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Intraoperative Electrophysiologic Variations Caused by the Scalar Position of Cochlear Implant Electrodes

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Objective: The position of cochlear implant (CI) electrodes in the cochlea is fundamental for the interaction between the implant and the neurons of the spiral ganglion. The scalar position of the electrode in the cochlea is assumed to be an important parameter for the clinical outcome. In our study, the intraoperative electrophysiologic characteristics in dependence of the position of CI electrodes in the scala tympani or in the scala vestibuli after scalar change should be determined.
Materials and Methods: The intraoperative impedances and neural response telemetry (NRT) data of 23 patients implanted with a Nucleus Advance Contour (Cochlear Pty, Sydney, Australia) electrode were recorded. One CI surgeon and two radiologists evaluated the electrode array's position independently radiologically by flat-panel tomography. Results from 17 patients with the electrode positioned in the scala tympani and six patients with the electrode changing intraoperatively from the tympanic into the vestibular scala were retrospectively analyzed.
Results: We found a statistically significant difference with an NRT threshold–based ratio for the groups. An estimation of the (radiologically confirmed) scalar position based on the NRT ratio was possible retrospectively.
Conclusion: The evaluation of specific intraoperative electrophysiologic data allowed separating between a regular and an irregular (i.e., scalar changing) position of CI electrodes. This noninvasive methodology can support the postoperative radiologic evaluation of the CI electrode array position. **Key Words:** Cochlear implant—Flat-panel tomography—Neural response telemetry—Scalar position.
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Cochlear implantation is a safe and effective procedure for deaf patients and those with residual hearing with severe and profound sensorineural hearing loss. The position of the electrode array in the cochlea is fundamental for the interaction between the implant and the auditory neurons. The position of the electrode in the scala tympani of the cochlea seems to be important for the clinical outcome. Incomplete or incorrect insertion of the electrode array into the cochlea can cause major complications (1). Complicated electrode insertion into the cochlea can cause malinsertion, for example, with translocation into the vestibule and into the horizontal semicircular canal (2). Symptoms may vary from transient vertigo to low speech perception. Initial inappropriate positioning of the electrode array within the cochlea required revision surgery in 13% because of disappointing audiologic outcomes (3). Different studies describe cochlear implantation revision surgery in 17% to 33% of cases because of positioning failure of the electrode array (1,3–5).

The specific incidence of scala vestibuli insertions and reported incidence of primary scala tympani insertions with secondary translocation into the scala vestibuli are higher using the Cochlear Nucleus Contour electrode array (6). The translocation from the scala tympani into the scala vestibuli usually occurred at approximately 180-degree electrode insertion depth (6). The frequency of translocation from the scala tympani into the scala vestibuli was reduced using the perimodiolar Cochlear Contour Advance electrode array with the Advanced Off-Stylet technique. In postoperative speech recognition tests, the best results were seen after insertion into the scala tympani and poorer results after translocation from the scala tympani into the scala vestibuli (7). In a study of 15 patients supplied with the Advanced Bionics electrode array, it was seen that inappropriate placement of the electrode is possible and should be avoided because word scores correlate negatively with the number of electrodes in the scala vestibuli (8).

A variety of imaging techniques may be used to determine the intracochlear position of the electrode array. These radiologic technologies include postoperative computed tomography (CT), flat-panel tomography, or cone-beam scans. In recent years, the need for intraoperative visualization of the electrode in the cochlea has increased. An

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intraoperative three-dimensional (3-D) rotational x-ray scanning technique can be used to produce high-quality images of the cochlea and the electrode array in the operating room (7,9). Additional time in the operating room is necessary, but these techniques provide reliable evidence about the position of the electrode array and, if misplacement occurs, corrections can be made immediately during surgery. The positioning of the electrode array within the cochlea may also be evaluated by electrophysiologic measurements. Electrophysiologic measurements of the spread of excitation are able to identify electrode array fold-overs (10). The electrically evoked cochlear action potential amplitude depends on the distance between the electrode array and the spiral ganglion cells (11). Based on those findings, we postulated that, in cases of a scalar change of the electrode array position, a modified electrophysiologic pattern would be expected because of the increased distance to the spiral ganglion cells in the apical part of the electrode where there has been incursion into the scala vestibuli.

It was therefore the aim of the present study to measure and describe electrophysiologic characteristics as related to the scalar position of cochlear implant (CI) electrodes.

MATERIALS AND METHODS

The study was reviewed and supported by the institutional review board (IRB-ukb-HNO-2013/24). Twenty-three patients were included in the study. Preoperatively, CT scanning of the temporal bone and magnetic resonance imaging of the neurocranium were performed. All subjects showed normal temporal bone anatomy preoperatively. A mastoidectomy and a posterior tympanotomy were performed, and a round window or modified round window approach was used to access the cochlea (12). A single surgeon performed all surgeries. The Advanced Off-Stylet technique was used to insert the perimodiolar Nucleus Contour Advance electrode. Primary scala tympani insertions with complete insertion of all electrode arrays were achieved in all patients without any surgical complications.

Data Acquisition and Electrophysiologic Recordings

After complete insertion, electrophysiologic recordings were made under sterile conditions in the operation room. Software-based impedance measurements were performed, followed by neural response telemetry (NRT) recordings. Cochlear's Custom Sound Suite 3.2 was used (Auto-NRT mode) to measure and evaluate the NRT threshold (t-NRT). Two automated series were recorded. We could fully evaluate intraoperative impedance and t-NRT data sets in all 23 patients implanted.

Data Processing and Analysis

To allow a comparison of the t-NRT data and control for global differences among subjects, the threshold levels of the electrode contacts were normalized to the fourth electrode within the electrode array as the electrode array was expected in the scala tympani in this portion in both groups. After normalization to the fourth electrode, the apical and basal portions showed normal distribution (Kolmogorov-Smirnov test, $p > 0.05$), and data were analyzed with the unpaired t test.

Our postoperative imaging results from the 23 patients were used to separate the subjects into two groups based on the observed scalar position of the electrode arrays. The first group (Group 1) contained 17 patients with the electrode positioned in the scala tympani. The second group (Group 2) contained six patients with the electrode shifted from the scala tympani to the scala vestibuli.

By using the t-NRT values in the apical and basal portions, a ratio could be calculated. In every patient, the arithmetic average of the t-NRT value from electrodes 16 to 18 was divided by the arithmetic average of the t-NRT from electrodes 5 to 7 (Fig. 1).

Postoperative flat-panel tomography was performed on all patients to determine the scalar position of the electrode array as determined by the surgeon and two experienced radiologists. The subjects were selected for a specific group after the scalar position of every implant was agreed on by every rater. The translocation from the scala tympani into the scala vestibuli is known to be at approximately 180-degree electrode insertion depth (6). Determination of the electrode positions was performed using an Allura Xper FD20 system (Philips Medical Systems, Best, The Netherlands) with a flat-panel detector. The parameters of the system were as follows: entrance field, 22 cm; 274 mAS; 95 kV; 180-degree rotation; 241 projections; filter, 0.90 mm Cu + 1.00 mm Al; and posteroanterior. The focus panel distance was determined and constant for the entire rotation at a frequency of 30 frames per seconds. The 3-D tomography was performed in the unsubtracted mode. From this volume data set, the temporal bones were secondarily enlarged (field of view of 100 mm), digitally stored, and sent for two-dimensional and 3-D reconstruction to an external workstation (Extended Brilliance Workspace; Philips, Cleveland, OH, USA).

RESULTS

The preoperative radiologic evaluation showed normal anatomic proportions for all the patients' temporal bones and cochlea in particular. With the radiologic results in

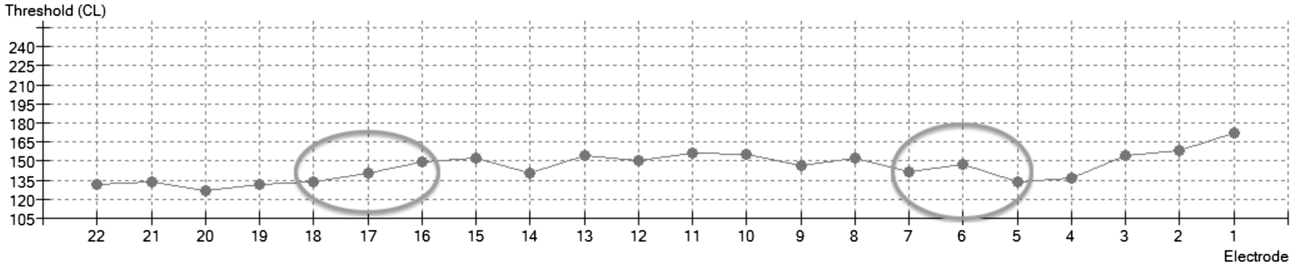

FIG. 1. t-NRT values (current levels) across the electrode array (E1 = basal) in a sample subject from Group 1. The *circled values* for electrodes 16 to 18 (apical region) and 5 to 7 (basal region) were used to calculate the t-NRT ratio as described in the text.

mind, we expected scalar changes in the middle of the electrode arrays (7).

Radiologic Results

The subjects included in Group 1 showed the normal intended position of the implant within the scala tympani (Fig. 2). In Group 2, the translocation of the electrode array was between electrodes 10 and 14 in four subjects, between electrodes 11 and 15 in one subject, and between electrodes 6 and 9 in one subject (Fig. 3).

Results of t-NRT Measurements

In Group 1, the apical threshold levels were statistical lower than the basal thresholds ($p < 0.001$; paired t test) (Table 1). In Group 2, the difference between the higher absolute threshold levels in the apical and the lower threshold levels in the basal portion of the electrode array showed a statistical difference ($p < 0.001$; paired t test) (Fig. 4). The apical absolute threshold levels between Groups 1 and 2 were statistically different ($p < 0.001$; unpaired t test), whereas the basal absolute threshold levels showed no statistical difference ($p = 0.148$; unpaired t test).

Normalization was performed with reference to electrode 4 in the basal region of the electrode array (Fig. 5) because the scalar changes occurred in the middle of the electrode array and to exclude a bias and global differences among subjects. Differences in stimulus levels between the two groups for the apical and basal electrodes after normalization to the fourth electrode were significant for the apical electrodes ($p < 0.001$; unpaired t test) but not significant for the basal electrodes ($p = 0.299$; unpaired t test) (Table 1). Within the groups, the difference between the apical and the basal electrodes after normalization to electrode 4 was significant. The normalized values were lower in the apical electrodes than in the basal electrodes in Group 1 ($p < 0.001$; paired t test) and significantly higher in the apical electrodes than in the basal electrodes in Group 2 ($p < 0.001$; paired t test).

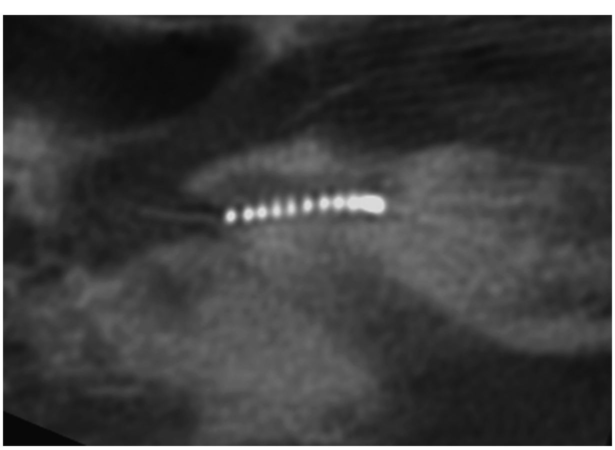

FIG. 2. Flat-panel tomography with a CI electrode array placed within the scala tympani.

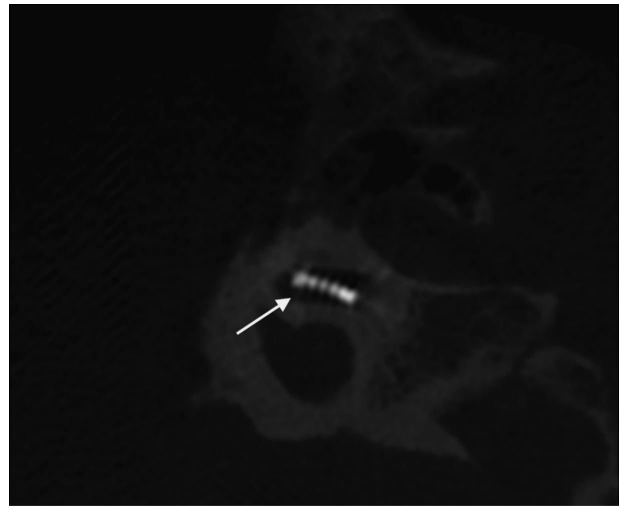

FIG. 3. Flat-panel tomography with a CI electrode array translocated into the scala vestibuli. The translocation is between electrodes 10 and 14; the *arrow* points to the empty apical scala tympani.

Comparison of the t-NRT ratio between Groups 1 and 2 showed significant differences (t test; $p < 0.001$) (Fig. 6). In Group 1, the ratio ranged from 0.75 to 1.05 whereas, in Group 2, the ratio ranged from 1.05 to 1.36.

Impedance measurements showed regular inconspicious values across both groups.

DISCUSSION

The position of the electrode array in the cochlea is fundamental for the interaction between the implant and the auditory neurons. Incomplete or incorrect insertion of the electrode array into the cochlea can cause various complications and should be avoided (1–5).

Therefore, electrophysiologic data were recorded in 23 patients implanted with the Nucleus Contour Advance electrode array. During all 23 surgeries, we did not register any complications. Postoperatively, the evaluation of the imaging data revealed that six electrode arrays had shifted from the scala tympani into the scala vestibuli. Similar to previous reports (6) in our six patients, the electrode array translocation from the scala tympani into the scala vestibuli mainly occurred in the middle of the electrode array.

For radiologic evaluation, flat-panel tomography was used. As flat-panel tomography imaging is valuable as a means of identifying scalar positions, the reliability of the exact intracochlear position can vary. In the apical part of the cochlea, the informational value of the flat panel is reported to be 68% whereas, in the basal part, the informational value is 100% (13). Other studies report accurate radiologic intrascalar determination and histologic confirmation of the intrascalar position between 85% and 100% (14,15).

Impedance measurements were made to identify any anomalous electrodes and were inconspicious. We could

TABLE 1. *Mean absolute and mean normalized values*

	Absolute Apical (16–18) t-NRT	Absolute Basal (5–7) t-NRT	Normalized (E4) Apical (16–18) Values	Normalized (E4) Basal (5–7) Values	Absolute Apical versus Basal t-NRT, *P* Value	Normalized (E4) Apical versus Basal Values
Group 1	166.75 ±22.45	176.63 ±20.73	0.957 ±0.128	1.010 ±0.086	sig. $p < 0.001$	sig. $p < 0.001$
Group 2	194.44 ±23.28	168.50 ±18.79	1,141 ±0.127	0.987 ±0.067	sig. $p < 0.001$	sig. $p < 0.001$
p	sig. $p < 0.001$	n.s.	sig. $p < 0.001$	n.s.		

Measures are means ± SD. Units are current level for the t-NRT or dimensionless quantity for normalized values.
E4 indicates electrode 4; n.s., not significant; sig., significant.

show significant statistical differences of the t-NRT recordings between the scalar changing electrode arrays and those placed correctly within the scala tympani. In the apical portion of the electrode array, the electrodes required a significantly higher electrical stimulus to elicit an NRT response if the electrode array had moved into the scala vestibuli than being placed correctly in the scala tympani. In the basal portion of the electrode array, the stimulus required to elicit a neural response was significantly lower if the electrode array had shifted from the scala tympani to the scala vestibuli. In perimodiolar electrodes, the electrically evoked cochlear action potential threshold is lower than that in straight electrodes (16). The reason for these different thresholds for different electrodes is the distance between the electrode array and the spiral ganglion (11).

The distance between the electrode array in the scala vestibuli and the spiral ganglion is greater than the distance between the electrode array in the scala tympani and the spiral ganglion. Because of this greater distance, the t-NRT thresholds were significantly increased in the apical part of the electrode array if a scalar change had occurred. Furthermore, we assume that, if the electrode array translocates into the scala vestibuli, because of the given preformation of the electrode array, a relative approximation to the modiolus occurs in the basal portion of the cochlea. NRT stimulus levels were significantly lower in Group 2.

In our view, intraoperative electrophysiologic measurements should be taken into account to obtain intraoperative insights into the electrode's position within the cochlea.

Intraoperative electrophysiologic recordings can detect electrode array fold-overs (10). It is well known that using a perimodiolar electrode array results in a lower stimulus to elicit t-NRTs (16–18). The t-NRT ratio between the apical and the basal portions as described above can be used as a predictive tool for these perimodiolar electrodes. When the ratio is less than 1.05, it can be assumed that the perimodiolar electrode array is in a regular position within the scala tympani.

Nevertheless, the number of the spiral cell ganglia should be kept in mind because these parameters can vary and even regional spiral ganglion cell degenerations are known. So-called dead or semidead regions could cause threshold shifts with irregular t-NRT patterns. Furthermore, multiple scalar changes in the electrode array will influence the electrophysiologic parameters in the cochlea and may influence the validity of the predictive value of the NRT ratio.

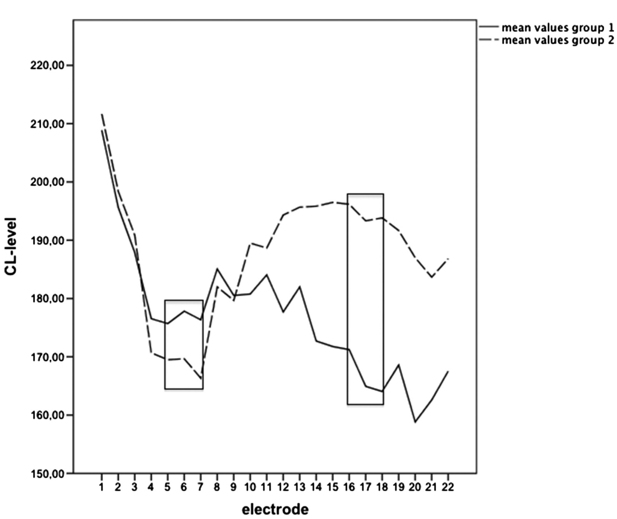

FIG. 4. Mean absolute t-NRT values across the electrode array for subject Groups 1 and 2. Encircled are apical and basal values for the respective electrodes.

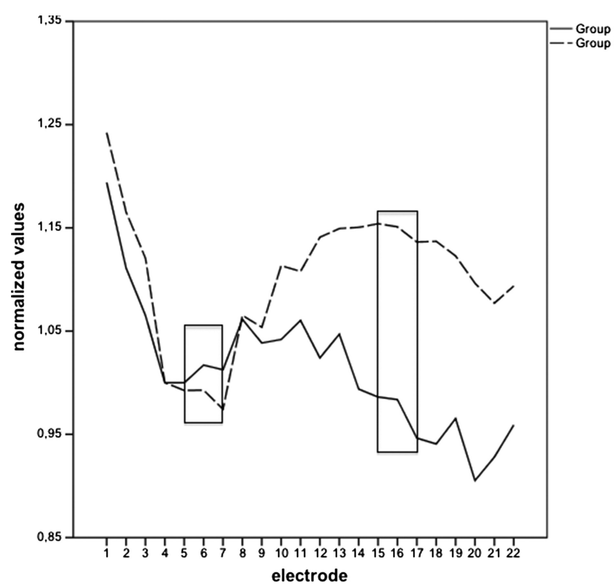

FIG. 5. Mean t-NRT values across the electrode array for subject Groups 1 and 2, normalized to electrode 4. Encircled are apical and basal values for the respective electrodes.

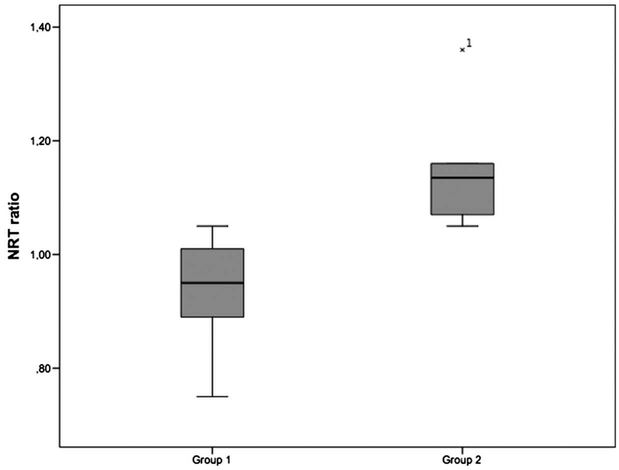

FIG. 6. NRT ratio for Groups 1 and 2. The *asterisk* indicates one subject with an outlier.

It is also not yet clear from the present data if the observed ratio is transferable to different electrode types because lateral wall electrodes have a distinctly greater distance to the spiral ganglion area.

In essence, a postoperative radiologic evaluation and confirmation of a correct insertion into the scala tympani cannot be completely replaced by electrophysiologic measurements, but the latter can and should support the radiologic evaluation and provide the surgeon with helpful information intraoperatively. This information might be of particular relevance in children, where an x-ray load should be very carefully considered. Therefore, theoretically regular and irregular positions of the electrode could be estimated, and intraoperative revision could be made even without any radiologic control. Furthermore, the NRT ratio can be used as a quality management tool if radiologic imaging is not available.

CONCLUSION

The evaluation of specific intraoperative electrophysiologic data allows the distinction between a regular and a scalar changing position of CI electrodes. This finding can support the postoperative radiologic position monitoring of a CI electrode array.

REFERENCES

1. Cohen NL, Hoffman RA. Complications of cochlear implant surgery in adults and children. *Ann Otol Rhinol Laryngol* 1991;100:708–11.
2. Tange RA, Grolman W, Maat A. Intracochlear misdirected implantation of a cochlear implant. *Acta Otolaryngol* 2006;126:650–2.
3. Lassig AA, Zwolan TA, Telian SA. Cochlear implant failures and revision. *Otol Neurotol* 2005;26:624–34.
4. Rotteveel LJ, Proops DW, Ramsden RT, et al. Cochlear implantation in 53 patients with otosclerosis: demographics, computed tomographic scanning, surgery, and complications. *Otol Neurotol* 2004;25:943–52.
5. Balkany TJ, Hodges AV, Gomez-Marin O, et al. Cochlear reimplantation. *Laryngoscope* 1999;109:351–5.
6. Aschendorff A, Kubalek R, Turowski B, et al. Quality control after cochlear implant surgery by means of rotational tomography. *Otol Neurotol* 2005;26:34–7.
7. Aschendorff A, Kromeier J, Klenzner T, et al. Quality control after insertion of the nucleus contour and contour advance electrode in adults. *Ear Hear* 2007;28:75S–9.
8. Skinner MW, Holden TA, Whiting BR, et al. In vivo estimates of the position of advanced bionics electrode arrays in the human cochlea. *Ann Otol Rhinol Laryngol Suppl* 2007;197:2–24.
9. Carelsen B, Grolman W, Tange R, et al. Cochlear implant electrode array insertion monitoring with intraoperative 3-D rotational x-ray. *Clin Otolaryngol* 2007;32:46–50.
10. Grolman W, Maat A, Verdam F, et al. Spread of excitation measurements for the detection of electrode array foldovers: a prospective study comparing 3-dimensional rotational x-ray and intraoperative spread of excitation measurements. *Otol Neurotol* 2009;30:27–33.
11. Shepherd RK, Hatsushika S, Clark GM. Electrical stimulation of the auditory nerve: the effect of electrode position on neural excitation. *Hear Res* 1993;66:108–20.
12. Todt I, Basta D, Ernst A. Does the surgical approach in cochlear implantation influence the occurrence of postoperative vertigo? *Otolaryngol Head Neck Surg* 2008;138:8–12.
13. Guldner C, Weiss R, Eivazi B, et al. [Intracochlear electrode position: evaluation after deep insertion using cone beam computed tomography]. *HNO* 2012;60:817–22.
14. Kurzweg T, Dalchow CV, Bremke M, et al. The value of digital volume tomography in assessing the position of cochlear implant arrays in temporal bone specimens. *Ear Hear* 2010;31:413–9.
15. Saeed SR, Selvadurai D, Beale T, et al. The use of cone-beam computed tomography to determine cochlear implant electrode position in human temporal bones. *Otol Neurotol* 2014;35:1338–44.
16. Gordon KA, Papsin BC. From nucleus 24 to 513: changing cochlear implant design affects auditory response thresholds. *Otol Neurotol* 2013;34:436–42.
17. Seidman MD, Vivek P, Dickinson W. Neural response telemetry results with the nucleus 24 contour in a perimodiolar position. *Otol Neurotol* 2005;26:620–3.
18. Pasanisi E, Vincenti V, Bacciu A, et al. The nucleus contour electrode array: an electrophysiological study. *Laryngoscope* 2002;112:1653–6.