Vestibular function assessment in cochlear implant patients

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Received 5 July 2018
Accepted 1 August 2018

The Egyptian Journal of Otolaryngology
2019, 35:63–70

Background
Anatomical and embryological relations between cochlear and vestibular end organs predispose them to same noxious or developmental factors, thus these may affect either or both systems. Cochlear implantation being a widely used procedure for restoration of hearing in patients who are not candidates for regular amplification, may affect by different means the vestibular system. One of these factors include the surgical procedure. The aim of this study is to assess the vestibular function in cochlear implant candidates before surgery to exclude co-existing vestibular affection with the sensorineural hearing loss (SNHL). Reassessment after operation was done to determine the risk posed by surgery and for correlating the surgical approach to vestibular findings.

Materials and methods
The case series presented herein is of cochlear implant candidates who underwent full audiological and radiological assessment. Vestibular assessment was done before and after operation and included cervical vestibular evoked myogenic potential (cVEMP) and ocular vemp (oVEMP) for evaluation of otolith organs. Video head impulse test (VHIT) was used to evaluate semicircular canal.

Results
Preliminary results show that patients may exhibit vestibular loss concomitant to the SNHL even with the absence of vestibular complaints. Patients who had normal preoperative vestibular function showed affected vestibular tests after the surgery. There was a mismatch between these objective findings and the subjective complaint of imbalance or vertigo.

Conclusion
Despite the minor risk posed by cochlear implant (CI) surgery for the subjective vestibular affection, the side with worse vestibular function should be chosen for CI if other factors are equal to avoid postoperative vestibular loss.

Keywords:
cochlear implant, vestibular affection in cochlear implant, vHIT

Egypt J Otolaryngol 35:63–70

1012-5574

Introduction

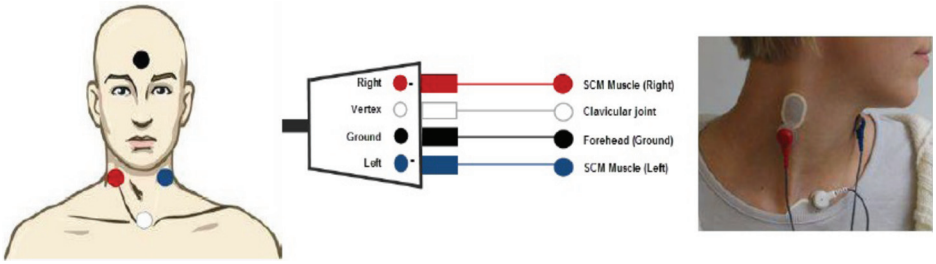
The cochlear and vestibular systems share common anatomical and embryological origin with continuous membranous structure. This close proximity in vascular supply and innervation predisposes them to same noxious or developmental factors. Thus prenatal, perinatal, or postnatal injury and trauma may cause damage and affect one or both systems. As a result, studies showed that patients with hearing loss may have concomitant vestibular loss [1].

The prevalence of vestibular system disturbance was estimated to be among 70% of children presenting with sensorineural hearing loss (SNHL), with 20–40% having severe bilateral vestibular loss [2]. Patients with profound hearing loss may have higher prevalence of vestibular loss [3]. Vestibular loss is more common in patients with severe acquired (after birth) hearing loss than in patients with severe inherited hearing loss [4].

There are well-identified etiologies of hearing loss that have well-known associated vestibular loss, and these include incomplete partitions (types I, II, and III), enlarged vestibular aqueduct syndrome, Usher syndrome, meningitis, congenital cytomegalo virus (CMV) infection, and children treated with ototoxic agents, with the meningitis and cochleovestibular anomalies having the highest rates of severe dysfunction [2]. Moreover, patients with auditory neuropathy [5] and cochlear nerve deficiency may have vestibular impairment as an association [2].

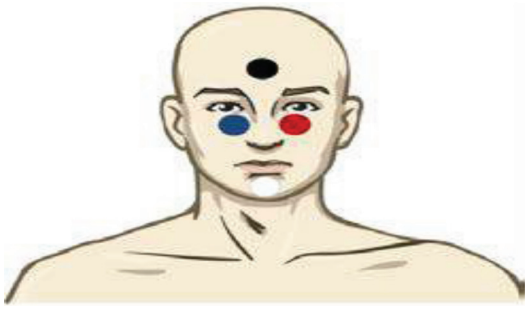
With the cochlear implant being the procedure of choice for hearing restoration in patients with severe to profound hearing loss and with broadening criteria

Figure 1



Electrode montage for c-vemp as recommended by the manufacturer.

Figure 2



Electrode montage for o-vemp a recommended by manufacturer.

for cochlear implant (CI) candidacy and the recent development of bilateral CI, understanding the risk of CI-induced vestibular impairment is extremely important [6,7].

The surgical procedure for a CI involves a normal mastoidectomy with an approach to promontory through a posterior tympanotomy, followed by insertion of electrodes either through round window with removal of the round window lip and inferior widening, or an alternative cochleostomy performed localized anterior to the round window niche. The insertion through round window is reported to cause less disturbance in the vestibular system [8]. Insertion of electrodes in the scala tympani is preferred over the scala vestibuli as it is wider, the stapes does not have to be removed and it is on the nonvestibular side of the cochlear duct and so in theory have less risk on balance and vestibular system [9].

Postmortem histopathological temporal bones studies proved the vestibular damage attributed to the cochlear implant surgery. The saccule is more susceptible to damage than the utricle or semicircular canals because of its proximity to the pathway of the inserted electrodes with saccular membrane distortion. Moreover, replacement of vestibular contents by fibrosis sometimes with calcification and ossification and reactive neuromas [10].

The following etiologies for post-CI dizziness have been postulated: (a) spreading of electric current when the implant is turned on [11,12], (b) mechanical disturbance in the membranous labyrinth, (c) perilymphatic fistula owing to cochlear fenestration or intraoperative loss of perilymph [13,14], (d) direct surgical trauma to the afferent vestibular pathways, and (e) serous labyrinthitis secondary to insertional trauma or to the presence of a foreign body which also causes a reduction of vestibular function [15].

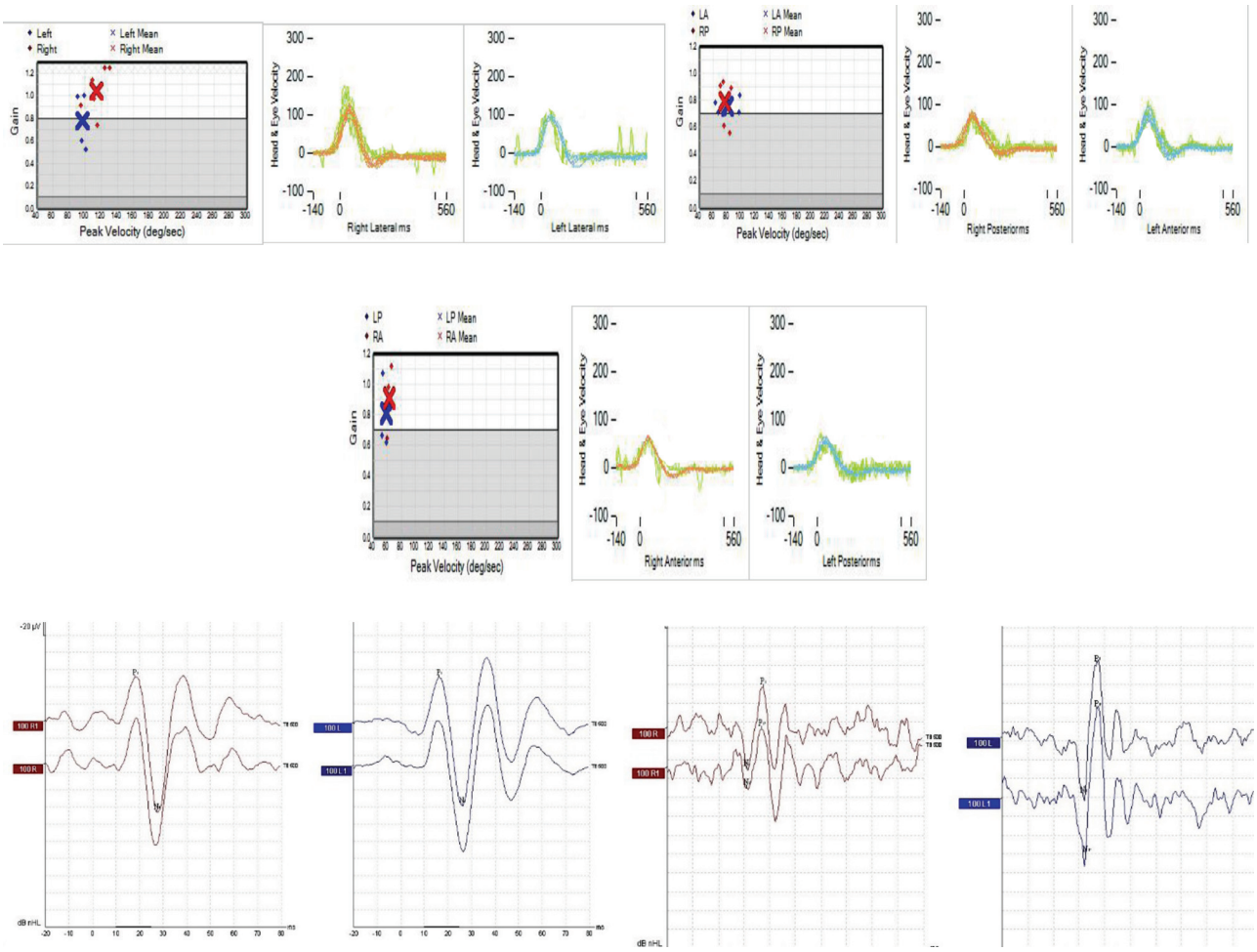
Various forms of dizzinesss may occur after CI, such as light-headedness, unsteadiness while walking, a floating sensation or spinning vertigo during head turning, and oscillopsia [14].

There are a lot of tests used by different studies in vestibular evaluation of CI patients. As saccule is the most commonly affected vestibular organ, cervical vestibular evoked myogenic potential (cVEMP) is the most common test performed in most studies [16–20]. Most studies concentrated on caloric stimulus on ENG testing [16,17,20], which is equivalent to a 0.001–0.01 Hz head rotation. Rotary chair testing probes the low-frequency to mid-frequency range of the vestibule-ocular reflex (VOR) response (0.1–1 Hz) [16]. As for the head impulse test, the stimulus frequency includes the spectral range of 1–15 Hz, which is most physiologically relevant to function of the VOR in daily life [21,22].

With the risk of possible preoperative vestibular affection and with increasing the popularity of bilateral simultaneous and second ear cochlear implant, vestibular testing before and after operation becomes more essential.

In this study, a case series is presented.

Figure 3



Preoperative vHIT for all six canal and cVEMP and oVEMP. Gain: Rt lateral canal: 1.04, Lt lateral canal: 0.78, Rt posterior canal (RP) 0.8, Lt anterior (LA) canal: 0.79, Rt anterior (RA): 0.91, Lt posterior (LP): 0.81. Rt cVEMP P1 latency: 18 ms, N1 latency: 27.33 ms, N1–P1 Amp: 156.4. Lt cVEMP P1 latency: 16.33 ms, N1 latency: 26 ms. N1–P1 Amp: 149.3. Rt oVEMP N1 latency: 11 ms, P1 latency: 17.33 ms. N1–P1 Amp: 4.330. Lt oVEMP N1 latency: 11.67 ms, P1 latency: 17 ms, N1–P1 Amp: 6.979. Lt, left; Rt, right.

Materials and methods

Cases presented were candidates for cochlear implants, who had undergone full audiological (including pure tone audiometery (PTA), immitance measures, and aided thresholds) and radiological [including high resolution CT (HRCT) and MRI] assessment for enrollment in the vestibular testing protocol.

Vestibular assessment was performed preoperatively and postoperatively. Testing the function of otolith organs was done using the cVEMP for saccule and oVEMP (oVEMP) for the utricle using 'Interacoustics Eclipse'.

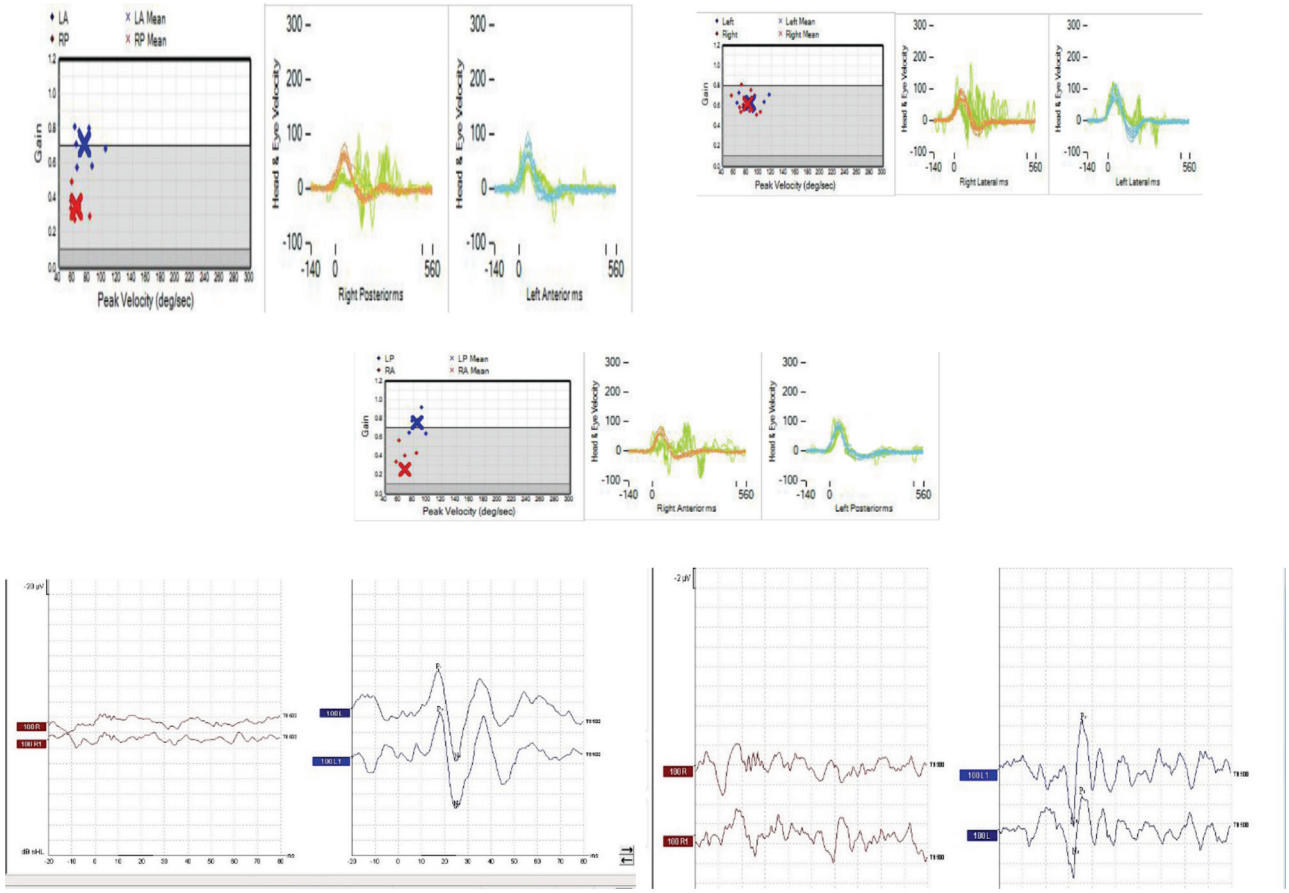
(1) Electrode montage for cVEMP and oVEMP is shown in Figs 1 and 2, respectively.
(2) Stimulus parameters: type of stimulus was 500 Hz tone burst Blackman gating at a rate of 5 Hz and intensity: 100 dBnHL.
(3) Position for cVEMP: patient sitting with head turned to contralateral shoulder (45°). Before starting, keep tonic activation of sternoclenomastoid muscle (SCM); this was monitored by the patient EMG monitor.
(4) Position for oVEMP: the tested ear will be contralateral to the measured eye. Participants will be in a seated position and will be asked to maintain an upward gaze at a fixed mark in the ceiling.

P1–N1 latencies (representing P13, N 23 in cVEMP) and N1–P1 amplitude were measured and compared before and after the surgery. Criteria for change in postoperative VEMP were as follows:

(1) Disappeared VEMP in postoperative testing.
(2) An absolute value of VEMP amplitude ratio less than 0.5 [17].

$$P1\text{–}N1_{postoperative}/P1\text{–}N1_{preoperative} < 0.5.$$

Figure 4



Postoperative vHIT for all six canal and cVEMP and oVEMP. Gain: Rt lateral canal: 0.62, Lt lateral canal: 0.63, Rt posterior canal (RP) 0.35, Lt anterior canal (LA): 0.71, Rt anterior (RA): 0.26, Lt posterior (LP): 0.75. Rt cVEMP: absent. Lt cVEMP P1 latency: 17 ms, N1 latency: 26 ms. N1–P1 Amp: 116.2. Rt oVEMP: absent, Lt oVEMP: N1 latency: 11.67 ms, P1 latency: 16.33 ms. Lt, left; Rt, right.

Testing the function of semicircular canal (SCC) was done using the video head impulse test (vHIT) 'ICS Otometrics'. The patient is kept 1 m distance from the fixation dot on which they keep their gaze stable on. Test will be done in the lateral, left anterior Right posterior (LARP) and right anterior left posterior (RALP) semicircular canal planes. Head is passively thrusted into a 15° angle. The head impulses should be presented in an unpredictable manner and direction. Gain is measured, and observation for appearance of catch up saccades is reported and compared before and after the surgery. Criteria for change in postoperative vHIT are as follows:

(1) Decrease in gain below normal (<0.8 for lateral canal and <0.7 for vertical canals).
(2) Appearance of overt or covert saccades.

Cases

Case 1

A 14-year-old female patient (S.M.) had bilateral profound SNHL, where hearing loss was progressive in nature. CT showed bilateral large vestibular aqueduct syndrome (LVAS). Patient was implanted by Medel SYNCHRONY standard electrode with Sonnet audio processor. Figures 3 and 4 show preoperative and postoperative vHIT for all six canals and cVEMP and oVEMP, correspondingly.

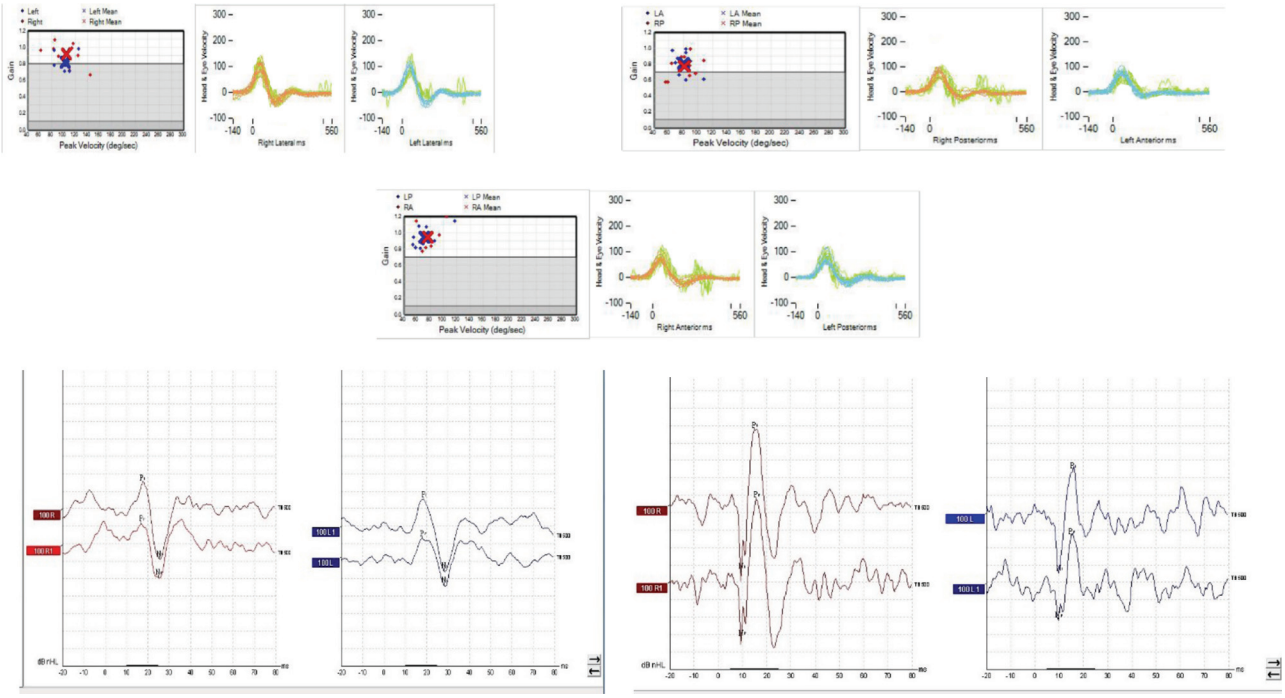
Case 2

A 29-year-old male patient (K.M.) had bilateral profound SNHL, which was progressive in nature. CT showed bilateral LVAS with hypoplastic modiolus, a picture of incomplete partition type II (Mondini malformation). Patient was implanted by Medel SYNCHRONY standard electrode with Sonnet audio processor. Figures 5 and 6 show preoperative and postoperative vHIT for all six canals and cVEMP and oVEMP, correspondingly.

Case 3

A 41-years-old female patient (R.A.) had with bilateral profound hearing loss progressive in nature since 15 years. The patient had normal CT findings. Figure 7

Figure 5



Preoperative vHIT for all six canal and cVEMP and oVEMP. Gain: Rt lateral canal: 0.92, Lt lateral canal: 0.82, Rt posterior canal (RP): 0.77, Lt anterior canal (LA): 0.81, Rt anterior (RA): 0.94, Lt posterior (LP): 0.94. Rt cVEMP P1 latency: 17 ms, N1 latency: 25.33 ms, N1–P1 Amp: 86.96. Lt cVEMP P1 latency: 18 ms, N1 latency: 28.33 ms. N1–P1 Amp: 82.16. Rt oVEMP N1 latency: 9.67 ms, P1 latency: 15 ms. N1–P1 Amp: 16.20. Lt oVEMP N1 latency: 9.67 ms, P1 latency: 15 ms, N1–P1 Amp: 11.73. Lt, left; Rt, right.

shows preoperative VHIT for all six canals and cVEMP and oVEMP, correspondingly.

Discussion

Cochlear implant surgery and its effect on residual cochlear function have been well studied, and recent attention is now paid to the effect of CI surgery on the vestibular function.

Case 1 patient had LVAS with no vertigo or imbalance complaint preoperatively or postoperatively. Case 2 patient had Mondini malformation and complained of dizziness for 5 days postoperatively, which subsided later. Provocative dizziness of short duration appears to be the most common vestibular symptom after the CI surgery, followed by light-headedness, unsteadiness, and oscillopsia [14].

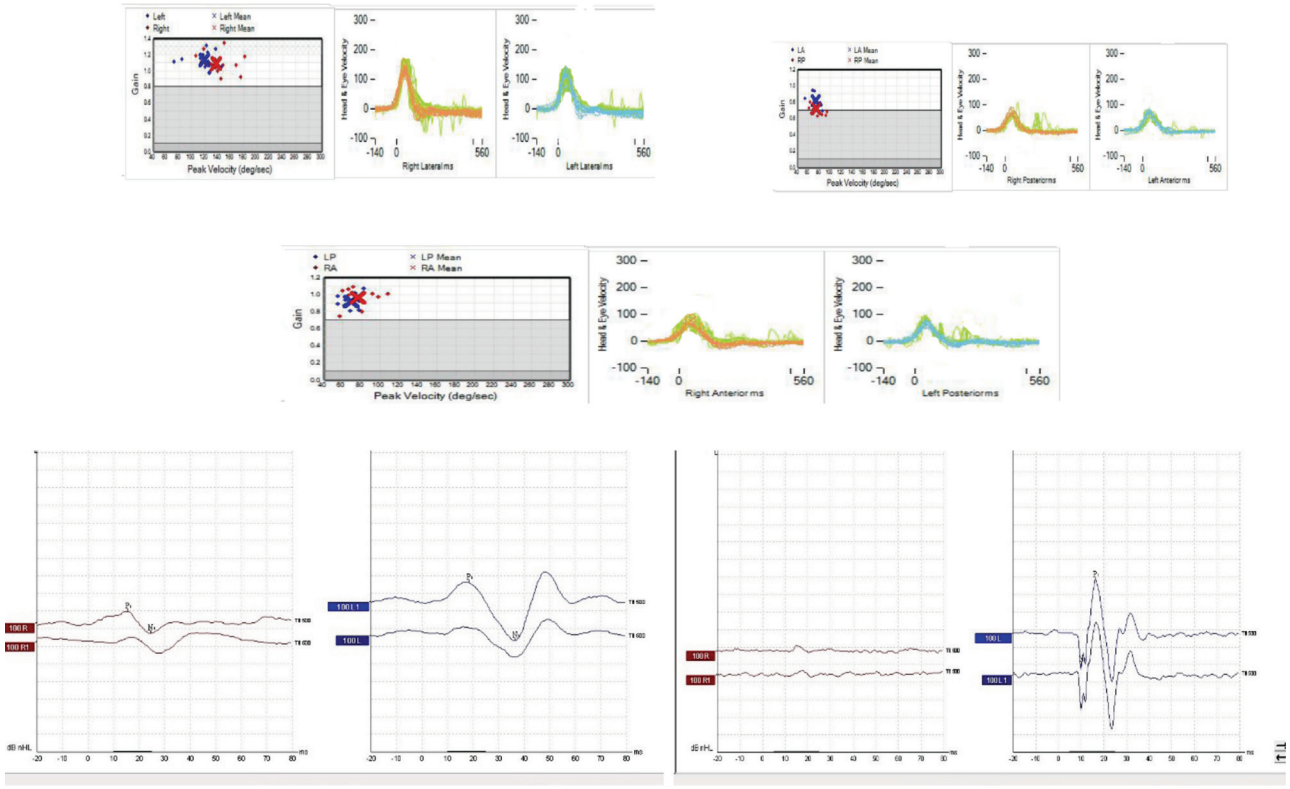
Even though patient 1 had decreased gain in VHIT in all SCC and absent cVEMP and oVEMP after the surgery in the implanted ear (mean gain decreased from 1.04, 0.8, 0.91 to 0.62, 0.35, 0.26 in right lateral, posterior and anterior canal respectively), there was a mismatch between these objective findings and the subjective complaint of imbalance or vertigo, which is also reported in many studies [22,23].

Patient 2 had decreased amplitude in cVEMP postoperatively compared with preoperative findings (amplitude of cVEMP decreased from 86.96 to 24.57 μV with amplitude ratio of 0.28) and absent oVEMP after the surgery. The gain of vHIT was comparable before and after surgery.

The findings in patients 1 and 2 and the mismatch between the vestibular objective tests and the subjective sense of vertigo or dizziness can be explained by efficient vestibular compensation, where the presence of the contralateral labyrinth provides sufficient redundancy, so that unilateral vestibular loss is usually well tolerated after a period of compensation. For healthy adults and children, adaptive mechanisms as proprioceptive and visual sensory systems most likely allow these individuals to compensate. Another explanation mentioned in literature was that changes in VOR testing results are not predictive of CI-induced vestibular problems [7].

These findings agree with other studies, where in normal preoperatively vestibular function CI candidates, the risk of impairment postoperatively in lateral SCC had wide range in different studies using caloric tests, from 32% [24] to 93% [25]. Studies using the vHIT test reported 10% [22] to 33% [26] risk of impairment. As for the saccule, the risk of impairment ranged from 21% [8] to

Figure 6



Postoperative vHIT for all six canal and cVEMP and oVEMP. Gain: Rt lateral canal: 1.09, Lt lateral canal: 1.13, Rt posterior canal (RP): 0.72, Lt anterior canal (LA): 0.82, Rt anterior (RA): 0.96, Lt posterior (LP): 0.92. Rt cVEMP P1 latency: 15.67 ms, NI latency: 25 ms, N1–P1 Amp: 24.57. Lt cVEMP P1 latency: 18 ms, N1 latency: 35 ms. N1–P1 Amp: 66.18. Rt oVEMP: absent, Lt oVEMP: N1 latency: 10 ms, P1 latency: 16 ms N1–P1 Amp: 28.26. Lt, left; Rt, right.

100% [27]. Because of its proximity, the saccule is especially at risk, followed by the utricle and the SCC. Hemorrhage, inflammation, or vascular damage from insertion trauma, which can lead to new bone formation, has been implicated as possible causes for vestibular affection after the surgery [10].

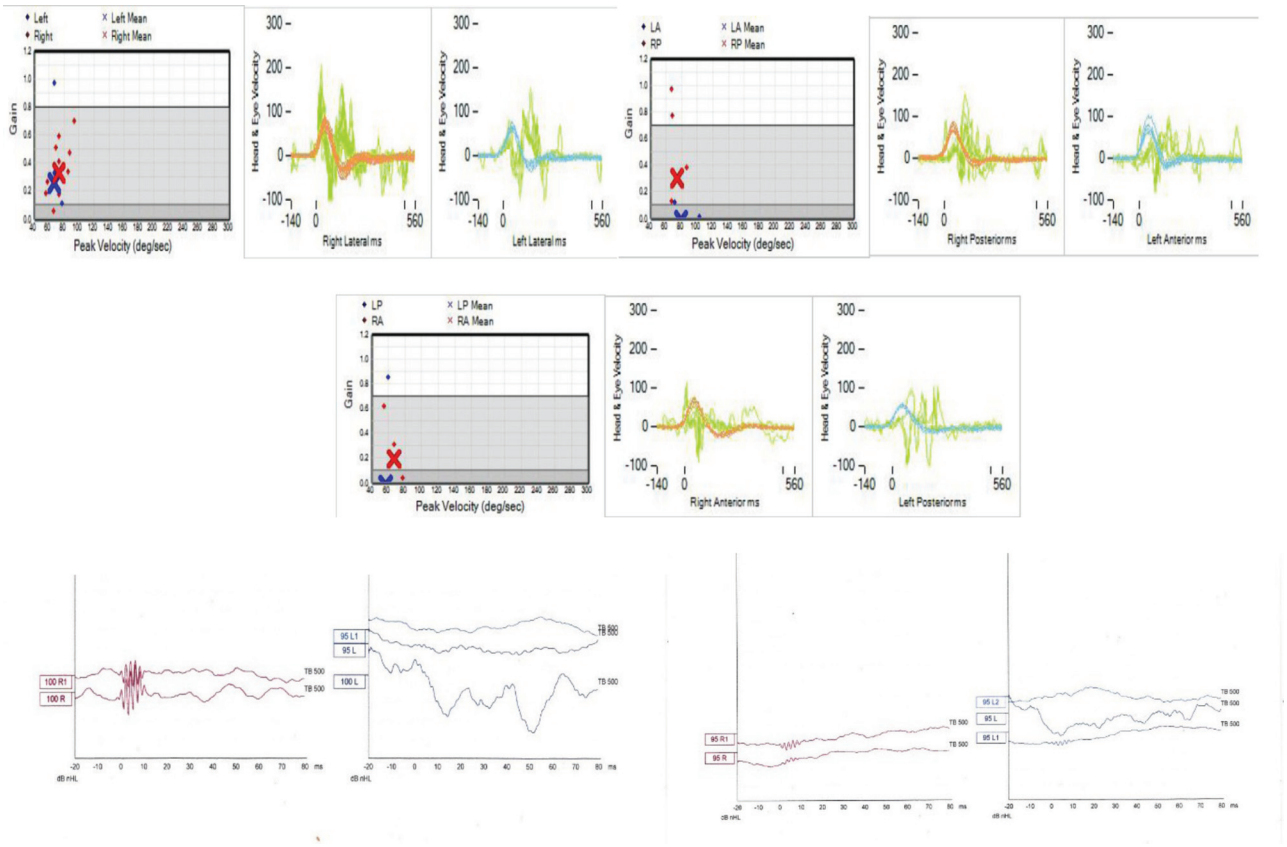
Postmortem histopathological studies showed that cochlear hydrops with saccular collapse are most common findings owing to ductus reuniens being blocked either externally by the fibrosis or internally by the debris from the cochlear duct. There is evidence however that unilateral saccular damage (as seen in the implanted patients) could remain asymptomatic [15].

Case 3 patient showed bilateral vestibular loss evidenced in high-frequency canal function in the form of bilateral low gain in all six SCC (<0.8 for lateral canals and <0.7 for vertical canals) with catch up saccades and in the otolith function in the form of bilateral absent cVEMP and oVEMP. The patient presented with bilateral progressive SNHL but no evidence of vertigo or dizziness preoperatively. Saccades play a role as part of compensation in patients with deficient VOR where the changes in saccadic pattern are a very effective way of overcoming the loss. The very high velocity of the saccade will degrade the retinal image and suppress vision during and around the time of a saccade. So the patient's gaze is kept over the target not by slow compensatory eye movements but by a ballistic eye movement that eliminates the smeared retinal image. This mechanism can explain why patients with vestibular loss did not complain of any vestibular symptoms [28].

Even if cochlear implant presents minor risk for ipsilateral loss of vestibular function, it is recommended though to implant the ear with lower vestibular function in unilateral cochlear implantation if all other factors are equal. The risk of iatrogenic bilateral vestibulopathy with a persistent balance dysfunction can occur in bilateral CI or in patients implanted in ear with normal vestibular function with previous unilateral vestibular loss preoperatively in the other ear [22].

Financial support and sponsorship
Nil.

Figure 7



Preoperative vHIT for all six canal and cVEMP and oVEMP. Gain: Rt lateral canal: 0.33, Lt lateral canal: 0.26, Rt posterior canal (RP): 0.30, Lt anterior canal (LA): –0.01, Rt anterior (RA): 0.19, Lt posterior (LP): –0.01. Rt cVEMP absent. Lt cVEMP absent. Rt oVEMP absent. Lt oVEMP absent. Lt, left; Rt, right.

Conflicts of interest

There are no conflicts of interest.

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