Tinnitus suppression after cochlear implantation in patients with single-sided deafness

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Background
Tinnitus associated with single-sided deafness (SSD) is frequent and often incapacitating, and is difficult to treat. Numerous studies have reported the suppression of tinnitus by electrical stimulation of the acoustic pathway through a cochlear implant (CI), with a low risk of worsening of tinnitus after implantation.
Objective
The main aim of this study was to demonstrate the effectiveness of CI as a treatment option in patients with SSD and incapacitating tinnitus.
Patients and methods
We studied the tinnitus-suppression effect of CI in a series of 13 patients with unilateral profound sensorineural hearing loss (SSD), associated with incapacitating tinnitus with normal hearing in the contralateral ear. Tinnitus impact was measured with the Tinnitus Handicap Inventory (THI), and tinnitus severity was measured with the Tinnitus Rating Scale (TRS) before and after CI.
Results
Thirteen patients were enrolled in this study, eight men and five women, ranging in age from 24 to 60 years with a mean±SD of 40±10 years. Mean scores for THI and TRS were obtained preoperatively and at 1 and 3 months postoperatively after activation of the CI. Mean scores for the THI total scores ranged from 79.6±7 preoperatively to 12±13.5 at 3 months postoperatively. Mean scores for the TRS ranged from 4.53±0.5 preoperatively to 1.46±0.5 at 3 months postoperatively. The postoperative THI and TRS improved significantly as compared with the baseline preoperative scores ($P<0.005$).
Conclusion
The outcome of the current study supports the belief that CI is not only a treatment option for hearing loss in SSD but also a treatment option to suppress tinnitus.

Background

Tinnitus is a frequent and often incapacitating condition that is difficult to treat. It is defined as a phantom sensation in the absence of an external sound. The word tinnitus is derived from the Latin word 'tinnire', which means ringing. The prevalence of chronic tinnitus in adults ranges between 6 and 20%, with 1–3% experiencing severe and disabling tinnitus that interferes with daily life [1]. It has a prevalence between 66 and 88% in patients who are candidates for cochlear implantation (CI) [2].

Unilateral idiopathic sudden sensorineural hearing loss (SNHL) as a common cause of single-sided deafness (SSD) has an incidence of 2–20/100 000 adults per year. This type of hearing loss is irreversible in more than 60% of cases in spite of therapy and ends in permanent SSD [3]. Chiossoine-Kerdel et al. [4] reported that the majority (86%) of patients with SSD demonstrated a significant hearing handicap when assessed with the Hearing Handicap Inventory for Adults. The same authors also reported that tinnitus in the affected ear may be disabling, using the Tinnitus Handicap Inventory (THI) [5].

The most recent theories suggest that tinnitus consecutive to sudden deafness is generated at a cochlear level, with a later perception in the central auditory pathways; however, several studies have shown that there are many potential mechanisms involved in the generation of this tinnitus [6]. Therefore, tinnitus consecutive to sudden deafness with poor recovery remains a therapeutic challenge [7]. Contralateral routing of signal and bone-anchored hearing aids can be utilized in auditory rehabilitation, with varying degrees of success [8], but

little or nothing can be offered for relief of the tinnitus. A CI on the affected side will not only reduce the hearing handicap but may also provide relief for the tinnitus [3].

Numerous studies have shown the suppression of tinnitus by electrical stimulation of the acoustic pathway through a CI, with a low risk for worsening after implantation. Total suppression of tinnitus after CI varies from 15 to 83% [9]. However, the risk of worsening or developing tinnitus as a result of implant surgery is generally very low [3]. Eggermont [10] reported that the mechanisms behind the tinnitus-suppressive effects of electrical stimulation of the auditory periphery are not well understood, but we believe that tinnitus-suppressive effects of the CI can be explained by the masking effects and plastic changes in the auditory system caused by enrichment of the peripheral auditory input.

The main aim of this study was to demonstrate the effectiveness of CI as a treatment option in patients with SSD with severe incapacitating tinnitus. We also aimed to subjectively quantify tinnitus before and after CI in patients with SSD.

Patients and methods

After obtaining the approval of the Hospital Ethics Committee, we studied the tinnitus-suppression effect of CI in patients suffering from SSD. A total of 13 patients with unilateral severe-to-profound SNHL associated with tinnitus were enrolled in this study. We performed this study with a design including repeated measurements, in which each participant acted as his or her own control. The study group included patients who underwent CI at the ENT Department between June 2011 and January 2015. Patients were assessed before the intervention to determine candidacy and to establish baseline tinnitus status. Participants were selected on the basis of the following inclusion criteria.

(1) Patients of either sex, of an age greater than 18 years.
(2) Severe-to-profound SNHL in the ear to be implanted.
(3) The better-hearing ear had a pure-tone average (PTA$_{0.5-4\,kHz}$) of 25 dB or less.
(4) Presence of stable tinnitus in the ear to be implanted that failed to respond to any of the traditional treatments of tinnitus, including hearing aid and maskers.
(5) Degree of disability in THI more than 58%.

(6) Duration of hearing loss and tinnitus less than 5 years in the ear to be implanted.
(7) On the basis of a battery of medical, audiological, and psychological evaluation, no other causes were suspected for tinnitus other than the presence of severe-to-profound SNHL.

We excluded all patients with suspected central tinnitus secondary to neurological or psychological problems. Furthermore, patients with diabetes mellitus or hypertension or other systemic problems that could contribute to tinnitus were also excluded. Participants initially underwent standardized preoperative evaluation that included a battery of clinical, audiological, and radiological workup. Preoperative audiologic assessment included immittance measures, standard pure-tone audiometry, and speech discrimination scores. The preoperative radiological evaluation was in terms of high-resolution computed tomography and MRI of the temporal bones to determine CI candidacy. The surgical technique including the depth of insertion of the electrodes was identical in all patients; even the intervention was performed by the same surgeons.

To quantify the effect of CI as a treatment option for tinnitus in patients with SSD, the assessment protocol included the following: an evaluation questionnaire for tinnitus (THI) and the Tinnitus Rating Scale (TRS). The THI is an internationally validated, 25-question tinnitus scoring system that is used to measure the disability caused by tinnitus in terms of quantifying the impact of tinnitus on the patient's psychology and activities of daily living, with a score between 0 (slight tinnitus) and 100 (catastrophic tinnitus). Tinnitus severity was measured using the TRS, through which the patient was asked to categorize the severity of his tinnitus on a numeric scale, as shown in Table 1 [11].

All participants gave their written informed consent and were asked to complete the THI and the TRS preoperatively and postoperatively at 1 and 3-month intervals after CI activation. We analyzed changes in the THI and the TRS scores through the two postoperative interviews by comparing the scores with the initial baseline preoperative evaluation. The

Table 1 Rating scale of tinnitus

1	Not present
2	Present, but not disturbing the patient
3	Present, disturbing but without psychological disturbances
4	Present, severely disturbing, but does not affect the ordinary daily activities
5	Present and debilitating

degree of postimplantation tinnitus was also analyzed in relation to the type of implant used. The etiology of hearing loss in this series of patients varied and was unknown in many cases. Therefore, it was difficult to use this information statistically in this study.

For the statistical analysis of all outcomes, repeated-measures analysis of variance was employed (assessment at preoperative baseline and follow-up postoperatively at 1 and 3 months after CI activation). P-value less than 0.05 was considered significant. SPSS software (version 16.0; SPSS Inc., Chicago, Illinois, USA) was used for analysis.

Results

Descriptive and demographic features of the study group are presented in Table 2. Thirteen patients were enrolled in this study, eight men and five women, ranging in age from 24 to 60 years with a mean±SD of 40±10 years. All patients had unilateral severe-to-profound SNHL (SSD) (PTA 0.5–4 kHz of ≥75 dB) in the ear to be implanted. In the contralateral ear, all patients had normal hearing (PTA 0.5–4 kHz of ≤25 dB). The etiology of hearing loss varied among patients as it was unknown in five (40%) patients. In

four (30%) patients, hearing loss was related to postviral sudden SNHL. Other etiologies were labyrinthitis in two (15%) patients and post-traumatic cause in two (15%) patients.

The onset of hearing loss was sudden in the majority of patients (8/13=60%) and progressive in five (40%) patients. The average duration of hearing loss in the implanted ear was generally short (8–42 months), being less than 2 years in 70% of patients. Postoperatively, the average usage of the device was between 12 and 18 h/day. Most of the patients (six patients=45%) were implanted with MEDEL CONCERTO (CONCERTO: MEDEL, AUSTRIA) CI, four (30%) patients were implanted with nucleus CI (COCHLEAR, AUSTRALIA) (CI24RE) with contour advance perimodiolar electrode array, and three (25%) patients were implanted with Advanced Bionic (HiRes90K, Valencia, CA 91355, USA) Mid-Scala electrode array. Details are listed in Table 2.

Mean scores for THI and TRS are shown in Table 3. The scores were obtained preoperatively and 1 and 3 months postoperatively after the activation of the CI. Mean scores for the THI total scores ranged from

Table 2 Descriptive and demographic features of the study group

Patient ID	Age[a]	Sex[b]	CI ear[c]	Etiology	Onset	Duration (months)[d]	PTA CI ear[e]	PTA CL ear[e]	Implant[f]	Average usage (h/day)
1	33	Female	Right	SSNHL	Sudden	8	95	15	CI24RE	17
2	24	Male	Right	Labyrinthitis	Sudden	22	90	20	CONCERTO	15
3	28	Male	Left	SSNHL	Sudden	27	85	25	CONCERTO	12
4	35	Male	Right	Unknown	Progressive	10	100	25	CI24RE	17
5	44	Female	Left	Labyrinthitis	Sudden	13	105	10	CONCERTO	16
6	47	Male	Left	SSNHL	Sudden	16	90	15	HiRes90K	14
7	51	Female	Right	Unknown	Progressive	12	115	25	CONCERTO	15
8	55	Male	Right	Post-traumatic	Sudden	28	110	20	HiRes90K	12
9	60	Male	Right	Unknown	Progressive	12	95	20	CONCERTO	16
10	35	Female	Left	Post-traumatic	Sudden	10	NR	25	CI24RE	18
11	40	Male	Right	Unknown	Progressive	42	105	15	CI24RE	12
12	39	Male	Left	Unknown	Progressive	31	85	15	HiRes90K	14
13	32	Female	Right	SSNHL	Sudden	9	95	25	CONCERTO	17

CI, cochlear implant; CL, contralateral; NR, not reported; PTA, pure-tone average; SSNHL, sudden sensorineural hearing loss. [a]Age (mean±SD)=40±10. [b]Male/female ratio=8/5. [c]CI ear: right/left ratio=8/5. [d]Duration (months) of hearing loss before CI. [e]PTA CI ear and PTA CL ear average at 0.5, 1, 2 and 4 kHz. [f]Implant devices (CI24RE : CONCERTO : HiRes90K=4 : 6: 3).

Table 3 Outcome measures (Tinnitus Handicap Inventory and Tinnitus Rating Scale) before and after cochlear implantation
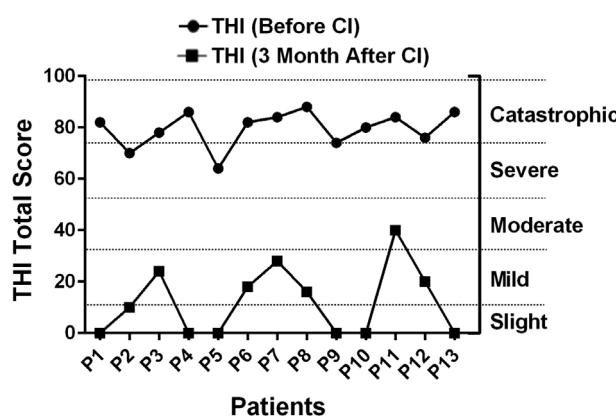
Outcome measures	Before CI	After CI (mean±SD)		P-value
		One month	3 months	
THI	79.6±7	24.7±18.9	12±13.5	<0.05*
TRS	4.53±0.5	1.76±0.7	1.46±0.5	<0.05*

CI, cochlear implantation; THI, Tinnitus Handicap Inventory; TRS, Tinnitus Rating Scale. *P<0.05, statistically significant (repeated-measures analysis of variance).

79.6±7 preoperatively to 12±13.5 at 3 months postoperatively. Mean scores for the TRS ranged from 4.53±0.5 preoperatively to 1.46±0.5 at 3 months postoperatively. The postoperative THI and TRS improved statistically significantly as compared with the baseline preoperative scores ($P<0.005$).
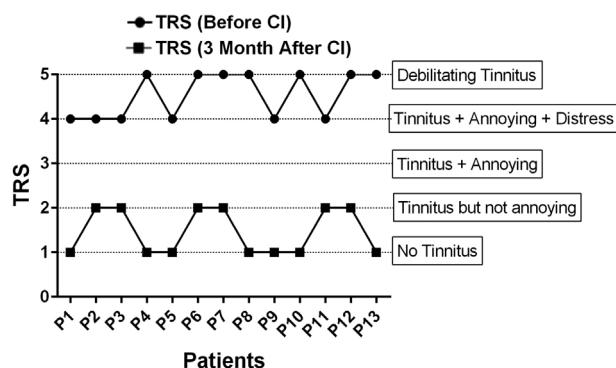
The THI disability grading and the tinnitus severity scale in the study group before and after CI are illustrated in Figs 1 and 2. Nine (70%) patients demonstrated catastrophic disability in THI, whereas four (30%) patients demonstrated severe disability before CI. In terms of TRS, most of the cases demonstrated level 4–5 (debilitating tinnitus). After implantation, seven (55%) patients had a complete suppression of their tinnitus, whereas six (45%) patients demonstrated significant reduction in the perception of their tinnitus on the basis of the TRS. After CI, none of the patients demonstrated any deterioration in tinnitus.

Figures 3 and 4 demonstrate the progress of the tinnitus measures (THI and THS) postoperatively after the activation of the device over the first 3 months as compared with the preoperative baseline. After CI and over the first 3 months' follow-up, the tinnitus level was reduced significantly. These reductions were observed in all implanted devices (CI24RE, HiRes90K, and CONCERTO). There was no significant difference among the three devices with regard to the tinnitus-suppression effects of CI (Fig. 5).

Figure 3

Tinnitus Handicap Inventory (THI) progress in the study group at 1 and 3 months after cochlear implantation (CI) activation.

Figure 1

Tinnitus Handicap Inventory (THI) grading for each patient in the study group before and after cochlear implantation (CI).

Figure 4

Tinnitus Rating Scale (TRS) in the study group before cochlear implantation (CI) and at 1 and 3 months after CI activation.
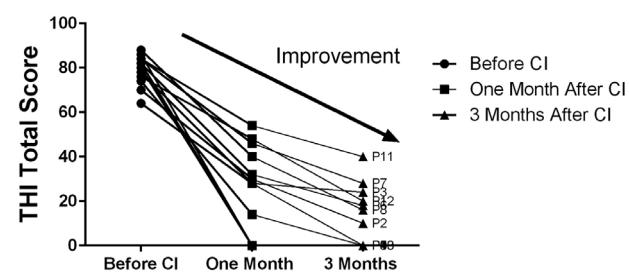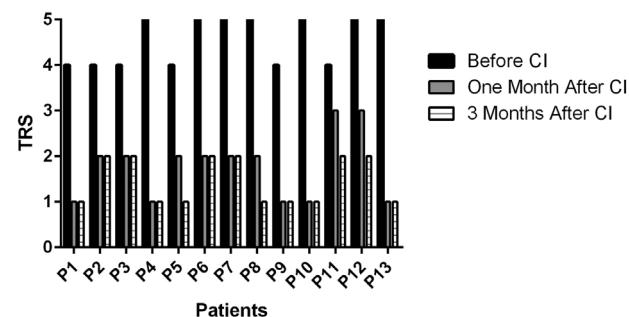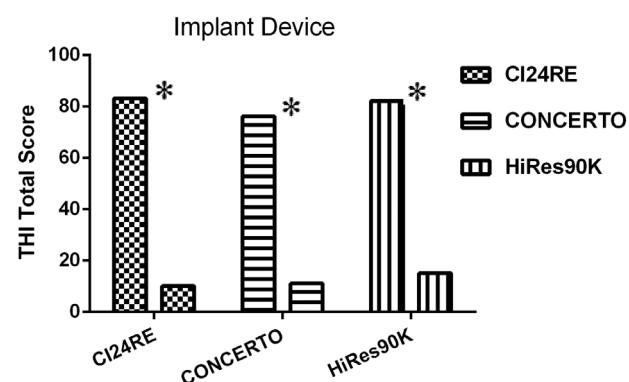
Figure 2

Tinnitus severity rating for each patient in the study group before and after cochlear implantation (CI). TRS, Tinnitus Rating Scale.

Figure 5

THI before and after CI in relation to different CI devices. All CI devices (CI24RE, Concerto, and HiRes90K) elicited a significant reduction in tinnitus levels in implanted patients (*$P<0.05$; analysis of variance test). CI, cochlear implant; THI, Tinnitus Handicap Inventory.

Discussion

CIs represent one of the most important achievements of modern medicine, as for the first time in history an electronic device is able to restore a lost or never-existed sense (hearing) [12]. Távora-Vieira et al. [13] reported that the number of cochlear implantees was steadily increasing worldwide despite the related cost; this could be attributed to the fact that significant advances in technology and better knowledge of the outcomes are constantly changing the criteria for CI candidacy. This is mainly because implanted patients are now obtaining increasing amounts of open-set word recognition with the available devices [2]. Hence, changes in patient selection have included implanting patients with SSD, adult candidates with residual hearing, and children at younger ages or with additional disorders.

Tinnitus suppression was reported by House [14] after implantation of single-channel extra-cochlear devices. Since then, several studies have confirmed this outcome and CI has been used to suppress tinnitus in several cases of SSD all over the world [15]. The negative impact of tinnitus in patients with SSD is more severe than one might expect; hence, tinnitus treatment and restoration of hearing are important in those patients [2]. Participants enrolled in this study had unilateral severe-to-profound SNHL (SSD) and incapacitating tinnitus, and complied with the defined inclusion and exclusion study criteria.

The study group (13 patients) was implanted with multichannel implant (CONCERTO, CI24RE and HiRes90K) devices (Fig. 5). They reported that they had used their devices during most of their waking hours (12–18 h/day) for the 3-month duration of the study. They were asked to rate the efficacy of CI treatment in the suppression of tinnitus by conducting the THI and TRS at 1- and 3-month intervals after activation of the CI. Statistically significant improvements in measures of tinnitus impact (THI) and tinnitus severity (TRS) were achieved in the study group (Table 3). Figs 1–4 demonstrate that the vast majority of patients showed a statistically and clinically significant reduction in their tinnitus with variable degrees of improvement based on the outcome measures (THI and TRS). Furthermore, postoperative reductions in THI total scores for all patients were highly correlated with TRS scores. Hence, our data support the hypothesis of suppression or improvement of tinnitus after CI.

The current study demonstrated that 54% of patients had postoperative complete suppression of their tinnitus, whereas 46% demonstrated significant reduction in the perception of their tinnitus. This finding is consistent with other studies that used quantitative measures to evaluate CI as a treatment option for tinnitus in patients with hearing loss. Ito et al. [16] reported tinnitus suppression in 77% of their patients. Souliere et al. reported an overall improvement in 74% of patients [18].

Moreover, in similar studies, Pan et al. [17] reported that after CI, tinnitus disappeared in 61% of patients and reduced in 39% of patients, but 12% of patients demonstrated newly developed tinnitus [18]. Kompis et al. [19] reported elimination of tinnitus in 20% of patients after CI, with 51.2% of patients showing subjective improvement after 6 months of CI; in the same study, 7.2% of patients demonstrated worsening of preoperative tinnitus and 10% demonstrated newly developed tinnitus in the nontinnitus group.

Our results demonstrated that none of our patients experienced worsened tinnitus after CI. In the literature, other studies demonstrated that 4–26% of patients reported worsening of tinnitus or newly developed tinnitus after CI [20]. The current study's outcome could be attributed to the short follow-up period and the small size of the study group. Bovo and colleagues suggested that a more accurate method is needed to investigate the postoperative development or worsening of tinnitus as some patients may have difficulty in differentiating environmental noise from tinnitus after CI. The mechanism underneath tinnitus suppression after CI could be attributed to surgery, direct stimulation of the cochlear nerve, or auditory masking [20]. Andersson et al. [21] suggested that masking is the predominant mechanism in the suppression of tinnitus after CI.

Special techniques have been suggested by Baguley and Atlas [22] for maximal tinnitus suppression in CI implantees, including usage of nondirectional microphones to increase environmental noise, low-compression knee points, and a fast pulsatile strategy. Furthermore, programming of the CI during night-time usage has been found useful in patients with sleep difficulties. Tinnitus suppression after CI also includes contralateral suppression and residual inhibition of the tinnitus after switching off the processor [15]. The mechanisms of contralateral suppression and residual inhibition are still vague in the literature, but most of the theories suggest that this could be attributed to alterations of the tinnitus

generator by the implant or alteration of central perception of the tinnitus signal.

The methods to quantify tinnitus suppression after CI vary from study to study. The TRS and the questionnaire, which are utilized in the current study, were designed to measure and statistically analyze the severity and impact of tinnitus on the patients. The differences in the reported efficacy of CIs in the suppression of tinnitus among different studies could be attributed to the differences in the rating scales used in those studies [18]; moreover, this could be explained by the differences in the processing strategies and rehabilitation techniques used in different centers. The current study demonstrated an outcome that is qualitatively similar to the outcome of the study conducted by Souliere and colleagues.

Conclusion

The current study demonstrated the outcome of CI in a series of 13 patients with unilateral profound SNHL (SSD), associated with incapacitating tinnitus with normal hearing in the contralateral ear. Statistically significant improvements in measures of tinnitus impact (THI) and tinnitus loudness (TRS) were achieved in all patients. The outcome of the current study supports the belief that CI is not only a treatment option for hearing loss in SSD but is also a treatment option to suppress tinnitus.

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Conflicts of interest
There are no conflicts of interest.

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