ORIGINAL ARTICLE

Cochlear Implant in Patients With Sudden Unilateral Sensorineural Hearing Loss and Associated Tinnitus

Ángel Ramos, a Rubén Polo, b Elisabeth Masgoret, a Ovidio Artiles, a Isidoro Lisner, a,* Maria L. Zaballos, a Cecilia Moreno, a Ángel Osorio a

a Servicio de Otorrinolaringología, Complejo Hospitalario Universitario Insular Materno-Infantil, Las Palmas de Gran Canaria, Spain
b Servicio de Otorrinolaringología, Hospital Ramón y Cajal, Madrid, Spain

Received 27 March 2011; accepted 27 July 2011

KEYWORDS
Cochlear implant; Tinnitus; Sudden hearing loss

Abstract
Introduction and objectives: To assess the efficacy of cochlear implantation in patients with unilateral sudden sensorineural hearing loss and associated disabling tinnitus.
Methods: Ten patients suffering from severe-to-profound sudden hearing loss and tinnitus in the affected ear received implants. The sample comprised 4 men and 6 women, with a mean age of 42.7 years (range 34–62) at implantation. The severity of the tinnitus was evaluated with the Spanish validated version of the Tinnitus Handicap Inventory (THI) and a visual analogue scale. These assessments were obtained before and after implantation.
Results: Tinnitus suppression was observed in 2 patients. In 7 cases, we observed an improvement in the THI, in different degrees, and 1 patient remained without changes. Tinnitus worsening was not found in the series studied.
Conclusions: Tinnitus reduction following cochlear implantation can be explained by several mechanisms, such as habituation, acoustic masking, direct stimulation of the cochlear nerve and reorganisation of cortical areas. Even though further research is required, cochlear implantation is an effective method for the treatment of disabling tinnitus in patients with severe-to-profound unilateral sensorineural hearing loss.
© 2011 Elsevier España, S.L. All rights reserved.

PALABRAS CLAVE
Implante coclear; Acúfeno; Hipoacusia súbita

Resumen
Introducción y objetivos: Valorar la eficacia del implante coclear en pacientes con hipoacusia súbita unilateral y acúfeno incapacitante asociado.

* Corresponding author.
E-mail address: llisner@hotmail.com (I. Lisner).
**Métodos:** Se han implantado 10 pacientes con hipofucusía súbita severa-profunda unilateral y acúfenos asociados, entre los cuales 4 son varones y 6 mujeres, con media de edad a la implantación de 42,7 años (rango: 34-62). Hemos evaluado la severidad del acúfenos mediante el *Tinnitus Handicap Inventory* (THI) en su versión validada al castellano y una escala analógica visual pre y postimplantación.

**Resultados:** Se ha observado una supresión del acúfenos en dos pacientes. Siete pacientes han experimentado una mejoría del THI en distintos grados y no se han producido cambios en un paciente. No ha habido empeoramiento del acúfenos en ningún caso de la serie estudiada.

**Conclusions:** La reducción del acúfenos tras implantación coclear se puede deber a varios mecanismos, tales como la habituación, enmascaramiento acústico, estimulación directa del nervio coclear y reorganización de las áreas corticales. Aunque sean precisos más estudios, el implante coclear es un método efectivo para el tratamiento del acúfenos incapacitante en pacientes con hipofucusía súbita severa-profunda unilateral.

© 2011 Elsevier España, S.L. Todos los derechos reservados.

**Introduction**

Tinnitus is defined as an auditory sensation without an external stimulus. It is a common symptom in patients who are candidates for cochlear implant and has a prevalence between 66% and 88%.¹

Numerous studies have shown the suppression of tinnitus by electrical stimulation of the acoustic pathway through a cochlear implant, with a low risk of worsening after implantation.²⁴

A recent, innovative indication with promising results has been the cochlear implant fundamentally to treat the tinnitus in patients with unilateral sensorineural hearing loss and associated disabling tinnitus.⁵⁻⁸

The purpose of our study was to assess the effectiveness of cochlear implantation in patients with sudden, unilateral, severe/profound hearing loss and associated disabling tinnitus.

**Methods**

We performed a descriptive study with a design including repeated measurements, in which each subject acted as their own control. These subjects were 10 patients included in the study according to the following criteria:

1. Ethical approval by the hospital and the Department of Health.
2. Severe/profound sensorineural hearing loss in the ear to be implanted; disyllabic tests <40% without lip reading at 65 dB SPL.
3. Normal hearing or moderate hearing loss in contralateral ear. Disyllabic tests >50% in silence at 65 dB SPL in the best conditions, without the aid of lip reading.
4. Degree of disability in Tinnitus Handicap Inventory (THI) >58%.
5. Tinnitus in the ear to be implanted. Onset after sudden idiopathic hearing loss.
6. Failure of prior treatments.
7. Duration of hearing loss <10 years in the ear to be implanted.
8. Duration of tinnitus <3 years.
9. No central source of tinnitus (diabetes, etc.).

Patients were assessed before the intervention using a battery of medical, audiological and psychological tests to determine correct treatment and to establish tinnitus and speech perception ability. The assessment protocol used for the study (Table 1) was based on a set of tests that investigated the involvement of 3 symptoms (tinnitus, hyperacusis and hearing loss). With respect to tinnitus assessment, we carried out a tinnitus test measuring 3 characteristics (timbre, intensity and minimum masking level), along with objective evaluation tests for tinnitus that included an initial evaluation questionnaire, a visual analogue scale⁹ (VAS) and THI¹⁰,¹¹ through 25 questions designed to measure the disability caused by tinnitus.

As for quantifying the hyperacusis, we carried out the hyperacusis test (HST),¹²⁻¹⁴ a numerical scale of discomfort caused by sounds and a list of activities that the patient could not perform secondarily.

The hearing assessment included a complete audiometry with air conduction, bone conduction, logaudiometry and threshold of discomfort. This last test allowed us to assess the association of tinnitus with hearing loss and thus regulate the prostheses adequately. We also carried out a tonal and verbal assessment of the prosthesis using headphones, open field without hearing aids and open field with hearing aids.

The study included a total of 10 patients, of which 4 were male and 6 were female, with a mean age at implantation of 42.7 years (range between 34 and 62 years). The mean duration of hearing loss was 3.8 years (range between 1 and 5 years), while the mean duration of tinnitus was 1.5 years (range between 1 and 3 years). Patients presented profound, unilateral sensorineural hearing loss with a mean value of 90 dB (range between 83 and 110 dB); the right ear was implanted in 5 patients and the left in the remaining 5. We performed a follow-up period ranging between 3 and 18 months. All patients had been implanted and, depending on the degree of their hearing loss, were carriers of a cochlear implant model Freedom (4), Nucleus CI 512 (1) or Nucleus Hybrid L24 (5) (Table 2).

With respect to the assessment of tinnitus (Tables 3 and 4), 3 patients reported a holocranial location, 4 a bilateral location and 3 a unilateral location. Constant tinnitus was identified in all patients; frequencies were low (250–1000 Hz) in 4 patients, high (>5000 Hz) in...
Table 1  Evaluation Protocol Used in the Study of Tinnitus: Set of Tests That Evaluate the Implication of the 3 Symptoms (Tinnitus, Hyperacusis and Hearing Loss).

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Measurement</th>
<th>Test to Obtain Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinnitus</td>
<td>Intensity</td>
<td>Tinnitus test</td>
</tr>
<tr>
<td></td>
<td>Timbre MML</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Degree of disability</td>
<td>THI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Subjective discomfort scale</td>
</tr>
<tr>
<td>Hyperacusis</td>
<td>Presence and degree of symptom</td>
<td>HST</td>
</tr>
<tr>
<td></td>
<td></td>
<td>List of activities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Numerical scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of discomfort with sounds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduced dynamic range</td>
</tr>
<tr>
<td>Hearing loss</td>
<td>Full audiological exploration</td>
<td>Tonal audimetry</td>
</tr>
<tr>
<td></td>
<td>Location of the lesion</td>
<td>Verbal audimetry</td>
</tr>
<tr>
<td></td>
<td>Functional gain</td>
<td>Open field with and without hearing aid</td>
</tr>
</tbody>
</table>

HST: hyperacusis test; MML: minimum masking level; THI: tinnitus handicap inventory; VAS: visual analogue scale.

3, complete frequent in 2 patients and with a value of 2000 Hz in 1 patient. The mean intensity of the tinnitus was 4.5 dB (range between 4 and 5 dB).

Patient evaluation was carried out at 1, 3 and 6 months after implant activation. After activation of the cochlear implant, tinnitus retraining therapy (TRT) was applied in those patients who did not show sufficient improvement in tinnitus in the second evaluation after 3 months. This sound therapy used habituation noises through the audio input of the cochlear implant processor.

All participants were scheduled according to a specific method based on tests and trials conducted during a pilot study, in which a tinnitus test was used to calculate the frequency of tinnitus. The electrodes that corresponded to the frequency determined by the tinnitus test were stimulated so as to identify which one was closest to the tinnitus. Once the electrode was identified, the 4 collateral electrodes were given the same levels of T. These 5 electrodes maintained their similar T as if they were acting as a single electrode, but with a greater bandwidth frequency. To determine the C level of the tinnitus areas, we increased the intensity until it equaled that of tinnitus. This C level was also applied to the 4 collateral electrodes. The T and C levels in other areas were determined according to the programming of the standard cochlear implant. We created 4 maps and, after 10 days, 1 of them was maintained as the reference map to start working on the implant programming. The processor configuration was modified on a monthly basis to improve the acceptance of the device and speech understanding.

Results

The mean score obtained in the preoperative THI was 72.1%. After cochlear implantation, THI values at 1 and 3 months fell to 27.4% and 14.3%, respectively (Fig. 1). In 2 of the 10 patients, we observed complete suppression of tinnitus; in the remaining 8, we observed a significant decrease in its perception.

In relation to the degree of disability according to the THI score (absence of disability: 0%–16%, mild disability: 18%–36%, moderate disability, 38%–56%, severe disability: >58%), 10 patients presented a severe disability prior to cochlear implantation. Three months after surgery, 8 patients presented no disability, 1 patient presented mild disability and severe disability persisted in another patient despite an improvement in THI score.

The VAS showed a reduction from 7.9 points preoperatively to 2.7 points at 3 months postoperatively (Fig. 2).

As for the perception of tinnitus in percentage of hours per day, there was a reduction from 100% (preoperative value) to 11% (3 months postoperatively). It was observed that the improvement in tinnitus perception remained even when the implant was switched off.

In selected cases with residual hearing and in cases with contralateral hearing loss, hybrid and bimodal

Table 2  Comparison of the 10 Patients in the Study Through the Tinnitus Evaluation Protocol.

<table>
<thead>
<tr>
<th>No.</th>
<th>MAT Right Ear</th>
<th>MAT Left Ear</th>
<th>Implant Side</th>
<th>Contralateral Side</th>
<th>Cochlear Implant Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>86.67</td>
<td>51.67</td>
<td>Right</td>
<td>Hearing aid</td>
<td>CI24REH L</td>
</tr>
<tr>
<td>2</td>
<td>83.33</td>
<td>70</td>
<td>Right</td>
<td>Hearing aid</td>
<td>CI24RE (CA)</td>
</tr>
<tr>
<td>3</td>
<td>93.33</td>
<td>83.33</td>
<td>Right</td>
<td>Hearing aid</td>
<td>CI24RE (CA)</td>
</tr>
<tr>
<td>4</td>
<td>43.33</td>
<td>86.67</td>
<td>Left</td>
<td>Hearing aid</td>
<td>CI24REH L</td>
</tr>
<tr>
<td>5</td>
<td>98.33</td>
<td>61.67</td>
<td>Right</td>
<td>Hearing aid</td>
<td>CI24RE (CA)</td>
</tr>
<tr>
<td>6</td>
<td>16.67</td>
<td>85</td>
<td>Left</td>
<td></td>
<td>CI24REH L</td>
</tr>
<tr>
<td>7</td>
<td>13.33</td>
<td>105</td>
<td>Left</td>
<td></td>
<td>CI512</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>80</td>
<td>Left</td>
<td></td>
<td>CI24REH L</td>
</tr>
<tr>
<td>9</td>
<td>38</td>
<td>82</td>
<td>Left</td>
<td></td>
<td>CI24REH L</td>
</tr>
<tr>
<td>10</td>
<td>Deafness</td>
<td>25</td>
<td>Right</td>
<td></td>
<td>CI24RE (CA)</td>
</tr>
</tbody>
</table>

MAT: mean auditory threshold at 0.5, 1, 2 and 4 kHz.
Table 3  Characteristics of Tinnitus Regarding Location, Type, Frequency and Intensity.

<table>
<thead>
<tr>
<th>Type of Implant</th>
<th>Hybrid 1</th>
<th>Hybrid 2</th>
<th>Hybrid 3</th>
<th>Hybrid 4</th>
<th>Hybrid 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Unilateral</td>
<td>Bilateral</td>
<td>Holocranial</td>
<td>Holocranial</td>
<td>Unilateral</td>
</tr>
<tr>
<td>Type</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td>Frequency</td>
<td>250–5000 Hz</td>
<td>250 Hz</td>
<td>6000 Hz</td>
<td>250–1000 Hz</td>
<td>250–5000 Hz</td>
</tr>
<tr>
<td>Intensity</td>
<td>5 dB</td>
<td>5 dB</td>
<td>4 dB</td>
<td>5 dB</td>
<td>5 dB</td>
</tr>
</tbody>
</table>

Table 4  Characteristics of Tinnitus (Location, Type, Frequency and Intensity).

<table>
<thead>
<tr>
<th>Type of Implant</th>
<th>CI24Re(CA)1</th>
<th>CI24Re(CA)2</th>
<th>CI24Re(CA)3</th>
<th>CI24Re(CA)4</th>
<th>CI512</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Bilateral</td>
<td>Bilateral</td>
<td>Unilateral</td>
<td>Holocranial</td>
<td>Bilateral</td>
</tr>
<tr>
<td>Type</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
</tr>
<tr>
<td>Frequency</td>
<td>5000 Hz</td>
<td>2000 Hz</td>
<td>6000 Hz</td>
<td>250–1000 Hz</td>
<td>250–1000 Hz</td>
</tr>
<tr>
<td>Intensity</td>
<td>5 dB</td>
<td>4 dB</td>
<td>5 dB</td>
<td>5 dB</td>
<td>4 dB</td>
</tr>
</tbody>
</table>

Figure 1  Graph showing Tinnitus Handicap Inventory (THI) values preoperatively, 1 month and 3 months after cochlear implantation.

Figure 2  Visual analogue scale (VAS) for the evaluation of tinnitus preoperatively and after cochlear implantation.
Implant in Patients With Sudden Unilateral Sensorineural Hearing Loss and Associated Tinnitus

**Discussion**

According to Bauer, the estimated prevalence of adults with chronic tinnitus varies between 6% and 20%. Of these, between 1% and 3% suffer disabling tinnitus that interferes with their quality of life. The genesis of tinnitus is explained as a negative consequence of neural plasticity of the central nervous system after a peripheral aggression.

Scientific evidence has shown that reorganisation processes take place in the auditory cortex after suffering tinnitus associated to sensorineural hearing loss, as well as an overstimulation of certain tonotopic cortical areas. Herhaiz et al. found that acoustic rehabilitation reduced the impact of this reorganisation and improved tinnitus.

Numerous studies support the suppression or improvement of tinnitus after cochlear implantation. On average, between 60% and 90% of tinnitus cases in implanted patients with hearing loss show an improvement in perception, which sometimes even reaches its disappearance. This effect may persist for a certain time after switching off the processor, probably in relation to residual inhibition. Moreover, in some patients electrical stimulation of the auditory pathway succeeds in improving or even suppressing contralateral tinnitus.

In our study, we observed a suppression of tinnitus in 2 patients (20%), whereas 8 experienced an improvement in its perception (80%). In connection with the score obtained on the THI, there was a reduction from 72.1% in the preoperative period to 14.3% in the 3 postoperative months.

Bovo et al. conducted a study on 51 patients with profound, bilateral sensorineural hearing loss, who were candidates for cochlear implantation. The study cohort for tinnitus and cochlear implant was reduced to 36 patients; in 11 patients (30.5%), there was a suppression of tinnitus; in 16 (44.4%), its perception decreased; in 5 (13.9%), there was no change and in 4 patients (11.1%), there was a worsening. In connection with THI, there was an improvement in 72.2% of patients, no change in 2.8% and a worsening in 25% of cases. Of the 36 patients, 27 presented bilateral tinnitus and there was an improvement of contralateral tinnitus in 10 of them (45%).

Di Nardo et al. established 2 study groups: group A, composed of 20 patients with preimplantation tinnitus, and group B, composed of 10 patients without preimplantation tinnitus. No patient in group B presented postimplantation tinnitus. In group A, there was a suppression of tinnitus in 8 patients (40%), its perception decreased in 6 (30%), 5 patients (25%) did not experience any changes and 1 patient (5%) reported a worsening of tinnitus.

In recent years, cochlear implants have been used in a novel way in patients with unilateral, severe-profound sensorineural hearing loss with associated disabling tinnitus and normal contralateral hearing with good results. The largest series studied to date includes 5 patients. Of these, tinnitus was suppressed in 3 and its perception improved in 2.

Our study results are encouraging, but we must be cautious in their interpretation. Undoubtedly, further work with a larger patient cohort is needed to refine the selection criteria in these cases.

**Conclusions**

Cochlear implants can reduce or suppress incapacitating tinnitus in patients with unilateral, severe-profound sensorineural hearing loss and normal contralateral hearing. It is a valid and effective therapy when other treatments have failed. In selected cases with residual hearing and in cases suffering contralateral hearing loss, hybrid and bimodal stimulation, respectively, have shown good results in hearing and in the control of tinnitus.

The reduction of tinnitus after cochlear implantation may be due to several mechanisms, such as habituation, acoustic masking, direct stimulation of the cochlear nerve and reorganisation of cortical areas.

**Conflict of Interests**

The authors have no conflicts of interest to declare.

**References**