Research Article

# Can Video Head Impulse Test Determine the Early Effect of Cochlear Implantation on the Semicircular Canals Function?

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## Highlights

- vHIT is a useful method to detect an early effect of implantation on SCCs functions
- The effect of cochlear implantation is more obvious for lateral and superior SCCs

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## ABSTRACT

**Background and Aim:** Although cochlear implantation (CI) is a safe surgical procedure for severe to profound sensorineural hearing loss (SNHL) but, due to the embryological and anatomical connection between the vestibular and cochlear structures, vestibular dysfunction may occur after CI. Video head impulse test (vHIT) is a reliable test for assessing the function of semicircular canals (SCCs). This study aimed to determine the early effect of CI on SCCs function, by comparing pre- and post-operative vHIT results.

**Methods:** In this cross-sectional study, participants were 22 adults with SNHL scheduled for unilateral CI in the right ear and 22 age-matched healthy subjects as a control group. The vHIT was conducted before and two weeks after CI.

**Results:** The mean vHIT gains in the SNHL group were significantly lower than in controls, with a large effect size. Furthermore, the mean vHIT gains in the right lateral SCCs ($p<0.001$) and right anterior SCCs ($p=0.003$) were significantly reduced after CI, compared to the gain values before CI, with a large pooled effect size. However, these differences were not statistically significant for the right posterior SCCs. The comparison of vHIT gains in the non-implanted ear showed no statistically significant difference between pre- and post-operative phases.

**Conclusion:** The vHIT is a useful clinical method to detect the early effects of CI on the function of SCCs. These effects are more obvious in the lateral and superior SCCs in the implanted ear.

**Keywords:** Cochlear implantation; semicircular canals; video head impulse test

## Introduction

Cochlear implantation (CI) currently is an effective approach for restoring hearing in patients with severe to profound sensorineural hearing loss (SNHL) [1-3]. It is a safe surgical method but, due to the proximity of the vestibule and cochlea structures, vestibular dysfunction may also occur following surgery [4-6]. It has been recognized that vestibular dysfunctions after CI occurs quite frequently, with a reported incidence of 3%-70% [7, 8]. This variation is expected since there are five peripheral vestibular system organs and various tests for each of them. The types of dizziness following CI vary widely, from a gradual sense of light-headedness or unsteadiness to acute attacks of vertigo. The exact mechanism for vestibular dysfunction following CI is still unclear. It has been suggested that CI may potentially lead to vestibular dysfunction through direct electrical stimulation, direct traumatic damage to the vestibular sensory cells, change in the fluid balance within the inner ear, or inflammatory reactions [9, 10].

Video head impulse test (vHIT) is a useful method for quantitative assessment of eye movements in response to head impulses, and has become popular in recent years. It examines the function of all semicircular canals (SCCs) and evaluates the sensitivity of the vestibular system at higher frequencies [11-13]. The vHIT evaluates the vestibulo-ocular reflex (VOR) by observing rapid eye movements in response to short head movements in such a way that only one SCC is stimulated [14-17]. The vHIT is quick for perform, and unlike a caloric test, does not induce nausea/vomiting or vertigo [17]. Moreover, it is easily conducted and well-tolerated. Then, it can be utilized as an effective method to assess vestibular functions after otologic surgeries [10].

Several studies have used vHIT to quantify VOR function in people with CI. Barbara et al. [4] evaluated vestibular function in a group of 27 patients (aged 19-83 years) undergoing unilateral CI. All surgeries were conducted with a round window or extended round window insertion methods. The authors recorded the vHIT and cervical vestibular evoked myogenic potentials (cVEMP) preoperatively and postoperatively in both implanted and non-implanted ears. Their findings revealed that the vHIT gain of the lateral, superior, and posterior SCCs were significantly reduced in 15 (55.6%), 7(25.9%), and 9 (33.3%) of the implanted ears, respectively. In all hypofunctional patients, cVEMP responses were absent. Moreover, in the patients (21.7%) in whom cVEMP were preoperatively present and normal on the implanted side, the absence of a cVEMP response was postoperatively recorded. In a retrospective cohort study, Stultiens et al. [7] evaluated the impact of CI on the function of SCCs. Their findings revealed that the mean vHIT gain reduced with 0.04, 0.05, and 0.06 for lateral, posterior, and anterior SCCs, respectively.

Assessment of VOR gain early after CI provides an opportunity for specialists to acquire a better understanding of probable surgical damage to the inner ear components. The vHIT is a rapid, safe, and repeatable test for objective assessment of VOR gain early in the CI recovery period when patients are unlikely to tolerate other vestibular function tests. Furthermore, it can help determine if transient VOR change contributes to post-CI vestibular dysfunctions [6, 18-20]. However, data on the value of the vHIT for the evaluation of vestibular function in patients who received a CI are limited. The current study aimed to determine the early effect of CI on SCC function, by comparing pre- and post-operative vHIT test results.

## Methods

### Participants

In this analytical cross-sectional design, participants were 28 post-lingual adults with bilateral severe to profound SNHL (aged 28-45 years), recruited from March 2019 to June 2021. All subjects were scheduled for unilateral CI surgery. Of 28 samples, six were excluded due to lack of cooperation in vestibular testing, or loss to follow-up. Finally, 22 cochlear-implanted patients entered the study. All patients were selected from the national CI registry database [21]. Exclusion criteria were a history of mental or psychological disorders, systemic diseases (e.g. renal failure, diabetes), middle ear disorders, dizziness/vertigo, imbalance, inner ear anomalies based on magnetic resonance imaging and temporal bone computed tomography, and lack of cooperation. Twenty-two age-matched healthy subjects (aged 28-45 years) with normal hearing thresholds were also recruited as a control group.

All experimental procedures were in compliance with the ethical regulations for research on human subjects set by the Declaration of Helsinki.

### Cochlear implant surgery

An experienced surgeon conducted the CI. For all CI patients, the electrodes were inserted via a cochleostomy anterior inferior to the round window niche with a minimally invasive method. All implanted electrodes were fully inserted in the right ear cochlea and the electrodes array insertion was checked by X-ray imaging. During the surgery, no steroid medications were administered intratympanically or intravenously, or by intra-cochlear approaches.

### Vestibular testing

The EyeSeeCam system (Interacoustics, Middelfart, Denmark) was used for the vHIT. Prior to testing, calibration of the device was conducted based on the standard recommendations. Patients were asked to sit in an upright position and fixate on a static target in front of them. Then, their head was suddenly and unpredictably moved with an amplitude of 5-15° and at a high peak velocity range of 150-300°/s. To assess the lateral SCC function, the head movements were applied in the right or left direction. To evaluate the anterior and posterior SCC functions, patients' heads were moved down or up in the sagittal plane and then turned about 45° to the right to assess the left anterior right posterior (LARP) plane, and 45° to the left to assess the right anterior left posterior (RALP) plane. The VOR gain by the vHIT was calculated by the ratio of eye velocity (°/s) to head velocity (°/s) for each SCC. The VHIT gain in healthy individual's ranges from 0.7 to 1.0. This range for lateral SCC is usually higher than for anterior and posterior SCCs across different head velocities. This variability in vHIT gain may be due to factors such as patients' cooperation, goggle slippage, age, or gender [19]. We conducted the vHIT one week before and two weeks after the CI surgery [22].

### Data analysis

Data were described using frequency, mean, and percentage. Shapiro-Wilks and Levene's tests were used to assess for normality of data distribution and the equality of variances, respectively. Paired sample t-test was used to analyse difference in vHIT gain between the pre-operative and post-operative conditions. Cohen's d was also utilized to express the effect size [23]. Statistical analyses were performed in SPSS v.17 software. A $p<0.05$ was considered as the statistically significance level.

## Results

A total of 22 CI patients (13 males and 9 females, mean age=35.36±7.58 years) and 22 healthy subjects (11 males, 11 females, mean age=37.55±8.21 years) participated in this study. We found no significant differences between the two groups in terms of gender ($p=0.763$) based on chi-square test results and age ($p=0.365$) based on independent t-test results. The etiology of SNHL was idiopathic (n=10), meningitis (n=2), Meniere's disease (n=2), autoimmune inner ear disease (n=1), otosclerosis (n=1) head trauma (n=3), and chronic otitis media (n=3).

Table 1 shows the vHIT gain values in different SCCs for control and SNHL groups. Our results indicated that the mean vHIT gains in the SNHL group were significantly lower than in controls, with a large effect size (Cohen's $d>0.8$). Furthermore, no significant difference in vHIT gain between the right and left sides was observed in any group. In our study, all patients received CI in the right ear. No noticeable complications were reported during surgery. Five patients (22.72%) had complaints about dizziness after surgery: one had instability (4.54%), two had vertigo (9.08%), and two complained of imbalance (9.08%).

Table 2 presents the pre- and post-operative vHIT gains for lateral, anterior, and posterior SCCs. The results of paired t-test showed that the mean vHIT gain in the right lateral SCCs ($p<0.001$, $d=1.78$) and right anterior SCCs ($p=0.003$, $d=0.95$) were significantly reduced after CI compared to the gain values before CI, where there was a large pooled effect size. However, these differences were not statistically significant for the right posterior SCCs ($p=0.089$). The mean vHIT gain in the left SCCs was not statistically significant between the pre- and post-operative phases ($p>0.05$).

## Discussion

Although CI is a non-invasive and successful surgical approach that has been used for SNHL rehabilitation for years, it may induce vestibular dysfunction and dizziness, especially early after surgery [24]. The exact mechanism of vestibular dysfunction following CI is not unknown yet. It seems that the direct traumatic damage during insertion of multiple-channel implants, the opening of the cochlea that alters the cochlear fluid homeostasis (with endolymphatic hydrops or perilymphatic loss) and leads to inner ear fluid imbalance, the inflammatory process due to the presence of a foreign material in the body that may lead to fibrotic process, and the electrical vestibular stimulation by the device may influence vestibular function in CI recipients [25-27]. Bittar et al. [22] evaluated 31 patients (mean age=49.6±15.3 years) scheduled for unilateral CI and found that six patients had dizziness complaints after implantation: two with imbalance, two with vertigo, and two complained of instability.

**Table 1.** Comparison of the mean and standard deviation of vestibulo-ocular reflex gain between healthy adults (n=22) and patients with sensorineural hearing loss (n=22) before cochlear implantation

| Semicircular canal | Test group | Control group | p | Effect size (d) |
|---|---|---|---|---|
| Right lateral | 0.89±0.058 | 0.97±0.029 | <0.001 | 1.73 |
| Left lateral | 0.90±0.082 | 0.97±0.033 | 0.012 | 1.12 |
| Right anterior | 0.88±0.054 | 0.96±0.025 | 0.001 | 1.90 |
| Left anterior | 0.89±0.062 | 0.95±0.026 | 0.001 | 1.26 |
| Right posterior | 0.88±0.058 | 0.97±0.022 | <0.001 | 2.05 |
| Left posterior | 0.90±0.046 | 0.98±0.022 | <0.001 | 2.21 |

Our findings indicated a significant difference in vHIT gain between the control and SNHL groups. Because of the close proximity of the vestibule and cochlea structures, disruptions in cochlear function which can lead to SNHL, can result in vestibular dysfunction; these structures share the membranous labyrinth of the inner ear [28]. We also found that the mean vHIT gain in the right lateral and right anterior SCCs were significantly decreased after CI, where the effect size was large. However, these gain differences were not statistically significant for the right posterior SCC and the effect size was large (d=0.73).

Jutila et al. [29] determined the alternation in vestibular performance in 44 patients receiving a unilateral CI. They recorded horizontal high-frequency VOR using the motorized head impulse rotator before, two months after (early), and 19 months after (late) CI. Their findings revealed that the mean VOR gain in the implanted ear was 0.77 before surgery which changed to 0.75 two months after, and 0.73 19 months after surgery. These VOR changes were not statistically significant. They also found that VOR gain was reduced more in four patients (10%) in the early post-operative and in two patients (7%) in the late post-operative phases. The authors concluded that late high-frequency deterioration of vestibular function is rare but possible after CI surgery. In other study by Wang et al. [8], 16 children with a large vestibular aqueduct syndrome were participated. Otolith and SCC functions were evaluated prior to CI and 12 months after using cVEMP, Ocular VEMP (oVEMP), and vHIT tests. Systematic measurements before and after CI showed that saccular and utricular functions were involved in these patients according to abnormal cVEMP and oVEMP responses. Contrary to our findings, none of three SCCs were affected after implantation. They also reported that, in contrast to children with a normal cochlea, children with enlarged vestibular aqueduct are more likely to preserve their otolith function following CI surgery. Nassif et al. [25] also reported the high-frequency VOR gain of lateral SCC in 16 children (aged 5-17 years) receiving bilateral (n=4) and unilat-

**Table 2.** Comparison of the mean and standard deviation of vestibulo-ocular reflex gain before and after cochlear implantation in patients with sensorineural hearing loss who were candidate for cochlear implantation

| Semicircular canal | Time of assessment | | p | Effect size (d) |
|---|---|---|---|---|
| | Pre-CI | Post-CI | | |
| Right lateral | 0.90±0.044 | 0.77±0.093 | <0.001 | 1.78 |
| Left lateral | 0.89±0.056 | 0.86±0.074 | 0.144 | 0.35 |
| Right anterior | 0.89±0.074 | 0.81 ±0.092 | 0.003 | 0.95 |
| Left anterior | 0.88±0.066 | 0.87±0.047 | 0.425 | 0.17 |
| Right posterior | 0.87±0.094 | 0.81±0.068 | 0.089 | 0.73 |
| Left posterior | 0.87±0.061 | 0.87±0.064 | 0.227 | 0 |

CI; cochlear implantation

eral (n=12) CI compared to a group of 20 age-matched healthy children. In CI patients, vHIT was evaluated for both ears in the "CI-OFF" and "CI-ON" conditions. Their results revealed that in the unilaterally implanted group, the VOR gain at the "CI-OFF" condition was significantly lower than at the "CI-ON" condition, both in the non-implanted and implanted ears. However, in the bilaterally implanted group, there was no significant difference between the "CI-OFF" and "CI-ON" conditions in any either ear.

In the present study, the CI electrodes were inserted via a cochleostomy approach. Todt et al. [30], in a retrospective cohort study, evaluated the effect of different cochleostomy methods on vestibular receptor integrity and vertigo after CI. They suggested that the round window technique (compared to the anterior technique) for the insertion of CI electrodes should be preferred to reduce the risk of vestibular dysfunction and the occurrence of dizziness or vertigo. In a double-blind randomized clinical trial, vestibular function after CI surgery was compared between the groups received round window insertion (n=29) and cochleostomy (n=23) approaches. vHIT test was conducted preoperatively, one day and one month after the operation. Their results demonstrated no statistically significant changes in the vHIT gain between the two groups [31]. It is noteworthy that the incidence rate of vestibular dysfunctions after CI may vary. An important factor that contributes to the inconsistent results is the fact that CI users are not homogeneous in different studies. They are selected from different age groups, including children and older adults, suffering from severe-to-profound SNHL. Different age groups have different etiologies for hearing impairment and can influence the vestibular system function even after CI surgery. Surgical procedures can also affect the CI outcomes. The electrode insertion site, electrode length, electrode insertion speed, and electrode insertion depth may have a significant impact on the vestibular system integrity [30-32].

The present study had some limitations. There were different causes of SNHL in the patients, sample size was small, and the definite cause of hearing loss was not being determined. Therefore, we could not determine the relationship between the etiology of SNHL and the risk of imbalance. Moreover, we only studied the effect of CI on the function of SCCs; the effect of CI on otolith function (e.g. through VEMP responses) was not investigated. Therefore, further studies with a complete vestibular system examination are required to confirm our results.

## Conclusion

The vHIT is a useful method to detect the early effects of CI on the function of SCCs. These effects are more prominent on the lateral and superior SCCs in the implanted ear.

## Ethical Considerations

### Compliance with ethical guidelines

The regional Ethical Committees approved this study (Registration number: IR.AJUMS.REC.1398.582). All participants signed a written informed consent before the study.

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### Authors' contributions

MK: Study design, analysis of the results, writing the manuscript; RA: Study design, data collection, interpretation the data, writing the manuscript; ASM: Statistical analysis, Interpretation the data, writing the manuscript; AK: Study design, writing the manuscript; SS: Study design, data collection, writing the manuscript.

### Conflict of interest

The authors have no conflicts of interest to disclose.

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