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Does cochlear implantation influence postural stability in patients with hearing loss?

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ABSTRACT

Background: Cochlear implantation (CI) procedure carries the potential risk for vestibular system insult or stimulation with resultant dysfunction due to its proximity to the cochlea. The vestibular system plays an essential role in crucial tasks such as postural control, gaze stabilization and spatial orientation.
Research question: How does standard cochlear implantation influence postural stability in patients with hearing loss?
Methods: The study included 21 individuals (age 51 ± 18 years) qualified to undergo CI due to severe or profound hearing loss. Participants were qualified for both groups by a physician based on an interview, an otoneurological examination and vestibular tests. The first group included patients without vestibular dysfunction, whereas the other group consisted of persons with vestibular dysfunction. The research methodology included medical examinations, anthropometric measurements and stabilometry on the Biodex Balance System SD (BBS) platform. The examinations were carried out twice, i.e. prior to and 3 months post implantation. The recorded data was compared between the first and the second examination using a non-parametric Wilcoxon test. The analysis of variance (ANOVA) and Tukey's post-hoc HSD unequal sample sizes were performed for patients with and without vestibular dysfunction.
Results and Significance: Study showed that 52.4% of the participants obtained results within the norm, while 47.6% scored below it. The comparison of stability indices of the examined individuals, with and without vestibular dysfunction, did not reveal statistically significant differences. The only difference was the anterior-posterior stability index assessed in static conditions. Three months after the implantation, no changes in the majority of indices were noted, with the exception of anterior-posterior stability index, which improved following the implantation. CI does not affect postural stability changes in the study participants.

1. Background

The aim of cochlear implantation (CI) is to restore hearing abilities and to improve the quality of life of hearing-impaired patients [1]. A surgical procedure involves inserting an electrode into the cochlea [2,3]. CI procedure carries the potential risk for vestibular system insult or vestibular irritation [4–6] due to its proximity to the cochlea [5,7]. The proper functioning vestibular system enables the postural control, gaze stabilization and spatial orientation [8].

Shoman et al. [9] conducted the research regarding the presence and character of pre- and post-CI vestibular symptoms. Responses were provided by 110 out of 227 patients (48%). Fifty-three respondents (48.3%) experienced dizziness prior to CI, while 64 patients (58.2%) felt similar effects after CI. Forty-one participants (37.3%) noted a new onset of balance symptoms or a change in their symptoms after CI [9]. Although CI has been accepted as a safe procedure, the insertion of an electrode into the cochlea may have an adverse effect on vestibular receptors, thus resulting in dizziness [10]. In fact, subjective post-operative dizziness is said to affect from 2% to 47% of patients [11,12]. Vestibular function without CI and after CI is difficult to comprehend, as subjective vestibular symptoms seem uncorrelated with the results of objective tests. As a consequence, clinicians may struggle to decide

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what assessments to perform for a symptomatic patient [10].

It is not quite clear where these symptoms stem from. According to one theory, the loss of vestibular function depends on cochleostomy techniques [7]. A round window insertion approach proved to be an exceptionally effective method in treating partial hearing loss, as it reduced the risk of complications [7,13,14]. However, the risk of balance disorders after cochlear implantation is always present. Additionally, it may result from factors other than a surgery. A number of mechanisms could explain the observed association between hearing loss and falls. There may be concomitant dysfunctions of both the cochlear and vestibular sense organs given their shared location within the bony labyrinth of the inner ear. Decreased hearing sensitivity may also directly limit an access to auditory cues that are necessary for environmental awareness. Attentional resources are critical for maintaining postural control [15] and decrements in attentional and cognitive resources imposed by hearing loss [16] may impair the maintenance of postural balance in real-world situations and increase the risk of falling.

A thorough evaluation of the vestibular function could not only be helpful when making a more accurate prognosis of fall risk following CI, but it might also provide proper vestibular rehabilitation for at-risk patients [17]. The effect of with loss on equilibrium, particularly in the short term following surgery, and the risk of falling due to this loss is unknown [18]. The aim of the study was to assess the effects of CI performed with the use of standard cochlear implant electrodes inserted via the round window membrane on postural stability in patients with hearing loss.

2. Material and methods

2.1. Participants

The study included 21 individuals with severe or profound hearing loss who underwent CI at the World Hearing Centre, the Institute of Physiology and Pathology of Hearing. The group consisted of 9 females aged 48.3 ± 19.2 and 12 males aged 52.4 ± 19.2 (Table 1). The implantation was performed on the right side in 13 subjects, on the left in 8. The study exclusion criteria were as follows: mental barrier that prevented some individuals from undergoing an operation, unwillingness to undergo implantation as well as any contraindications to being anaesthetized during an operation.

The first group included patients without vestibular dysfunction, whereas the other group consisted of persons with vestibular dysfunction. Participants were qualified for both groups by a physician based on an interview, an otoneurological examination and vestibular tests: videonystagmography (VNG), cervical and ocular vestibular evoked myogenic potentials (VEMP), the video head impulse test (vHIT), which were performed pre- and postoperatively. The patients were subsequently classified as those with normal vestibular function (N = 11,) and vestibular dysfunction (N = 10) preoperatively. Due to the small number of patients, the group with preoperative vestibular dysfunction included both the patients with complete (N = 6), partial(N = 2) unilateral vestibular damage as well as those with bilateral damage (N = 2). Complete vestibular damage was defined as the damage of otolith function (absence of cVEMP and oVEMP response) and weaken horizontal semicircular canal function (UW in caloric test > 25% or vHIT gain < 0,6 or the presense of covert or overt saccade in vHIT). Partial vestibular damage meant the damage of otolith function (absence or incorrect amplitude asymmetry ratio in cVEMP and/or oVEMP) with normal semicircular canal function.

Demographics for the group are presented in Table 1. The arithmetic mean of the Body Mass Index for the group of the study participants indicated that they were slightly overweight, according to the WHO standards.

An approval was received from the Institute Research Ethics Commission and additional informed consent was obtained from all patients for whom identifying information is included in this article.

2.2. Measurements

Postural stability was measured with the use of the Biodex Balance System SD (BBS), an instrument designed to measure and improve postural stability on static or unstable surfaces. The BBS device is interfaced with dedicated software (Biodex Medical Systems, Inc. version 1.3.4), allowing the BBS to measure the degree of tilt in each axis, providing an average sway score. Eight springs located underneath the outer edge of the platform provide resistance to movement (stability level of the platform), with resistance levels ranging from 12 (most stable) to 1 (least stable). The BBS has a display which gives feedback about the posture in real time and it is calibrated before use.

In all trials, the participants were standing on the BBS facing the display. All the trials were conducted without shoes and foot position was recorded using coordinates on the platform grid to ensure the same stance and, therefore, consistency with future tests. In this research, five measurement protocols were used:

- Postural Stability Test (PST) - stable platform with eyes open,
- Postural Stability Test (PST) - stable platform with eyes closed,
- Postural Stability Test (PST) - unstable platform level 12 with eyes open,
- Postural Stability Test (PST) - unstable platform level 12 with eyes closed
- Fall Risk Test (FRT) - unstable platform with eyes open, starting at level 6 and completing at level 2. If the patients were not able to follow the protocol three times, the set-up of the platform was changed to starting at level 12 and completing at level 8.

unstable platform level 6-2 with eyes open, if the patients were not able to follow the protocol three times the set-up of the platform was changed to the level 12-8.

In FRT, the platform is unstable and thus permits investigators to measure the Fall Risk Index (FRI). This test was conducted using the standard software configuration: three trials of 20 s each, with a 10-second rest period between tests, and platform levels varying from 6 to 2 with eyes open, and 12 to 8 with eyes closed, where 12 is the most stable setting and 2 is the least stable. Participants were starting the test on a platform with their eyes open from level 6. During the 20 s test platform would change the setting every 4 s, so it would end up on level 2. The test with the eyes closed was performed in a similar manner. Participants were starting on the level 12 and platform would change the setting every 4 s and end up on level 8.

Each test was performed in standing on both legs. Feet position on the platform was unchanged for all tests. Four stability indexes were analysed: overall stability index, given as OSI= $\sqrt{\frac{\sum[0\text{-}x]^2+\sum[0\text{-}y]^2}{\#\,\text{samples}}}$, anterior/posterior stability index, medial/lateral stability index and fall risk

Table 1
Participants' anthropometrics (mean ± SD).

Groups	Age [yrs]	Body mass [kg]	Body height [cm]	BMI	Gender	Etiology of deafness
Experimental	50.66 ± 18.02	78.19 ± 18.40	167.76 ± 11.16	27.45 ± 4.85	F = 9 M = 12	15 unclear 2 after mumps 2 meningitis 1 congenital 1 otosclerosis

index. High level of postural stability index means substantial displacements of the center of pressure (CoP) that reflect problems with maintaining balance of the person examined [19].

2.3. Statistical analysis

The recorded data were analyzed with the use of STATISTICA (v.12). Normality of distribution was analyzed with the Shapiro-Wilk test. In some cases, the results were subjected to a natural logarithmizing procedure to obtain normal distribution. Each parameter was described using descriptive statistics [means and standard deviations]. The analysis of variance (ANOVA) and Tukey's post-hoc HSD test for unequal sample sizes were performed for groups without vestibular dysfunction and with vestibular dysfunction. The ANOVA was performed, with stability parameters being dependent variables whereas the measurements eyes open and closed represented independent variables. Due to the fact that the tested features did not have normal distributions, variables were compared between the first and the second test using a non-parametric Wilcoxon test. Statistical significance was set at the customary level of $p \leq 0.05$ for all analyses.

3. Results

At the beginning, the number of persons who scored within the norm in FRT (test 6–2) was determined. According to the Biodex norms, 52.4% of the study participants obtained results within the norm, while 47.6% scored below it (including 5 individuals who did not finish the test with their eyes open, because it was too hard for them). At the next stage, the subjects were divided into two groups, i.e. individuals with and without vestibular dysfunction. Table 2 illustrates postural stability results taking into account this division.

The comparison of stability indices of the examined individuals taking into consideration the division into groups with and without vestibular dysfunction did not reveal expected statistically significant differences, with the exception of the anterior-posterior stability index assessed in static conditions. In the group of study participants with vestibular dysfunction, 5 persons did not perform dynamic tests (unstable platform level 6–2) with eyes open, while only 1 person completed the test with eyes closed (unstable platform level 12–6). Participants were not able to perform the procedure because of bad stability, they were grabbing the safety rail, thus helping themselves during the test. For this reason, these comparisons were omitted.

Because of this, it was checked whether the visual factor had a considerable influence on stabilometric performance. One-way ANOVA revealed that the visual factor was crucial in maintaining balance, while the subjects compensated for vestibular dysfunctions (Fig. 1). There

Table 2
Baseline measures for the subjects without and with vestibular dysfunction.

Stability Index	1 (n = 11)	2 (n = 10)	p-value
OSI EO - static	0.22 ± 0.08	0.37 ± 0.19	0.0962
APSI EO – static	0.14 ± 0.05*	0.30 ± 0.12*	0.0236*
MLSI EO - static	0.10 ± 0.00	0.13 ± 0.11	0.7106
OSI EC - static	1.12 ± 0.44	1.23 ± 0.68	0.8931
APSI EC – static	0.96 ± 0.38	1.02 ± 0.59	0.8401
MLSI EC - static	0.36 ± 0.18	0.51 ± 0.41	0.9459
OSI EO -12	1.00 ± 0.43	1.01 ± 0.39	0.9221
APSI EO -12	0.61 ± 0.25	0.65 ± 0.26	0.7780
MLSI EO - 12	0.62 ± 0.28	0.64 ± 0.28	0.8404
FRT EO (6-2)	2.13 ± 1.85	2.29 ± 2.51	0.8868

Note:All values: mean ± SD, OSI – overall stability index, APSI – anterior-posterior stability index, MLSI – medial-lateral stability index, EO – eyes open, EC – eyes closed, 12 – dynamic balance level 12, static – platform stable Group 1: individuals without vestibular dysfunction; Group 2: individuals with vestibular dysfunction.

* Analysis of variance ANOVA $p < 0.05$.

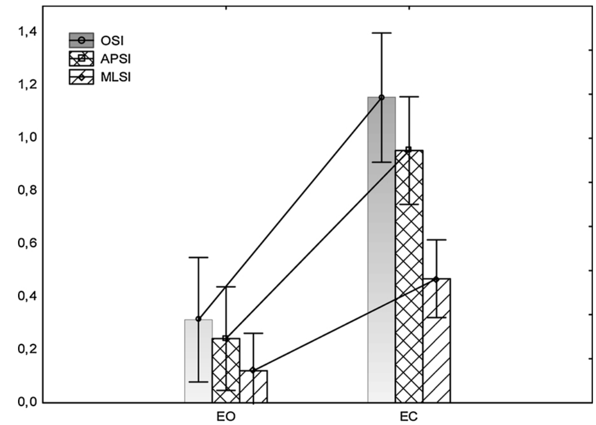

Fig. 1. Results of stability indices under static conditions with eyes open and closed.

occurred significant differences between eyes open and eyes closed in all indices in all the subjects under static conditions at the level of OSI; F (4.75) = 26.99, P = 0.000029, APSI F (3.41) = 26.9, P = 0.000023, MLSI F (0.81) = 12.34, P = 0.001706 (Fig. 1).

Excluding visual cues in dynamic tests was not easy for the participants; therefore, not all of them were capable of performing the tests with eyes closed on an unstable surface. With the highest stability of the platform at the level of 12, only 8 out of 21 individuals completed the test, while FRT was performed by 4 subjects only.

Table 3 shows results 3 months post implantation. The comparison of results with the Wilcoxon test did not reveal significant differences in static conditions in all the tests of bilateral stance. Dynamic tests (unstable platform level 12) showed a significant improvement in the case of the medial-lateral stability index. It is worth noting that the patients after cochlear implantation achieved better results in Fall Risk Test without statistical significance. However, the tendency of improving the results of FRI (from 219 ± 2.07 to 1.79 ± 1.46) is visible. In the tests performed with eyes closed, the tendecy is totally different. After the cochlear implantation, the parameters deteriorated, but the difference was still statistically insignificant. The significant tests could not be performed for FRI due to a small number of participants who completed the test after the implantation. Same participants that failed the test before CI also failed it after the procedure.

4. Discussion

Cochlear implants revolutionized the way we approach rehabilitation of patients with severe to profound hearing loss [20]. In the present study, we checked this possibility by examining balance function in adults with profound sensorineural hearing loss who have a cochlear implant. In our study conducted on the BBS platform, the patients divided according to whether they had vestibular dysfunction demonstrated similar results. As for static and dynamic tests with eyes open, the results were similar except for the medial-lateral stability index in a static format. It was not until more demanding test performance conditions were applied, which did not allow patients to compensate for balance loss, e.g. unstable surface [21] or no visual control [22] that patients' difficulties in maintaining balance were revealed. Dynamic tests were harder for a lot of participants and the fact that some of them did not perform these tests made it difficult to draw proper conclusions. It may stem from the fact that compensation of balance disorders is harder under dynamic conditions. Some individuals make use of their vision more often, while others rely more on proprioception and exteroceptors. The optic canal provides a great deal of information about body positioning in space [22,23]. It is confirmed by the study of Maciaszek et al. [24], who noted that an increased difficulty of task conditions (eyes closed) leads to significantly greater disturbances, in static

Table 3
Comparison of pre- and post-implantation values for stability indices (mean ± SD).

Stability Index	Eyes open				Eyes closed			
	n	Pre	Post	p	n	Pre	Post	p
OSI - static	21	0.31 ± 0.17	0.31 ± 0.13	0.88	21	1.19 ± 0.59	1.29 ± 0.85	0.81
APSI – static	21	0.24 ± 0.12	0,23 ± 0.11	0.72	21	1.00 ± 0.50	1.04 ± 0.73	0.33
MLSI - static	21	0.12 ± 0.66	0.14 ± 0.09	0.17	21	0.46 ± 0.35	0.57 ± 0.49	0.46
OSI -12	19	1.01 ± 0.40	0,89 ± 0.40	0.11	8	1.44 ± 0.77	1.65 ± 0.59	0.73
APSI -12	19	0.62 ± 0.24	0.63 ± 0.32	0.85	8	0.87 ± 0.36	0.96 ± 0.29	0.53
MLSI - 12	19	0.63 ± 0.27*	0.49 ± 0.25*	0.0069	8	1.04 ± 0.48	1.17 ± 0.45	0.75
FRT (6-2)	17	2.19 ± 2.07	1.79 ± 1.46	0.75	4	3.92 ± 2.69	5.22 ± 5.54	–

Note: All values: mean ± SD, OSI – overall stability index, APSI – anterior-posterior stability index, MLSI medial-lateral stability index, EO – eyes open, EC – eyes closed, 12 – dynamic balance level 12, static – platform stable.

* Non-parametric Wilcoxon test.

body balance in elderly men. FRT is one of the most important tests taken by the patients in this study. It shows their actual postural stability in changing conditions, which may be most commonly encountered in real life. It is a particularly hard task for individuals with vestibular dysfunction. It can be seen in the findings of the study, where the second group achieved slightly worse mean results than the first group. These results were not significantly different, since only 7 persons from the group with vestibular dysfunction managed to perform the test with eyes open and nobody was capable of completing it with eyes closed. According to Lin and Ferrucci [25], individuals with hearing loss are far more likely to fall than healthy persons. These researchers claim that for every 10 dB of hearing loss, the fall risk increases by 1.4 times. In the case of the group with at least severe hearing loss, the risk is 10 to 12 times higher. It definitely shows the scale of the problem that these persons have to deal with in their everyday lives.

What is interesting is that Fall Risk Test (FRT) also allows us to compare our outcomes with mean scores of the same-age population. This is the index which shows to what extent the result of an examined person is different from the norm. In the case of our examinations, the results clearly indicated which groups the subjects belonged to. The participants from the first group obtained better scores than their counterparts with vestibular dysfunction from the second group. Obviously, there were some deviations; however, it should be stressed that at the beginning the subjects demonstrated different balance levels, which often depended on their age, body height or physical activity.

Many studies focused on the effects of CI-related vestibular dysfunction on balance control [5,17,26–28]. The studies are equivocal when it comes to the effects of implantation on balance.

The analysis of pre- and post-implantation results revealed no significant changes except for medial-lateral stability index improvement. FRT results improved slightly, which allows us to assume that standard cochlear electrodes implanted via the round window membrane produced expected outcomes. Going one step further and taking into consideration the fact that the second examination was performed in a relatively short time after the surgery (3 months only), we might assume that the results will gradually improve in the course of time. Parietti-Winkler et al. [26] claimed that unilateral CI is not harmful for postural performances. Conversely, postural stability improves within one year after CI. This improvement could be an indirect consequence of the recovery of auditory information. Indeed, patients may be less dependent and move more, thus strengthening postural control. Parietti-Winkler et al. [29] conducted their examinations two days pre- and one year post-implantation. They noted that patients improved their performance both under static and dynamic conditions as well as with eyes closed, which shows that implantation allows for normal functioning also in conditions that are more demanding in terms of balance, e.g. when walking after dark. Unfortunately, there are also works that act as counterarguments to this thesis. The findings of the study by Bernard-Demanze et al. [30] are different from those presented above. Having analysed research results from before and one to six years after the implantation, they claimed that in the majority of tests the scores were worse than prior to the operation. It was particularly noticeable in the tests with eyes closed, where patients could not use their vision for compensation. According to Ibrahim et al. [31], CI surgery has a significant negative effect on the results of caloric as well as VEMP tests. No significant effect of CI surgery was detected in posturography.

The literature review shows that the findings regarding this issue are equivocal. It often stems from the fact that different research techniques are employed and the subjects themselves differ. Technological developments play a key role in minimizing trauma to the cochlea during the placement of electrodes [20]. The strong point of our research is the group of patients with partial hearing loss operated with a round widnow approach, using hearing preservation techniques [13,32,33]. This approach ensures that the cochlear implant array is introduced into the correct scala (tympani) and reduces the risk of either residual hearing damage due to drilling or basilar membrane perforation that may arise if the electrode traverses from scala tympani to scala media and/or scala vestibule [34]. In the group of patients with partial hearing loss, it was risky to perform traditional cochleostomy, as patients could lose their hearing completely. This method minimized post-operative complications, and owing to our research it may be stated that this technique does not have a negative influence on postural stability. The present study also revealed similarities with the findings of other researchers, particularly when it comes to the occurrence of balance disorders in individuals with hearing loss or validity of dynamic tests, in the form of fall risk. When dealing with a similar issue in the future, we ought to bear in mind that the most objective conditions for examining postural stability are: tests with eyes closed and tests on changing surface instability. An unstable surface forces participants to make use of their full functional capabilities. However, the present study constitutes good evidence that CI via the round window membrane reduces the risk of complications in the form of post-operative balance disorders. Still, further research should include a larger sample size that would make it possible to formulate objective conclusions.

5. Conclusions

CI (round window insertion approach) does not affect postural stability changes in the study participants.

Declaration of Competing Interest

The authors declare no conflicts of interest in preparing this article.

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