Difficult cochleostomy in the normal cochlea

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Background
The concept that the morphological and the spatial orientation of the labyrinth does not change postnatally is undergoing a worldwide discussion by cochlear implant surgeons. The main objective of this study was to examine the basal turn angulation of the cochlea relative to the midsagittal line to find a possible relationship with the difficulty in implanting the normal cochlea.

Participants and methods
A retroprospective descriptive study was conducted on two equal groups, each consisting of six cochlear implantees. All patients of both groups were having bilateral profound sensorineural hearing loss with normal patent cochlea. The basal turn angle (BTA) of the cochlea relative to the midsagittal plane was measured using the preoperative axial view of the computed tomography (CT) imaging.

Results
A retrospective study was performed on the first group of six cochlea implantees without difficult cochleostomy as noted in the operative notes and correlated with the postoperative BTAs (range = 55–60°) measured later, using patients' preoperative CT images, which were within the normal range. A blind prospective study was performed on the second group of six patients undergoing cochlear implantation in which difficult cochleostomy was faced intraoperatively in one patient (number 2), whose preoperatively measured BTA was 65° (i.e. more obtuse than the normal range), predicting a rotated cochlea with difficult cochleostomy, which was actually faced intraoperatively. BTAs of other five implantees in this group (55, 62, 50, 56, and 57°, respectively) were within the same range as our first group, predicting no difficulty, and this was also found intraoperatively.

Conclusion
Our results were comparable to those of the three pediatric cochlear implantees reported with difficult cochleostomy in whom the BTAs were more obtuse than normal, indicating a rotated cochlea. The possibility of a rotated cochlea should be borne in mind when difficult cochleostomy is encountered. Measuring the BTA of the cochlea relative to the midsagittal plane in all preoperative CT scans is advised to identify cases in which the basal turn of the cochlea may have an unusual orientation. Scala vestibuli insertion or a combined approach technique in case of encountered difficult cochleostomy is highly recommended.

Keywords:
apparent normal cochlea, cochlear basal turn angle, cochlear implantation, difficult cochleostomy, rotated cochlea

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Introduction and objective

In the past, it was believed that the otic capsule at birth is in a mature state. Nowadays, the concept that the morphological and the spatial orientation of the labyrinth does not change postnatally is undergoing a worldwide discussion by cochlear implant surgeons. Difficult cochleostomy in apparently normal cochlea may be due to cochlear rotation, tilting, or misalignment. Our objectives were as follows:

(a) to study and examine the basal turn angulation of the cochlea relative to the midsagittal line to find a possible relationship with the difficulty in implanting normal cochlea;
(b) to compare our results with those of Lloyd *et al.* [1], who considered a rotated cochlea when the measured basal turn angle (BTA) was more obtuse than that of the normal age standard;
(c) to draw the attention of cochlear implant surgeons toward the possibility of a rotated cochlea when they face difficulty in implanting normal cochlea.

Design and setting

A retroprospective descriptive study was conducted on 12 cochlear implantees at King Abdulaziz University Hospital (KAUH), Riyadh, in the period between 30 November 2011 and 9 May 2012.

Participants and methods

Two equal groups, each consisting of six cochlear implantees, were studied. All patients of both groups had bilateral profound sensorineural hearing loss with normal patent cochlea and a negative history for congenital anomalies, middle-ear infection, trauma,

or meningitis. The BTA of the cochlea relative to the midsagittal plane was measured in both groups by the second author, using the preoperative axial view of the computed tomography (CT) imaging. CT-imaging picked up by Centricity Radiology RA 1000 Workstation, (GE Healthcare, Barrington, USA) and the CT-scanner used to acquire the imaging was Phillips Brilliance iCT 256slice Helical Scanner (Holland).

The first group

Six cochlear implantees (age range = 3 years 9 months to 5 years 6 months) were studied retrospectively in the period between 30 November 2011 and 8 February 2012 (Table 1).

The second group

A prospective blind study was conducted on six patients (age range = 4 years 5 months to 39 years 7 months) undergoing cochlear implantation in the period between 22 February 2012 and 9 May 2012 (Table 2). We compared our results with those of Lloyd *et al.* [1], who considered a rotated cochlea when the measured BTA was more obtuse than that of the normal age standard.

Results

The first group

Six cochlear implantees (three female, three male) with an age range from 3 years 9 months to 5 years 6 months, were

Table 1 The retrospective group

Number of patients	1	2	3	4	5	6
Age at CI date	3 years and 9 months	2 years and 9 months	5 years and 6 months	4 years and 4 months	3 years and 11 months	4 years and 2 months
Sex	F	M	M	F	F	M
CI side	Left CI	Right CI	Right CI	Right CI	Right CI	Right CI
Cochleostomy and electrode insertion	No difficulty	No difficulty	No difficulty	No difficulty	No difficulty	No difficulty
Preoperative CT scan of temporal bone	Cochleae were bilaterally normal	Cochleae were bilaterally normal	Cochleae were bilaterally normal	Cochleae were bilaterally normal	Cochleae were bilaterally normal	Cochleae were bilaterally normal
BTA, later postoperative BTAs measurement	55°	58°	60°	56°	55°	55°
Transorbital plain radiograph	The electrode was *in situ*	The electrode was *in situ*	The electrode was *in situ*	The tip of electrode was coiled at the first turn of right cochlea	The electrode was *in situ*	The electrode was *in situ*

A study of the documented patient data including surgical and imaging findings revealed that cochleae were normal and a difficult cochleostomy was not faced. Later postoperative measurement and study of BTAs was in accordance with the surgical findings. BTA range: 55–60°; mean: 56.5°; SD = 1.89. These BTAs were within the normal range suggested by Lloyd *et al.* [1]; BTA, basal turn angle; CT, computed tomography.

Table 2 The prospective blind group

Number of patients	1	2	3	4	5	6
Age	39 years and 7 months	4 years and 5 months	4 years and 5 months	5 years and 5 months	4 years and 9 months	5 years and 1 month
Sex	M	M	M	F	F	M
Preoperative CT scan of temporal bone	Patent cochleae	Patent cochleae	Patent cochleae	Patent cochleae	Patent cochleae	Patent cochleae
BTA, a preoperative measuring study of BTAs	Left 55°	Right 65° suspecting intraoperative difficult cochleostomy	Right 62°	Right 50°	Left 56°	Right 57°
CI side	Left CI	Right CI	Right CI	Right CI	Left CI	Right CI
Cochleostomy	No difficulty	Difficult cochleostomy	No difficulty	No difficulty	No difficulty	No difficulty
Electrode insertion	Full insertion	Full insertion	Full insertion	Full insertion	Full insertion	Full insertion
Postoperative transorbital radiograph	The electrode is *in situ*	The electrode is *in situ*	The electrode is *in situ*	The electrode is *in situ*	The electrode is *in situ*	The electrode is *in situ*

The patients' CT images were studied preoperatively, and BTAs were measured only by the second author. The CI surgeon was not informed of the values of the BTAs measured preoperatively. The second author assisted the CI surgeries to gather the intraoperative findings, correlating them with the BTAs measured preoperatively. BTA range: 50–65°; mean: 57.5°; SD = 4.86. A difficult cochleostomy was faced in patient number 2 of this group, which correlated with his BTA 65° (i.e. more obtuse than those of the normal age standard suggested by Lloyd and colleagues in Table 3). This case was comparable to those of Lloyd *et al.* [1] who reported three cases with a more obtuse BTA than normal and difficult cochleostomy was also faced. Other patients in our group had BTAs that were within the normal range suggested by Lloyd *et al.* [1], and therefore, a difficult cochleostomy was not faced. The BTAs measured preoperatively predicted the intraoperative findings of this group; BTA, basal turn angle; CT, computed tomography.

prelingually deaf. Measurement of BTAs was performed later postoperatively using patients' preoperative CT images. The measured BTAs (55, 58, 60, 56, 55, and 55°, respectively) (Table 1, Figs. 1-3) were within the normal range suggested by Lloyd *et al.* [1] (Table 3) and correlated with the documented surgical findings of these individuals' cochlear implantation without difficulty.

The BTA range was 55–60° with a mean of 56.5° and an SD of 1.89.

This retrospective group did not reveal any difficult cochleostomy. The BTAs were in accordance with the intraoperative findings in this group.

The second group

Six patients were included in this group: one adult male (39 years 7 months) and five children (three male, two female) with an age range from 4 years 5 months to 5 years 5 months. All children were prelingually deaf.

The BTA was measured preoperatively (Table 2). The BTA range was 50 to 65° with a mean of 57.5° and an SD of 4.87.

In patient number 2 (Figs. 4 and 5), the BTA was 65°. This degree of BTA was outside the normal range suggested by Lloyd *et al.* [1]. Difficult cochleostomy was faced in this patient. Drilling towards the stapes foot plate was the solution to find a cochleostomy (probably into the scala vestibuli).

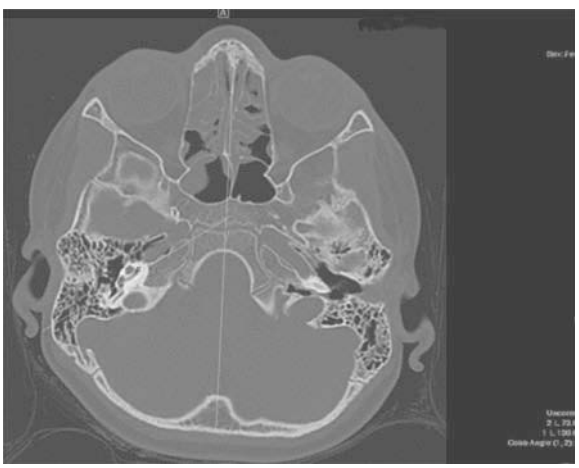
BTAs (55, 62, 50, 56, and 57°) in patients number 1, 3, 4, 5, and 6, respectively, were in the same range as those in the first group, predicting no difficulty in cochleostomy (Figs. 6–9) and correlated with the intraoperative findings of straightforward electrode insertion.

Statistics

We compared our results with those of Lloyd and colleagues by conducting some statistical analyses. The Statistical Package of Social Science (SPSS), version 22 (USA) was used. The pediatric cochlear implantees without difficult cochleostomy were gathered from the first and the second groups (Table 4). This group included 10 children (five male, five female) with an age range from 2 years 9 months to 5 years 6 months. All children were prelingually deaf.

The measured BTAs were 55, 58, 60, 56, 55, 55, 62, 50, 56, and 57° (Table 4). The BTA range was 50–62° with a mean of 56.4° and an SD of 3.2. The

Figure 1



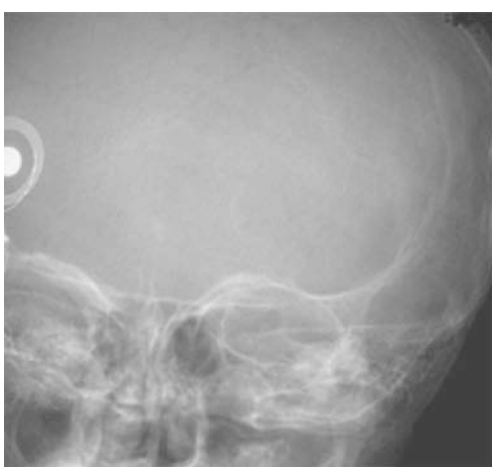
CT-scan of patient number 4 in the retrospective group (axial view of temporal bone): the right basal turn angle of 56 degree.

Table 3 The mean basal turn angle relative to the midsagittal plane grouped into age categories by Lloyd *et al.* [1]

Age category (years)	*N*	Mean (deg.)	SD
0–1	6	55.5	4.0
2–5	14	57.0	3.9
6–10	10	55.3	5.0
11–15	13	56.2	3.0
16–20	15	54.8	3.8
21–30	18	53.9	2.9
31–40	24	54.5	2.7
41–50	20	53.4	3.5
51–60	16	53.2	3.6
61–70	11	54.5	3.7
71–80	12	53.6	2.5
Total	159	54.6	3.5

They found that the mean BTA of the total population was 54.6° (range: 46.8–63.8°; SD = 3.5). Lloyd *et al.* [1] considered a rotated cochlea when the measured basal turn angle was more obtuse than that of the normal age standard.

Figure 2



Transorbital Radiography of patient number 4 in the retrospective group: the tip of the electrode coiled at the first turn of the right cochlea.

unpaired *t*-test was used to compare the mean of this group with the mean of the same age category 2 of Lloyd *et al.* [1] (14 children, BTA mean = 57°, and SD = 3.9 as mentioned in Table 3). The unpaired

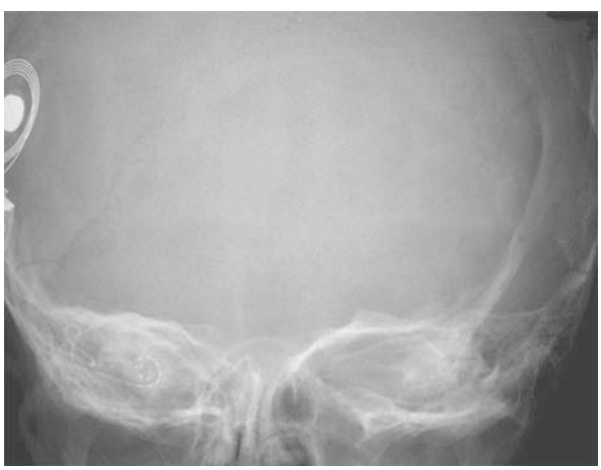
Figure 3

Mastoid Radiography of patient number 4 in retrospective group: the tip of the electrode coiled at the first turn of the right cochlea.

Figure 4

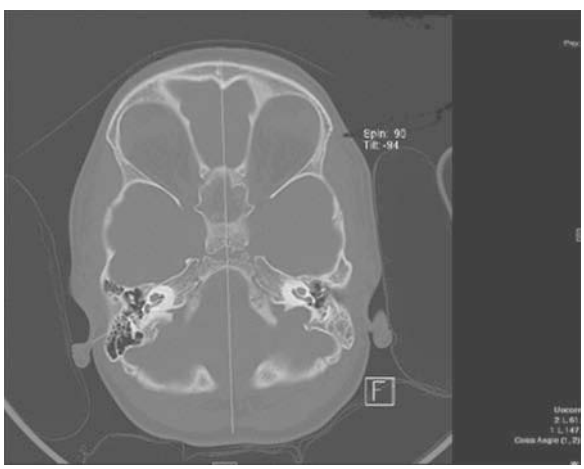
CT-scan of patient number 2 in the prospective group (axial view of temporal bone): the right basal turn angle pf 65 degree i.e. more obtuse than those of the normal age standard suggested by Lloyd and colleagues in Table 3, meaning a rotated cochlea.

Figure 5



Transorbital Radiography of patient number 2 in the prospective group: the tip of the electrode coiled within the right cochlea.

Figure 6



CT-scan of patient number 3 in the prospective group (axial view of temporal bone): the right basal turn angle of 62 degree.

Table 4 Pediatric cochlear implantees without difficult cochleostomy were gathered from the first and the second groups of the current study

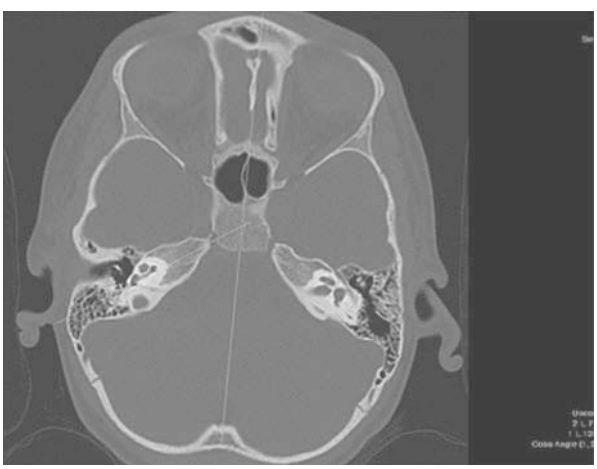
Patient number	Age at CI	Sex	Side implanted	Cochlear BTA	Cochleostomy
1	3 years and 9 months	F	L	55°	No difficulty
2	2 years and 9 months	M	R	58°	No difficulty
3	5 years and 6 months	M	R	60°	No difficulty
4	4 years and 4 months	F	R	56°	No difficulty
5	3 years and 11 months	F	R	55°	No difficulty
6	4 years and 2 months	M	R	55°	No difficulty
7	4 years and 5 months	M	R	62°	No difficulty
8	5 years and 5 months	F	R	50°	No difficulty
9	4 years and 9 months	F	L	56°	No difficulty
10	5 years and 1 month	M	R	57°	No difficulty

This group included 10 children (five male, five female) with an age range from 2 years 9 months to 5 years 6 months. All children were prelingually deaf. The basal turn angle range was 50–62° with a mean of 56.4° and SD = 3.2; BTA, basal turn angle.

Figure 7

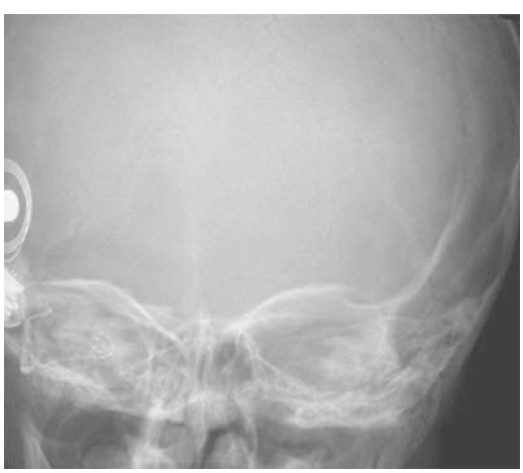
Transorbital Radiography of patient number 3 in the prospective group: the tip of the electrode coiled within the right cochlea.

Figure 8



CT-scan of patient number 6 in the prospective group (axial view of temporal bone): the right basal turn angle of 57 degree.

Figure 9



Trasorbital Radiography of patient number 6 in the prospective group: the tip of the electrode coiled within the right cochlea.

t-test result revealed that a two-tailed *P*-value equal to 0.6936, the confidence interval (95%), and the difference were considered to be not statistically significant ($P > 0.05$), that is, comparable to that of Lloyd *et al.* [1].

The cochlear BTA of the pediatric cochlear implantee with a difficult cochleostomy in this current study was 65°. This angle was above the upper limit of the range of pediatric cochlear implantees without a difficult cochleostomy, who had cochlear BTAs range from 50 to 62°. This difficult case is also comparable to the three reported cases of Lloyd *et al.* [1] because it fulfilled the same parameters of such reported three cases (apparently normal cochlea in preoperative CT-scan, an obtuse BTA exceeding the upper limit of the age category BTA range, and encountered intraoperative difficult implantation).

Discussion

In the past, it was believed that the otic capsule at birth is in a mature state. Nowadays, the concept that the morphological and the spatial orientation of the labyrinth does not change postnatally is undergoing a worldwide discussion by cochlear implant surgeons.

Currently, there is considerable variation in the cochleostomy location [2].

Al-Muhaimeed *et al.* [3] were the first to describe a rotated cochlea in a report of six pediatric cochlear implantees with difficult cochleostomy. Unfortunately, the preoperative CT images were not available. Therefore, documentation of the BTA was not possible, although reports showed normal patent cochlear ducts. The studies of Lloyd *et al.* [1] and Erixon *et al.* [4] drew our attention to examine the BTA to find out what difficulties may be faced in these cases.

The first group in the current study consisted of six cochlear implantees without a difficult cochleostomy as noted retrospectively in the documented surgical notes and correlated with the BTAs measured later, using patients' preoperative CT images. These measured BTAs were 55, 58, 60, 56, 55, and 55°, respectively, and were within the normal range of Lloyd *et al.* [1].

The second group represented a sample of six patients (one adult and five children) undergoing cochlear implantation in which difficult cochleostomy was faced intraoperatively in only one patient (number 2), whose preoperatively measured BTA was 65° (i.e. more obtuse than the normal range), predicting a rotated cochlea with difficult cochleostomy. BTAs (55, 62, 50,

56, and 57°, respectively) of the other five implantees in this group were within the normal range as in our first group, predicting no difficulty, which was indeed found intraoperatively. The second group was a blind group in which the main surgeon was not informed of the values of the BTAs measured preoperatively.

Regarding the BTAs, statistical analysis of the pediatric cochlear implantees without difficult cochleostomy in the current study revealed no significant difference when compared with the age category 2 of Lloyd *et al.* [1].

Preoperative BTA measurement may therefore point toward a suspected difficult cochleostomy due to possible encountered rotated cochlea. Preoperative BTA within the normal range may rule out the presence of a rotated cochlea, and difficult cochleostomy will not be faced. In contrast, the detection of a more obtuse than normal BTA preoperatively can draw the attention of the Cochlear Implant toward the fact that a difficult cochleostomy may be faced due to the presence of a rotated cochlea.

Our results were comparable to those of Lloyd *et al.* [1], who reported three pediatric cochlear implantees with difficult cochleostomy in whom the BTAs were more obtuse than normal, indicating a rotated cochlea. The BTAs measured in these individuals were 66, 63, and 71°, which was comparable to one of our cases with a BTA of 65°. Lloyd *et al.* [1] stated that there is a statistically significant reduction in the basal turn angulation relative to the midsagittal plane with increasing age, and the obtuse angulation of the basal turn relative to the midsagittal plane may make cochlear implantation more difficult. They added that children are more likely to have an obtusely angled basal turn, which may predispose them to difficult implantation.

Patient number 4 in the first group of the current study did not show a difficult cochleostomy and the BTA (56°) was within the normal range (Fig. 1). Postoperative transorbital and mastoid radiography revealed that the electrode was coiled at the first turn of the right cochlea (Figs. 2 and 3). This may be explained by the findings of Erixon *et al.* [4] who suggested that an unusual anatomy such as tilting or misalignment of the first and the second turns may account for difficulties for the electrode to glide upward and reach the second turn without causing trauma.

McRackan *et al.* [5] stated that many surgeons believe that CI can be more difficult in the pediatric population as compared with adults. They evaluated high-resolution computed tomographic scans of 24 pediatric (46 ears) and 20 adult patients (40 ears) to test whether there are significant differences in the pediatric and the adult temporal bone anatomy as related to CI surgery. They found several significant differences with the orientation about the round window and the cochlea. The angles between the long axis of the basal turn of the cochlea and the lateral portion of the external auditory canal as well as the angle between the long axis of the basal turn of the cochlea and the plane of the facial recess were statistically more acute in children compared with adults, producing a narrower view of the round window and possibly increased difficulty with electrode insertion. The radiological findings in the study of McRackan and colleagues had no intraoperative correlations.

Erixon *et al.* [4] studied the anatomy of 73 archival human cochleae with potential implications for cochlear implantation surgery. They described anatomic variations such as an unusual 'coiling pattern' and asymmetries of individual turns that may influence the introduction of the electrode array into the cochlea. They suggested that the human cochlea is individually shaped, varying significantly in dimensions (fingerprint), which might explain the occasional difficulties in inserting electrode arrays even in apparently 'normal' cochleae. Cochlear anatomic variations should be taken into account when performing surgery on the cochlea because they may not always be appreciated from a routine preoperative CT scan. In the study of Erixon *et al.* [4], the sampled cochleae were from unidentified autopsy materials, and hence, no information was available regarding the sex or the age. The study of Erixon and colleagues did not include a direct application on cochlea implantees to correlate their imaging cochlear anatomic findings with intraoperative data regarding suspected surgical difficulties.

We believe that further study of possible cochlear rotation around its modiolus axis (clockwise vs. anticlockwise) is required to understand its impact on CI, and agree with Yoo *et al.* [6], who suggest that three-dimensional geometric modeling of the cochlea using helico-spiral approximation could provide an accurate assessment of the cochlear orientation.

Berrettini *et al.* [7] stated that scala vestibuli implantation may allow complete insertion of an electrode array in cases of partially ossified cochlea. Kiefer *et al.* [8] also performed the same technique successfully in four cases with obstruction of the scala tympani and considered scala vestibuli insertion as a valuable alternative in these cases. They found no adverse effect related to the site of insertion compared with scala tympani insertion in terms of speech understanding.

Scala vestibuli insertion can therefore be an alternative when difficult cochleostomy is encountered even in

normal patent cochlea as we did in one of our patients in the second group.

The current study investigated the effect that the rotation of the cochlea has on the difficulty of cochlea implantation. It is therefore potentially useful to surgeons in their preoperative planning of the surgical approach.

Conclusion and recommendation

The possibility of a rotated cochlea should be borne in mind when a difficult cochleostomy is encountered during implanting an apparently normal cochlea.

Measuring the BTA of the cochlea relative to the midsagittal plane in all preoperative CT scans is advised to identify cases in which the basal turn of the cochlea may have an unusual orientation.

Scala vestibuli insertion or a combined approach technique in case of an encountered difficult cochleostomy is highly recommended. Intraoperative CT-guided cochlear implantation [9] and endoscopic transcanal approaches [10] are recent techniques that can help in case of preoperatively suspected rotated cochlea.

Despite the rarity of cases, we recommend conducting a future comparative study of two groups with difficult implantation and nondifficult implantation and compare the cochlear BTAs between the two groups.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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