ORIGINAL ARTICLE

Is a pulling sensation in the anteroposterior direction associated with otolith dysfunction?

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Abstract

Conclusion: A pulling sensation in the anteroposterior direction is suggested to originate from a dysfunction of the otolith organs. Objectives: Previous study with vestibular evoked myogenic potential (VEMP) confirmed that a falling sensation (in an up or down direction) and a lateral tilt sensation (in a right or left direction) were caused by otolith lesions. The purpose of this study was to clarify whether a pulling sensation in the anteroposterior (forward or backward) direction originates from otolith dysfunction. Methods: The otolith function was assessed by cervical and ocular VEMPs (cVEMPs and oVEMPs) in 12 patients who complained of a forward or backward pulling sensation. cVEMPs were evaluated by the asymmetry ratio (AR) of the amplitude of the p13-n23 wave and the peak latencies of the p13 and n23 waves. oVEMPs were evaluated by the AR of the amplitude of the n1-p1 wave and the peak latency of the n1 and p1 waves. Results: Abnormal ARs on cVEMP were observed in 7 of 12 patients. Nine of 12 patients had abnormal oVEMP results including 3 bilateral absent responses. Most (10 of 12) patients had abnormal cVEMP and/or oVEMP results. The latency of each detected wave was within the normal ranges.

Keywords: VEMP, otolith organ, saccule, utricle

Introduction

Caloric testing has been widely used for evaluating inner ear functions in patients with balance problems since it reflects the function of the lateral semicircular canal. Therefore, much is known about vestibular disorders. Rotatory vertigo is the common symptom of patients with canal dysfunction. Less, however is known about disequilibrium caused by otolith dysfunction since evaluation of otolith function has previously been difficult. It was suggested that otolith symptoms include a tilting sensation or a sense of moving to and fro, and these are associated with the somatosensory illusion of walking on pillows or on uneven ground [1]. To date, the relationships between such symptoms and otolith function have not been discussed in detail.

Two decades have passed since the first report of vestibular evoked myogenic potential (cervical VEMP, cVEMP) in sternocleidomastoid muscle (SCM) [2]. The origin of the response was confirmed as being the saccular organs in an animal study [3]. Since then, cVEMP testing has become established as an examination for saccular function. More recently, it was reported that the evoked myogenic response was recorded around the eye by bone-conducted vibrations (ocular VEMP, oVEMP) [4]. The origin of oVEMP has been suggested as being the utricular organs [5]. oVEMPs can also be recorded by air-conducted sound stimulation. The amplitudes of oVEMPs to air-conducted sound are also extremely close to those of oVEMPs to bone-conducted vibrations [6]. Thus, measurements of oVEMPs to air-conducted sound have been used for assessing the function of the utricle [7,8]. cVEMP and oVEMP testing can thus now be used for evaluation of the function of both the saccule and utricle.

The most well-known otolith symptom may be Tumarkin’s drop attack, which is a sensation of being
pushed, thrown or knocked to the ground, or the falling sensation in patients with Meniere’s disease [9]. These patients frequently have cVEMP abnormalities [10]. Even in patients without Meniere’s disease, abnormal cVEMP results were obtained from five of seven patients who experienced a falling sensation [11]. These findings indicate that a falling sensation arises from the sensation of up-and-down movement caused by a dysfunction of the saccule, which senses acceleration in an up-and-down direction (gravity) [12]. On the other hand, oVEMP results were reported to be abnormal in 9 of 10 patients with a lateral tilt sensation [7]. Thus, lateral tilt sensation in a right or left direction is related to a dysfunction of the utricle, which senses acceleration in a right and left direction. The above-mentioned studies indicate that a disequilibrium within linear acceleration arises from a dysfunction in the otolith organs associated with acceleration. The question also arises as to whether a pulling sensation in a forward or backward direction has an otolith origin. The purpose of this study was to find an answer to this question, and so we examined oVEMP and cVEMP testing in patients who complained of a pulling sensation in the anteroposterior direction.

Material and methods

Subjects

Patients who complained of a pulling sensation in either a forward or backward direction and who underwent cVEMP and oVEMP testing were considered candidates for this study. Subjects who had any of the following criteria were excluded: (1) diagnosis of well-known vestibular disorder or other disorders that cause vertigo and/or dizziness; (2) abnormal results from routine examinations conducted at our institution, including primary equilibriometry (gaze, positional, and positioning nystagmus tests, Romberg test, and stepping test), pure tone audiometry, calorid, eye tracking, and optokinetic pattern tests; and (3) cerebellar signs or intracranial lesions detected by brain magnetic resonance imaging.

In total, 12 subjects from our database were enrolled in this study, including 3 males and 9 females who ranged in age from 8 to 59 years (mean 44.7 years). The patient characteristics are shown in Table I.

cVEMP measurement

cVEMP measurements were performed in the usual manner at our institute using a Neuropack Sigma® (Nihon Kohden, Tokyo, Japan) [11]. The active electrodes were placed on the upper half of the SCM muscle, the reference electrode was placed on the upper manubrium sterni, and the ground electrode on the forehead. A tone-burst sound of 135 dB SPL with a frequency of 500 Hz (rise/fall time, 1 ms; plateau time, 4 ms; repetition rate, 5 Hz) was delivered to the ipsilateral ear through a headphone. The evoked myogenic potentials were recorded and averaged 100 times. A bandpass filter from 5 Hz to 1 kHz was used. During the recordings, the subjects lay in a supine position and were instructed to keep their heads rotated to the contralateral side to maintain tonic contraction of the SCM muscle. The average of two runs was used for analysis.

Previous reports have assessed cVEMP results by evaluating the asymmetry ratio (AR) of the p13-n23 amplitude and the peak latencies of the p13 and n23 waves [11]. The ratio was expressed as the percentage difference between the larger and smaller amplitudes, divided by the sum of the two. To define the normal range, 31 healthy volunteers who had neither otological nor neurotological disorders were examined. Their ages ranged from 22 to 59 years (mean 32.7 years). The mean AR was 12.6% (SD, 11.8), and so the normal range was less than 36.3% (mean ± 2 SD). The mean peak latencies of the p13 and n23 waves were 13.6 ms (SD, 1.4) and 22.4 ms (SD, 2.0), respectively. Thus, the normal ranges (mean ± 2 SD) for the p13 and n23 waves were from 10.8 to 16.3 ms, and from 18.4 to 26.4 ms, respectively. When the AR and/or the peak latency extended beyond the normal range, we considered the results to be abnormal.

oVEMP measurements

oVEMPs were measured as described previously using a Neuropack Sigma® [8]. The active electrodes were placed just below the eyelid with the reference electrode 2 cm lower, and the ground electrode was positioned on the forehead. Subjects lay in a supine position and were instructed to maintain a visual fixation point approximately 30° upward during the recording. A tone-burst sound of 135 dB SPL with a frequency of 700 Hz (rise/fall time, 1 ms; plateau time, 4 ms; repetition rate, 5 Hz) was delivered to the contralateral ear through a headphone. Evoked potentials were recorded, and averaged at least 50 times. The bandpass filter was set from 5 Hz to 500 Hz. We defined the initial negative–positive peaks that occurred less than 20 ms after the stimulus as n1 and p1, respectively. To eliminate artifacts, amplitudes smaller than 2 μV were rejected. The average of two runs was used for analysis. Results were also evaluated using the AR of p1-n1 amplitude [8]. This ratio was calculated in the same way as for the cVEMP readings. The mean AR in normal
volunteers was found to be 12.8% (SD, 9.4), and so the normal range was defined as less than 31.6% (mean ± 2 SD). The mean peak latencies of the n1 and p1 waves of the normal volunteers were 10.4 ms (SD, 0.92) and 16.4 ms (SD, 1.1), respectively. Thus, the normal ranges (mean ± 2 SD) for n1 and p1 were from 8.5 to 12.2 ms, and from 14.3 to 18.6 ms, respectively [8]. When the AR and/or the peak latency extended beyond this normal range and when no obvious wave could be obtained from the bilateral ears, we considered the results to be abnormal.

Results

Ten patients complained of a backward pulling sensation and the other two patients complained of a forward pulling sensation (Table I). Some sort of movement triggered episodes of pulling sensations in nine patients. The duration of the episode was less than a few minutes for all patients. Four patients complained of a momentary pulling sensation. None fell down to the ground.

In the cVEMP study, all patients showed responses in at least one ear (Figure 1a). No responses were detected in a unilateral ear in three patients. The peak latencies of the n13 and p23 waves were within the normal range for all detected waves. Abnormal AR results were observed in 7 of the 12 patients. Ten of the 12 patients had abnormal cVEMP and/or oVEMP results, and 6 patients had abnormal results for both cVEMP and oVEMP.

Discussion

In this study, most (10 of 12) patients who experienced a pulling sensation in the anteroposterior direction had abnormal results on cVEMP and/or oVEMP testing. Abnormal results on oVEMP suggested a disturbance of the utricle and/or the superior vestibular nerve. In the present study, all cases showed normal results on caloric testing, which reflects the function of the superior vestibular nerve. Therefore, the abnormal results of oVEMP indicated utricular dysfunction. Also, abnormal results on cVEMP suggested dysfunction of the saccule and/or the inferior vestibular nerve. The nerve also consisted of the afferent fibers from the posterior semicircular canal, thus abnormal cVEMP results suggest dysfunction of the saccule and/or the posterior canal. Kim et al. reported cases with abnormal results of both head impulse tests on posterior canal and cVEMP [13]. All of their patients complained of spells of vertigo; however, none of our cases did. Thus it was suggested that our case with abnormal cVEMP indicated normal posterior semicircular canal function but saccular dysfunctions.

Table I. Subject characteristics.

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Trigger</th>
<th>Direction</th>
<th>Duration</th>
<th>cVEMP</th>
<th>oVEMP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Right ear (μV)</td>
<td>Left ear (μV)</td>
</tr>
<tr>
<td>1</td>
<td>46</td>
<td>F</td>
<td>Walking</td>
<td>Forward</td>
<td>Few minutes</td>
<td>57</td>
<td>91</td>
</tr>
<tr>
<td>2</td>
<td>56</td>
<td>F</td>
<td>Lying down</td>
<td>Backward</td>
<td>Few minutes</td>
<td>–</td>
<td>259</td>
</tr>
<tr>
<td>3</td>
<td>41</td>
<td>F</td>
<td>Walking</td>
<td>Backward</td>
<td>Few minutes</td>
<td>248</td>
<td>140</td>
</tr>
<tr>
<td>4</td>
<td>59</td>
<td>F</td>
<td>Lying down</td>
<td>Backward</td>
<td>Few minutes</td>
<td>–</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>55</td>
<td>M</td>
<td>Riding in a car</td>
<td>Backward</td>
<td>Few minutes</td>
<td>46</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>F</td>
<td>None</td>
<td>Backward</td>
<td>Momentary</td>
<td>250</td>
<td>103</td>
</tr>
<tr>
<td>7</td>
<td>59</td>
<td>F</td>
<td>Shaking her head</td>
<td>Backward</td>
<td>Momentary</td>
<td>76</td>
<td>98</td>
</tr>
<tr>
<td>8</td>
<td>38</td>
<td>F</td>
<td>None</td>
<td>Forward</td>
<td>Few seconds</td>
<td>313</td>
<td>211</td>
</tr>
<tr>
<td>9</td>
<td>34</td>
<td>M</td>
<td>None</td>
<td>Backward</td>
<td>Momentary</td>
<td>136</td>
<td>74</td>
</tr>
<tr>
<td>10</td>
<td>57</td>
<td>M</td>
<td>Walking</td>
<td>Backward</td>
<td>Momentary</td>
<td>319</td>
<td>143</td>
</tr>
<tr>
<td>11</td>
<td>43</td>
<td>F</td>
<td>Getting up</td>
<td>Backward</td>
<td>Few seconds</td>
<td>82</td>
<td>37</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>F</td>
<td>Getting up/lying down</td>
<td>Backward</td>
<td>Few seconds</td>
<td>62</td>
<td>28</td>
</tr>
</tbody>
</table>
As mentioned above, our results strongly suggest that dizziness in the anteroposterior direction originates from saccular and/or utricular dysfunction. The saccular membrane is located almost within the sagittal plane and the utricular membrane is located almost within the horizontal plane; sensory cells respond to linear acceleration within these planes [14]. The anteroposterior axis comprises both the sagittal and horizontal planes, and thus it is responsible for the forward or backward pulling sensation that originates from saccular and/or utricular organs.

Under low intensity of otolith stimulation by linear acceleration, subjects feel the sensation of movement without direction. As the intensity increases, a sensation of linear movement is felt and finally a tilting sensation [14]. Thus, a pulling sensation originates from a certain intensity of stimulation of the otolith. The otolith input reaches the extensor muscles of the lower limbs via the vestibular nuclei and the vestibulospinal tract [15]. Otolith dysfunction may therefore cause leg weakness and continuous falling spells, but none of our series of patients complained of falling. This suggests that the pulling sensation does not originate from a failure of the otolith spinal reflex. Meng et al. reported that vestibulothalamic neurons are activated by otolith stimulation [16], and it is known that stimulation of the thalamus evokes a sensation of motion in humans [17]. We therefore speculate that the pulling sensation detected by VEMP originates from the vestibulothalamic pathway.

In the present study, all patients complained of a pulling sensation that was of short duration. Previous studies have also reported that otolith symptoms only last for a short period (that is, for a few seconds to several minutes, and less than several hours) [7,11]. Ishiyama et al. confirmed damage of the otolith membrane in surgical specimens taken from patients with drop attacks without Meniere’s disease [18]. Thus, complete otolith disturbance might result in symptoms of short duration. Why does persistent otolith dysfunction cause short-lasting symptoms? To answer the question, accumulated knowledge about otolith symptoms is required.

What was the etiology of the dysfunction in the otolith organs alone? Seo et al. reported cases with endolymphatic hydrops in the cochlea and the saccule [19]. Schuknecht reported experimental degeneration of otolith membrane by cutting the anterior vestibular artery [20]. We are not sure of the etiology of our cases. To elucidate the answer to this question, accumulation of pathological evidence is required.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References