Piezosurgery-, neuroendoscopy-, and neuronavigation-assisted intracranial approach for removal of a recurrent petrous apex cholesteatoma: technical note

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Current approaches for resection of petrous bone cholesteatomas (PBCs), such as canal wall up (closed) and canal wall down (open) mastoidectomies, in the pediatric population present recurrence rates ranging between 17% and 70% with a high rate of postoperative complications involving hearing loss and facial nerve weakness. This technical note illustrates an alternative intracranial approach that was used in combination with the techniques of piezoelectric surgery, neuroendoscopy, and neuronavigation for safe and effective removal in a difficult pediatric case of recurrent PBC.

The third recurrence of a PBC in a 14-year-old girl was diagnosed by CT and MRI. A retrosigmoid approach gave access to the petrous apex, allowing for the safe and complete removal of the lesion and decompression of the facial nerve and internal carotid artery. The intraoperative implementation of piezoelectric surgery, neuronavigation, neuroendoscopy, and neuromonitoring ensured better intraoperative visualization, safer bone removal, and preservation of nerve function, facilitating a macroscopically total resection of the pathology without additional neurological damage of the adjacent tissues.

Cholesteatoma extension could be clearly verified by intraoperative neuronavigation. Neuroendoscopy and piezoelectric surgery provided good support in the safe bone removal in close vicinity to neurovascular structures and in full vision inside the cholesteatoma cavity beyond the line of sight of the microscope. Hearing and facial nerve function could be preserved.

The presented intracranial retrosigmoid approach combined with multiple intraoperative assisting techniques proved to be effective for the safe and complete removal of recurrent PBC, providing excellent intraoperative visualization and the possibility of preserving cranial nerve function.

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Cholesteatomas of the petrous bone are a relatively uncommon pathology, accounting for 4%–9% of all petrous lesions.19,22,28,31 They may be congenital, arising from persistent embryonic epidermal cell rests within the petrous bone, or acquired, due to recurrent infections or trauma.20,28,36 Cholesteatomas are nonneoplastic lesions, but they may gradually expand as a result of progressive exfoliation of keratinous material and can cause serious complications by eroding surrounding structures.35 Therefore, the treatment is complete surgical excision with the principal goals of maximizing functional preservation and minimizing the risk of recurrence posing a great chal-
challenged for the surgeon due to the complex anatomy of the petrous bone and the proximity to important structures, such as the cochleovestibular labyrinth, facial nerve, internal carotid artery, and jugular bulb.32

Numerous surgical approaches, including infralabyrinthine, translabyrinthine, supralabyrinthine, subtotal petrosectomy, or middle cranial fossa approaches, have been described in the past.19,26 The approach must be tailored to each individual situation, taking into account the extent and the location of the disease, anatomical variation, and the presence of hearing and facial nerve function.12,20 Current approaches for resection of petrous bone cholesteatomas (PBCs), such as canal wall up (CWU; closed) and canal wall down (CWD; open) mastoidectomies, present recurrence rates ranging between 17% and 70%, with a high rate of postoperative complications involving hearing loss and facial nerve weakness.30 In the CWU procedure, the anatomic middle ear is preserved, allowing for simpler postoperative care and maintenance; this procedure therefore does not limit patients in their future activities, which might be of particular importance in younger and pediatric populations.30 In the CWD procedure, the posterior semicircular canal is removed, resulting in improved visualization of the disease and the affected middle ear anatomy.30

This technical note describes an alternative method for removal of a recurrent petrous apex cholesteatoma in a 14-year-old girl via a retrosigmoid approach using the techniques of piezoelectric surgery, neuroendoscopy, and neuronavigation. Whereas the latter 2 techniques are well established in skull base surgery, piezoelectric surgery is a comparatively new technique utilizing microvibrations in an ultrasonic frequency range generated by the piezoelectric effect, resulting in selective bone-cutting properties without injuring adjacent soft tissues.33,34 The retrosigmoid intracranial approach in combination with these additional supporting techniques allowed the safe and complete removal of the recurrent cholesteatoma with functional preservation of hearing and facial nerve function.

Surgical Technique

Resection of the recurrent cholesteatoma was performed via a standard retrosigmoid craniotomy under continuous neurophysiological monitoring. Neuronavigation and neuroendoscopy were used for better intraoperative visualization. The technique of piezoelectric surgery was used for bone removal at the petrous apex to minimize the risk of neurovascular injury. Continuous neurophysiological monitoring with acoustic evoked potentials and electromyography for cranial nerves (CNs) IV, VI, VII, IX, X, and XI was performed throughout the operation (ISIS, Inomed GmbH). MRI and CT DICOM data were preoperatively matched and loaded to the Stryker iNtellect cranial navigation system. The system was then set up with fiducial marker registration before draping the patient, and the accuracy of the system was verified.

Neuroendoscopy was suitable for better visualization of the cholesteatoma cavity inside the petrous apex, particularly for the lateral tumor parts. A 70° endoscope (Richard Wolf GmbH) was used for this purpose.

Piezoelectric surgical removal of the petrous bone was performed with the Mectron Piezosurgery II device mounted with the OT5 insert. The device provides 2 different modes, the “root mode” and the “bone mode,” with 2 and 4 different power levels, respectively. Furthermore, a variety of inserts with different tips, angles, and diameters are available for the device. In the case presented here, the OT5 insert was used in the “bone mode.” Bone cutting is performed by moving the oscillating tip with only mild pressure in a “shaping” manner, thereby removing bone layer by layer without any rotating power.

This study was approved by the ethics committee of the University of Freiburg Faculty of Medicine, and written informed consent was obtained from the patient and her parents.

Case Report

History and Presentation

This girl was first operated on in 1999 at the age of 4 years when a congenital cholesteatoma on the left side was diagnosed by members of our otorhinolaryngology (ear, nose, and throat [ENT]) department. At that time she presented with fetid otorrhea and hearing loss on the left side. Pure tone audiometry (PTA) showed essentially a mild hearing loss of up to 30 dB at 8 kHz and a conductive hearing loss of 5–10 dB, affecting all frequencies. A CT scan revealed a large mass in the left tympanic cavity; destruction of the petrous bone could not be reliably demonstrated. The cholesteatoma was removed via a mastoidectomy, the infiltrated auditory ossicles were resected, and a ceramic total ossicular replacement prosthesis (TORP) was implanted. The patient’s postoperative course was uneventful; there was no facial paresis after the operation and hearing function was improved.

Routine follow-up imaging showed recurrence of the cholesteatoma in 2001; the patient had no complaints at that time, but her PTA findings showed slight worsening, with a conductive hearing loss of 20–30 dB, affecting all frequencies. The recurrent cholesteatoma was resected, again with an uneventful postoperative course and no new deficit.

In 2005 the patient presented again to the ENT outpatient clinic with a suspected infection of the radical cavity and severe conductive hearing loss. The infection could have been treated successfully with local and systemic antibiotic therapy, but a sample taken from the external auditory canal for histological examination showed recurrence of the cholesteatoma. Therefore, the girl was operated on for the third time. Intraoperatively, however, no recurrent cholesteatoma could be macroscopically identified. The ceramic TORP was replaced with a titanium TORP to restore hearing.

The current presentation of the patient to the ENT outpatient clinic, at the age of 14 years (2010), was due to new symptoms of vertigo and otalgia. MRI and CT showed a large recurrent cholesteatoma of the petrous apex with suspected infiltration of the internal auditory canal (IAC) (Figs. 1 and 2). Diffusion-weighted imaging could not be performed at that time because of artifacts from a fixed dental brace. PTA and speech discrimination testing on
the left side showed a bone conduction of 15 dB, air conduction of 75 dB, hearing loss of 85 dB, and a speech recognition threshold of 40% at 110 dB.

We decided, together with the patient and her parents, to reoperate to remove the recurrent cholesteatoma via a retrosigmoid approach, with the surgery to be performed by an interdisciplinary team of neurosurgeons and ENT surgeons.

Operation

Surgery was performed with the patient in the semisitting position. Her head was fixed in a Mayfield skull clamp. Neuronavigation and neurophysiological monitoring were set up. A retrosigmoid craniectomy was performed, the dura and the cerebellopontine cistern were opened for cerebrospinal fluid drainage, and the cerebellum was slightly retracted. The petrous bone and the IAC with CNs VII and VIII became visible. There was no cholesteatoma visible, but there was a bony prominence of the petrous bone cranial and ventral to the IAC. Intraoperative neuronavigation confirmed the suspected tumor location behind the bony prominence (Fig. 3A). The Mectron Piezosurgery device, which selectively cuts bone and preserves soft tissue without any rotating power, was used for removal of the petrous bone to reduce the risk of cranial nerve injury. The Piezosurgery device was equipped with the OT5 insert, and

FIG. 1. Preoperative axial plane bone window CT (left) and axial plane T2-weighted MR (right) images showing bone erosion and cholesteatoma formation in the left petrous bone. Figure is available in color online only.

FIG. 2. Segmentation of the cholesteatoma in the left petrous bone for better visualization after 3D volume rendering of cranial CT scan (Brainlab Elements). Figure is available in color online only.

FIG. 3. Intraoperative images showing the surface of the petrous bone with underlying cholesteatoma (A), the Piezosurgery device with OT5 tip for removal of bone (B), cholesteatoma matrix after bone removal (C), and removal of the cholesteatoma with forceps (D). Figure is available in color online only.
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FIG. 4. Intraoperative images visualizing the bony cavity with the endoscope (A), removal of cholesteatoma matrix (B), bone cavity after complete microsurgical and endoscope-assisted removal of cholesteatoma (C), and sealing the cavity with a piece of muscle and fibrin glue (D). Figure is available in color online only.

Bone could be easily removed with shaping movements, as with a curette, without any injury to neurovascular or soft tissue (Fig. 3B). The cranial nerves were not manipulated and were left intact during the cutting process as indicated by stable neuromonitoring. After the bone layer was removed, the cholesteatoma became visible (Fig. 3C) and could be carefully removed piecemeal with microdissectors and grasping forceps (Fig. 3D). It could be completely dissected from the petrous bone cavity, as it showed no distinct adherence to the petrous bone. The consistency of the cholesteatoma was relatively soft and somewhat cloddy and friable. The cholesteatoma cavity could not be fully visualized by only microscopic view. The lateral part of the cavity with residual cholesteatoma tissue around the facial nerve in its intrapetrous course and the internal carotid artery could then be visualized only with the assistance of neuroendoscopy. A 70° endoscope was used for visualization to remove the lateral parts of the cholesteatoma and to carefully dissect the cholesteatoma from the facial nerve with a blunt microdissector and an angled hook (Fig. 4A and B). This was the most difficult part of the operation because the cholesteatoma showed much stronger adherence to the facial nerve than to the petrous bone. The facial nerve was stimulated intermittently with a current of 0.1 A and showed normal response throughout the operation.

After the cholesteatoma was removed (Fig. 4C), gross-total resection was confirmed by means of intraoperative neuronavigation and final careful microscopic and endoscopic inspection of the petrous bone. The bone cavity was sealed with a piece of muscle and fibrin glue (Fig. 4D). The surgical incision was then closed, and the patient was moved to the neurosurgical intensive care unit for postoperative monitoring.

Postoperative Course

The patient’s postoperative course was uneventful. Her preexisting House-Brackmann grade II facial paresis did not worsen, and findings of PTA and speech discrimination testing and 1-syllable understanding remained stable. She was discharged home on the 7th postoperative day. Follow-up examinations at the neurosurgical and ENT outpatient clinics at 3, 15, and 27 months and 6 years after surgery also showed an uneventful course: the patient had no complaints, the wound was completely unremarkable, the mild facial paresis resolved completely, and PTA and speech discrimination testing showed no measurable differences.

MRI and CT studies performed 3 months after surgery showed a tiny area of contrast enhancement at the resection cavity, but there was no evidence of residual cholesteatoma (Fig. 5). MRI studies, including diffusion-weighted imaging, performed 15 and 27 months and 6 years after surgery also showed no evidence of recurrent cholesteatoma.

Discussion

Cholesteatoma is defined as pathological growth of squamous epithelium in the middle ear and mastoid. These lesions may progress, distracting the surrounding bone structures and usually resulting in conductive hearing loss. In children with no prior middle ear disease and an unaffected tympanic membrane, these lesions are classified as congenital, with all other manifestations of the disease considered acquired. Despite many existing theories, as yet the pathogenesis of the congenital lesions remains unclear.

Acquired forms of the disease usually arise from focal retractions of the tympanic membrane, trapping metabolically active desquamating cells, which expand through eroding the surrounding bone tissues, leaving behind keratinous debris, which may get infected and result in chronic purulent drainage. Resection remains the treatment of choice for both congenital and acquired lesions to prevent further expansion and consequent destruction of adjacent eloquent anatomical structures or secondary infection. The goal of the surgical treatment is complete resection of the lesion, because this has been found to be the most important factor for avoiding recurrence of acquired and congenital cholesteatoma.

In the case presented here, the lesion recurred 3 times, and a transmastoid approach was chosen for the first 2 resections. The third recurrence of the tumor extended into the apex of the petrous bone, laterally compressing the petrous segment of the facial nerve and the internal carotid artery and reaching medially to the IAC. The localization, extension, and geometry of the pathology within the petrous bone apex, as displayed in Fig. 2, necessitated the reevaluation of the scenario of a third transmastoid resection and exploration of alternatives. A main aim of the treatment strategy was the functional preservation of CNs VII and VIII.

Several surgical approaches to target lesions in different locations within the petrous bone have been previously published, with the most important being the transtemporal supralabyrinthine, the transotic (translabyrinthine-transcochlear), the transcochlear, and several infra–temporal fossa approaches. We decided on a lateral suboccipital retrosigmoid approach, with supportive use of the techniques of piezoelectric surgery, endoscopy, and neuronavigation.
to achieve a complete resection of the cholesteatoma under the safest possible circumstances.

Piezoelectric surgery is a relatively new technique, introduced in 2000 by Vercellotti, and is based on micro-vibrations generated by the piezoelectric effect. Certain ceramics and crystals deform when an electric current is passed across them, resulting in oscillation at varying ultrasonic frequencies and amplitudes. These properties result in selective bone-cutting ability with preservation of adjacent soft tissues.

Piezoelectric surgery was first used in the field of dental and implant surgery. Later, studies in the fields of otorhinolaryngology, craniomaxillofacial, orthopedic, and neurosurgery were performed, demonstrating that piezoelectric surgery increases the extent and safety of bone removal through integrity-preserving dissection of critical neurovascular structures. Moreover, bone tissue can be removed by piezoelectric surgery layer by layer with shaping movements without any rotating power, which makes the device easy to handle and allows for safe and precise bone cutting.

In the presented approach the surgical corridor to the pathology is deep, making the use of a high-speed rotating drill near the sensitive neurovascular structures in the cerebellopontine angle unsuitable and dangerous. Therefore, the technique of piezoelectric surgery was applied to easily and safely open the petrous bone and gain access to the cholesteatoma. No injuries to neurovascular structures, such as cranial nerves, the labyrinthine or posterior inferior cerebellar artery, or the brainstem occurred. The electrophysiological monitoring remained stable during the entire cutting process.

Intraoperative use of neuronavigational systems has been proven to be precise and invaluable in cases in which the pathology poses difficulties for macroscopic identification. In our approach, this technology guided our resection strategy at the beginning of the operation where the lesion was not visible to determine the best entry point for bone removal and the spatial dimensions of the cholesteatoma. Additionally, it allowed verification of the resection margins in the final stages of the operation.

Neuroendoscopy has been applied in neurosurgery for many years and is now widely used. The flexible optical fibers and lenses used in new-generation neuroendoscopes offer high-definition visualization of anatomical areas that lie outside of the surgeon’s direct visual micros- copy field, allowing remote areas affected by pathologies to be reached with the appropriately angled instruments.

In the presented case, the use of neuroendoscopy was crucial to achieve a complete resection of the cholesteatoma, since the endoscopic view provided full sight into the cavity within the petrous bone, ensuring a complete resec-
tion of the remote lateral parts of the pathology covering the internal carotid artery and the intrapetrosal course of the facial nerve.

Facial nerve and hearing preservation rates in the literature vary among the different surgical approaches. With our approach, a mild transient facial paresis (House-Brackmann grade II) has been documented to be most likely due to the intraoperative manipulation of the nerve. Our patient’s hearing was not affected by surgery, as documented by extensive pre- and postoperative testing.

In 2009, Dubey et al. summarized the most common complications after neurosurgical operations in the posterior cranial fossa, with an overall rate of 31.8%. Thirteen percent of the cases presented with cerebrospinal fluid leak and consequently headaches, while 9.2% developed meningitis, 7% a wound infection, and 4.8% a cranial nerve palsy. Additionally, intraoperative retraction of the cerebellum could lead to transient or irreversible homonymous dysdiadochokinesia. With our approach in combination with the techniques of piezoelectric surgery, neuronavigation, and neuroendoscopy, only slight retraction was necessary and no complications occurred.

Conclusions

This technical note demonstrates an alternative surgical approach for the resection of a recurrent petrous bone apex cholesteatoma. To achieve the best postoperative results, multiple intraoperative techniques were used. Piezoelectric surgery selectively, precisely, and safely removed the surrounding bone without traumatizing eloquent nerve structures, proving to be very effective in this special case. Neuronavigation allowed precise use of the resection tools in the affected area and also allowed confirmation of complete resection of the pathology, which is a key factor for preventing recurrence. The use of an angled endoscope expanded the visual active field of resection into areas previously not visible through the microscope.

In conclusion, the intracranial retrosigmoid approach combined with the techniques of piezoelectric surgery, neuronavigation, and neuroendoscopy proved to be an alternative safe way to achieve macroscopically complete resection in this difficult case of a recurrent petrous apex cholesteatoma.

References


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**Disclosures**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

**Author Contributions**

Conception and design: J Grauvogel, Kaminsky. Acquisition of data: J Grauvogel, T Grauvogel, Kaminsky, Vasilikos. Analysis and interpretation of data: all authors. Drafting the article: J Grauvogel, Vasilikos. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: J Grauvogel.

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