



Cochlear Implantation of Bilaterally Deafened Patients with Tinnitus Induces Sustained Decrease of Tinnitus-Related Distress

Steffen Knopke¹, Agnieszka J. Szczepek^{2*}, Sophia Marie Häussler¹, Stefan Gräbel¹ and Heidi Olze^{1*}

¹ Department of Otorhinolaryngology, Head and Neck Surgery, Charité – University Hospital Berlin, Campus Virchow-Klinikum, Berlin, Germany, ² Department of Otorhinolaryngology, Head and Neck Surgery, Charité – University Hospital Berlin, Campus Charité Mitte, Berlin, Germany

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*Correspondence:

Agnieszka J. Szczepek
agnes.szczepek@charite.de;
Heidi Olze
heidi.olze@charite.de

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Objective: Tinnitus is a common symptom of hearing impairment. Patients who are bilaterally hard of hearing are often affected by tinnitus. However, they cannot undergo any of the standard tinnitus therapies, since they rely on hearing. Cochlear implantation (CI) used to treat severe hearing disabilities, such as bilateral hearing loss, was also shown to reduce tinnitus. Our goal was to determine if CI induces sustained reduction of tinnitus. We performed prospective, longitudinal analyses of tinnitus-related distress in a uniform group of bilaterally deafened patients after CI.

Patients and Methods: The homogenous sample consisted of 41 patients who met the inclusion criteria and were consecutively included in this study. The impact of unilateral CI on tinnitus-related distress, health-related quality of life (HRQoL), and hearing abilities was studied with validated instruments. The follow-up appointments were scheduled at 6, 12, and 24 months after CI surgery. During the appointments, hearing abilities were estimated with monosyllabic Freiburg test, whereas the tinnitus-related distress, the HRQoL, and the subjective hearing were measured with standard questionnaires [Tinnitus Questionnaire (TQ), Nijmegen Cochlear Implantation Questionnaire, and Oldenburg Inventory, respectively].

Results: Tinnitus-related distress decreased significantly from the mean TQ score of 35.0 (SD = 19.6) prior to surgery to the mean TQ = 27.54 (SD = 20.0) 6 months after surgery and remained sustained low until the end of follow-up period. In addition, CI significantly improved the hearing abilities and the HRQoL of all patients.

Conclusion: The results from our prospective study suggest that in a homogenous sample of bilaterally deafened, implanted patients who report having tinnitus prior to surgery, CI alone not only improves the hearing abilities but also significantly reduces the tinnitus-related distress and improves the HRQoL in a sustained way.

Keywords: cochlear implantation, hearing impairment, health-related quality of life, tinnitus-related distress, depressive symptoms, anxiety

INTRODUCTION

Tinnitus is a common symptom of hearing impairment (1–3). Therapeutic use of hearing aids to treat mild-to moderate hearing loss was demonstrated to correlate with a decrease of tinnitus (4), although the data generated by clinical research neither support nor dismiss the use of hearing aids in tinnitus treatment (5). Of all types of hearing impairment, the most cumbersome is the severe bilateral hearing loss, which is often treated with cochlear implantation (CI) (6–10). Bilateral hearing impairment affects 12.7% (30 million) of the US Americans above 12 years of age, and the prevalence of bilateral hearing impairment increases with age (11). We and others have previously reported the incidence of tinnitus among the bilaterally hearing-impaired patients ranging between 70 and 90% (12–14) and making tinnitus a serious complaint in this particular group of patients.

Already decades ago, clinical observations linked the CI-mediated hearing recovery with the reduction in tinnitus (15–17). Ever since, various studies addressed the relationship between cochlear implants and tinnitus (12); however, the outcomes of the studies were somewhat conflicting. There are three main reasons for this: the first is varying sample size (from 1 to 26); the second is using different follow-up times (from 1 to 24 months) (18, 19); and the third is that despite recent recommendations to measure tinnitus-related distress before and after CI (10), the methods and the domains vary extremely from study to study (20). Furthermore, the design of clinical trials is often retrospective and the patients included have various types of hearing impairment (21–23). Moreover, the methods of treatment are frequently dissimilar and include unilateral hearing impairment treated with unilateral CI to bilateral hearing impairment treated with bilateral CI.

In our earlier studies, we concentrated on measuring the influence of CI on the quality of life (24), tinnitus-related distress, and psychological comorbidities (13, 14). We have demonstrated significant improvement of all domains measured following the CI. However, the follow-up time was rather short (13) and the patient sample was not homogenous (14).

The outstanding question in the field is how the cochlear implants affect tinnitus and tinnitus-related distress. The full answer to this question will be possible upon accumulation of high-quality evidence. This, in turn, can only be achieved by using specific batch of standardized validated instruments and by applying prospective longitudinal design to the studies.

Our present aim was to study tinnitus-related distress in a relatively homogenous group of patients over a longer period after CI. Our main question was if in this defined cohort, tinnitus-related distress improves solely upon auditory rehabilitation, and if yes, if this improvement is sustained over longer period.

PATIENTS AND METHODS

Inclusion Criteria

The patients of both genders were consecutively included in the study upon signing written consent. Following inclusion criteria were used:

- diagnosis of bilateral severe or profound hearing loss with speech recognition $\leq 40\%$ in the Freiburg Monosyllabic Test in quiet and with hearing aid; 65-dB sound pressure level
- tinnitus
- meeting of the clinical criteria for CI:
 - possibility to use general anesthesia
 - exclusion of retrocochlear disorder (e.g., vestibular schwannoma)
 - unremarkable cochlear anatomy
 - motivation for postoperative audiological rehabilitation
 - post-lingual deafness.

Description of Study

Forty-one patients met the inclusion criteria and were followed for 2 years after CI. The data were collected between 2009 and 2016; the patients were admitted to the hospital between April 2009 and May 2014 for unilateral CI, and their last follow-up appointment was scheduled between July 2011 and February 2016. The appointments were scheduled at 6, 12, and 24 months after the surgery (see **Figure 1**). There were 22 women and 20 men in the sample—descriptive statistics are presented in **Table 1**.

Test Performed

All patients were audiological examined. In addition, they were asked to complete psychometric questionnaires before surgery and during each consecutive appointment. The audiological tests and psychometric questionnaires used were previously described in detail (14, 25) and are presented in **Table 2**.

Statistical Evaluation

For the statistical analyses, SPSS version 23 was used. Normal distribution was tested prior to statistical analysis using the Shapiro–Wilk test and a histogram. Because of lack of normal distribution in the majority of dataset, the Wilcoxon signed-rank test was used to compare the scores before and after CI. Correlations between Tinnitus Questionnaire (TQ) and Nijmegen Cochlear Implantation Questionnaire (NCIQ) scores were performed by computing the Spearman's rank correlation coefficient.

RESULTS

Postimplantation Sustained Decrease of Tinnitus-Related Distress

Tinnitus was the main inclusion criterion. Prior to CI, the mean TQ score reflecting tinnitus-related distress was 35 (**Table 3**). TQ score decreased significantly already 6 months after CI, and this improvement was sustained over the 24-month follow-up period (**Figure 2**). Significant improvement of tinnitus-related distress was noted in 64.5% of all patients in the cohort. Regarding the individual TQ subscales, the emotional and cognitive distress were significantly reduced 12 and 24 months after implantation but the intrusiveness of tinnitus-related distress decreased already 6 months after surgery and stayed on a significantly lower level as compared to that before CI (**Table 3**). There was a trend in improvement regarding the subscales “auditory perception difficulties” and “somatic complaints,” but this trend has not reached the statistical significance.

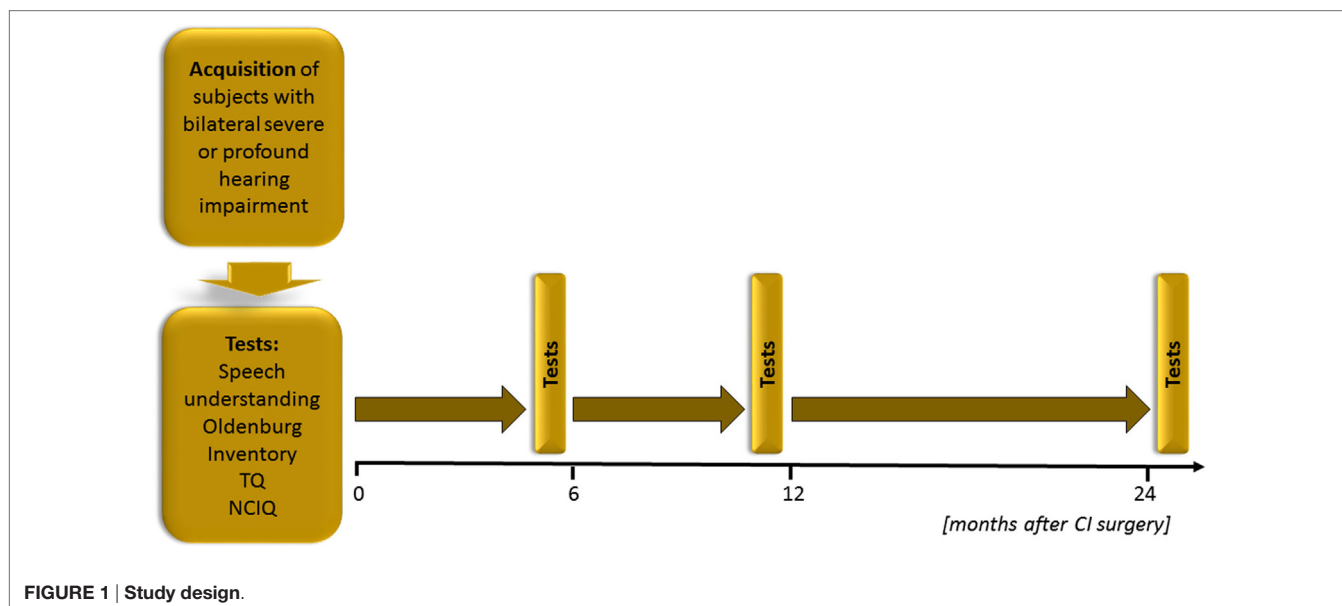


FIGURE 1 | Study design.

TABLE 1 | General patients' characteristics.

	Mean	Minimum	Maximum	SD
Age	61	25	81	13.45
Duration of hearing impairment (years)	18.82	1	67	18.84
Percent of speech recognition using monosyllabic Freiburg test 65-dB sound pressure level on the ear scheduled for implantation	7.86	0	40	13.21

Prior to CI, 13 patients were affected by a severe, decompensated, tinnitus-related distress (TQ score = 47 or more). Six months after surgery, four patients had TQ scores on the compensated level, 12 months after surgery, five patients were compensated, and 24 months later, seven patients were compensated. In two patients with compensated TQ scores prior to surgery, tinnitus-related distress progressed further to the severe, decompensated form after CI (Figure 3).

Post-Surgery Improvement of the Health-Related Quality of Life (HRQoL), Speech Perception, and Auditory Performance

The HRQoL measured by NCIQ also improved significantly, and the improvement was sustained over the period of study (Figure 4). In detail, the scales measuring basic sound perception, advanced sound perception, self-esteem, activity, and social interactions improved significantly 6 months after CI and remained so over the 24 months of the follow-up period. The only scale without statistically significant changes but with a trend toward improvement was “speech production” (Table 3).

Six months after CI, Oldenburg Inventory (Figure 5) demonstrated significant improvement in speech understanding in quiet and noise, as well speech localization at all measured time points of the follow-up period (Table 3). Similarly, monosyllabic Freiburg test indicated significant recovery of the hearing

TABLE 2 | Questionnaires used in this study.

Health-related quality of life (HRQoL): Nijmegen Cochlear Implantation Questionnaire (NCIQ)	NCIQ is a validated tool designed to determine the HRQoL of implanted patients. The three main domains “physical,” “psychological,” and “social” are derived from six subdomains: 1 Basic sound perception 2 Advanced sound perception 3 Speech production 4 Self-esteem 5 Activity 6 Social interactions. The score ranges from 0 (very bad) to 100 (optimal).
Speech perception: Freiburg Monosyllabic Test	The Freiburg Monosyllabic Test was used to determine the preoperative speech recognition in silence at 65-dB sound pressure level with optimized hearing aid and postoperative with cochlear implant again as well
Subjective audiological assessment: Oldenburg Inventory (OI)	Data were collected preoperatively and postoperatively about the subjective hearing with the OI. The OI additionally includes a total score in 3 categories: “hearing in quiet,” “hearing with background noise,” and “localization.” The 12 closed questions about everyday situations were marked with points from 1 to 5. The higher the score, the better the subjective hearing
Tinnitus distress: Tinnitus Questionnaire (TQ)	The tinnitus distress can be determined with TQ (26). Collected data represent 6 subdomains: emotional and cognitive distress, intrusiveness, auditory perceptual difficulties, sleeping disturbances, somatic complaints. The mean value is used to determine tinnitus grade: light (0–30 points), average (31–46 points), high (47–59 points), and very high (60–84 points). In addition, separation into compensated (≤46 points) and decompensated (47–84 points) tinnitus can be done based on the total score. The test-retest reliability is 0.94 for the total value and between 0.86 and 0.92 for the subscales. Cronbach’s α is 0.94 for the total value of the TQ and between 0.74 and 0.92 for the subscales

abilities by the implanted ear (Table 3). The speech recognition improved rapidly after surgery and was stable during the observation period of 2 years.

TABLE 3 | Changes in parameters measured as compared to their values prior to cochlear implantation.

	Prior to surgery			6 months after surgery			12 months after surgery			24 months after surgery		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
SR 65-dB sound pressure level (SPL)	7.9	0.0	13.2	40.4**	43.8	35.9	41.6**	35.0	34.2	43.2**	46.3	25.2
NCIQ 1	40.1	39.4	20.9	59.6**	60.0	20.0	62.1**	65.0	22.4	57.6**	60.0	18.1
NCIQ 2	42.4	40.0	19.2	56.1**	55.0	20.5	54.9**	55.0	21.0	53.2**	52.5	19.4
NCIQ 3	64.4	67.5	22.6	72.1	75.0	20.4	66.9	72.2	20.6	71.7	71.9	24.0
NCIQ 4	42.6	41.7	17.5	50.9**	45.0	19.7	52.9**	52.5	18.9	53.8**	50.0	21.4
NCIQ 5	37.9	37.5	18.2	49.1**	47.5	22.8	49.3**	47.5	23.0	47.5**	43.8	18.6
NCIQ 6	41.5	40.0	22.5	51.2**	50.0	25.7	53.0**	52.8	23.3	50.3**	50.0	18.9
NCIQ total	53.8	43.2	58.7	56.6**	55.1	18.5	57.5**	55.5	19.8	55.8**	56.8	15.2
TQ E	9.0	8.0	6.0	7.4	4.0	6.8	7.1*	5.0	6.6	7.2	7.0	6.4
TQ C	6.9	7.5	4.5	5.7	4.0	5.0	5.4*	4.5	4.4	5.6	4.5	4.5
TQ E + C	15.9	14.0	10.0	13.1	9.0	11.5	12.3*	9.5	10.9	12.7*	13.0	10.6
TQ I	8.2	9.0	4.1	6.1**	5.0	5.2	5.6**	5.5	4.7	5.8**	6.0	4.3
TQ A	6.6	6.0	4.8	5.2	5.0	4.9	5.1	5.5	4.7	5.2	5.5	4.5
TQ SI	2.5	2.0	2.4	1.8*	0.0	2.5	1.9	1.0	2.3	2.3	1.5	2.7
TQ SO	1.8	1.5	1.7	1.3	0.0	2.0	1.8	0.5	2.4	1.5	1.0	1.9
TQ total	35.0	33.5	19.6	27.5*	23.0	24.0	26.7**	26.5	22.8	27.6*	30.0	22.3
Ol quiet	2.4	2.4	0.9	3.4**	3.6	1.0	3.4**	3.4	0.8	3.4**	3.4	0.9
Ol noise	1.8	1.6	0.6	2.7**	2.6	1.0	2.7**	2.5	0.9	2.6**	2.4	0.8
Ol localization	1.9	2.0	0.8	2.8**	3.0	1.0	2.7**	2.5	1.0	2.7**	2.5	1.0
Ol total	2.1	1.9	0.7	3.0**	2.9	0.9	3.0**	2.9	0.8	2.9**	2.8	0.8

Asterisks indicate significant differences between respective variables when compared to their values prior to surgery as per Wilcoxon signed-rank test; * $p \leq 0.05$, ** $p \leq 0.01$. SR, speech recognition (Freiburg Monosyllabic Test, 65-dB SPL); NCIQ, German version of Nijmegen Cochlear Implantation Questionnaire (1 basic sound perception; 2 advanced sound perception; 3 speech production; 4 self-esteem; 5 activity; and 6 social interactions); TQ, Tinnitus Questionnaire (E, emotional distress; C, cognitive distress; E + C, combined psychological distress; I, intrusiveness; A, auditory perception difficulties; SI, sleep disturbances; SO, somatic complaints; total, total score); Ol, Oldenburg Inventory.

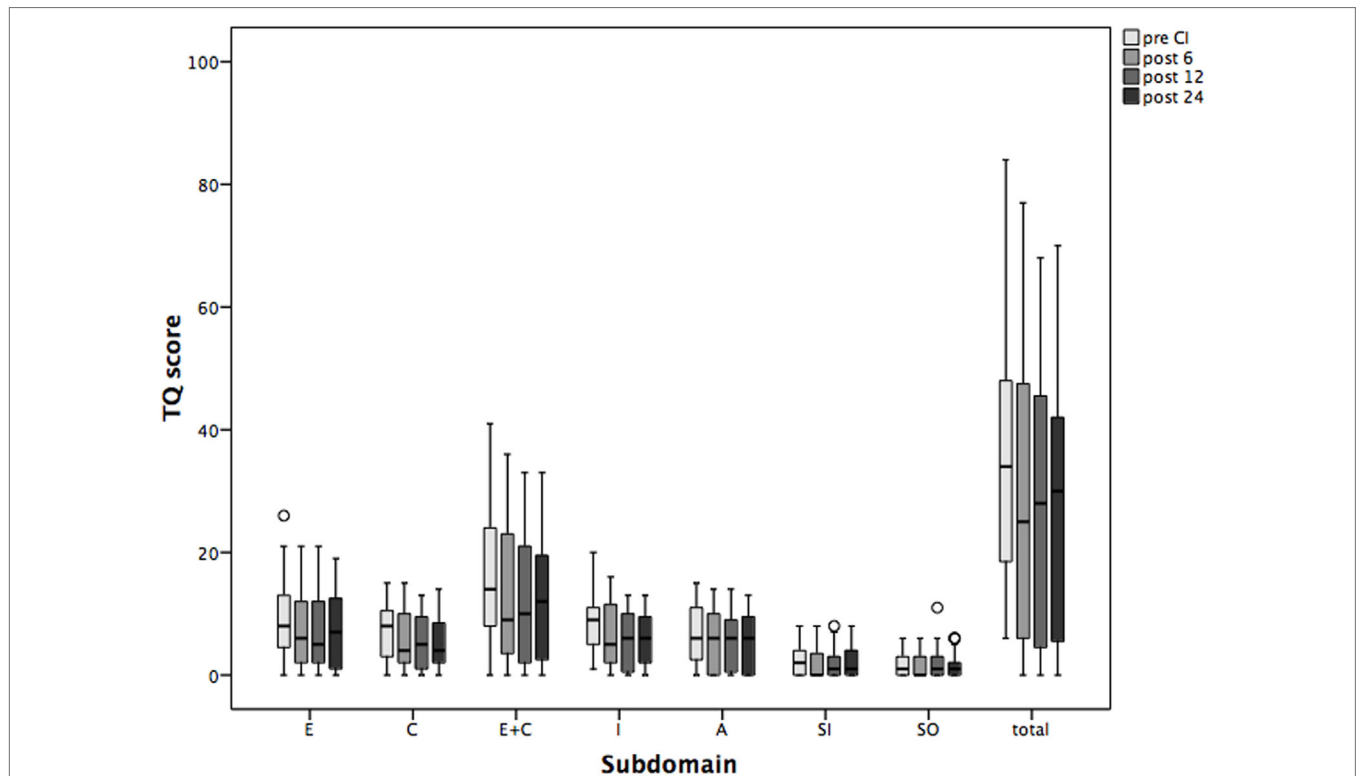


FIGURE 2 | Changes in tinnitus distress [Tinnitus Questionnaire (TQ)] and its subscales over the period of 2 years following cochlear implantation (CI). Shown are mean values and the range. Shown are mean values and the 95% CI. Pre CI, before CI; post 6, post 12, and post 24, 6, 12, and 24 months after surgery. E, emotional distress; C, cognitive distress; I, intrusiveness; A, auditory perceptual difficulties; SI, sleeping disturbances; SO, somatic complaints; total, total value.

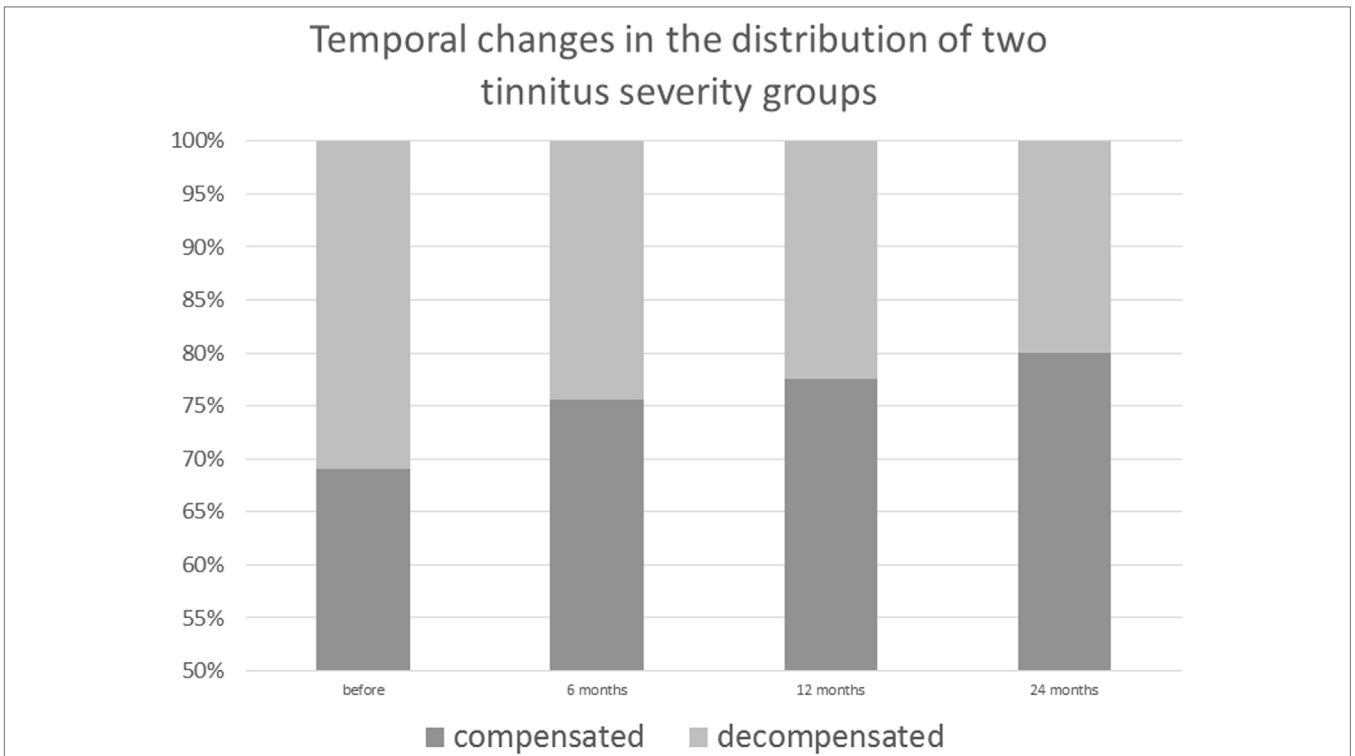


FIGURE 3 | Post-cochlear implantation decrease in decompensated, severe form of tinnitus among implanted patients.

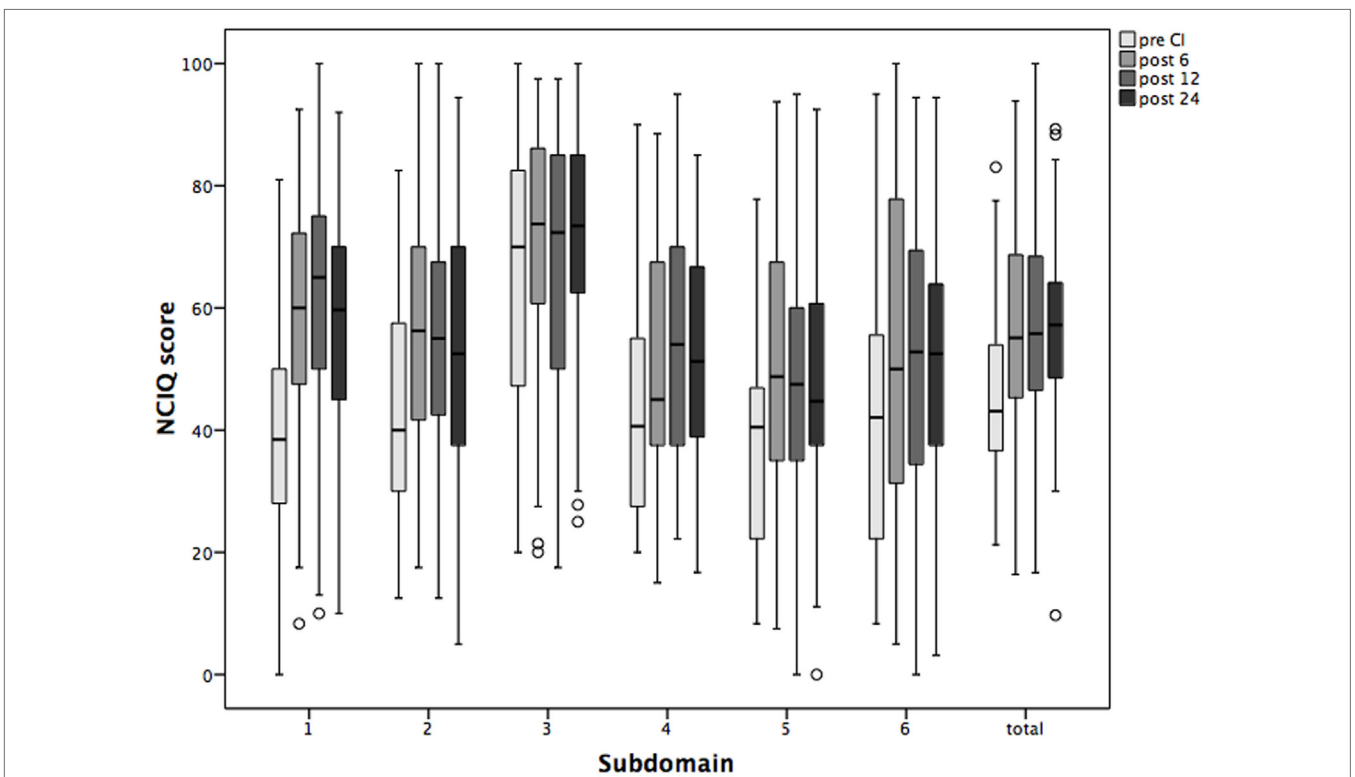


FIGURE 4 | Changes in the health-related quality of life Nijmegen Cochlear Implantation Questionnaire (NCIQ) and its subdomains over the period of 2 years following cochlear implantation (CI). Shown are mean values and the 95% CI. Pre CI, before CI; post 6, post 12, and post 24, 6, 12, and 24 months after surgery. 1 basic speech perception; 2 advanced speech perception; 3 speech production; 4 self-esteem; 5 activity; and 6 social interactions.

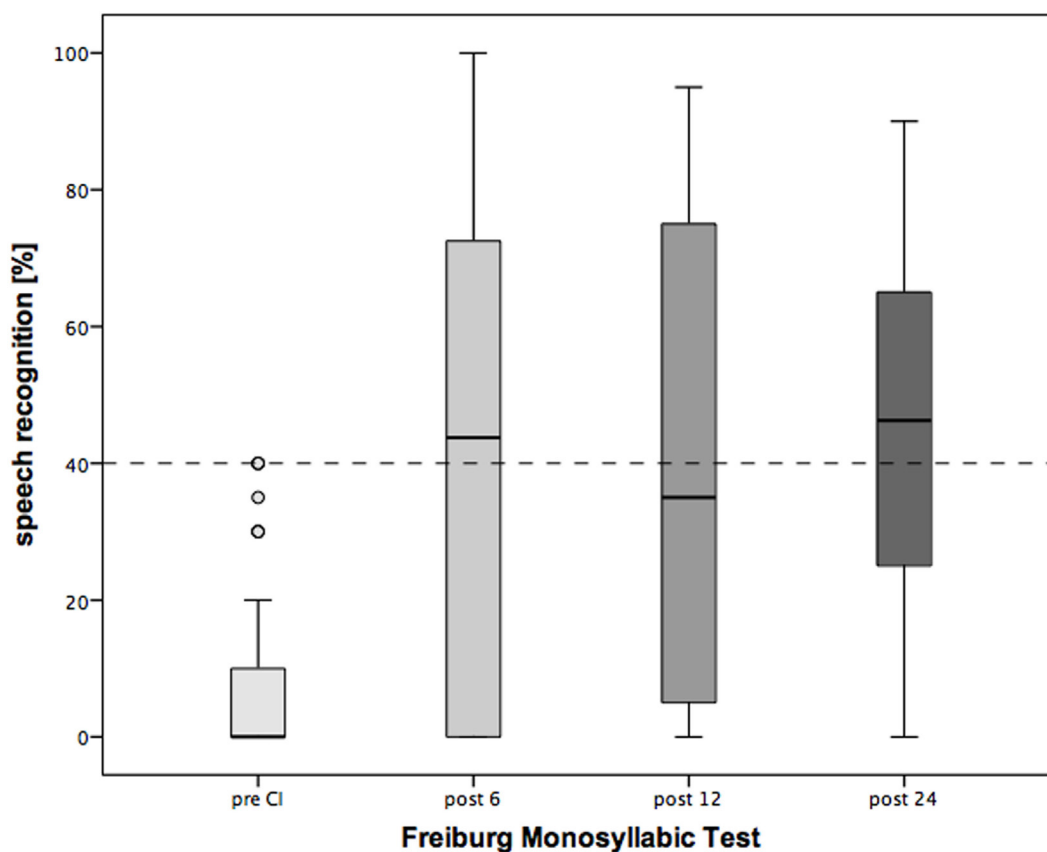


FIGURE 5 | Changes in speech recognition over the period of 2 years following cochlear implantation (CI). Shown are mean values and the range. Shown are mean values and the 95% CI. Dotted line: clinical criteria for CI.

Relationship between TQ and NCIQ

To determine if and how tinnitus-related distress affects the HRQoL, we computed the Spearman correlation coefficient for the respective variables. First, we analyzed the data obtained before CI (Table 4). We observed negative correlation between total TQ score and speech production (NCIQ3). The subscales indicating cognitive and emotional subscales as well as auditory difficulties reported by TQ were particularly affected. In addition, somatic complaints correlated negatively with the background—and advanced sound perception as well as with self-esteem and social interactions (Table 4). Six months after CI, we found significant negative correlations between the total TQ score and all subdomains of NCIQ (Table 5), and 12 months after the CI, this was also the case (Table 6). Interestingly, 24 months after the CI, the correlations between total TQ score and NCIQ subscales “self-esteem” and “social interaction” were no longer significant (Table 7).

Compliance

Of 42 subjects originally included in this study, 41 patients filled the NCIQ questionnaire at the study onset, 39 patients after 12 months, and 40 patients after 2 years.

DISCUSSION

Tinnitus is often a symptom of hearing loss. Here, we demonstrated that in the bilaterally hearing-impaired patients with tinnitus, CI not only restores the auditory abilities but also reduces tinnitus-related distress and that this reduction was sustained for 2 years following surgery. To the best of our knowledge, our present study demonstrates for the first time the course of tinnitus-related distress in a homogenous cohort of bilaterally hard of hearing and tinnitus-positive patients, before and after CI. In addition, we show the relationship between tinnitus-related distress and the HRQoL and the postoperative auditory improvement over the 2-year course.

Prior to CI, the TQ score (total and subscales “emotional and cognitive distress” and “auditory difficulties”) correlated significantly with the third subscale of the HRQoL NCIQ “speech production,” whereas the total score of NCIQ correlated significantly (negative correlation) with the TQ subscale “somatic complaints” (Table 4). All correlations between NCIQ and TQ were negative, meaning that the decrease of tinnitus-related distress correlated with improvement of the quality of life and *vice versa*. Although these correlations decreased with time, they remained significant throughout the 24 months of the follow-up period (Tables 5–7),

TABLE 4 | Correlation between tinnitus and health-related quality of life before cochlear implantation.

			NCIQ1	NCIQ2	NCIQ3	NCIQ4	NCIQ5	NCIQ6	NCIQ total
Spearman-Rho	TQ E	Correlation coefficient	-0.202	-0.093	-0.313*	-0.097	-0.174	-0.146	-0.162
		Significance	0.205	0.561	0.046	0.548	0.276	0.362	0.313
		N	41	41	41	41	41	41	41
TQ C	Correlation coefficient <i>t</i>	-0.118	-0.113	-0.315*	-0.144	-0.257	-0.240	-0.187	
	Significance	0.464	0.483	0.045	0.370	0.105	0.131	0.241	
	N	41	41	41	41	41	41	41	
TQ E + C	Correlation coefficient	-0.172	-0.108	-0.324*	-0.130	-0.232	-0.204	-0.191	
	Significance	0.281	0.500	0.039	0.417	0.145	0.202	0.233	
	N	41	41	41	41	41	41	41	
TQ I	Correlation coefficient	-0.287	-0.074	-0.300	-0.104	-0.210	-0.159	-0.199	
	Sig. (2-seitig)	0.069	0.647	0.057	0.516	0.187	0.322	0.212	
	N	41	41	41	41	41	41	41	
TQ A	Correlation coefficient	-0.258	-0.210	-0.437**	0.031	-0.044	0.043	-0.142	
	Significance	0.104	0.187	0.004	0.849	0.784	0.791	0.378	
	N	41	41	41	41	41	41	41	
TQ SI	Correlation coefficient	-0.354*	-0.315*	-0.263	-0.124	-0.279	-0.140	-0.259	
	Significance	0.023	0.045	0.097	0.440	0.077	0.384	0.102	
	N	41	41	41	41	41	41	41	
TQ SO	Correlation coefficient	-0.408**	-0.407**	-0.253	-0.274	-0.432**	-0.278	-0.413**	
	Significance	0.008	0.008	0.111	0.083	0.005	0.078	0.007	
	N	41	41	41	41	41	41	41	
TQ total	Correlation coefficient	-0.299	-0.205	-0.405**	-0.126	-0.243	-0.173	-0.260	
	Significance	0.057	0.199	0.009	0.434	0.126	0.280	0.101	
	N	41	41	41	41	41	41	41	

* $p \leq 0.05$.** $p \leq 0.01$.

Subscales of Nijmegen Cochlear Implantation Questionnaire (NCIQ): 1 basic sound perception; 2 advanced sound perception; 3 speech production; 4 self-esteem; 5 activity; and 6 social interactions.

Subscales of Tinnitus Questionnaire (TQ): E, emotional distress; C, cognitive distress; E + C, combined psychological distress; I, intrusiveness; A, auditory perception difficulties; SI, sleep disturbances; SO, somatic complaints.

TABLE 5 | Correlation between tinnitus and health-related quality of life 6 months after cochlear implantation.

			NCIQ1	NCIQ2	NCIQ3	NCIQ4	NCIQ5	NCIQ6	NCIQ total
Spearman-Rho	TQ E	Correlation coefficient	-0.308	-0.397*	-0.421**	-0.331*	-0.553**	-0.365*	-0.462**
		Significance	0.050	0.010	0.006	0.034	0.000	0.019	0.002
		N	41	41	41	41	41	41	41
TQ C	Correlation coefficient <i>t</i>	-0.347*	-0.399**	-0.446**	-0.421**	-0.586**	-0.413**	-0.524**	
	Significance	0.026	0.010	0.003	0.006	0.000	0.007	0.000	
	N	41	41	41	41	41	41	41	
TQ E + C	Correlation coefficient	-0.335*	-0.417**	-0.461**	-0.384*	-0.581**	-0.394*	-0.502**	
	Significance	0.032	0.007	0.002	0.013	0.000	0.011	0.001	
	N	41	41	41	41	41	41	41	
TQ I	Correlation coefficient	-0.378*	-0.466**	-0.486**	-0.368*	-0.613**	-0.444**	-0.535**	
	Sig. (2-seitig)	0.015	0.002	0.001	0.018	0.000	0.004	0.000	
	N	41	41	41	41	41	41	41	
TQ A	Correlation coefficient	-0.320*	-0.476**	-0.396*	-0.327*	-0.510**	-0.425**	-0.449**	
	Significance	0.041	0.002	0.010	0.037	0.001	0.006	0.003	
	N	41	41	41	41	41	41	41	
TQ SI	Correlation coefficient	-0.145	-0.185	-0.191	-0.357*	-0.527**	-0.240	-0.344*	
	Significance	0.365	0.246	0.231	0.022	0.000	0.131	0.028	
	N	41	41	41	41	41	41	41	
TQ SO	Correlation coefficient	-0.381*	-0.398**	-0.390*	-0.294	-0.457**	-0.413**	-0.449**	
	Significance	0.014	0.010	0.012	0.062	0.003	0.007	0.003	
	N	41	41	41	41	41	41	41	
TQ Total	Correlation coefficient	-0.331*	-0.435**	-0.430**	-0.359*	-0.589**	-0.404**	-0.497**	
	Significance	0.035	0.004	0.005	0.021	0.000	0.009	0.001	
	N	41	41	41	41	41	41	41	

* $p \leq 0.05$.** $p \leq 0.01$.

Subscales of Nijmegen Cochlear Implantation Questionnaire (NCIQ): 1 basic sound perception; 2 advanced sound perception; 3 speech production; 4 self-esteem; 5 activity; and 6 social interactions.

Subscales of Tinnitus Questionnaire (TQ): E, emotional distress; C, cognitive distress; E + C, combined psychological distress; I, intrusiveness; A, auditory perception difficulties; SI, sleep disturbances; SO, somatic complaints.

TABLE 6 | Correlation between tinnitus and health-related quality of life 12 months after cochlear implantation.

			NCIQ1	NCIQ2	NCIQ3	NCIQ4	NCIQ5	NCIQ6	NCIQ total
Spearman-Rho	TQ E	Correlation coefficient	-0.377*	-0.545**	-0.362*	-0.329*	-0.409**	-0.386*	-0.400*
		Significance	0.018	0.000	0.024	0.041	0.010	0.015	0.010
		N	39	39	39	39	39	39	40
	TQ C	Correlation coefficient <i>t</i>	-0.505**	-0.593**	-0.372*	-0.408**	-0.477**	-0.447**	-0.488**
		Significance	0.001	0.000	0.020	0.010	0.002	0.004	0.001
		N	39	39	39	39	39	39	40
	TQ E + C	Correlation coefficient	-0.424**	-0.558**	-0.368*	-0.340*	-0.414**	-0.402*	-0.424**
		Significance	0.007	0.000	0.021	0.034	0.009	0.011	0.006
		N	39	39	39	39	39	39	40
	TQ I	Correlation coefficient	-0.454**	-0.598**	-0.490**	-0.332*	-0.472**	-0.446**	-0.490**
		Sig. (2-seitig)	0.004	0.000	0.002	0.039	0.002	0.004	0.001
		N	39	39	39	39	39	39	40
	TQ A	Correlation coefficient	-0.345*	-0.456**	-0.414**	-0.308	-0.348*	-0.306	-0.385*
		Significance	0.032	0.004	0.009	0.056	0.030	0.058	0.014
		N	39	39	39	39	39	39	40
	TQ SI	Correlation coefficient	-0.339*	-0.401*	-0.332*	-0.254	-0.350*	-0.307	-0.314*
		Significance	0.035	0.011	0.039	0.119	0.029	0.057	0.048
		N	39	39	39	39	39	39	40
	TQ SO	Correlation coefficient	-0.309	-0.356*	-0.331*	-0.323*	-0.358*	-0.433**	-0.312*
		Significance	0.056	0.026	0.039	0.045	0.025	0.006	0.050
		N	39	39	39	39	39	39	40
	TQ total	Correlation coefficient	-0.404*	-0.531**	-0.408**	-0.323*	-0.411**	-0.403*	-0.417**
		Significance	0.011	0.001	0.010	0.045	0.009	0.011	0.007
		N	39	39	39	39	39	39	40

* $p \leq 0.05$.** $p \leq 0.01$.

Subscales of Nijmegen Cochlear Implantation Questionnaire (NCIQ): 1 basic sound perception; 2 advanced sound perception; 3 speech production; 4 self-esteem; 5 activity; and 6 social interactions.

Subscales of Tinnitus Questionnaire (TQ): E, emotional distress; C, cognitive distress; E + C, combined psychological distress; I, intrusiveness; A, auditory perception difficulties; SI, sleep disturbances; SO, somatic complaints.

TABLE 7 | Correlation between tinnitus and health-related quality of life 24 months after cochlear implantation.

			NCIQ1	NCIQ2	NCIQ3	NCIQ4	NCIQ5	NCIQ6	NCIQ total
Spearman-Rho	TQ E	Correlation coefficient	-0.416**	-0.499**	-0.358*	-0.174	-0.384*	-0.346*	-0.328*
		Significance	0.008	0.001	0.023	0.282	0.014	0.029	0.039
		N	40	40	40	40	40	40	40
	TQ C	Correlation coefficient <i>t</i>	-0.408**	-0.452**	-0.359*	-0.170	-0.341*	-0.277	-0.353*
		Significance	0.009	0.003	0.023	0.296	0.031	0.084	0.026
		N	40	40	40	40	40	40	40
	TQ E + C	Correlation coefficient	-0.406**	-0.474**	-0.362*	-0.165	-0.351*	-0.308	-0.327*
		Significance	0.009	0.002	0.022	0.308	0.026	0.053	0.039
		N	40	40	40	40	40	40	40
	TQ I	Correlation coefficient	-0.434**	-0.496**	-0.357*	-0.215	-0.411**	-0.351*	-0.339*
		Sig. (2-seitig)	0.005	0.001	0.024	0.183	0.008	0.026	0.032
		N	40	40	40	40	40	40	40
	TQ A	Correlation coefficient	-0.301	-0.462**	-0.439**	-0.135	-0.393*	-0.280	-0.257
		Significance	0.060	0.003	0.005	0.405	0.012	0.080	0.109
		N	40	40	40	40	40	40	40
	TQ SI	Correlation coefficient	-0.415**	-0.434**	-0.522**	-0.176	-0.385*	-0.277	-0.396*
		Significance	0.008	0.005	0.001	0.278	0.014	0.083	0.011
		N	40	40	40	40	40	40	40
	TQ SO	Correlation coefficient	-0.413**	-0.460**	-0.357*	-0.210	-0.409**	-0.355*	-0.371*
		Significance	0.008	0.003	0.024	0.194	0.009	0.025	0.019
		N	40	40	40	40	40	40	40
	TQ total	Correlation coefficient	-0.419**	-0.526**	-0.416**	-0.169	-0.372*	-0.311	-0.334*
		Significance	0.007	0.000	0.008	0.297	0.018	0.051	0.035
		N	40	40	40	40	40	40	40

* $p \leq 0.05$.** $p \leq 0.01$.

Subscales of Nijmegen Cochlear Implantation Questionnaire (NCIQ): 1 basic sound perception; 2 advanced sound perception; 3 speech production; 4 self-esteem; 5 activity; and 6 social interactions.

Subscales of Tinnitus Questionnaire (TQ): E, emotional distress; C, cognitive distress; E + C, combined psychological distress; I, intrusiveness; A, auditory perception difficulties; SI, sleep disturbances; SO, somatic complaints.

suggesting that the tinnitus-related emotional and cognitive distress as well as tinnitus-related auditory difficulties negatively influenced the life quality of the CI patients. Longer follow-up time should clarify if these correlations decay completely with time.

Before the CI, patients' quality of life (total score) was not affected by the tinnitus-induced auditory difficulties (Table 4) confirming our earlier observations (13). Six months after implantation, there was a large ($Rho = -0.449$) and significant ($p = 0.003$) negative correlation between these two variables (Table 5), very likely reflecting the fact that the process of regaining auditory abilities can be negatively affected by the tinnitus percept. In fact, this correlation and its significance declined 12 months after CI ($Rho = -0.385$, $p = 0.014$) (Table 6) and were no longer of significance 24 months after the surgery (Table 7).

Tinnitus is a complaint of 70–90% of hearing-impaired patients (12–14). In cases of patients who are bilaterally hard of hearing, tinnitus percept is a particularly disturbing symptom, because it is the only auditory input perceived by patients. In such cases, diverting the auditory attention from tinnitus to other sounds is problematic, making the therapeutic approaches difficult if not impossible. The two major therapies globally used for tinnitus treatment are tinnitus retraining therapy (TRT) and cognitive behavioral therapy (CBT). The neurophysiological model proposed by Jastreboff (27, 28) suggests the existence of auditory–limbic–sympathetic network responsible for negative effects of tinnitus sound and inducing the distress and inability to divert the attention of patients from the tinnitus sound. TRT, designed by Jastreboff based on the above theory, has since years been a frequent therapeutic choice of many clinicians (29–31). The second method widely used for tinnitus is the CBT, which was developed to treat anxiety disorders, depression, eating disorders, chronic low back pain, personality disorders, depression, and anxiety and successfully applied in the treatment for tinnitus (32–35). TRT, CBT, or a combination of both require at least some hearing abilities and can only be used to treat the patients who are hard of hearing and have tinnitus following successful auditory rehabilitation with CI.

The first positive effect of CI on tinnitus was reported in 1976 by House (15). Ever since, various studies with different sample sizes and inclusion criteria were performed. Corroborating our present results, the decrease of tinnitus-related distress after CI ranging from 46 to 95% was observed previously by others (12, 36, 37). In our present study, we also observed the reduction of tinnitus-related distress in half of the patients who had severe (decompensated) tinnitus prior to CI.

The central question addressing the mechanism in which CI reduces tinnitus-related distress remains open. The evidence collected in our present study suggests following possible scenarios:

- Following CI, the auditory abilities improve to the degree where the patients can focus their auditory attention on sounds other than tinnitus.
- Following CI, the improved auditory abilities increase the quality of life, thus decrease overall stress and positively affect the loop “stress-tinnitus.”

- Following CI, the direct electrical stimulation of the auditory nerve induces plastic changes in the auditory reducing the tinnitus percept.

More quality evidence needs to be accumulated to determine, which of the presented scenarios is essential for tinnitus reduction after CI. It can also not be excluded that all three mechanisms play a role in tinnitus reduction and habituation. Future trials with specific tinnitus-oriented fitting of cochlear implants could shed more light on that topic.

While until recently, the clinical research involving cochlear implants was focused mainly on the audiological gain; at present, many authors are increasingly interested in changes of the quality of life and tinnitus-related distress (12, 38, 39). Quaranta et al. reported bilateral disappearance of tinnitus after unilateral CI in 65.8% of the patients (40), as measured by the Tinnitus Handicap Inventory—an instrument that is similar—but not identical—to TQ (41). Also, we have demonstrated earlier that the CI, in addition to having positive effect on hearing abilities, improves the life quality and decreases the tinnitus-related distress and psychological comorbidities (13, 42–45). There are several psychometric instruments measuring various parameters and domains used in tinnitus research and clinical routine. These instruments vary depending on the clinical orientation of the treating unit (audiology, ORL, clinical psychology or psychosomatic medicine) and on the country. Here, we propose creation of a specific set of standardized, validated, and internationally available instruments to measure CI-specific outcomes, which would include various aspects of tinnitus percept and tinnitus-related distress. In our present work, we used instruments that are widely available in the German-speaking countries. The Nijmegen Cochlear Implant Questionnaire NCIQ is an internationally validated, disease-specific instrument created for the assessment of the quality of life in patients with cochlear implants. OI is a popular, standardized instrument measuring perceived benefit of hearing aids. Also, the German version of TQ, which measures the tinnitus-related distress, is frequently used in the inpatient and outpatient settings to monitor the severity of tinnitus and its response to treatment. In order to study the influence of tinnitus on the outcome of CI, we suggest designing prospective, longitudinal clinical trials and using defined monitoring batch. Despite using such design, our present study is not free of pitfalls, as it could have included larger sample, and it was neither double blinded nor randomized. In addition, an appropriate control group is lacking. However, blinded and randomized design in the field of cochlear implant is difficult to be implemented because of specific features of the CI treatment, preventing the design of high-level evidence studies (19). Control group, which for instance could comprise patients who were implanted but their cochlear implants remain switched off, cannot be used because of obvious ethical reasons.

Previously reported high prevalence of tinnitus in the hearing-impaired patients puts the choice of tinnitus treatment in these patients up for discussion (12). In particular, the task of developing appropriate approach for the tinnitus treatment in bilaterally hearing-impaired patients remains open. The increasing incidence of hearing impairments, including the age-related hearing

loss in context of demographic changes in our society, emphasizes the need for improvement in the therapy guidelines (46).

In addition, although we observed the most pronounced decrease of tinnitus-related distress 12 months after the implantation, the maximal correlation between TQ score and speech recognition (Table 3) occurred 6 months after implantation. These results do not contradict each other; rather, they point at the dependence of auditory rehabilitation on tinnitus treatment. Since the auditory benefit is patient specific, it is difficult to measure. Speech recognition—a typical parameter that measures hearing improvement—when used alone is not enough to act as an adequate indicator of tinnitus suppression. This is reflected by the results obtained 2 years after CI. Similarly, the TQ scores suggest that a unilateral acoustic stimulation with noticeable postoperative asymmetry does not lead to an unfavorable influence on the tinnitus-related distress, even over several years. The bilateral CI could be an ultimate target of hearing rehabilitation. In fact, sustained improvement of TQ scores was observed in 40 patients subjected to sequential bilateral CI (25).

Final Conclusion

Taken together, our results suggest that patients who are bilaterally hard of hearing and have tinnitus profit from CI not only by regaining their auditory skills but also by a significant and sustained improvement of the HRQoL and reduction of

tinnitus-related distress. Moreover, the negative correlation between tinnitus and the HRQoL indicates the importance of tinnitus as an obstacle in auditory rehabilitation of CI patients. It is tempting to speculate that therapy for tinnitus used after CI would further decrease tinnitus-related distress and, therefore, could increase the quality of life in this specific group of patients.

ETHICS STATEMENT

The local Ethics Committee (permit number EA2/030/13) approved this prospective, non-interventional, and longitudinal study. All investigations were conducted according to the principles expressed in the Declaration of Helsinki. All patients have given their informed written consent.

AUTHOR CONTRIBUTIONS

SK and HO designed the study. SK, SG, and SH collected the data. SK, AS, and HO interpreted the data. SK and AS drafted the manuscript. HO critically revised the manuscript.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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