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Impact of the surgical experience on cochleostomy location: a comparative temporal bone study between endaural and posterior tympanotomy approaches for cochlear implantation

Clair Vandersteen[1] · Thomas Demarcy[2] · Coralie Roger[3] · Eric Fontas[3] · Charles Raffaelli[4] · Nicholas Ayache[2] · Hervé Delingette[2] · Nicolas Guevara[1]

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Abstract The goal of this study was to evaluate, in the hands of an inexperienced surgeon, the cochleostomy location of an endaural approach (MINV) compared to the conventional posterior tympanotomy (MPT) approach. Since 2010, we use in the ENT department of Nice a new surgical endaural approach to perform cochlear implantation. In the hands of an inexperienced surgeon, the position of the cochleostomy has not yet been studied in detail for this technique. This is a prospective study of 24 human heads. Straight electrode arrays were implanted by an inexperienced surgeon: on one side using MPT and on the other side using MINV. The cochleostomies were all antero-inferior, but they were performed through an endaural approach with the MINV or a posterior tympanotomy approach with the MPT. The positioning of the cochleostomies into the scala tympani was evaluated by microdissection. Cochleostomies performed through the endaural approach were well placed into the scala tympani more frequently than those performed through the posterior tympanotomy approach (87.5 and 16.7 %, respectively, $p \leq 0.001$). This study highlights the biggest challenge for an inexperienced surgeon to achieve a reliable cochleostomy through a posterior tympanotomy, which requires years of experience. In case of an uncomfortable view through a posterior tympanotomy, an inexperienced surgeon might be able to successfully perform a cochleostomy through an endaural (combined approach) or an extended round window approach in order to avoid opening the scala vestibuli.

Keywords Cochlear implantation · Cochleostomy · Minimally invasive surgery · Endaural approach · Learning skills · Surgery resident

✉ Clair Vandersteen
vdsclair@gmail.com

[1] Department of Ear Nose Throat Surgery, Institut Universitaire de la Face et du Cou, Centre Hospitalo-Universitaire, 32 rue hôtel des postes, "Le Lafayette" bloc B, 06000 Nice, France

[2] Asclepios Research Team, INRIA, Valbonne, France

[3] Department of Biostatistics, Cimiez's Hospital, Centre Hospitalo-Universitaire, Nice, France

[4] Department of Radiology, Pasteur's Hospital, Centre Hospitalo-Universitaire, Nice, France

Introduction

For the past 25 years, cochlear implantation has been routinely provided to adults who present with profound to total post-lingual deafness following the failure of hearing aids. More recently, this implant has also been provided to individuals with severe deafness [1–3]. The principle of cochlear implants is prosthetic rehabilitation of deafness based on an electrical stimulation of the auditory pathways for which the electrical coding must use a frequency and intensity that are as close as possible to those of normal auditory electrical signaling.

Without considering the surgery, the hearing benefits derived from a cochlear implant depend on a multitude of factors that vary from patient to patient [4–10]. The surgery also influences the outcomes by opening the tympanic cavity (ossicles, facial nerve, middle ear muscles and tympanic membrane for the major structures) and performing the intra-cochlear insertion. The installation of a cochlear implant usually requires the use of an empirical surgical access technique described by House in 1961 [11], a mastoidectomy with posterior tympanotomy (MPT).

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Since 2010, we have used a new minimally invasive surgical approach [12] (MINV) to the tympanic cavity that has the benefits, without the drawbacks of prior minimally invasive methods published in the international literature [13–19] (Fig. 1). The surgical procedure has been previously described, but the main principles are as follows. After lifting a tympanic flap, a single landmark hole is drilled into the anterior wall of the facial recess, allowing evaluation of its depth. The inner rim of the bony canal is left intact in order to protect the chorda tympani and to prevent later potential electrode array extrusion. A minimal mastoidectomy is then visually drilled in the mastoid area behind the external auditory canal. A tunnel is carefully made without supplementary tool from the depth of the mastoidectomy to the posterolateral part of the facial recess (2 mm burr, 15,000 rpm), under continuous irrigation, allowing communication between the tympanic and the posterior cavity. The facial nerve, which is continuously monitored, always remains deeper than the drill trajectory. The insertion of the electrode array through this tunnel, and a cochleostomy performed by the endaural approach, is made in the axis of the basal turn. No major complications were encountered in a pilot study using this procedure [12].

The scala tympani is the most suitable part to receive the electrode array because its anatomy allows a better electric stimulation of neural structures with less risk of impairing residual hearing due to a lesion of the scala media [20, 21]. This approach results in a reduced number of traumas from insertion, providing better functional auditory outcomes [4, 22–26]. The suitability of the location for the electrode array directly depends on the position of the cochlear opening [through the round window (RW) or by cochleostomy].

In our department, residents learn both techniques (MPT and MINV), but their performances in terms of cochleostomy positioning has never been studied in detail. The main objective of this work was to evaluate, in the hands of an inexperienced surgeon, the cochleostomy location of our endaural approach (MINV) compared to the conventional posterior tympanotomy (PT) approach.

Materials and methods

This is a comparative, prospective, monocentric study in which cadaver heads were used as their own reference sample. The study was undertaken at the Nice anatomy laboratory on human heads that were collected from March 2014 to June 2014. Each cadaver came from the Nice anatomy laboratory, where all human body donations are centralized in Nice. Before their death, every person had provided written consent to give their entire body to science and had, therefore, indirectly consented to our work, which was accepted by the laboratory team. This written consent is confidential. The experimental procedures reported in this work are in accordance with the declaration of Helsinki of 1975 and its subsequent modifications.

The heads were removed within 48 h of death of the donor and maintained in a cold room at 4 °C. The various stages of the study were performed within 8 days of the initial removal. A conventional temporal bone CT scan was systematically performed and studied by surgeons (CVDS,

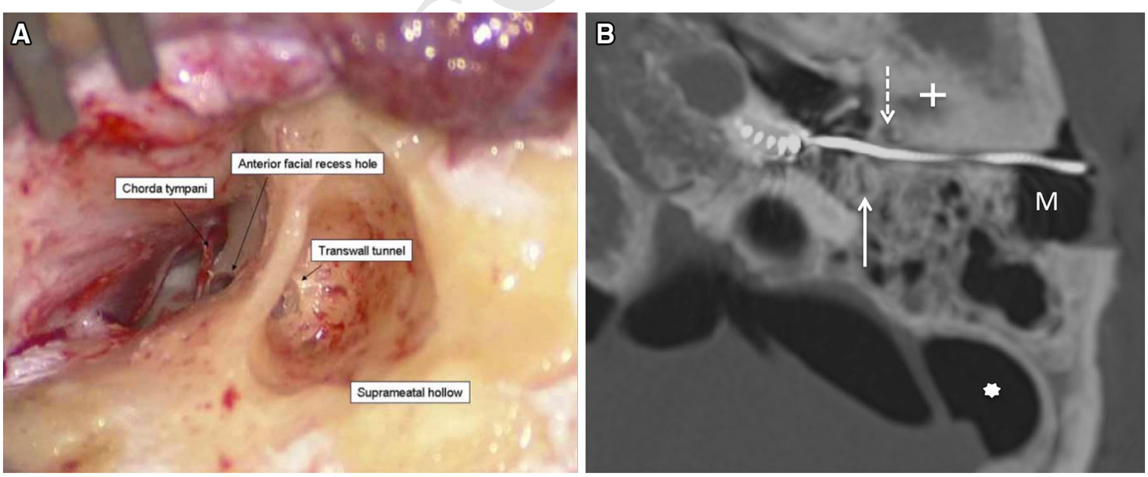

Fig. 1 The MINV technique on a left ear. **a** This photo is provided by courtesy of doctor Nicolas Guevara, Nice university: patient surgical microscopic view of the minimal mastoidectomy (*Suprameatal Hollow*) and the tunnel (*Transwall tunnel*) reaching the tympanic cavity. The landmark hole (*anterior facial recess hole*) is clearly visible under the *Chorda tympani*. **b** Axial CT scan of an implanted cadaver (Digisonic SP®, Oticon Medical Neurelec, Vallauris, France) with the MINV technique; *white star* lateral sinus plenty of air (beheaded cadaver); *white cross* external auditory canal; *white full arrow* third portion of the intrapetrous facial nerve, the stapedian muscle is just ahead; *dashed arrow* extremity of the landmark hole made initially in the MINV description. *M* minimal mastoidectomy. Guevara et al. [12]

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NG) prior to the implantation (General Electric; GE, Milwaukee; light speed vct 64 slices). Its double readout, in conjunction with input from a radiology expert (CR), allowed for the exclusion of heads that exhibited a congenital mastoidal malformation, ossicular or inner ear malformations, a temporal bone fracture, otological surgery side effects, or the presence of implanted prosthetic material.

Implantation

In light of the pronounced anatomical similarity between the two temporal bones of the same subject [27, 28], we AQ3 performed two procedures on each head. Each head was immobilized in an operating position using a flexible head brace, allowing the surgeon to perform MINV on one side and MPT on the other by changing the side for each head. The first technique performed on each head was randomized across heads. The same inexperienced surgeon (resident), having the same experience of both techniques, performed all surgical steps supervised by a senior otologist surgeon.

An atraumatic cochleostomy was then performed without senior supervision [29] (1 mm diamond bit at 15,000 rpm with ample irrigation) at an antero-inferior position relative to the RW, through a PT approach for the MPT side and an endaural approach for the MINV side.

A real straight electrode array, not connected to the implantable receiver (Digisonic SP®, EVO electrode, Oticon Medical Neurelec, Vallauris, France) was manually inserted, as slow as possible and in a supero-lateral to infero-medial axis, until resistance was experienced. The array consisted of 20 electrodes and had a notched surface, a proximal diameter of 1.07 mm, a distal diameter of 0.5 mm and a length of 25 mm. No lubricant was used. The same insertion process was used for both surgical techniques. When finished, the extra-cochlear portion of the array was glued in place (cyanoacrylate glue) and shortened.

Each temporal bone was removed, and the cochlear section was ground out and isolated from the rest of the temporal bone. A senior otologist surgeon (NG) performed microdissection of the cochlea without using any fixation of the membranous labyrinth and without knowing the surgical technique used for each cochlea. A high-resolution photograph of the microscopic view of the microdissected cochlea at 1.6× (Operating microscope, KAPS SOM82, POURET MEDICAL, Clichy, France) was obtained along the axis of the modiolus. Microdissection was then used to ascertain the positioning of the cochleostomy.

Evaluation

AQ4 The position of the cochleostomy was classified in the following manner: correctly placed inside the scala tympani, straddling the RW, straddling the basilar membrane or situated in the scala vestibuli (Fig. 2).

Statistical analysis

Given the paired design of the study, the McNemar test was used to compare these two techniques for categorical data (cochleostomy precision). The level of significance was set as $p \leq 0.05$. Statistical analysis was performed using SAS software (SAS Enterprise Guide v5.1, Cary, North Carolina, USA).

Results

Twenty-four heads were implanted bilaterally: 54 % were males ($n = 13$) and 46 % were females ($n = 11$). Twelve heads had an MINV procedure on the left and an MPT on the right. The remaining 12 had the sides reversed. The endaural cochleostomies were strictly situated into the scala tympani (i.e., without touching the basilar membrane or the round window) in 87.5 % of cases versus 16.7 % of cases that were performed with the posterior tympanic approach ($p \leq 0.001$). The results on the precision of the cochleostomy in the total population as a function of the AQ5 technique used are summarized in Table 1.

Discussion

In our study, cochleostomies performed by the endaural approach had a greater probability of placement within the scala tympani. The high rate of misplaced cochleostomies (defined as not being completely located within the scala tympani) can be partially explained, not only by the surgeon's experience, but also by our choice of classifying extended cochleostomy (i.e., across the RW) as a misplaced cochleostomy: although some surgeons perform so-called "marginal" cochleostomies straddling the RW [30] without any post-operative complications, the RW has a protective role in regulating molecular exchanges (antibiotics, local anesthetics) between the materials derived from the tympanic cavity and vestibule [31]. From this point of view, 46 and 92 % of the cochleostomies performed, respectively, through a PT or an endaural approach were into the scala tympani without injuring the basilar membrane, some of them being extended cochleostomies.

Endaural cochleostomies

The cochleostomies for MINV in our study were performed through an endaural approach, which is similar to the suprameatal approach (SMA) [17] and the Veria approach

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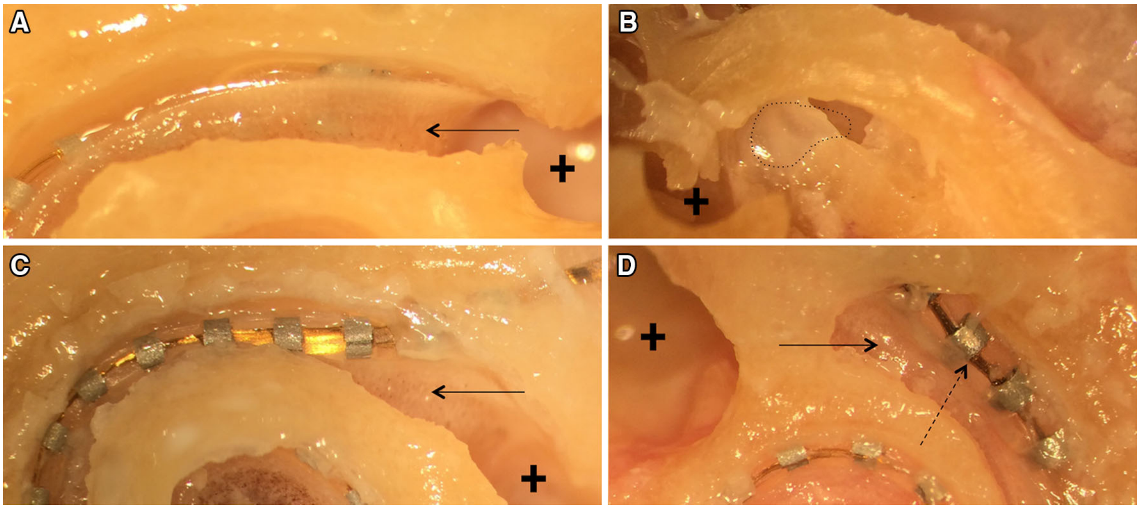

Fig. 2 Optical microscopy classification of the cochleostomy quality (X1, 6). **a** Cochleostomy strictly in the scala tympani; **b** cochleostomy across the round window membrane delimited by a *dotted line*. The electrode is not present on this picture in order to appreciate the lesion; **c** cochleostomy into the scala vestibuli; **d** cochleostomy straddling the basilar membrane but staying into the scala tympani (the basilar membrane covering the electrode is visible after the lesion); *black cross* vestibular cavity; *black arrow* spiral lamina of the initial part of the basal turn; *black dashed line* basilar membrane of the initial part of the basal turn ripped by the electrode array

Table 1 Qualitative results regarding the precision of the cochleostomy according to the surgical technique used on all the temporal bones

Type	Posterior tympanotomy (MPT) $N = 24$		Endaural (MINV) $N = 24$		*p*
	N	%	*N*	%	
Cochleostomy into the ST					
Strictly into the ST	4	16.7	21	87.5	**≤0.001**
Across the basilar membrane	12	50	2	8.3	**0.0016**
Across the round window	7	29.1	1	4.2	**0.0339**
Cochleostomy into the SV	1	4.2	0	0	–*

ST scala tympani, *SV* scala vestibuli, *MPT* mastoidectomy with posterior tympanotomy, *MINV* minimally invasive surgery

* Because of the absence of cochleostomy located in the scala vestibuli in the MINV group, *p* could not be calculated

[18]. In a histological study comparing these two preceding approaches (perimodiolar electrode arrays), Shapira et al. [32] highlighted the lower number of endocochlear traumas in the initial part of the basal turn with an endaural cochleostomy than with a RW approach or with a "marginal" one performed by the PT approach. The authors explained their results by noting the more distal positioning of the endaural cochleostomy along the scala tympani projection on the promontory, which is a concept that was already raised by Kronenberg in a prior anatomical study [17]. That distal positioning, with a more vertical drilling approach corresponding to a good insertion vector [33], allowed one to go past the dangerous "roller coaster" area (basilar membrane and osseous spiral lamina shapes) near the RW, especially with a straight electrode array. However, a comparative study of the outcomes of residual hearing preservation with 109 patients that was undertaken by Postelmans et al. [34] did not reveal significant differences between the SMA approach and MPT. This finding suggests that hearing outcomes do not solely depend on the quality of the cochleostomy. With endaural access to the tympanic cavity, the improved visualization of the promontory and larger projection of the basal turn on its surface [35] might allow better positioning of an antero-inferior cochleostomy compared to a PT approach. However, sometimes it might be impossible to correctly visualize the RW area with the endaural approach, and these cases would require the use of MPT or an endoscope [19].

Posterior tympanotomy approach cochleostomies

Through this approach, the round window area is not always largely accessible. In a retrospective 3D radiologic study (20 temporal bones), Jeon et al. [36] found that the space

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between the facial and chorda tympani measures 3.60 ± 0.2 mm and the top of the PT triangle angle measures 18.40° ± 1.05°. In a prospective study evaluating the accessibility of the round window through an optimal PT, Leong et al. [37] found the incidence of a partially visible round window to be 17 % and that of a hidden round window to be 7 %. In case of extensive exposure drilling, it might expose the facial nerve and chorda to a higher risk of injury, especially for an inexperienced surgeon. In a histological study, Adunka et al. [25] compared antero-inferior cochleostomies ($n = 7$) to strictly inferior cochleostomies ($n = 21$) performed with MPT. In all cases, the inferior cochleostomies avoided the spiral ligament, basilar membrane, spiral lamina and modiolus, while providing systematic access to the scala tympani, confirming the anatomic recommendations made by Tóth et al. [35]. Briggs et al. [38] also recommend performing a cochleostomy in an inferior position with the PT approach. These procedures require one to drill the anterior pillar of the RW to clear its lower region, causing acoustic trauma of approximately 100–130 dB should the burr touch the endosteum [39] (1 mm diamond bit, ≈24,000 rpm). Even if a cochlear implantation is performed in case of severe-to-profound deafness (≥70 dB HL), one should endeavor to preserve residual hearing, especially given the growing number of studies demonstrating that electro-acoustic hearing may improve outcomes in certain patients. Based on histological sections, Li et al. [40] recently generated a 3D model of the fine endocochlear round window region structures and assessed their relationship: they found that inferior cochleostomies carry a risk of injury to the inferior cochlear vein and cochlear duct, which can cause degeneration of the ciliated cells and stria vascularis [41] and that strictly anterior cochleostomies carry a risk of injury to the spiral ligament, basilar membrane, scala media and extremity of the osseous spiral lamina. The ideal location, at least 1 mm from all of these at-risk structures, is antero-inferior according to these authors. But even if you are an experienced otologist surgeon, the antero-inferior cochleostomy position tends to “slip” more forward than initially anticipated: in the study of Adunka et al. [25] the seven temporal bones of the antero-inferior cochleostomy group exhibited avulsion of the spiral ligament, which is similar to our results (Table 1). Two other temporal bones of this group had a fracture of the osseous spiral lamina. The work of Li et al. [40] may provide a likely explanation for the failures reported by Adunka et al. [25], and ours, in which the antero-inferior cochleostomies had slipped too far forward.

The survey results of Adunka et al. and Iseli et al. [42, 43] revealed that with the surgical vantage point via a posterior tympanotomy (100 otologist surgeons), the more experienced surgeons (≥50 cochlear implantations per year) had a greater likelihood of indicating a cochleostomy placement to be in an inferior and anterior location. The experienced surgeons also had a higher probability of indicating an inferior and anterior cochleostomy location even in cases with incomplete round window visualization; perhaps reflecting better knowledge of temporal bone anatomy when compared to less experienced surgeons. Moreover, the optimal insertion vector, which might start at a supero-lateral position progressing to an infero-medial one (as near to the buttress or the emergence of the chorda tympani [33]), may not be as optimal as it should be, likely resulting from the anterior position of the cochleostomy.

By enlarging their cochleostomies, some surgeons have observed a decrease in traumas of the basilar membrane [44] or scala vestibuli opening [23] due to better visualization of endocochlear structures. Others have observed an increase in traumas [45]. Thus, experienced surgeons (≥50 cochlear implantations per year), for Adunka et al. [42], tended to perform small cochleostomies (≤1 mm). The functional impacts on perilymphatic liquid leakage have not yet been described, but the directional effect of a tight cochleostomy on the electrode array is useful as long as the axis of insertion and cochleostomy are optimized in order to not aim, from the beginning of insertion, toward critical structures.

Finally, small inferior cochleostomies, performed through a PT approach, seem to be safer in practice than others, although they expose the cochlear duct or vein to injury. However, it requires a great surgical experience, probably explaining the poorer results of the inexperienced surgeon cochleostomies performed through a PT approach. In contrast, better exposure of the promontory with the endaural approach improves theoretically the potential for a safer antero-inferior cochleostomy, while preventing forward slippage and exposition hindrance of tight anatomical settings of the PT. In case of an anatomically difficult PT triangle and RW exposition, this study underscores the importance of an inexperienced surgeon to consider performing a “reduced-risk” cochleostomy through an endaural approach. However, this approach requires lifting a tympano-meatal flap, which can result in 1–3 % post-operative complications [46–49], the most serious being an infection near the prosthesis. Since 2010, our department has not observed any occurrence of such infectious complication using the MINV, probably because the inner rim of the bony canal is left intact in order to prevent later potential electrode array extrusion.

Conclusion

For an inexperienced surgeon, a safe cochleostomy seems easier to perform by the endaural approach than by PT. The cochleostomy via a PT is a difficult surgical step, even for a

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confirmed surgeon. It may generate some difficulties in case of a hidden round window area requiring a facial nerve and chorda tympani skeletonization. Moreover, the risk of "slipping" forward while drilling the cochleostomy should be taken into account. We advise inexperienced surgeons, in case of poor or incomplete round window area exposure through a PT, to perform an endaural cochleostomy (namely, a combined approach) or, at least, an extended round window approach in order to avoid opening the scala media or vestibuli.

Compliance with ethical standards

Conflict of interest The authors have no conflict of interest or financial ties to disclose.

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