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OTOLOGY

Dizziness and vestibular function before and after cochlear implantation

Yoon Chan Rah[1,2] · Joo Hyun Park[1] · Jae Hong Park[1] · Byung Yoon Choi[1] · Ja-Won Koo[1]

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Abstract Vestibular problems after cochlear implantation (CI) were explored by categorizing them according to clinical course and changes in objective vestibular function. The changes in vestibular function of 62 patients (66 ears) were analyzed and vestibular symptoms were divided into three categories by their time course and nature. Etiologies were determined by analyzing the symptoms in combination with changes in objective vestibular function, measured using the caloric and/or video head impulse test. Before surgery, vestibular function was normal in 31 cases (47.0 %), unilaterally hypofunctional in 14 (21.2 %), and bilaterally hypofunctional in 21 (31.8 %). Eight cases (12.1 %) reported dizziness before surgery. A total of 18 cases (27.3 %) experienced postoperative dizziness. Ten patients experienced immediate transient dizziness (including 2 cases of benign positional paroxysmal vertigo); four experienced immediate prolonged dizziness (including 3 cases of bilateral vestibular hypofunction); and four experienced recurrent episodic dizziness (including 3 cases of suspicious endolymphatic hydrops). The sums of the maximal slow-phase velocities (SPVs) of the implanted ears were changed from 22.70 ± 17.31 to 12.55 ± 12.02°/s after implantation ($p = 0.004$) with very little changes in the other side (32.65 ± 24.85–31.40 ± 29.10°/s). Careful review of vestibular status is an important step, especially when deciding implantation in the only vestibular functioning ear or bilateral implantation.

Keywords Cochlear implantation · Dizziness · Vestibular function

✉ Ja-Won Koo
jwkoo99@snu.ac.kr

[1] Department of Otorhinolaryngology-Head and Neck Surgery, Seoul National University College of Medicine, Seoul National University Bundang Hospital, 166, Gumi-ro, Bundang-gu, Seongnam, Gyeonggi 463-707, Republic of Korea

[2] Korea University College of Medicine, Korea University Ansan Hospital, Ansan, Republic of Korea

Introduction

Over the past 30 years, cochlear implantation (CI) has become the standard hearing rehabilitation procedure for patients with profound hearing loss. Although the procedure is considered to be safe, damage to vestibular function remains possible [1–3]. CI was originally developed to restore hearing, but it is reasonable to consider the effects of CI on vestibular function because the auditory and vestibular systems are closely associated and share the same mechanism of neural transmission. Some studies have found that electrode insertion may potentially affect vestibular end-organs [4, 5]. Postmortem histopathological studies of the temporal bones of CI recipients have reported significant structural changes in end-organs including the saccule, the utricle, and the semicircular canals [6, 7]. Intraoperative loss of perilymph, endolymphatic hydrops caused by disruption of endolymphatic flow, and/or labyrinthitis induced by a foreign body reaction may all be associated with vestibular deterioration [8–10]. Whether electrical stimulation may affect the vestibular system remains controversial. Most studies have described vestibular deterioration after implantation [11–14]. However, a recent study reported that balance became stabilized upon static condition of dynamic posturography performed after implantation [15]. The estimated incidence of vestibular deterioration varies widely, from 39 to 74 % [15–18]. The incidence of impaired vestibular function of

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the horizontal semicircular canal may be as high as 93 % [1, 4, 11, 16, 19–23]. The indications for CI are becoming increasingly broad and currently bilateral implantations became popular [24, 25]. Because bilateral vestibular hypofunction generally causes significant disability, it is important to study the possible post-CI changes in vestibular function as well as their etiologies.

In this study, we reviewed the prevalence and etiologies of vestibular symptoms, and assessed their possible correlations with functional changes of horizontal canal. We also investigated the status of the vestibular function before and after CI using objective measurements of horizontal canal function.

Patients and methods

Patients

Among 176 patients who underwent CI (March 2006 to April 2013) at Seoul National University Bundang Hospital, 62 (including 4 who underwent bilateral implantation) had undergone preoperative evaluation of horizontal canal function, and were included in the present study. The age range was 7–80 years (median 46.0 years), and 36 patients were male. Patients with inner ear anomalies determined on temporal bone CT and MRI were excluded. Causes of hearing loss were as follows: idiopathic (52 cases, 83.8 %), post-meningitic (6 cases, 9.7 %), post-traumatic (3 cases, 4.8 %), chronic otitis media (1 case, 1.7 %). There was no patient who possibly had organic disorders that causes dizziness or imbalance including central nervous system disease or orthopedic disorders. All patients had severe hearing loss (>70 dB) before the cochlear implantation. Among them, 43 cases (65.1 %) had profound hearing loss (>90 dB). The study was approved by the Seoul National University Bundang Hospital Institutional Review Board (IRB Number B-0708-048-010).

Data acquisition and analysis

We comprehensively reviewed clinical data on subjective dizziness, exam under video Frenzel goggles, laboratory vestibular function test results, imaging data, and all surgical details. Postoperative dizziness was categorized by time course and nature, as immediate and transient (less than 1 month to complete remission), immediate and prolonged (longer than 1 month to complete remission), or recurrently episodic dizziness [10]. Vestibular function was evaluated primarily using the bithermal caloric test, run both prior to implantation and about 1 year after implantation. Vestibular status was assessed using the rotary chair and video head impulse tests (GN Otometrics, Taastrup, Denmark) in patients who could not take the bithermal caloric test because of inappropriate middle ear status. Postoperative dizziness was explored by analyzing vestibular symptoms and the results of vestibular function tests. However, laboratory vestibular function tests could not be conducted in early postoperative period. Instead, exams under Frenzel goggles were performed during early postoperative period and followup visit. When paralytic nystagmus (spontaneous nystagmus, post head shaking nystagmus) was observed under video Frenzel goggles and was resolved within 1 month, those were categorized as "Transient vestibular paresis". Imaging studies were principally reviewed to determine whether inner ear anomalies were evident. A detailed review of surgical records yielded information on the surgical approaches taken and findings during surgery. The sums of the maximal slow-phase velocities (SPVs) yielded by the bithermal caloric test were calculated when each ear was subjected to warm and cool irrigation; data obtained before and after implantation were compared. The comparison was carried out separately for implanted ($n = 20$) and non-implanted ($n = 20$) ears and cases with preoperatively normal vestibular function on implanted side ($n = 10$) were also separately analyzed. Statistical analyses were performed using Wilcoxon's signed-rank test with SPSS software version 21 (IBM, New York, USA). In all analyses, a value of $p < 0.05$ was taken to indicate statistical significance.

Results

Preoperative vestibular status

Preoperative caloric tests revealed normal vestibular function in 31 cases (47.0 %) and unilateral hypofunction in 14 (21.2 %) (nine cases were implanted on the ear with vestibular hypofunction, while five cases were implanted on the ear with normal vestibular function). Bilateral hypofunction was evident in 21 cases (31.8 %). Eight patients (12.1 %) reported dizziness prior to surgery (Table 1).

Postoperative dizziness and vestibular function

Of the 31 cases who had normal preoperative vestibular function, two suffered from dizziness prior to implantation. Both developed postoperative dizziness accompanied by vestibular deterioration. A total of ten cases developed dizziness after implantation. Seven experienced immediate transient dizziness (with deterioration of vestibular function in four), two had recurrent episodic vertigo (with deterioration of vestibular function in one), and one had

Table 1 Preoperative status and postoperative changes in vestibular function and subjective dizziness

Preop VFT	Cases	Preop Dizz	Postop VFT	Cases	Postop Dizz	Category[a]	Cases
Normal	31	2	Normal	26	5	Immediate, transient	3
						Immediate, prolonged	1
						Recurrent episodic	1
			Ipsilat hypo	5	5	Immediate, transient	4
						Recurrent episodic	1
Ipsilat hypo	9	2	Ipsilat hypo	8	–	–	–
			Bilat hypo	1	1	Recurrent episodic	1
Contra hypo	5	1	Contra hypo	4	2	Immediate, transient	2
			Bilat hypo	1	1	Recurrent episodic	1
Bilat hypo	21	3	Bilat hypo	21	4	Immediate, transient	1
						Immediate, prolonged	3

Preop preoperative, *Postop* postoperative, *VFT* vestibular function test, *Dizz* dizziness, *Ipsilat* ipsilateral, *Contra* contralateral, *Bilat* bilateral

[a] Classification of postoperative dizziness by onset and nature

immediate prolonged dizziness without vestibular deterioration.

Of the nine cases with vestibular hypofunction on the side of implantation, two suffered from dizziness prior to implantation. One of those with preoperative dizziness experienced recurrent episodic dizziness after implantation with vestibular deterioration on the other side, and ultimately developed bilateral vestibular hypofunction. No other patient of this group experienced postoperative dizziness or vestibular deterioration.

Of the five cases with vestibular hypofunction on the side that was not implanted, one had dizziness prior to implantation. The same patient developed dizziness after implantation with vestibular deterioration on implanted side resulting in bilateral hypofunction. Two patients who did not complain preoperative dizziness experienced immediate transient dizziness without vestibular deterioration.

Of the 21 cases with bilateral hypofunction, three suffered from dizziness prior to implantation. All with preoperative dizziness experienced immediate prolonged dizziness postoperatively and one patient without preoperative dizziness had immediate transient dizziness after implantation. The onsets and natures of all dizziness are summarized in Table 1.

Vestibular diagnosis of postoperative dizziness

Of ten cases who experienced immediate transient dizziness, eight developed transient vestibular paresis after implantation. The remaining two patients experienced benign paroxysmal positional vertigo (BPPV) postoperatively. Both developed BPPV on the non-implanted side; one had posterior semicircular canal BPPV and the other had horizontal semicircular canal BPPV.

Three of the four cases who experienced recurrent episodic dizziness after implantation were diagnosed with endolymphatic hydrops (two cases on the side of implantation and one on the other side); all showed deterioration of vestibular function after surgery. The remaining case was diagnosed with vestibular migraine without deterioration of vestibular function.

Of the four cases who experienced immediate prolonged dizziness, three cases showed bilateral vestibular hypofunction before surgery. In these patients, additional deterioration of vestibular function on the surgical side might worsen subjective dizziness, and vestibular compensation might be protracted due to limited functional reservoir. The cause of dizziness in the remaining one patient could not be determined since the vestibular function was normal before and after surgery and the patient's complaint did not meet the diagnostic criteria of any other causes of dizziness. The etiologies of postoperative dizziness are summarized in Table 2.

Caloric responses before and after CI

The implanted ear showed a significant decrease in SPV (22.70 ± 17.31–12.55 ± 12.02°/s, $p = 0.004$; Fig. 1) after implantation whereas the other ear exhibited almost no change (32.65 ± 24.85–31.40 ± 29.10°/s, $p = 0.705$; Fig. 1) regardless of preoperative status. Patients with normal preoperative caloric response also showed a significant decrease in SPV after implantation in the implanted ear (36.67 ± 10.46–20.11 ± 13.34°/s, $p = 0.014$;

Table 2 Etiologies of postoperative dizziness

Category[a]		Etiology	
	Cases		Cases
Immediate, transient	10	Transient vestibular paresis	8
		BPPV[b]	2
Recurrent episodic	4	Endolymphatic hydrops[c]	3
		Vestibular migraine	1
Immediate, prolonged	4	Bilateral hypofunction	3
		Unknown etiology	1

BPPV benign paroxysmal positional vertigo

[a] Classification of postoperative dizziness by onset and nature

[b] All in the non-implanted side

[c] Two in the implanted side and one in the non-implanted side

Fig. 1) whereas the other ear exhibited almost no change (38.22 ± 19.61–40.89 ± 30.64°/s, $p = 0.636$; Fig. 1).

Surgical approach

The conventional cochleostomy approach was carried out in 57 cases (78.7 %) and round window approach was carried out in nine cases (13.6 %). In conventional cochleostomy approach group, 12 cases (21.0 %) newly developed dizziness and six cases (9.0 %) experienced additional deterioration in the lateral canal function after implantation. In round window approach group, none newly developed dizziness nor experienced additional deterioration in the lateral canal function after implantation. With these data, the round window approach group seems to be better in terms of postoperative dizziness after implantation. However, two-tailed p value by Fisher's exact test could not reveal statistical significance due to the small number of the round window approach group.

Discussion

A total of 18 cases (27.3 %) experienced post-operative dizziness and 11 (16.7 %) newly developed dizziness after implantation. Six patients (9.1 %) experienced newly aggravated vestibular function after implantation. Previously, the side for implantation has mainly been chosen by reference to audiological considerations such as the extent and duration of hearing loss or anatomical variation. We found that considerable numbers of patients experienced dizziness and vestibular deterioration after implantation, suggesting that vestibular function should be considered when choosing the side of implantation, especially when the traditional criteria do not indicate any marked preference. Since bilateral vestibular hypofunction causes prolonged balance impairment, preservation of vestibular function is particularly important for cases with planned bilateral implantation.

Evaluation of the etiology of dizziness that develops after implantation is important in terms of both prevention

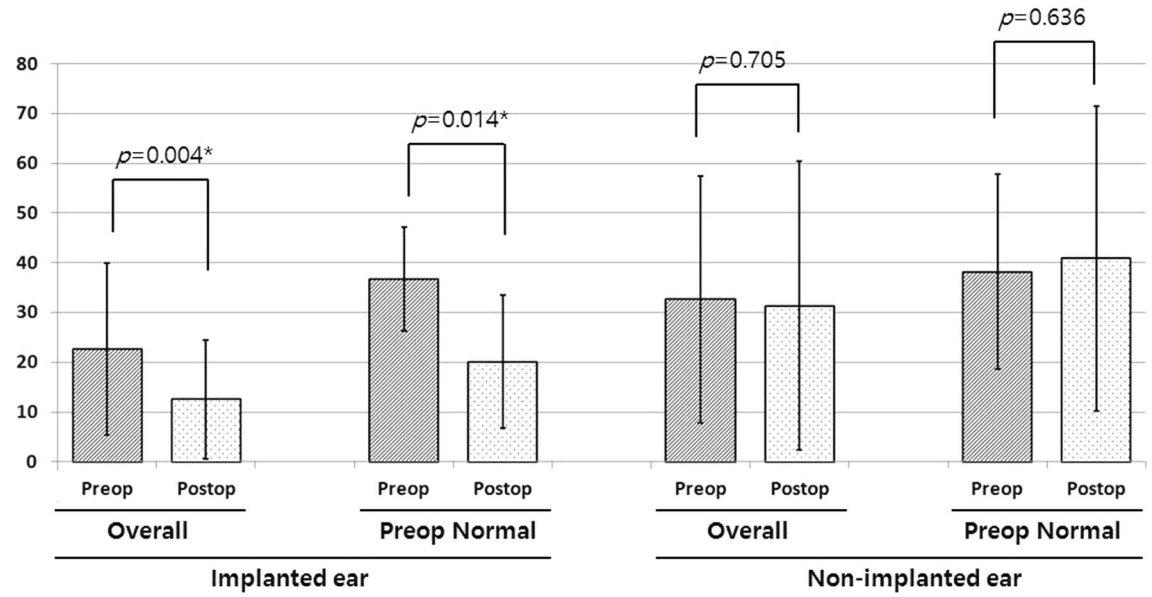

Fig. 1 Changes in the sums of the slow-phase velocities (SPVs) of the caloric test after implantation. Significant decreases were evident upon warm and cool irrigations of implanted ears ($n = 20$, $p = 0.004$), and implanted ears with normal preoperative horizontal canal function ($p = 0.014$). In contrast, the SPVs of non-implanted ears did not show significant changes for all cases ($p = 0.705$) or cases with normal preoperative horizontal canal function ($p = 0.636$). *Preop* preoperative, *Postop* postoperative

and treatment. The most frequent cause of postoperative dizziness was transient vestibular paresis (eight cases, 44.4 %); the patients recovered rapidly with complete disappearance of symptoms. BPPV also caused immediate transient dizziness after implantation and it should be always considered as one of the possible diagnosis because BPPV can be treated using relatively simple repositioning maneuvers. Two cases (11.1 %) of BPPV were confirmed. Interestingly, both developed BPPV on the non-implanted side. This phenomenon was also reported and explained in the recent report on BPPV development after surgical drilling of the temporal bone [26]. The authors speculated that surgical drilling may dislodge otoconia from both utricles, but particles dislodged in the contralateral ear are more likely to move into the gravity-dependent semicircular canals during surgery. Furthermore, predominant contralateral ear-down head position after surgery due to compressive mastoid bandage also facilitates the migration of otolith particles into the gravity-dependent semicircular canals in the contralateral ear. The development of endolymphatic hydrops after CI was reported in several previous reports [6, 7, 9], and our cohort also included three cases that showed clinical characteristics of Meniere's disease. Recurrent episodic attacks of vertigo with tinnitus developed at an average of 3 months after implantation. Subjective hearing fluctuation was reported but this was difficult to measure because hearing was already impaired. Two patients developed vestibular hypofunction in the side of implantation although they did not experience dizziness preoperatively, and the other one patient developed vestibular hypofunction in the other side although the patient presented episodic vertigo (1–2 times/year for 8 years) preoperatively with ipsilateral vestibular hypofunction. In this patient, severe recurrent vertigo reappeared at 6 months after CI and delayed endolymphatic hydrops of the other side was considered as the cause of recurrent dizziness [27]. Handzel et al. suggested three possible mechanisms by which endolymphatic hydrops could develop after CI [6]. First, obstruction of endolymphatic flow at the ductus reuniens might trigger hydrops of the cochlea and collapse of the saccule because the cochleostomy tract is usually located anterior and inferior to the ductus reuniens. Second, obstruction of the cochlear duct is possible, because this duct in the hook region lies close to the cochleostomy site. Last, damage to the lateral cochlear wall may cause endolymphatic hydrops although both the ductus reuniens and cochlear duct remain patent.

In the present study, one patient with preoperative ipsilateral vestibular hypofunction and newly developed vestibular deterioration on the other side (caused by endolymphatic hydrops) ultimately developed bilateral hypofunction with recurrent vertigo. Another case with preoperative contralateral vestibular hypofunction and newly developed vestibular deterioration on the implanted side developed borderline bilateral hypofunction (the sum of the SPVs of four irrigations was 15°/s on the postoperative caloric test). Such poor outcomes emphasize the need to consider vestibular function when deciding the side of CI, especially in patients with unilateral vestibular hypofunction.

Many reports have shown that peak slow-phase velocity (SPV) of caloric test is significantly decreased after CI [21, 23, 28] as in our series. Recent meta-analysis reported that 37 % of patients demonstrated reduced peak SPVs [29]. However, in some reports, deterioration of vestibular function was less than 10 % of cases [19, 30–32].

Postoperative caloric test was preserved in patients who received electric acoustic stimulation (EAS) CI [30]. A soft surgery with round window electrode insertion prevented the deterioration of residual inner ear function [22, 30]. We also investigated the functional outcomes in our cases according to surgical approaches of electrode insertion and found similar result though statistical significance could not be achieved. There is also a contrary report that surgical approaches did not influence on the postural control and caloric test results since vestibular function after CI remained normal in the majority of CI patients [32].

The changes of vestibular function were primarily evidenced by changes in SPV of caloric test because the test is still highly sensitive and the data correlate reliably with clinical symptoms despite limitations in investigating frequency range [25, 33]. Vestibular deterioration developed not only in patients who were preoperatively normal but also in those with preoperative hypofunction. Residual vestibular function is important in terms of postural control in patients with vestibular neuritis [34]. Thus, preservation of residual vestibular function even in patients with preoperative vestibular hypofunction is important to minimize balancing problems after implantation.

The caloric response measured by maximal SPV was significantly decreased in the operated ear after CI. Potential causes of this attenuation after surgery can be speculated as follows: (1) progressive postoperative change in the inner ear due to fibrosis, which might impede the endolymphatic flow in the semicircular canal [35], (2) immediate damage by surgical trauma, which might affect the vestibular system [36], and (3) decreased thermal transmission in caloric test due to alterations in anatomical structures [37–39]. Especially, the averaged four-irrigation maximal SPV was reported to decrease by 6.3–28.9 % after posterior tympanotomy, which need to be considered in the interpretation of our data although far more decrease (44.7 %) was found at the same condition in our cases [35].

Conclusion

Dizziness newly developed in 16.7 % of patients and vestibular function newly deteriorated in 9.1 % of cases after CI. Careful review of vestibular status when choosing the side of implantation, and use of a minimally traumatic approach, are important, especially for patients with pre-operative vestibular hypofunction or for whom bilateral CI is planned.

Compliance with ethical standards

Funding The authors have no funding or financial relationship to disclose.

Conflict of interest The authors have no conflict of interest to disclose.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent The present study was exempted from the informed consent according to the protocols of the IRB committee.

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