Original Article

Annals of Otology, Rhinology & Laryngology
1–6

DOI: 10.1177/0003489416675355
aor.sagepub.com
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Radiological and NRT-Ratio–Based Estimation of Slim Straight Cochlear Implant Electrode Positions: A Multicenter Study

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Abstract

Objectives: An intraoperative neural response telemetry-ratio (NRT-ratio) was established, which can provide information about the intraoperative intracochlear electrode array position for perimodiolar electrodes.

Methods: In a retrospective controlled study in 2 tertiary referral centers, the electrophysiological data sets of 50 patients with measured intraoperative auto-NRTs and postoperative radiological examinations were evaluated. All patients were implanted with Nucleus slim straight electrodes. The NRT-ratio was calculated by dividing the average auto-NRT data from electrodes 16 to 18 with the average from electrodes 5 to 7. Using a flat panel tomography system or a computed tomography, the position of the electrode array was certified radiological.

Results: Radiologically, 2 out of 50 patients were identified with an electrode translocated from the scala tympani into the scala vestibuli. The radiologically estimated electrodes indicating a scalar change showed a regular NRT-ratio but nonspecific NRT-level changes at the localization of translocation.

Keywords

neurophysiology, cochlear implants, electrode design, hearing loss, NRT

Introduction

Cochlear implantation for the auditory rehabilitation of deaf patients and those with profound sensorineural hearing loss (SNHL) is a worldwide accepted procedure. For the optimal hearing benefit with the cochlear implant (CI), the position of the implant should be within scala tympani.[1-4] Inappropriate placement of the CI electrode array within the scala vestibuli, or electrode translocation from the scala tympani into the scala vestibuli, can be correlated with poorer audiological outcomes.[3,5,6] Due to the structural behavior of periomodiolar electrode arrays, previous evidence demonstrates that the translocation occurs at an angle of insertion of approximately 180°.[7,8] However, the Advanced Off-Stylet technique (AOS) for perimodiolar electrode arrays has been shown to reduce damage to the basilar membrane and consequently the rate of translocations.[9]

To verify the electrode's scalar position intra- and postoperatively, computed tomography (CT), flat panel tomography, or digital volume tomography (DVT) are frequently used.[10] These imaging modalities have been previously validated to accurately determine the intracochlear and scalar position of the electrode array.

Apart from radiologic interpretation, electrophysiological measurements can be used to determine the intracochlear CI electrode array position. The electrically evoked cochlear action potential (ECAP) threshold is dependent on the distance between the electrodes and the spiral ganglion cells[11] and hence lower in perimodiolar electrodes than in straight electrodes.[12,13] If the perimodiolar electrode array dislocates into the scala vestibuli, the distance between the spiral ganglion and the electrode array will increase. Thus, a higher ECAP threshold can be expected in the apical region for perimodiolar electrodes.

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The neural response telemetry-ratio (NRT-ratio) is based on each individual electrode's ECAP threshold[11-13] and can identify the intracochlear electrode array position in perimodiolar electrodes.[14] The NRT-ratio showed a good reliability for the determination of the intracochlear electrode array position compared to the radiologic control intraoperatively and a good stability after a 6 months' follow-up time.[15,16] Calculation of the NRT-ratio is done by dividing the arithmetic average of the t-NRT values from the apical electrodes 16 to 18 divided by the arithmetic average of the basal t-NRT from electrodes 5 to 7. With a NRT-ratio above 1.05, a high chance of a scalar change was rather likely, and a NRT-ratio below 1.05 was associated with a high chance of an electrode array position within the scala tympani.[14] Limited applicability of the NRT-ratio is known to occur in patients with intraoperative complications, long-term deafness, syndromic disorders with reduced or inhomogenous density of spiral ganglion cells, or chronic diseases with neural degeneration.[15]

The NRT-ratio is known to be reliable for perimodiolar electrodes. With previous evidence showing that the NRT-ratio can evaluate the electrode position, it was the aim of the present study to verify the accuracy of the NRT-ratio as correlated to the intracochlear position of the CI electrodes in a group of patients with straight electrode arrays from 2 different centers.

Materials and Methods

The study was reviewed and supported by the Institutional Review Board (IRB-ukb-HNO-2015/07) and has been conducted according to the principles expressed in the Declaration of Helsinki. Inclusion criteria were completed intraoperative NRT-measurements and postoperative radiological imaging by either CT or RT. Exclusion criteria were incomplete postoperative electrophysiological measurements, CI revisions, and postoperative 2-dimensional X-ray. All subjects underwent implantation with the Nucleus slim straight electrode of the 422 or 522 device (Cochlear Ltd, Lane Cove, Australia) between 2010 and 2015 with a standard surgical procedure at the Department of Otolaryngology, Head and Neck Surgery at the University Essen or at the Unfallkrankenhaus Berlin by 3 experienced surgeons. The standard surgical approach included a post-auricular transmastoid approach, a facial recess, and a round window insertion. All subjects showed stable intraoperative t-NRT sweeps.

Radiologic evaluation

The electrode's position was confirmed postoperative radiologically with rotational tomography (RT) with a digital flat panel detector or high resolution computed tomography. Flat panel tomography was performed on all patients at the study institution in Berlin to determine the scalar position of the electrode array by 2 surgeons and 2 neuroradiologists.[3,7] This method was previously shown and validated by Aschendorff et al[3,7] and Marx et al.[17] Determination of the electrode positions was performed using an Allura Xper FD20 system (Philips Medical Systems, Best, Netherlands) with a flat panel detector. The parameters of the system were as follows: entrance field of 22 cm, 274 mAS, 95 kV, 180° rotation, 241 projections, filter 0.90 mm Cu + 1.00 mm Al and posteroanterior (PA). The focus panel distance was determined and constant over the entire rotation at a frequency of 30 frames/s. The 3D tomography was performed in the unsubtracted mode. From this volume data set, the temporal bones (TBs) were secondarily enlarged (FoV of 100 mm), digitally stored, and sent for 2D and 3D reconstruction to an external workstation (Extended Brilliance Workspace, Philips, Cleveland, Ohio, USA). At the study institution in Essen, flat panel CT examinations were performed on a Philips Allura C-arc angiographic unit (Philips Medical Systems) connected to a 3DRA workstation (Philips Medical Systems). With patients' temporal bone in system isocenter, the scan was performed with a propeller movement covering 207° of the circular trajectory. Six hundred twenty-two frames were exposed during the 20.7 second scan (30 frames/s), utilizing a detector format of 33 × 40 cm. Total examination time, including bedding of the patient on the examination table, demanded less than 2 minutes. Source images were transferred to the workstation during and after the rotational acquisition, and a volume data set was created. The reconstruction appeared on the workstation monitor. Multiplanar MIP reconstructions parallel to the cochlea were performed with a slice thickness of 1.5 mm and orthogonal to the cochlea with a slice thickness of 0.41 mm.

Data Acquisition and NRT Evaluation

NRT data were recorded intraoperatively in all included patients. Software-based NRT recordings (Cochlear's "Custom Sound" in the current version) were used (auto-NRT mode) to measure and evaluate the NRT thresholds (t-NRT). The NRT-ratio gives an estimation of the intracochlear position of the electrode array. To calculate the NRT-ratio, the sum of the NRT values (in CL) from electrodes 18 to 16 in the apical part is divided by the sum of the NRT value (in CL) from electrodes 7 to 5 in the basal part of the electrode array. With a NRT-ratio above 1.05, a scalar change is rather probable, and a NRT-ratio below 1.05 is rather probable with scala tympani position.[14-16] To investigate whether a significant association between the electrophysiological estimated scalar position and the radiological verified position exists, statistical evaluation was conducted using Fisher's exact test with SPSS (Version 21.0; IBM Co, Armonk, New York, USA) with a level of significance with $P < .05$.

Results

In 2 study institutions, a total of 50 patients were included in the study (Table 1). By radiological evaluation, only 2 patients were identified with an apical electrode translocation

Table 1. Patients.

Patient	Age	Gender	Hearing Loss Duration (y)	Diagnoses	NRT-Ratio	Position
1	77	M	1	Progressive	0.95	ST
2	73	M	2	Progressive	1.00	ST
3	43	M	5	Progressive	0.88	SC
4	40	F	27	Mumps	0.82	ST
5	63	F	10	Progressive	0.97	ST
6	72	F	2	Sudden hearing loss	0.95	ST
7	50	F	32	Sudden hearing loss	0.95	ST
8	70	F	4	Otosclerosis	0.92	ST
9	58	F	2	Sudden hearing loss	0.84	ST
10	62	M	1	Sudden hearing loss	0.97	ST
11	66	M	0.5	Sudden hearing loss	0.87	ST
12	42	M	0.5	Otosclerosis	0.69	ST
13	69	F	2	Progressive	0.91	ST
14	61	F	57	Idiopathic	0.86	ST
15	79	F	30	Sudden hearing loss	0.94	ST
16	69	M	5	Progressive	1.12	ST
17	68	M	10	Gentamicin	1.14	ST
18	70	F	4	Progressive	0.85	ST
19	74	F	1	Progressive	0.80	ST
20	54	F	1	Progressive	0.85	ST
21	49	F	4	Otosclerosis	0.83	ST
22	43	F	41	Meningitis	0.99	ST
23	35	F	5	Progressive	0.87	ST
24	74	M	2	Progressive	0.90	ST
25	63	M	1	Sudden hearing loss	0.92	ST
26	58	F	1	Progressive	0.85	ST
27	10	F	1	Congenital	0.84	ST
28	74	F	1	M.Menière	0.89	ST
29	57	F	1	Congenital	0.87	ST
30	27	F	10	Congenital	0.91	ST
31	25	M	0.5	Infectious	0.94	ST
32	70	F	1	Sudden hearing loss	0.87	ST
33	43	F	0.5	Progressive	0.97	ST
34	67	F	0.5	Congenital	0.99	ST
35	21	F	5	Traumatic	0.75	ST
36	39	F	0.5	progressive	0.85	ST
37	57	F	1	Progressive	0.87	ST
38	75	M	5	Progressive	0.87	ST
39	62	F	26	Progressive	0.92	ST
40	72	F	0.5	Sudden hearing loss	0.88	ST
41	28	F	0.5	Infectious	0.83	ST
42	20	F	1	Progressive	0.76	ST
43	66	F	1	Sudden hearing loss	0.90	ST
44	20	F	1	Congenital	0.84	ST
45	5	F	0.2	Progressive	0.85	ST
46	74	F	0.5	Progressive	0.89	SC
47	57	F	1	Progressive	0.88	ST
48	57	F	0.5	Progressive	0.88	ST
49	58	F	1	Progressive	0.98	ST
50	78	M	1	Progressive	0.91	ST

Abbreviations: SC, scalar change; ST, scala tympani.

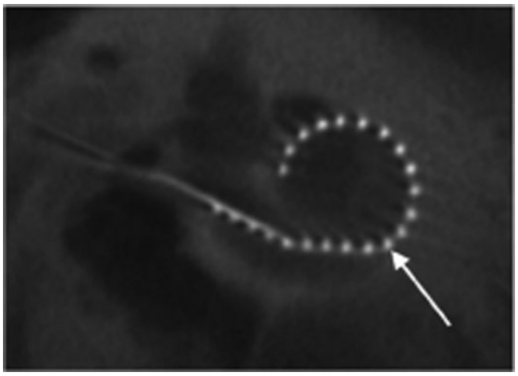

Figure 1. Flat panel tomography of the exemplary patient. Reconstructed "Cochlear view." The arrow marks the 10th electrode where the electrode array translocates from scala tympani (ST) into scala vestibuli (SV).

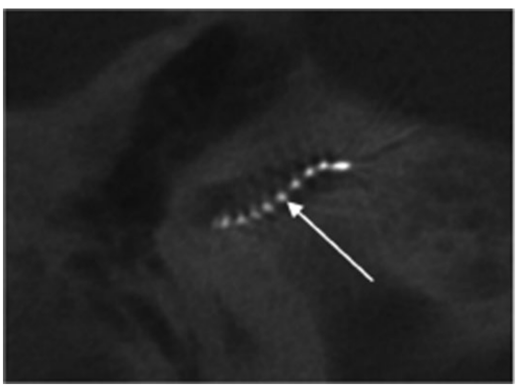

Figure 2. Flat panel tomography of the exemplary patient. The arrow marks the 10th electrode, where the electrode array translocates from scala tympani (ST) into scala vestibuli (SV).

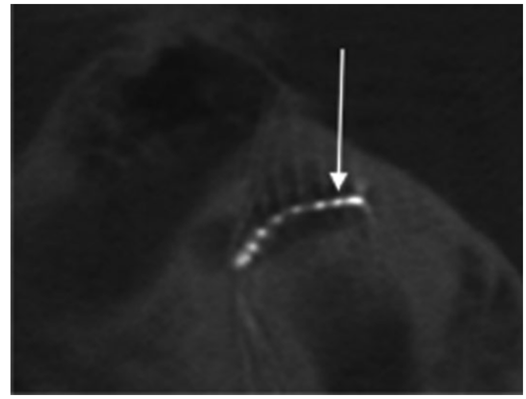

Figure 3. Flat panel tomography of the exemplary patient. The arrow marks the 15th electrode, where the electrode array translocates back into scala tympani (ST).

from scala tympani into scala vestibuli. After evaluation of the electrophysiological data from these 50 subjects (with complete intraoperative data sets), an electrode translocation from scala tympani into scala vestibuli was unlikely in 48 patients as based on the NRT-ratios. In those subjects, the NRT-ratio was below 1.05 (0.69-1.0). In the other 2 individuals, the NRT-ratio was above 1.05 (1.12 and 1.14), and the radiologically estimated position was in the scala tympani. In the group of 48 patients with a NRT-ratio below 1.05, 46 patients (95.83%) had a radiological confirmed electrode array position within scala tympani, and 2 were identified with a scalar translocation into scala vestibuli (4.17%). Both cases showed a dislocation into scala vestibuli at the 10th and between the 8th and 9th electrodes, respectively. In both electrodes, they translocated back into the scala tympani in a more apical location at the 15th and the 13th electrode, respectively (Figures 1, 2, 3). In both cases, the NRT thresholds do not show a homogeneous decrease of current levels from the base to the apex (Figure 4).

Statistical evaluation revealed that there was no statistically significant association between the NRT-ratio and the radiology for determination of the intracochlear position, with $P > .999$.

Discussion

Cochlear implantation as treatment for patients with profound SNHL and nonsatisfactory residual hearing is a safe and reliable procedure. The correct position of the electrode array within the cochlea is fundamental for the optimal audiological outcome. Irregular positioning of the electrode array can result in worse speech perception, cause various complications, and should be avoided.[18-22] The NRT-ratio is a nonradiological tool for the detection of the intracochlear position of perimodiolar electrode arrays[14,15] but is in summary not as reliable for straight electrode arrays.

The aim of the current study was to investigate whether the previous established NRT-ratio for perimodiolar electrode arrays is applicable for the detection of scalar electrode position in patients with straight electrode arrays, which are known to be less traumatic.

The basic idea for the NRT-ratio is the relative variation of distance between the electrode array and the spiral ganglion in different cochlear regions.[11] The translocation into scala vestibuli occurs in the basal turn at about 180° insertion depth angle in perimodiolar electrodes.[3,8] The proper placement within scala tympani for straight electrodes is more common.[8,23,24] The latter is basically due to the fact that the slim straight electrodes are rather slim and flexible in contrast to the rather voluminous and stiff precurved electrode arrays. A scalar change in straight electrodes is less common and can be expected in a more apical region than in perimodiolar

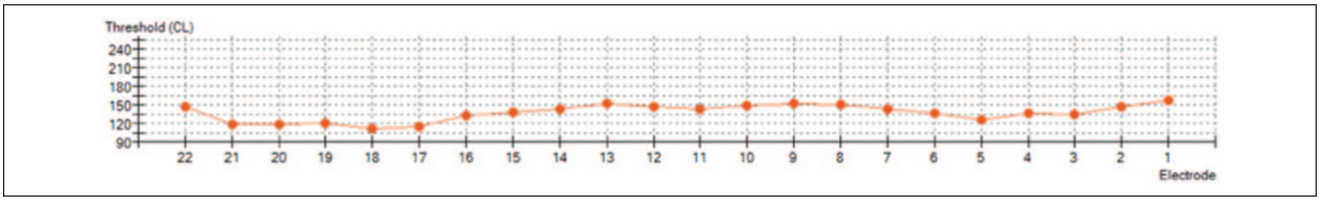

Figure 4. Auto neural response telemetry (NRT) values of the exemplary patient. Translocation into scala vestibuli (SV) occurs at the10th electrode and translocation back into scala tympani (ST) at the 15th electrode.

electrodes.[8] In perimodiolar electrodes, a scalar change can be detected with the NRT-ratio as in the apical part, the distance between the electrode array and the spiral ganglion is proportionally greater than in correctly placed perimodiolar electrode arrays. The NRT-ratio below 1.05 indicates a certain electrode position within scala tympani.[15]

The NRT levels for straight electrodes are higher than for perimodiolar electrode arrays.[12] As the straight electrodes are commonly placed along the lateral wall, the distance to the modiolus and spiral ganglion is rather great.[25] If a scalar translocation occurs in a straight electrode, the distance between the electrode array and the spiral ganglion will increase proportionally less than in precurved electrodes. All cases were inconspicuous implantations without any intraoperative specifics. Only 2 cases (4%) with interscalar changes were observed by postoperative RT or CT scans, which is in line with the literature.[8] Both cases showed 2 interscalar translocations. The NRT-ratio was below 1.05 in both cases and did not predict the scalar change. These results are inconsistent with our previous studies with the NRT-ratio in perimodiolar electrodes[14-16] but may be influenced by the multiple scalar changes of the electrode array. The radiologic course of the electrode array can be retraced by the course of the NRT values, but it seems that regarding the NRT-ratio and the NRT values in straight electrodes alone is less sensitive and specific. In our previous studies, we were able to show a strong correlation between the radiological determined intracochlear position of the perimodiolar electrode array and the NRT-ratio. The NRT-ratio can be affected and may be misleading by variable neural structures (eg, otosclerosis[26] or superficial siderosis[27]), increased numbers of so-called "non-homogenous dead" or "semi-dead regions,"[28] or patients with long-term deafness.

Our study has some limitations. Only 2 patients had radiologic estimated scalar translocation. As this is a small sample size, the results have to be regarded critical as the basic idea of the NRT-ratio was to detect scalar translocations. The value is limited due to the small sample size as it may be too small to detect a significant difference. Furthermore, the study only deals with Nucleus slim straight electrodes. The results cannot be transferred into other lateral wall electrodes from different manufacturers. Last, the study design is retrospective and is less significant than a prospective study. Further investigations with greater sample sizes and especially patients with certain scalar translocations are needed.

Conclusion

The slim straight cochlear implant electrode is less likely to translocate from scala tympani into scala vestibuli than a perimodiolar electrode. The NRT-ratio allows the nonradiological separation between regular scala tympani positions and a scalar changing position of perimodiolar CI electrodes. For the slim straight electrode array, the NRT-ratio is less specific and does not show clear determination of the intracochlear position. But at the area of electrode, translocation changes of the NRT level were observed. A certain scalar localization can currently only be done radiologically supported with flat panel tomography or high resolution computed tomography.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by Cochlear Pty. (Sydney, Australia) (IIR 1209).

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