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OTOLOGY

Transcanal surgery for vestibular schwannomas: a pictorial review of radiological findings, surgical anatomy and comparison to the traditional translabyrinthine approach

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Abstract The most popular approaches for vestibular schwannoma (VS) removal are retrosigmoid, middle cranial fossa and translabyrinthine (TL). All require a certain degree of invasivity, bone removal, or brain manipulation. Recently, the authors described the transcanal transpromontorial approaches (TTA), which allow the inner ear to be accessed directly through the external auditory canal (EAC), either with a microscopic (Expanded TTA, or ExpTTA) or even an exclusive endoscopic technique (Endoscopic TTA, or EndoTTA). The advantages compared to traditional approaches are a direct view of the internal auditory canal (IAC) from lateral to medial, very little or no superficial tissue dissection and very little petrous bone drilling. In summary, from an anatomical point of view, they could be considered to be minimally invasive approaches. The radiologic outcome and the anatomical correspondence of these new approaches are described so as to share with the readers the possible radiologic findings and to compare and differentiate them from classic transpetrous approaches such as the TL approach. *Level of evidence* 4.

Keywords Lateral skull base · Transcanal approach · Endoscopic ear surgery · Temporal bone · Vestibular schwannoma · Translabyrinthine approach

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Introduction

Traditional approaches for vestibular schwannoma (VS) removal are retrosigmoid, middle cranial fossa and translabyrinthine. The translabyrinthine (TL) approach gained popularity among otolaryngologists and neurosurgeons starting from the 1950s, since it guaranteed safe dissection of the facial nerve, complete control of the internal auditory canal (IAC), and no necessity for cerebellar or cerebral displacement compared to the middle cranial fossa and retrosigmoid approaches, respectively [1].

Recently, the authors developed the transcanal transpromontorial approaches (TTA) to access the inner ear directly through the external auditory canal (EAC), either using a microscopic (Expanded TTA, or ExpTTA) [2] or even an exclusive endoscopic technique (Endoscopic TTA, or EndoTTA) [3]. These approaches, passing through the EAC, provide a direct corridor to the IAC. Although similar in their route and surgical technique, the EndoTTA is basically an exclusive endoscopic technique, without any external incision, while the ExpTTA is mainly based on a microscopic technique, and requires a small external incision (Schambaugh type), and enlargement and calibration of the bony EAC, as already described in detail in earlier articles [2, 3].

Just as with the TL approach, these emerging approaches do not allow hearing preservation, so they are only indicated in patients with hearing loss. The advantages compared to the traditional TL approach are that they provide a direct view of the IAC from lateral to medial, very little or no superficial tissue dissection and very little petrous bone drilling; in summary, they can be considered to be minimally invasive approaches from an anatomical point of view. The first clinical studies seemed to confirm their minimal invasivity, showing very good results in terms of facial preservation, and very low rates of complications [2, 3]. Of course, the anatomical indications for the TTA are limited compared to the TL approach, since it can only be performed in cases of VS involving the IAC and the most lateral part of the cerebellopontine angle (CPA) (mainly Koos I stage in EndoTTA, and Koos I/II in ExpTTA) (Fig. 1a, b).

The aim of this study is to describe the radiologic outcomes and anatomical correspondence of these emerging approaches, so as to share with the scientific community the possible radiologic outcomes and to differentiate them from classic transpetrous approaches such as TL.

Materials and methods

This was a retrospective chart review of post-operative radiologic outcomes of patients who underwent a TL approach or TTA for VS treatment at the University Hospital of Modena, or at the University Hospital of Verona, Italy. Images are discussed and analyzed for further consideration and comparison.

Summary of the surgical approaches

Transcanal transpromontorial approach (Fig. 2a)

Both EndoTTA and ExpTTA basically involve elevation of the whole skin in the EAC and its removal, en bloc with the tympanic membrane, exposing the bony EAC and the middle ear. An enlargement of the EAC is performed so as to increase the room for surgical instruments and visualization. In the case of ExpTTA, a small (2 cm) incision is also made between the tragus and the helix, so as to place retractors to further enlarge the surgical field (Fig. 3), and more extensive drilling is performed at the most anterior part of the EAC, towards the temporomandibular joint (TMJ). The ossicular chain is then removed, so as to widely access the medial aspect of the tympanic cavity. Then, starting from the oval window, extensive drilling of the promontory is performed, to expose the inner ear structures and to identify landmarks: the vestibule and spherical recess in the saccular fossa. The oval window is enlarged removing the promontorial bone and progressively exposing the basal, middle and apical turns of the cochlea. Cochlea and modiolus are removed, and important landmarks are identified in the medial aspect of the bony labyrinth. Identification of the important landmarks for this approach continues with exposure of the middle cranial fossa (MCF) dura superiorly (by removing the tympanic tegmen), the carotid artery anteriorly below the tympanic tube orifice (in the protympanic space), the jugular bulb inferiorly, and the third tract of the facial nerve posteriorly. An imaginary line from the geniculate ganglion to the spherical recess passing just above the apical turn of the cochlea indicates the route of the facial nerve into the inner ear. The dura of the IAC is progressively exposed inferiorly and posteriorly from the fundus to the porus of the IAC until the reflection of the dura on the petrous bone is reached. The dura along the IAC is then opened to access the tumor. Removal of the pathology is performed from the meatus to the fundus of the IAC using a "piecemeal" technique until a radical removal is obtained. The extension of the neoplasm to the CPA is removed with further bone drilling to enlarge the opening of the IAC meatus, following the acoustic-facial bundle towards the entry zone. The transpromontorial defect created is closed with a

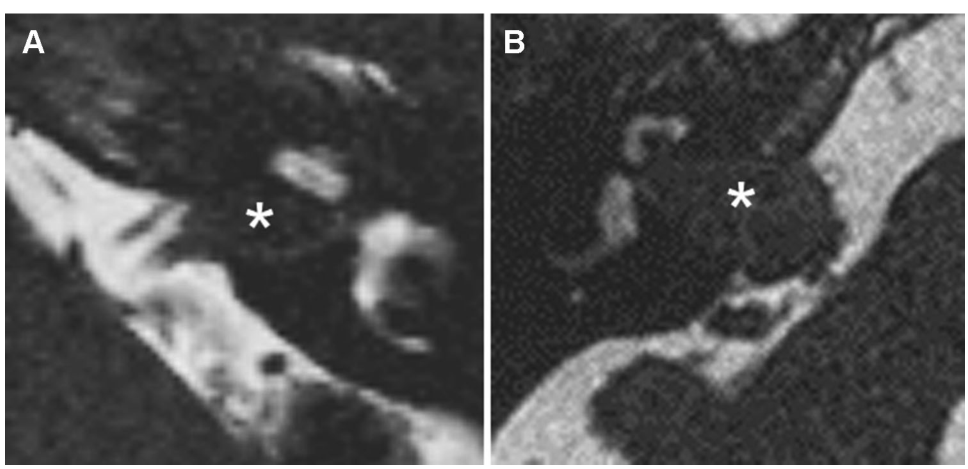

Fig. 1 **a** Head MRI T2-weighted DRIVE axial image. Left *vestibular schwannoma* (*) involving the IAC, stage Koos I. **b** Head MRI T2-weighted DRIVE axial image. Right *vestibular schwannoma* (*) involving the internal auditory canal with minimal invasion of the cerebellopontine cistern, <2 cm, stage Koos II

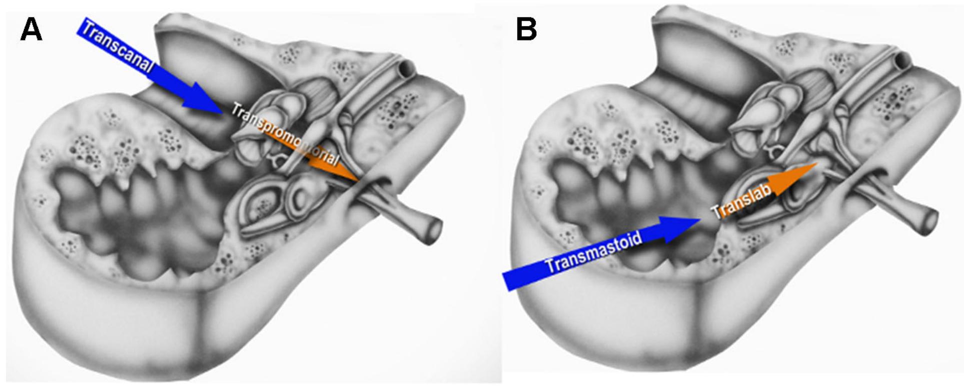

Fig. 2 **a** Schematic drawing (*superior view*) showing the surgical corridor of the TTA, to reach the IAC. **b** Schematic drawing (*superior view*) showing the surgical corridor of the TL approach

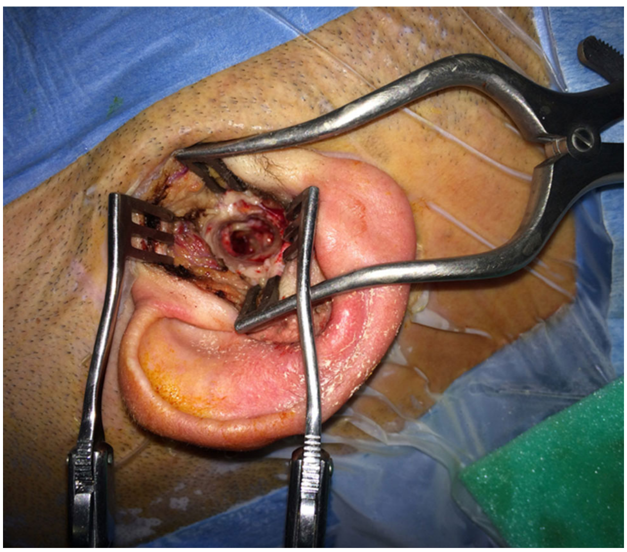

Fig. 3 External view of the Shambaugh incision as required for ExpTTA approach

fat pad harvested from the abdomen and positioned between the inner and middle ear. Thereafter, the graft is covered by fibrin glue. The final step is cul-de-sac closure of the residual skin of the EAC.

Main surgical steps of each technique are summarized in Fig. 4 (TTA) and Fig. 5 (ExpTTA).

Translabyrinthine approach (Fig. 2b)

A C-shaped incision is made behind the ear; the skin and then the periosteum are elevated. A wide cortical mastoidectomy is performed exposing the MCF superiorly, the sigmoid sinus posteriorly and the posterior border of the EAC anteriorly. Through the mastoid antrum, the incus and then the fallopian canal are identified and the vertical tract of the facial nerve is skeletonized.

Labyrinthectomy begins by entering the lumen of the lateral semicircular canal (LSC), and then the posterior semicircular canal (PSC), the vestibule and the LSC are removed. The sigmoid sinus is then followed and skeletonized until the jugular bulb, exposing it.

The dura of the IAC is uncovered and the IAC is drilled for 270° around its circumference leaving only the anterior bony wall intact. The jugular bulb is the inferior limit of drilling and the superior limit is the dura mater of the MCF. The falciform crest is identified indicating the superior vestibular nerve upon it. The dura of the IAC is then opened medially and the facial nerve can be dissected from the tumor mass. The dissection continues laterally and then inferiorly and superiorly leading to the presigmoid posterior fossa dura. The VS is removed carefully. To complete the procedure, a fat graft usually taken from the abdomen is used to close the wound. The periosteum, muscle and skin are closed in layers. The final step is cul-de-sac closure of the residual skin of the EAC.

Results

At the end of the TTA, performed as described above, some typical features are evident in the post-operative imaging, normally performed by high resolution CT (HRCT) scan. First of all, the direct corridor created from the IAC to the EAC can be easily recognized. The corridor appears hypodense to soft tissue due to the fat grafts used to obliterate the cavities at the end of the operation (Fig. 6). Enlargement of the EAC by calibration is seen in particular when compared with the contralateral side. The partial removal of the posterior (vestibule) (Fig. 7a, b) and anterior (cochlea) labyrinth (Fig. 7a) can be seen.

The ExpTTA differs radiologically from the EndoTTA in some characteristics: first, the calibration of the EAC will be more extensive compared with the EndoTTA. In most patients, the anterior part of the EAC (representing the posterior aspect of the TMJ) will be drilled away; so the calibration of the EAC will be wider compared to the EndoTTA (Fig. 8a, b). Also drilling of the labyrinth and IAC will be more extensive, and as a result, it will be easier

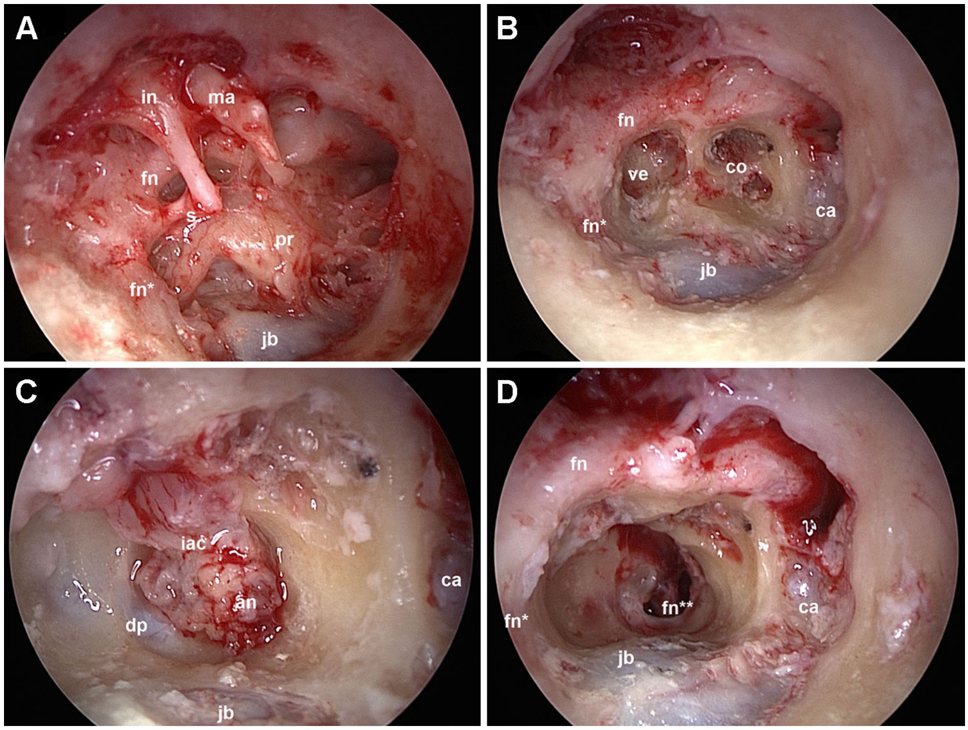

Fig. 4 Exclusive endoscopic transcanal transpromontorial approach (TTA): right ear. **a** Wide drilling of the EAC is made exposing the tympanic cavity; principal landmark of middle ear, uncovered facial nerve and jugular bulb can be seen. **b** After ossicular chain removal and promontory drilling the turns of the cochlea and vestibule are exposed. **c** The dissection proceeds reaching the IAC; the dura is opened showing the vestibular schwannoma. **d** Final tympanic cavity after acoustic neuroma removal with preserved facial nerve. *In* incus, *ma* malleus, *s* stapes, *ve* vestibule, ca carotid artery, *jb* jugular bulb, *co* cochlea, *fn* facial nerve (tympanic tract), *fn** facial nerve (mastoid tract), *fn*** facial nerve (IAC segment), *iac* internal auditory canal, *an* acoustic neuroma, *dp* reflection of the dura from the porus

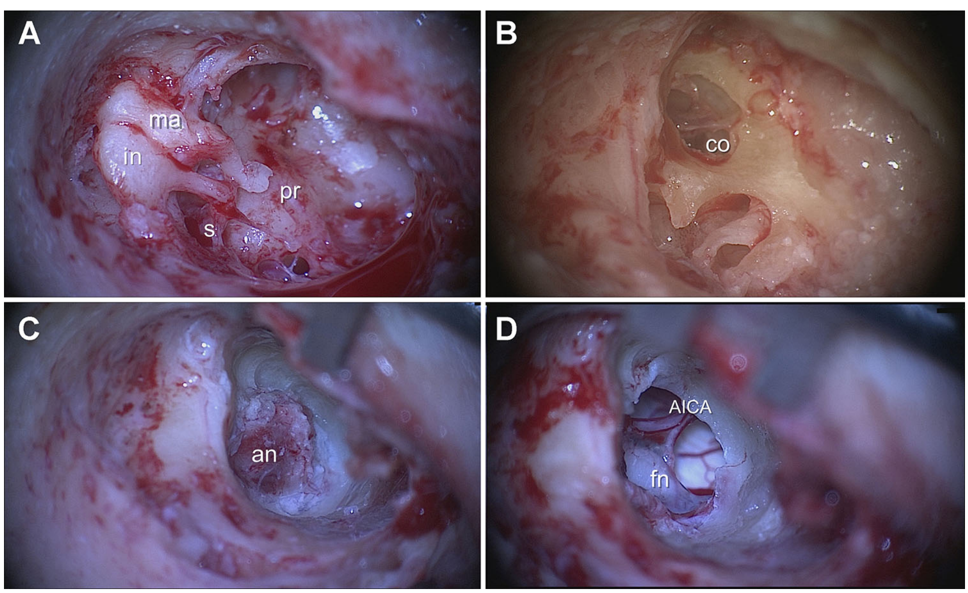

Fig. 5 Expanded transcanal transpromontorial approach (ExpTTA): right ear. **a** Endoscopic view, tympanic cavity exploration after Shambaugh incision and wide calibration of the EAC. Main landmarks of middle ear are shown. **b** Endoscopic view, after complete removal of the ossicular chain the promontory is drilled and the cochlea is exposed. **c** Microscopic view, drilling of the internal auditory canal (IAC) to expose the acoustic neuroma. The dura is opened and the tumor is removed. **d** Microscopic view, AICA, brainstem and facial nerve can be seen. *In* incus, *ma* malleus, *s* stapes, *co* cochlea, *an* acoustic neuroma, *fn* facial nerve (IAC segment), *AICA* anterior inferior cerebellar artery

to visualize the entire corridor from EAC to IAC in only one axial slice in most patients (Fig. 7).

As mentioned above, the TTA and TL approach are very different in terms of soft tissue dissection and bone removal. In fact, the TTA requires no external incision in the case of the EndoTTA, or a very small Schambaugh incision in the case of the ExpTTA (Fig. 3). In contrast, the TL approach requires a wide retroauricular incision, with partial resection of the temporalis muscle, and elevation of the skin subcutaneously and muscular tissue, to gain sufficient room for dissection of the petrous bone. The removal of petrous bone can be easily documented on post-operative CT scans. Typically, almost the entire mastoid and temporal bone air cells will be drilled away (Fig. 9). The sigmoid sinus, and the dura mater of the posterior and middle cranial fossae will be exposed in the surgical field, to gain as much room as possible. A difference compared to the TTA will be the removal of the labyrinth, which will only occur in its posterior (vestibular) part in the TL approach (Fig. 9). This difference is because the TL technique approaches the IAC from posteriorly to anteriorly, as shown in Fig. 2b, whereas the TTA approaches the IAC from lateral to medial, in an even more direct way (Fig. 2a). Of course in the TL approach, preservation of hearing will not be possible, just as in the TTA. A fat graft as seen in Fig. 9 will be used to close the defect created by surgery in TTA and TL approaches.

3D images of the corridors created by the TTA, and their relationship to vital structures are shown in Fig. 10.

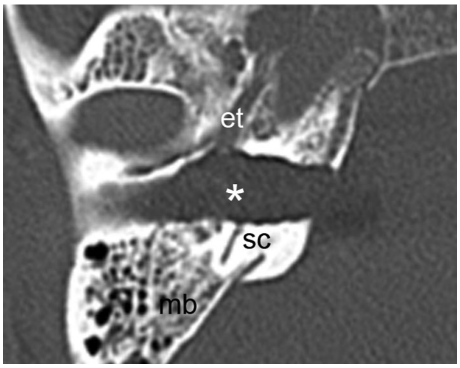

Fig. 6 Temporal bone high resolution CT (HRCT) scan axial view of the right ear showing postoperative surgical corridor (*) filled with fat graft, hypodense compared to the surrounding soft tissue. *mb* mastoid bone, *sc* posterior bony labyrinth, *et* Eustachian tube

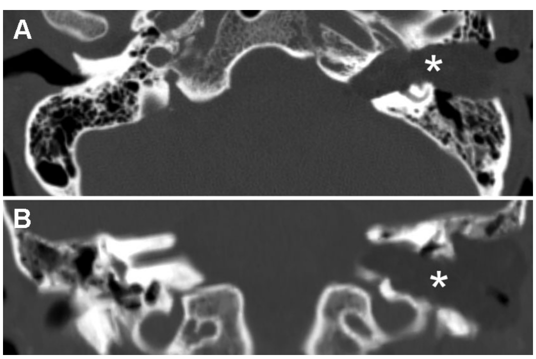

Fig. 7 Temporal bone high resolution CT (HRCT) scan axial view (**a**) and coronal view (**b**) showing the entire surgical corridor (*) from EAC to IAC after the ExpTTA procedure. Calibration of the EAC and drilling of its anterior wall/TMJ are visible

Discussion

The internal auditory canal (IAC) and cerebellopontine angle (CPA) are classically reached through indirect surgical approaches. The retrosigmoid and TL approaches use posterior surgical corridors; whereas the middle cranial fossa approach uses superior access. These approaches have been used for many years and the advantages, disadvantages, clinical indications, morbidity and mortality have been carefully described [1, 4]. However, to access the pathology, a craniotomy is necessary in the

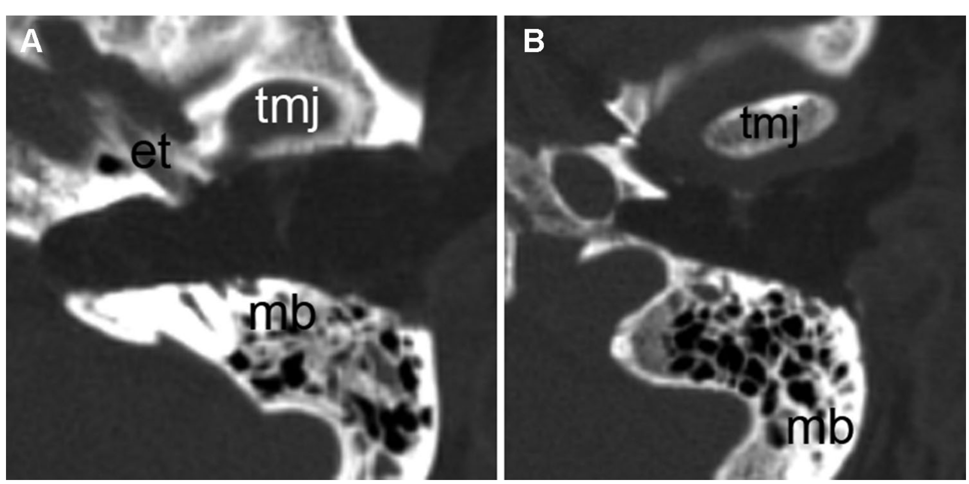

Fig. 8 **a** Temporal bone high resolution CT (HRCT) scan axial view of the left ear showing the surgical corridor of the EndoTTA with preserved temporomandibular joint/anterior wall of the bony EAC. **b** Temporal bone HRCT scan axial view of the left ear showing the surgical corridor of the ExpTTA: a drilled TMJ/anterior wall of the EAC is shown. *mb* mastoid bone, *et* Eustachian tube, *tmj* temporomandibular joint

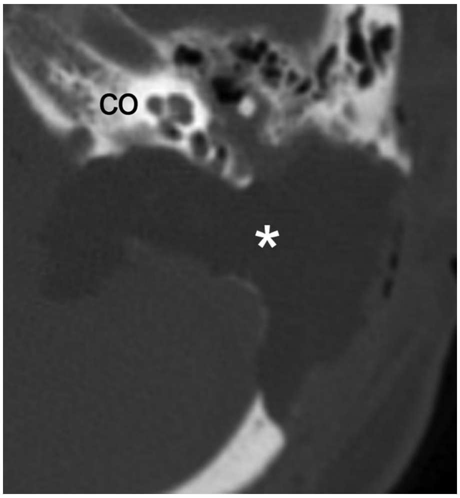

Fig. 9 Temporal bone high resolution CT (HRCT) scan axial view of the left ear, showing the surgical corridor (*) of the TL approach. The cochlea (CO) is recognizable while the entire petrous bone is completely drilled away. Hypodense tissue (fat graft) fills the cavity. *co* cochlea

retrosigmoid and middle cranial fossa approaches. They also require displacement of the cerebellum or temporal lobe, with consequent risks of intraparenchymal contusions or hematomas. There may be a risk of CSF leakage postoperatively in the retrosigmoid approach, because the posterior aspect of the petrous bone must be drilled in order to reach the pathology at the fundus of the IAC, which is otherwise not easily visualized. In the TL approach, some of these disadvantages are not present, but it requires wide external incisions anyway, and significant bone work [1, 4].

Since the 1990s, endoscopic techniques have been developed to gain access to middle ear pathology [5]. Initially, the endoscope was used as an aid/support to conventional microscopic operations to explore hidden recesses thanks to angulated scopes [6]. Over the years, the technique developed to the point where it could be used as the main tool in the surgical treatment of middle ear cholesteatoma, and the microscope was needed in the case of mastoid involvement of the pathology [7]. A typical characteristic of the endoscopic technique is the absence of external incisions, since the operations are only performed through the EAC. The growing endoscopic middle ear experience has allowed novel endoscopic approaches to be introduced to the lateral skull base [8]. New techniques have been developed allowing direct access to the inner ear through the EAC, and an endoscopic assisted microscopic or even an exclusive endoscopic technique can now be used [9].

Prior to a clinical application, several cadaveric dissections were performed to develop new surgical corridors to skull base surgery; this was mandatory to properly understand the anatomy of the surgical site and to identify appropriate surgical instruments [10]. The first exclusive endoscopic approach to the IAC was clinically achieved in March 2012. Without any external incision, a cochlear schwannoma (CS) involving the IAC was removed by passing the endoscope from the EAC through the middle ear and cochlea and reaching the IAC; this was the first example of a TTA reported in the literature [11]. The results of the first exclusive TTA case series to remove vestibular schwannomas (VS) involving the IAC were then published, using both endoscopic and microscopic techniques (EndoTTA and ExpTTA) [2, 3]. As described in the above-mentioned articles, TTA approaches have very selected indications. The EndoTTA is suitable for removing a neoplasm involving the IAC (Koos I) in patients with no serviceable hearing. The ExpTTA is suitable in patients

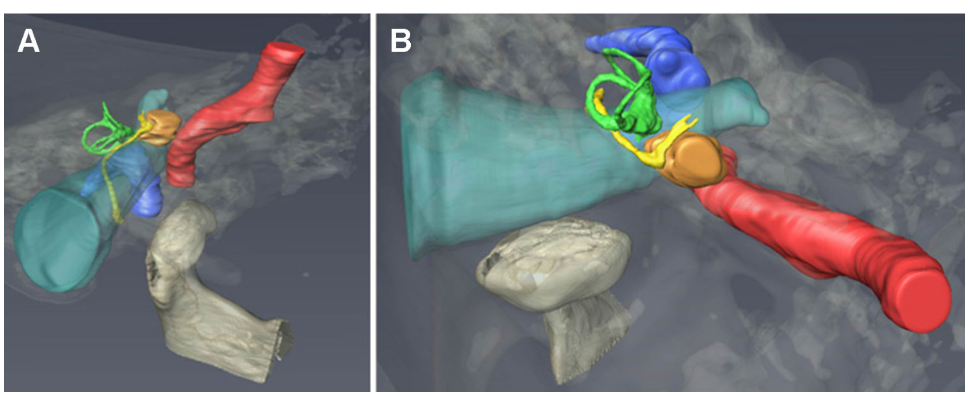

Fig. 10 A 3D reconstruction (Amira 3D software; Visualization Sciences Group, France and Zuse Institute Berlin, Germany) of temporal bone after right EndoTTA with surrounding vital structures and remnants of the cochlea and vestibule. **a** Anterolateral view. **b** Superior view. Surgical corridor (*aquamarine*), IAC (*red*), jugular bulb (*blue*), semicircular canals (*bright green*), facial nerve (*yellow*), cochlea (*orange*), ramus of the mandible (*gray*)

with neoplasms involving more than just the IAC and with minimal involvement of the CPA (Koos II). The advantage of using a purely endoscopic technique (EndoTTA) is because less bone work and less enlargement of the corridors involved are required; however, the use of one hand can be a limitation in an exclusive endoscopic approach. While dissecting the neoplasms in the CPA, it may be crucial to operate with two hands: this is the main reason why the ExpTTA is indicated for Koos II stages. It must be emphasized that a straight-line approach provides a direct view and is, therefore, suitable for the microscopic technique (ExpTTA).

The method of surgical treatment of VS confined to the IAC and < 1 cm in diameter is still a matter of debate, since wait-and-scan policies and radiosurgery can be viable options [12]. In selected cases, these new surgical approaches may offer a good alternative, in terms of low invasivity, low complication rates, and low morbidity to the facial nerve [2, 3]. We have to consider, that the TTA, as described in the present and earlier articles, does not allow post-operative cochlear implantation. In fact, the anterior labyrinth with all of the cochlear turns is removed. For this reason, the level of contralateral hearing may influence indications for a TTA. In fact, some modifications of the approach, which could allow cochlear turns to be spared, at least in part, are ongoing. Anyway, in both the TTA and TL approach, hearing function is removed; so functionally, they can be considered to be comparable. The TL approach guarantees the possibility of a cochlear implant when indicated, but the TTA guarantees very good functional results for the facial nerve. Anatomically, the TL approach requires wide external incisions, superficial soft tissue dissection and elevation, wide mastoidectomies and partial labyrinthectomy (mostly posterior), dura manipulation, and a certain amount of fat tissue harvesting to fill the defect. The TTA requires no superficial tissue dissection, small or no external incisions, a lower quantity of fat tissue harvesting, and partial labyrinthectomy (mostly anterior). In TTA, the ossicular chain is removed and the EAC is drilled, but clearly this cannot influence the functional results. For these reasons, in the authors' opinion, the TTA can be considered to be a less invasive approach compared to TL. Of course, definite results in terms of minimal invasivity must be confirmed in future by ad hoc studies focused on QoL comparison between classical approaches and the new ones.

Conclusions

The TTA, involving direct corridors that pass through the EAC, is able to reach the IAC. Compared to the TL approach, it guarantees much less tissue dissection and elevation, and less petrous bone removal. These characteristics are easily identifiable radiologically, in particular at CT scan. Some differences between the EndoTTA and ExpTTA can be identified at post-operative imaging. Knowledge of the characteristics of the TTA and differences between the approaches (whether using the EndoTTA or ExpTTA) may improve the interpretation of post-operative images by radiologists.

Compliance with ethical standards

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Conflict of interest The authors declare no conflict of interests.

Ethical approval This IRB ethical approval is not required at our institution for this kind of article type.

Informed consent For this type of study formal consent is not required.

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