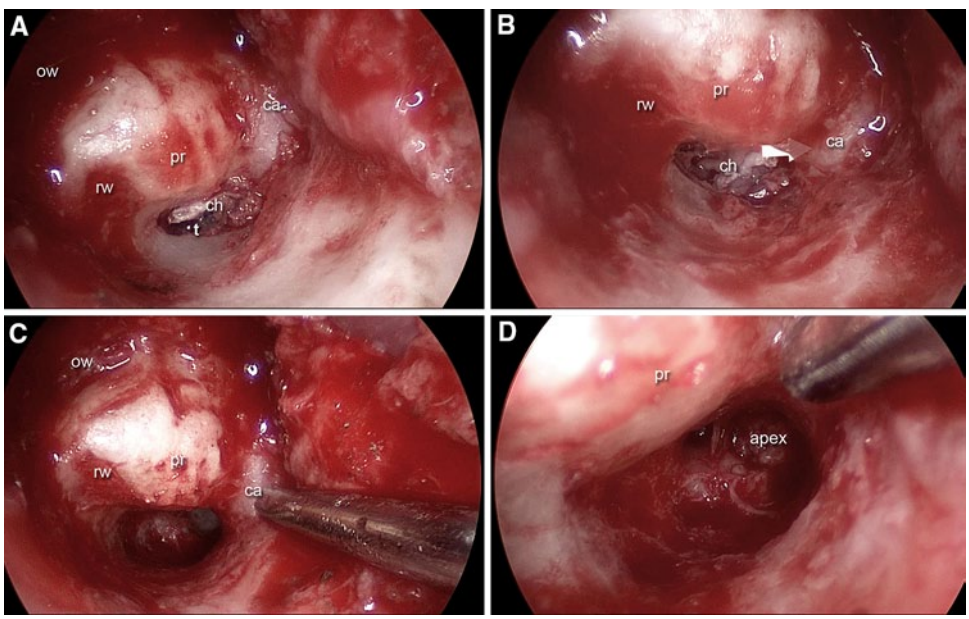

Fig. 8 (Right ear) Infracochlear approach in pediatric subjects affected by tympanic cavity cholesteatoma with involvement of the petrous apex through the tunnel of the subcochlear canaliculus. **a** a cholesteatoma matrix is endoscopically visible extending into the tunnel of the subcochlear canaliculus. **b** extension of the cholesteatoma into the depth of the subcochlear canaliculus, medially with respect to the internal carotid artery. **c** endoscopic infracochlear approach after cholesteatoma removal from the petrous apex conserving the cochlea. **d** endoscopic magnification of the petrous apex below the cochlea after cholesteatoma removal *ch* cholesteatoma, *rw* round window, *t* tunnel of subcochlear canaliculus, *ca* carotid artery, *pr* promontory, *ow* oval window, *white arrow* deep extension of the subcochlear canaliculus medially with respect to the internal carotid artery into the petrous apex

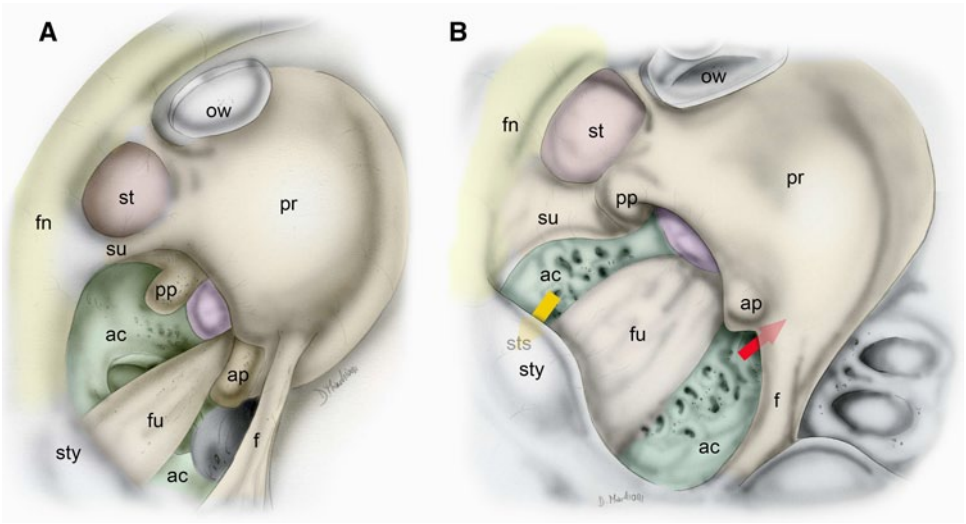

Fig. 9 (Right ear) **a** 23-week-old fetus: the bony structure forming the inferior wall of the round window chamber forming, the connection between the round window chamber (fustis and area concamerata) and the anterior portion of the round window niche (finiculus and anterior pillar) is in progress. **b** anatomy of retrotympanum and round window chamber in adult: the pneumatisation posteriorly under the styloid prominence of the area concamerata is forming the sinus subtympanicus (*yellow arrow*); the lack of fusion between the fustis with the area concamerata and the finiculus is forming the tunnel of the subcochlear canaliculus, connecting the round window chamber with the petrous apex cells lying below the cochlea (*red arrow*). *pp* posterior pillar, *ap* anterior pillar, *red arrow* tunnel of subcochlear canaliculus, *ac* area concamerata, *f* finiculus, *su* subiculum, *fu* fustis, *sty* styloid complex, *fn* facial nerve, *pr* promontory, *st* sinus tympani, *ow* oval window, *sts* sinus subtympanicus (*yellow arrow*)

walls are the first to appear while the inferior wall is completely absent at this time. 1 week later, a bony process grows into the niche forming its inferior wall but this process will only reach the anterior wall by the 18th week [5]. In the 23-week-old fetus the bony structure forming the inferior wall appears, the so-called fustis. This structure runs in the middle of the inferior wall and points to the crest of the round window (Fig. 9a). After the 20th prenatal week an intensive growth can be observed in the anterior wall where the inferior tympanic artery and the tympanic nerve run [5]. During this week some form a complete bony canal around the tympanic nerve and the inferior tympanic artery; this bony structure arises from the anterior pillar and runs inferiorly to the hypotympanic cells, forming the so-called finiculus [5].

As mentioned earlier, in some subjects a deep tunnel between the fustis and the finiculus into the Proctor's area concamerata was found, and named the "subcochlear canaliculus". This area seems to have some anatomical importance, particularly during cholesteatoma surgery because it consists of a deep extension to the petrous apex cells lying below the cochlea, and medially with respect to the vertical portion of the internal carotid artery. It is very likely that the formation of the subcochlear canaliculus could arise from the defect of fusion between the inferior wall (fustis and area concamerata) and the superior wall (anterior pillar and finiculus) of the round window during fetal development. This event could be the basis of the formation of the subcochlear canaliculus with a variable deep extension versus the petrous apex cells lying under the cochlea (see Fig. 9a, b). On the contrary, when a well-developed area concamerata is fused with the finiculus the subcochlear canaliculus would not be present.

For sure in present authors' opinion there is an impact of the variations of subcochlear canaliculus. For example in cochlear implant surgery the presence of a wide tunnel, during a microscopic approach through posterior tympanotomy, could be mistaken for the round window niche. In those cases a wrong placement of the cochlear implant array could verify, and the array could be inserted into the tunnel. Notably there could even be an unlikely but potential risk of carotid damage, since based on our anatomic studies, the infracochlear pneumatization represents a way to the petrous tract of the carotid artery (C1 and C2).

In our previous experience we described the presence of a very well-defined sinus lying inferiorly to the sinus tympani, forming a well-delineated space between the subiculum superiorly and posteriorly and the finiculus inferiorly and anteriorly, the styloid prominence posteriorly and laterally, and the otic capsule posteriorly and medially, calling this space sinus subtympanicus [1]. This anatomic region is open anteriorly and medially toward the round window niche. From an anatomical point of view the retrotympanum can be divided into two portions; the superior retrotympanum represented by the sinus tympani and the posterior sinus, lying superiorly with respect to the subiculum and

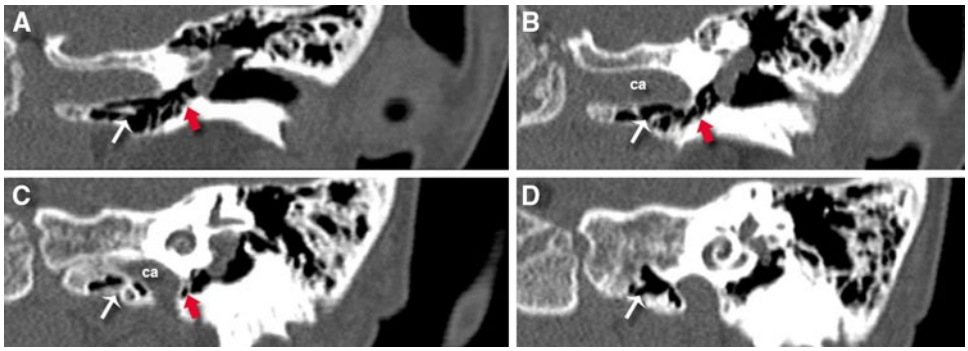

Fig. 10 CT Scan (coronal view) in a subject affected by a tympanic cavity cholesteatoma involving the round window chamber, note the presence of a well-developed subcochlear canaliculus (*red arrow*), connecting the round window chamber to the petrous apex cells lying around the internal carotid artery, below the cochlea (*white arrow*), *ca* carotid artery

the inferior retrotympanum represented by the sinus subtympanicus lying inferiorly with respect to the subiculum and confluent medially with the round window niche [1]; (Fig. 9b). In that study, the depth of this space appeared variable, depending on the pneumatization of the retrotympanic spaces. In two subjects, a very deep sinus subtympanicus was observed extending posteriorly with respect to the third portion of the facial nerve. In these cases, the posterior portion of the sinus subtympanicus was in the form of a recess delimited by the styloid prominence and the third portion of the facial nerve laterally and the bony labyrinth medially.

Since the round window niche and chamber represent the anatomical area where the sinus subtympanicus is confluent anteriorly and medially, we decided to investigate this area endoscopically to define the impact of its anatomical conformation on cholesteatoma surgery. Based on our observations the round window chamber represents a key area for cholesteatoma surgery. This is of particular importance when the cholesteatoma is present as an infiltrative matrix involving the medial wall of the tympanic cavity; an endoscopic exploration of the round window chamber should be performed carefully to detect the presence of the residual disease extending into the area concamerata or into the subcochlear canaliculus (Fig. 10). Special attention should be also given when an infiltrative matrix cholesteatoma occurs in the pediatric population, as a wide subcochlear canaliculus is expected (in 10 pediatric subjects 9 presented a Type A round window chamber conformation), and this anatomical area could be infiltrated by cholesteatoma. When a cholesteatoma matrix is extending into the subcochlear canaliculus the petrous apex cells lying below the promontory could be involved by the disease. In this scenario an infracochlear approach should be attempted, thereby allowing for the preservation of cochlear function, with removal of the finiculus and the bone between the cochlea superiorly, the carotid artery anteriorly and the jugular bulb inferiorly. Although not in every patient the conformation of the round window chamber can be estimated at the preoperative CT scan, the presence of a well pneumatized temporal bone, in particular at the most inferior and medial portion of the petrous apex (the region in close relationship to cochlea and internal auditory canal) may represent a predicting factor of a Type C conformation: this could help in planning an intraoperative thorough exploration of the infracochlear canaliculus cholesteatoma cases.

In this study we found 3/146 subjects affected by cholesteatoma with extension under the finiculus, involving the subcochlear canaliculus and the petrous apex cells, requiring an infracochlear approach.

In one of these cases (a child) a cholesteatoma infiltrating a deep sinus subtympanicus was found and the subtympanic sinus was confluent posteriorly with a deep sinus tympani (Type C according to our former sinus tympani classification) [6]: a combined approach was required in this case using a transcanal endoscopic and a microscopic transmastoid retrofacial approach to remove the residual disease lying posteriorly with respect to the third portion of the facial nerve.

Conclusions

Endoscopic approaches can guarantee a very detailed observation and exploration of the round window niche region, allowing the intraoperative identification of structures like the sinus subtympanicus, subcochlear canaliculus, area concamerata and fustis. An exact anatomical knowledge of this region can offer important advantages during surgery, since pathology can invade cavities or tunnels otherwise not visible by straight-line view instrumentation (e.g. microscope).

Conflict of interest None have financial relationships to disclose.

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