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Review articles

Vestibular dysfunction and postural balance in cochlear implant users: a narrative literature review

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ABSTRACT

Cochlear implants directly stimulate nerve fibers and ganglion cells of the auditory nerve, which transform sound energy into low levels of electrical current, stimulating the remaining fibers of the auditory nerve in patients with severe to profound hearing loss, in order to provide the significant range of auditory sensation and speech comprehension. Due to the close relationship between cochlea and vestibular receptors, some patients may present vestibular and postural balance changes concomitantly after surgery. This study aimed to perform a narrative review of the main studies that relate vestibular symptoms in patients implanted in the last six years. The research was performed through the databases: SciELO, LILACS and PubMed, using associated descriptors for "cochlear implant", "vestibular dysfunction", "vertigo" and "balance", totalizing 21 studies that fitted the inclusion criteria. The results were described in a chronological order of publication, showing the main conclusions. Of the total studies analyzed, 18 related vestibular function to cochlear implant and only 3 studies did not find such a relationship. The literature characterize the effects of the cochlear implant on the vestibular system, however, the results are contradictory.

Keywords: Postural Balance; Dizziness; Vestibular Diseases; Cochlear Implants

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INTRODUCTION

The cochlear implant (CI) represents the most important advance in the treatment of persons with severe and profound hearing disability[1]. This implant has the purpose to stimulate, directly, the nervous fibers and the ganglion cells of the auditory nerve[2], which are damaged or are not present, transforming the sound energy at low levels of electrical current, stimulating the remaining fibers of the auditory nerve[3], in order to provide a significant range of the auditory sensation and the speech comprehension.

Currently, with the possibility of neonatal hearing screening and diagnosis of hearing loss in the first year of life, the CI potentiated the acquisition of children's oral communication. No more doubts that the CI can bring benefits to children with pre-lingual hearing disability. In the post-lingual hearing disability, the benefits have already been demonstrated due to the effectiveness of the CI, in adults with delayed auditory deficiency[1].

For pre and postoperative monitoring of patients with CI, it is necessary the work of a multidisciplinary team capable of performing several evaluations and procedures, being such a team consisting of an otological surgeon, professionals in the areas of neurology, Pediatrics, Genetics, psychology, social assistance and speech therapy, in which the later professional is responsible for vestibular, auditory and language rehabilitation[1,3].

As in any surgery, there are risks regarding the surgery itself and those not directly related. The choice of the procedure in the placement of electrodes during surgery should be cautious, because it may present some risks, such as: facial paralysis, extrusion or deviation in the positioning of the electrodes, alteration of taste and presence of tinnitus[3,4]. Some complications may occur during the implantation of electrodes in the cochlea, namely: alteration of the normal homeostasis of fluids in the inner ear, trauma in the vestibular sensory structures or inflammation induced by surgery, resulting in fibrosis or loss of ciliated cells. Associated to this, electrical stimulation by CI can cause pathological changes in the inner ear with subsequent dysfunction of the structures, resulting in vestibular alterations, mainly, in the moments before and after surgery[5-7].

The incidence of patients with vestibular problems related to the cochlear implant, who developed a benign postural vertigo (VPB), after the surgery is 159/100,000 per year, being its frequency greater than in the general population (ratio of 64/100,000 per year)[8]. The occurrence of changes in body balance, including all the pathologies in the postoperative period to the cochlear implant can vary from 31 to 75%[9,10].

It is believed that there is a greater occurrence of vestibular alteration, clinically significant in patients with bilateral CI, because those with unilateral implantation are more able to compensate for the vestibular alteration at the injured side[11].

Since some patients evolved with dizziness after CI, researches have been carried out correlating vestibular tests in time before and after the surgery, according to a literature review carried out in the period from 1977 to 2008[2], in large part, the results proved to be controversial. Based on this assumption, it was decided to perform a narrative review of the studies that describe the vestibular symptoms and postural balance in patients at the moment pre and post-surgical of cochlear implant.

METHODS

A study of narrative review was performed with consultation in the data bases: SciELO, LILACS, and PubMED, using the following descriptors (DeCS): "cochlear implant", "vestibular dysfunction", "Vertigo" and "postural balance", in the period from January 1st 2010 to January 31st 2017. The search was performed by isolated descriptors and, subsequently, the association among these.

As criteria for inclusion of studies, it was opted to select prospectives and retrospectives and with comparison pre and after CI, with option of researches developed with children and adults of both genders and different ages, which evaluated the results of the balance after the uni or bilateral CI, available in its entirety in Portuguese and English, in the pre-set time period. Articles that reported opinions of experts, practical guidelines, case reports, summaries of conferences and chapters of books were excluded, in addition to the articles that after thorough reading, did not meet the objective of the study.

After initial search with the inclusion criteria, it was found a total of eighty-five articles and two theses.

With the complete reading of the material selected, sixty-six articles were excluded, for not having a direct relationship with the objectives of the study, in which only twenty-one studies (Nineteen articles and two theses) were used for analysis. Figure 1 shows the identification data of the studies and Figure 2, the sequential Organogram of studies selection.

#	Authors	Year of Publication	Type of Study	n	Vestibular Function x CI
1	Krause E *et al.*	2010	Prospective	32	yes
2	Kluenter HD *et al.*	2010	Prospective	52	no
3	Huang MW *et al.*	2011	Control-Case	24	yes
4	Eustaquio ME *et al.*	2011	Control-Case	74	no
5	Abdelghaffar H *et al.*	2011	Prospective	45	yes
6	Holinski F *et al.*	2012	Prospective cohort	30	yes
7	Parmar A *et al.*	2012	Retrospective Cohort	177	yes
8	Coordes A *et al.*	2012	Retrospective and prospective	140	yes
9	Sousa AMM	2012	Cross sectional.	100	yes
10	Rajan GP *et al.*	2013	Prospective cohort	40	yes
11	Katsiari E *et al.*	2013	Prospective	20	no
12	Cushing SL *et al.*	2013	Prospective and cross-sectional	113	yes
13	Bernard-Demanze L *et al.*	2014	Cross-Sectional	24	yes
14	Abramides P	2014	Prospective	24	yes
15	Zawawi F *et al.*	2014	Prospective	122	yes
16	Batuecas-Caletrio A *et al.*	2015	Prospective descriptive	30	yes
17	Wolter NE *et al.*	2015	Retrospective	21	yes
18	Thierry B *et al.*	2015	Retrospective Cohort	43	yes
19	Robart L *et al.*	2015	Prospective	35	yes
20	Gavin, J *et al*.	2016	Prospective	30	yes
21	Greters, M *et al*.	2017	Cross-Sectional	14	yes

Legend: CI =Cochlear Implant

Figure 1. Description of the studies selected for analysis

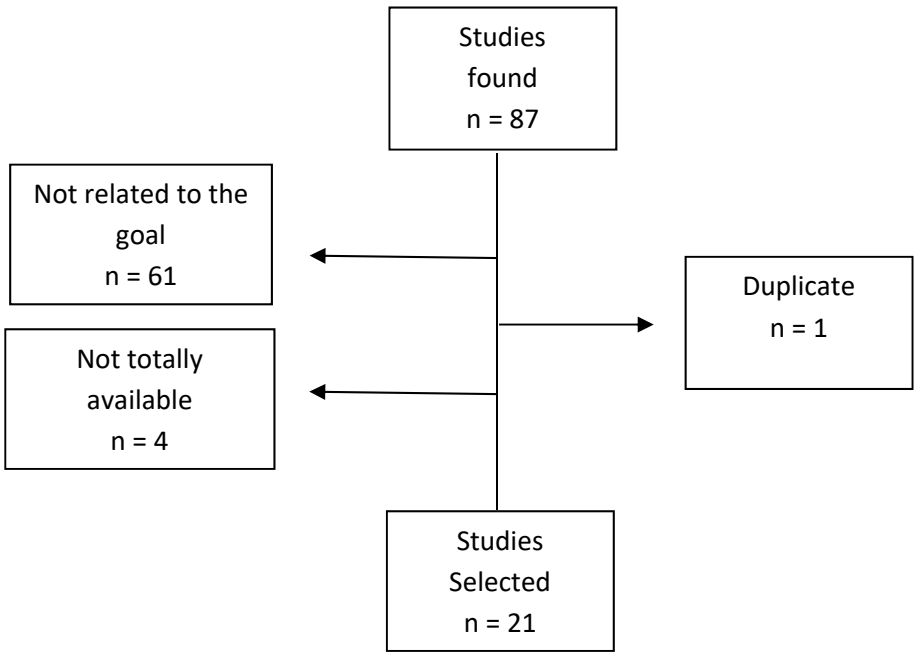

Figure 2. Sequential Organogram of the selection of studies

LITERATURE REVIEW

For the development of literature review, it was opted for the descriptive and chronological form of publication, with notes of the main findings.

Of the total number of studies analyzed 18 studies verified the effects of the CI in the vestibular function and only three studies found no such relationship.

Krause et al.[12] evaluated the influence of HF, in function of the peripheral vestibular receptor, in the implanted side, to examine a possible correlation with symptoms of dizziness. CI represented a significant risk factor for disability of the horizontal semicircular canal ($p<0.001$) and saccular insufficiency ($p=0.047$) in the implanted ear. There was no correlation between the vestibular function and symptoms of dizziness, the function of the contralateral side remained unchanged ($p>0.05$). CI is a risk factor relevant to the damage of peripheral vestibular receptor function, therefore, the preservation not only of the residual auditory function, but also of the vestibular function should be targeted, using minimally invasive surgical techniques.

In a study[13] performed by comparing two techniques used to insert the electrodes inside the cochlea, during the CI surgery (standard cochleostomy and round window approach), in order to analyze whether it is possible to influence the vestibular function, reported that the insertion approach did not influence postural control after The CI surgery. The majority of patients already had vestibular dysfunction prior to surgery, and there was no alteration of balance after surgery of HF, in most patients, but the static postural balance improved after six weeks of surgery.

One study evaluated the role of static balance in two groups of adolescents, one with CI and another with normal hearing (control group), through the stabilometry in different situations (CI on and off). It was verified that the function of static balance, in adolescents, with long-term use of CI was worse than the control group, being presented major difference when the visual and somatosensory inputs were interrupted. Regarding the postural stability, it was similar with the CI on or off[14].

Eustaquio et al.[15] assessed the functional body balance in three cohorts of children from 4 to 17 years: those who have unilateral cochlear implants, with bilateral cochlear implants and children not implanted with severe to profound bilateral hearing loss. No statistical differences in the groups studied were found. However, all groups tested showed lower performance than the average validated for a healthy population of children.

The hyporeflexia of lateral semicircular canal and of the saccule were evaluated on the long-term effects on the CI. 45 children participated in the study (21 males and 24 females) between 5 and 6 years of age. All patients were diagnosed with severe or profound sensorineural hearing loss and bilateral or unilateral hypofunction of the peripheral vestibular system. All subjects received the multichannel CI. The evaluation of the vestibular system was done prior to the deployment of bi-thermal caloric irrigation and the Vestibular Evoked Myogenic Potential (VEMP). Vestibular evaluation was performed in three moments after activation of the CI: after one month, after twelve months and after twenty-four months. Nineteen patients (42%) showed improvement of the response of the lateral channel and ten of them presented VEMP answer identifiable in 90 and 100 dBnNA. They concluded that although the results of the study show positive impact of the CI in Hypofunction of the vestibular system, the delayed effects of chronic electrical stimulation of the vestibular system, still need to be explored[16].

A study[17] examined the vestibular disorder after the CI in forty-one patients. They found the presence of clinic dizziness in 11/41 (24.4%): acute in 5/41 (12.2%), continuous in 1/41 (2.4%), delay of 6-18 months in 5/41 (12.2%). In the caloric test, 3/27 (11.1%) of the vestibular organs showed hypofunction ($p=0.16$). Three of eight patients (37.5%) with clinic dizziness after surgery showed vestibular hypofunction ($p=0.08$). The authors concluded that postoperative dizziness did occur more frequently in patients with pre-operative vestibular hypofunction than in patients with normal results. Therefore, pre-operative vestibular function tests may not be an indicator for the frequency of dizziness after CI.

In order to study if the relationship between the CI on the side of the best vestibular function leads to a greater perception of dizziness by the sick people than the CI, on the side of the worst function, thus, records of 177 adults were analyzed , who received the unilateral CI and were reviewed retrospectively, in two groups. In group A, the patients included with an implant in the ear with worse or similar caloric responses. Group B included patients with an implant in the ear with stronger caloric response. All patients underwent preoperative bi-thermal proof, in which a clinically significant difference, was defined by a paresis of the lateral channel of 20%. For the evaluation

of dizziness in the postoperative period, it was used the Dizziness Handicap Inventory (DHI) questionnaire and supplementary questions. Dizziness was reported in 57% in both groups in the first seven postoperative days. At two months, 20% of group A and 34% of group B experienced some dizziness. Fourteen percent of Group A and 10% of group B, considered that the cochlear implant resulted in impairment of balance. The DHI scores of 86% of the group A (Average score 0) and 76% of those in group B (average score 10) corresponded to low disadvantage. There was no relationship significantly different between groups A and B, but the authors emphasized that the CI may result in dizziness, almost always mild and of short duration, even when the ear with stronger caloric response is deployed[18].

A study investigated whether electrical stimulation of the auditory structures through electrodes of HF might affect the vestibular system and induce dizziness. In the first group of patients without any dizziness induced by preoperative sound (n=104), 20 patients (18%) reported dizziness induced by sound, which occurred after the CI. In the second group, an acoustic stimulus presented by means of the speech processor of the CI provoked a response from the Vestibular evoked myogenic potential in four out of the twenty-six patients as a sign of co-vestibular stimulation. Vertical and horizontal nystagmus were triggered, while the utricular function and postural stability remained unchanged. In conclusion, in this way, that the dizziness induced by sound can occur in patients with CI, suggesting that it could have been caused, mainly, by the co-electrical stimulation of the saccule as part of otolithic organs[19].

In search of comparison of body balance between children with typical development and children with hearing disabilities (DA), users and non-users of CI, by means of the force platform, there was a tendency for children with DA have greater difficulty of postural control in upright quiet position, when compared with listeners. It can be argued that the children users of CI does not achieve better performance, therefore, presented greater difficulty of postural control in relation to the listeners[20].

In relation to the surgical form of CI, it was investigated if the speed and the characteristic of insertion of the electrode interfere in the preservation of the vestibular function clinic and the hearing. The studies concluded that a slow speed of insertion of electrodes seems to facilitate the insertion of the same completely, reducing the occurrence of resistance to insertion. Thus, it is promoted the preservation of residual hearing and vestibular function after the CI[21].

Researchers investigated the influence of CI in the vestibular function of the horizontal semicircular canal, the saccular function and the incidence of vestibular symptoms before and after the CI. Twenty patients with unilateral CI were evaluated in the preoperative period, after one and six months after the operation, with tests of caloric, electronystagmography (ENG), recordings and Vestibular Evoked Myogenic Potential (VEMP). Statistically significant difference was found in the percentage of paresis of the lateral canal ($p = 0.01$), and the percentages of the VEMP ($p = 0.002$) among the measures used in the side with CI, while on the side without CI, no difference was ($p > 0.05$) found. Four patients complained of vestibular postoperative symptoms. In three of them, the symptoms lasted less than six months postoperatively, but the fourth patient still had with dizziness, six months after the CI. The alterations of the peripheral vestibular function of the implanted side were found and the permanent dizziness was rare. Predictive factors for the occurrence of vestibular symptoms in the postoperative period may not be identified[22].

The function of the horizontal semicircular canal (CSH) was studied by means of response to caloric and rotatory stimulus, and the saccular function was examined using Vestibular Evoked Myogenic Potential (VEMP) in children with CI. The CSH function was changed in response to caloric stimuli in 50% (69/139) of the cases, being that 18/69 of cases changed, which are equivalent to 26% were mild to moderate unilateral abnormalities. The severe hypofunction or areflexia occurred in 37% (51/139). The function of the CSH in response to the rotation was abnormal in 47% (64/139). The saccular function was absent bilaterally in 21% (32/135) and unilaterally in 30% (40/135). All children with meningitis (n = 11) and 46% with cochleovestibular radiological abnormalities (n=31) presented a dysfunction of the CSH, while 45% and 46%, respectively, showed saccular dysfunction. The unilateral dysfunction of the CSH or saccule was equally distributed between the implanted ear and without CI (14:9 and 22:18, respectively), and the differences in proportions were not statistically significant[23].

The effects of postural control were studied in postlingual, deaf patients users of CI. The vestibular function was assessed by comparing the postural performance of patients with healthy individuals of the same age during a simple task performed in static and dynamic

platform, and during a condition of dual task (visual or hearing memory). Postural tests were performed, in open and closed eyes, under conditions of IC activated and deactivated. The results showed that the postural performance of patients with CI differ strongly on condition eyes closed. Patients with CI showed significantly reduced limits of stability and increased postural instability in static conditions. In dynamic conditions, they spent much more energy to maintain balance, behaved in a dynamic way without vision as an inverted pendulum, while the controls showed a strategy for the whole body. In the condition of dual task, patients with CI, even when activated, showed no improvement in the dynamic postural performance, concluding that patients with CI became heavily visually dependent, especially in challenging postural conditions[24].

It was evaluated sequentially the balance pre and after CI unilateral in patients with post-lingual deafness over a year, by means of the vestibular evaluation (caloric and rotatory chair and Dynamic Posturography (CDP) and questionnaire on dizziness, applied preoperatively, 60, 120, 180 days and one year after the CI surgery. Dizziness was reported by 13 (54.2%) pre-CI patients, while 11 (45.8%) did not present the complaint. At the end of the study 11 subjects (84.6%) reported improvement of dizziness in 1 (7.7%) remained unchanged and in 1 (7.7%) worsened. Of the 24 patients who were monitored, only 5 individuals (20.8%) developed dizziness in the immediate postoperative period, with complete resolution after one month. The caloric test identified 7 (29.2%) subjects with normal reflexes, 8 (33.3%) with unilateral hyporeflexia or areflexia, 3 (12.5%) with bilateral hyporeflexia and 6 (25%) with bilateral vestibular areflexia (AVB). There was interference of electrical stimulation in both ears and in the evolution of the postural recovery after activation of the CI, which promoted a significant improvement of the indices of the PDC over one-year follow-up. At the end of the study, the numerical averages of conditions assessed by the PDC showed to be higher in individuals who presented a response to caloric in relation to those who possessed AVB. It was concluded that the presence or absence of post-caloric response was decisive in the evolution of body balance over the course of a year. The absence of post-caloric response in the pre-operative evaluation resulted in a worse prognosis in the body balance evolution. However, the best postural performance of subjects with AVB can be explained by better use of visual information. It is essential to document the presence of vestibular function before the CI surgery, because it depends on the prognosis of individuals in relation to the skills of learning and postural recovery over time[25].

The impact after the CI implantation was studied in terms of dizziness and in quality of life using the DHI. 122 patients were enrolled in this study, which is the largest sample size reported in the literature so far. The most common subtype of dizziness was the instability, and the dizziness was evidenced in 45.9% of the population after CI and 27% pre CI, being in the majority of patients considered mild[26].

The vestibular function, before and after the CI was also assessed with 30 consecutive patients with profound sensorineural hearing loss which were subjected to CI, by means of the test of caloric test, cephalic impulse test with video (vHIT) and the DHI questionnaire. It was concluded that even if the CI surgery being safe, with few complications, it is a procedure that may cause dizziness. vHIT reveals that 30% of the patients in the postoperative period demonstrated change in vestibular function along with a worse score in the DHI score, being tests of great importance in clinical practice[27].

With the intention of seeking to determine the role of the vestibular dysfunction and postural balance in children, which showed failures on the implanted device, the vestibular function in 35 children with failure in the CI was compared with 165 children, who have not experienced the failure, through the evaluation of the function of the horizontal semicircular canal. The authors concluded that the vestibular dysfunction and its commitment were identified as important risk factors for the failure of the CI in children. Early identification and treatment of such deficiencies may prevent or retard CI failures and prevent children experiencing periods of deprivation of sound, which could impact the acquisition of speech and language[28].

The vestibular function was analyzed after unilateral CI, in 43 children in the period from 2001 to 2010, by means of computed tomography (CT) of the temporal bone before surgery, as well as through caloric tests, cephalic impulse test and Vestibular Evoked Myogenic Potentials. The studies concluded that half of the children presented initial vestibular dysfunction. The malformation of the bilateral inner ear was recovered in 16%. Before the surgery, 50% of the children had normal vestibular responses in 12 cases had bilateral partial dysfunction and two had asymmetric vestibular dysfunction. In this group, after surgery, two children had worsening of vestibular dysfunction, and no child in

just on the side of the CI. 19% of the children exhibited greater vestibular hypofunction, asymmetrical, on the side of the CI, and 75% had normal contralateral vestibular function, concluding that 20% of the CI could have worsened the vestibular function, being the vestibular function important in choosing which side should be implemented[29].

The vestibular function was evaluated in 35 patients, with a mean age of 49 years, before and after the CI, by means of Vestibular Evoked Myogenic Potential (VEMP) and videonystagmography. Before deployment, VEMP was found in 73% of cases. They are modified after the CI for 13 patients, of which 12 showed a reduction in the potential of the implanted side ($p = 0.0015$). At the caloric tests a significant decrease was found in the reflection of the implanted ear ($p < 0.0001$). Vestibular symptoms were independent of changes in the vestibular exams. There was no relation between the occurrence of vestibular symptoms after the surgery and the results of the vestibular investigations. However, the performing of these exams is not easy, especially for children, and only a part of the vestibule is tested. In conclusion, the vestibular evaluations help to choose the side of the deployment, assess the preoperative vestibular condition and evaluate and location of vestibular lesions[30].

A pilot study was conducted in Canada with patients during the following periods: Pre-operative of CI, immediate post-surgical, one week and one month after surgery. The evaluations were performed by the DHI, subjective Visual Vertical survey (SVS) and the test *Timed up and go* (TUG). When necessary, the test was repeated with the CI on and off. It was found that many patients deviated the SVS in preoperative evaluation and postoperative complications However, no alterations were observed, statistically significant, when it was compared the SVS preoperative and postoperative or when it was compared the SVS with the CI on and off. It was verified that the DHI improved in five patients and had a worsening in the score in two patients, however, no statistically significant change was found in the DHI scores or in tests of TUG[31].

The auditory performance was evaluated as a predictor of postural control and compared among users of CI with good auditory performance with auditory performance unsatisfactory and with CI performed with at least six months after the surgery, by means of tests of Dynamic Posturography (CDP) of sensory organization (TOS) and adaptation (TAd), with the aim of assessing the learning ability, in the short term, in postural recovery strategies. CI users, with good auditory performance, had a higher incidence of postural recovery, when compared to CI users with unsatisfactory auditory performance[32].

Of the twenty-one studies presented, five reported that the preoperative vestibular evaluations can assist in the choice of the side to be implanted. The dysfunction in the pre-surgery moment can be an important risk factor for the CI failure, as well as the choice of the side to be implanted[17,25,28-30].

Recent technological advances provided to a portion of the population with hearing disabilities, the possibility of CI, with reports of likely implications on the vestibular system and the postural balance as a whole.

Of the two studies that analyzed the techniques used in the CI surgical procedure, one showed that the insertion approach did not influence the postural control after the CI surgery [13], since the patients already had vestibular dysfunction prior to surgery and another study found that the speed of insertion of the electrode interferes in the preservation of the vestibular and auditory function[21]. Despite the advances regarding surgical techniques, the preparation of the multidisciplinary team and modifications in programs for hearing health, the vestibular function and postural balance are still hampered in implanted patients.

Despite the possible complications of CI on the vestibular system and the balance, the analyzed studies have methodological differences, both in relation to the evaluation of the outcomes, and in relation to the training protocol, which hampers the standardization and better comparison of results. Another difficulty was to group the studies around a common point, since they presented different objectives.

Only one study reported improvement of the vestibular system function in implanted patients who had bilateral or unilateral hypofunction of the peripheral pre-surgery vestibular system [6].

Studies that investigated only the vestibular function in patients already implanted, concluded that they may present sensation of temporary dizziness[18,19].

It is expected that this review will provide a base of evidences for future studies on the effects of the CI regarding the postural balance in general and, more specifically, the symptomatology of dizziness, mainly, in the long term, in addition to the necessary interventions and their results, thus contributing to viable and effective clinical interventions in relation to these symptoms.

Prospective controlled studies, which measure the results more consistently and with control of selection biases and observation, are necessary to improve the quality of the evidence regarding the characteristics of dizziness after CI and its clinical interventions to support any future recommendations for the clinical management of these patients.

CONCLUSION

The vestibular function and balance are still hampered in patients in the CI preoperative and postoperative moments. Even with the advancement of technology, surgical techniques, preparation of the multidisciplinary team and modifications in the programs of hearing health, studies with many different goals and vestibular tests try to seek answers to minimize the occurrence of these changes.

Several studies have attempted to characterize the effects of CI on the vestibular system, however, their results are contradictory, demonstrating that the vestibular system and the balance is still a very complex subject, especially in pre-symptomatic patients.

Future researches should focus on the systematic search for articles that meet the eligibility for inclusion on the topic in question with respect to real elucidation of the effects of the surgical procedure for the placing of CI in relation to postural balance and dizziness in the long term, in addition to clinical trials, aimed at understanding other factors related to the CI, as well as the restoration of balance and dizziness in these patients.

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