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The effects of cochlear implantation on vestibular function in 1–4 years old children

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ABSTRACT

Objectives: Although cochlear implants offer an effective hearing restoration option in children with severe to profound hearing loss, concern continues to exist regarding the possible effects of cochlear implantation on the vestibular system and balance.
Methods: In a prospective cohort study, 27 children with bilateral profound hearing loss (all candidates for cochlear implantation) were evaluated for their vestibular function before and after cochlear implantation. Vestibular evaluations consisted of Vestibular Evoked Myogenic Potentials, caloric testing and the Head-Impulse Test.
Results: Mean age at the time of cochlear implantation was 27.19 months. Without considering vestibular evaluation results, one of the ears was selected for surgery. Vestibular tests after surgery were not indicative of any statistically significant change in vestibular system or balance.
Conclusion: This limited data shows that cochlear implantation did not impair the vestibular system of these patients. By the results of our study we may conclude that round window implantation does not have any disturbing impact on vestibular function in children. The generalization of this result needs further research.

1. Introduction

Cochlear implantation (CI) has offered an effective hearing restoration option for children with bilateral severe to profound sensorineural hearing loss (SNHL) for the last three decades. Without a CI, severe to profound SNHL would lead to definite disability and can have adverse effects on quality of life and development of communication skills [1]. Despite the great effect of CIs on hearing, it may have some adverse insults on the vestibular system. In fact vestibular function might be impaired in some cases following CI. This may be due to damage to the vestibular receptors during traumatic insertion of the electrode into the cochlea [1,2]. The saccule appears to be the most commonly affected organ [3]. Vestibular dysfunction may affect patients' ability to form an accurate environmental percept and may impact balance [4].

Results of the previous studies show great variability in respect to the prevalence of vestibular dysfunction after CI. Some studies have shown that some of the vestibular function tests change following CI [5,6] and the others have not shown any significant vestibular changes [5,7]. This variability is partly due to study design, type of the vestibular assessments, and sample size, CI device, surgical techniques and time of the evaluation after surgery. Comparison between studies is difficult because of this variability.

Among vestibular system tests, the Vestibular Evoked Myogenic Potentials (VEMPs) explore the saccular system quantitatively and can be used in children [8]. The main objective of this study was to evaluate vestibular function before and after CI surgery in children. In this study VEMPs, the Head Impulse Test (HIT) and caloric testing were used as study tools.

2. Material and methods

In this prospective cohort study, 27 children with severe to profound SNHL within 12–56 months of age (mean 27.19 months)

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were recruited to the study. The study protocol was approved by the medical ethics committee of Baqiyatallah University of Medical Sciences. All of the CI candidates were the waiting list for receiving a unilateral CI for the first time. The test procedure was explained to parents and they signed a written consent. All of the tests were non-invasive and patients' information was kept secret. Parents could leave the research process any time they wanted.

Children were tested one week prior to cochlear implantation. The test battery consisted of VEMPs, caloric testing and the HIT.

Then 6–8 weeks after the surgery and before activating CI device for the first time, all of the children were re-evaluated. Therefore none of the infants had experienced electrical activity before vestibular tests and all the results could be attributed to surgical process. Due to young age and lack of cooperation, caloric testing could be tested only on 13 children and the HIT on 8 children. The VEMP testing was performed on all the subjects. Therefore, the VEMP test was main vestibular test in present study.

2.1. VEMP testing

Recordings were performed using ICS Chartr EP manufactured by BioLogic (GN Otometrics, Denmark) with 500 Hz tone burst at 90 dBnHL, with alternating polarity and 5.1/s rate. Stimuli were delivered through TDH39 headphones (Telephonics). The electrode array was as follows: reference electrode on middle part of sternocleidomastoid muscle (SCM), active electrode on upper part of sternum, ground electrode on forehead. Children sat on their parent's lap. Subjects turned their head to the contralateral side, thereby tensing the ipsilateral SCM muscle. The device showed and monitored muscle contraction (RMS) automatically. The amplitude of biphasic p13-n23 wave was measured from the most positive peak of the wave (p13) to the most negative peak (n23) in microvolts.

2.2. Caloric testing

Caloric testing is a part of Videonystagmography (VNG) test battery. It shows low-frequency function of lateral semicircular canal. Caloric testing with air stimulation (24 °C and 50 °C) was done with Interacoustic VNG test system (Denmark). Presence of jerk nystagmus in response to cold air was defined as normal. Caloric stimulation is not well tolerated in young children.

2.3. HIT

The head-impulse test, subjective test of the horizontal semicircular canal, was done manually. When the head is turned to one side in the plane of the semi-circular canal to be tested, the vestibulo-ocular reflex (VOR) maintains visual fixation. The breaking of visual fixation, shown by a corrective saccade, indicates a lateral canal disorder. As the repetition of this movement is not well tolerated, this test requires an experienced operator. This test is possible as soon as the child can hold his head steady.

2.4. Surgical approach for CI

Under general anesthesia, after post auricular incision, simple mastoidectomy and facial approach were performed, the round window membrane tore off, and the device electrode was gently and non-traumatically fully introduced by the first author.

3. Results

27 children (11 female and 16 male) 12–56 months old (mean 27.19 ± 12.55 months) with severe to profound SNHL were included in this study from Baqiyatollah cochlear implant center (Tehran, Iran). Values written within parentheses are standard deviations (SDs).

Paired *t*-test showed no significant change in mean p13-n23 amplitude in both ears before and after surgery (p value = 0.23 for right ear and = 0.09 left ear) (Table 1).

Cochlear Implant surgery was performed on right ear in 22 (±81.5%) children and on left ear in 5 children (±18.5%) (Table 2). Paired *t*-test showed that "operation ear" did not have any significant effect on VEMP amplitude (p value = 0.47 for right ear and = 0.46 for left ear).

The cochlear implant device in 10 (37%) subjects was "Advanced Bionics Cochlear Implant" (Advanced Bionics, Switzerland) and in 17 (63%) subjects was "Cochlear Nucleus Implants" (Cochlear, Australia) (Table 3). Independent *t*-test showed that device type did not have any significant effect on VEMP amplitude after surgery (p value = 0.20 for right ear and = 0.36 for left ear).

Before surgery two children did not have VEMP responses in either ear, two children did not have VEMP responses in the right ear and three children did not have VEMP responses in the left ear. Only one child who had VEMP responses before surgery, lost the response completely after CI surgery (left ear).

The caloric testing could be performed on only 13 children before and after surgery. Other children were uncooperative and could not tolerate stimulation. Among 13 children, caloric responses in one patient (3.7%) were absent in both ears and the remaining children showed normal response. Results did not change after surgery (Table 4).

The HIT could be performed on only 8 patients before and after surgery as other children were uncooperative. All 8 subjects had normal HIT results. This test was a subjective test and absence of a corrective saccade was interpreted as a normal result.

Pearson correlation showed good correlation between HIT results and caloric responses ($r = 0.54$, p value = 0.00). Correlations between caloric responses and VEMPs ($r = -0.20$, p value = 0.29) and between the HIT and VEMPs ($r = 0.22$, p value = 0.26) were insignificant.

4. Discussion

The results of present study showed that cochlear implant surgery did not have any significant effect on vestibular function at least in children younger than 5 years old. Effect of CIs on vestibular function and balance was first evaluated on adults. Ito (1998) examined vestibular function in 55 adult patients who underwent CI surgery. A caloric stimulation test was performed before surgery, and 67% of patients showed hyporeflexia or areflexia. One month after surgery 38% of patients showed functional deterioration. After surgery 47% of the patients reported subjective dizziness and 18% of the patients felt dizziness when device was "on", indicating that electrical current spread from the implant device to the vestibular nerve. The others did not report any relationship between the use of their CIs and dizziness [9]. We performed vestibular tests before using the CI devices for the first time, so there was not any interfering electrical activity. Jacot et al. (2009) tried to find prevalence and types of vestibular impairments after cochlear implantation. From 89 children, 51 (71%) had changes in vestibular function including 10% who showed lack of caloric response in same side of CI. Others developed ipsilateral low or high caloric responses. Vestibular modifications occurred after the third month of surgery. In long-term follow-up, two of the 7 patients with ipsilateral lack of caloric responses, showed partial vestibular recovery. They recommended that semicircular canal and otolith functional tests are vital part of implantation to assure that dysfunctional vestibule is considered for CI surgery [10]. Their results do not match ours. We

Table 1
Pre- and Post-surgical VEMP results.

	Right-ear-evoked VEMP amplitude (μv)	Left-ear-evoked VEMP amplitude (μv)
Before surgery	57.31 (±30.85)	50.00 (±31.95)
After surgery	54.27 (±31.96)	46.71 (±31.40)

Table 2
Surgery ear and Post-surgical VEMP results.

	Right-ear-evoked VEMP amplitude (μv)	Left-ear-evoked VEMP amplitude (μv)
Right ear operation	52.14 (±32.99)	48.87 (±30.99)
Left ear operation	63.67 (±28.12)	42.38 (±35.06)

Table 3
CI device and post-surgical VEMP results.

	Right-ear-evoked VEMP amplitude (μv)	Left-ear-evoked VEMP amplitude (μv)
Advanced Bionics	72.07 (±20.88)	48.87 (±23.54)
Cochlear Nucleus	63.81 (±33.18)	37.21 (±31.40)

Table 4
Caloric results before and after CI.

	Before surgery		After surgery	
	Right ear	Left ear	Right ear	Left ear
Caloric response (SPV degree)[a]	18.30 (±5.58)	17.60 (±5.70)	17.69 (±5.64)	18.46 (±5.95)

[a] Slow Phase Velocity.

may conclude that electrical stimulation by the functioning device may have caused vestibular damage.

Jin et al. (2006) studied the diagnostic value of VEMPs in cochlear implant patients. The click-evoked myogenic potentials of twelve children who underwent CI were investigated. Before surgery, six of the twelve children showed normal VEMPs, one showed a decrease in the amplitude and five showed no VEMP response. After surgery, with turning off the device, one child showed a decreased VEMP amplitude and eleven showed no VEMPs at all. With the cochlear implant device on, four children showed VEMPs and eight did not. The results suggest that the saccule of most children with cochlear implants can easily be damaged in CI surgery. Also, in most of the children, the vestibular nerve was not stimulated by the cochlear implant and this stimulation did not spread to the vestibular nerve in children [6]. We may conclude that traumatic electrode insertion may have causative impact on destroying saccular receptors. Todt et al. (2008) investigated the impact of different cochleostomy techniques on vestibular receptor integrity and vertigo after CI. 62 patients (17–84 years of age) underwent CI via an anterior or round window insertion approach. The patients were tested by a questionnaire (Dizziness Handicap Inventory, DHI), caloric irrigation (VOR) and by VEMP recordings for saccular function. Significant differences of postoperative VEMP responses and electromystagmography (ENG) results were found with respect to the 2 different insertion techniques. The results showed that round window approach for electrode insertion should be preferred to decrease the risk of loss of vestibular function and the occurrence of vertigo [1]. This study supports that round window membrane insertion has priority for prevention of saccular damage during CI surgery. Thierry et al. (2015) showed that 20% of CI could have worsened vestibular function. They suggested that vestibular function evaluations should be part of the choice in CI candidacy and side of the implantation and they stated that vestibular tests are difficult to perform in children [11].

Enticott et al. (2006) searched for incidences of vestibular dysfunction after cochlear implantation. 146 adult implant recipients, mean age, 60 years (range, 20–90 years old) were selected. Subjective assessments and bithermal caloric tests were used. 32% of patients reported vestibular disturbance and poor caloric results in the implanted ear after surgery [12]. Tin and Linthicum (2002) studied histopathologic changes of the vestibular end organs after CI. Eleven pairs of temporal bones from unilateral implantees were studied. Significant histopathologic damage of the vestibular end organs was noted in 6 patients (54.5%) [13]. Todt et al., 2008 proposed that saccular impairment is induced most likely by the insertion trauma of the cochlear implant electrode when advancing it into the inner ear. A possible coactivation of the inferior vestibular nerve by the electrical stimulation might have effects in generating dizziness after implantation [3]. We may conclude that soft insertion of the device electrode helps save saccular function. Handzel et al. (2006) described the histology of the peripheral vestibular system in temporal bones from patients who had undergone CI surgery in life. Their age range at the time of implantation was between 52 and 82 years old and they had their device for 1–15 years before death. Cause of bilateral deafness was meningitis, ototoxic drugs, noise induced, otosclerosis, progressive idiopathic, Ménière's disease and measles. In 59% of the implanted bones, the cochlea was hydropic, and in the majority of these bones the saccule was collapsed. CI does not cause deafferentation of the peripheral vestibular system. Cochlear hydrops along with saccular collapse is common and may cause delayed vertigo attacks, resembling Ménière's syndrome. Hydrops may happen as a result of endolymphatic flow disruption in the ductus reuniens or in the hook of the cochlea or by damage to the lateral cochlear wall in implantation [14]. These results are different from present study. Main differences between our study and previous ones is the age range and performing vestibular tests before activating cochlear implant prostheses. So our subjects did not have any experience of electrical stimulation.

Buchman et al. (2004) examined potential risk for vestibular system impairment or stimulation in CI. Assessment was performed on 86 patients. These assessments consisted of DHI, caloric irrigations (ENG) and rotational chair with sinusoidal harmonic accelerations (SHA), and Computerized Dynamic Platform Posturography (CDP) at preoperative, 1-month, 4-month, 1-year and 2-year post implantation. Selecting the ear for CI was carried out without respect to the preoperative vestibular function test results. Unilateral CI rarely results in significant adverse effects on the vestibular system as measured by these tests. Unlikely, patients with CI, showed significant improvements in the objective measures of postural stability as measured by CDP. Although VOR testing demonstrated some decreases in the response, patients did not suffer from disabling vestibular effects following CI. The mechanism underlying these findings are still under research. These findings should be a part of CI counseling [5]. The results of this study are in agreement with ours.

Vibert et al. (2009) determined the influence of CIs on vestibular function. 15 patients (9–77 years old) underwent a vestibular examination before and after CI. ENG was performed on patients. Pre- and post-operative evaluation included caloric testing and rotatory chair test. CIs did not usually disturb vestibular function, but temporary semicircular canal dysfunction was seen in 20% of cases. Otolithic function remained normal in CI patients [15]. This result is in agreement with our research.

5. Conclusion

A comparison of vestibular function before and after CI surgery in children to the best of our knowledge, has not been published especially for this age range. By the results our study and in accordance of some other studies we may conclude that round window CI surgery might not have any disturbing impact on vestibular function in children. However, further studies should be performed to confirm the results. We did not evaluate vestibular function after device activation, therefore this result cannot generalize to cochlear implant device activation.

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