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Tinnitus before and 6 Months after Cochlear Implantation

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Key Words
Tinnitus · Cochlear implants · Tinnitus loudness · Tinnitus-related distress

Abstract
In this prospective multicenter study, tinnitus loudness and tinnitus-related distress were investigated in 174 cochlear implant (CI) candidates who underwent CI surgery at a Swiss cochlear implant center. All subjects participated in two session, one preoperatively and one 6 months after device activation. In both sessions, tinnitus loudness was assessed using a visual analogue scale and tinnitus distress using a standardized tinnitus questionnaire. The data were compared with unaided pre- and postoperative pure tone thresholds, and postoperative speech reception scores. 71.8% of the subjects reported tinnitus preoperatively. Six months after CI surgery 20.0% of these reported abolition of their tinnitus, 51.2% a subjective improvement, 21.6% no change and 7.2% a deterioration. Of the 49 (28.2%) subjects with no tinnitus preoperatively, 5 developed tinnitus 6 months after CI. These 5 had poorer speech understanding after CI surgery with their device than the group who remained tinnitus free. We found no correlation between tinnitus improvement, age, duration of tinnitus, or change in unaided hearing thresholds between the two sessions.

Introduction

Tinnitus in cochlear implant (CI) candidates is frequent. Several authors reported a prevalence between 74 and 86% [Baguley and Atlas, 2007; Quaranta et al., 2004; Hazell et al., 1995; Andersson et al., 2009]. The mechanisms underlying tinnitus are unclear [Quaranta et al., 2008].

Cochlear implantation has been shown to improve or even eliminate tinnitus in 46–95% of the cases in several studies [Baguley and Atlas, 2007, Quaranta et al., 2004; Pan et al., 2009]. The effect of the electrical stimulation by a CI on tinnitus suppression has been shown in CI users with positron emission tomography [Mirz et al., 2002; Osaki et al., 2005]. Additionally, a limited number of subjects with normal or almost normal hearing in one ear and deafness and tinnitus in the other ear have been implanted and their tinnitus improved significantly after cochlear implantation [Vermeire and van de Heyning, 2009; Buechner et al., 2010].

Unfortunately, tinnitus can also become worse after cochlear implantation. Several studies suggest that in 4–26% of the CI recipients tinnitus may deteriorate [Quaranta et al., 2004; Baguley and Atlas, 2007]. Even more troubling, in some recipients tinnitus may be present after cochlear implantation, even though they did not

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report tinnitus before CI [Baguley and Atlas, 2007; Pan et al., 2009].

The change in tinnitus perception as a result of cochlear implantation is relevant for preoperative patient counseling. As the range of known outcomes – from the abolition of an existing tinnitus to the development of a tinnitus – is large, it would be valuable to predict the outcome in a given candidate with reasonable certainty. To date, it is not clear, which patients benefit from total, partial or no relief from tinnitus [Pan et al., 2009]. In 1993, Dauman and Tyler suggested a relationship between poor performance with the CI after surgery in terms of speech understanding and high tinnitus annoyance. Pan et al. [2009] found that there is a tendency for older CI candidates and for those with a shorter time of hearing loss to develop a new tinnitus after cochlear implantation. However, the average differences between those with and without tinnitus were relatively small and the authors concluded that it is difficult to determine the unique characteristic correlating with the development of tinnitus because of the limited number of subjects [Pan et al., 2009].

Unfortunately, most studies to date have small numbers of subjects [Bovo et al., 2011]. Pooling the data of several studies is difficult because of the different criteria and different reporting used [Baguley and Atlas, 2007; Quaranta et al., 2004]. Ideally, studies should report at least tinnitus loudness and distress due to tinnitus, as suggested by Bovo et al. [2011].

We are aware of only 3 tinnitus and CI studies which include more than 100 subjects. Hazell et al. [1995] analyzed the data of 256 CI recipients. However, only 59 patients were compared before and after CI. In 2009, Andersson et al. published a cross-sectional study with 151 CI users. In this study though, the change of tinnitus due to the cochlear implantation was neither in the focus of interest, nor was it analyzed. The largest study so far comparing tinnitus before and after implantation included 244 subjects and was published by Pan et al. [2009]. This valuable study had the limitation that although tinnitus handicap was assessed, tinnitus loudness was not. The delay between CI surgery and the administration of the postoperative questionnaire was on average 57 months. The actual range is not reported and might be important, given the number of open issues concerning tinnitus after CI surgery.

We aimed to answer the following questions:

(1) How does tinnitus change in CI recipients after 6 months of CI use when compared to the preoperative status?
(2) How do the following 3 different methods of assessment correlate with each other: tinnitus-related distress (tinnitus questionnaire), subjective tinnitus loudness (visual analogue scale, VAS) and direct question 6 months after surgery (Is your tinnitus better now than before surgery?)?
(3) Is there an influence of age, duration of tinnitus before implantation, the initial hearing loss or the postoperative hearing loss on postoperative tinnitus?
(4) Is speech understanding with CI after 6 months correlated with postoperative tinnitus?
(5) How does cochlear implantation influence tinnitus in the implanted ear and in the contralateral ear?
(6) How is tinnitus influenced by the speech processor being switched on or off?

Materials and Methods

All 5 cochlear implant centers of Switzerland, located in Bern, Geneva, Basel, Lucerne, and Zurich, participated in this prospective multicenter study. The study protocol was approved by the ethics committee at the managing center in Bern and by local ethics committees.

Study Protocol

Participants were enrolled at the time of their preoperative audiological evaluation for their first CI. During this evaluation, they filled in a questionnaire (questionnaire 1) describing the present state of their tinnitus. In questionnaire 1, the presence or absence of tinnitus was assessed and, if present, the ear in which it was perceived (possible answers: right ear only, louder in the right ear, similar in both ears, louder in the left ear, left ear only). The subjects were asked to report or to estimate the duration of their tinnitus (if any) and its current subjective loudness using a VAS similar to the one proposed by the ADANO [ADANO, 1998]. Furthermore, a 10-question tinnitus questionnaire [Goebel and Hiller, 2000] was used to assess the tinnitus-associated distress. This questionnaire is a short version of a longer 52-question questionnaire by the same authors [Goebel and Hiller, 1998] and similar to the subsequently published 12-question version [Hiller and Goebel, 2004], with 7 identical, 3 similar questions, and questions 2 and 5 removed.

Six months after the first fitting of the speech processor, all participants filled in a second questionnaire (questionnaire 2). Again, the participants were asked whether they currently perceived any tinnitus, and, if so, in which ear it was perceived, while using their CI system. The subjective loudness and tinnitus-related distress were assessed using the same VAS and tinnitus questionnaire as described above in questionnaire 1, along with the tinnitus questionnaire [Goebel and Hiller, 1998].

In addition, participants were asked, how their tinnitus had changed when compared to the preoperative situations with the possible answers 'much better', 'somewhat better', 'approximately the same', 'somewhat worse', or 'much worse'. In the last question, it was assessed how tinnitus changed when the speech processor

of the CI system was switched off (same 5 possible answers as above).

Questionnaires 1 and 2 were first generated in German and then translated to French by a native French speaker who was also proficient in German (co-author of this paper, M.P.). To ascertain that the translation was correct, it was then translated back into German independently by two bilingual persons working at the ENT department in Bern, who were otherwise not involved in this study.

The data were complemented with the unaided air conduction hearing thresholds of both ears at the time of the preoperative evaluation and 6 months postoperatively, and speech understanding of monosyllabic words at 60 and 80 dB with the CI system 6 months after surgery. The side and type of the implants was taken from the Swiss CI registry, which encompasses all Swiss cochlear implantations.

Subjects

Subjects had to be at least 16 years old and fluent in either German or French and able to understand and to fill in questionnaires regarding their tinnitus by themselves. 174 subjects (93 women and 81 men; ages 16–86, mean age 51.2 years) participated in the study. All were candidates for cochlear implantation at the time of their enrollment and received 1 CI (79 right ear, 95 left ear) between 2003 and 2010 at 1 of the 5 CI centers in Switzerland (80 in Bern, 47 in Geneva, 21 in Basel, 15 in Lucerne, and 11 in Zurich). Due to organizational restrictions, subject recruitment and data collection was terminated earlier in Lucerne (after 2007) and in Zurich (2005). There were no significant differences between the study populations of these 2 centers and the other 3 centers in terms of age, sex, side of implantation, or prevalence of tinnitus. Patients with re-implantations, e.g. due to device failure or a second CI in their contralateral ear, were excluded. Seventy-eight subjects received a Medel CI (12 Combi+, 43 Pulsar, 23 Sonata), 66 a Nucleus CI (19 from the 24R family and 47 from the 24RE family), 27 a Clarion/Advanced bionics CI (2 CII, 23 HiRes 90K), and 2 a Neurelec CI (both DX10C).

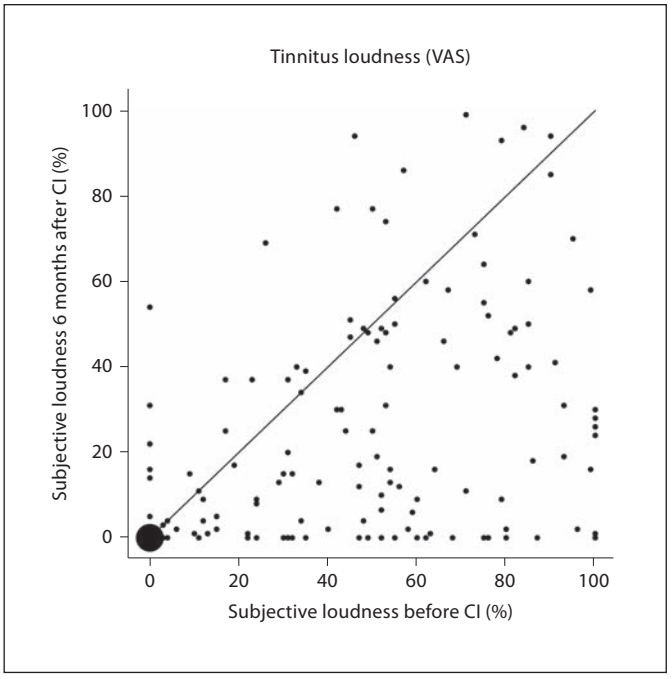


Fig. 1. Subjective tinnitus loudness before and 6 months after cochlear implantation. The area of each data points is proportional to the number of subjects with a given data combination.

Results

Of the 174 subjects, 49 (28.2%) reported no tinnitus before CI surgery. Five of these participants reported a tinnitus 6 months after CI, and 44 remained tinnitus free. Of the 125 subjects (71.8%) with tinnitus before CI, 25 had no tinnitus anymore 6 months later.

Of the 100 subjects who reported tinnitus before and after CI surgery, tinnitus loudness had decreased by more than 10% in 60 subjects, and increased by more than 10% in 11 subjects. Tinnitus distress (i.e. the score of the tinnitus questionnaire) had improved by 2 or more points in 35 subjects and deteriorated by 2 points or more in 10 subjects. In the direct question, 64 subjects reported that their tinnitus had become 'much better' or 'somewhat better' 6 months after surgery. For 27, it remained 'approximately the same' and 9 subjects reported their tinnitus had become either 'somewhat worse' or 'much worse'.

Figure 1 shows the relation of tinnitus loudness before and after CI. The 44 subjects without tinnitus before or after CI surgery are shown as a large data point in the lower left corner. In 85 subjects, tinnitus loudness had improved by 10% or more, and in 16 it had deteriorated by more than 10%, including 5 subjects who had no tinnitus before CI.

Figure 2 shows the change in tinnitus-related distress, as assessed by the tinnitus questionnaire. Forty-nine subjects had a score of 0 points (no distress) before as well as after cochlear implantation. In 14 subjects, the score was higher by 2 or more points 6 months after surgery, indicating higher tinnitus-related distress. In 60 subjects, the score was better (lower) by at least 2 points.

Figure 3 summarizes the perceived change in tinnitus after 6 months, as assessed by the direct question. Ninety-three subjects with preoperative tinnitus stated that it had become better or even much better, and 44 out of 49 subjects without tinnitus before the surgery reported no tinnitus 6 months later. However, 8 participants wrote that their tinnitus had become worse, and another 6 that it had become much worse.

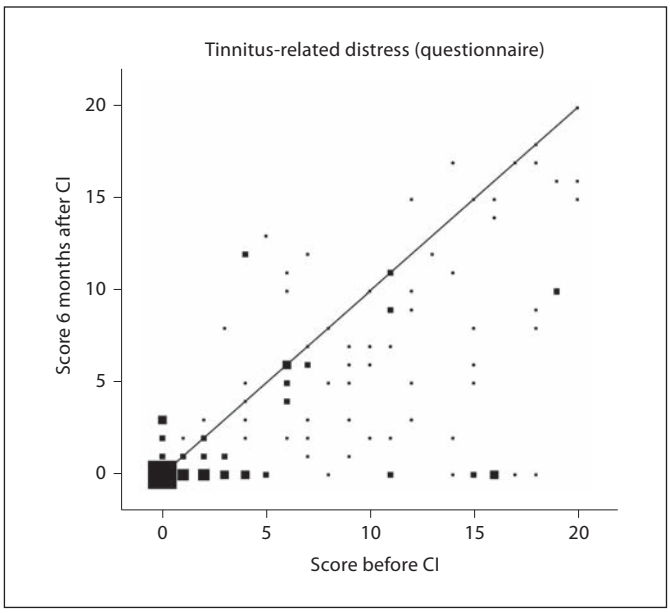


Fig. 2. Tinnitus distress as assessed with the tinnitus questionnaire before and 6 months after cochlear implantation. The area of each data point is proportional to the number of subjects with a given data combination.

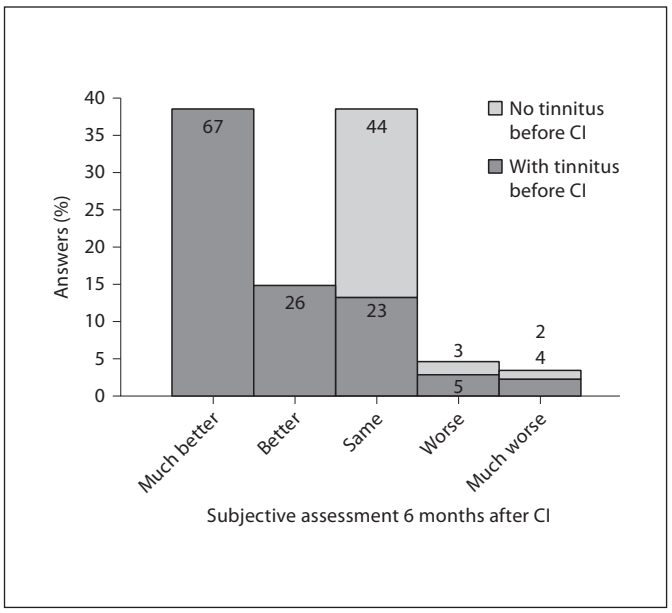


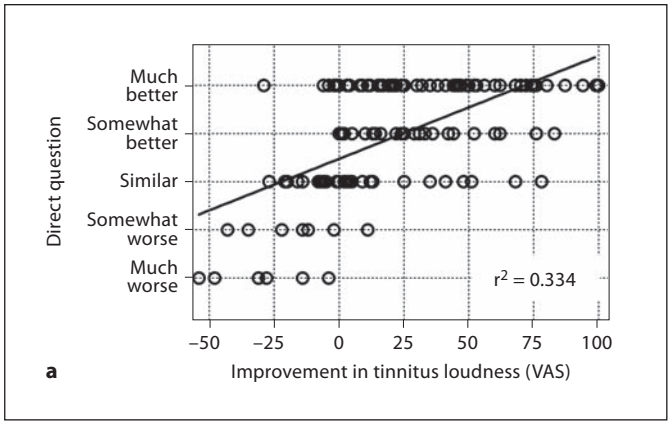
Fig. 3. Distribution of the answers to the direct question regarding the evolution of the tinnitus.

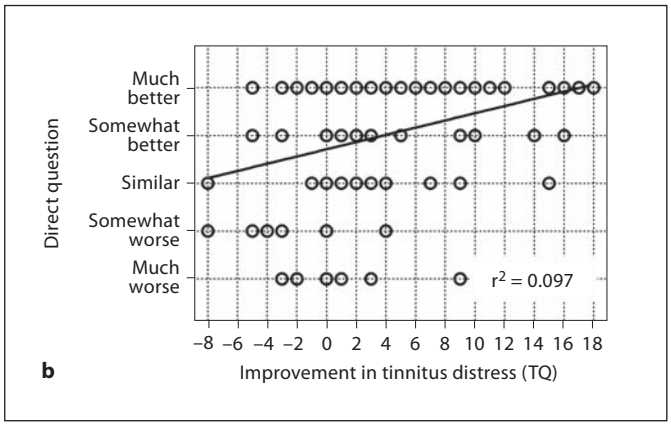
Figure 4 shows the relationship between the 3 different measures used to assess tinnitus (tinnitus loudness, tinnitus distress and direct question, as depicted individually in fig. 1–3). Generally, the correlation is relatively low, and lowest for the relationship between tinnitus-related distress and the answer to the direct question ($r^2 = 0.097$; fig. 4b). It is higher for both correlations where tinnitus loudness is one of the variable, with $r^2 = 0.334$ when compared to the answer to the direct question (fig. 4a) and $r^2 = 0.348$ when compared to tinnitus-related distress (fig. 4c). As tinnitus loudness correlates best with the other two methods of assessment, in the following figures it is used to represent the development of tinnitus, rather than the answer to the direct question or tinnitus distress.

The influence of age at implantation and duration of tinnitus before CI surgery on the improvement in tinnitus loudness between the preoperative and postoperative sessions was analyzed. There was no consistent trend for either of the two variables. Linear regression analysis shows very low regression coefficients ($r^2 < 10^{-4}$ for age at implantation and $r^2 = 0.00025$ for duration of tinnitus). The slope of these two regression lines does not differ significantly from 0. The maximal improvement in subjective tinnitus loudness was 100% (reached in 2 subjects), whereas the largest deterioration was considerably lower (–54%).

An analysis of the air conduction hearing thresholds before and 6 months after implantation was performed. The median preoperative hearing thresholds of the ears which were implanted ranged from 100 dB at 500 Hz to 120 dB at 2 kHz with a uniform drop of 10 dB per octave. At 4 kHz, the median threshold was greater than the audiometer limit of 120 dB. The median hearing thresholds of the contralateral ears were higher by 10–12.5 dB for the frequency range of 500 Hz to 2 kHz, and at 115 dB for 4 kHz. After surgery, there was a small drop in the thresholds of the nonimplanted ear (median loss –5 dB at 500 Hz, –5 dB at 1000 Hz, –2.5 at 2000 Hz, and greater than the audiometer limit at 4000 Hz), presumably reflecting the natural course of progressive hearing loss. In contrast, median hearing thresholds were greater than the audiometer limit for all frequencies in the implanted ears, reflecting a complete hearing loss postoperatively in more than half of these ears.

Figure 5 shows the change in tinnitus loudness between the two sessions as a function of the additional hearing loss in the implanted ear over the same time period. To represent the hearing loss, the pure-tone average (PTA) over the frequencies 500, 1000, 2000 and 4000 Hz





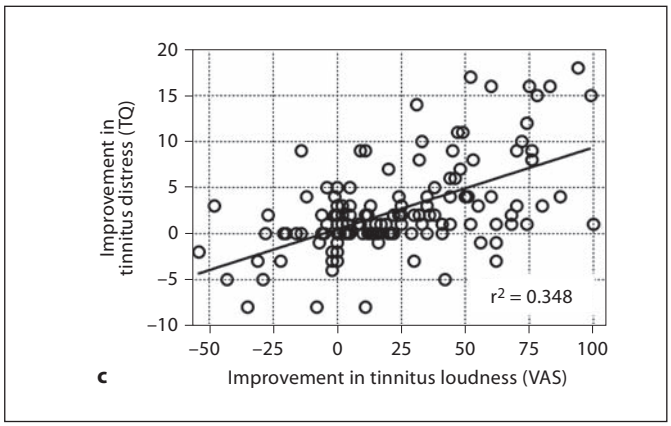


Fig. 4. Pairwise correlations between tinnitus loudness, distress and answers to the direct question regarding the evolution of the tinnitus. TQ = Tinnitus questionnaire.

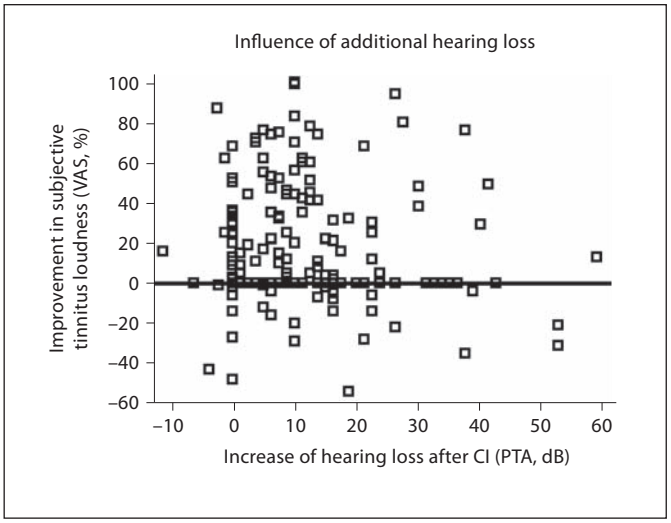


Fig. 5. Influence of additional hearing loss (PTA over the frequencies of 500, 1000, 2000 and 4000 Hz) in the implanted ear on change in perceived tinnitus loudness.

has been taken, assuming, again, thresholds beyond the audiometer limit to be at 125 dB. Most additional hearing losses are in the range of 0–20 dB. In 3 cases, they were higher than 50 dB. In 7 cases, there was a small improvement in the hearing thresholds. There was no discernible trend for tinnitus loudness to either increase or to decrease as a function of the additional hearing loss, and the slope of the linear regression line (not shown in fig. 5) does not differ statistically significantly from 0.

Among the 49 participants who reported no tinnitus before surgery, 5 developed tinnitus postoperatively. We analyzed the data of these 5 subjects and compared them with the group of those 44 subjects who had no tinnitus either before or 6 months after cochlear implantation.

The tinnitus that was only present postoperatively was rated as 'much worse' by 2 subjects and as 'somewhat worse' by 3 subjects. Tinnitus loudness ranged from 14 to 54% (mean 27.4%), and tinnitus-related distress, as assessed by the tinnitus questionnaire, ranged from 0 to 3 points (mean 2.2 points). On average, the 5 subjects who developed tinnitus postoperatively were older (mean 57.1 years), had slightly better preoperative hearing thresholds in the implanted ear (500–4000 Hz: 118.0 dB PTA) and higher additional hearing losses due to the cochlear implantation (22.8 dB PTA) than those who did not develop tinnitus (average age 37.7 year, mean preoperative hearing loss 107.5 dB PTA, mean additional loss 12.8 dB). None of these differences was, however, statistically significant ($p = 0.160–0.522$, two-tailed Mann-Whitney test, no correction for multiple testing). However, speech understanding with the CI system after 6 months of use was significantly poorer in the group who developed tinnitus (on average 11% correctly repeated monosyllabic words,

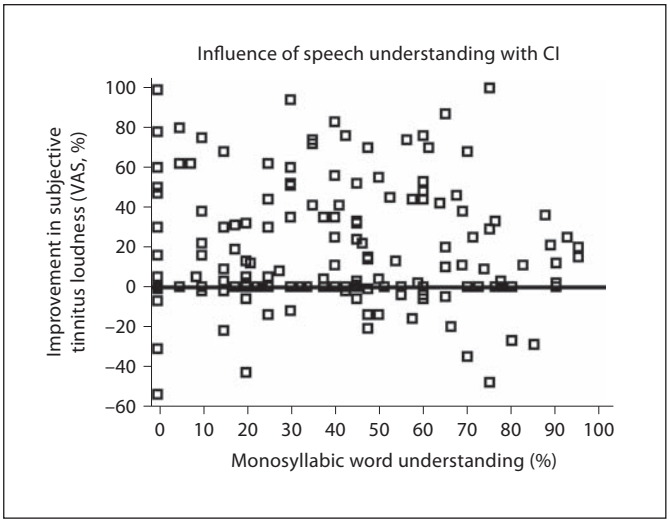


Fig. 6. Influence of speech understanding with CI and perceived improvement in tinnitus loudness.

compared to 33% for those who did not develop tinnitus, $p = 0.038$).

This raises the question, whether a correlation between tinnitus and speech understanding with CI can be found if the entire study group is taken into account. Figure 6 shows that this is not the case with our data. There is no obvious trend, and linear regression yields a slope which is not significantly different from 0. There is no visible difference between monosyllabic speech understanding at 60 or at 80 dB. For figure 6, word understanding at 60 and at 80 dB was averaged. Similarly, there is no correlation between speech understanding with a CI and tinnitus loudness either before or after cochlear implantation (data not shown).

If tinnitus was reported, its lateralization was assessed preoperatively and postoperatively using a corresponding question with the possible answers 'only in the left ear', 'more in the left ear', similar in both ears', 'more in the right ear', and 'only in the right ear'. The data were then matched with the side of the CI and the pre- and postoperative responses were compared.

Interestingly, most combinations exist including for example a change from a 'more contralateral' to an 'only ipsilateral' tinnitus (1 instance). Here the terms ipsilateral and contralateral refer preoperatively to the side where the CI was placed for 51% of the participants who reported tinnitus before as well as after CI; tinnitus lateralization did not change. If tinnitus was present preoperatively, it was reported more in the ear which was implanted later (83 subjects) than in the other ear (53 subjects, where subjects with bilateral tinnitus are counted in both categories). If tinnitus either disappeared completely or developed after CI when there was no tinnitus before surgery, the implanted ear was affected either predominantly or exclusively about 3 times as often (18 instances) as the contralateral ear (7 instances).

In addition, we analyzed the influence of the speech processor of the CI system being turned on or off for those subjects who reported any tinnitus postoperatively. In 45 patients, tinnitus became somewhat or even much better with the speech processor switched on, in 32 subjects there is no difference and in 8 subjects tinnitus was worse. For the 8 subjects who reported a worse tinnitus with the CI system on, tinnitus was localized either exclusively in the CI ear (3 subjects) or in both ears (5 subjects). It was never perceived predominantly or exclusively in the contralateral ear.

Discussion

To our knowledge, this is the second largest study on tinnitus and CI to date [Pan et al., 2009] and the largest study taking into account tinnitus loudness, tinnitus-related distress and pure-tone audiometric thresholds before and after surgery.

In our study population, 71.8% of the subjects reported tinnitus before cochlear implantation. Within this group, tinnitus was abolished in 20.0% of the cases after CI, and clearly improved in 28.0–51.2% of the cases, depending on which measure was used to rate the tinnitus. Tinnitus grew worse in approximately 7–9% of this group. These figures correspond approximately with those of several earlier studies, which have found a prevalence of tinnitus before CI between 62% [Pan et al., 2009] and 100% in small studies [McKerrow et al., 1991] with a mean of 80% in the poled data of 18 studies [Baguley and Atlas, 2007].

The total rate of improvement, i.e. improvement and complete abolishment of tinnitus, of 48.0–71.2% in our study is also similar to earlier reports. In the 19 studies reviewed by Baguley and Atlas [2007], tinnitus was improved in 67.9% of the total of 832 study subjects. Pan et al. [2009] report a range of 46–93% in 9 relatively recent studies and 100% improvement or complete suppression in their own population. Note that reporting is not consistent throughout the studies [Baguley and Atlas, 2007; Quaranta et al., 2004]. We allowed a margin of 10% in tinnitus loudness or tinnitus-related distress (score of the

tinnitus questionnaire), within which we assumed that tinnitus had remained essentially the same. Narrowing or widening this margin would affect the number of improvements.

Similarly, the rate of deterioration of an existing tinnitus of 7–9% in our study is within the range of 4 and 26% reported earlier [Quaranta et al., 2004; Baguley and Atlas, 2007]. Regarding the induction of new tinnitus, our rate of 5 out of 47 subjects or 10.6% is close to the rate of 12% reported in the large study by Pan et al. [2009] and higher than the lower limit of 4% derived by Baguley and Atlas [2007] from an analysis of multiple studies.

In our study, we found that the 5 subjects with a tinnitus induced by CI surgery had lower speech recognition scores with their CI system than those 44 subjects who remained free of tinnitus. Because of the small numbers, the finding must be interpreted with care. However, it is interesting that a link between poor performance with the CI system and newly induced hearing loss had already been suspected 18 years earlier [Dauman and Tyler, 1993].

Currently, there is no objective correlate to tinnitus which could be routinely assessed. Therefore, questionnaires and VAS, both highly subjective, are the main instruments for its assessment. In our data, the correlation between tinnitus loudness (assessed through a VAS) and tinnitus-related distress (assessed using a tinnitus questionnaire) is relatively weak ($r^2 = 0.348$), similar to the correlation between change in perceived tinnitus loudness and a direct question about tinnitus improvement ($r^2 = 0.334$), and much higher than between the change in the score of the tinnitus questionnaire and the answer to the direct question ($r^2 = 0.097$). For research purposes, we therefore recommend using at least two separate measures; one for tinnitus distress and one for loudness. If only one measure is practicable, tinnitus loudness seems to be better suited as a single number to represent the tinnitus due to its higher correlation with the results of the two other assessment methods used in this investigation.

If tinnitus was newly induced or – inversely – if an existing tinnitus was abolished through cochlear implantation, the change was about 3 times as frequent in the implanted ear than in the contralateral ear. This suggests that, if both ears are otherwise equally suited for CI, the ear with tinnitus or with the louder tinnitus should be chosen.

In our population, we found no influence of age, duration of tinnitus before surgery or the additional hearing loss caused by the implantation on tinnitus improvement or deterioration. Specifically, we found no indication that higher hearing preservation in general will also lead to lower tinnitus.

Electrical stimulation via the CI had a beneficial effect on tinnitus for over half of our subjects. This may suggest a considerable central component of the tinnitus. Tinnitus which becomes louder if the CI system is turned on is relatively rare and is perceived predominantly on the side of the implant. It is possible that this type of tinnitus is actually an artifact of the electrical stimulation which might be reduced by different programming of the speech processor. Special programming techniques to reduce tinnitus have been proposed: no directional microphone and low knee point compression [Baguley and Atlas, 2007] as well as fast pulsatile (as opposed to slower or analogue) strategies have been suggested [Quaranta et al., 2008]. In particular, for tinnitus in the ipsilateral ear which becomes louder when the CI is switched on, lower threshold values should at least be tried to avoid constant audible stimulation.

Clearly, cochlear implantation can influence tinnitus in both, the ipsilateral and the contralateral ears [Quaranta et al., 2008; Baguley and Atlas, 2007]. As a possible explanation, experimental evidence of contralateral influence on the ipsilateral auditory pathway has been proposed [Davis, 2005; Baguley and Atlas, 2007].

It is an intriguing finding, as our data in figure 5 suggest, that the hearing thresholds of a few CI recipients actually get better after cochlear implantation. There are several possible explanations, including fluctuating thresholds, reproducibility of pure-tone audiometric measurements or even simple measurement errors. Also, our data are very limited. Only 7 out of 174 subjects show such an improvement, and only 3 of those show an improvement in excess of 4 dB (PTA, 500–4000 Hz). Nevertheless, we cannot discount the intriguing possibility that electrical stimulation might improve hearing slightly in some patients.

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