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INTRODUCTION

Recently, some medical centers have started using cochlear implantation as a treatment for tinnitus in patients with single-sided deafness. Since cochlear implantation does not always reduce tinnitus, and may even have deleterious effects, it is important to know which factors influence the outcome of cochlear implantation on tinnitus. Previous studies describing the factors influencing the outcome of cochlear implantation on tinnitus did not show consistent results, and in some even contrary outcomes were reported.

Some factors have been reported to predict a positive effect of cochlear implantation on tinnitus. These include: higher preoperative tinnitus handicap scores, especially higher scores on the emotional subscale of tinnitus handicap questionnaires, a higher age at implantation, higher preoperative hearing handicap scores, higher preoperative stress levels, as well as fewer years of hearing loss. However, a relationship between age at implantation, the number of years of tinnitus before implantation, and the level of hearing loss before implantation could not consistently be confirmed as exerting a positive effect of implantation on tinnitus.

In cochlear implant candidates who receive their implant because of severe hearing loss, besides being able to predict a positive effect of cochlear implantation on tinnitus, it is also important to be able to predict a negative effect, ie, deterioration or the onset of tinnitus. Knowing negative predictive factors might help clinicians in their preoperative counselling on the risks of developing tinnitus after the operation. Previous studies suggest that a higher age at implantation, higher preoperative tinnitus handicap scores, better hearing before implantation, a shorter period of hearing loss before implantation, higher additional hearing loss after implantation and worse phoneme scores after implantation correlate with a negative effect of implantation on tinnitus. However, most of these correlations lack statistical significance.

Since there is no clear evidence concerning which factors reliably predict the effects of cochlear implantation, we created models predicting positive or negative changes in tinnitus after implantation.

MATERIALS AND METHODS

The present study describes logistic regression analyses of data that were reported in an earlier paper by Kloostra et al. As that paper extensively described, patients who received a cochlear implant between 2000 and 2009 in the University
of implantation can, of course, only be assessed in patients that experienced tinnitus prior to surgery. Hence, 61 out of 117 patients were included in the analyses of a positive effect of implantation on tinnitus. Within this group of patients, we compared the subgroup who experienced a positive effect of implantation on their tinnitus with the subgroup who did not experience a positive effect of the implantation.

Of the 61 patients included with preoperative tinnitus, 34 patients experienced a positive effect of implantation on their tinnitus, ie, suppression or cessation of tinnitus after cochlear implantation.

We classified patients as having a negative effect of cochlear implantation on tinnitus when they answered the question with C) ‘I started to experience tinnitus after implantation’ and D) ‘my already existing tinnitus got worse after implantation’. In order to predict which cochlear implant candidates had more chance of a negative effect of implantation on tinnitus, we included all 117 patients that completed the questionnaires in the analyses, because we wanted to know from the whole group of operated patients which type of patient experienced a negative outcome of implantation on tinnitus. Of 117 patients, 16 experienced a negative effect on their tinnitus, ie, a worsening of tinnitus (n = 5) or onset (n = 11) of tinnitus after implantation.

Based on previous studies and our own expectations, we included the following continuous pre-operative predictors in our analyses: tinnitus handicap (THI and THQ), personality characteristics (social inhibition, negative affect (DS14), optimism (LOT)), anxiety and depression (HADS), hearing handicap (APHAB), pre-operative speech comprehension scores, mean pre-operative hearing loss in decibels, years of tinnitus before implantation, and the age at the time of inclusion. To test which factors could be relevant as predictors, we first analyzed the factors by means of t-tests (THI, PTA of 1000Hz/2000Hz/4000Hz, APHAB) or Mann Whitney U-tests (THQ, HADS-depression, HADS-anxiety, DS14-negative affectivity, DS14-social inhibition, LOT, phoneme scores, age at inclusion and years of preoperative tinnitus), dependent on whether the variables were normally distributed or not. With these t-tests and Mann Whitney U-tests, we tested whether there was a relevant difference in the scores for these factors between the positive effect group and the no effect + negative effect group. In addition, we tested if there was a relevant difference in the scores between the negative effect group and the no effect group + positive effect group, since this may identify this factor as a predictor of the postoperative effect. As a rule of thumb, we included variables in the subsequent logistic regression analysis if the corresponding difference was significant at $P < .25$.

For statistical analyses we used IBM SPSS Statistics 20.

RESULTS

Positive Effect of Cochlear Implantation on Tinnitus

A total of 61 of 117 patients were included in the logistic model for a positive effect of implantation on tinnitus. The initial analysis (Table II) revealed relevant differences ($P < .25$) in THI and DS-14 negative affectivity scores between patients with and without a positive effect of implantation on tinnitus. Therefore, we considered these variables to be potential predictors of a positive effect of implantation on tinnitus. Binary logistic analyses with these variables as predictors in the model identified neither THI-scores nor DS14-negative affectivity as a significant predictor of a positive effect of implantation on...
TABLE II.
P-values of the Difference in Means of Patients With or Without a Positive Effect of CI on Tinnitus

<table>
<thead>
<tr>
<th></th>
<th>P-values</th>
<th>Mean patients with positive effect (N = 34)</th>
<th>Mean patients without positive effect (N = 27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>THI</td>
<td>.142</td>
<td>34.94</td>
<td>26.45</td>
</tr>
<tr>
<td>APHAB</td>
<td>.979</td>
<td>76.73</td>
<td>76.63</td>
</tr>
<tr>
<td>Mean dB hearing loss</td>
<td>.656</td>
<td>105.69</td>
<td>104.08</td>
</tr>
<tr>
<td>Mann-Whitney U tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>THQ</td>
<td>.268</td>
<td>43.89</td>
<td>36.75</td>
</tr>
<tr>
<td>DS14 Negative affectivity</td>
<td>.082</td>
<td>13.00</td>
<td>10.12</td>
</tr>
<tr>
<td>DS14 Social inhibition</td>
<td>.844</td>
<td>12.88</td>
<td>12.84</td>
</tr>
<tr>
<td>LOT</td>
<td>.853</td>
<td>20.44</td>
<td>20.24</td>
</tr>
<tr>
<td>years of tinnitus</td>
<td>.429</td>
<td>25.38</td>
<td>21.89</td>
</tr>
<tr>
<td>Phonemescores</td>
<td>.358</td>
<td>7.93</td>
<td>9.30</td>
</tr>
<tr>
<td>Age at inclusion</td>
<td>.366</td>
<td>61.35</td>
<td>64.54</td>
</tr>
<tr>
<td>HADS-anxiety</td>
<td>.428</td>
<td>9.88</td>
<td>9.32</td>
</tr>
<tr>
<td>HADS-depression</td>
<td>.333</td>
<td>7.16</td>
<td>6.56</td>
</tr>
</tbody>
</table>

APHAB = abbreviated profile of hearing aid benefit; CI = cochlear implantation; DS14 = type D-scale; THI = tinnitus handicap inventory; LOT = life orientation test; THQ = tinnitus handicap inventory; DS14-na = type D scale negative affectivity; DS14-si = type D social inhibition; HADS = hospital anxiety and depression scale; HADS-a = hospital anxiety and depression scale-anxiety; HADS-d = hospital anxiety and depression scale-depression; THQ = tinnitus handicap inventory; THI = tinnitus handicap inventory.

Negative Effect of Cochlear Implantation on Tinnitus

All 117 patients were included in the logistic model for a negative effect of implantation on tinnitus. The initial analysis (Table III) found relevant differences (P < .25) between patients with and without a negative effect of CI in tinnitus for the variables: THI, THQ, APHAB, DS14-negative affectivity, DS14-social inhibition, HADS-anxiety, and HADS-depression. Therefore, these variables were considered to be potential predictors of a negative effect of implantation. In a first binary logistic analysis, we included all of these variables and identified a significant model (P < .001, Nagelkerke R² = 0.066) and when these variables were included separately (THI: P = .133, Nagelkerke R² = 0.051; DS14-negative affectivity: P = .996, Nagelkerke R² = 0.063). With these variables, we created a model with a significance of P < .001 and a Nagelkerke R² of 0.529 (Table V). Both THQ (P = .004 Wald statistic, P = .001 THQ 0.89-0.977) and APHAB (P = .031 Wald statistic, P = .026 APHAB 0.899-0.995) were each significantly related to a negative effect of implantation on tinnitus. The relation of the THQ with a negative of implantation on tinnitus is only relevant for patients with tinnitus deterioration after implantation and not relevant for patients with tinnitus onset after implantation because these last patients did not fill in the preoperative THQ. Our model indicates that the lower the preoperative tinnitus handicap (B = -0.056) and the lower the preoperative hearing handicap (B = -0.070), the higher the chance a patient has of experiencing a negative effect of cochlear implantation on tinnitus.

Our model fulfilled all assumptions for logistic regression analysis. We tested the linearity of the logit of the model and found that none of the interaction terms were significant (THQ x LnTHQ P = .305, APHAB x LnAPHAB P = .736). This indicates that the assumption of linearity of the logit had been met. We tested multicollinearity by tolerance- and VIF-values. All tolerance values were larger than 0.1 and all VIF values were smaller than 10, which makes multicollinearity unlikely (see Table VI).

**DISCUSSION**

Because the predictors of the effect of cochlear implantation on tinnitus were unclear, in this study we...
created prognostic models for positive and negative changes in tinnitus after cochlear implantation.

Unfortunately, we could not create a well-fitted model to predict a positive effect on tinnitus in patients with preoperative tinnitus. In contrast, for the negative effects of cochlear implantation on tinnitus, predictors could be established. The strongest predictors for a negative effect of cochlear implantation were a low preoperative tinnitus handicap and a low preoperative hearing handicap.

With regard to a positive effect of cochlear implantation on tinnitus, we could not confirm the results from previous studies in which the years of hearing loss, higher preoperative hearing handicap scores, higher preoperative tinnitus handicap scores and a higher age at implantation predicted better effects of cochlear implantation on tinnitus. Most likely this is due to there being other factors involved in the effect of cochlear implantation on tinnitus that we did not include in our models. Higher preoperative tinnitus handicap scores as a predictor in previous studies could also be explained by the “regression toward the mean” principle, ie, if the tinnitus handicap is extreme on its first measurement (before cochlear implantation), it will tend to be closer to the average on its second measurement (after cochlear implantation).

Concerning the negative effect of cochlear implantation on tinnitus, the strongest predictors in the binary logistic model were the preoperative tinnitus handicap and the preoperative hearing handicap.

A low preoperative tinnitus handicap (only relevant for patient with preoperative tinnitus) score as a predictor of a negative effect on tinnitus is consistent with our expectations. This outcome could be explained by the fact that the less handicap patients experience before the operation, the greater the chance that the postoperative outcome is disappointing. Besides, in patients with a high level of tinnitus handicap, the physiology of the brain can be changed due to the changed pattern of spontaneous activity of the neural system that occurs in tinnitus. Possibly, this makes the brain of these patients less sensitive to (negative) changes in tinnitus after cochlear implantation, in contrast to patients with a low tinnitus handicap in whom these changes in the physiology of the brain have not (yet) occurred.

The result that a lower hearing handicap predicts a negative effect on tinnitus also confirms our expectations. This outcome could also be explained by same mechanisms as described above with a greater tinnitus handicap.

Our results concerning hearing handicap are in agreement with those described before by Kompis et al. who describe that patients that develop tinnitus postoperatively had slightly better preoperative hearing thresholds in the implanted ear.

Also, some studies describe a positive relationship between the amount of hearing handicap and the amount of tinnitus distress a patient experiences. Thus a hearing handicap as a predictor of a negative effect of cochlear implantation on tinnitus is possibly mediated by a tinnitus handicap.

Our results should be read with caution due to the retrospective design, which might cause bias in two areas.

First, the retrospective method is susceptible to recall bias. Since participants completed the questionnaires after the implant surgery, it is possible that they could not remember the situation before implantation. This could magnify the effects; for example patients with

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>Standard error</th>
<th>Significance (Wald)</th>
<th>Exp (B)</th>
<th>95% Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>THI</td>
<td>−0.027</td>
<td>0.046</td>
<td>0.552</td>
<td>0.973</td>
<td>0.890–1.064</td>
</tr>
<tr>
<td>THQ</td>
<td>−0.027</td>
<td>0.038</td>
<td>0.488</td>
<td>0.974</td>
<td>0.903–1.050</td>
</tr>
<tr>
<td>DS14-na</td>
<td>0.029</td>
<td>0.096</td>
<td>0.761</td>
<td>1.030</td>
<td>0.854–1.242</td>
</tr>
<tr>
<td>DS14-si</td>
<td>−0.165</td>
<td>0.104</td>
<td>0.113</td>
<td>0.848</td>
<td>0.691–1.040</td>
</tr>
<tr>
<td>APHAB</td>
<td>−0.065</td>
<td>0.029</td>
<td>0.027</td>
<td>0.937</td>
<td>0.885–0.992</td>
</tr>
<tr>
<td>HADS-a</td>
<td>−0.094</td>
<td>0.203</td>
<td>0.644</td>
<td>0.911</td>
<td>0.612–1.355</td>
</tr>
<tr>
<td>HADS-d</td>
<td>−0.127</td>
<td>0.208</td>
<td>0.541</td>
<td>0.880</td>
<td>0.585–1.324</td>
</tr>
</tbody>
</table>

(APHAB = abbreviated profile of hearing aid benefit; CI = cochlear implantation; DS14 = type D-scale; DS14-na = type D scale negative affectivity; DS14-si = type D-scale social inhibition; HADS = hospital anxiety and depression scale; HADS-a = hospital anxiety and depression scale-anxiety; HADS-d = hospital anxiety and depression scale-depression; THI = tinnitus handicap inventory; THQ = tinnitus handicap questionnaire)

First measurement (before cochlear implantation), it will tend to be closer to the average on its second measurement (after cochlear implantation).

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a negative effect of implantation on tinnitus may remember the situation before implantation better than it actually was. This could result in lower preoperative tinnitus handicap scores and lower hearing handicap scores. This would mean that in our analyses of the negative effect of cochlear implantation on tinnitus, the predictive power of lower preoperative tinnitus and hearing handicap is overestimated.

Second, there is potential contamination in the data because of factors such as social desirability and effort justification. Consequently, our data could be more in favor of a positive effect of cochlear implantation on tinnitus, because patients want to fulfill our expectations. Social desirability and effort justification may affect the data in two ways: First, not all patients with a negative effect of cochlear implantation on tinnitus might mention their negative effect in our questionnaires, which could bias our study populations. Second, patients might score their preoperative tinnitus and hearing handicap higher and again falsely make these factors predictors for a negative effect of cochlear implantation on tinnitus.

CONCLUSION
A regression analysis of possible predictive indicators of the effect of cochlear implantation on tinnitus did not reveal a good predictive model for a positive effect. In contrast, the negative effects of cochlear implantation on tinnitus could be modelled and were mainly related to low preoperative tinnitus and low hearing handicap scores. This predictive model needs to be viewed with caution due to the retrospective character of our study. More research needs to be done, preferable in a big prospective study, to make this model instrumental for clinical decision making and preoperative patient counselling. However, our results might suggest that preoperative THQ and APHAB screening could be meaningful. Especially in patients who are afraid to develop tinnitus or tinnitus worsening as complication of cochlear implantation.

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BIBLIOGRAPHY