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Original Article

Anterior Cervical Disc Fusion Does not Affect the Presence of Cervical Vestibular–Evoked Myogenic Potential

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OBJECTIVE: Cervical spondylosis and cervical disk herniation are the most frequent forms of degenerative disease in the cervical spine. Surgical treatment mainly includes anterior cervical disk fusion. However, information concerning vestibular-evoked myogenic potential (VEMP) recording in patients undergoing cervical spine surgery is limited. The present prospective study aimed to investigate the effect of anterior disk fusion surgery on cervical VEMP (cVEMP) parameters.

MATERIALS and METHODS: Twenty-five patients were enrolled in this study, and 20 patients (10 men and 10 women) completed cVEMP testing. Patient ages ranged from 29 to 76 y (mean, 52 y). Patients with conductive hearing loss or vestibular dysfunction were excluded. The cVEMP test was recorded preoperatively and 1 and 4 months postoperatively. Air-conducted tone-bursts of 500 Hz were used.

RESULTS: We found no statistically significant difference between the preoperative and postoperative cVEMP values.

CONCLUSION: Cervical spine surgery (anterior cervical disk fusion) for treating cervical spondylosis does not appear to affect the presence of cVEMP or the parameters of cVEMP, when using air-conducted tone-bursts of 500 Hz. Moreover, cVEMP testing can be used in the postoperative phase for evaluating vertigo in patients who have undergone anterior cervical disk fusion.

KEYWORDS: Cervical VEMP, spondylosis, anterior cervical disc fusion

INTRODUCTION

Cervical spondylosis and cervical disk herniation are the most frequent forms of degenerative disease in the cervical spine. In some cases, they occur with myelopathy, increasing the risk of severe disability. The major indicators of these conditions are neck pain, stiffness, radiculopathy, and symptoms related to the affected part of the spinal cord [1]. Studies have mentioned that 75%-90% of patients with cervical radiculopathy will show improvement with nonoperative management [2, 3]. Upon failure of nonoperative conservative treatment, operative treatments including anterior cervical disk fusion (ACDF) combined with corpectomy in some cases and placement of plates and screws, laminectomy, and posterior fusion, or a combination of these techniques are employed [4-8]. Robinson and Smith first described ACDF, and after 3 years, Cloward et al. [6] performed discectomy with a special reamer combined with fusion using an autologous iliac bone graft [7]. In 1988, Bagby et al. [4] were the first authors to describe arthrodesis using an interbody fusion cage.

The vestibular-evoked myogenic potential (VEMP) is a relatively new approach for evaluating different parts of the vestibular system. More particularly, the cervical VEMP (cVEMP) presents a short latency and large amplitude myogenic potential, which presumably represents the saccule's response to sound when using an air-conducted stimulus [9-11]. The cVEMP is characterized by a

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Table 1. VEMP values in 20 subjects consisting the comparison group

Patient No.	Age	Lat p1 RE (ms)	Lat n1 RE (ms)	Amp RE (μV)	Lat p1 LE (ms)	Lat n1 LE (ms)	Amp LE (μV)
1	70	13.08	19.59	460.20	12.74	20.26	337.40
2	31	17.25	26.77	219.24	15.08	24.43	347.90
3	65	18.42	28.61	249.76	18.75	28.44	494.14
4	57	15.92	24.93	202.64	16.92	26.10	225.59
5	46	16.58	25.77	132.21	16.75	24.77	158.45
6	66	18.75	28.11	120.08	19.59	28.44	178.43
7	48	17.42	28.94	145.26	17.25	26.60	187.75
8	59	18.25	28.94	105.67	16.92	25.77	175.05
9	69	16.92	26.10	217.04	15.92	26.10	312.11
10	35	16.58	26.10	275.88	16.75	27.44	281.25
11	38	18.42	27.61	58.56	19.09	29.44	78.54
12	37	17.75	31.28	151.12	19.59	30.28	142.82
13	71	17.25	26.77	257.57	16.92	26.60	92.76
14	61	20.76	30.28	109.12	21.09	30.95	150.15
15	44	22.09	35.12	238.04	17.92	32.62	455.57
16	32	18.92	29.44	80.56	17.92	28.11	220.95
17	74	16.42	27.27	440.43	17.25	28.94	500.73
18	62	25.77	34.12	156.49	22.43	34.62	194.34
19	43	16.42	28.11	64.69	16.42	26.77	119.39
20	63	16.92	26.10	621.83	21.43	29.78	262.21

Lat p1 RE: latency of n13 right ear; Lat n1 RE: latency of p23 right ear; Lat p1 LE: latency of n13 left ear; Lat n1 LE: latency of p23 left ear; Amp: amplitude

Table 2. Stimulus characteristics used in our study for recording the cVEMP

Stimulus Type	500 Hz tone burst 2:1:2 cycle
Polarity	Rarefaction
Level	106.5 dBSPL
Rate	5.0/s
Filters	10-1,000 Hz
Repetitions	100-150
Amplifier gain	x 5,000
Artifact rejection	off

ABR: Auditory brainstem response; ASSR: auditory steady-state response

biphasic waveform beginning with a primary positive waveform after approximately 13 ms (p13 or P1) followed by a negative deflection at approximately 23 ms (n23 or N1) [11].

The short-onset latency of VEMP indicates that an oligosynaptic pathway is likely involved in its mediation [12]. The origin of cVEMP is thought to be the ipsilateral saccular macula, and the responsible neural pathway passes through the inferior vestibular nerve to the vestibular nuclei, which includes the afferent limb of the sacculocollic reflex. The efferent limb is then routed ipsilaterally through the medial vestibulospinal tract to the motor nucleus of the accessory cranial nerve (CNXI). The reflex terminates at the sternocleidomastoid muscle (SCM) [11, 13].

The cVEMP is almost always present in healthy subjects, whereas some elderly subjects exhibit an absence of response, suggesting dysfunction of the sacculocollic pathway. If the examiner records no VEMP response, the first step is to exclude technical errors, such as an inadequately placed headphone and underlying conductive hearing loss [14]. However, the absence of cVEMP recording may be attributed to further local causes in the end organ of the vestibulo-collic reflex, which is the SCM. On closely assessing the final part of the reflex, it is found that the neural fibers of the medial vestibulospinal tract reach the motoneurons of the spinal cord at the C2 and C5 levels and then enter the SCM through the spinal accessory nerve. This process requires activation and contraction of the SCM to create a measurable myogenic potential. In fact, the amplitude of the potential increases proportionately with the mean level of tonic muscle activation [9].

It is unclear what happens with cVEMP recording after operation in the cervical spine. Additionally, experience regarding VEMP recording in patients with known cervical spine lesions and patients undergoing cervical spine surgery is limited. Therefore, the present study aimed to examine the effect of ACDF on cVEMP parameters.

MATERIALS and METHODS

Subjects

In the present study, 25 subjects who were diagnosed with cervical myelopathy and cervical disk herniation by healthcare professionals were enrolled. These patients underwent ACDF treatment. The study only included patients with cervical myelopathy involving C2-C7 (and T1). In all patients, we used a polyetheretherketone (PEEK) anatomical cervical cage filled with allograft bone [15, 16]. Twenty patients (10 men and 10 women) completed cVEMP testing for data analysis, and the patient age ranged from 29 to 76 years (mean±standard deviation, 52.4±13.8 y). The participants provided written informed consent according to the Declaration of Helsinki, and the local ethics committee approved this study. The patient demographic character-

Table 3. VEMP values in 20 patients treated with ACDF (Raw Data)

Patient		Affected	Lat p1 RE (ms)			Lat n1 RE (ms)			Amp RE (μV)			Lat p1 LE (ms)			Lat n1 LE (ms)			Amp LE (μV)		
No.	Age	Cervical Disc	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third	First	Second	Third
1	76	C4-5, C5-6, C6-7	14.42	13.58	13.7	24.05	25.07	25.16	80.60	90.85	89.68	14.55	14.10	14.03	24.59	24.52	23.85	95.47	120.87	116.61
2	39	C4-5, C5-6	15.58	14.67	15.10	28.11	27.85	28.78	62.50	70.10	901.12	16.08	15.59	15.85	27.10	28.65	27.41	31.98	40.05	41.74
3	34	C4-5, C5-6	13.24	13.24	12.74	21.93	21.93	22.93	221.44	109.38	196.53	13.74	13.74	13.74	23.43	23.43	22.93	287.35	100.34	173.83
4	57	C5-6, C6-7	13.58	13.74	13.24	11.93	22.93	24.43	109.86	99.37	218.75	14.58	13.58	13.74	21.43	21.43	24.43	186.79	114.01	68.60
5	46	C4-5, C5-6	12.74	11.74	14.25	23.43	22.93	27.77	77.88	97.66	125.24	13.08	13.08	13.58	19.59	25.77	27.77	176.27	112.79	83.98
6	66	C3-4, C4-5, C5-6, C6-7	12.58	13.89	13.5	22.85	23.17	22.52	65.50	60.89	70.69	13.64	13.96	13.22	21.64	21.74	20.69	87.35	68.95	93.45
7	47	C5-6, C6-7	11.91	11.91	15.41	22.43	24.77	22.93	89.77	36.38	40.04	14.08	15.58	14.08	24.43	24.43	22,.93	28.56	32.23	43.95
8	57	C5-6, C6-7	17.72	17.42	13.24	28.11	26,.77	25.77	66.41	71.78	21.73	12.58	12.58	10.24	27.94	30.78	25.77	46.88	58.59	31.25
9	55	C3-4, C4-5, C5-6, C6-7	14.91	13.74	15.08	27.27	23.76	27.27	130.37	130.86	103.03	14.91	14.91	14.91	30.28	27.44	27.27	39.06	181.64	147.46
10	53	C5-6	14.60	13.74	14.2	23.15	24.57	24.76	110.58	120.25	106.98	12.66	13.34	13.98	27.58	26.36	27.05	100.50	119.82	115.76
11	37	C4-5, C5-6	12.41	14.91	14.91	22.59	21.93	21.93	48.83	48.09	48.09	13.08	14.58	14.58	21.93	25.27	21.93	79.35	107.91	107.91
12	37	C5-6	13.58	12.74	12.74	22.93	20.59	21.09	60.06	74.71	75.44	13.74	13.74	14.58	20.93	21.59	21.09	62.99	57.86	20.51
13	71	C4-5, C5-6	20.09	18.75	18.75	30.95	28.94	31.95	59.08	104.98	135.99	15.41	16.42	15.58	33.12	30.78	31.95	79.10	87.65	41.75
14	61	C4-5, C5-6, C6-7, C7-T1	15.41	15.41	15.41	23.43	23.43	23.43	229.00	229.00	229.00	13.08	13.08	13.08	21.43	21.43	23.43	147.95	147.95	147.95
15	44	C4-5, C5-6, C6-7	14.25	16.08	16.08	23.93	25.77	25.77	188.48	168.95	168.95	12.74	13.24	13.24	22.59	26.60	25.77	146.00	134.28	134.28
16	29	C6-7	14.25	13,.08	13.08	20.76	20.76	20.76	49.80	163.09	125.00	11.24	13.08	13.08	17.42	19.25	20.76	90.33	82.76	131.35
17	74	C3-4, C4-5	13.74	12.74	12.74	20.93	19.76	19.76	74.46	134.28	134.28	11.91	13.08	13.08	18.25	22.09	19.76	117.43	166.75	166.75
18	59	C3-4, C4-5	14.97	15.65	15.8	26.05	25.69	26.19	115.65	126.26	111.31	19.25	18.00	18.25	27.44	26.01	27.07	85.20	90.65	73.49
19	43	C6-7	13.08	13.74	13.74	28.11	29.78	29.78	101.07	99.12	99.12	16.75	14.91	14.91	27.94	30.28	29.78	197.75	180.42	180.42
20	63	C4-5, C5-6	13.16	13.88	14.2	25.65	26.89	25.98	82.44	76.96	80.68	12.67	13.52	13.31	23.59	24.25	23.12	73.58	71.74	69.13

The measurements were made preoperatively (first), on the first postoperative month (second) and on fourth postoperative month (third). Lat p1 RE: latency of n13 right ear; Lat n1 RE: latency of p23 right ear; Lat p1 LE: latency of n13 left ear; Lat n1 LE: latency of p23 left ear; Amp: amplitude

istics and preoperative values recorded from the right and left ears were compared with normative data acquired from a comparison group of patients with similar ages, who had negative histories of vestibular or cervical spine disorders and head trauma, and normal vestibular and impendence audiometry findings (Table 1). The mean age for the comparison group was 53.5±14.3 y (range, 31-74 y). cVEMP measurements were carried out at the following three time points: (i) preoperatively, (ii) the first postoperative month, and (iii) the fourth postoperative month.

Clinical Screening

Before cVEMP testing, each patient reported their detailed medical history and underwent a detailed neurological examination and researchers conducted comprehensive audiological assessments in all patients. The standard investigation consisted of pure-tone and speech audiometry (using aural earphones), impedance audiometry (tympanometry and acoustic reflexes), and evaluation of the vestibular system with bithermal caloric testing. We recorded cVEMP using an air-conducted stimulus with a 500-Hz tone burst.

The exclusion criteria were as follows: (i) presence of conductive hearing loss (air-bone gap >10dB) (e.g., middle ear effusion, otosclerosis, tympanic membrane perforation, etc.); (ii) tympanograms other than A or As according to Jerger's classification [17]; (iii) absent acoustic reflexes; and (iv) abnormal screening vestibular test results. On the basis of the above-mentioned criteria, we excluded five individuals from the study because of conductive hearing loss (middle ear effusion [two patients], tympanic membrane perforation [one patient], and abnormal screening vestibular test results [two patients]).

Recorded Parameters

Measurements were performed according to the current recommendations for cVEMP recording [18]. It has been well-documented that amplitude scales are in proportion to tonic electromyographic activity [9, 19, 20]. Therefore, it is important to monitor the electromyographic activity of the SCM and keep muscle activity as constant as possible to obtain reproducible results. Subsequently, the mean rectified activity was measured for the prestimulus time interval, and this value was used to calculate normalized or corrected amplitudes (P1-N1 amplitude divided by prestimulus mean rectified EMG). The average SCM activity was kept between 50 and 200 μV [18, 21]. To control the level of background tonic EMG activity, a self-monitoring protocol was used (biofeedback). The stimulus parameters used are presented in Table 2.

Table 4. Mean peak latencies (±SD) of p13 and n23 and mean amplitudes for the right side, measured preoperatively (first measurement), on the first postoperative month (second measurement), and on fourth postoperative month (third measurement)

	Mean Latency (msec)		
RIGHT SIDE	**p13**	**n23**	**Mean Amplitude (μV)**
First Measurement	14.43 (2.14)	23.79 (4.51)	99.27 (65.7)
Second Measurement	14.23 (2.06)	23.86 (3.04)	111.98 (50.99)
Third Measurement	14.39 (1.70)	24.68 (1.70)	122.94 (64.57)

ABR: Auditory brainstem response; ASSR: auditory steady-state response

Table 5. Mean peak latencies (±SD) of p13 and n23 and mean amplitudes for the left side, measured preoperatively (first measurement), on the first postoperative month (second measurement), and on fourth postoperative month (third measurement)

	Mean Latency (msec)		
LEFT SIDE	**p13**	**n23**	**Mean Amplitude (μV)**
First Measurement	14.14 (2.00)	24.08 (4.47)	112.69 (72.55)
Second Measurement	13.04 (3.77)	23.37 (7.42)	104.35 (53.27)
Third Measurement	14.04 (1.70)	23.33 (7.66)	103.57 (55.08)

Statistical Analysis

The data for cVEMP measurements were analyzed using SAS/STAT® 9.4 software (SAS Institute, Cary, NC, USA) to determine whether the responses and their characteristics differed significantly preoperatively and postoperatively. An independent sample *t*-test was used to compare characteristics between the patient group and the comparison group, and no statistically significant differences regarding age, latencies, and amplitudes were noted between the two groups. Owing to small sample size and skewed data distribution, we used the non-parametric Wilcoxon signed-rank test to compare pre- and postoperative parameters. Statistical significance was set at a $p<0.05$.

RESULTS

The raw data of the recorded values are presented in Table 3.

Presence of cVEMP Response

The percentage of elicited cVEMP responses was 100% (present in all 20 patients for all preoperative and postoperative measurements). The median for each characteristic was reported.

Effects of Patient Characteristics on cVEMP

To assess the associations of demographics (age, sex, sternocleidomastoid muscle length, height, and weight) with preoperative and postoperative changes, we used a series of linear models. The Wilcoxon test did not show any statistically significant differences regarding the effects of age, sex, height, and weight of the patients and length of the sternocleidomastoid muscle on cVEMP parameters (latency and amplitude) ($p>0.05$).

Preoperative and Postoperative Developments of cVEMP

We compared the latency and amplitude medians of p13 and n23 waveforms of the cVEMP preoperatively and at the first and fourth postoperative months. The mean peak latencies of p13 and n23 and the mean amplitudes for each side are presented in Tables 4 and 5. We found no statistically significant differences in the peak latencies of p13 and n23 and the mean amplitudes among the three measurements. The results of the Wilcoxon signed-rank test, after comparing the values preoperatively and postoperatively ($p>0.05$), were consistent with this interpretation.

DISCUSSION

The cVEMP test is widely used for assessing otolithic/inferior vestibular nerve function. Based on current knowledge, it consists of a specific test of saccular function, providing quantitative separate information about otolith and vestibular nerve function for each side. The output for cVEMP responses is the SCM innervated by the accessory (11th) cranial nerve. Because inhibitory inputs to the SCM of vestibulo-collic reflexes produce the cVEMP, the SCM must be contracted during the examination [14, 22]. There are four different methods for contraction of the SCM. One method is the elevation method, where an administrator asks the subjects to raise their heads from a bed or a chair in the supine position or in the semi-recumbent position. Another method is the rotation method, where an administrator asks subjects to rotate their heads toward the contralateral side of the stimulated ear [18]. Some researchers use a combined method in which the patient rotates and lifts the head in the supine position, while others use a pushing method in which subjects are asked to push their heads to an object [23, 24]. The head position itself does not affect VEMP responses [25]. However, researchers should note that when bilateral activation is used, it is difficult to monitor EMG activity as two muscles are being activated at the same time. For this reason, in our study, electromyographic activity was measured from each muscle separately to normalize the response. Postoperative facts contraindicated the rotation method immediately; therefore, we preferred to use the elevation method of stimulating the SCM for all recordings.

As mentioned previously, cVEMPs are usually present in healthy subjects, whereas some elderly subjects exhibit an absence of response [14]. Dysfunction of the end organ of the sacculocollic arc (the SCM) is a factor in this process that should be considered. In the present study, we tried to observe if surgery on the cervical spine could cause the absence of a cVEMP response in patients with cervical spondylosis. This should be useful for critically analyzing possible negative results in otherwise healthy subjects. Our study showed that neither cervical myelopathy itself nor cervical spine surgery interfered with cVEMP recording. To our knowledge, this is the first study about the effect of ACDF on the cVEMP. The study results are consistent with the findings of the study by Shirley et al. [26], in which a statistically significant difference in the amplitude of the cVEMP was not identified among patients with spinal cord lesion. Another important point of the study is the fact that cVEMP responses were recorded even in the first postoperative month. This indicates that anatomical alterations (edema and stiffness) occurring immediately postoperatively do not interfere with cVEMP recording. This assumption could be generalized for a large group of cervical surgical procedures, which do not limit the use of cVEMP. Further studies are required to confirm these results.

Moreover, it appears that the use of cVEMP as a diagnostic tool is not limited postoperatively and may further help assess other causes of vertigo in patients who undergo ACDF. In cases of cervical spine sur-

gery, postoperative vertigo might be attributable to intraoperative cervical spine trauma and injuries of central vestibular pathways, the vestibulospinal tract, neck receptors in neck muscles, and ligamentous structures. As cervical afferent input allows for posture control, spatial orientation, and head and eye coordination, it is believed that cervical mechanoreceptor dysfunction may cause dizziness [27, 28]. Disturbances of the vertebral artery may also play a role [29]. However, based on the results of the present study, it appears that the vestibulo-collic tract itself is not involved in eliciting postoperative vertigo, at least in patients who undergo ACDF. It appears that neither the underlying pathology nor the intraoperative trauma and possible postoperative anatomical alterations affect the characteristics of the cVEMP.

The present study has few methodological limitations. The sample size was relatively small, but we used non-parametric tests, and no parameter for each ear showed a statistically significant difference in the preoperative and postoperative periods. Therefore, we do not think that our sample size limited the significance of the results. However, further studies with a larger sample size would help obtain more generalized conclusions. We performed our study using air-conducted tone-bursts; therefore, the results are specific for the parameters of this stimulus. However, considering that we excluded the presence of conductive hearing loss through audiological screening tests and considering that tone burst is the most commonly used approach, it appears that different results using different stimulus options would be unlikely. We also minimized possible bias that might result from the equipment or the individualized examiner by using only one experienced examiner to conduct the measurements with the same equipment and environmental factors, and the same surgeon for performing the cervical surgery in all subjects. Moreover, our results cannot be generalized to every surgical intervention in the cervical spine. This study is limited to ACDF, which consists of a very common orthopedic procedure.

CONCLUSION

Our study showed that cervical spine surgery (ACDF) for treating cervical myelopathy/cervical disc herniation does not influence the presence of cVEMP or the parameters of cVEMP when using air-conducted tone-bursts of 500 Hz. Furthermore, cVEMP testing can be used in the postoperative phase for evaluating vertigo in patients who have undergone ACDF.

Ethics Committee Approval: Ethics committee approval was received for this study from the local ethics committee (Approval Date: 04.07.2012/Approval No: 388-12).

Informed Consent: Written informed consent was obtained from patients which participated in the study.

Peer-review: Externally peer-reviewed.

Author contributions: Concept - I.K., N.Z., A.Z.; Design - I.K., P.S.; Supervision - I.K., N.J.; Resource - I.K., V.R., A.Z.; Materials - I.K., V.R., A.Z., N.Z.; Data Collection and/or Processing - I.K., N.Z., V.R., A.Z., P.S.; Analysis and/or Interpretation - I.K., P.S., N.Z., O.R.; Literature Search - I.K., P.S., O.R.; Writing - P.S., I.K., N.Z., O.R.; Critical Reviews - I.K., O.R., P.S.

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