The Laryngoscope

The Effect of Cochlear Implantation on Vestibular Evoked Myogenic Potential in Children

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Objectives/Hypothesis: We conducted this study to assess the effects of unilateral cochlear implantation (CI) on otolith function by observing the changes in ocular vestibular evoked myogenic potential (oVEMP) and cervical vestibular evoked myogenic potential (cVEMP) in children.

Study Design: Prospective case series.

Methods: The oVEMP and cVEMP elicited by air-conducted sound in 35 children were analyzed preoperatively and at 5 days, 1 month, and 2 months after surgery.

Results: Before CI, the response rates of oVEMPs and cVEMPs were 81.4% and 91.4%, respectively. In the implanted side, oVEMPs and cVEMPs were reduced by 37.1% and 68.6%, respectively, 5 days after CI. One month after CI, oVEMPs and cVEMPs were 34.6% and 72%, respectively, with the device switched off, and 50% and 73.1%, respectively, with the device switched on. Two months after CI, the oVEMPs and cVEMPs were 36% and 80%, respectively, when the implant was turned off, and 70.8% and 75%, respectively, when the implant was turned on.

Conclusions: The study confirmed the value of VEMP testing in the clinical setting and that absent VEMPs could indicate impairment of otolith function after CI.

Key Words: Cochlear implantation, vestibular evoked myogenic potential, saccule, utricle.

Level of Evidence: 4

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INTRODUCTION

Cochlear implantation (CI) is becoming increasingly used in auditory rehabilitation of hearing-impaired patients, but adverse vestibular symptoms after CI have been widely reported in previous studies with incidences ranging from 0.33% to 75%.[1–4] According to the review, postoperative vertigo was observed in 7.4% of patients; the results of the meta-analysis confirmed a significant increase in postoperative vertigo after CI.[5] Previous studies have shown that otolith organs play an important role in vestibular function; children with absent cervical vestibular-evoked myogenic potentials (cVEMPs) found it harder to learn to walk and had significantly weaker static balance than those with normal cVEMP responses.[6,7]

Vestibular-evoked myogenic potential (VEMP) can be used to evaluate the function of the saccule and utricle system quantitatively. There are two types of VEMPs: 1) the cVEMP, which is derived from the saccule and mainly reflects the function of the saccule and the inferior vestibular nerve[8]; and 2) the ocular VEMP (oVEMP), which is derived from the utricle and mainly reflects the function of the utricle and the superior vestibular nerve.[9] In a recent review that analyzed cVEMPs and oVEMPs, the results demonstrated that normal cVEMP and oVEMP responses were detected in 46.7% to 100% and 63.5% of children with sensorineural hearing loss (SNHL), respectively, whereas 15.6% to 83% and 45.5% of children with CI had normal cVEMP and oVEMP responses, respectively.[10] Assessment of vestibular function in children is much more difficult than in adults because of the difficulty in testing and unclear reliability of the tests.[11,12] Some researchers were able to perform the caloric test in only three of 42 and 13 of 27 children.[13,14] The objective of the present study was to use a combination of the oVEMP and cVEMP tests to examine the effect of CI on otolith function and to explore the feasibility of VEMP testing in children.

MATERIALS AND METHODS

This was a single-center case series study. Thirty-five children undergoing CI at the Department of Otorhinolaryngology–Head and Neck Surgery, Shanxi Provincial People's Hospital from July 2017 to March 2018 were enrolled. All patients were diagnosed with bilateral severe to profound SNHL and had no past history of vertigo symptoms; this was their first surgery. The cause of deafness was congenital. Otoscopy and tympanogram were performed in all patients to ensure intact eardrums and normal middle ear function. The diameter of the aqueduct at midpoint greater >1.5 mm was defined as enlarged vestibular aqueduct (EVA) on imaging examination.[15] All patients underwent cVEMP and oVEMP testing 2 days prior to CI. During the postoperative period, follow-up testing was performed at 5 days,

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TABLE I.
Results of cVEMPs and oVEMPs Before and After Cochlear Implantation.

VEMP	Side	Preoperation	5 Days Postoperation	1 Month Postoperation		2 Months Postoperation	
				CI Off	CI On	CI Off	CI On
cVEMPs (R/T)	I	33/35	24/35*	18/25	19/26	20/25	18/24
	N	31/35	28/35	20/25	19/26	21/25	20/23
oVEMPs (R/T)	I	27/35	13/35*	9/26*	12/24	9/25*	17/24†
	N	30/35	25/35	20/26	19/24	17/26	22/26†

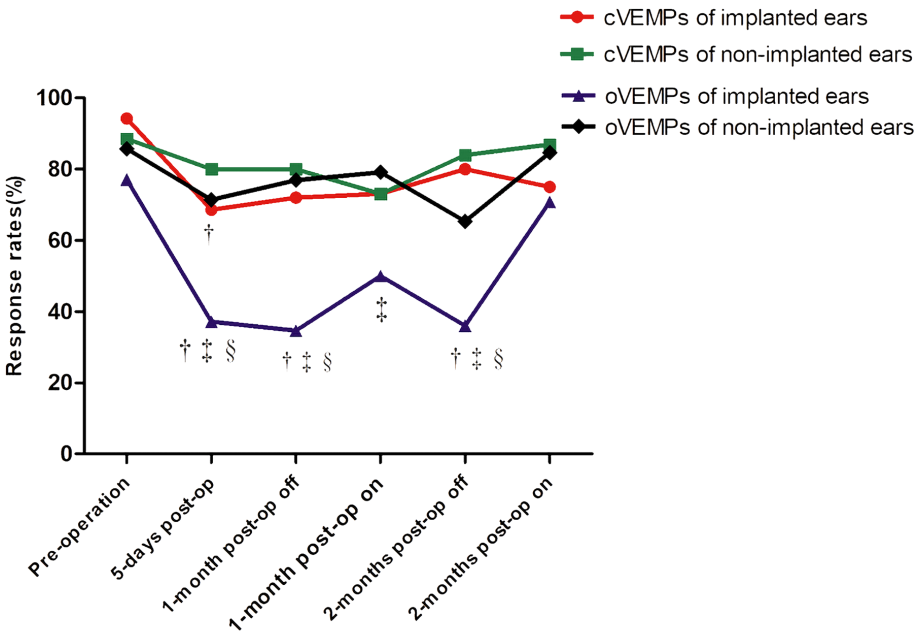
*$P < .05$ compared with preoperative.
†$P < .05$ compared with 5 days postoperative.
CI off = cochlear implant switch off; CI on = cochlear implant switch on; cVEMP = cervical vestibular evoked myogenic potential; I = implanted side; N = non-implanted side; oVEMP = ocular vestibular evoked myogenic potential; R = responsive ears; T = total ears.

1 month, and 2 months on both the implanted and nonimplanted sides, with the cochlear implant off or on. We also recruited 20 healthy children (mean age = 6.3 ± 2.3 years; range = 4–11-years, male/female = 9/11) as controls in this study. The study protocol was approved by the medical ethics committee of Shanxi Provincial People's Hospital. All patients provided written informed consent before beginning the study.

One ear was selected for surgery according to the patient's hearing and anatomy. The device was implanted on the right side (n = 30) and on the left side (n = 5) by two different surgeons (distribution 25:10). The surgery was performed by the round window (RW) approach, and successful implantations were confirmed. Five different types of cochlear implants were used: 29 from (Freedom n = 28, CI422 n = 1) Cochlear (Sydney, Australia), 4 from (SONATA, n = 3; CONCERTO, n = 1) MED-EL (Innsbruck, Austria), and 2 from (CS-10A, n = 2) Nurotron (Hangzhou, China).

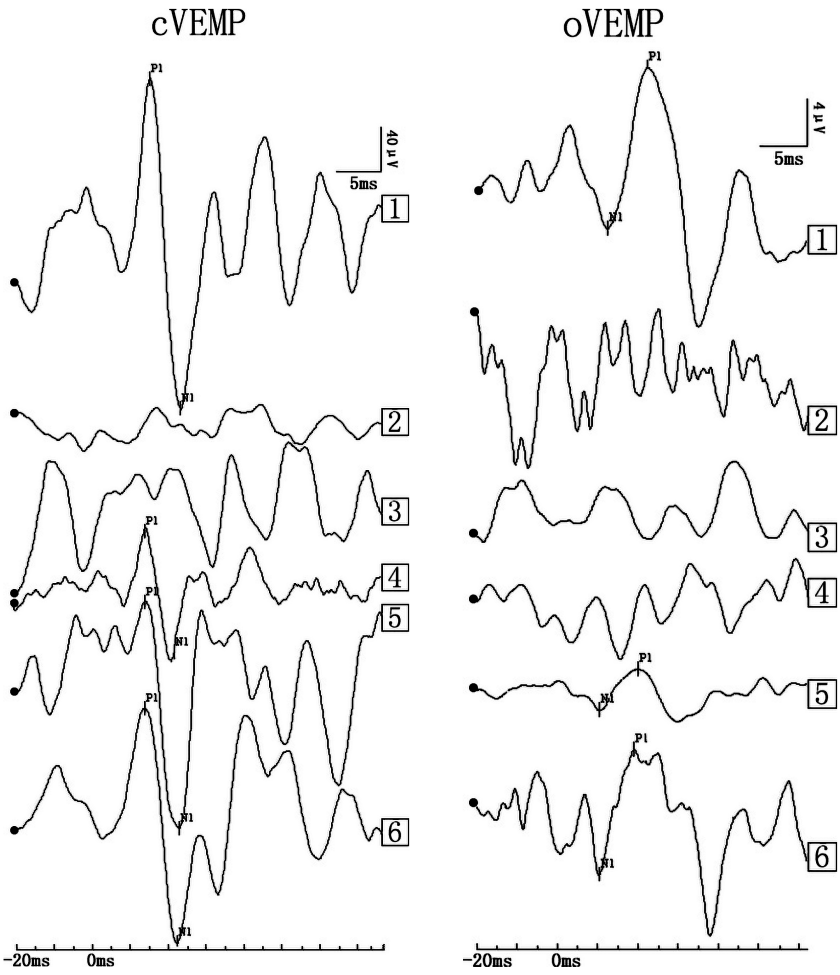
VEMP recordings were performed with a full-featured auditory evoked potential analyzer (ICS CHARTR EP; GN Otometrics (Taastrup, Denmark)). The stimulus was a 500 Hz pure-tone burst (rise/fall time = 1 millisecond; plateau time = 2 milliseconds), which was delivered through a calibrated earphone (3M E-A-R TONE Insert Earphone) (3M company, Paul, MN, United States). The frequency of stimulation was set at 5.1 times per second, the cumulative number of times was set at 100 times, and the width of the recording window was 50 milliseconds; the band-pass filter was set at 20 to 2,000 Hz. The impedance of the recording electrode was maintained below 5 kΩ.

With the patient lying in the supine position, the active electrode was placed on the upper third to midpoint of the sternocleidomastoid (SCM) muscle, a reference electrode was placed on the sternum, and the ground electrode was placed on the forehead.[16] The patients were instructed to raise their heads off the pillow and turn the head to the contralateral side 45° to generate a constant tonic pretension of the



† P<0.05 compared with preoperation, ‡ P<0.05 compared with non-implanted ears,
§ P<0.05 compared with cVEMPs of cochlear implanted ears.

Fig. 1 Response rates of ocular vestibular evoked myogenic potentials (oVEMPs) and cervical VEMPs (cVEMPs) preoperatively and 5 days, 1 month, and 2 months after surgery when the implant was turned on and off. † P < 0.05 compared with preoperation, ‡ P < 0.05 compared withnon-implanted ears, § P < 0.05 comparedwith cVEMPs of cochlear implanted ears.



Normal cVEMPs/oVEMPs appeared before CI (line 1). cVEMPs/oVEMPs were disappeared at five days after CI (line 2) and one month after CI when the cochlear implant switched off (line 3). Within one month after CI when the cochlear implant switched on (line 4), oVEMPs disappeared and cVEMPs could still be elicited, but cVEMPs impairment could be observed. Two months after CI when the cochlear implant switched off or on (line 5,6), cVEMPs/oVEMPs could still be elicited, but oVEMPs impairment could be observed. The y-axis represents amplitude in μV.

Fig. 2 Recordings of cervical vestibular evoked myogenic potential (cVEMP) and ocular VEMP (oVEMP) on the implanted side from a patient with bilateral severe-to-profound sensorineural hearing loss and cochlear implantation on the right side. Normal cVEMPs/oVEMPs appeared before CI (line 1). cVEMPs/oVEMPs were disappearedat five days after CI (line 2) and one month after CI when the cochlear implantswitched off (line 3). Within one month after CI when the cochlear implantswitched on (line 4), oVEMPs disappeared and cVEMPs could still be elicited, but cVEMPs impairment could be observed. Two months after CI when the cochlearimplant switched off or on (line 5,6), cVEMPs/oVEMPs could still be elicited,but oVEMPs impairment could be observed. The y-axis represents amplitude in 7μV.

SCM during the recording. The cVEMP waveform was recorded on the ipsilateral SCM of the ear being tested to serve as the response signal of the ear to acoustic stimulation.

During the oVEMP test, participants were instructed to direct their gaze to a dot on the ceiling while lying supine. The active electrode was positioned inferior to the contralateral eye

TABLE II.
Specific Parameters of VEMPs in Patients on the Implanted Side Before Cochlear Implantation and in the Normal Control Group.

VEMP	Group	T	Threshold, dB SPL	P1 Latency, ms	N1 Latency, ms	Interpeak Latency, ms	Amplitude, μV
cVEMPs	CI	33	120.36 ± 5.94	13.98 ± 1.04	21.60 ± 2.50	7.6 ± 2.12	264.89 ± 205.04
	Normal	20	119.34 ± 4.74	14.01 ± 0.82	21.08 ± 2.36	7.08 ± 1.86	354.87 ± 155.07
oVEMPs	CI	27	120.89 ± 6.99	16.17 ± 1.11	10.83 ± 0.81	5.3 ± 0.96	10.67 ± 10.18
	Normal	20	118.36 ± 3.74	15.56 ± 1.10	11.06 ± 0.74	5.06 ± 0.84	13.88 ± 9.01

The first positive wave in the cVEMP waveform is P1, and the first negative wave is N1. The first negative wave is N1 and the first positive wave is P1 in the oVEMP waveform.

CI = cochlear implant; cVEMP = cervical vestibular evoked myogenic potential; oVEMP = ocular vestibular evoked myogenic potential; T = total ears; VEMPs = vestibular evoked myogenic potentials.

of the ear being tested, about 1 cm below the lower eyelid. The reference electrode was placed 1 cm below the active electrode, and the ground electrode on the root of the nose. The oVEMP waveform was recorded infraorbitally on the contralateral orbit of the ear being tested as a response signal to the acoustic stimulus.

For all VEMP tests, at least three trials were conducted. If there were unrecognizable or unrepeatable waveforms, the VEMP response was considered absent. The VEMP thresholds (dB SPL) were defined as the lowest stimulus intensity for obtaining a clear and repeatable biphasic wave. A stimulus level of 131 dB SPL was used to assess whether the patient's VEMPs could be elicited. The VEMP response rates, amplitudes (μV), latencies, and interpeak latency (milliseconds) were recorded with a stimulus of 131 dB SPL. The typical VEMP waveform is bidirectional, the first positive wave in the cVEMP waveform is P1, and the first negative wave is N1. The first negative wave is N1 and the first positive wave is P1 in the oVEMP waveform. The latencies of P1 and N1 were determined between 0 milliseconds and the maximal peak of P1 and N1. The interpeak latency was the absolute value of the time between P1 and N1. The amplitudes were defined as the vertical distance between the peaks of P1 and N1.[17]

All the data were analyzed by IBM SPSS Statistics 23.0 (IBM, Armonk, NY). Statistical comparisons were performed by paired-samples t test and the independent t test. A value of $P < .05$ was considered statistically significant.

RESULTS

The study group consisted of 21 male and 14 female patients with an average age of 8.26 ± 4.95 years (range = 3–18 years). Preoperative imaging showed a bilateral EVA in 14 patients. The results of cVEMPs and oVEMPs before and after CI are presented Table I. A comparison of the preoperative and postoperative response rates of VEMPs are presented (Fig. 1). The representative examples are shown (Fig. 2).

In all the preimplantation tests, the VEMP testing revealed a prevalence of otolith dysfunction, with a response rate for cVEMPs in 64 (91.4%) and oVEMPs in 57 (81.4%) of the 70 tested ears. There was no statistically significant difference between the response rates of cVEMPs and oVEMPs. The extraction rate of the normal control group was 100%. Specific parameters of VEMPs in patients and those in the normal group are detailed in Table II. There was no significant difference between the preoperative parameters of CI and the normal control group.

Five days after surgery, VEMPs on the implanted side disappeared, and the response rates of cVEMPs and oVEMPs were reduced to 68.6% and 37.1%, respectively. Statistical analysis showed significant changes in VEMPs compared to the preimplantation results ($P = .004$ for cVEMP, $P < .001$ for oVEMP). In addition, all 19 ears without VEMP responses before CI also had absent VEMPs postoperatively. The Δparameters (mean value [postoperatively] − mean value [preoperatively]) indicated that there were significant changes in VEMPs after surgery (Table III). A series of abnormalities were discovered; the two major changes were the threshold elevation and the amplitude reduction. The latencies of VEMPs were prolonged. The oVEMP latency of N1 was significantly prolonged on the implanted side ($P < .05$). The remaining changes in latencies were not statistically significant.

One month after surgery, the response rates of cVEMPs and oVEMPs on the implanted side in all patients who could cooperate with the test decreased to 72% and 34.6%, respectively, when the device was switched off, and 73.1% and 50%, respectively, when the device was switched on. Similar results were observed 2 months after surgery. Our results showed that at 2 months after surgery, the extraction rates of cVEMPs and oVEMPs on the implanted side decreased to 80% and 36%, respectively, when the device was switched off, and 75% and 70.8%, respectively, when the device was switched on. The changes in various

TABLE III.
The Δ Parameters of oVEMP and cVEMP on the Implanted Side Preoperatively and 5 Days, 1 Month, and 2 Months Postoperatively.

Time	T	ΔThreshold, dB SPL	ΔP1 Latency, ms	ΔN1 Latency, ms	ΔInterpeak Latency, ms	ΔAmplitude, μV
cVEMP						
5 days postop	24	6.29*	0.31	0.65	0.33	−198.08*
1 month postop off	18	1.17	0.71	−0.17	−0.88	−138.63†
1 month postop on	19	5.16†	0.38	−0.56	−0.94	−95.68†
2 months postop off	20	6.05*	0.79	0.93	0.13	−115.43†
2 months postop on	18	4.78*	0.61	1.21†	0.60	−88.20
oVEMP						
5 days postop	13	4.31†	0.24	0.86†	−0.63	−5.34†
1 month postop off	9	6.78†	−0.32	0.14	−0.46	−5.70†
1 month postop on	9	8.67†	−0.57	−0.04	−0.53	−3.33
2 months postop off	8	4.38	0.45	0.63	−0.18	−3.80
2 months postop on	14	4.93†	0.77	1.03*	−0.25	−4.77†

Δ Parameter = mean value (postoperatively) − mean value (preoperatively).
*$P < .01$, compared with the ipsilateral ear preoperation.
†$P < .05$.
cVEMP = cervical vestibular evoked myogenic potential; oVEMP = ocular vestibular evoked myogenic potential; postop off = postoperation when the cochlear implant was switched off; postop on = postoperation when the cochlear implant was switched on; postop = postoperation; T = total ears.

TABLE IV.
Overview of Clinical Research on the Function of the Otolith Before and After Cochlear Implantation.

Reference	Age Range	Surgical Method	cVEMP Absent Pre/N (%)	oVEMP Absent Pre/N (%)	Follow-up, d	cVEMP Absent Post/N (%)	oVEMP Absent, Post/N (%)	* or †	Stimulus	Amplitude Normalization
Jin[18]	2–7 yr	NI	5/12 (41.7%)	ND	NI	8/12 (66.7% On), 11/12 (91.7% Off)	ND	3* On, 6* Off	ACS (clicks)	ND
Todt[22]	17–84 yr	C or Rw	23/62 (37.1%)	ND	6–8 wk	34/62 (54.8%)	ND	13*	ACS, BCV	ND
Melvin[23]	23–69 yr	Ap	7/19 (36.8%)	ND	4–8 wk	NI	ND	5†	ACS (clicks)	Y
Krause[24]	15–83 yr	Ap	16/30 (53.0%)	ND	2 mo	22/30 (73.3%)	ND	6*, 6†	ACS (tb)	ND
Wagner[25]	11–58y	Rw or Ap	18/40 (45%)	ND	32.9 ± 25 mo	NI	ND	5*	ACS, BCV	ND
Katsiari[26]	10–78 yr	NI	10/20 (50.0%)	ND	1 and 6 mo	16/20 (80% 1 mo), 15/19 (79% 6 mo)	ND	6*, 6 mo; 6*, 6 mo	ACS (tb)	ND
Tsukada[28]	30–60 yr	Rw	0/11 (0%)	ND	1 mo	0/13 (0%)	ND	0 *	ACS (clicks)	ND
Robard[29]	1–86 yr	Rw	2/30 (6.7%)	ND	5 mo	2/32 (6.2%)	ND	13†	ACS	ND
Ajalloueyan[14]	12–56 mo	Rw	9/54 (16.7%)	ND	6–8 wk	NI	ND	1*	ACS (tb)	Y
Chen[30]	5–65 yr	Rw	10/34 (29.4%)	15/34 (44.1%)	4 wk	20/34 (58.8%)	22/34 (64.7%)	cVEMP: 10,*	ACS (tb)	ND
Xu[17]	3–12 yr	C	32.3%	9/31 (29.0%)	1 mo	32.0% On, 34.8% Off	4/31 (12.9% On), 5/26 (19.2% Off)	oVEMP: 7 * cVEMP: 10* On, 9* Off, oVEMP: 18* On, 15* Off	ACS (tb)	ND
Psillas[27]	1.5–4 yr	Ap	3/10 (33.3%)	ND	10th d and 6 mo	10/10 (100%)	ND	7†	ACS	ND
Inoue[7]	20–97 mo	ND	21/62 (33.9%)	ND	ND	ND	ND	ND	ACS (tb)	Y

Follow-up in days means the time from preoperative test to postoperative test. Amplitude normalization. Real-time rectified electromyography activity was monitored to ensure adequate contraction of the muscle for detection of the relaxation response.

*Number of individuals with test results from normal to loss.

†Number of individuals with test results from normal to abnormal.

Absent Post = number of individuals with absent test results after surgery; Absent Pre = number of individuals with absent test results before surgery; ACS = air-conducted sound; AP = location of the cochleostomy anterior to promontorial lip of the round window. BCV = bone-conducted vibration; C = cochleostomy approach; cVEMP = cervical vestibular evoked myogenic potential; N = number of individuals tested; ND = not detected; NI = not identified; Off = the cochlear implant was switched off; On = the cochlear implant was switched on; oVEMP = ocular vestibular evoked myogenic potential; RW = round window approach; tb = tone burst; Y = yes.

parameters are shown in Table III. There were no statistical differences in the number of excluded patients.

Further comparison of the percentage of VEMPs recorded at four different time points on the implanted side showed statistically significant differences (Fig. 1), particularly for oVEMP. With regard to cVEMP, the McNemar test revealed no statistically significant differences between the different time points, except for one time point (pre- vs. 5-days postoperative). In addition, the amplitudes of cVEMP gradually recovered over time, whereas those of oVEMPs recovered slowly. For the non-implanted side, there was a reduction of VEMP amplitudes as well as an elevation of VEMP thresholds and no statistically significant differences in the response rates.

After surgery, statistically significant differences were found in the response rates of oVEMPs between the implanted and non-implanted sides (Fig. 1). For the cVEMPs, the response rates of the implanted side were lower than those of the nonimplanted side, but the difference was not statistically significant.

The oVEMPs and cVEMPs were analyzed 1 and 2 months after surgery while the implant was switched on and off. We found that the response rates of oVEMPs were lower when the implant was switched off after implantation, and a significant difference was observed (2 months postoperatively) on the implanted side.

Ears with complete data of both oVEMPs and cVEMPs were assessed. A higher response rate could be observed in cVEMPs than in oVEMPs on the implanted side. There were significant differences among the three different time points (Fig. 1).

Eleven of the 35 patients with cochlear implants complained of postoperative vertigo. The symptoms started on the first day postoperatively and lasted less than 7 days postoperatively. No correlation was found between the occurrence of postoperative vertigo and the absence of VEMPs, patient age and sex, implant type, implant side, surgeon, sealing the RW with connective tissue, and perilymph fluid loss during surgery. In our study, EVA was revealed to be a risk factor for vertigo after CI ($P = 0.013$).

Table IV shows different researchers using different test methods and displays the different examination results.

DISCUSSION

In this study, we assessed the effects of unilateral CI on otolith function by observing the changes in oVEMPs and cVEMPs in children. We observed a reduction in response rates of oVEMPs and cVEMPs postoperatively, with the most severe reduction occurring within 5 days after CI.

Due to the close embryological and anatomical connection between the cochlea and vestibular end organs,[18] patients with hearing loss may have varying degrees of vestibular dysfunction, as has been demonstrated in many studies.[6,7,11,19–21] However, there are some differences in the results of these studies (Table IV). Our research showed that the response rates of cVEMPs are higher than those of previous studies,[18,22–27] but similar to those of some recent studies.[7,14,17,28–30] The higher response rates of VEMPs in the more recent studies are probably due to more sensitive examination methods. The literature regarding utricle function before and after implantation is still limited.[17,30] In our study, after further analysis of amplitude asymmetry, we found that only 40% of our patients had normal symmetrical cVEMP and oVEMP responses before CI. These data can be used for choosing the side with weaker vestibular function for CI.

In our study, the response rates of cVEMPs and oVEMPs reduced significantly 5 days after surgery on the implanted side. The damage rate of the saccule after surgery was observed to range from 21% to 100% in previous studies (Table IV).[18,20,22–24,27,29] A review evaluating the effects of CI surgery on adult vestibular function over the past 20 years found that 68.3% patients had normal cVEMPs before surgery, and 56% retained normal cVEMPs after surgery. However, none of the included studies used oVEMPs, and the response rates of cVEMPs had a wide range.[31] These differences could have been partly due to the surgical technique and the time point of the evaluation after surgery. There are very few studies that have conducted continuous testing for evaluating both utricle and saccule function pre- and postoperatively, especially in children. Our study also showed that, in cases where VEMPs could be elicited on the operated side 5 days after CI, there was a reduction of VEMP amplitude and elevation of the VEMP threshold. These findings are consistent with previously published studies.[13,17,22–24,29] One study revealed that the cVEMP amplitude reduction rate was 60% after CI in 15 older children.[13] Another study pointed out that cVEMPs in five out of 16 adults appeared either as a disappearance of previously measured cVEMPs or an increase in threshold of more than 10 dB nHL after implantation.[23] The other study showed an increase in the VEMP threshold, decrease in amplitude, prolonged latency of N1 and P1, and shortened interval 1 month after CI.[17] In our study, we evaluated the VEMPs before using the implant device; therefore, there was no interference with electrical activity. The results could be attributed to the surgical process itself and the short-term pathological changes. It seems more likely that this was due to postoperative inflammatory changes and edema, or perhaps loss of perilymph. Thus, our study demonstrated that CI could damage the utricle and saccule, and indicated that the most severe damage occurs within 5 days after CI in children.

In particular, the saccule is a vestibular sensor closest to the cochlea. Hence, we hypothesized that the saccule might be the first vestibular sensor to be impaired by CI. A review revealed that cVEMPs were the most often impaired after CI; however, there were only five studies involving cVEMPs, and no article about oVEMPs was included.[32] This conclusion (i.e., cVEMPs are the most frequently impaired) is not supported by some recent studies.[17,33] One study found that 53.1% patients had nonresponsive cVEMPs and 74% had nonresponsive oVEMPs in 96 tested ears with cochlear implants.[33] Another study found that the response rates of cVEMPs were 15.4% with the implant switched on and 13.1% with the implant switched off (higher than those of oVEMPs) after CI.[17] These results are in agreement with ours. Our results showed that significant differences were

found between the response rates of oVEMPs and cVEMPs after CI. We also found that unlike cVEMPs, the amplitude of oVEMPs did not gradually recover, indicating that recovery of utricle function after operation lagged behind that of the saccule. Therefore, this study highlights the fact that CI can impair the function of the utricle. For the low extraction rate of oVEMPs, it may also be due to the different types of cochlear implants and surgical techniques in this study. It is also possible that air tends to accumulate in the utricle during surgery. This conclusion needs to be confirmed by further studies with a larger sample size.

In our study, electrode insertion was performed via the RW in all patients. We conclude that the RW implantation approach can decrease the risk of impairing saccule function, and this may explain our relatively high response rates of cVEMPs after CI, similar to other studies. The study compared cochleostomy and the RW insertion approach, and found that the latter approach had significantly better results (50% vs. 13% changed from normal to absent cVEMPs responses).[22] Another study found that no patient had absent cVEMP response in the operated ear by RW approach with soft electrodes.[28] Regarding oVEMPs, for the first time, we found utricle damage caused by the RW implantation approach.

The testing time for VEMPs was variable in previous studies; therefore, there is no consensus on when to perform the test. The response rates of cVEMPs in our study revealed no statistically significant differences postoperatively. Our findings are consistent with those of other studies.[14,20,26] One study compared 1- and 6-month results in 20 patients after CI when the devices were switched off, and indicated that there were no changes in cVEMPs.[26] Another study reported no significant differences in cVEMPs in all 27 children investigated preoperatively and 6 to 8 weeks postoperatively before activating the CI device.[14] Our oVEMP results showed that there was a statistically significant difference between the preoperative and postoperative periods. Therefore, we presume that the function of the utricle is not fully recovered 2 months after surgery. Hence, we believe that postoperative oVEMPs need long-term dynamic monitoring more than cVEMPs.

We also compared the changes in VEMPs when the cochlear implant was switched on versus off. A few previous studies have evaluated this relationship. The study examined the saccule function after CI, and demonstrated that 11 out of 12 children showed no response in cVEMPs when the cochlear implant was off, and four children had reproducible cVEMPs when the cochlear implant was switched on.[18] In our study, the response rates of oVEMPs were lower when the device was switched off postoperatively; this result is consistent with those in another study.[17] Our results suggest that electrical stimulation of the comfort threshold may affect otolith function in some patients.

EVAs were revealed to be a risk factor for vestibular symptoms after CI, and there was no correlation between the factors mentioned above and the occurrence of postoperative vertigo in our study. These findings also have been reported in previous studies.[4,20,30] Vestibular symptoms were temporary, and the short duration could also be explained by the well-known central vestibular compensatory mechanisms[3,24] and young age of our patients.

CONCLUSION

The present study confirmed the value of VEMP testing in the clinical setting. Our study demonstrated that CI can damage the utricle and saccule in children, as revealed by the changes in VEMPs. The most severe otolith function impairment occurs within 5 days after CI. We also confirmed that EVA is a risk factor for the development of vestibular symptoms after CI. Implantation via the RW may decrease the risk of saccule function impairment.

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