The Effect of Cochlear Implant Stimulation on Postural Control

Original Investigation

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Abstract

Objective: There are contradictory reports on the effect of cochlear implantation on postural control. Associated vestibular loss, electrode insertion trauma, and electrical stimulus of a cochlear implant can influence postural control. This study focused on the electrical stimulation of the cochlea. We aimed to examine whether a cochlear implant's electrical stimulation affects postural control measured by posturography.

Methods: Thirty-three patients with unilateral cochlear implants were included. We used three preprogrammed main tests and their nine subtests in posturography. Postural stability [general stability index (GSI)], fall risk index (FRI), and sensory integration [modified clinical test of sensory integration of balance (m-CTSIB)] were calculated. All tests were performed under three conditions: implant off (1), implant on (2), and implant on music (3).

Results: The mean age was 46.29±16.09 years. GSI was above normal limits in 78% of adult cochlear implant users. We found that FRI was high in 30% of patients, and m-CTSIB was defective in 42%. There were no statistically significant differences in GSI, FRI, and m-CTSIB. Cochlear implant stimulation was found to have positively affected postural control when the subject's data were visualized individually. GSI, FRI, and m-CTSIB dropped to 39%, 24%, and 24%, respectively, when music was on. There was a significant correlation between age and fall index. But this correlation disappeared when music was playing.

Conclusion: Cochlear implant stimulation affected the vestibular system in almost all patients. The effect was positive in most patients.

Keywords: Cochlear implant, postural control, posturography, fall risk, hearing implant, postural balance

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Introduction

Cochlear implants (CIs) have become the commonly chosen option to rehabilitate profound or severe sensorineural hearing loss at any age. Although its effects on the hearing system are thoroughly examined, its effects on the vestibular system are still a topic of discussion.

When investigating the interaction between the vestibular system and CIs, various factors must be considered. First, people with severe and profound hearing loss can also have sensory loss in the vestibular end organs. 2.7% of the patients with CIs have been reported to have preoperative dizziness (1).

Furthermore, the risk of falling in older adults with hearing loss was 2.39 times higher than in those without (2). Second, the CI electrode placement is a physical intervention within the sense organ. In addition to the cochlear part, significant damage was observed in the vestibular part in 54% of the samples (3). Vestibular fibrosis, saccular membrane degradation, reactive neuroma, and new bone formation were the most common injuries (4). Third, CIs send continuous electrical signals to the cochlear nerve near the vestibular nerves. Interference with the vestibular system is possible (5).

Vestibular damage has been reported numerous times with organ-specific tests after cochlear implantation surgery. However, the results of the functional tests were inconsistent with the injury. A recent meta-analysis showed that CI surgery had a significant negative effect on caloric test and vestibular evoked myogenic potentials but had no impact on posturography, head impulse test and dizziness handicap inventory (6). Louza et al. (7) measured the risk with portable posturography. They reported that patients with CIs already had a higher risk than usual before surgery, but there was no significant change in fall risk after the surgery.

This study focused on the effect of CIs on functional balance. We aimed to examine whether postural tests are affected by the implant-turn-on/-off conditions. We also aimed to determine whether continuous background sound (continuous electrical stimulation of the cochlear nerve) affected postural balance in patients.

Methods

Participants

Thirty-three patients aged between 16 and 80 years who underwent CI surgery were included in the study. The patients were retrospectively selected from the list and prospectively tested with a posturography. All patients aged over 16 years in our retrospective list were invited to the study. There was no time limit for the duration after surgery. Those with an additional disability, communication problems, bilateral CIs, neurological or psychiatric disease, visual impairment, or orthopedic problems in the lower extremities were not included. None of them were wearing any additional devices like hearing aids during tests. All participants were informed and gave their written informed consent. Permission was obtained from the Pamukkale University Non-invasive Clinical Research Ethics Committee (no: 60116787-020/20941, date: 23.03.2018). The study is registered with clinicaltrials.gov (NCT04404205).

Outcome Measurements

The Biodex Balance System SD (BBS) (Biodex Medical Systems Inc., New York) was used for posturography. The BBS was a valid device for dynamic and static balance assessment (8). The platform was designed to measure postural stability. The reliability was tested in different age groups (9). Three main tests:

Postural stability test: Stable platform with eyes open. The balance of postural stability was measured using three parameters: General stability index (GSI), anterior-to-posterior stability, and median-to-lateral stability. A high score highlights poor balance. When interpreting the results, we used the normal limits mean ±2 standard deviation (SD) (0–1.36) calculated from mean ± SD (0.64±0.36) (10).

Fall risk test (FRI): Unstable platform with eyes open, starting at level 12 and completing at level 1. The device calculates the risk of falling based on the patient's age and GSI. The higher the value, the higher the risk of falling. When interpreting the results, we accepted the normal limits mean ±2 SD (0.39–3.19) calculated from mean ± SD (1.79±0.70) (10).

Modified clinical test of sensory integration of balance (m-CTSIB): Four subtests were included: i) eyes open firm surface (OF), ii) eyes closed firm surface (CF), and iii) eyes open foam surface (OO), iv) eyes closed foam surface (CO). They provide a detailed evaluation of the relationships between sensory integration and visual, somatosensory, and vestibular stimuli. When interpreting the results, we used normal limits mean ±2 SD (0.66–1.7) calculated from mean ± SD (1.18±0.26) (11).

During the test, the patients were asked to stand on the BBS platform with their hands shoulder-width apart and on their sides in the most comfortable position to maintain balance and be upright. The patient's foot coordinates were recorded. The tests were carried out at the same time of day (between 10:00 and 14:00). Each patient was informed about the trials and rules. Patients were subjected to a practice study for each condition to eliminate the possible effects of learning and fatigue. All patients were tested three times; each test took 20 seconds and had 10 seconds of rest between tests. The average of the three trials was automatically calculated and recorded by BBS.

All tests were carried out under three conditions:

1. CI off (baseline),

2. CI on,

3. CI on and music on [non-directional music played by multiple speakers from the different parts of the room at a comfortable level (50 dB)]. We chose music rather than simple sounds to represent daily life.

Factors such as age, sex, and implant duration were also studied.

Statistical Analysis

Statistical analysis was performed using the SPSS 10.0 program (Statistical Package for Social Sciences). Results were compared with related samples, Friedman's two-way analysis of variance, and the t-test for equality of means. The Pearson correlation coefficient was also calculated between the selected pairs. Statistical significance was established at $p<0.05$ for all analyses.

Results

Thirteen males and 20 females, a total of 33 patients, were tested. The mean age was 46.29±16.09 years at the time of the study. Implantation age was 44.7±16.6 years [minimum (min) 14–maximum (max) 78.5]. The mean duration from implant surgery to test day was 579.12±38.4 days (min 28–max 1463).

All test parameters are summarized in Table 1. No statistically significant differences existed between the three conditions in any of the test parameters. However, when we grouped the patients according to normal and abnormal test results, most patients were seen to be affected to some extent in an increasing or decreasing manner.

GSI was above normal limits in 78% of adult CI users. We found that FRI was high in 30%, and the m-CTSIB composite score was defective in 42% of the patients. CI stimulation was found to have positively affected postural control when the subject's data were visualized individually. The number of patients with normal GSI increased with increasing stimulation (Figure 1). The FRI was better at baseline. There were 23 normal patients at the beginning of the study (Figure 2). The m-CTSIB composite score was normal in 19 patients at baseline (Figure 3). GSI, FRI, and m-CTSIB dropped to 30%, 21%, and 36%, respectively, when the CI was on. When the music was on, m-CTSIB decreased to 24%, while the other parameters increased slightly.

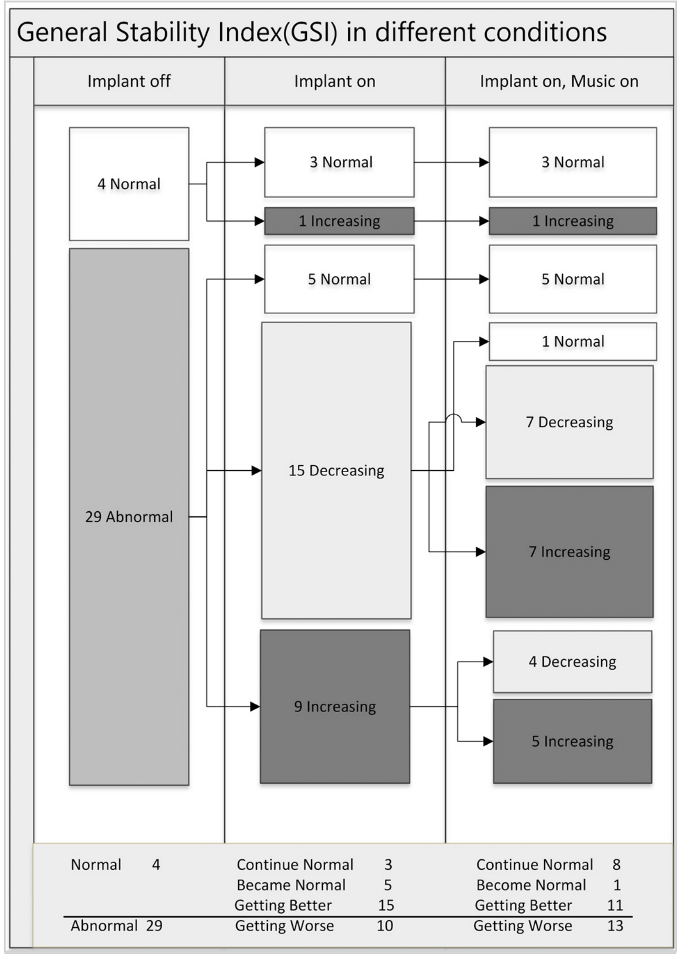

Figure 1. Figure plots the GSI of all patients and their change during the two experimental conditions. At the bottom, the total numbers were included. The postural stability index was above normal limits in 78% of adult cochlear implants

Table 1. Posturographic parameters were obtained in 3 different conditions. They were compared with related samples Friedman's two-way analysis of variance

	Implant off		Implant on		Implant on, music on		
	Mean ± SD	**Median (min–max)**	**Mean ± SD**	**Median (min–max)**	**Mean ± SD**	**Median (min–max)**	**p-value**
GSI	3.57±2.12	3.4 (0.5–9.8)	3.12±2.04	3.05 (0.5–10.4)	2.94±1.82	2.55 (0.6–7.7)	0.209
APS	2.01±1.53	1.55 (0.3–8)	2.03±1.82	1.6 (0.3–10.1)	1.55±1.05	1.25 (0.4–3.9)	0.754
MLS	2.47±1.73	2.1 (0.4–7)	1.93±1.29	1.6 (0.3–5.7)	2.12±1.63	1.85 (0.4–6.9)	0.1
FRI	2.87±1.72	2.75 (0.7–10)	2.42±1.66	2 (0.3–6.2)	2.9±1.85	2.55 (0.3–8.2)	0.317
m-CTSIB -OF	0.68±0.38	0.57 (0.28–1.95)	0.72±0.45	0.59 (0.25–2.2)	0.65±0.4	0.53 (0.25–2)	0.281
m-CTSIB -CF	1.24±0.48	1.22 (0.58–2.68)	1.19±0.72	1.12 (0.38–4.47)	1.25±0.83	0.97 (0.44–4.31)	0.337
m-CTSIB -OO	1.28±0.45	1.24 (0.51–2.28)	1.29±0.45	1.19 (0.61–2.38)	1.34±0.85	1.08 (0.41–4.12)	0.086
m-CTSIB -CO	3.54±1.53	3.35 (1.12–8)	3.59±1.57	3.06 (1.65–8.55)	3.62±1.68	3.14 (1.19–8.54)	0.703
m-CTSIB	1.68±0.45	1.58 (0.82–2.94)	1.7±0.51	1.67 (0.87–2.76)	1.71±0.68	1.49 (0.78–3.22)	0.476

GSI: General stability index, APS: Anterior-to-posterior stability, MLS: Medial-to-lateral stability, FRI: Fall risk index, m-CTSIB: Modified clinical test of sensory integration of balance, OF: Eyes open/Firm surface, CF: Eyes closed/firm surface, OO: Eyes open/foam surface, CO: Eyes closed/foam surface, SD: Standard deviation, min–max: Minimum–maximum

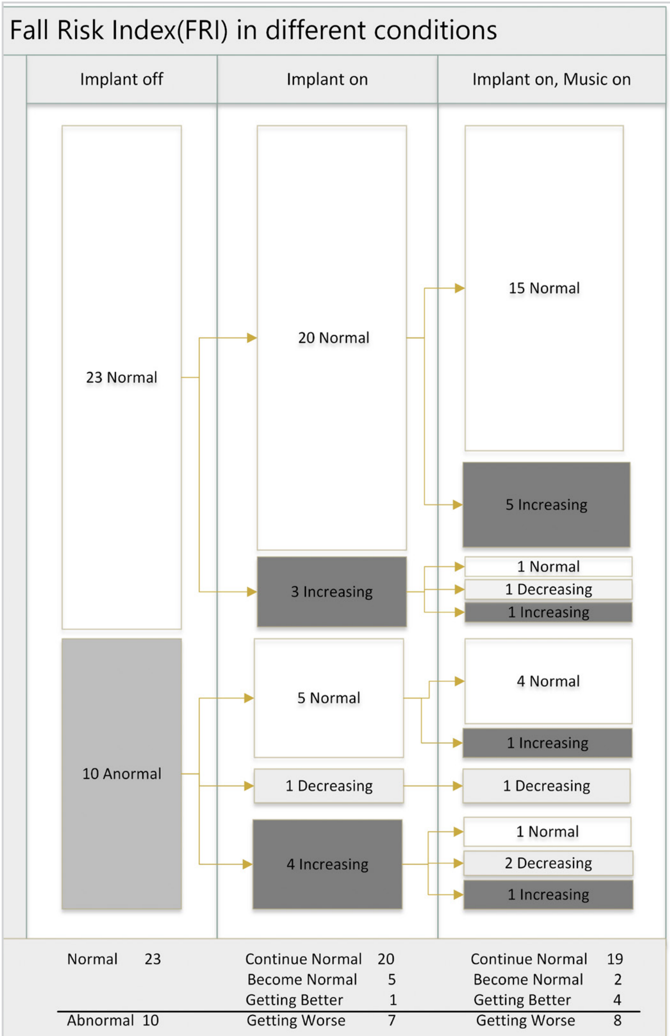

Figure 2. Figure plots the FRIs of all patients and their changes during the two experimental conditions. At the bottom, the total numbers were included. The FRI was initially high in 30% of the patients

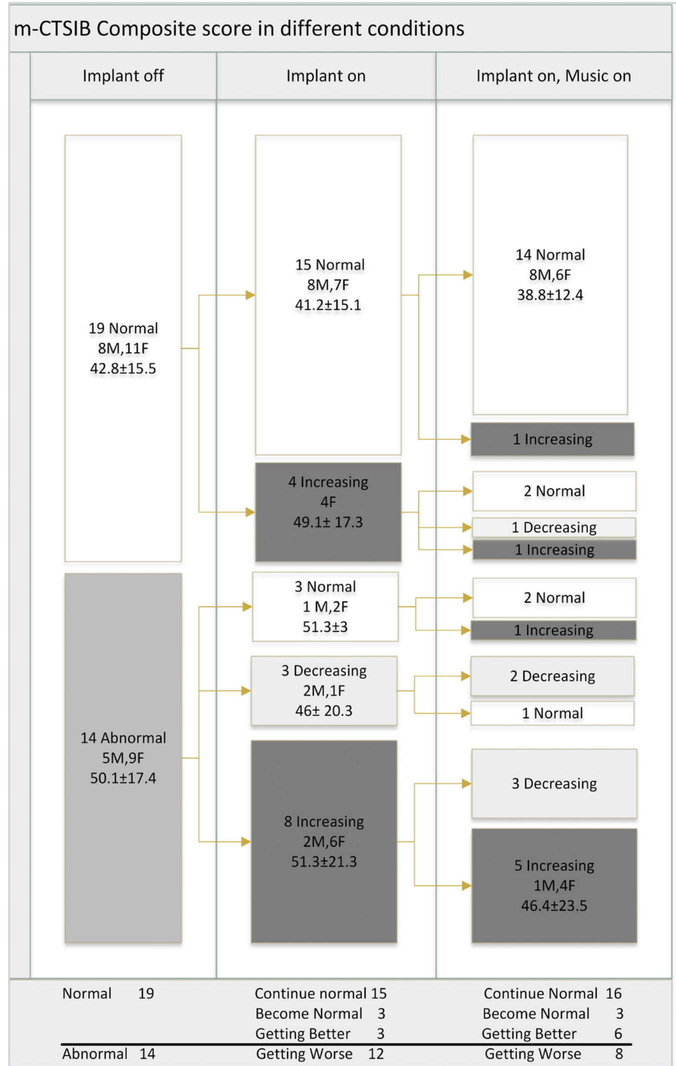

Figure 3. Figure plots the GSI of all patients and their change during the two experimental conditions. Sensorimotor control was defective in 42% of the patients in the baseline. The mean ± SD age and the male/female numbers of the groups were also added to see the relationship between postural control and these factors

GSI: General stability index, SD: Standard deviation

As expected, age and FRI had a moderate correlation ($p=0.004$). Interestingly, this correlation disappeared when music was on [implant off ($r=0.48$, $p=0.004$), implant on ($r=0.429$, $p=0.011$), music on ($r=0.317$, $p=0.068$)]. When we divided the patients according to age into three groups [group 1:16-40 years (n=13), group 2: 41-59 years (n=13), group 3: 60 years or above (n=7)], statistically significant differences were found in some test conditions like implant off (FRI, $p=0.04$), implant on (m-CTSIB-OF, $p=0.025$), music on (m-CTSIB-OF, $p=0.023$, m-CTSIB-OO, $p=0.043$). However, no other statistical difference existed in any of the parameters or test conditions.

There was no correlation between postoperative days and balance. When we divided the group into early [shorter than one year (13 patients)] and late [longer than one year (20 patients)] groups, there were no statistically significant relations in any of the parameters or conditions ($p>0.05$).

Discussion

In this study, we examined the effect of CI stimulation on postural control. We tested patients under different conditions, such as implant on, implant off, and music playing in the room. There were no significant differences between these conditions in any of the parameters; however, the postural control of several subjects improved with CI stimulation. This effect was most prominent in GSI. An interesting finding of the study was the disappearance of the correlation between age and fall risk when music was played in the room.

After placing the CI, an additional factor is added: sound or electrical stimulation of the cochlear nerve. This hypothesis was first studied with hearing aids. The use of hearing aids helps to maintain postural balance in older adults with hearing loss (12). Postural oscillation improved in 41% of healthy people standing in the dark and those with vestibular insufficiency when a sound stimulus was added to the setting (13). In settings where visual warnings were on, the effect of sound stimulation was minimal (13). Adult patients with bilateral CIs or bimodal hearing solutions were tested with the devices on and off. A 45 dB narrowband white noise from the anterior side was used as a structured sound stimulus. They reported that the sound reduced the patient's anteroposterior head tilt in the dark when the devices were on (14). In another study, patients with CIs scored lower in the sensory organization test before surgery but approached the normal score in the first year after surgery. The authors concluded that this improvement could be due to increased auditory signals (15).

The effect is more prominent when electrical pulses stimulate the electrode. Biphasic pulse trains at a rate of 900/s improved tilt perception during the subjective visual vertical test in a group of children with CIs (5). However, the gait test yielded conflicting results. When patients with bilateral CIs or bilateral hearing aids were tested in the on/off condition of the devices during gait, there were no significant differences in the on/off states. There was also considerable variation in gait parameters between patients. In the end, the authors suggested that it worked in some specific groups of patients but could not determine a common specification for these patients (16).

Hallemans et al. (17) conducted a more detailed analysis while the patients were walking. Patients with bilateral areflexia and CIs were tested under implant on/off conditions. They also conducted an additional test by playing music from two speakers located at the end of the walkway at a comfortable level. Although there was little difference between the implant on/off conditions, pelvic motion, knee, ankle, and stride length increased, and stride duration was shortened when music was left on in the test room.

The activation in music-assisted environments has an additional positive effect on postural balance (18). We mostly observed a change in patients' postural conditions when the implant was on.

Interestingly, the positive correlation between age and fall risk index disappeared when music was on. Louza et al. (19) observed comparable results in older adults using music for stimulation. Auditory-motor interactions when playing music have been extensively reviewed extensively (20). Positive effects of music or rhythm were observed in movement disorders. The authors proposed that this effect might be due to the cognitive representation of music and added that further studies were needed to investigate the relationship between music and postural control in vestibular disorders.

Twenty-five children with unilateral implants and bilateral vestibular hypofunction were tested while the implant was turned on and off. The authors used three settings: a double stand with eyes open and closed, a double stand with a dual task, and a transition from a double stand to a single stand. Significant reductions in the anteroposterior and mediolateral displacements were found in the double stance-eyes open condition. They concluded that auditory information positively affected postural balance parameters (21).

There were some limitations in our study. The study group was not evaluated according to the function of the preoperative vestibular system. We used the implant of the condition as a baseline value. The study did not include parameters such as active electrode number, current level, or patient fitness status.

Conclusion

When we looked at individual data, we found that CI stimulation was affecting most patients' vestibular systems. The positive effect was more prominent than the negative effect. The parameters we used could not explain the difference between negatively and positively affected subjects. The age of the subject might be one of these factors. The disappearance of the positive correlation between age and fall risk when the music was on was supporting evidence.

Further studies using different parameters such as active electrode number, current level, patient fitness status, duration of implant use, directional sound stimulation, and proximity of electrodes to the vestibuler nerve will better understand the effect of CI stimulation on balance.

Ethics Committee Approval: This study was carried out in accordance with the principles of the Declaration of Helsinki. The approval was granted by the Pamukkale University Non-invasive Clinical Research Ethics Committee (no: 60116787-020/20941, date: 23.03.2018).

Informed Consent: All participants were informed and gave their written informed consent.

Authorship Contributions

Surgical and Medical Practices: F.N.A., F.T., A.A., F.A., Concept: F.N.A., F.T., A.A., F.A., Design: F.N.A., F.T., A.A., F.A., Data Collection and/or Processing: F.N.A., F.T., A.A., F.A., Analysis and/or Interpretation: F.N.A., F.T., A.A., F.A., Literature Search: F.N.A., F.T., A.A., F.A., Writing: F.N.A., F.T., A.A., F.A.

Conflict of Interest: The authors have no conflicts of interest to declare.

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Main Points

- The postural stability index was beyond normal limits in 78% of adult cochlear implant (CI) users.
- We found the fall risk index was high in 30%, and sensorimotor control was defective in 42% of patients.
- When the CI was on, the positive effect on postural stability was more prominent than the negative effect.
- Additional music also increased this positive effect in some patients.
- We could not find any specific parameter to explain the difference between patients affected positively and negatively.
- Age might be one of these factors, according to our data.

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