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The Role of Electrode Placement in Bilateral Simultaneously Cochlear-Implanted Adult Patients

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ABSTRACT

29 **Objective:** To evaluate the influence on hearing performance of the electrode placement in
30 adult patients simultaneously and bilaterally cochlear implanted.

31 **Study Design:** Case series with planned data collection

32 **Setting:** Tertiary referral university centers

33 **Subjects and Methods:** The postoperative CT scan of nineteen patients simultaneously and
34 bilaterally implanted with a long straight electrode array was studied. The size of the cochlea
35 was measured considering the major cochlear diameter and the cochlear height. The
36 electrode-to-modiolus distance for the electrodes positioned at 180- and 360-degrees, and the
37 angular depth of insertion of the array were also measured. Speech perception was assessed at
38 1-year and at 5-years postimplantation using disyllabic words lists in quiet and in noise, with
39 the speech coming from the front, and a cocktail-party background noise coming from 5
40 loudspeakers.

41 **Results:** At 1-year postimplantation, the electrode-to-modiolus distance at 180-degrees was
42 correlated with the speech perception scores in both quiet and noise. In patients with a full
43 electrode insertion, no correlation was found between the angular depth of insertion and
44 hearing performance. The speech perception scores in noise gradually declined as a function
45 of the number of inserted and active electrodes. No relationship between electrode position
46 and speech scores was found at 5-years postimplantation.

47 **Conclusion:** In adult patients simultaneously and bilaterally implanted, the use of a long
48 straight array, the full electrode array insertion, and the proximity to the modiolus might be
49 determining factors to obtain the best speech performance at 1-year, without influence on the
50 speech scores after long-term use.

51 **Key words:** bilateral implantation, speech perception, electrode position, cochlear implant,
52 angular depth of insertion, cochlear size

INTRODUCTION

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The preservation of the inner ear structures during the insertion of cochlear implant, together with the identification of the ideal site of stimulation in the cochlea, should allow the best hearing performance. As a consequence, the quality of insertion of the cochlear implants has been extensively studied during the last decades¹⁻⁵. In this context, three parameters have been more accurately investigated: the translocation of the array with the subsequent basilar membrane rupture, the depth of insertion of the electrode array, and the proximity of the electrodes to the spiral ganglion cells. To date, it is not clear how the position of the electrode in the cochlea can impact the hearing performance results, since many variables may influence this outcome. All the currently available electrode arrays have their own specific length, diameter, shape, and physical properties that influence the trajectory during the insertion and determine the final position in the cochlear lumen. Furthermore, variations in human cochlear anatomy, as well as the intersubject variability, have been described in several studies⁶⁻⁸, whereas little is known about the intrasubject difference, i.e. the differences between the two ears.

Considering the hearing performance after cochlear implantation, intraindividuals variability in speech perception scores has been demonstrated among bilaterally cochlear implanted recipients^{9,10}. In fact, in a prospective multicenter study, poor performance of one or both ears was reported at 1-year postimplantation in about 40% of simultaneously implanted patients with similar hearing loss history between the two ears (hearing deprivation, duration of deafness, etiology)¹⁰. An explanation for poor hearing performance and/or asymmetry between the two ears could be differences in the electrode position within the cochlea⁵. The aim of the present study is to explore the correlation between speech performance and electrode placement parameters in patients simultaneous and bilaterally implanted, and to

78 investigate whether cochlear anatomy differences could explain inter- and intraindividual
79 differences in hearing performance.

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MATERIALS AND METHODS

82 Selection criteria and subjects

83 Study participants were 19 adult patients presenting a post-lingual bilateral profound or total
84 hearing loss. Specific subject demographics are summarized in Table 1. The duration of
85 deafness, of hearing deprivation, of hearing aid use, and the etiologies were similar for both
86 ears. Enrolling criteria, speech perception evaluation setting, and results at 1- and at 5-years
87 have been previously reported^{10,11}. To be implanted, patients were required to have a
88 maximum of 10% open set disyllabic word recognition score in quiet at 60 dB in the best-
89 aided condition, a difference of profound hearing loss duration between the two ears of less
90 than 5 years, and no malformations of the cochlea. Speech perception tests in quiet and in
91 noise (SNR of +15 dB, +10 dB and +5 dB) were performed before implantation, at 1-year,
92 and 5-years after activation. Responses were scored as the percentage of words correctly
93 identified. All patients underwent bilateral implantation by expert otologists (more than 100
94 CI procedures) in a simultaneous surgical procedure with the same device (MED-EL Combi
95 40+, Standard Electrode Array, 31 mm length; Innsbruck, Austria).

96 A multi-slice helical CT scan (500 μ m slice thickness), was realized in the immediate
97 postoperative period.

98 All participants gave their informed written consent, and the study was approved by the local
99 ethical committee (Saint-Louis, Paris, No. 61D0/22/A).

100

101 Radiological analysis

102 The DICOM (Digital Imaging and Communications in Medicine) data were analyzed by
103 Osirix program (Osirix v 4.0 64-bit; Pixmeo Sarl, Bernex, Switzerland). This program
104 allowed multiplanar reconstructions of cochlear anatomy and position of the arrays in the
105 cochlea. All the images, acquired by different CT scans in the different centers, were
106 reconstructed with 0.1 mm increments in order to standardize the measurement technique and
107 reduce the error of measurement. To examine the cochlear sizes and their relationship with the
108 insertion depth, a three-dimensional coordinate system was used, in accordance with the
109 consensus of cochlear coordinates¹², with the exception of the cochlear height that was
110 measured in a reformatted coronal view. The largest cochlear diameter (distance A) going
111 from the center of the round window membrane to the opposite lateral wall¹³, was calculated
112 on a plane perpendicular to the modiolus axis and coplanar to the basal turn, named ‘cochlear
113 view’ by Xu et al.¹⁴ (Fig. 1A). The cochlear height was measured from the mid-point of the
114 basal turn to the mid-point of the apical turn on a coronal section^{15,16} (Fig. 1B). The
115 electrode-to-modiolus distances (EMD) for electrodes positioned at 180- and 360-degrees
116 were measured on the mid-modiolar plane, crossing the mid of the round window (Fig. 1C).
117 The angular depth of insertion of the array was measured in the ‘cochlear view’ (slice thick of
118 5 mm), considering the mid-point of the round window as the 0-degrees reference (Fig. 1D).
119 To minimize the error, all the measurements were performed blindly by an otologist, each
120 measurement was repeated three times in nonconsecutive days, and the mean value was then
121 considered.

122

123 **Statistical analysis**

124 Values are expressed as means \pm standard error of the mean (SEM). For correlations between
125 cochlear anatomy and cochlear array localization, and its relation with speech perception
126 scores, Pearson’s correlation coefficient (r) was calculated, and the ANOVA was used to test

127 the slope of the linear regression line. One-way ANOVA was used to analyze the influence of
128 the number of activated electrodes on speech performance. Student's t-test was used for
129 comparisons between groups (male/female, right/left cochleae, full/partial insertions). For all
130 comparisons, $p < 0.05$ was considered as significant. All statistical analyses were performed
131 using IBM SPSS for Windows (v 22.0, SPSS Inc., Chicago, Illinois, USA).

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133

134

RESULTS

135 The mean speech performance in quiet and noise have previously been reported¹⁰. At 1-year
136 post-implantation, 7 patients were poor performers (speech perception scores in quiet < 60%
137 in bilateral condition). Among the good performers, 9 patients obtained asymmetrical
138 performance (difference of speech scores in quiet between the two ears $\geq 20\%$).

139

140 Cochlear anatomy and electrode position

141 The cochlear anatomical data are reported in Table 2. The distance A was positively
142 correlated with the cochlear height ($r=0.52$, $p=0.0007$, data not shown). Surprisingly, the
143 distance A and the cochlear height were different between the two ears (difference of mean
144 distance A: 0.22 ± 0.05 mm, $p=0.04$; difference of mean cochlear height: 0.3 ± 0.06 mm,
145 $p=0.001$, Student's t tests); no right or left ear predominance was observed. The distance A
146 and the cochlear height were different as well between male and female ears, the males
147 having a diameter and a cochlear height greater than females ($p=0.0001$, Student's t tests).

148 A full insertion of the electrode array was achieved in 26 ears, and a partial insertion in 12
149 ears (3 patients with a bilateral partial insertion, and 6 patients with a unilateral partial
150 insertion). In ears with an incomplete insertion, the number of extra-cochlear electrodes

151 ranged from 1 to 4. The size of the cochlea (i.e. distance A and cochlear height) was similar
152 between the ears with a full insertion and ears with a partial insertion (Table 3).
153 In the 26 ears with a full electrode insertion, the angular depth of insertion in the cochlea
154 varied widely [510-880-degrees] (Fig 2), and was negatively correlated with the distance A
155 ($r=-0.55$, $p=0.003$) (Fig. 3A), on the other hand no correlation was found with the cochlear
156 height (Fig 3B). The EMD was positively correlated with the distance A at both 180- ($r=0.47$,
157 $p=0.0004$) and 360-degrees ($r=0.66$, $p=0.0002$, Fig. 3C), and with the cochlear height at 360-
158 degrees ($r=0.6$, $p=0.001$, Fig. 3D). The EMD distance at 180- and at 360-degrees was not
159 correlated with the angular depth of insertion. These results indicate that in large cochleae
160 (distance A), the electrode array was less deeply inserted and more distant from the modiolus
161 at the basal turn (EMD at 180-degrees and 360-degrees). In the present study, the distance A
162 was sufficient to define the cochlear size and reliable for the prediction of the position of the
163 implant within the cochlea.

164

165 **Correlation between electrode position and speech perception**

166 At 1-year after cochlear implantation (38 implanted ears), speech perception scores were
167 negatively correlated with EMD at 180-degrees both in quiet ($r=-0.34$, $p=0.02$) and in noise
168 (SNR +15 dB: $r=-0.44$, $p=0.006$; SNR +10 dB: $r=-0.63$, $p=0.0005$; SNR+5 dB: $r = -0.52$,
169 $p=0.01$, Fig. 4). The greater the EMD was, the poorer was the performance. No correlation
170 was observed at 360-degrees. The number of inserted electrodes was correlated with speech
171 perception in noise at SNR +15 dB and SNR +10 dB (ANOVA, $p=0.02$); the speech
172 perception scores in noise gradually decreased as a function of the number of inserted
173 electrodes (post hoc Dunnett's t test $p=0.02$) (Table 3). Considering the obvious
174 interdependence between the number of intracochlear electrodes and the depth of insertion,
175 we analyzed the influence of electrode position on hearing outcomes among the 26 ears with a

176 full insertion of the electrode array. No correlation was found between the speech perception
177 scores and the angular depth of insertion, both in quiet and in noise, whereas the speech
178 perception scores were negatively correlated with EMD at 180-degrees both in quiet ($r=-$
179 $0.38, p=0.048$) and in noise (SNR +15 dB: $r=-0.4, p=0.049$; SNR +10 dB: $r = -0.62, p=0.006$;
180 SNR+5 dB: $r=-0.51, p=0.032$, data not shown).

181 A multifactorial ANOVA was performed and failed to demonstrate that the anatomic cochlear
182 variations (distance A, cochlear height), and the different electrode position (EMD at 180- and
183 360-degrees) between the two ears, were the reason of the asymmetric speech score
184 (difference $\geq 20\%$ between better and poorer ear) at 1-year in 9 patients.

185

186 At 5-years post-implantation, most of the patients (85%) achieved good speech performance
187 (speech perception score $\geq 60\%$ in quiet in bilateral condition); the speech score of the poorer
188 ear in noise continued to improve over time, and the majority of the patients with poor speech
189 scores improved their performance both in quiet and in noise¹¹. Studying the relationship
190 between the electrode insertion parameters and the hearing outcomes, no correlation was
191 found at 5-years postimplantation between speech perception scores and the angular depth of
192 insertion, both in the entire sample and in the group with full insertion of the electrode array.
193 In contrast to what observed at 1-year postimplantation, the EMD was not correlated with
194 speech perception scores, both at 180-degrees and 360-degrees (data not shown).

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DISCUSSION

199 We have previously shown that in adult patients simultaneously and bilaterally implanted,
200 poor or asymmetrical hearing performance at 1-year postimplantation are present in 40% of

201 cases, and that the speech scores of the poorer ear continues to improve over time^{10,11}. In the
202 present study, we demonstrate that both the distance between electrode array and modiolus at
203 180-degrees, and the number of inserted electrodes, are important variables that influence the
204 early achievement of the best speech perception scores. The variability in cochlear anatomy
205 could explain the differences in hearing outcomes between patients; nevertheless we failed to
206 demonstrate an influence of cochlear geometry on intraindividual speech perception
207 asymmetry, probably due to the small number of patients with asymmetric speech scores.

208

209 **The variability in cochlear anatomy influences electrode array position**

210 Several studies investigated the influence of cochlear anatomy on electrode array position
211 within the cochlea¹⁷⁻²¹. Important variations in the first segment of the scala tympani, such as
212 unusual narrowing or constriction, have been reported. The basal end of the cochlea is in fact
213 of major interest in cochlear implant surgery; it bends in three dimensions, resembling to a
214 “fish hook”, and in some cases its anatomical variations lead to a difficulty for the surgeon to
215 choose the ideal cochleostomy site in order to reach the scala tympani without damaging any
216 inner ear structure⁷.

217 In this study the cochlear size was assessed using the major cochlear diameter of the basal
218 turn, that is assumed to be a good predictor of the length of the two first turns of the
219 cochlea^{22,23,24}, and using the cochlear height; our results are in line with the data present in
220 literature^{6,8,13,15,16}. These two measures are clearly correlated to each other, meaning that a
221 greater basal turn diameter is associated to a higher cochlea. Both distance A and cochlear
222 height vary with sex, males having bigger cochlea compared to females, as already described
223 in the literature^{13,16,20}. Additionally, we observed an asymmetry between the two ears in
224 distance A (0.22 mm), that was only described by Escude et al.¹³, and in cochlear height (0.3
225 mm). No ear predominance was found, as previously reported^{16,20,23-25}.

226

227 In patients implanted with long (31 mm) and straight electrode arrays, we demonstrated that
228 as expected, the smaller the diameter of the cochlea is, the closer is the electrode array to the
229 modiolus at the basal turn, and the deeper is the array insertion. The depth of array insertion
230 was strongly correlated ($r=-0.63$) with the major cochlear diameter measurement, with a
231 shallower insertion in bigger cochlea and deeper insertion in smaller cochlea. Van der Marel
232 et al.²⁰ found a weaker correlation (Pearson's $r = -0.3$) analyzing 362 cochleae implanted with
233 Advanced Bionics implants. In other studies, a more significant correlation between depth of
234 insertion and cochlear diameter was found using straight electrodes^{21,26}.

235 An incomplete insertion of the electrode array was observed in 12/38 ears (32%). This
236 observation is in accordance with a histopathological study, which reported the 52% of
237 incomplete insertion in absence of intrascalar bony or soft tissue that could explain a partial
238 insertion²⁷. The anatomical study of Rask-Andersen et al.⁷ describes a narrowing of the
239 cochlear duct or a sharp bend of cochlear coiling between the first and the second turn as
240 another possible cause for incomplete insertion. No significant difference in the size of the
241 cochlea between ears with incomplete and complete insertions was found in our study,
242 nevertheless it should be noticed that the three cochleae with 4 electrodes outside, had a
243 smaller distance A than the other ears (see Table 3). On the base of the cochlear length
244 equation based on distance A value (Alexiades et al.²⁴), we can assume that a 31 mm length
245 array was too long to be totally inserted in these three ears. At the present, different lengths of
246 cochlear arrays are available, and it is crucial to measure the distance A before implantation in
247 order to adapt the type (and length) of the electrode array to be implanted.

248

249 **Is the electrode position related to speech perception?**

250 If we consider the ears with full insertion of the electrode array, despite a large variation of
251 the angular depth of insertion, no correlation was found between this variable and the hearing
252 performance. This observation is consistent with a histological analysis over a series of 27
253 temporal bone specimens of subjects with cochlear implant²⁸. Van der Marel et al.²⁹ analyzed
254 six position-related variables including the angular and linear insertion depth of the array and
255 did not find any correlation with speech outcomes at 2-years postoperative. In a prospective
256 randomized study including 13 patients, Buchman et al.³⁰ didn't find a difference in speech
257 scores between MedEl standard array (mean angular depth of insertion 657-degrees) and
258 medium array (mean angular depth of insertion 423-degrees), although better performance
259 was found in the standard array group when 6 more patients were included retrospectively. On
260 the contrary, other studies reported poorer performance in case of deeper insertions³¹,
261 explained by the increased number of electrodes in the scala vestibuli, reduced pitch
262 discrimination, decreased basal stimulation³², and pitch confusion at apical contacts³³. The
263 negative correlation between the electrode angular depth of insertion and hearing outcomes
264 found by Yukawa et al.³⁴ may be explained by the presence of confounding factors, such as
265 the lower number of activated electrodes in case of partial insertion. Indeed, in the present
266 study, in case of incomplete insertion, the speech perception scores in noise at 1-year
267 decreased as a function of the number of inserted electrodes (see Table 3).

268 Considering the distance between the electrode array and the modiolus, it has been shown that
269 a closer position to the spiral ganglion cells is associated with better speech perception^{18,32}.
270 This effect may be related to the minimization of channel interaction, which leads to reduction
271 of electrical thresholds and/or improvement of the spatial selectivity. Our findings are in
272 accordance with Esquia-Medina et al.¹⁸ who reported a correlation between speech perception
273 scores and average EMD of the 6 most basal electrodes of MED-EL devices (corresponding
274 approximately to the region from 0- to 180-degrees) at 6 months, whereas no correlation was

275 found at 12 months. In this study, as well as the present one, such relationship was not present
276 for the electrode at 360-degrees, possibly due to the narrowing of the scala tympani from base
277 to apex³⁵ that reduces the variability of the array position. This relationship between the EMD
278 and the hearing performance could point out a preferential use of perimodiolar electrode array
279 in order to obtain a rapid hearing rehabilitation. Nevertheless, Doshi et al.³⁶ reported no
280 differences between speech perception outcomes at 3- and 9-months in patients implanted
281 with either straight or perimodiolar electrodes array. A reason could be the more frequent
282 dislocation from scala tympani to scala vestibuli in case of perimodiolar electrodes³⁷.
283 Although such scalar dislocation is difficult to assess in standard CT scan, it might negatively
284 influence the cochlear implant outcome^{4,5,33,38}. An aspect that has not been explored in this
285 study is the surgeon's gesture. A recent study described a high intra- and inter-individual
286 variability of the insertion axis of the array into the cochlea; yet, this variability was reduced
287 among expert surgeons³⁹. Since all the participants to the present study were senior otologists,
288 we estimate that this doesn't represent a great factor of bias of the study; furthermore, how the
289 insertion axis influences the trajectory of insertion or the final position of the array has not yet
290 been described or reported. An additional limitation of this study could be represented by the
291 migration of the array that can occur between 1- and 5-years. Nevertheless, in all patients the
292 most basal electrodes remained activated with stable impedance values over time and
293 providing auditory responses, thus an extrusion of the electrodes should be unlikely⁴⁰.
294 In conclusion, whereas 1-year results suggest that the number of inserted electrodes and the
295 distance electrode-to-modiolus are related to good performance, these parameters does not
296 influence the speech scores after long term use. In order to obtain a rapid hearing
297 rehabilitation and the best results at 1-year, the preoperative measurement of the cochlear
298 diameter (distance A) may guide the choice of the correct array length allowing a complete
299 insertion. In case of unilateral implantation the choice of the side to be implanted should be

300 oriented, in presence of equal clinical and audiological conditions of the two ears, to the
301 smaller cochlear diameter.

302

303

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308

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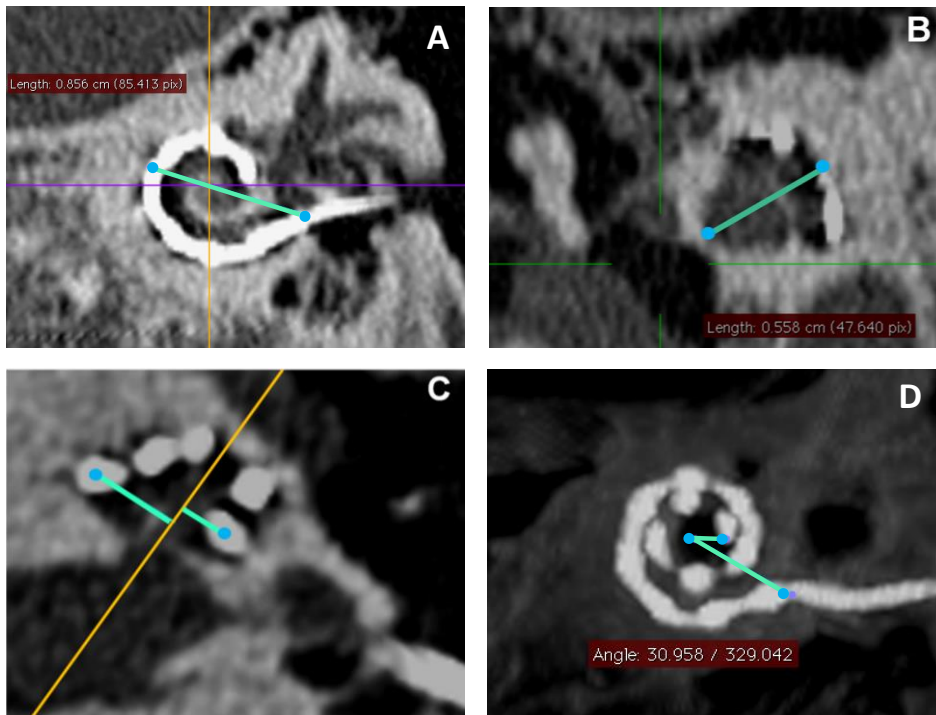
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428 **FIGURES**

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431 Figure 1:

432 Radiological analysis (CT scan). A. Cochlear diameter (Distance A). B. The cochlear height

433 was measured in the coronal reconstruction. C. The electrode-to-modiolus distance (EMD) at

434 180-degrees and 360-degrees. D. Angular depth of insertion.

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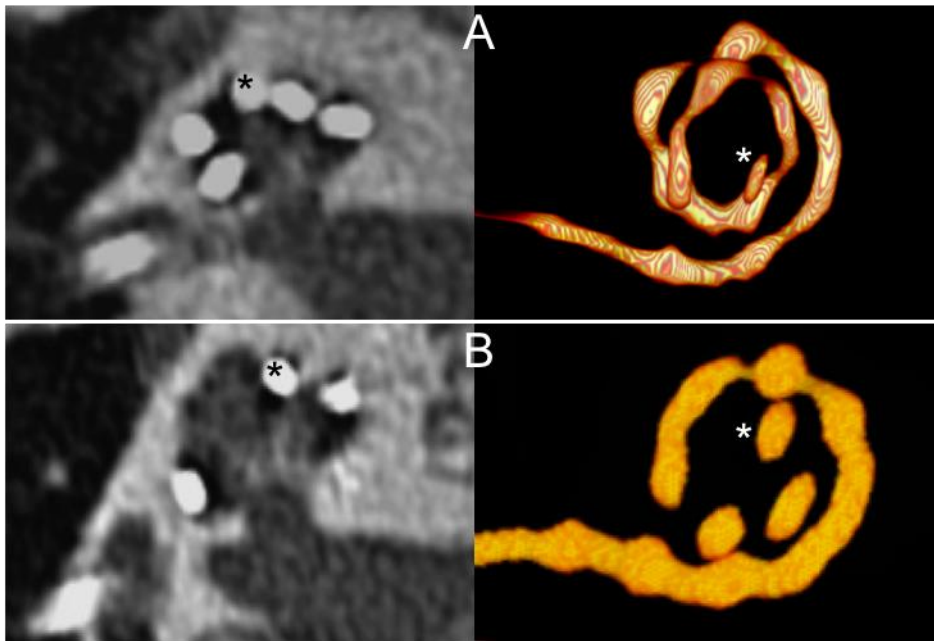
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445 Figure 2: Variability of the angular depth of insertion among cochleae with complete array
446 insertion in mid-modiolar cuts and 3D volumetric reconstruction of the array. A. 880-degree
447 insertion. B. 550-degree insertion. The asterisks (*) represent the apical electrode.

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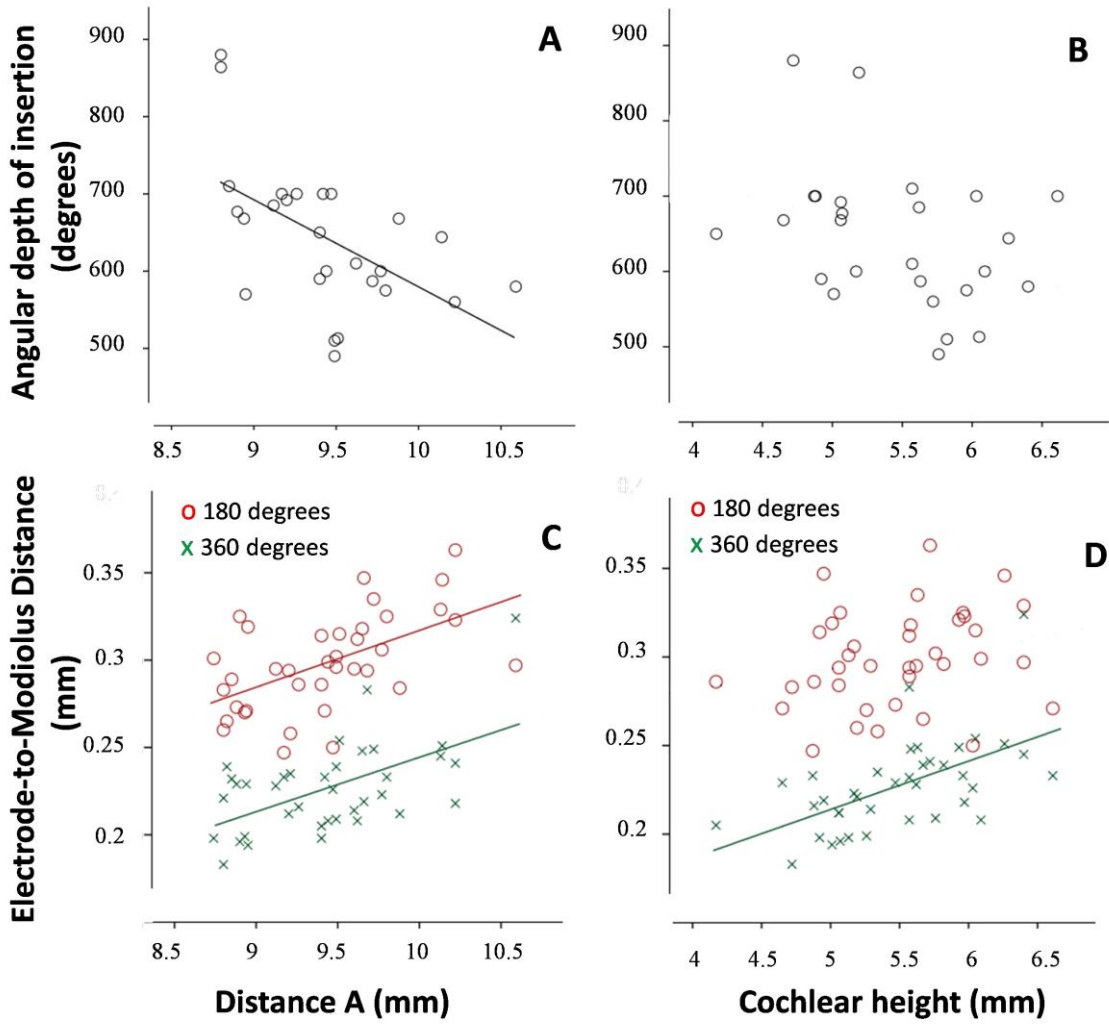
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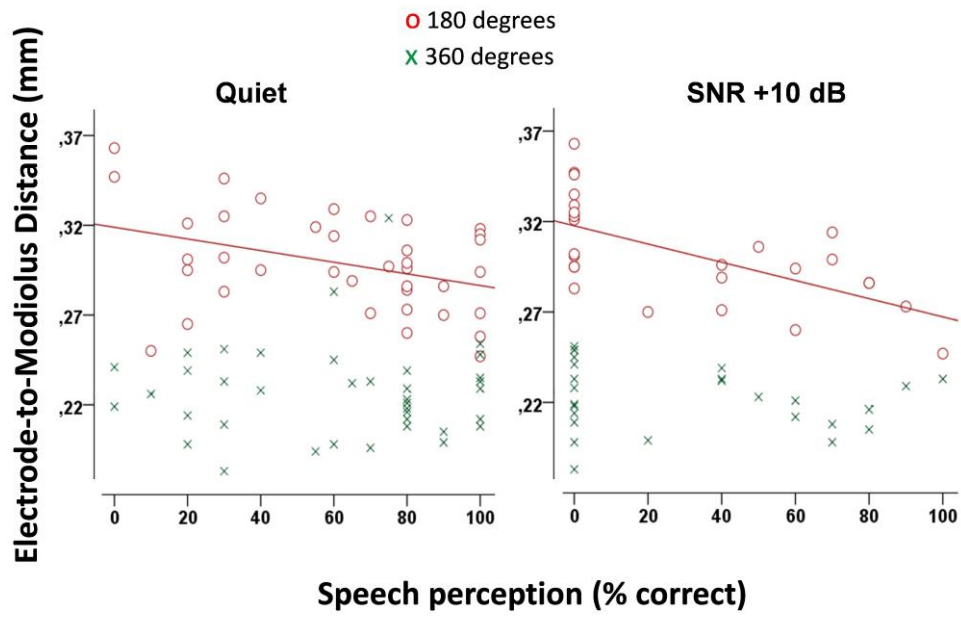


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462 Figure 3: Correlation between the size of the cochlea (cochlear diameter, cochlear height) and

463 the position of electrode array (Electrode-to-modiolus distance, angular depth of insertion).

464 The lines represent the significant linear regression.



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466 Figure 4: Correlations between the electrode array position and the speech perception scores
 467 in quiet and at SNR +10 dB at 1-year at 180-degrees. No correlation was found at 360-
 468 degrees. The lines represent the significant linear regression.

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478 **Table 1: Patients Demographics (n = 19)**

Age at implantation (yrs)		46 ± 3 [24-68]
	Sex: Male/Female	5/14
Duration of hearing loss (yrs)		
	Right ear	23.5 ± 3.0 [1-51]
	Left ear	23.4 ± 3.2 [1-51]
Duration of profound hearing loss (yrs)		
	Right ear	3.0 ± 0.5 [1-9]
	Left ear	2.7 ± 0.5 [0-9]
Use of hearing aids before implantation		
	Bilateral	12
	Unilateral	1
	None ^a	6
Duration of hearing aid use (yrs)		
	Right ear	10 ± 3 [1-41]
	Left ear	10 ± 3 [1-41]
Etiology ^b		
	Unknown	6
	Sudden hearing loss	6
	Genetic/Familial	4
	Traumatism	1
	Otosclerosis	1
	Meningitis	1

479 Values are expressed as mean ± SEM [range] or only number of patients

480 a. These patients never tried hearing aid because of sudden total bilateral hearing loss. b.

481 Same etiology for both ears.

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486 **Table 2: Cochlea measurement and electrode array placement on CT scan (19 patients,**
 487 **38 ears)**

Distance A (mm), n = 38 ears	9.4 ± 0.08 [8.8 – 10.6]
Male (n = 10)	9.9 ± 0.12 [9.7-10.6]
Female (n = 28)	9.3 ± 0.07 [8.8-10.2] *
Ears with full insertion of electrode array (n = 26)	9.4 ± 0.09 [8.8-10.6]
Ears with partial insertion of electrode array (n = 12)	9.6 ± 0.16 [8.9-10.2]
Cochlear height (mm), n = 38	5.5 ± 0.09 [4.2 - 6.4]
Male (n = 10)	6 ± 0.09 [5.5 - 6.4]
Female (n = 28)	5.5 ± 0.09 [4.2 - 6.6] **
Ears with full insertion of electrode array (n = 26)	5.4 ± 0.12 [4.2 - 6.6]
Ears with partial insertion of electrode array (n = 12)	5.5 ± 0.13 [4.9 - 6.4]
Angular depth of insertion (degrees)	
Ears with full insertion (n = 26)	643 ± 93 [510 - 880]
Ears with partial insertion (n = 12)	403 ± 82 [318 - 590] **
Total (n = 38)	567 ± 23 [318 - 880]
EMD 180-degrees (mm)	
Ears with full insertion (n = 26)	0.29 ± 0.004 [0.25 - 0.36]
Ears with partial insertion (n = 12)	0.29 ± 0.008 [0.26 – 0.35]
EMD 360-degrees (mm)	
Ears with full insertion (n = 26)	0.22 ± 0.004 [0.18 - 0.32]
Ears with partial insertion (n = 12)	0.23 ± 0.006 [0.2 – 0.28]

488 Values are expressed as mean ± SEM [range]. A full electrode array insertion was achieved in
 489 26 ears and a partial electrode array insertion in 12 ears. Comparison of distance A and
 490 cochlear height between males and females, and of angular depth of insertion between ears
 491 with full or partial insertion, * $p < 0.05$, ** $p < 0.001$, Student's t test. EMD: electrode-to-
 492 modiolus distance

493 **Table 3: number of inserted electrodes, cochlear measurements and speech perception**
 494 **score at 1 year**

Inserted Electrodes	Distance A (mm)	Cochlear height (mm)	Speech score at 1-yr	
			Quiet	SNR +15 dB
<i>Full insertion</i>				
12 electrodes (26 ears, 16 patients)	9.4 ± 0.08 [8.8 - 10.6]	5.4 ± 0.12 [4.2 - 6.6]	64 ± 6	54 ± 7
<i>Partial insertion</i>				
11 electrodes (3 ears, 3 patients)	9.5 ± 0.14 [9.2 - 9.6]	5.2 ± 0.12 [5.3 - 4.9]	63 ± 27	46 ± 13
10 electrodes (4 ears, 4 patients)	9.7 ± 0.32 [8.8 - 10.2]	5.9 ± 0.19 [5.6 – 6.4]	52 ± 18	30 ± 4
9 electrodes (2 ears, 2 patients)	9.8 ± 0.13 [9.6-10.1]	5.7 ± 0.25 [5.6 – 5.9]	60 ± 40	15 ± 15
8 electrodes (3 ears, 2 patients)	8.8 ± 0.09 [8.7 – 8.9]	5.3 ± 0.17 [5.1 – 5.5]	43 ± 18	10 ± 10 *

495 Values are expressed as mean ± SEM [range]. The mean number of electrodes outside the
 496 cochlea was 2.4 (range: 1-4). More than 3 electrodes out of the cochlea influenced the speech
 497 scores in noise. * $p = 0.02$, One-way ANOVA, post hoc Dunnett's t test.

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