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How does cochlear implantation affect five vestibular end-organ functions and dizziness?

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ABSTRACT

Objective: To evaluate all five vestibular end-organ functions (lateral, anterior, posterior semicircular canal, utricule, and saccule) and to investigate the relationship between Dizziness Handicap Inventory (DHI) and vestibular functions prior to CI (cochlear implantation) and at postoperative day 3 and month 3.

Methods: A total of 42 patients (age 16–70 years) with normal vestibular functions preoperatively and undergoing unilateral CI were included in this prospective descriptive study. Video head impulse test (vHIT) for three semicircular canal (SSC) functions, ocular vestibular-evoked myogenic potential (oVEMP) for utricule function, cervical vestibular-evoked myogenic potential (cVEMP) for saccule function and DHI for subjective vertigo symptoms were performed prior to CI and at postoperative day 3 and month 3.

Results: There was a significant impairment of vestibular function in 12 patients (28.5%) on the implantation side and significant DHI increase was observed in 13 of 42 (30.9%) patients at postoperative day 3 after CI ($p < 0.05$). We found SSC dysfunction in 7 patients (16,6%) who underwent observation with vHIT, saccule dysfunction in 8 patients (19%) with cVEMP and utricule dysfunction in 5 patients (11.9%) with oVEMP on the operated side 3 days after surgery ($p < 0.05$). Posterior SSC functions (5 patients) were more affected than lateral SSC functions (3 patients). At postoperative month 3, six patients (14.2%) still had deteriorating results in the objective tests and significant DHI increase was continued in 4 (9.5%) patients ($p < 0.05$). The deterioration in vHIT continued in only 1 (2.3%) patient ($p > 0.05$). The deterioration in cVEMP continued in 5 (11.9%) patients ($p < 0.05$). The deterioration in oVEMP continued in 2 (4.7%) patients ($p > 0.05$). There was a significant correlation between DHI and objective vestibular tests both in the early and late postoperative period ($r = 0.795$; $p < 0.05$).

Conclusion: Our study showed that both canal and otolith functions can be damaged after CI especially in the early postoperative period. Surprisingly, posterior SSC functions were more affected than lateral SSC. Therefore, a gold standard vestibular test battery that can evaluate each of three SSC canals and two otoliths functions is essential. Since a single vestibular test for this purpose is not available, we recommend the use of the three available vestibular tests together. This test battery, which is capable of evaluating five vestibular end-organ functions in preoperative and postoperative vestibular evaluations, can provide more accurate results not only for CI but also for most otologic surgeries.

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1. Introduction

Cochlear implantation (CI) is the gold standard therapy for total or severe sensorineural hearing loss. CI is a safe surgical procedure, but because of the proximity of the cochlea and vestibule, postoperative vestibular disorder may occur. We know that the effects of cochlear implant on vestibular receptors have been shown in many studies before [1–4]. Also morphological differences have been seen in saccule, utricule and horizontal semicircular canal receptors in postmortem histopathological studies [5,6]. The main reason for vestibular receptor dysfunction is still unknown; possible reasons may be trauma caused by the insertion of the electrode, intraoperative perilymphatic loss, labyrinthitis caused by foreign body reaction, endolymphatic hydrops or postoperative perilymph fistula [7–11].

After understanding the improvements in speech perception in noisy environments, better sound localization and better social communication offered by bilateral cochlear implantation, the indications for CI are increasing [12,13]. However, bilateral vestibular disorder resulting from bilateral CI is a serious complication and makes preoperative vestibular evaluation tests essential.

Post-CI vestibular function can be evaluated with objective methods such as cervical vestibular-evoked myogenic potential (cVEMP), ocular vestibular-evoked myogenic potential (oVEMP), caloric test, electronystagmography, videonystagmography, scleral coil head impulse test, video head impulse test (vHIT), post-headshake nystagmus (HSN), dynamic visual acuity, and posturographic tests [2,3,14,15]. The Dizziness Handicap Inventory (DHI) can also be used to evaluate subjective vertigo symptoms before and after CI [2,14,16].

In the research conducted on vestibular function evaluation of patients with CI to date, vertical canal functions evaluation has not been widely conducted; instead, a caloric test and cVEMP have been typically used to evaluate lateral canal functions and saccule functions [1,3,17,18]. In fact, one of the main reasons was that the search coil technique, which has been considered to be the gold standard for all three semicircular canal (SSC) HIT objective evaluations, was difficult and invasive. However, with the introduction of vHIT into common practice, the objective evaluation of horizontal and vertical canals has become easy, quick and non-invasive [19]. vHIT is a fast, practical, noninvasive and common vestibular test used to evaluate all three semicircular canals [19]. Gain is calculated by the ratio of head velocity to eye velocity. Low gain suggests canal dysfunction. Overt saccades are seen after head movement, and covert saccades are seen before the end of head movement. Covert saccades are hard to observe with the naked eye. Saccades are also pathological findings, even if the gain is normal [20,21]. Gain values and covert and overt saccades can be recorded with vHIT [22].

We aimed in this study to explore objective changes in all five vestibular end-organ functions and to evaluate the relationship between objective vestibular test results and subjective DHI before and after CI.

2. Materials and methods

This descriptive study was performed in Cukurova University Hospital, Department of Otorhinolaryngology. Forty-two of 264 patients with bilateral profound to severe sensorineural hearing loss, who do not benefit from conventional hearing aids and who underwent unilateral cochlear implantation between January 2015 and October 2017, were included in our study. Two hundred twenty-two patients were not included in the study because they did not comply with the criteria. The study was approved by the local ethics committee.

All patients were operated on by three senior surgeons. Med-EL and Nucleus brand implants were used. We use “Med-EL syncrony ST + Medium electrode” (MED-EL GmbH, Innsbruck, Austria) and “Nucleus CI422 with Slim Straight electrode” (Cochlear Ltd., Sydney, Australia). The main surgical method was electrode insertion through the round window. A promontorium cochleostomy was performed when the round window was difficult to identify. These patients were not included in the study. All patients were operated with minimal invasive technique. During the drilling of the round window, drill rate was reduced to 5000 rate per minute. Incision was performed gently on round window and care was taken to avoid aspirating the perilymphatic fluid. Electrode was moved very slowly and delicately through scala tympani at once, without any resistance and with an insertion time of at least 120 s. We use local and systemic corticosteroid for all the patients. Auditory nerve response telemetry and neural response telemetry was obtained in all patients.

We performed vHIT for anterior, lateral, and posterior semicircular canal functions, oVEMP for utricle function, cVEMP for saccule function and DHI for subjective vertigo symptoms before the cochlear implantation and at postoperative day 3 and month 3. Both operated and contralateral ears were evaluated with vestibular tests.

Exclusion criteria were abnormal results in preoperative vHIT, cVEMP, and oVEMP, preoperative vertigo symptoms, abnormal otoscopic findings (stenosis, adhesive membrane etc.), less than 16 years of age, and former surgical history in the implanted ear.

2.1. vHIT evaluation

The video head impulse test (vHIT) was performed for the vestibulo-ocular reflex. The ICS impulse^R video HIT system (GN Otometrics, Denmark) was used. vHIT has specially designed, very light (60 g) glasses and a computer software program that analyzes the data recorded with these glasses. The glasses have a gyrometer to measure head movement velocity, a camera to measure eye movement velocity and a half-silvered mirror to reflect right eye movement to the camera. Before starting the test, the patient wore the glasses, and calibration was performed. The patient stared at a cursor 100 cm away. The clinician performed fast and unexpected head movements on the patient of 10–20° in order to evaluate the semicircular canal function. Twenty impulses were performed for each semicircular canal, and the average gain value was calculated. Overt and covert saccades were also recorded. Normal values of gain were accepted as 0.8 for the horizontal canal and 0.7 for the vertical canal. Gain results below these values and overt saccades and covert saccades were accepted as pathological.

2.2. cVEMP evaluation

GSI Audera Standard auditory brainstem response (ABR) equipment (Grason-Stadler, USA) was used for cVEMP measurements. The test was performed with air-conduction short tone bursts in a quiet room while the patient was sitting. The patient's head was turned 45° contralateral to the stimulated ear, while the sternocleidomastoid (SCM) muscle was stimulated with regular tonic activity. The electromyographic (EMG) responses of the SCM muscle were recorded ipsilaterally via the surface electrode. The active electrode was placed over the middle of the SCM, the reference electrode was placed over the sternoclavicular joint and the ground electrode was placed in the middle of the forehead. The resulting impedance of the recording electrodes was below 5 kΩ. The acoustic stimulus (95 dB nHL and 500 Hz; rate = 5.1/s; rise and fall time = 2 ms; and plateau = 1 ms, duration = 5 ms) was delivered through an earphone. The analysis time was 120 ms, and the EMG signal was band-pass filtered from 10 Hz to 750 Hz. Every set of 100 stimuli was averaged and repeated twice to verify the reproducibility of the response. If a recognizable or reproducible waveform was seen, cVEMP response is accepted as positive, if not, it was considered to be negative.

2.3. oVEMP evaluation

GSI Audera Standard auditory brainstem response (ABR) equipment was used for oVEMP measurements. The test was performed with air-conduction short tone bursts in a quiet room while the patient was sitting. The EMG was recorded from the contralateral eye with a surface electrode. During the test, the patient was asked to look up at a 30-° angle. The active electrode was placed on the skin 1 cm below the center of the lower eyelid, and the reference electrode was placed on the skin 1 cm below of the active electrode. The ground electrode was placed in the middle of the forehead. The resulting impedance of the recording electrodes was below 5 kΩ. The acoustic stimulus (95 dB nHL and 500 Hz; rate = 5.1/s; rise and fall time = 2 ms; and plateau = 1 ms, duration = 5 ms) delivered through an earphone. The analysis time was 100 ms, and the electromyographic (EMG) signal was band-pass filtered from 10 to 750 Hz. Every set of 100 stimuli was averaged and repeated twice to verify the reproducibility of the response. If a recognizable or reproducible waveform was seen, oVEMP response is accepted as positive, if not, it was considered to be negative.

vHIT, cVEMP and oVEMP were performed while the cochlear implant was turned off for standardization.

The presence of an abnormal result (vHIT, cVEMP, oVEMP) in at least one of the vestibular tests was considered as vestibular dysfunction.

2.4. Vertigo evaluation

A Turkish version of the DHI questionnaire was proven in previous studies to be a statistically reliable and sensitive method to evaluate vertigo. The Turkish version of DHI was developed by the "translation-reverse translation" method. The Cronbach alpha for DHI total was 0.92 [23].

All patients were asked to respond to the DHI questionnaire. The test consisted of 7 physical, 9 emotional and 9 functional questions, for a total of 25 questions. The maximum score is 100 [24]. The questionnaire and its aim were carefully explained to patients. Patients gave their answers as "always", "sometimes" and "no"; the points for these answers are 4, 2, and 0, respectively. The minimum score is 0. A change in total DHI score above 6 is accepted as meaningful [25].

2.5. Data analysis

The data were analyzed with SPSS 20.0. The descriptive data of the study were evaluated by number, mean, standard deviation and percentage. Since the assumptions of the parametric tests were not provided, non-parametric Friedman test was used to compare more than two dependent groups. The Friedman test is used if the same study sample is measured in more than two different cases or in more than two different conditions. Therefore, Friedman test was used to compare each vestibular test (vHIT, cVEMP, oVEMP) before the cochlear implantation and at postoperative day 3, and also before the cochlear implantation and at postoperative month 3. For Post-Hoc tests (bonferroni correction), non-parametric Wilcoxon signed rank test were used to determine from which groups the difference originated and the p values obtained by the Wilcoxon signed rank test were multiplied by three. Spearman correlation analysis was used when the significance of the relationships (between vestibular disfunction and significant DHI increase) was tested. A p value of 0.05 or less was considered to be significant in all tests.

3. Results

The mean age of the 42 patients was 34.7 ± 16.7 years; the age range was 16–70 years. Twenty-six of the patients (61.9%) were female, and 16 (38.1%) were male. The causes of deafness are unknown in 18 (43%), patients, meningitis in 7 (17%), genetic in 6 (14%), sudden hearing loss in 6 (14%), traumatic in 5 (12%). The surgery was performed in the right ear in 27 patients and in the left ear in 15.

3.1. Early postoperative period (at postoperative day 3) objective and subjective evaluation results

Early postoperative period evaluation revealed a significant change on at least one of the objective vestibular function tests (vHIT, cVEMP, oVEMP) in 12 of 42 patients (28.5%) ($p < 0.05$). There was no change in the non-operated ears of these patients. We found vestibular deterioration in 7 patients (16,6%) who underwent observation with vHIT, 8 patients (19%) with cVEMP and 5 patients (11.9%) with oVEMP on the operated side at postoperative day 3 ($p < 0.05$) (Fig. 1).

In total, 5 patients (11.9%) had posterior semicircular canal (PSC) and 3 patients (7.1%) had lateral semicircular canal (LSC) function loss ($p < 0.05$). Three patients had gain loss in the PSC, 2 patients had covert saccade in the PSC, 2 patients had

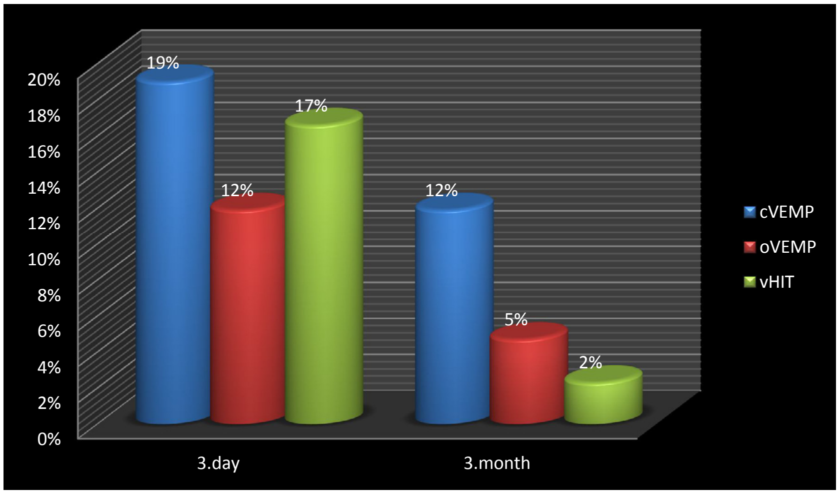

Fig. 1. Deterioration rates in vestibular tests at postoperative day 3 and month 3.

gain loss in the LSC and 1 patient had covert saccade at LSC in vHIT results (Table 1). Mean gain scores of 34 patients were reduced from 0.912 to 0.890 at LSC, 0.833–0.813 at anterior semicircular canal (ASC) and 0.845–0.776 at PSC. In all three semicircular canals, there was a statistically significant mean gain loss at postoperative day 3 ($p < 0.05$).

Among 8 patients with VEMP response absence, 5 had response absence in both cVEMP and oVEMP, whereas 3 had cVEMP response absence only (Table 1).

According to objective vestibular test results at postoperative day 3, the most protected vestibular end-organs are ASC (100%), LSC (92.8%), PSC (88%), utricle (88%) and saccule (80.9%) respectively (Fig. 2).

A significant DHI increase was observed in 13 of 42 patients (30.9%) on day 3 after CI ($p < 0.05$); also, impaired vestibular function test results were observed in all except one of these 13 patients (Table 1). There was a high positive correlation between the percentages of patients with vestibular disfunction and patient with significant DHI increase at postoperative day 3 ($r = 0.945$; $p < 0.05$) (Fig. 3).

3.2. *Late postoperative period (at postoperative month 3) objective and subjective evaluation results*

In the late postoperative period, recovery was observed in half of the patients on the objective tests. Six patients (14.2%) out of the 12 (28.5%) who had vestibular dysfunction in the early postoperative period still had deteriorating results in the objective tests at the late postoperative period (Table 2). Four of these 6 patients (66.6%) were above 60 years old. There was no change in the non-operated ears of these patients.

There was a statistically significant deterioration only in the cVEMP at postoperative month 3. The deterioration in vHIT continued in only 1 (2.3%) patient ($p > 0.05$). The deterioration in cVEMP continued in 5 (11.9%) patients ($p < 0.05$). The deterioration in oVEMP continued in 2 (4.7%) patients ($p > 0.05$) (Fig. 1). Mean gain scores of 34 patients were changed from 0.912 to 0.922 at LSC, 0.833–0.840 at ASC and 0.845–0.840 at PSC. In all three semicircular canals, there was no significant mean gain change at postoperative month 3 ($p > 0.05$).

Table 1
Detailed view of patients with vestibular test impairment and/or significant DHI increase in the early postoperative period (at postoperative day 3).

Patients	AC-vHIT	LC-vHIT	PC-vHIT	cVEMP	oVEMP	DHI
1	N	N	N	−	−	⇧ (24)
2	N	N	⇩	−	−	⇧ (18)
3	N	N	N	−	−	⇧ (22)
4	N	N	N	−	+	⇧ (22)
5	N	⇩	N	+	+	⇧ (30)
6	N	N	N	−	+	⇧ (24)
7	N	N	N	−	−	⇧ (48)
8	N	CS	N	+	+	⇧ (28)
9	N	N	CS	+	+	⇧ (36)
10	N	N	⇩	−	+	⇧ (32)
11	N	N	CS	−	−	⇧ (22)
12	N	⇩	⇩	+	+	⇧ (33)
13	N	N	N	+	+	⇧ (15)

AC: anterior canal, LC: lateral canal, PC: posterior canal, vHIT: video head impulse test, cVEMP: cervical vestibular evoked myogenic potentials, oVEMP: ocular vestibular evoked myogenic potentials, DHI: Dizziness Handicap Inventory, N: normal, CS: covert saccade, ⇩: gain decrease, ⇧: significant DHI increase (above 6 points), +: existent VEMP response, −: absence VEMP response

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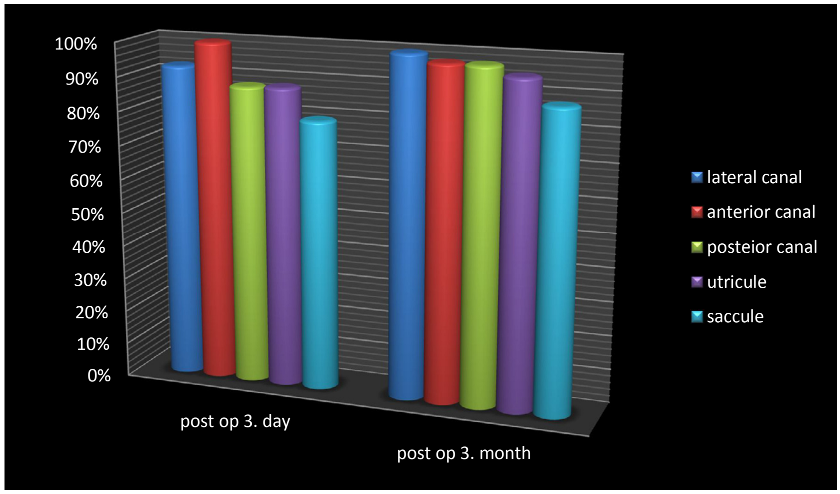

Fig. 2. Rates of prevention of peripheral vestibular end-organ function at postoperative day 3 and month 3.

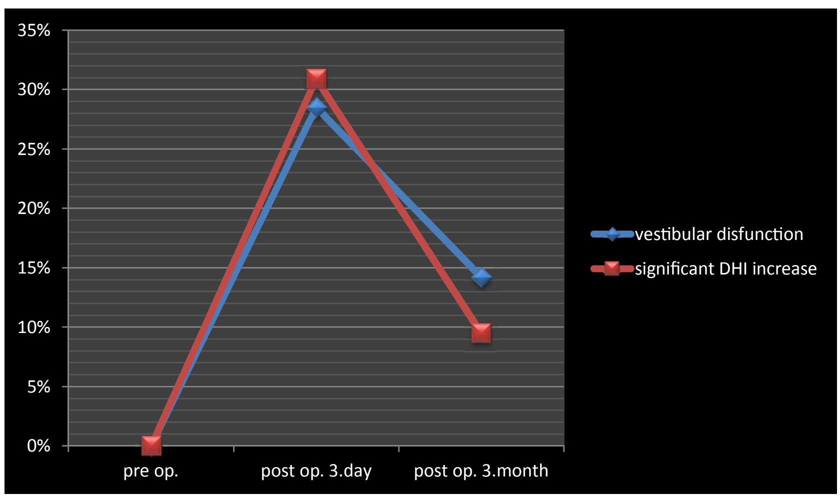

Fig. 3. The percentages of patients with vestibular disfunction (patients with at least one objective vestibular test impairment) and patients with significant DHI increase (>6 points) at postoperative day 3 and month 3.

According to objective vestibular test results at postoperative month 3, the most protected vestibular end-organs are ASC (100%), LSC (97.6%), PSC (97.6%), utricule (95.2%) and saccule (88%) respectively (Fig. 2).

A significant DHI increase was continued in 4 patients (9.5%) at postoperative month 3 ($p < 0.05$); impaired vestibular function test results were observed in all 4 of these patients. There was no significant increase in DHI in the other 2 patients with vestibular dysfunction (Table 2). There was a positive correlation between subjective DHI and objective vestibular function tests results at postoperative month 3 ($r = 0.795$; $P < 0.05$) (Fig. 3).

No nystagmus was observed in any of the patients neither early nor late period. There was no statistically significant

Table 2
Detailed view of patients with vestibular test impairment and/or significant DHI increase in the late postoperative period (at postoperative month 3).

Patients	AC-vHIT	LC-vHIT	PC-vHIT	cVEMP	oVEMP	DHI
1	N	N	N	−	−	⇧ (10)
2	N	N	N	−	+	N (6)
3	N	N	N	−	−	⇧ (10)
4	N	N	N	−	+	N (4)
5	N	N	N	−	+	⇧ (17)
6	N	⇩	⇩	+	+	⇧ (21)

AC: anterior canal, LC: lateral canal, PC: posterior canal, vHIT: video head impulse test, cVEMP: cervical vestibular evoked myogenic potentials, oVEMP: ocular vestibular evoked myogenic potentials, DHI: Dizziness Handicap Inventory, N: normal, ⇩: gain decrease, ⇧: significant DHI increase (above 6 points), +: existent VEMP response, −: absence VEMP response.

difference on vestibular test results between Med-EL and Nucleus devices in the early and late postoperative period.

4. Discussion

Although CI is a safe and successful method that has been applied for sensorineural hearing loss rehabilitation for many years, it may lead to vestibular dysfunction and dizziness, especially in the early postoperative period. We know that the effects of cochlear implant on vestibular receptors have been shown in many studies before. But the results showed great variability in the literature. This variability might be due to the different testing measures and different test timing. The vestibular receptor dysfunction rate ranges from 30% to 74% in the literature [2,17,26–28]. Additionally, post CI, subjective vertigo is seen in 12%–49% of patients [11,14,29].

In contrast to our study, no previous study showed how would the CI affect all 5 vestibular end-organ receptor functions. In our study, vestibular receptor dysfunction (including five vestibular end-organ) was seen in 12 patients (28.5%) in the early postoperative period, whereas 6 patients (14.2%) in the late postoperative period. Also our study showed thats CI surgery can significantly affect the results of vHIT, cVEMP and oVEMP tests in the early postoperative period. But only cVEMP results was showed significantly deterioration in the late postoperative period. Therefore, patients and their relatives should be informed about vertigo especially in the early postoperative period and same time it should be kept in mind that if bilateral implantation is performed simultaneously, there may be more serious balance problems in the early postoperative period.

Except for one of the 7 patients with impaired canal function in the early postoperative period, the patients completely recovered in the late postoperative period. Additionally, the functions in 3 of 8 patients with saccule dysfunction and 3 of 5 patients with utricle dysfunction recovered. These results suggest that the early-onset vestibular receptor function loss tended to improve with time, whereas saccule function loss is more likely to occur and persist. In previous studies, it has been shown that saccule functions were more influenced than canal functions; this finding is similar to that in our study [1,17,30]. In the histopathological study performed by Tien et al., morphological changes, in accordance with physiological studies, were observed more frequently in the saccule and utricle and less frequently in the SSC [5]. The saccule is closer to the round window and cochlea. This proximity can make them more vulnerable to surgical trauma during electrode insertion and drilling. The recovery of most of the impaired canal functions can be explained by anatomic location too.

Unlike many studies in the literature ours showed a positive correlation between objective vestibular tests and subjective vertigo evaluation [1,3,14]. Our opinion on the cause of this inconsistency with other studies is that they did not evaluate all five vestibular end-organ functions, so existing vestibular pathologies in some patients could not be demonstrated with objective test results. A review study by Abouzayd et al. states that there is no single test that achieved more than 50% sensitivity; this represents a poor correlation between the objective vestibular tests and subjective symptoms [31]. We recommend evaluating all five vestibular receptors to increase the sensitivity of vestibular assessment. Unfortunately, there is no single test that can evaluate all five vestibular receptor functions, but as in our study, a combination of vHIT, cVEMP and oVEMP can make it possible.

In our study with the aid of vHIT, both horizontal and vertical SSC (posterior and anterior) evaluations were conducted, and showed that surprisingly; PSC functions (5 patients) are more likely to be affected than LSC functions (3 patients). Although the ASC mean gain scores showed a significant decrease in the early period, there was no deterioration in ASC function both early and late postperative period. This situation may be explained by the posterior canal ampulla's proximity and anterior canal ampulla's distance to the round window [32]. We were not able to diagnose patients when they had dysfunction in the posterior canal if we did not perform a vertical channel assessment, and we could not find the reason for the significant increase in DHI in these patients. Inclusion of vertical channels assessment in our study with the help of vHIT has also increased the correlation between the DHI and objective vestibular tests. Therefore, we think that an evaluation of the five vestibular end-organs including the vertical canal is important for a complete vestibular evaluation. Considering this, vHIT has been an important contributor to this particular study.

Nystagmus is objective finding of vestibular dysfunction. As in many studies in the literature, nystagmus has not been observed in our study after cochlear implantation [2,3,27,30]. One possibility is that; this may be due to vestibular damage that would lead to dysfunction in objective vestibular tests but it would not cause clinically nystagmus or maybe vestibular tests are sufficiently sensitive to detect changes in vestibular function that are not observed clinically nystagmus. Another possibility is that; All patients were operated with minimal invasive technique and it may have prevented the occurrence of vestibular damage in a significant amount to create nystagmus.

In our study, we observed that 4 of 6 (66.7%) patients who had vestibular function loss and significant increasing DHI in late postoperative period after CI were over 60 years of age. Previous studies have also shown that cochlear implantation is associated with more vestibular receptor impairment and dizziness in elderly patients [30,33]. Therefore, it should be kept in mind that the loss of vestibular function and dizziness after CI may last longer, and elderly patients should be informed about this. Vestibular rehabilitation techniques may contribute to elderly patients who have deteriorated objective vestibular test results in the late postoperative period and whose vertigo symptoms are still present.

4.1. Limitations of this study

In our study, alongside the evaluation of all three SSC high frequencies with vHIT, a caloric test could have been used to evaluate low frequencies in more detail, but since the caloric test causes disturbing symptoms such as severe dizziness, nausea, vomiting and anxiety, and since it would be difficult and time

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consuming to conduct the test three times for each patient, we decided not to use it. Also vHIT stimulates at higher frequencies, similar to the physiological stimuli of daily life, whereas the caloric test stimulates lower VOR frequencies, and is a non-physiological stimulus [34]. Also more patient counts could give us safer results, but most of the CI candidates already complained of vertigo or had vestibular dysfunction before the surgery preventing many CI candidates from taking part in the study [33].

There is a possibility that would, anesthesia, wound etc. influenced the examination (especially VEMP) in the early postoperative period. Because of this at the beginning of the tests, especially before the VEMP, a detailed explanation of how to perform tests was given to the patients. At the same time, no pain or other pathology which prevented neck movements was observed before the test. Neuromuscular blockers used as anesthetic agents were rocuronium and the half-life was only 20 min and only used intravenous, not given as an infusion. Sevoflurane and desflurane were used as inhalation agents. These agents are also eliminated from the body long before the post operative day 3. Nevertheless, this may be one of the limitations of our work.

5. Conclusion

Our study clearly shows that both canal (vertical and horizontal SSC) and otolith (utricule, saccule) functions can be damaged after CI, especially in the early postoperative period. Even surprisingly, the PSC was the most affected canal. Therefore, assessment of five vestibular end-organ functions for complete vestibular evaluation before and after CI increased both the sensitivity of the test battery and the relationship between DHI and objective tests especially in the early postoperative period. We believe that the combined use of vHIT with oVEMP and cVEMP, which can assess not only lateral canal and otolith functions but also vertical canal functions, may be a gold standard vestibular battery. Also, we showed that the early-onset vestibular function loss tended to improve with time, and vestibular function loss is seen more prominently in elderly patients. CI candidates and their relatives should be informed about these issues.

Our study is the first report in the literature that can evaluate all five vestibular end-organ functions by vHIT, cVEMP, and oVEMP. This test battery, can provide more accurate results not only for CI but also for most otologic surgeries.

Disclosure statement

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