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ORIGINAL ARTICLE

Relationship between intracochlear electrode position and tinnitus in cochlear implantees

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Abstract

Conclusion: Cochlear implant electrode position has an impact on the rate of tinnitus suppression and generation. *Objective:* Suppression of pre-operative tinnitus or a generation of a new tinnitus in cochlear implantees is a known effect of cochlear implantation. The aim of the current study was to evaluate different cochlear implant electrode positions and their relationship with tinnitus suppression and tinnitus generation. *Method:* This study retrospectively evaluated four groups of CI recipients with radiologically evaluated electrode positions in relation to their subjective tinnitus quality, as evaluated by an analogue loudness scale (ALS) and a questionnaire. Group 1 consisted of 19 patients with a scalar change of the electrode position. Group 2 consisted of 18 patients with a scala tympani position and a perimodiolar electrode. Group 3 consisted of 10 patients with a scala tympani position and a lateral wall electrode. Group 4 consisted of eight patients with a scala vestibuli position. *Results:* An overall tinnitus suppression rate of 45.9% and a generation of a new tinnitus or the deterioration of an existing one of 5.6% were observed. A significant difference in tinnitus suppression was found between groups 1 and groups 2, 3, and 4 in tinnitus suppression and tinnitus generation.

Keywords: *Cochlear implant, tinnitus, radiology*

Introduction

The suppression of tinnitus is a well-known effect of electrical stimulation to the cochlea [1]. Besides transcutaneous, transtympanal, round window, and intra-cochlear forms of cochlear stimulation [2], effects of a cochlear implantation on tinnitus have been described [3].

Pre-operative tinnitus in cochlear implantees is frequently discussed and the occurrence rate varies between 65–100% [3]. The rate of tinnitus suppression or improvement by cochlear implantation differs in the literature between 54% [4] and 93% [5]. Although in most of the studies a positive effect on tinnitus is associated with cochlear implantation, less frequently an increase of tinnitus perception or even generation of tinnitus is described. These rates were shown to be between 0% [5] and 28% [6]. Although it is assumed that a suppressive effect of the cochlear implant is related to the electrical masking effect, the knowledge about causes and contributing factors is limited. The surgery itself, as a potentially traumatic procedure, is assumed to have an effect on suppression and generation of tinnitus [7].

The electrode position of the cochlear implant determines physically the interaction between nervous structures and the cochlear implant. The intra-cochlear electrode position can be estimated by different radiological techniques, e.g. digital volume tomograhy, cone beam scan, flat panel tomography, or multi-slice computed tomography [8], and has been shown, if sufficiently performed, to correlate with the histologically evidenced electrode position [9]. It is widely accepted that a scala

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tympani position is most favourable because of the likelihood of a better audiological outcome with the cochlear implant [10]. Scalar electrode changes from the scala tympani to the scala vestibuli are less favourable since they cause an intra-cochlear lesion by disrupting the basilar membrane. As some types of tinnitus are known to be generated intra-cochlearly, the intra-cochlear position of the electrode might have an effect on the generation/suppression of tinnitus in cochlear implantees. The aim of the present study was, therefore, to evaluate the effect of the cochlear implant electrode position on tinnitus in cochlear implantees.

Materials and methods

A post-operative radiological evaluation of the cochlear implant electrode position is part of our regular clinical protocol. Out of this data pool, four groups were retrospectively further evaluated.

The first group included 19 patients with a scalar change of the position of the cochlear implant electrode from the scala tympani to the scala vestibuli. Fifteen patients of this group were implanted with a Cochlear Advance Contour electrode, two with an Advanced Bionics Helix electrode inserted without a tool, and two with an Advanced Bionics IJ electrode. The second group included 18 patients chronologically implanted between September 2010 and August 2011 with a Nucleus Advance perimodiolar electrode in a scala tympani position. The third group included 10 patients chronologically implanted between June 2011 and June 2012 with a Nucleus 422 array in a scala tympani position. The fourth group included eight patients. In this one, the electrode was inserted into the scala vestibuli. Scala vestibuli insertion was related to an obstructed scala tympani (e.g. due to meningitis, otosclerosis).

Patients were only included in one of the four groups if two radiologists and one surgeon estimated independently the electrode position as described above with the grouping criteria. All patients with electrode positions that the reviewers did not completely agree upon were excluded (Figure 1).

To minimize a selection bias, the patients for groups 2 and 3 were chronologically included. This was not possible for groups 1 and 4, since these patients are rare in our implantees population.

In all groups, a mastoidectomy and a posterior tympanotomy followed by a round window insertion or a modified round window approach was performed to access the inner ear. For all patients, flat panel tomography was performed for the determination of the scalar position of the electrode. Determination of the electrode position was performed with an Allura Xper FD20 system (Philips Medical Systems, Best, Netherlands) with a flat panel detector. 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 (p.a.). The focus panel distance was determined and constant over the whole rotation at a frequency of 30 pic/s. Three-dimensional (3D) angiography was performed in the unsubtracted mode. From this volume dataset, the temporal bones were secondarily enlarged (FoV of 100 mm), digitally stored, and sent to an external workstation (Extended Brilliance Workspace, Philips, Cleveland, OH) for two-dimensional (2D) and 3D reconstruction.

Tinnitus was retrospectively evaluated by the TQ12 questionnaire and a visual analogue loudness scale (ALS; 1–10). Time points taken of the occurrence of tinnitus included the day before surgery, 6 weeks to 2 months post-operatively, and at the final day of this investigation (variable). End-points for groups 2 and 3 were between 9–30 months; for group 2, it was between 17–30 months (mean = 23.4 months), and for group 3 it was between 9–19 months (mean = 14.5 months). The mean end-point for group 1 was 40.4 months (SD = 20.1 months) and for group 4 it was 60.7 months (SD = 28.5 months). Although the end-point between the groups was variable, we found it to be comparable since the end-point was after the end-point of other follow-up studies (6 months) [6], and further changes of the tinnitus condition can be assumed to occur rarely 6 months after the first fitting. The first timepoint (6 weeks to 2 months) was chosen since at this time the first fitting was performed. This timepoint is, therefore, very well to be remembered by the patient. In addition, the patients were questioned whether the speech processor in operation changes the loudness/intensity of their tinnitus. Changes in the questionnaire scores were considered significant if the score of the TQ12 [11] was changed by 5 points and the ALS by 2 points. The study was approved by the institutional review board (IRB-HNO-201301).

Results

The overall incidence of pre-operative tinnitus was 65.5% (36 out of 55). While in group 1, 73.6% (14 out of 19) disclaimed pre-operative tinnitus, 50% (9 out of 18) in group 2, 60% (6 out of 10) in group 3, and 87.5% (7 out of 8) in group 4 described it. The mean pre-operative scores for the TQ12 and ALS were 3.69 and 5.57, respectively.

We observed an overall tinnitus suppression rate of 45.9% and a tinnitus generation rate of 5.6%.

For group 1, two patients described generation of tinnitus and one described an increase of loudness of a

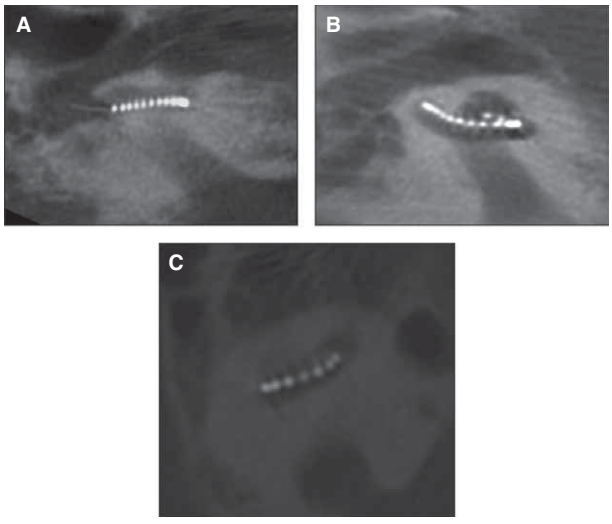

Figure 1. (A) Scala tympani position of an electrode. (B) Scala vestibuli position of an electrode. (C) Scalar change of electrode position.

noise that existed before surgery. Thus, 16.7% of patients showed a deterioration of the tinnitus situation. In 10 out of 14 patients (71.4%), suppression of tinnitus was found post-operatively, while in four patients no change occurred.

In group 2, we observed no generation or deterioration of tinnitus, but five out of eight patients (62.5%) showed suppression. For three patients of this group, the tinnitus was unchanged.

In group 3, no generation or deterioration of tinnitus was found. In one patient (16.7%), suppression was described and, for five patients, the situation was unchanged.

In group 4, no patients described generation of tinnitus. For two out of seven patients (28.6%) we found suppression, and for four patients the situation was unchanged.

The statistical analysis showed a significant difference as related to the deterioration effects between group 1 and the controls, with no scalar change (groups 2, 3, and 4; Chi-square, $p < 0.05$). Additionally, a significant difference as related to suppression was observed between group 1 and the controls (groups 2, 3, and 4; Chi-square, $p < 0.05$; Figures 2 and 3). This level of statistical significance was mainly caused by the low degree of tinnitus suppression in groups 3 and 4. Groups 1 and 2 had almost similar results regarding suppression, but not for the generation of tinnitus. Both groups included mainly patients implanted with perimodiolar electrodes. Generation or deterioration of tinnitus occurred only in group 1.

Pre-operatively, the mean TQ12 scores were 6.9 for group 1, 3.81 for group 2, 4.8 for group 3, and 6.75 for group 4. The ALS scores were 4.21 for group 1, 2.41 for group 2, 3.5 for group 3, and 4.63 for group 4.

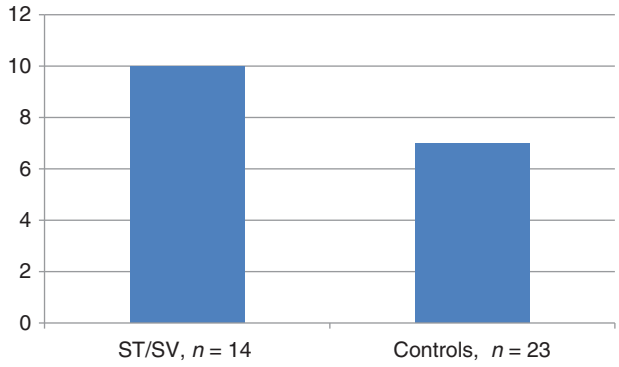

Figure 2. Difference in tinnitus suppression in patients between group 1 (scalar changing) and control groups 2, 3, and 4 (Scala tympani position or scala vestibuli position) with previous tinnitus.

Non-users of the speech processors

While mean TQ12 and ALS scores without SP changed in group 1 and group 2 after surgery, at the 6 weeks to 2 months time-point (group 1 TQ12 = 6.3; ALS = 3.5; group 2 TQ12 = 2.5; ALS = 1.8) and the changes were significant by the end-point of observation (group 1 TQ12 = 6.22; ALS = 3.15; group 2 TQ12 = 1.91; ALS = 1.25), the tinnitus situation for groups 3 and 4 was less affected. If we exclude the patients with generation of tinnitus, TQ12 and ALS scores for group 1 were 5.06 and 3.18, respectively, for 6 weeks to 2 months, and 4.06 and 2.43, respectively, for the end-point (Figure 4).

Mean TP12 and ALS scores changed in group 3 and group 4 after surgery, at the 6 weeks to 2 months time-point (group 3 TQ12 = 5.4; ALS = 3.1; group 4 TQ12 = 9; ALS = 6). Further changes were observed at the end-point for both groups (group 3 TQ12 = 5.9; ALS = 3.6; group 4 TQ12 = 7.75; ALS = 4.5) without SP.

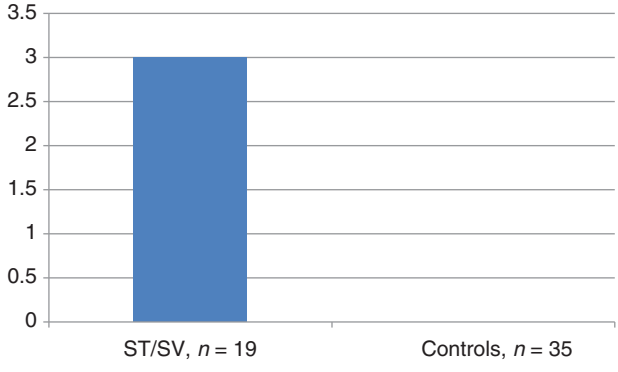

Figure 3. Difference in tinnitus generation/worsening between group 1 (scalar changing) and control groups 2, 3, and 4 (Scala tympani position or scala vestibuli position).

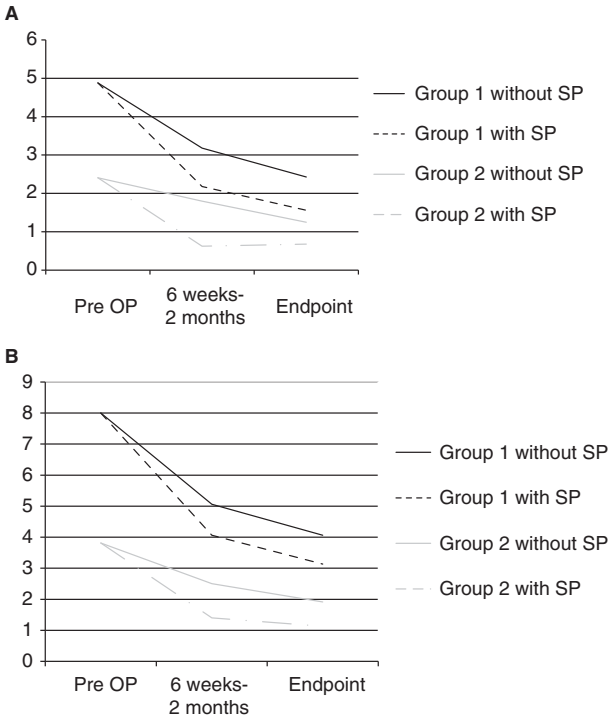

Figure 4. (A) Mean tinnitus changes evaluated by the ALS questionnaire with and without audio processor in groups 1 and 2 excluding cases of tinnitus generation. (B) Mean tinnitus changes evaluated by the TQ12 questionnaire with and without the audio processor in groups 1 and 2, excluding cases of tinnitus generation.

Usage of the SP

While mean TQ12 and ALS scores with SP changed in group 1 and group 2 after 6 weeks to 2 months (group 1 TQ12 = 5.2; ALS = 2.6; group 2 TQ12 = 1.4; ALS = 0.63) and showed a significant change at the end-point of observation for both groups (group 1 TQ12 = 5.71; ALS = 2.31; group 2 TQ12 = 1.13; ALS = 0.68), the tinnitus situation for groups 3 and 4 was less affected. If we exclude the patients with generation of tinnitus, the TQ12 and ALS scores for group 1 were 4.06 and 2.18, respectively, for 6 weeks to 2 months and 3.13 and 1.56, respectively, for the end-point (Figure 4).

We observed changes in mean TP12 and ALS scores in groups 3 and 4 after 6 weeks to 2 months (group 3 TQ12 = 5.3; ALS = 3.4; group 4 TQ12 = 8.25; ALS = 4.8) and further changes at the end-point of observation (group 3 TQ12 = 5.6; ALS = 3; group 4 TQ12 = 7; ALS = 4) with SP.

Discussion

The effect of cochlear implantation on tinnitus is well known, mainly in terms of suppression, but also, to a lower extent, generation of tinnitus [6]. Since the generation of tinnitus is known to be associated with intra-cochlear trauma (acoustic or mechanical), the impact of cochlear implantation—as a positive factor in terms of electrical masking and a possible negative impact due to the surgical trauma—is of high relevance.

The current explanation for the suppression of tinnitus is based on the masking effect due to the electrical current provided through the implant itself [7]. Based on this assumption, it could be speculated that suppression should be independent of the electrode position and electrode design.

Our data describe a statistically significant difference concerning the suppressive effect of a cochlear implant between the study groups with a scalar change in electrode position and with regularly positioned electrodes in the scala tympani or scala vestibuli (Figure 2). Looking further into the electrode types used, excluding scalar change as a contributing factor, and if we assume that a scalar vestibuli-positioned electrode is more distant to the spiral ganglion cells, we see an advantage of closely positioned perimodiolar electrodes (group 2, rate of suppression 62.5%) over more distant spiral ganglion-positioned electrode arrays (groups 3 and 4, rate of suppression 16.7% and 28.5%, respectively) for suppression of pre-operative tinnitus. Based on this, we can assume that the distance of the electrode to spiral ganglion cells might be a factor not only for audiological outcome, but also for tinnitus suppression.

Besides the positive effect of the cochlear implantation itself, two additional factors can be assumed to affect the suppression of pre-operative tinnitus: (1) intra-cochlear trauma by the electrode; and (2) perimodiolar position.

An explanation for the positive effect of cochlear implantation-induced injury might be given by the work of Salvi et al. [12], which showed cortical re-organization after cochlear injury. Such plasticity has been demonstrated both in animals [13] and in humans with high-frequency hearing loss [14,15]. The implantation itself should lead to a second central re-organization through neuroplasticity of the central auditory pathway. The marked neuroplastic changes within the cortex associated with a cochlear implant use have been described by Giraud et al. [16]. It can be assumed that a third re-organization occurs if cochlear implantation is associated with a cochlear trauma, as described for group 1.

The more positive effect of perimodiolar electrodes (group 2) in comparison with lateral wall-positioned electrodes (group 3) or scala vestibuli-positioned arrays (group 4) might be

caused by a more current-focused interaction of the cochlear implant electrode with the tonotopic positioned spiral ganglion cells, related to their distance to the cells.

The negative side-effect of a scalar change in group 1 was that the rate of tinnitus generation (16.7%) was higher in comparison with group 2 (0%) and group 3 (0%). A cochlear injury with subsequent peripheral and central re-organization [12] could even be the explanation in the case of tinnitus generation.

The role of the SP was also asked in the questionnaire. Using the SP led to a significant decrease in the ALS and TQ12 scores in cases with pre-operative tinnitus, mainly in groups 1 and 2. Interestingly, non-usage of the SP also led to a decrease of the tinnitus and ALS and TQ12 scores in comparison with the pre-operative data (Figure 3A and B). For groups 3 and 4, the data were almost unchanged.

The suppressive effect of the SP is a well-described observation. A sub-group-specific suppression without using the SP has never been described before and needs to be further evaluated. A purely intra-cochlear injury-related re-organization of the pathway might be an explanation for this effect, since lateral wall electrodes (group 3) are known to be less traumatic than the perimodiolar electrodes used by the majority of patients in groups 1 and 2. The limited effect of cochlear implantation on tinnitus in group 4 might be explained by the intense pre-operative intra-cochlear changes in this group.

Based on the evaluated data, two mechanisms of tinnitus suppression by cochlear implantation can be assumed: (1) re-organization by electrical stimulation; and (2) re-organization by intra-cochlear trauma. Based on the data for group 1, the re-organization after cochlear implantation can be assumed to also generate tinnitus.

Conclusion

Cochlear implant electrode position has an impact on the rate of tinnitus suppression and generation. Although a traumatic position has the highest rate of tinnitus suppression, it cannot be favoured since it is associated with tinnitus generation. Even not wearing the SP has a positive effect on tinnitus suppression compared with the pre-operative tinnitus situation in specific sub-groups.

***Declaration of interest*:** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

[1] Tyler RS, Rubinstein PJ, Pan T, Chang S-A, Gogel SA, Gehringer A, et al. Electrical stimulation of the cochlea to reduce tinnitus. Semin Hear 2008;29:326–32.

[2] Tyler RS. The psychoacoustical measurement of tinnitus. In Tyler RS, editor. Tinnitus Handbook. San Diego, CA: Singular. 2000. p 149–79.

[3] McKerrow WS, Schreiner CE, Snyder RL, Merzenich MM, Toner JG. Tinnitus suppression by cochlear implants. Ann Otol Rhinol Laryngol 1991;100:552–8.

[4] Mo B, Harris S, Lindbaek M. Tinnitus in cochlear implant patients–a comparison with other hearing-impaired patients. Int J Audiol 2002;41:527–34.

[5] Ito J. Tinnitus suppression in cochlear implant patients. Otolaryngol Head Neck Surg 1997;117:701–3.

[6] Kompis M, Pelizzone M, Dillier N, Allum J, DeMin N, Senn P. Tinnitus before and 6 months after cochlear implantation. Audiol Neurootol 2012;17:161–8.

[7] Baguley DM, Atlas MD. Cochlear implants and tinnitus. Prog Brain Res 2007;166:347–55.

[8] Arweiler-Harbeck D, Monninghoff C, Greve J, Hoffmann T, Goricke S, Arnolds J, et al. Imaging of electrode position after cochlear implantation with flat panel CT. ISRN Otolaryngol 2012; Article ID 728205.

[9] Marx M, Risi F, Escudé B, Durmo I, James C, Lauwers F, et al. Reliability of cone beam computed tomography in scalar localization of the electrode array: a radio histological study. Eur Arch Otorhinolaryngol 2014;271:673–9.

[10] Aschendorff A, Kromeier J, Klenzner T, Laszig R. Quality control after insertion of the nucleus contour and contour advance electrode in adults. Ear Hear 2007;28:75S–9S.

[11] Hiller W, Goebel G. Rapid assessment of tinnitus related psychological distress using the Mini-TQ. Int J Audiol 2004; 43:600–4.

[12] Salvi RJ, Ding D, Wang J, Jiang HY. A review of the effects of selective inner hair cell lesions on distortion product otoacoustic emissions, cochlear function and auditory evoked potentials. Noise Health 2000;2:9–26.

[13] Rajan R, Irvine DR, Wise LZ, Heil P. Effect of unilateral partial cochlear lesions in adult cats on the representation of lesioned and unlesioned cochleas in primary auditory cortex. J Comp Neurol 1993;338:17–49.

[14] Harrison RV, Nagasawa A, Smith DW, Stanton S, Mount RJ. Reorganization of auditory cortex after neonatal high frequency cochlear hearing loss. Hear Res 1991;54: 11–19.

[15] Dietrich V, Nieschalk M, Stoll W, Rajan R, Pantev C. Cortical reorganization in patients with high frequency cochlear hearing loss. Hear Res 2001;158:95–101.

[16] Giraud AL, Price CJ, Graham JM, Frackowiak RS. Functional plasticity of language-related brain areas after cochlear implantation. Brain 2001;124:1307–16.