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Influence of cochlear implantation on the vestibular function

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Abstract The aim of the present study was to examine the influence of cochlear implantation on vestibular function. The function of the horizontal semicircular canal, the saccular function, and the incidence of vestibular symptoms were assessed before and after cochlear implantation. Twenty unilaterally cochlear implant patients were evaluated preoperatively, 1 and 6 months postoperatively, with caloric testing with electronystagmography (ENG) recordings and vestibular evoked myogenic potentials (VEMP) testing. A medical history was taken from every subject, noting the presence or absence of vertigo before and after the operation. A possible correlation between the appearance of postoperative vertigo and age, sex, implant side, preoperative caloric results and VEMP status, and postoperatively recorded changes in caloric and VEMP testing was also investigated. A statistically significant difference was found in the percentages of canal paresis ($p = 0.01$) and the percentages of VEMP waveform absence ($p = 0.002$) between the repeated measurements in the implanted side, whereas in the non-implanted side no difference was ($p > 0.05$) found. Four patients complained of postoperative vestibular symptoms. In three of them the symptoms lasted less than 6 months postoperatively, but the fourth patient was still dizzy 6 months after cochlear implantation. No correlation was found between the above-mentioned factors and the occurrence of postoperative vertigo. In conclusion, although changes of the peripheral vestibular function of the implanted side were recorded in our patients, permanent vertigo was rare. Predictive factors for the occurrence of postoperative vestibular symptoms could not be identified.

Keywords Cochlear implantation · Caloric test · VEMPs · Vestibular symptoms

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Introduction

Cochlear implants represent the most important advance in treatment of individuals with profound deafness in the past century [1]. Although the first cochlear implants aimed to provide patients with little more than awareness of environmental sounds and some cues to assist visual speechreading, the technology has advanced rapidly. Most people with modern cochlear implants can understand speech using the device alone, at least in favorable listening conditions [2]. In the past, patients had to be almost completely deaf before cochlear implantation could be considered. Nowadays, the indications of cochlear implantation have been broadened and bilateral cochlear implantation has become an established concept, especially in children [3], as profoundly deaf bilaterally implanted children are more likely to use vocalization to communicate and to use audition when interacting vocally with an adult, compared with unilaterally implanted children [4]. It has thus become more important to evaluate the possible risks of this procedure.

Although cochlear implantation is considered to be safe, with minimal risk of complications, the traumatic action of the electrode insertion into the scala tympani of the cochlea carries the potential risk of impairing the vestibular function. Direct trauma from insertion caused by the electrode [5], intraoperative loss of perilymph [6], acute serous labyrinthitis due to cochleostomy [7], foreign body reaction with labyrinthitis [8], endolymphatic hydrops [7], and electrical stimulation by the implant [9] could be plausible mechanisms of this impairment. Histopathological studies on temporal bones from patients who had been implanted some time before to improve their hearing have shown that cochlear implantation can damage the vestibular end organ. Structural changes have been demonstrated in the saccule, utricule, and semicircular canals [10, 11] and lead to a measurable decrease in peripheral vestibular function. The estimated risk of impairment varies widely from 6.3 to 93% [7, 12–20] for the horizontal semicircular canal and from 21 to 100% [13, 15, 20–22] for the saccule. However, not all cochlear implant patients suffer from post-operative vertigo symptoms. Although adverse vestibular symptoms after cochlear implantation have been commonly reported in the literature especially in adults, their incidence varies widely from 0.33 to 75% [12].

The aim of this study was to examine the influence of cochlear implantation on peripheral vestibular function. The function of the horizontal semicircular canal and the saccular function were assessed before and after cochlear implantation. The incidence of vertigo symptoms was also evaluated.

Materials and methods

Twenty patients who underwent unilateral cochlear implantation in the Otorhinolaryngology Department, Hippokration Athens Hospital, University of Athens, between January 2007 and May 2010, were included in the study. Nine were males and eleven females, with mean age 47.6 years $\pm$ 20.2 and age range 10–77 years. The study was approved by the local ethics committee. Informed consent was obtained from all patients included. The indication for cochlear implantation was based on a severe to profound bilateral deafness with no benefit from hearing aids. The operation was performed on the right side in eleven patients (55%) and on the left side in nine patients (45%).

The causes of deafness were heterogeneous: drug/toxic induced (four patients), acute idiopathic sensorineural hearing loss (three), presbycusis (two), meningitis (one), and trauma (one). In nine patients, the cause of deafness was not identifiable.

All patients were evaluated preoperatively with bithermal caloric testing with electronystagmography (ENG) recordings and vestibular evoked myogenic potential (VEMP) testing. After cochlear implantation, follow-up testing was performed at 1- and 6-month intervals; all measurements were performed when the devices were switched off. A medical history was taken from every subject, noting the presence or absence of vertigo before and after the operation.

Test procedures

VEMP recordings were performed with a GN Otometrics (Taastrup, Denmark) EP version 5.2 analyser. Patients were seated in an upright position, with their heads turned contralaterally to the stimulated ear, to achieve sufficient and constant contraction to the sternocleidomastoid muscle during recordings. The skin was scrubbed, and the impedance of the recording electrodes was maintained below 5 kOhms. The two active electrodes were placed symmetrically over the midpoint of each sternocleidomastoid muscle, a reference electrode was placed on the upper forehead, and the ground electrode was applied in the middle of the forehead. The acoustic stimuli (short tone bursts, 95 dB HL, 500 Hz, rate 5.1/s, ramp 1 ms, plateau 0 ms) were delivered monaurally through headphones (TDH-40; Telephonics, NY, USA) with no contralateral masking, and the myogenic potential was recorded ipsilaterally by surface electrodes. The analysis time was 100 ms, and the electromyographic (EMG) signal was band-pass filtered from 2 to 500 Hz. Every set of 150 stimuli was averaged and repeated twice to verify the response reproducibility. If there were no recognizable or reproducible waveforms, the VEMP response was considered absent.

For the bithermal caloric tests, a Hortmann Airmatic air caloric stimulator (GN Otometrics, Taastrup, Denmark) was used. Electronystagmography recordings were performed with a Life-Tech model 3002 electronystagmograph (Stafford, TX, USA). Details of these methods have been reported elsewhere [23]. In our laboratory, caloric asymmetry of more than 22% was defined as unilateral canal paresis. Bilateral canal paresis was considered to be present if the total response from both sides was less than 15°/s [23].

Statistical analysis

Statistical analysis of the data was performed using the Statistical Package for the Social Sciences (SPSS), version 17.0 (SPSS, Inc., Chicago, IL, USA). Continuous variables were expressed as mean $\pm$ standard deviation and categorical variables were expressed as frequencies and percentages. The Cochran's Q and the Mc Nemar tests were used to compare findings between repeated measurements in the same subjects. The Chi-square test was used to evaluate

Table 1 Caloric results preoperatively, 1 and 6 months postoperatively, and statistical comparisons across sessions

Caloric results	Patients N (%)					
	Preoperatively		1 Month postoperatively		6 Months postoperatively	
Ear	Implanted	Non implanted	Implanted	Non implanted	Implanted	Non implanted
Bilaterally normal	7 (35)	7 (35)	5 (25)	5 (25)	4 (21.1)	4 (21.1)
Unilaterally normal	3 (15)	5 (25)	0 (0)	6 (30)	0 (0)	7 (36.8)
Bilateral canal paresis	5 (25)	5 (25)	9 (45)	9 (45)	8 (42.1)	8 (42.1)
Unilateral canal paresis	5 (25)	3 (15)	6 (30)	0 (0)	7 (36.8)	0 (0)
Cochran's Q test	Implanted ear: $p = 0.01$			Non-implanted ear: $p = 0.37$		
Mc Nemar test	Pre versus post 1 month	Pre versus post 6 months	Post -1 month versus post 6 months	Not performed		
	$p = 0.1$	$p = 0.03$	$p = 1$			

any potential association between categorical variables. A one-way between-groups analysis of variance (ANOVA) was used to compare means. All p values were two tailed and statistical significance was considered for p values less than 0.05.

Results

Caloric tests

Preoperatively, caloric results were normal bilaterally in seven patients (35%). The remaining 13 patients (65%) demonstrated canal paresis on caloric testing: five bilaterally and eight unilaterally (five on the ear to be implanted and three on the contralateral ear).

One month postoperatively, the following results of caloric testing were found: (1) From the group of seven patients with normal preoperative caloric responses, no change in four of them was noticed, whereas the remaining three patients showed change from normal caloric response to canal paresis on the implanted ear. (2) Those five patients with preoperative bilateral canal paresis demonstrated no change on caloric responses. (3) All of the three patients with unilateral canal paresis on the non-implanted ear showed change from normal caloric response to canal paresis on the implanted ear, presenting thus bilateral canal paresis. (4) Finally, in the group of five patients with unilateral canal paresis on the ear to be implanted, three patients showed no change on caloric responses. One patient showed, surprisingly, change from normal caloric response to canal paresis on the non-implanted ear, presenting, thus, bilateral canal paresis. Finally, the last patient from this group demonstrated improvement of the vestibular function (change from canal paresis to normal caloric response) on the implanted ear. Therefore, 1 month after the operation, five patients (25%) had normal vestibular function, nine patients (45%) showed bilateral canal paresis, and the remaining six (30%) had canal paresis on the implanted ear.

Six months postoperatively, one patient with preoperative and post-one-month bilateral canal paresis was missed from follow-up in vestibular testing. All the other patients demonstrated no changes on caloric responses compared with previous evaluation, except from one. This patient had been found with unilateral canal paresis on the ear to be implanted preoperatively, which reversed to normal 1 month postoperatively. However, in the last 6-month postoperative evaluation, unilateral canal paresis on the implanted ear had recurred. Therefore, 6 months after the operation, four patients (21.1%) had normal vestibular function, eight patients (42.1%) showed bilateral canal paresis, and seven (36.8%) had canal paresis on the implanted ear. The percentages are also presented in Table 1.

The Cochran's Q test was performed to compare the percentages of recorded canal paresis among the three different time points (preoperatively, one month and six months postoperatively) in the implanted side and the non-implanted side too. In the implanted side a statistically significant difference was found ($p = 0.01$). The Mc Nemar test that followed revealed that the measurements which differed from the others were those made preoperatively (p pre vs. 1-month post-op = 0.1, p pre vs. 6-months post-op = 0.03, p 1-month vs. 6-months post-op = 1). For the non-implanted side Cochran's Q test revealed no statistically significant difference between time points ($p = 0.37$).

VEMPs

Preoperatively, VEMP testing revealed a presence of waveform bilaterally in ten patients (50%). The remaining ten patients (50%) showed absence of waveform: nine bilaterally and one unilaterally on the ear to be implanted.

Table 2 VEMP results preoperatively, 1 and 6 months postoperatively, and statistical comparisons across sessions

VEMPS	Patients *N* (%) Preoperatively		1 Month postoperatively		6 Months postoperatively	
Ear	Implanted	Non implanted	Implanted	Non implanted	Implanted	Non implanted
Bilateral presence	10 (50)	10 (50)	4 (20)	4 (20)	4 (21)	4 (21)
Unilateral presence	0 (0)	1 (5)	0 (0)	6 (30)	0 (0)	6 (31.6)
Bilateral absence	9 (45)	9 (45)	10 (50)	10 (50)	9 (47.4)	9 (47.4)
Unilateral absence	1 (5)	0 (0)	6 (30)	0 (0)	6 (31.6)	0 (0)
Cochran's Q test	Implanted ear: $p = 0.002$			Non-implanted ear: $p = 0.37$		
Mc Nemar test	Pre versus post 1 month $p = 0.03$	Pre versus post 6 months $p = 0.03$	Post 1 month versus post 6 months $p = 1$	Not performed		

One month postoperatively, the following results of VEMP testing were found: (1) From the group of ten patients with preoperative bilateral presence of waveform, no change in four of them was noticed, whereas the remaining six patients showed unilateral loss of waveform on the implanted ear. (2) The nine patients with preoperative bilateral absence of waveform demonstrated no change. (3) Finally, the patient with preoperative unilateral absence of waveform on the implanted ear showed loss of waveform on the non-implanted ear too, presenting thus bilateral absence of waveform. Therefore, 1 month after the operation, four patients (20%) had bilaterally present waveform, ten patients (50%) showed bilaterally absent waveform, and the remaining six (30%) had unilateral absence of waveform on the implanted ear.

Six months postoperatively, one patient with preoperative and post-one-month bilateral absence of waveform was missed from follow-up in vestibular testing. All the other patients demonstrated no change on VEMP testing compared with previous evaluation. Therefore, 6 months after the operation, four patients (21%) had bilaterally present waveform, nine patients (47.4%) showed bilaterally absent waveform, and six patients (31.6%) showed unilateral absent waveform on the implanted ear. Percentages are presented in Table 2.

The Cochran's Q test was performed to compare the percentages of waveform absence preoperatively, 1 and 6 months postoperatively in the implanted side and the non-implanted side too. In the implanted side a statistically significant difference was found ($p = 0.002$). The measurements which statistically differed from the others were those made preoperatively (Mc Nemar test: p pre vs. 1-month post-op = 0.03, p pre vs. 6-months post-op = 0.03, p 1-month vs. 6-months post-op = 1). For the non-implanted side Cochran's Q test revealed no statistically significant difference between time points ($p = 0.37$).

Vestibular symptoms

Preoperatively, seven patients (35%) experienced dizziness in various forms, such as lightheadedness, unsteadiness while walking, and vertigo. The remaining 13 (65%) did not complain of dizziness.

One month postoperatively, from the group of seven preoperatively dizzy patients, six were still complaining of dizziness of the same type, whereas one reported a relief from his vestibular symptoms. From the group of thirteen patients who were not dizzy preoperatively, nine still did not complain for postoperative dizziness, whereas the remaining four reported postoperative vestibular symptoms. These patients described their symptoms as mild to moderate episodes of spinning vertigo that lasted 1 day and started within 1 month after the implantation. Therefore, 1 month after the operation ten patients (50%) were dizzy and the remaining ten (50%) were not.

Six months postoperatively, one patient with preoperative and post-one-month dizziness was missed from follow-up. The remaining five patients who were dizzy preoperatively and 1 month after the operation, were still complaining for dizziness. The preoperatively dizzy patient, who reported relief of his symptoms 1 month after the operation, was still not dizzy. The nine patients, who did not complain of dizziness both before and 1 month after the operation, were still not complaining for vestibular symptoms. Finally, from the group of four preoperatively dizziness-free patients, who complained of postoperative vestibular symptoms 1 month after the operation, vestibular symptoms subsided within the next months in three of them, but one patient still complained of experiencing vertigo attacks. Therefore, 6 months after the operation six patients (31.6%) were dizzy and thirteen patients (68.4%) were not. The results are presented in Table 3.

Table 3 Vestibular symptoms in cochlear implant patients preoperatively and postoperatively and statistical comparison across sessions

Vestibular symptoms	Preoperatively	1 Month postoperatively	6 Months postoperatively
	N (%)	*N* (%)	*N* (%)
Absence	13 (65)	10 (50)	13 (68.4)
Presence	7 (35)	10 (50)	6 (31.6)
Cochran's Q test	$p = 0.17$		

Cochran's Q test was performed to compare the percentages of presence of vestibular symptoms between the three different time points of evaluation (before, one month and six months after cochlear implantation). No statistically significant difference was found ($p = 0.17$).

According to their postoperative symptoms the patients were classified into three different groups. (1) Group A: Patients who described no change in the presence or the quality of their dizziness after the operation, and consequently, their post-implantation dizziness was considered to be the continuation of their preoperative vestibular symptoms. (2) Group B: Patients without preoperative dizziness, who complained of postoperative vestibular symptoms. (3) Group C: Patients who did not complain of dizziness both before and after the operation. The patient with preoperative dizziness, who described a relief of his vestibular symptoms postoperatively, could not be classified under any of the groups described above.

In order to study the correlation between the appearance of postoperative vestibular symptoms and the side of implantation, patients' sex, preoperative caloric results (canal paresis in the implanted and/or non-implanted side), preoperative VEMP status (absence of waveform in the implanted and/or non-implanted side), recorded changes in caloric testing (implanted and/or non-implanted ear), and VEMP changes (implanted and/or non-implanted ear), a Chi-square test was performed between the three clinical groups (A,B,C). No statistically significant correlation was found ($p > 0.05$). A one-way between groups analysis of variance (ANOVA) was used to compare age averages in the three clinical groups (A,B,C), but no statistically significant difference was found either ($p > 0.05$).

Mean age, sex and implant side distribution and numbers of patients with abnormal preoperative caloric results, abnormal preoperative VEMP recordings, changes in caloric testing, and VEMP recordings 1 and 6 months postoperatively in the three clinical groups (A,B,C) are shown in Table 4.

Discussion

Our study showed that cochlear implantation can damage the function of the horizontal semicircular canal as well as the function of the saccule. This finding is in accordance with histopathological studies on temporal bones from patients who had been implanted during life [10, 11]. These studies demonstrated structural changes in the saccule, utricule, and semicircular canals. Although several authors [10, 15] stated that after cochlear implantation the saccule is the most frequent site of damage in the vestibular system, followed by the utricule and the semicircular canals, this is not supported by the present study. In our series, 60% of the implanted ears with normal preoperative caloric results showed canal paresis postoperatively and 60% of the implanted ears with preoperative VEMP presence showed a postoperative loss of VEMP waveform. Thus, the estimated risk of impairment was found to be equal for the saccule and the horizontal semicircular canal.

Several other authors have investigated the effects of cochlear implantation on the vestibular system, with variable results as already stated. These large differences between studies may be attributed to different numbers of investigated patients, types of implanted devices, surgical

Table 4 Comparison of the three clinical groups: patients' numbers, age, sex, implant side, and numbers of patients with abnormal preoperative caloric and VEMP results and changes in caloric results, and VEMP recordings

Group	A	B	C
N	6	4	9
Age (mean (SD); years)	56 (18.43)	31.75 (19.77)	47.67 (20.29)
Male *N* (%)	4 (66.7)	1 (25)	4 (44.4)
Female *N* (%)	2 (33.3)	3 (75)	5 (55.6)
Implanted in the right ear *N* (%)	4 (66.7)	2 (50)	4 (44.4)
Implanted in the left ear *N* (%)	2 (33.3)	2 (50)	5 (55.6)
Abnormal preoperative caloric results *N* (%)	5 (83.3)	3 (75)	4 (44.4)
Abnormal preoperative VEMP *N* (%)	3 (50)	2 (50)	4 (44.4)
Caloric changes (1 month postoperatively) *N* (%)	3 (50)	0 (0)	4 (44.4)
Caloric changes (6 months- postoperatively) *N* (%)	0 (0)	0 (0)	1 (11.1)
VEMP changes (1 month postoperatively) *N* (%)	2 (33.3)	0 (0)	5 (55.6)
VEMP changes (6 months- postoperatively) *N* (%)	0 (0)	0 (0)	0 (0)

techniques, and also different study design and variations of the sensitivity of the examination methods between laboratories.

We believe that the results in two of our patients should be specifically mentioned. One patient showed a change from normal caloric response to canal paresis on the non-implanted ear, and another patient demonstrated loss of the preoperatively present VEMP waveform on the non-implanted ear as well. Accordingly, it may be concluded that vestibular function may be postoperatively affected not only on the implanted side, but on the non-implanted too. It cannot be excluded that the insertion of an electrode in the scala tympani of an ear can influence the vestibular input to the brain and, secondarily, modify a complex vestibular response in the contralateral ear. It could also be hypothesized that this phenomenon is due to the fact that reproducibility of the results in a given individual over time is not perfect. However, according to several reports, caloric tests of the vestibular function have excellent reproducibility [24, 25]. With regard to the VEMP test, the overall VEMP response was found to have fair to good [26] or even good to excellent [27] test/retest reliability. Vibert et al. [28], who reported a similar finding, argued that areflexia in the contralateral ear may be related to the evolution of a bilateral progressive inner ear disease.

The improvement of the function (change from canal paresis to normal caloric response) of the horizontal semicircular canal on the implanted ear 1 month after the operation in one patient is another unexpected finding in our study. However, this improvement proved to be temporary, as normal function returned to preoperative status (canal paresis) 6 months after the operation. The mechanism underlying this phenomenon remains unclear. Ribári et al. [29] have also reported an improvement of the vestibular function on the implanted ear as it was recorded via bithermal caloric test and hypothesized that this might be due to the effect of chronic electrical stimulation on the labyrinth. Although this hypothesis seems to be plausible, it cannot explain the transient nature of the improvement that was observed in our patient. We may hypothesize that, in our patient initial improvement can be attributed to temporary readjustment of the vestibular system.

Although recorded changes on bithermal caloric and VEMP test were found to be permanent, in our series vestibular symptoms in the majority of postoperatively dizzy patients (three out of four) were transient. This, as well as the fact that no correlation was found between the appearance of postoperative vestibular symptoms and recorded changes in caloric results (implanted and/or non-implanted ear) or VEMP changes (implanted and/or non-implanted ear), may be due to central vestibular compensatory mechanisms that suppress peripheral vestibular dysfunction, as it has been proposed by other authors in the past [12, 15–17, 19].

In our study no correlation was found between the appearance of postoperative vertigo and patients' age, sex, side of implantation, preoperative caloric results, and preoperative VEMP status. Additionally, it should be mentioned that there was no correlation between temporary or persistent vestibular symptoms and level of difficulty in device fitting or adaptation to newly transduced auditory information. Other groups have investigated the influence of some of these factors in the occurrence of balance problems. Enticott et al. [14] found that age and preoperative caloric results could not predict postoperative vestibular symptoms. Fina et al. [7] found that preoperative caloric findings, ear of implantation, and gender did not seem to be predictive of postimplantation vestibular symptoms, but according to their study older subjects have a greater chance of dizziness. Krause et al. [15] stated that the characteristics of sex and implant side were not predictive, but advanced age is a risk factor for the development of postoperative vertigo. The influence of cochlear implantation on saccular function has been already studied in the past [13, 15, 20–22], but the preoperative VEMP status as a predictive factor for postoperative dizziness had never been investigated before. Although we found no correlation, this might be due to the limited number of our patients and it could be an issue for further study.

In the majority of the postoperatively dizzy patients, vestibular symptoms were temporary in our study. This finding is in accordance with Kubo et al. [8], who in a series of 94 adult cochlear implant patients, found postoperative dizziness to have occurred soon after surgery and subsided within 1 month in the majority (63%) of postoperatively dizzy patients. Dizziness lasting more than 6 months was a complaint in only two of their patients. Several authors have reported benign paroxysmal positional vertigo after cochlear implantation in their studies, with incidences varying from 2.2 [30] to 10% [31]. Krause et al. [3] also reported paroxysmal vertigo with duration of seconds to minutes in the majority of their patients. In our study no case of benign paroxysmal positional vertigo was found, which may be attributed to the transient nature of this benign clinical entity.

Several authors have attempted to identify the mechanism by which cochlear implantation can impair the vestibular function. Direct trauma from insertion caused by the electrode [5], acute serous labyrinthitis due to cochleostomy [7], foreign body reaction with labyrinthitis [8], and endolymphatic hydrops [7] have been proposed as plausible mechanisms of this impairment. Intraoperative perilymph loss [6] and electrical vestibular stimulation by the implant [9] have also been proposed. In our study only four patients were dizzy postoperatively. Their symptoms started within 1 month, but not immediately postoperatively, so they cannot be due to direct trauma, acute serum labyrinthitis due to cochleostomy, or intraoperative perilymph loss. Moreover, the fact that the onset of symptoms appeared to be irrespective of the activation argues against an electrical stimulation. However, serous labyrinthitis due to foreign body reaction and endolymphatic hydrops could explain our findings.

Although cochlear implantation leads to measurable changes of the peripheral vestibular function, permanent vertigo is rare. Most of the patients were only transiently affected in their everyday life. The factors investigated in this study were not found to be predictive of the occurrence of postoperative dizziness and further investigation is needed. In any case cochlear implanted candidates should be informed for the possibility of postoperative vestibular symptoms.

Conflict of interest The authors declare that they have no conflict of interest.

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