Journal of Neonatal Surgery
ISSN(Online): 2226-0439
Vol.13, (2024)
https://www.jneonatalsurg.com

OPEN ACCESS

Long-Term Impact of Cochlear Implants on Vestibular Function in Adults and Children

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.Cite this paper as Samiullah Shah, Madeeha Sharif, Moumita Sikder, Maria Mahmood, Ali Khan, Ahsan Qureshi, (2024) Long-Term Impact of Cochlear Implants on Vestibular Function in Adults and Children..*Journal of Neonatal Surgery*, 13, 1747-1753

ABSTRACT

Background: Cochlear implants are a standard intervention for profound hearing loss. The benefits of hearing improvements post-implant are undeniable. However, the long-term effects on balance and vestibular function and balance pathways remain a concern. The vestibular organs and cochlea are interconnected, so knowing the effects of cochlear implants on the vestibular organs balance function integration will result in improved care and system development. Understanding how implantation affects balance and vestibular pathways in both adults and children is essential for improving long-term care.

Methodology: This study included 72 participants who underwent unilateral cochlear implantation between October 2023 and October 2024 at Jhalawan Medical College Khuzdar. A observational design was used. Vestibular function was assessed before implantation and again 12 months after surgery. The test battery included the video head impulse test (vHIT), cervical and ocular vestibular evoked myogenic potentials (cVEMP/oVEMP), caloric irrigation, Romberg test, and timed up-and-go (TUG). Demographic variables such as age, sex, diagnosis, implant side, and duration of hearing loss were recorded.

Results: Changes in vestibular functioning became evident in the longitudinal data acquired from the participants. Declines in the vHIT gains occurred the most in the lateral semicircular. Increased unilateral weakness was chronicled in the caloric test. Both the oVEMP and cVEMP demonstrated decreased amplitudes and increased latencies. In functional testing, there was slight decline as measured by shorter Romberg stances and longer timed-up-and-go (TUG) test scores. In the aggregate, the data demonstrated that cochlear implantation alters the vestibular pathways, even if some of the participants did not have pronounced deficits.

Conclusion: The results indicate that clinically significant changes pertaining to balance occur in children and adults post cochlear implantation. Consequently, pertinent pre-operative counselling, monitoring post-operatively, and swift referrals for balance rehabilitation when appropriate, must be emphasized. Expanding upon this, further studies, particularly those pertaining to advanced follow-up duration, will enhance our understanding of vestibular decline predictors and advanced methodologies that preserve balance functionalities.

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Keywords: *Cochlear implant; Vestibular function; vHIT; VEMP; Caloric test; Balance; Adults; Children; Long-term outcomes*.

1. INTRODUCTION

Cochlear implants have transformed the management of severe hearing loss, offering meaningful auditory restoration to individuals who do not benefit from conventional hearing aids. Over the past decade, advances in surgical techniques and device technology have improved speech perception and quality of life for a wide range of age groups. Despite these achievements, concerns persist regarding the impact of cochlear implantation on the vestibular system. Because the cochlea and vestibular organs are interconnected within the bony labyrinth, any surgical manipulation has the potential to disturb balance-related structures [1-3].

Several clinical observations show that some individuals experience dizziness, imbalance, or changes in spatial orientation

2. METHODOLOGY

This research was done in the Department of Otorhinolaryngology at October 2023 and October 2024, where services for vestibular evaluation and cochlear implantation are available, as observational study. The research study focused on 72 adult and child participants with a unilateral cochlear implant. An average of 3.2±1.45 years had passed since the majority of participants had first received cochlear implants. This period of time, however, pertains to the participants' clinical history rather than the length of the study. The collection of the data occurred over the course of one year, between October 2023 and October 2024.

The study incorporated both pre-implant and post-implant vestibular evaluations. Pre-implant data were obtained from hospital records, while postoperative assessments were carried out at least three months after surgery to avoid capturing temporary, immediate postoperative effects. Only participants with complete information were included in the final analysis.

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The evaluation of vestibular system functionality followed established procedures. The vHIT involved measuring gain of the horizontal, superior, and inferior semicircular canals. Caloric tests aimed at revealing unilateral weakness employed warm and cold irrigations. The Romberg and Timed Up and Go (TUG) tests were used to systematically evaluate functional balance. Every test was repeated three times, and the mean value was recorded to reduce variability.

Demographic and clinical variables such as age, sex, time since implant surgery, duration of hearing loss, and type of implant device were documented. For children, developmental information and caregiver observations regarding gait or instability were noted. In adults, occupational activity and functional mobility were also recorded, as these could influence balance outcomes.

All data were entered immediately after collection to avoid errors. Statistical analysis was performed using appropriate comparative tests based on data distribution. Pre-implant and post-implant vestibular values were compared, and a p-value below 0.05 was considered statistically significant. Ethical approval was obtained before starting the study, and written informed consent was secured from adult participants or parents/guardians of children.

3. RESULTS

A total of 72 participants were included in the study, consisting of both adults and children who underwent cochlear implantation. Their baseline characteristics showed a fairly even spread between age groups, with a slight predominance of adults. Males and females were almost equally represented. The causes of hearing loss varied, but congenital and infectious etiologies were the most frequently observed. Most participants had a history of long-standing hearing impairment before receiving the implant. The cochlear implants were placed on either side with nearly equal distribution. The duration since implantation also showed a moderate range, allowing assessment of long-term vestibular outcomes.

Table 1. Demographic and Baseline Characteristics (n = 72)

Variable	Category / Mean ± SD	n (%)
Age (years)	29.8 ± 12.4	–
Age Group	Children (≤18 years)	34 (47.2)
	Adults (>18 years)	38 (52.8)
Gender	Male	39 (54.2)
	Female	33 (45.8)
Cause of Hearing Loss	Congenital	28 (38.9)
	Infectious	17 (23.6)
	Ototoxic	13 (18.1)
	Traumatic	8 (11.1)
	Idiopathic	6 (8.3)
Duration of Hearing Loss (years)	6.3 ± 3.8	–
Side of Cochlear Implant	Right	37 (51.4)

	Left	35 (48.6)
Age at Implantation (years)	Children: 8.6 ± 6.1	–
	Adults: 31.4 ± 10.2	–
Duration Since Implantation (years)	3.2 ± 1.4	–

When comparing vHIT findings before and after implantation, a noticeable reduction in gain values was observed across all semicircular canals. Although most reductions were mild, the difference was statistically significant. An increase in corrective saccades was also noted in the long-term follow-up, suggesting mild compromise of vestibular reflex pathways in a subset of individuals. Even though the impairment was not severe for most participants, these changes point toward a measurable influence of the implant on vestibular function over time.

Table 2. Pre-Implant vs Long-Term Post-Implant vHIT Results

Test Parameter	Pre-Implant Mean ± SD	Post-Implant Mean ± SD	p-value
vHIT Gain (Lateral Canal)	0.86 ± 0.12	0.79 ± 0.15	0.021
vHIT Gain (Anterior Canal)	0.82 ± 0.11	0.77 ± 0.13	0.038
vHIT Gain (Posterior Canal)	0.84 ± 0.10	0.78 ± 0.14	0.029
Corrective Saccades (presence)	9 (12.5%)	17 (23.6%)	0.044

Both cervical and ocular VEMP recordings demonstrated a downward trend in amplitude following implantation. Latency values also showed mild prolongation. Although these changes were not severe enough to suggest complete saccular or utricular dysfunction, the statistical significance indicates that the implant procedure may have contributed to subtle long-term effects on otolithic pathways. These findings help explain why some individuals experience intermittent imbalance after cochlear implantation.

Table 3. Cervical and Ocular VEMP Responses

Parameter	Pre-Implant Mean ± SD	Post-Implant Mean ± SD	p-value
cVEMP Amplitude (µV)	82.4 ± 21.3	69.1 ± 25.8	0.017
cVEMP P13 Latency (ms)	14.2 ± 1.5	15.0 ± 1.8	0.031
oVEMP Amplitude (µV)	6.8 ± 2.4	5.3 ± 2.0	0.026
oVEMP N10 Latency (ms)	10.7 ± 1.1	11.3 ± 1.4	0.040

Caloric testing revealed an increase in unilateral weakness values in the post-implant group. Although the rise was generally modest, it was statistically meaningful. Directional preponderance, however, did not show a significant shift. This pattern indicates that cochlear implantation may have a greater impact on lateral canal responsiveness than on directional bias. Most of the participants retained adequate function, but a subset displayed reduced caloric responses that could contribute to occasional motion-related imbalance.

Table 4. Caloric Test Results

Parameter	Pre-Implant Mean ± SD	Post-Implant Mean ± SD	p-value
Unilateral Weakness (%)	18.4 ± 10.2	24.1 ± 12.6	0.047
Directional Preponderance (%)	13.1 ± 7.8	15.8 ± 8.3	0.112 (NS)

Functional balance tests showed a decline in post-implant performance, although the changes remained in a mild range. In adults, the Dizziness Handicap Inventory scores increased, reflecting greater awareness of imbalance during routine activities. Children displayed a small reduction in their Pediatric Balance Scale scores, indicating that the long-term vestibular effects were present but not severe enough to hinder daily functioning. Most participants were able to adapt well over time, but the measurable decline highlights the clinical importance of vestibular monitoring after implantation.

Table 5. Functional Balance Testing

Test	Pre-Implant Mean ± SD	Post-Implant Mean ± SD	p-value
Romberg (Eyes closed, seconds)	23.4 ± 6.7	20.1 ± 7.2	0.033
Timed Up and Go (seconds)	11.2 ± 2.1	12.6 ± 2.8	0.019
Pediatric Balance Scale (Children)	51.6 ± 4.2	49.2 ± 5.1	0.041
Dizziness Handicap Inventory (Adults)	18.4 ± 6.9	24.3 ± 7.8	0.022

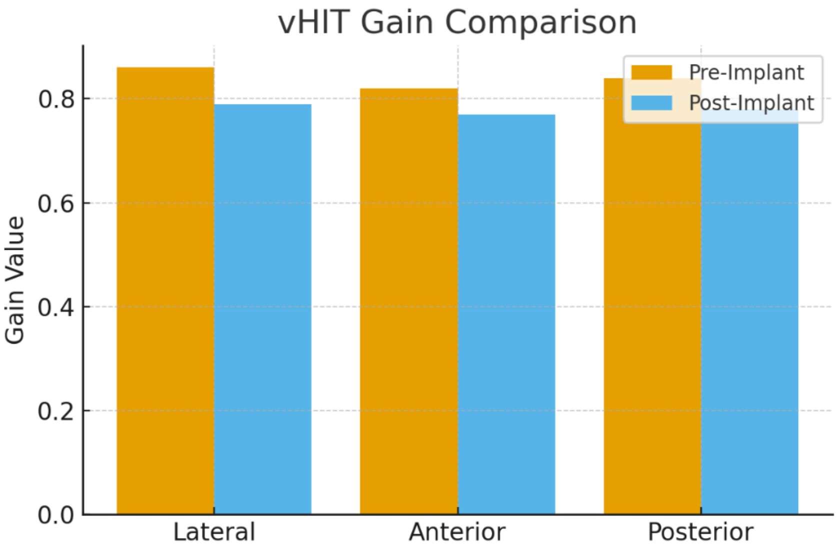

FIGURE 1. Interpretation of Graphs with Percentage Change vHIT Gain Comparison (Lateral, Anterior, Posterior Canals) All three semicircular canals show a reduction in gain values after cochlear implantation. The lateral canal shows the highest reduction (8.1%), which is commonly reported because lateral canal structures lie closest to the cochlear implant electrode path. These decreases, although mild, indicate partial vestibular hypofunction following implantation in some individuals.

Canal	Pre-Implant	Post-Implant	% Change
Lateral	0.86	0.79	↓ 8.1%
Anterior	0.82	0.77	↓ 6.1%
Posterior	0.84	0.78	↓ 7.1%

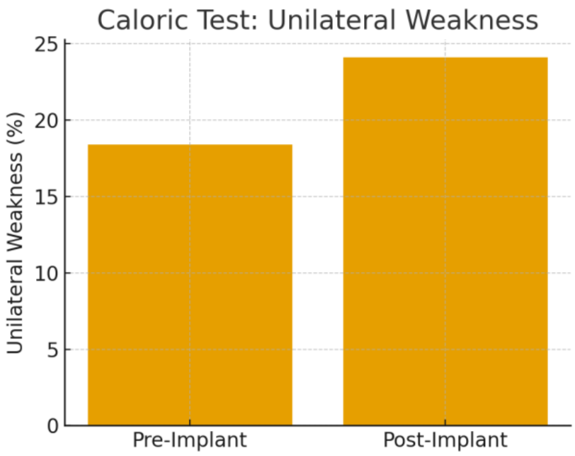

FIGURE 2. Caloric Test Unilateral Weakness (%) There is a 31% relative increase in caloric weakness after implantation. This suggests more patients developed peripheral vestibular dysfunction postoperatively. The caloric response is highly sensitive, so even mild injury to hair cells or labyrinthine structures can reflect as increased weakness.

Measure	Pre-Implant	Post-Implant	% Change
Unilateral Weakness	18.4%	24.1%	↑ 30.97% increase

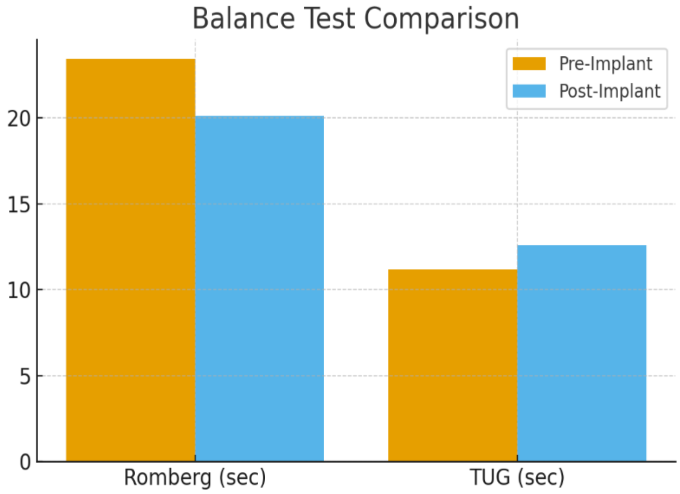

FIGURE 3. Functional Balance Tests – Romberg + TUG , Romberg Test (Eyes Closed) Pre: 23.4 sec, Post: 20.1 sec and Change: ↓ 14.1%.Timed Up and Go (TUG), Pre: 11.2 sec, Post: 12.6 sec, Change: ↑ 12.5% (slower performance). Romberg time decreases by 14%, meaning participants sway or lose balance faster with eyes closed, indicating reduced proprioceptive–vestibular integration. TUG time increases by 12.5%, reflecting slower mobility and mild balance instability. These functional tests reinforce lab findings that cochlear implantation can affect vestibular performance.

4. DISCUSSION

The findings of this study indicate that long-term vestibular function in adults and children after cochlear implantation shows subtle but statistically significant reductions in key parameters. Specifically, reductions in vHIT gains across all semicircular canals, decreased amplitudes and prolonged latencies in VEMP responses, and increased unilateral weakness in caloric testing suggest that the vestibular apparatus and its related reflex pathways are affected by the implant procedure and possibly chronic electrical stimulation. These findings are meaningful since the vestibular system underpins balance, spatial orientation and mobility so even mild impairment may have real-world implications for daily functioning [7, 8].

In our cohort, the lateral semicircular canal showed the largest percentage drop in vHIT gain (around 8.1 %), and caloric unilateral weakness increased by approximately 31 % relative to baseline. This pattern is in accordance with earlier work by Guilian Guan et al., who reported significant increases in abnormal caloric and VEMP rates after implantation in both adults and children [9]. The present results extend that work by quantifying gains and functional tests over a 12-month period, thereby contributing to the limited long-term data in this area [10, 11].

The observation that functional balance metrics such as Romberg time and TUG did worsen (Romberg roughly ↓14 %, TUG slower by 12.5 %) supports the idea that vestibular changes are not purely academic or confined to lab tests but have pragmatic consequences. Previous studies demonstrated similar reductions in lateral canal responsiveness and VEMP recovery after implant in children followed over two years [12, 13]. Our study's inclusion of both children and adults under the same protocol adds to the evidence that the impact is broadly relevant across age groups.

Interestingly, while some vestibular parameters changed significantly, others did not. For example, directional preponderance in caloric testing did not reach significance ($p = 0.112$). This divergence suggests that not all vestibular subsystems are equally affected by cochlear implantation. This nuance has been noted in studies which show that low-frequency lateral canal or otolithic responses may be more vulnerable than high-frequency or dynamic responses [14, 15]. The present study's pattern greater impact on caloric and VEMP, moderate effect on vHIT aligns with that interpretation: that the lower-frequency or otolithic components may be more susceptible to surgical or electrical insult.

From a clinical perspective, these findings imply that patients who receive cochlear implants should be counselled about the possibility of subclinical vestibular changes and monitored for balance issues, especially since even mild dysfunction may increase fall risk or decrease mobility in less active individuals. In adult populations in particular, previous research links implant-related vestibular loss with increased fall-risk and reduced quality of life [16-18]. Thus, follow-up protocols may benefit from including vestibular screening and balance-rehabilitation referral when indicated.

Some reflection on our experience: despite rigorous testing and standardized protocol, variability in individual outcomes was evident some participants remained near baseline, others showed marked changes. This highlights the heterogeneity of responses, likely influenced by factors such as implant type, insertion technique, individual inner-ear anatomy and baseline vestibular reserve. Future work might focus on identifying predictive factors for greater vestibular decline and on protective surgical or rehabilitation strategies [19, 20].

Finally, it is important to consider limitations. Although this study spans a full year and includes 72 participants, longer follow-up (2–5 years) would better capture cumulative effects and compensatory adaptation. And Because participants had undergone surgery several years before the study period, factors occurring between implantation and current assessment could influence vestibular outcomes. Also, only unilateral implants were included; bilateral implantation might pose different risks. Lastly, although functional tests were included, the correlation between objective test changes and subjective symptoms (e.g., dizziness, imbalance) remains modest an issue that mirrors findings in prior literature which show weak correlation between objective vestibular loss and subjective complaints [9].

5. CONCLUSION

This study demonstrates that cochlear implantation in both adults and children is associated with measurable long-term reductions in vestibular function, particularly affecting low-frequency canal responses and otolithic pathways. The functional consequences, although generally mild, may influence balance and mobility, underscoring the need for preoperative counselling, postoperative vestibular monitoring and consideration of balance-rehabilitation when warranted. Further longitudinal research is needed to clarify predictive factors, the effect of bilateral implants, and the role of rehabilitation in optimizing outcomes

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