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RESEARCH ARTICLE

Vestibular evaluation with video head impulse test in pediatric cochlear implant patients

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Abstract

Background: *The cochlear implant (CI) is effective for rehabilitating patients with severe to profound sensorineural hearing loss. However, its placement and use have been associated with various complications, such as those affecting the vestibular system. The objective of this study was to compare vestibular function using the video head impulse test (vHIT) in pediatric patients before and after CI placement.* **Methods:** *A descriptive and retrospective study was conducted. The outcomes of 11 pediatric patients of both sexes with a history of profound hearing loss were evaluated. The results of vestibular-ocular reflex (VOR) gain, saccades, asymmetry, Pérez Rey (PR) index, and VOR/saccade ratio for both ears obtained by the vHIT test before and after CI placement were compared.* **Results:** *Of the 11 patients evaluated, the VOR gain showed that 81.8% had normal function, 18.2% had hypofunction, and no patients had hyperfunction before implantation. No statistically significant differences were found when compared with post-implant off and post-implant on conditions ($p > 0.05$). The extracted variables, asymmetry, PR index, and the VOR/saccades ratio also showed no statistically significant differences between the pre- and post-implant conditions, whether off or on.* **Conclusions:** *The vestibular function of pediatric patients did not show significant changes before and after CI placement. The vHIT test is a valuable tool for assessing vestibular function and could be considered a criterion for surgical and rehabilitation decisions in patients undergoing CI placement.*

Keywords: *Cochlear implant. Hearing loss. Video head impulse test. Vestibular function.*

Evaluación vestibular con videoimpulso cefálico en pacientes pediátricos con implante coclear

Resumen

Introducción: *El implante coclear es un dispositivo eficaz para la rehabilitación de pacientes con hipoacusia neurosensorial severa a profunda. Sin embargo, su colocación y uso se ha asociado a diversas complicaciones, entre ellas a nivel del sistema vestibular. El objetivo del presente estudio fue comparar la función vestibular mediante la prueba de videoimpulso cefálico (vHIT) de pacientes pediátricos antes y después de la colocación del implante coclear.* **Métodos:** *Se llevó a cabo un estudio descriptivo y retrospectivo. Se evaluaron los resultados de 11 pacientes pediátricos de ambos sexos con antecedente de hipoacusia profunda. Se compararon los resultados de ganancia del VOR, sacadas, asimetría, índice PR así como la relación VOR/sacadas para ambos oídos obtenidos mediante la prueba vHIT antes y después de la colocación del implante coclear.* **Resultados:** *De los 11 pacientes evaluados, la ganancia del VOR mostró que el 81.8% tenía normofunción,*

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18.2% hipofunción y ningún paciente hiperfunción antes del implante. Al compararlo con la ganancia post implante apagado y post implante encendido no se encontraron diferencias estadísticamente significativas (p > 0.05). Las variables sacadas, asimetría, índice PR así como la relación VOR/sacadas tampoco mostraron diferencias estadísticamente significativas entre las condiciones pre y pos implante ya sea apagado o encendido. **Conclusiones:** *La función vestibular de pacientes pediátricos no mostró cambios significativos previo y posterior a la colocación del implante coclear. La prueba vHIT es una herramienta útil que permite evaluar la función vestibular y que podría considerarse como criterio para tomar decisiones quirúrgicas en pacientes que se encuentran en protocolo para implante coclear.*

Palabras clave: *Implante coclear. Hipoacusia. v-HIT. Función vestibular.*

Introduction

A cochlear implant (CI) is the electronic device of choice for the rehabilitation of patients with severe to profound sensorineural hearing loss, as it allows for an increase in the patient's quality of life and a reduction in disability, as well as the negative effects on the long-term sociocultural integration of hearing-impaired patients[1]. There are no precise reports on the prevalence of vestibular system disorders; however, it has been estimated that up to 50-70% of children with sensorineural hearing loss may present vestibular alterations, and up to 20-40% of these are severe. It is known that the incidence of complications after CI surgery is approximately 16-57%, although most of these complications are minor[2,3]. To this day, complications of CI are still being studied since, although it is considered a safe surgical procedure, there is a possibility of vestibular function damage; however, less attention has been paid to this aspect during the evaluation in assessment programs[2]. Different mechanisms have been reported that could lead to vestibular dysfunction during or after CI surgery, including direct trauma caused by electrode insertion, acute serous labyrinthitis due to a cochleostomy, foreign body reaction with labyrinthitis, endolymphatic hydrops, and electrical stimulation from the implant itself.

Postmortem studies on temporal bones of patients with CIs have shown significant alterations in the structures of the inner ear, such as fibrosis of the vestibule, decreased ganglion cells, formation of hydrops in the inner ear, morphological lesions in the osseous spiral lamina, vestibular receptors and basilar membrane, and morphological changes in the saccular and utricular macula and in the lateral semicircular canal[1,4].

At present, there is no formal consensus on tests to perform vestibular evaluation of hearing-impaired patients who are candidates for CI placement. Evaluations have included cervical vestibular myogenic evoked potentials (VEMPs) and caloric and rotary tests, among others[5]. However, although ideally, the combination of these tests provides us with more information about peripheral vestibular function, an objective, simple, fast, replicable test that provides quantitative information for the diagnosis of vestibular dysfunction is still needed, especially in the pediatric population[6,7].

In a healthy patient, the semicircular canals (SCC) accurately detect changes in head position on any axis and in any direction in space, sending the necessary signals to the extraocular muscles to generate a compensatory movement of the eyeball; in terms of velocity, perfectly opposite and supplementary, so that the illusion is generated that the eyes remain still with the gaze fixed on the object despite any head movement.

The video head impulse test (vHIT) measures the vestibular-ocular reflex (VOR), which is one of the fastest reflexes in the body (latency of just 7-10 ms), reflecting the body's ability to keep the gaze fixed on an object despite rapid and unexpected head movements[8]. It is useful for lateral canals (the easiest to evaluate) and also for vertical canals RALP (Right Anterior and Left Posterior) or LARP (Left Anterior and Right Posterior) evaluation. The vHIT can be used in children as young as 6 months of age[9,10].

For patients who are candidates for CI placement, this test will contribute to defining the ear to be implanted (in case of a unilateral implant) since, if there is any vestibular hypofunction, the ear with the worst vestibular function would be implanted, thus causing less direct damage and allowing a central compensatory mechanism with the contralateral ear.

In case of bilateral implantation and presenting hypofunction before implantation, the patient can be offered a vestibular rehabilitation program before and after the CI, which will help reduce long-term disability[11].

Methods

A retrospective and descriptive study was conducted on pediatric patients (2-7 years old) with bilateral severe to profound sensorineural hearing loss in the evaluation protocol for CI placement, assessed in the Department of Audiology and Phoniatrics and subsequently underwent implantation at the Hospital Infantil de México "Federico

Gómez", from 2019 to 2022. Patients who could not undergo the pre-implantation test or who did not complete the post-surgical follow-up and patients with bilateral implantation were excluded since they were not implanted simultaneously, leaving a sample of 11 patients with unilateral implantation.

The vHIT was performed using an ICS Impulse USB device from Otometrics® for the measurement of the VOR, consisting of a pair of glasses with a small video camera, a sensor (which measures head movement), and a mirror that reflects the image of the patient's right eye into the camera[12] (Fig. 1).

The pre-implantation VOR gain was measured 1 week before CI and during the first 30 days after CI placement. Gain values close to 1 were considered preserved VOR, while values close to zero were considered pathological VOR. The results of VOR gains in children can be comparable to those obtained in the adult population (0.83-1.21). The appearance of saccades was also considered to indicate an alteration of the VOR. For the study, the saccades were those present after completing the head movement (overt or uncovered saccades) or during it, which are detected with the naked eye, and covert or covert, which are imperceptible to the naked eye[13]. This study also included the Pérez Rey (PR) index, whose result is between 0 and 100, with a PR of 0 indicating minimal saccadic dispersion and 100 indicating maximum saccadic dispersion, functioning as a marker of compensation in vestibular hypofunction[14].

Figure 2 shows the vHIT report, which displays a hexagonal graph representing the six SCC. Each impulse records both the movement of the head and the eye, providing two curves of angular velocity over time. The relationship between both velocities accounts for the "VOR gain". In addition, we can observe the values of asymmetry, covert and overt saccades, PR index, and a table with saccade analysis (amplitude and latency)[13,15].

The statistical analysis was performed using the GraphPad Prism 9 statistical package. Descriptive statistical analysis was conducted for the total sample and by analysis groups. Frequencies and percentages were used for nominal variables, while measures of central tendency were employed for dimensional variables. Median, minimum, and maximum values were utilized for the age variable. The statistical analysis included normality tests for the exploratory analysis of the variables. Due to their non-normal distribution, non-parametric tests were applied. In all cases, the accepted level of significance was $p < 0.05$.

Figure 1. Video head impulse test realization.

Results

Eleven patients were included in the study, of which 81.8% (n = 9) were female and 18.2% (n = 2) were male; the median age was 4 (minimum 2 and maximum 6). Of the total number of included patients, 100% had the implant in the right ear.

VOR gain

The comparison between VOR gains in the right ear did not show a statistically significant difference in the various conditions: pre-implant, post-implant with the device off, and post-implant with the device on (0.85 ± 0.21 vs. 0.79 ± 0.17 vs. 0.82 ± 0.20, p = 0.2557). Similarly, in the left ear, no statistically significant differences were found when comparing the gains in pre-implant, post-implant with the device off, and post-implant with the device on (0.75 ± 0.17 vs. 0.79 ± 0.17 vs. 0.78 ± 0.19, p = 0.8255) (Fig. 3).

The VOR gain value was used to classify patients into three categories: normal function (0.8-1.2), hypofunction (< 0.8), and hyperfunction (> 1.2). In the right ear, 81.8% (n = 9) of the patients had normal function before implantation, 18.2% (n = 2) had hypofunction, and none had hyperfunction. In the left ear, 54.5% (n = 6) of the patients presented with hypofunction, 45.4% (n = 5) had a normal function, and none exhibited hyperfunction. After CI placement, while the device was off, 63.6% (n = 7) of the patients continued to have normal function in the right ear, and similarly, in the left ear, 63.6% (n = 7) had normal function and 36.4% (n = 3) had hypofunction. When the device was turned

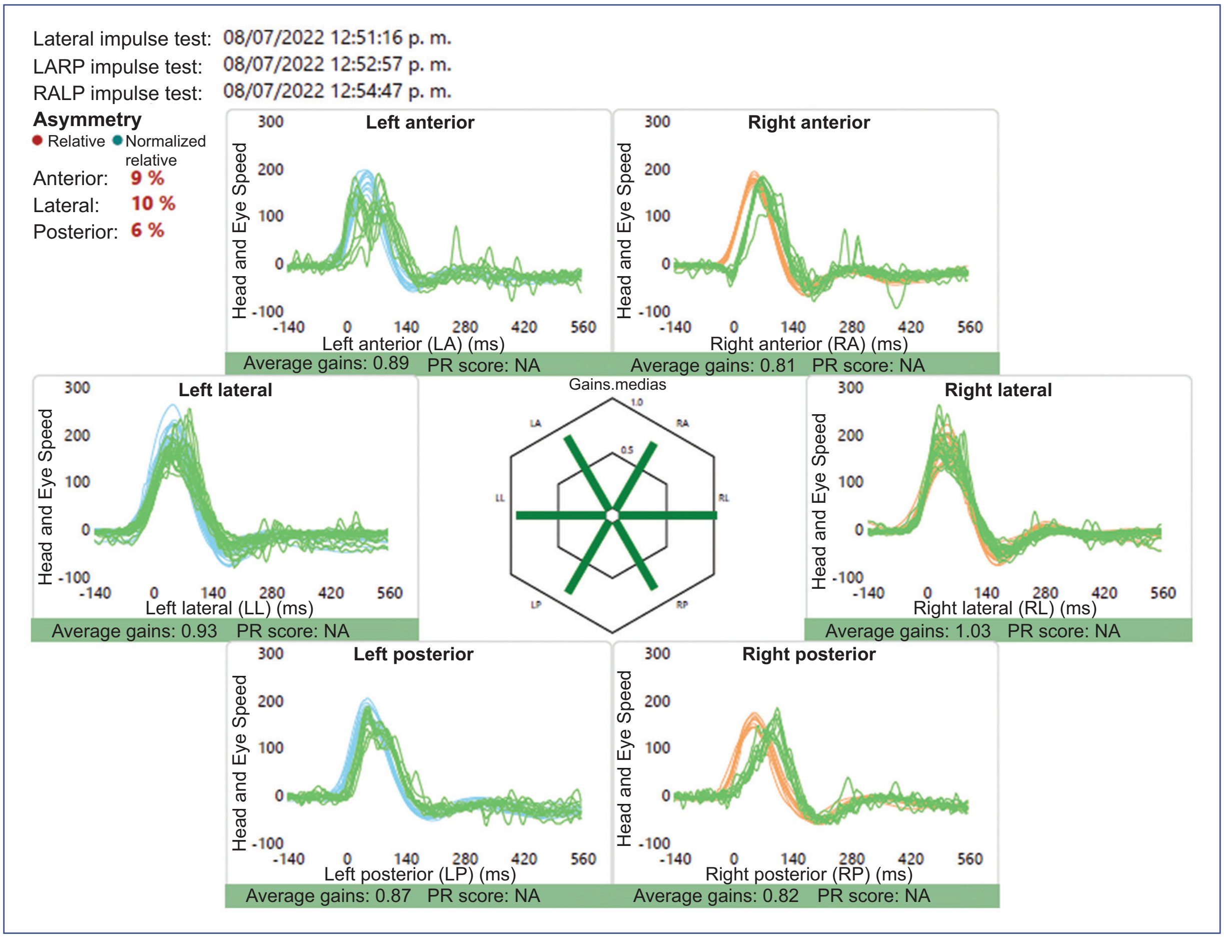

Figure 2. Video head impulse test report.

on, the distribution of patients changed, with 72.7% (n = 8) having normal function and 27.3% having hypofunction in the right ear. In the case of the left ear, the percentage of patients with normal function and hypofunction was the same as when the CI was off (Fig. 4).

Saccades

In the right ear, most patients did not present saccades before implant placement (63.7%). When the implant was placed, the percentage of patients without saccades decreased to 36.4%, and the same percentage was maintained when the implant was turned on. The percentage of patients with overt saccades increased from 27.3% pre-CI to 63.3% when the implant was placed and turned off; however, after turning it on, the percentage was 54.5%. Regarding covert saccades, they were present in 9.1% of patients before implantation. No patient was recorded with covert saccades when the implant was off, but when it was turned on, 9.1% continued to present covert-type saccades. In the left ear, considering that it did not undergo surgical manipulation, the percentage of patients without saccades predominated in the three conditions: pre-CI (54.5%), post-OFF (72.7%), and post-ON (63.6%). The presence of overt saccades was higher after implant placement, both when it was off (27.3%) and when it was on (27.3%), compared to pre-implantation (9.1%). However, the percentage of patients who presented covert saccades increased after turning the implant on (9.1%), as previously, no patient had presented this type of saccade (Table 1).

VOR/saccades

Anson et al. have described that saccadic movements can indicate vestibular hypofunction and are useful for identifying partial vestibular deficits. Therefore, this study analyzed the relationship between the presence of saccades (covert and overt) in patients with both normal function and vestibular hypofunction in the three

Table 1. Presence of saccades

Saccades presence	Pre-CI % (n)		Post-CI off % (n)		Post-CI on % (n)	
	Right ear	Left ear	Right ear	Left ear	Right ear	Left ear
No saccades	63.3 (7)	54.5 (6)	36.4 (4)	72.7 (8)	36.4 (4)	63.6 (7)
Overt saccades	27.3 (3)	9.1 (1)	63.6 (7)	27.3 (3)	54.5 (6)	27.3 (3)
Covert saccades	9.1 (1)	0 (0)	0 (0)	0 (0)	9.1 (1)	9.1 (1)

Pre-CI: pre-cochlear implant; Post-CI: post-cochlear implant.

Table 2. Relation of VOR gain to the presence of saccades

VOR gain/ saccades	Pre-CI % (n)			Post-CI off % (n)			Post-CI on % (n)		
	No saccades	Saccades		No saccades	Saccades		No saccades	Saccades	
Right ear			$\chi^2 = 4.278$ $\rho = 0.039$ *			$\chi^2 = 3.592$ $\rho = 0.58$			$\chi^2 = 2.357$ $\rho = 0.125$
With normal VOR	63.6 (7)	18.2 (2)		36.4 (4)	27.3 (3)		36.4 (4)	36.4 (4)	
With low VOR	0 (0)	18.2 (2)		0 (0)	36.4 (4)		0 (0)	27.3 (3)	
Left ear			$\chi^2 = 4.412$ $\rho = 0.036$ *			$\chi^2 = 7.219$ $\rho = 0.007$ *			$\chi^2 = 4.055$ $\rho = 0.044$ *
With normal VOR	45.5 (5)	9.1 (1)		63.3 (7)	0 (0) 27.3 (3)		54.5 (6)	9.1 (1)	
With low VOR	9.1 (1)	36.4 (4)		9.1 (1)			9.1 (1)	27.3 (3)	

VOR: vestibular-ocular reflex; Pre-CI: pre-cochlear implant; Post-CI off: post-cochlear implant off; Post-CI on: post-cochlear implant on.
*$p \leq 0.05$.

different situations of CI placement (pre, post-off, and post-on)[14]. Before implant placement, 63.6% of the patients had normal VOR and did not present saccades, 18.2% had normal VOR and saccades, and 18.2% had low VOR and saccades. After CI placement, while the implant was off, 36.4% of the patients had normal function and saccades (Table 2).

PR score

The absence of saccadic dispersion, represented by the PR score, was present in a higher percentage in both pre- and post-implanted patients, being similar for both ears. Saccadic dispersion after implant placement was present in 18.2% of the left ear following CI activation, in contrast to 9.1% when it was off.

Asymmetry

Abnormal asymmetry (> 20%) was present in 9.1% of pre-implanted patients, and no changes were observed after CI placement, even when it was turned on.

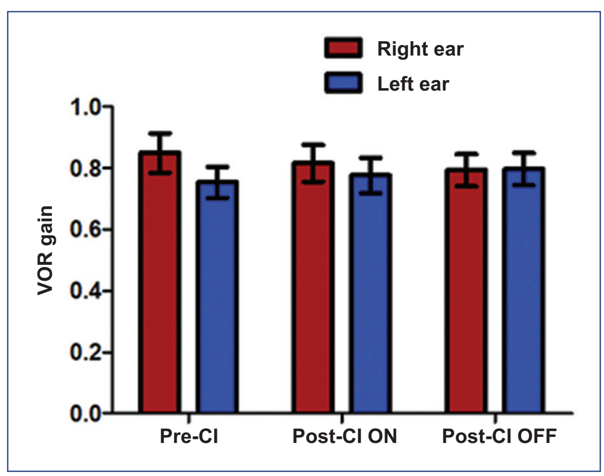

Figure 3. Vestibularocular reflex gain before and after cochlear implant placement.

Discussion

Hearing impairment has been associated with children's vestibular dysfunction and impaired motor development.

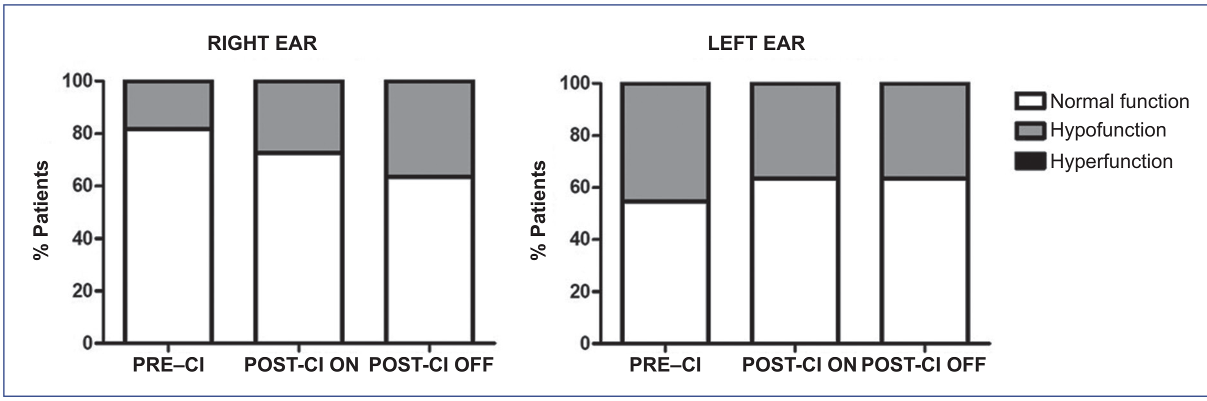

Figure 4. Vestibular function of patients before and after cochlear implant.

For this reason, vestibular function must be evaluated in every hearing-impaired patient or those in an evaluation program for CI placement. Assessing vestibular function in children is a challenging task, especially in those under 5 years of age.

Some of the vestibular studies (videonystagmography and caloric tests) performed to date are known to be poorly tolerated by children. Others, such as VEMPs, are well-tolerated and can be performed quickly; however, the information they provide is insufficient as they only provide data on otolith organs. The vHIT provides specific and quantitative data on the VOR at stimulus frequencies encountered in daily life, as well as the function of the 6 SCC for unilateral and bilateral peripheral vestibular losses, while the caloric test involves lower, non-physiological frequencies and does not require darkness that may induce fear or provoke vestibular symptoms[16]. The vHIT is also portable, non-invasive, and can be quickly administered (approximately 10-15 min)[12]. In addition to studying VOR gain, this study discusses the presence or absence of saccades, asymmetry, and PR score and aims to better understand these individual differences before and after CI placement to reduce vestibular damage secondary to implantation.

Gain

Regarding this data, the authors agree with the literature, where no statistically significant differences have been found in VOR gain before and after implant placement (on and off), as most patients maintained their normal function state[1,2,17].

However, the group of patients with vestibular hypofunction in the right ear increased after implantation (on and off). It is worth noting that these patients already showed vestibular damage before implantation, presumably congenital (inner ear malformations, audiovestibular syndromes), and having a foreign body phenomenon could further decrease this gain[18].

An increase in the percentage of patients with normal function was observed when the implant was on compared to when it was off, which coincides with the hypothesis of other studies, where there is a direct effect of electrical excitation and stimulation on vestibular receptors and afferent nerve neurons, especially in electrodes of the basal turn of the cochlea, which are closest to the vestibule[19,20].

Saccades

Since most of the patient group presented normal function before and after implantation, it is necessary to review other vHIT data that may indicate any suspicion of early vestibular damage or compensation. In this case, the covert or overt saccades that patients presented, despite having normal function, may indicate that the vHIT may not be as normal as believed. Therefore, a deeper analysis of patients' saccadic movement data is needed, especially for those who present it subtly. Covert saccadic movements have been associated with the severity of vestibular hypofunction. Thus, the presence of covert saccadic movements suggests that vestibular dysfunction has been compensated for, and eye-head coordination anticipates movements in real-life situations. We can assume that patients with "normal gains" but with saccades may indicate an early marker of vestibular dysfunction, which requires attention with post-implantation monitoring and even vestibular rehabilitation. It is very important to understand how the patient compensates for VOR loss, given its implications for vestibular rehabilitation and the prevention of long-term disability. Some studies report that patients who compensate with a “gathered pattern” saccadic strategy, with covert saccadic movements always at the same latency, will have lower levels of disability and postural instability than those with a “scattered saccadic strategy”[21].

PR score

The PR score is a recently proposed parameter of saccadic timing variation that indicates the state of vestibular recovery or compensation[22,23]. The PR score has not been reported in pediatric implanted patients. However, studies in other populations with vestibular disorders show that saccadic reorganization is a useful marker of vestibular compensation or reorganization after CI surgery in patients who presented with overt saccades. A high PR score in the late post-operative phase would indicate an alteration in vestibular adaptation, which is the first necessary step toward compensation.

In our study, no statistically significant differences were found between the PR score pre- and post-CI and in post-implanted patients before and after activation.

Asymmetry

Normal right-left asymmetry values are considered < 20%, with higher values being abnormal[24]. There were no changes before or after implantation in the group of patients studied.

Conclusions

Our results in children with CI showed no significant deterioration in VOR gain after CI placement. However, even though pediatric patients can compensate thanks to cerebral neuroplasticity and other afferents, allowing some alterations in vestibular function to go unnoticed, it is essential to perform objective evaluations of vestibular function to detect these alterations and organize a rehabilitation plan, providing tools for their development and to adequately perform daily life activities and thus avoid long-term disability.

The vHIT is a test that evaluates the function of high-frequency VOR and, due to its advantages, is proposed as the gold standard in children for the rapid measurement of vestibular function since it not only focuses on gain measurement but also shows us a broad overview of vestibular function, which helps us to demonstrate preliminary damage or vestibular compensation, even when the gain is within normal parameters. The Hospital Infantil de México “Federico Gómez” is the first implant center in Mexico where, since 2019, vestibular evaluation (clinical and instrumented) has been performed as part of the study protocol for patients in the candidacy program for CIs, taking into account vestibular function as a relevant criterion, both to decide the ear to be implanted in unilateral implants and, in case of presenting any congenital vestibular dysfunction before implantation, a rehabilitation program is proposed to avoid further vestibular damage and thus prevent long-term disability.

This study aims to continue performing and encouraging other implant centers to consider vestibular evaluation as a CI criterion and to increase the battery of standardized tests in children to obtain a comprehensive evaluation of vestibular function in patients in the CI programs.

Ethical disclosures

Protection of human and animal subjects. The authors declare that no experiments were performed on humans or animals for this study.

Confidentiality of data. The authors declare that they have followed the protocols of their work center on the publication of patient data.

Right to privacy and informed consent. The authors have obtained the written informed consent of the patients or subjects mentioned in the article. The corresponding author has this document.

Use of artificial intelligence for generating text. The authors declare that they have not used any type of generative artificial intelligence for the writing of this manuscript, nor for the creation of images, graphics, tables, or their corresponding captions.

Conflicts of interest

The authors declare no conflicts of interest.

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References

1. Meli A, Aud BM, Aud ST, Aud RG, Cristofari E. Vestibular function after cochlear implant surgery. Cochlear Implants Int. 2016;17:151-.
2. Ibrahim I, da Silva SD, Segal B, Zeitouni A. Effect of cochlear implant surgery on vestibular function: meta-analysis study. J Otolaryngol Head Neck Surg. 2017;46:44.
3. Gupta A, Raj P. Compensated vestibular dysfunction post cochlear implantation in children with sensorineural hearing loss: a prospective study. Indian J Otolaryngol Head Neck Surg. 2018;70:200-4.
4. El-Karaksy AA, Kouzo HS, Attallah MB, Talaat MA. Vestibular function assessment in cochlear implant patients. Egypt J Otolaryngol. 2019;35:63-70.
5. Robard L, Hitier M, Lebas C, Moreau S. Vestibular function and cochlear implant. Eur Arch Otorhinolaryngol. 2014;272:523-30.
6. Janky KL, Patterson JN, Shepard NT, Thomas ML, Honaker JA. Effects of device on video head impulse test (vHIT) gain. J Am Acad Audiol. 2017;28:778-85.
7. Ross LM, Helminski JO. Test-retest and interrater reliability of the video head impulse test in the pediatric population. Otol Neurotol. 2016;37:558-63.
8. Carriel C, Rojas OM. Prueba de impulso cefálico: bases fisiológicas y métodos de registro del reflejo vestíbulo oculomotor. Rev Otorrinolaringol Cir Cabeza Cuello. 2013;73:206-12.
9. Fetter M. Vestibulo-ocular reflex. Dev Ophthalmol. 2007;40:35-51.
10. Marioni G. Balance function assessment and management. Second edition. Audiol Med. 2015;13:178.
11. Diamante VG, Carmona S, Marquez R, Weinschelbaum R, Miranda JR, de la Torre Diamante DA. Impacto del implante coclear en la función vestibular periférica. Rev FASO. 2017;24:36-9.
12. Khater AM, Afifi PO. Video head-impulse test (vHIT) in dizzy children with normal caloric responses. Int J Pediatr Otorhinolaryngol. 2016;87:172-7.
13. Bachmann K, Sipos K, Lavender V, Hunter L. Video head impulse testing in a pediatric population: normative findings. J Am Acad Audiol. 2018;29:417-26.
14. Anson ER, Bigelow RT, Carey JP, Xue QL, Studenski S, Schubert MC, et al. VOR gain is related to compensatory saccades in healthy older adults. Front Aging Neurosci. 2016;8:150.
15. Weber KP, MacDougall HG, Halmagyi GM, Curthoys IS. Impulsive testing of semicircular-canal function using video-oculography. Ann N Y Acad Sci. 2009;1164:486-91.
16. Hamilton SS, Zhou G, Brodsky JR. Video head impulse testing (VHIT) in the pediatric population. Int J Pediatr Otorhinolaryngol. 2015; 79:1283-7.
17. Nayak N, Kellermeyer B, Dornton L, Heyd C, Kim CS, Wazen JJ. Vestibular dysfunction in cochlear implant candidates: prevalence and outcomes. Am J Otolaryngol. 2022;43:103171.
18. Nassif N, Balzanelli C, Redaelli de Zinis LO. Preliminary results of video head impulse testing (vHIT) in children with cochlear implants. Int J Pediatr Otorhinolaryngol. 2016;88:30-3.
19. Perez Fornos A, Guinand N, van de Berg R, Stokroos R, Micera S, Kingma H, et al. Artificial balance: restoration of the vestibulo-ocular reflex in humans with a prototype vestibular neuroprosthesis. Front Neurol. 2014;5:66.
20. Guinand N, van de Berg R, Cavuscens S, Stokroos RJ, Ranieri M, Pelizzone M, et al. Vestibular implants: 8 years of experience with electrical stimulation of the vestibular nerve in 11 patients with bilateral vestibular loss. ORL J Otorhinolaryngol Relat Spec. 2015;77:227-40.
21. Guajardo-Vergara C, Perez-Fernandez N. A new and faster method to assess vestibular compensation: a cross-sectional study. Laryngoscope. 2020;130(12):E911-7.
22. Rey-Martinez J, Batuecas-Caletrio A, Matiño E, Perez Fernandez N. HITCal: a software tool for analysis of video head impulse test responses. Acta Otolaryngol. 2015;135:886-94.
23. Matiñó-Soler E, Rey-Martinez J, Trinidad-Ruiz G, Batuecas-Caletrio A, Pérez Fernández N. A new method to improve the imbalance in chronic unilateral vestibular loss: the organization of refixation saccades. Acta Otolaryngol. 2016;136:894-900.
24. Newman-Toker DE, Saber Tehrani AS, Mantokoudis G, Pula JH, Guede CI, Kerber KA, et al. Quantitative video-oculography to help diagnose stroke in acute vertigo and dizziness: toward an ECG for the eyes. Stroke. 2013;44:1158-61.