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

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9 **Abstract** The goal of this study was to evaluate, in the
10 hands of an inexperienced surgeon, the cochleostomy
11 location of an endaural approach (MINV) compared to the
12 conventional posterior tympanotomy (MPT) approach.
13 Since 2010, we use in the ENT department of Nice a new
14 **AQ1** surgical endaural approach to perform cochlear implanta-
15 tion. In the hands of an inexperienced surgeon, the position
16 of the cochleostomy has not yet been studied in detail for
17 this technique. This is a prospective study of 24 human
18 heads. Straight electrode arrays were implanted by an
19 inexperienced surgeon: on one side using MPT and on the
20 other side using MINV. The cochleostomies were all
21 antero-inferior, but they were performed through an
22 **AQ2** endaural approach with the MINV or a posterior tympan-
23 otomy approach with the MPT. The positioning of the
24 cochleostomies into the scala tympani was evaluated by
25 microdissection. Cochleostomies performed through the
26 endaural approach were well placed into the scala tympani
27 more frequently than those performed through the posterior
28 tympanotomy approach (87.5 and 16.7 %, respectively,
29 $p \leq 0.001$). This study highlights the biggest challenge for
30 an inexperienced surgeon to achieve a reliable

cochleostomy through a posterior tympanotomy, which 31
requires years of experience. In case of an uncomfort- 32
able view through a posterior tympanotomy, an inexperi- 33
enced surgeon might be able to successfully perform a 34
cochleostomy through an endaural (combined approach) or 35
an extended round window approach in order to avoid 36
opening the scala vestibuli. 38

Keywords Cochlear implantation · Cochleostomy · 39
Minimally invasive surgery · Endaural approach · Learning 40
skills · Surgery resident 41

Introduction 42

For the past 25 years, cochlear implantation has been 43
routinely provided to adults who present with profound 44
total post-lingual deafness following the failure of hearing 45
aids. More recently, this implant has also been provided to 46
individuals with severe deafness [1–3]. The principle of 47
cochlear implants is prosthetic rehabilitation of deafness 48
based on an electrical stimulation of the auditory pathways 49
for which the electrical coding must use a frequency and 50
intensity that are as close as possible to those of normal 51
auditory electrical signaling. 52

Without considering the surgery, the hearing benefits 53
derived from a cochlear implant depend on a multitude of 54
factors that vary from patient to patient [4–10]. The surgery 55
also influences the outcomes by opening the tympanic 56
cavity (ossicles, facial nerve, middle ear muscles and 57
tympanic membrane for the major structures) and per- 58
forming the intra-cochlear insertion. The installation of a 59
cochlear implant usually requires the use of an empirical 60
surgical access technique described by House in 1961 [11], 61
a mastoidectomy with posterior tympanotomy (MPT). 62

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63 Since 2010, we have used a new minimally invasive
 64 surgical approach [12] (MINV) to the tympanic cavity that
 65 has the benefits, without the drawbacks of prior minimally
 66 invasive methods published in the international literature
 67 [13–19] (Fig. 1). The surgical procedure has been previ-
 68 ously described, but the main principles are as follows.
 69 After lifting a tympanic flap, a single landmark hole is
 70 drilled into the anterior wall of the facial recess, allowing
 71 evaluation of its depth. The inner rim of the bony canal is
 72 left intact in order to protect the chorda tympani and to
 73 prevent later potential electrode array extrusion. A minimal
 74 mastoidectomy is then visually drilled in the mastoid area
 75 behind the external auditory canal. A tunnel is carefully
 76 made without supplementary tool from the depth of the
 77 mastoidectomy to the posterolateral part of the facial recess
 78 (2 mm burr, 15,000 rpm), under continuous irrigation,
 79 allowing communication between the tympanic and the
 80 posterior cavity. The facial nerve, which is continuously
 81 monitored, always remains deeper than the drill trajectory.
 82 The insertion of the electrode array through this tunnel, and
 83 a cochleostomy performed by the endaural approach, is
 84 made in the axis of the basal turn. No major complications
 85 were encountered in a pilot study using this procedure [12].

86 The scala tympani is the most suitable part to receive the
 87 electrode array because its anatomy allows a better electric
 88 stimulation of neural structures with less risk of impairing
 89 residual hearing due to a lesion of the scala media [20, 21].
 90 This approach results in a reduced number of traumas from
 91 insertion, providing better functional auditory outcomes [4,
 92 22–26]. The suitability of the location for the electrode
 93 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 sci-
 ence 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,

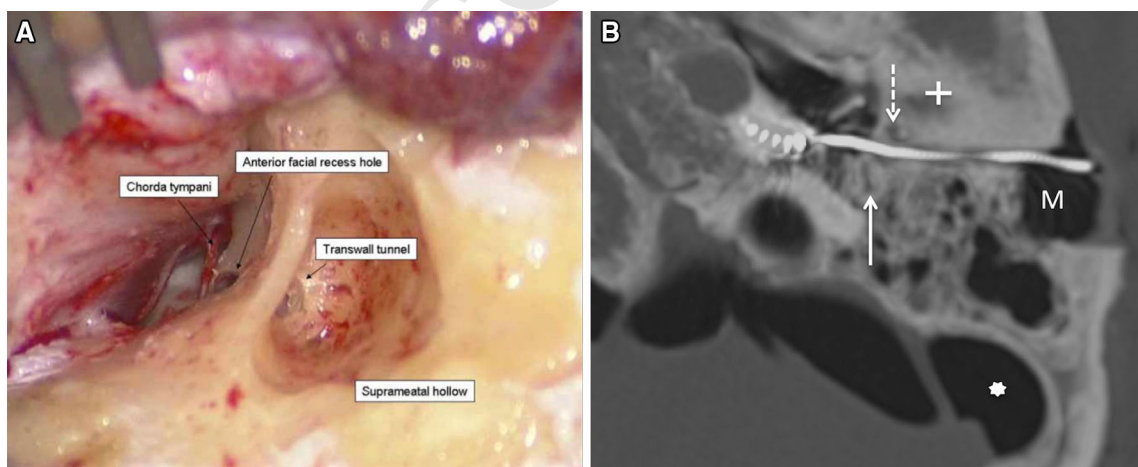


Fig. 1 The MINV technique on a left ear. **a** This photo is provided by courtesy of doctor Nicolas Guevara, Nice university: patient surgical microscopic view of the minimal mastoidectomy (*Suprameatal Hollow*) and the tunnel (*Transwall tunnel*) reaching the tympanic cavity. The landmark hole (*anterior 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]

122 NG) prior to the implantation (General Electric; GE, Mil-
123 waukee; light speed vct 64 slices). Its double readout, in
124 conjunction with input from a radiology expert (CR),
125 allowed for the exclusion of heads that exhibited a con-
126 genital mastoidal malformation, ossicular or inner ear
127 malformations, a temporal bone fracture, otological sur-
128 gery side effects, or the presence of implanted prosthetic
129 material.

130 Implantation

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

141 An atraumatic cochleostomy was then performed with-
142 out senior supervision [29] (1 mm diamond bit at
143 15,000 rpm with ample irrigation) at an antero-inferior
144 position relative to the RW, through a PT approach for the
145 MPT side and an endaural approach for the MINV side.

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

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

168 Evaluation

169 ^{AQ4} The position of the cochleostomy was classified in the
170 following manner: correctly placed inside the scala

tympani, straddling the RW, straddling the basilar mem- 171
brane or situated in the scala vestibuli (Fig. 2). 172

Statistical analysis 173

Given the paired design of the study, the McNemar test was 174
used to compare these two techniques for categorical data 175
(cochleostomy precision). The level of significance was set 176
as $p \leq 0.05$. Statistical analysis was performed using SAS 177
software (SAS Enterprise Guide v5.1, Cary, North Car- 178
olina, USA). 179

Results 180

Twenty-four heads were implanted bilaterally: 54 % were 181
males ($n = 13$) and 46 % were females ($n = 11$). Twelve 182
heads had an MINV procedure on the left and an MPT on 183
the right. The remaining 12 had the sides reversed. The 184
endaural cochleostomies were strictly situated into the 185
scala tympani (i.e., without touching the basilar membrane 186
or the round window) in 87.5 % of cases versus 16.7 % of 187
cases that were performed with the posterior tympanic 188
approach ($p \leq 0.001$). The results on the precision of the 189
cochleostomy in the total population as a function of the ^{AQ5} 90
technique used are summarized in Table 1. 191

Discussion 192

In our study, cochleostomies performed by the endaural 193
approach had a greater probability of placement within the 194
scala tympani. The high rate of misplaced cochleostomies 195
(defined as not being completely located within the scala 196
tympani) can be partially explained, not only by the sur- 197
geon's experience, but also by our choice of classifying 198
extended cochleostomy (i.e., across the RW) as a mis- 199
placed cochleostomy: although some surgeons perform so- 200
called "marginal" cochleostomies straddling the RW [30] 201
without any post-operative complications, the RW has a 202
protective role in regulating molecular exchanges (antibi- 203
otics, local anesthetics) between the materials derived from 204
the tympanic cavity and vestibule [31]. From this point of 205
view, 46 and 92 % of the cochleostomies performed, 206
respectively, through a PT or an endaural approach were 207
into the scala tympani without injuring the basilar mem- 208
brane, some of them being extended cochleostomies. 209

Endaural cochleostomies 210

The cochleostomies for MINV in our study were performed 211
through an endaural approach, which is similar to the 212
suprameatal approach (SMA) [17] and the Veria approach 213

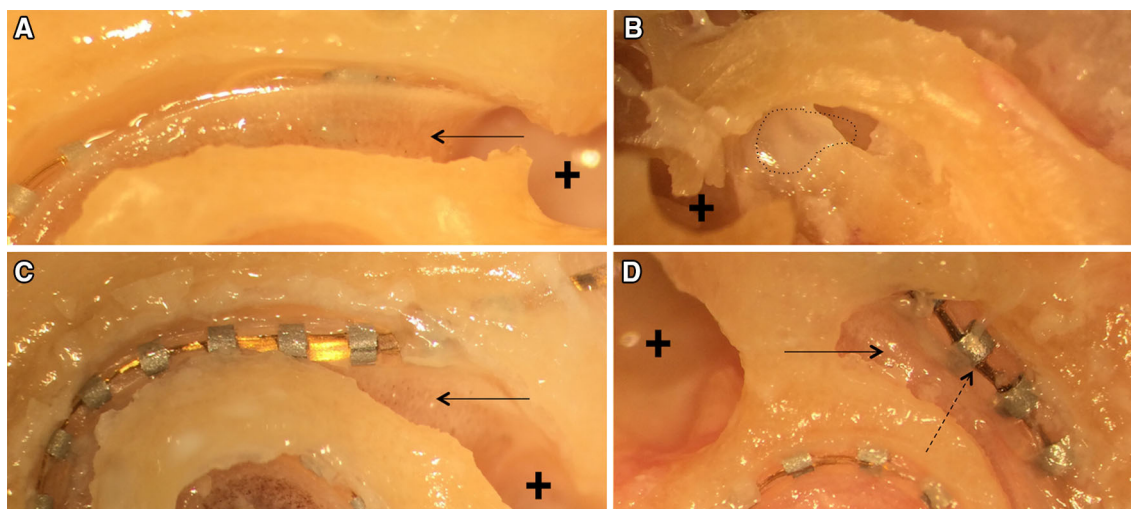


Fig. 2 Optical microscopy classification of the cochleostomy quality (X1, 6). **a** Cochleostomy strictly in the scala tympani; **b** cochleostomy across the round window membrane delimited by a dotted line. The electrode is not present on this picture in order to appreciate the lesion; **c** cochleostomy 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

214 [18]. In a histological study comparing these two preceding
 215 approaches (perimodiolar electrode arrays), Shapira et al.
 216 [32] highlighted the lower number of endocochlear traumas
 217 in the initial part of the basal turn with an endaural
 218 cochleostomy than with a RW approach or with a “mar-
 219 ginal” one performed by the PT approach. The authors
 220 explained their results by noting the more distal position-
 221 ing of the endaural cochleostomy along the scala tympani
 222 projection on the promontory, which is a concept that was
 223 already raised by Kronenberg in a prior anatomical study
 224 [17]. That distal positioning, with a more vertical drill-
 225 ing approach corresponding to a good insertion vector [33],
 226 allowed one to go past the dangerous “roller coaster” area
 227 (basilar membrane and osseous spiral lamina shapes) near
 228 the RW, especially with a straight electrode array. How-
 229 ever, a comparative study of the outcomes of residual
 230 hearing preservation with 109 patients that was undertaken

by Postelmans et al. [34] did not reveal significant differ-
 231 ences between the SMA approach and MPT. This finding
 232 suggests that hearing outcomes do not solely depend on
 233 the quality of the cochleostomy. With endaural access to
 234 the tympanic cavity, the improved visualization of the
 235 promontory and larger projection of the basal turn on its
 236 surface [35] might allow better positioning of an antero-
 237 inferior cochleostomy compared to a PT approach. How-
 238 ever, sometimes it might be impossible to correctly visu-
 239 alize the RW area with the endaural approach, and these
 240 cases would require the use of MPT or an endoscope [19].
 241

Posterior tympanotomy approach cochleostomies 242

Through this approach, the round window area is not always
 243 largely accessible. In a retrospective 3D radiologic study
 244 (20 temporal bones), Jeon et al. [36] found that the space
 245

246 between the facial and chorda tympani measures
 247 3.60 ± 0.2 mm and the top of the PT triangle angle mea-
 248 sures $18.40^\circ \pm 1.05^\circ$. In a prospective study evaluating the
 249 accessibility of the round window through an optimal PT,
 250 Leong et al. [37] found the incidence of a partially visible
 251 round window to be 17 % and that of a hidden round
 252 window to be 7 %. In case of extensive exposure drilling, it
 253 might expose the facial nerve and chorda to a higher risk of
 254 injury, especially for an inexperienced surgeon. In a histo-
 255 logical study, Adunka et al. [25] compared antero-inferior
 256 cochleostomies ($n = 7$) to strictly inferior cochleostomies
 257 ($n = 21$) performed with MPT. In all cases, the inferior
 258 cochleostomies avoided the spiral ligament, basilar mem-
 259 brane, spiral lamina and modiolus, while providing sys-
 260 tematic access to the scala tympani, confirming the
 261 anatomic recommendations made by Tóth et al. [35]. Briggs
 262 et al. [38] also recommend performing a cochleostomy in an
 263 inferior position with the PT approach. These procedures
 264 require one to drill the anterior pillar of the RW to clear its
 265 lower region, causing acoustic trauma of approximately
 266 100–130 dB should the burr touch the endosteum [39]
 267 (1 mm diamond bit, $\approx 24,000$ rpm). Even if a cochlear
 268 implantation is performed in case of severe-to-profound
 269 deafness (≥ 70 dB HL), one should endeavor to preserve
 270 residual hearing, especially given the growing number of
 271 studies demonstrating that electro-acoustic hearing may
 272 improve outcomes in certain patients. Based on histological
 273 sections, Li et al. [40] recently generated a 3D model of the
 274 fine endocochlear round window region structures and
 275 assessed their relationship: they found that inferior
 276 cochleostomies carry a risk of injury to the inferior cochlear
 277 vein and cochlear duct, which can cause degeneration of the
 278 ciliated cells and stria vascularis [41] and that strictly
 279 anterior cochleostomies carry a risk of injury to the spiral
 280 ligament, basilar membrane, scala media and extremity of
 281 the osseous spiral lamina. The ideal location, at least 1 mm
 282 from all of these at-risk structures, is antero-inferior
 283 according to these authors. But even if you are an experi-
 284 enced otologist surgeon, the antero-inferior cochleostomy
 285 position tends to “slip” more forward than initially anti-
 286 cipated: in the study of Adunka et al. [25] the seven temporal
 287 bones of the antero-inferior cochleostomy group exhibited
 288 avulsion of the spiral ligament, which is similar to our
 289 results (Table 1). Two other temporal bones of this group
 290 had a fracture of the osseous spiral lamina. The work of Li
 291 et al. [40] may provide a likely explanation for the failures
 292 reported by Adunka et al. [25], and ours, in which the
 293 antero-inferior cochleostomies had slipped too far forward.

294 The survey results of Adunka et al. and Iseli et al. [42,
 295 43] revealed that with the surgical vantage point via a
 296 posterior tympanotomy (100 otologist surgeons), the more
 297 experienced surgeons (≥ 50 cochlear implantations per
 298 year) had a greater likelihood of indicating a cochleostomy

299 placement to be in an inferior and anterior location. The
 300 experienced surgeons also had a higher probability of
 301 indicating an inferior and anterior cochleostomy location
 302 even in cases with incomplete round window visualization;
 303 perhaps reflecting better knowledge of temporal bone
 304 anatomy when compared to less experienced surgeons.
 305 Moreover, the optimal insertion vector, which might start
 306 at a supero-lateral position progressing to an infero-medial
 307 one (as near to the buttress or the emergence of the chorda
 308 tympani [33]), may not be as optimal as it should be, likely
 309 resulting from the anterior position of the cochleostomy.

310 By enlarging their cochleostomies, some surgeons have
 311 observed a decrease in traumas of the basilar membrane
 312 [44] or scala vestibuli opening [23] due to better visual-
 313 ization of endocochlear structures. Others have observed an
 314 increase in traumas [45]. Thus, experienced surgeons (≥ 50
 315 cochlear implantations per year), for Adunka et al. [42],
 316 tended to perform small cochleostomies (≤ 1 mm). The
 317 functional impacts on perilymphatic liquid leakage have
 318 not yet been described, but the directional effect of a tight
 319 cochleostomy on the electrode array is useful as long as the
 320 axis of insertion and cochleostomy are optimized in order
 321 to not aim, from the beginning of insertion, toward critical
 322 structures.

323 Finally, small inferior cochleostomies, performed
 324 through a PT approach, seem to be safer in practice than
 325 others, although they expose the cochlear duct or vein to
 326 injury. However, it requires a great surgical experience,
 327 probably explaining the poorer results of the inexperienced
 328 surgeon cochleostomies performed through a PT approach.
 329 In contrast, better exposure of the promontory with the
 330 endaural approach improves theoretically the potential for
 331 a safer antero-inferior cochleostomy, while preventing
 332 forward slippage and exposition hindrance of tight
 333 anatomical settings of the PT. In case of an anatomically
 334 difficult PT triangle and RW exposition, this study under-
 335 scores the importance of an inexperienced surgeon to
 336 consider performing a “reduced-risk” cochleostomy
 337 through an endaural approach. However, this approach
 338 requires lifting a tympano-meatal flap, which can result in
 339 1–3 % post-operative complications [46–49], the most
 340 serious being an infection near the prosthesis. Since 2010,
 341 our department has not observed any occurrence of such
 342 infectious complication using the MINV, probably because
 343 the inner rim of the bony canal is left intact in order to
 344 prevent later potential electrode array extrusion.

345 Conclusion

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

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

360 Compliance with ethical standards

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

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