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Subjective visual vertical deviation in patients with early-onset direction-changing horizontal positional nystagmus

Kohichiro Shigeno*

Shigeno Otolaryngology Vertigo-Hearing Impairment Clinic, 1-21 Ougi-machi, Nagasaki 852-8132, Japan

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ABSTRACT

Objective: Otolithic dysfunction is investigated in cases of direction-changing horizontal positional nystagmus (DCHPN) due to peripheral vestibular disorders.

Methods: The static-subjective visual vertical (S-SVV) was conducted in DCHPN cases within 48 h after onset.

Results: The absolute values of S-SVV deviations of patients with Light cupula and lateral canal-benign paroxysmal positional vertigo-cupulolithiasis (L-BPPV-Cup) were significantly different from those of healthy subjects ($p < 0.001$, $p < 0.05$, respectively), whereas there were no significant differences in those of patients with L-BPPV-Canalolithiasis-geotropic (L-BPPV-Can-g) or L-BPPV-Can-ageotropic (L-BPPV-Can-a) versus healthy subjects. Significant differences were found in S-SVV (+: deviation to the affected side, −: deviation to the unaffected side) between patients with Light cupula and those with L-BPPV-Can-g, L-BPPV-Can-a and L-BPPV-Cup ($p < 0.01$, $p < 0.05$, and $p < 0.001$, respectively), as well as between those with L-BPPV-Can-g and L-BPPV-Cup ($p < 0.01$). The S-SVV in patients with Light cupula, L-BPPV-Can-g, and L-BPPV-Can-a deviated more to the affected side, whereas that in patients with L-BPPV-Cup deviated more to the unaffected side.

Conclusion: Mild otolithic dysfunctions were found in patients with DCHPN due to the presence of peripheral vestibular disorders within 48 h after onset. The extent of otolithic (utricular) disorders in patients with DCHPN is estimated in decreasing order as follows: Light cupula > L-BPPV-Cup > L-BPPV-Can-g and L-BPPV-Can-a. Many patients with L-BPPV-Cup likely suffer from disorders of the pars externa of the utricular macula, whereas many patients with L-BPPV-Can-g likely suffer from disorders of the pars interna of the utricular macula. L-BPPV-Can-a and L-BPPV-Can-g must be induced by a common mild utricular disorder.

1. Introduction

Although direction-changing horizontal positional nystagmus (DCHPN) can be induced by central vestibular lesions, such as cerebellar or brain stem dysfunctions, most cases of DCHPN observed in daily clinical practice are induced by peripheral vestibular disorders, such as benign paroxysmal positional vertigo (BPPV) [1]. DCHPN due to peripheral vestibular disorders can be classified into the following three types of positional nystagmus depending on the direction and duration of the nystagmus in the supine right- and left-ear-down head position: transient direction-changing geotropic nystagmus (DCGN), persistent direction-changing apogeotropic nystagmus (DCAN), and persistent DCGN [2]. Among the three, transient DCGN and persistent DCAN are diagnosed as lateral

* Corresponding author: Kohichiro Shigeno, Shigeno Otolaryngology Vertigo-Hearing Impairment Clinic, 1-21 Ougi-machi, Nagasaki, 852-8132, Japan
E-mail address: mail@shigeno.info

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semicircular canal type BPPV (L-BPPV), whereas persistent DCGN is diagnosed as Light cupula [2]. However, it remains unclear whether Light cupula is a subtype of BPPV [3–7].

Current understanding regarding the pathophysiology of BPPV suggests that otoliths and the otolithic membrane detach from the utricular macula for certain reasons and then enter the semicircular canals [8]. Subsequently, head positioning alters the direction of gravity and causes the movement of the otolith masses within the semicircular canal (canalolithiasis: Can, [9]) or deviation of the cupula to which the otolith mass is attached (cupulolithiasis: Cup, [10]), resulting in characteristic types of nystagmus and vertigo. Accordingly, utricular dysfunction has been suspected in patients with BPPV. To date, several utricular function tests have shown that utricular dysfunction was associated with BPPV: eccentric rotation [11], off-vertical axis rotation [12], and ocular vestibular-evoked myogenic potentials [13]. Although these tests that impose an artificial stimulus on the utricle have been proven to be effective in examining the presence or absence of utricular lesions, comparing the extent of utricular lesions between the cases has been difficult.

The subjective visual vertical (SVV) is a test that measures the difference between a subjective visual vertical line and a gravitational vertical line. SVV abnormalities show a vestibular imbalance in the roll plane, which is generally tilted to the lesion side due to impairments in the otolith organ, vertical semicircular canals, vestibular nerve, and vestibular nucleus (medial and superior) [14]. Furthermore, the lateral semicircular canals are known to have little effect on SVV [15,16]. While spontaneous nystagmus shows an imbalance in the semicircular canal system, SVV has been considered to exhibit an imbalance in the otolithic system [17]. Given that the less invasive static-SVV with no stimulation (S-SVV) can be performed via a simple procedure, it has been clinically applied as an otolith function test for the acute phase of vertigo. Generally, the measurement is performed several times [17,18], taking the average value of S-SVV as the test result. S-SVV deviation exceeding 2 degrees is considered abnormal [17]. In addition, given that S-SVV is a continuous variable, comparison among cases is possible.

Reports have attempted to evaluate otolithic dysfunction in cases of BPPV using SVV [17,19,20]. Böhmer et al. suggested that in cases of posterior semicircular canal BPPV-canalolithiasis (P-BPPV-Can), almost S-SVV values deviated within the normal range and utricular disorders were mild [17]. Alternatively, Faralli et al. [19] found that S-SVV deviations in patients with P-BPPV-Can, within 48 h after the onset and before treatment, tilted to the affected side, albeit being within the normal range. Therefore, S-SVV deviations to the affected side, which were observed early in the onset of P-BPPV-Can, were considered to indicate a utricular disorder. Furthermore, S-SVV deviations in patients with P-BPPV-Can might ameliorate 5 days after onset [21].

The current study investigated S-SVV deviations in cases of L-BPPV-Can, L-BPPV-Cup, and Light cupula early after onset (within 48 h) and determined the relationship between these types of DCHPN and utricular dysfunction.

2. Materials and methods

2.1. Patients

A total of 397 patients with DCHPN visited the clinic over the course of 6 years from January 2013 to December 2018. From these 397 patients, those with a history or suspicions of central disorders (i.e., abnormal brain magnetic resonance imaging, a gaze nystagmus test or eye-tracking test revealing suspected central nervous system abnormality, or a stepping test revealing chronic ataxia), head trauma, obvious inner ear disorders (Ménière's disease, vestibular neuritis, sudden deafness with vertigo, and cases with a right–left difference of 20 dB or more in average hearing level), and unknown affected side were excluded. Additionally, patients with DCHPN within 48 h of onset were selected. Ultimately, 133 patients were included in this study.

This clinical study was approved by the Ethical Review Board of the Nagasaki City Medical Association (No. 2017-4-1). Informed consent was omitted; however, the study information was posted at the author's clinic, and all patients were given the choice to opt out.

2.2. Observation of head positional nystagmus and head positioning nystagmus and diagnosis of DCHPN subtype

Patients who visited the clinic due to a chief complaint of positional vertigo were administered a positional nystagmus test and positioning nystagmus test. For the positional nystagmus test, static nystagmus was observed in the following positions: sitting (upright), face-up supine, supine right-ear-down, and supine left-ear-down (right- or left-ear-down with the head position titled approximately 60° from face-up supine position), and prone. For the positioning nystagmus test, direction-changing nystagmus was induced via a supine head roll test in which the patient's head is rapidly moved from the supine right-ear-down position to the supine left-ear-down position and vice versa.

Diagnoses of lateral canal-BPPV-canalolithiasis-geotropic (L-BPPV-Can-g) and lateral canal-BPPV-cupulolithiasis (L-BPPV-Cup), as well as the identification of the affected side, were based on classification and diagnostic criteria established by the Bárány Society and the Japan Society for Equilibrium Research [2,22]. Diagnoses of lateral canal-BPPV-canalolithiasis-apogeotropic (L-BPPV-Can-a) and Light cupula, as well as the identification of the affected side, were performed according to the following criteria.

L-BPPV-Can-g was diagnosed as a DCGN that lasted for less than a minute and was characterized by an increase followed by a decrease in intensity (paroxysmal). The affected side was presumed to be the lower ear in the head position wherein the nystagmus and vertigo were more severe. Ultimately, the affected side was confirmed when improvement was observed with any repositioning maneuver. DCAN was induced in both the right-ear-down and left-ear-down head positions and both the face-up supine and prone positions. Furthermore, L-BPPV-Cup or L-BPPV-Can-a was diagnosed as nystagmus lasting for more than a minute without any

decrease in intensity (persistent). The affected side was presumed to be the lower ear in which horizontal nystagmus could be reversed with a head position change from the face-up supine position to a supine right- or left-ear-down head position (i.e., the side in which a neutral position existed [23]) or the ear in which the nystagmus and vertigo were milder when that ear was down. If a DCAN transitioned into a paroxysmal DCGN after repeating the supine head roll test or upon 360° rotation toward the healthy side [24], a diagnosis of L-BPPV-Can-a instead of L-BPPV-Cup was established [25]. However, cases were diagnosed as L-BPPV-Cup when no transition to a paroxysmal DCGN was observed. Cases with Light cupula exhibited a DCGN in the supine right- and left-ear-down positions, as well as in the face-up supine and prone positions [3–6], with the duration of the nystagmus being persistent. The presumed affected side was the lower ear for which a neutral position existed (when the head position changes from the sitting to the face-up supine position, horizontal nystagmus directed to the healthy ear could be observed in most cases) [4–6].

Positional and positioning nystagmus was observed and recorded using spectacles equipped with an infrared charge-coupled device (CCD) camera (SNIR-1, Nagashima Medical Instruments co., Ltd.), after which the presence or absence, duration, and direction of nystagmus were confirmed.

2.3. S-SVV measurement and S-SVV of healthy subjects

S-SVV measurements were performed in a dark room using an SVV measuring device (Nagashima Medical Instrument Co., Ltd.). With the patient in the standing position and head not fixed [17], the examiner tilted the light-emitting diode (LED) bar (length = 20 cm) that was installed approximately 60 cm in front of the eyes by around 30°. It was then rotated using a remote control to a position at which the patient felt vertical. The error from true gravitational vertical was displayed on the measuring device in units of 0.1°. The LED bar was tilted to the right or left, after which the S-SVV was measured four times. When one of the measured values displayed a value that differed greatly from the other three, that measurement was repeated. The average S-SVV value was calculated by setting the affected and unaffected deviation of the S-SVV to a positive and negative value, respectively. The S-SVV test was performed immediately after establishing a DCHPN subtype diagnosis on the first day of the examination and before repositioning maneuvers were performed.

The S-SVV was then measured in 45 healthy people living in the neighborhood without a history of hearing loss and dizziness. The age and sex distribution of the aforementioned people were as follows: 20–29 years (10 females, 5 males), 30–39 years (8 females, 4 males), 40–49 (8 females, 4 males), and 50–59 years (4 females, 2 males). The average age and standard deviation of healthy subjects were 35.8 ± 11.5 years, whereas the average S-SVV value (SD) was −0.04 ± 0.64. A total of 22 and 23 cases had S-SVV deviation to the right and left sides, respectively.

Evaluation of the reliability of the S-SVV test at the clinic showed that the correlation coefficient by the first and second test-retest methods (n: 45) was 0.74, with a contribution rate of 0.56 and 95% confidence interval of 0.46–0.81. The correlation coefficient between the mean S-SVV of 4 to 5 times and the mean S-SVV of 12 times (n: 21) was 0.81, with a contribution rate of 0.66 and a 95% confidence interval of 0.51–1.04. The validity of the S-SVV at the clinic was also examined. Among patients with vestibular neuritis (n: 48) and sudden deafness (n: 15) at the clinic, 72.9% and 26.7% exhibited a pathological S-SVV of 2 degrees or more, respectively. Among patients with vestibular neuritis (n: 36) and sudden deafness (n: 80) at another institution, 69.4% and 26.3% exhibited a pathological S-SVV of 2 degrees or more [18], which were practically the same as those observed at the clinic.

2.4. Statistical analysis

The Kruskal–Wallis test was used to compare patients with DCHPN according to sex, age, affected side, and initial onset and recurrence. Analysis of variance with a post hoc Tukey test was used to compare the absolute values of S-SVV deviations between each DCHPN patient and healthy subject as well as to compare S-SVV deviations (+: deviation to the affected side, −: deviation to the unaffected side) between patients with L-BPPV-Can-g, L-BPPV-Can-a, L-BPPV-Cup, and Light cupula. During analyses, $p < 0.05$ indicated statistical significance.

3. Results

3.1. Characteristics of each DCHPN within 48 h after onset (Table 1)

Table 1 presents the clinical features of DCHPN within 48 h after onset. No significant differences in sex, age, affected side, and recurrence was observed according to DCHPNs ($p = 0.64$, $p = 0.59$, $p = 0.74$, $p = 0.13$, respectively).

3.2. Direction of nystagmus in the sitting position and S-SVV

In the sitting position, the number and rates of DCHPN cases with nystagmus under spectacles equipped with an infrared CCD camera and without nystagmus under fixation were as follows: 4 in patients with L-BPPV-Can-g (10%, nystagmus toward the affected side: 2, nystagmus toward the unaffected side: 2), 3 with L-BPPV-Can-a (30%, the affected side: 2, the unaffected side: 1), 15 with L-BPPV-Cup (30%, the affected side: 14, the unaffected side: 1), and 12 with Light cupula (35%, the unaffected side: 12). The rates of DCHPN cases in which the direction of S-SVV deviation was the same or opposite to the direction of the nystagmus were as follows: patients with L-BPPV-Can-g, 2:2; L-BPPV-Can-a, 3:0; L-BPPV-Cup, 2:13; and Light cupula, 1:11.

Table 1. Characteristics of direction-changing horizontal positional nystagmus within 48 h after onset

DCHPN		Female/Male	(SD, range)	(Right/Left)	Initial Onset/Recurrence
L-BPPV-Can-g	39	31/8	56 (14, 30-84)	20/19	10/29
L-BPPV-Can-a	10	6/4	62 (11, 37-75)	5/5	3/7
L-BPPV-Cup	50	38/12	58 (16, 20-87)	21/29	12/37
Light cupula	34	26/8	59 (15, 28-88)	18/16	2/30 (unclear 2)

DCHPN: direction-changing horizontal positional nystagmus, L-BPPV-Can-g: lateral semicircular canal-BPPV-canalolithiasis-geotropic, L-BPPV-Can-a: lateral semicircular canal-BPPV-canalolithiasis-apogeotropic, L-BPPV-Cup: lateral semicircular canal-BPPV-cupulolithiasis

3.3. Comparison of absolute values of S-SVV deviations between each DCHPN patient and healthy subject and patholological S-SVV in each DCHPN (Fig. 1)

The absolute values of S-SVV deviations were as follows: L-BPPV-Can-g: 0.83 ± 0.63, L-BPPV-Can-a: 0.45 ± 0.38, L-BPPV-Cup: 0.92 ± 0.69, Light cupula: 1.52 ± 1.24, and healthy subjects: 0.49 ± 0.42. Significant differences were found between those with Light cupula ($p < 0.001$) and those with L-BPPV-Cup ($p < 0.05$) versus healthy subjects. No significant differences were observed between those with L-BPPV-Can-g or L-BPPV-Can-a versus healthy subjects.

Among the included patients, pathological S-SVVs exceeding 2 degrees to the affected or unaffected sides were found in 2/39 (5%, all deviations to the affected side) cases with L-BPPV-Can-g, 5/50 (10%, all deviations to the unaffected side) cases with L-BPPV-Cup, and 7/34 (21%, all deviations to the affected side) cases with Light cupula.

3.4. Comparison of S-SVV deviations to the affected and unaffected sides (Fig. 2)

In patients with L-BPPV-Can-g, L-BPPV-Can-a, L-BPPV-Cup, and Light cupula, the S-SVV (+: deviation to the affected side, −: deviation to the unaffected side, mean ± SD) were 0.37 ± 0.98, 0.26 ± 0.54, −0.43 ± 1.08, and 1.37 ± 1.41, respectively. Significant differences were found between those with Light cupula and those with L-BPPV-Can-g, L-BPPV-Can-a, and L-BPPV-Cup ($p < 0.01$, $p < 0.05$, $p < 0.001$, respectively). A significant difference was also found between those with L-BPPV-Can-g and L-BPPV-Cup ($p < 0.01$). No significant differences were observed between those with L-BPPV-Can-g and L-BPPV-Can-a and between those with L-BPPV-Can-a and L-BPPV-Cup.

4. Discussion

Mild otolithic dysfunctions were found in patients with DCHPN due to the presence of peripheral vestibular disorders within 48 h after onset. Furthermore, significant differences in the otolithic dysfunction were observed between them.

S-SVV measurements in this study were performed in the dark, with the patients standing, and without fixing the head, and were measured in units of 0.1 degrees. Moreover, to reduce the burden on patients with acute-phase vertigo, S-SVV values were measured only 4 to 5 times. However, the reliability and validity of the S-SVV test at the clinic were ensured.

Among patients with DCHPN, 10%–35% exhibited horizontal nystagmus in the sitting position. However, SVV measurements during the rotation and caloric stimulation tests revealed that the lateral semicircular canals do not affect the S-SVV [15,16]. Therefore, it was assumed that the horizontal nystagmus due to a disorder of the lateral semicircular canal had no effect on S-SVV. Those with L-BPPV-Cup had a nystagmus direction facing mostly toward the affected side, whereas those with Light cupula had a direction facing toward the unaffected side, a finding consistent with that presented in a previous report [26]. Given that the S-SVV measurements were performed without fixing the head, the head could have rotated toward the side of the slow phase of nystagmus in this study. Masuda et al. [27] reported the effects of the positional relationship between the visual target and the head on S-SVV. According to their report, when the target was moved to the right, the S-SVV was biased to the left and vice versa. This result indicated that when the head is rotated to the side of the slow phase of nystagmus, S-SVV may be biased to the side of the slow phase of nystagmus. In cases with L-BPPV-Cup and Light cupula, wherein nystagmus was observed in the sitting position, S-SVV was almost biased to the opposite side of the nystagmus (the side of the slow phase of the nystagmus); however, in cases with L-BPPV-Can-g and L-BPPV-Can-a, the relationship between the direction of nystagmus and S-SVV did not match. Therefore, factors other than the head rotation associated with nystagmus were considered to have influenced S-SVV.

Tomanovic et al. [28], who measured the subjective visual horizontal in patients with Light cupula, found abnormalities in approximately 60%, suggesting the presence of the otolithic dysfunction. In this study, the absolute values of S-SVV deviations in 21% of patients with Light cupula within 48 h after onset showed a pathological S-SVV tilted to the affected side and was significantly different from that in healthy subjects. Furthermore, S-SVV deviations to the affected and unaffected sides in cases with Light cupula were significantly different from those in cases with L-BPPV-Can-g, L-BPPV-Can-a, and L-BPPV-Cup. These results suggested that patients with Light cupula must have suffered from otolithic disorder and that the degree of the disorder in such patients was likely stronger than that in patients with L-BPPV-Can-g, L-BPPV-Can-a, L-BPPV-Cup. Though the true pathophysiology of Light cupula remains unknown, studies have speculated the involvement of changes in the specific gravity of the endolymph [3,4], attachment of a low-density substance to the cupula of the lateral semicircular canal [5,6], and changes in the cupula itself [7]. Although the pathophysiology of Light cupula in this

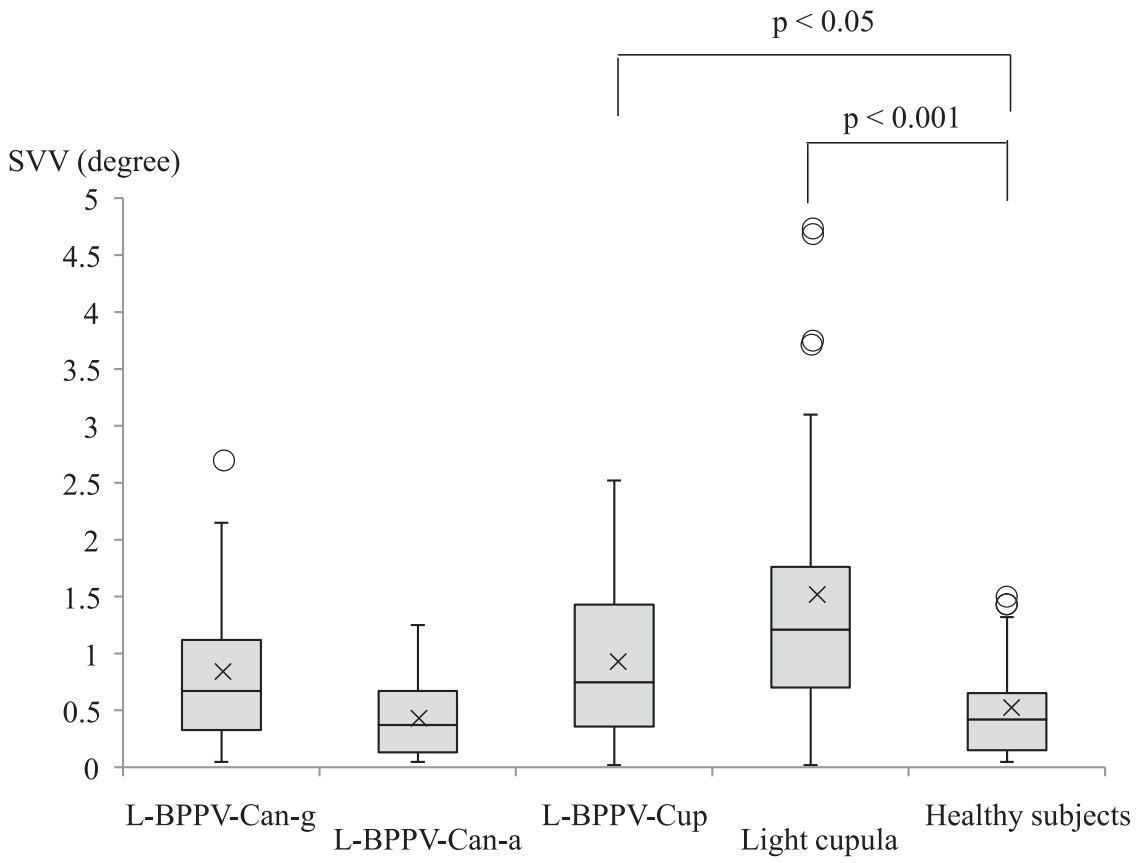

Fig. 1. Comparison of the absolute values of S-SVV deviations in each DCHPN patient within 48 h after onset versus healthy subjects
DCHPN: direction-changing horizontal positional nystagmus, L-BPPV-Can-g: lateral semicircular canal-BPPV-canalolithiasis-geotropic, L-BPPV-Can-a: lateral semicircular canal-BPPV-canalolithiasis-apogeotropic, L-BPPV-Cup: lateral semicircular canal-BPPV-cupulolithiasis. The horizontal bar in the box shows the median value, while X shows the average value. Open cycles represent the mild outlier.

study remains unclear, the otolithic disorder must have been involved in the onset of Light cupula.

Lee et al. [29] reported that S-SVV deviations in patients with L-BPPV-Can and L-BPPV-Cup did not significantly differ. Additionally, patients with L-BPPV-Can had a significantly different dynamic-SVV during eccentric rotation of the affected ear compared to healthy subjects; however, no such difference was observed in patients with L-BPPV-Cup. Therefore, they speculated that the utricular disorder differed between those with L-BPPV-Can and L-BPPV-Cup and that the utricular disorder with L-BPPV-Cup was smaller than that with L-BPPV-Can. In this study, only 5% of the patients with L-BPPV-Can-g within 48 h of onset showed pathological S-SVV tilting to the affected side. Moreover, no significant differences were found between the absolute S-SVV in patients with L-BPPV-Can-g and that in healthy subjects. However, significant differences in S-SVV deviations were observed between patients with L-BPPV-Can-g and those with L-BPPV-Cup. In patients with L-BPPV-Can-g,

S-SVV deviated more to the affected side, whereas in patients with L-BPPV-Cup, S-SVV deviated more to the unaffected side. Thus, S-SVV deviation to the affected side or the unaffected side, as well as the magnitude of its absolute value, must be indicative of an otolithic (utricular) disorder.

The pathophysiology of L-BPPV-Can-a has been considered to involve canalolithiasis, wherein the otoliths exist in the lateral semicircular canal ampulla or attachment to the cupula on the canal side [25]. Although this study included only a small number of patients with L-BPPV-Can-a, the S-SVV deviation to the affected side was similar to that in cases with L-BPPV-Can-g. This suggested that L-BPPV-Can-a and L-BPPV-Can-g must have been induced by a common mild utricular disorder.

In contrast, 10% of the patients with L-BPPV-Cup showed pathological S-SVV tilting to the unaffected side. Futhermore, the absolute S-SVV of patients with L-BPPV-Cup was significantly different from that of healthy subjects. Given that the extent of the otolithic (utricular) disorder in patients with DCHPN can be determined by the size of absolute values of S-SVV, they are estimated as follows: Light cupula > L-BPPV-Cup > L-BPPV-Can-g and L-BPPV-Can-a. In other words, a large S-SVV deviation may indicate sensory cell damage or neuropathy of the utricle, whereas a small S-SVV deviation may indicate damage to the otolithic membrane. In addition, S-SVV in many patients with L-BPPV-Cup deviated more to the unaffected side. This result differed from the common finding that S-SVV tilted toward the affected side in patients with inner ear disorders [17].

Studies have shown that S-SVV deviated to the unaffected sides in some patients who underwent stapes surgery [30], middle ear surgery [31], sudden deafness [18], Ménière's disease [32], or posterior canal-BPPV-Can [33]. In these patho-

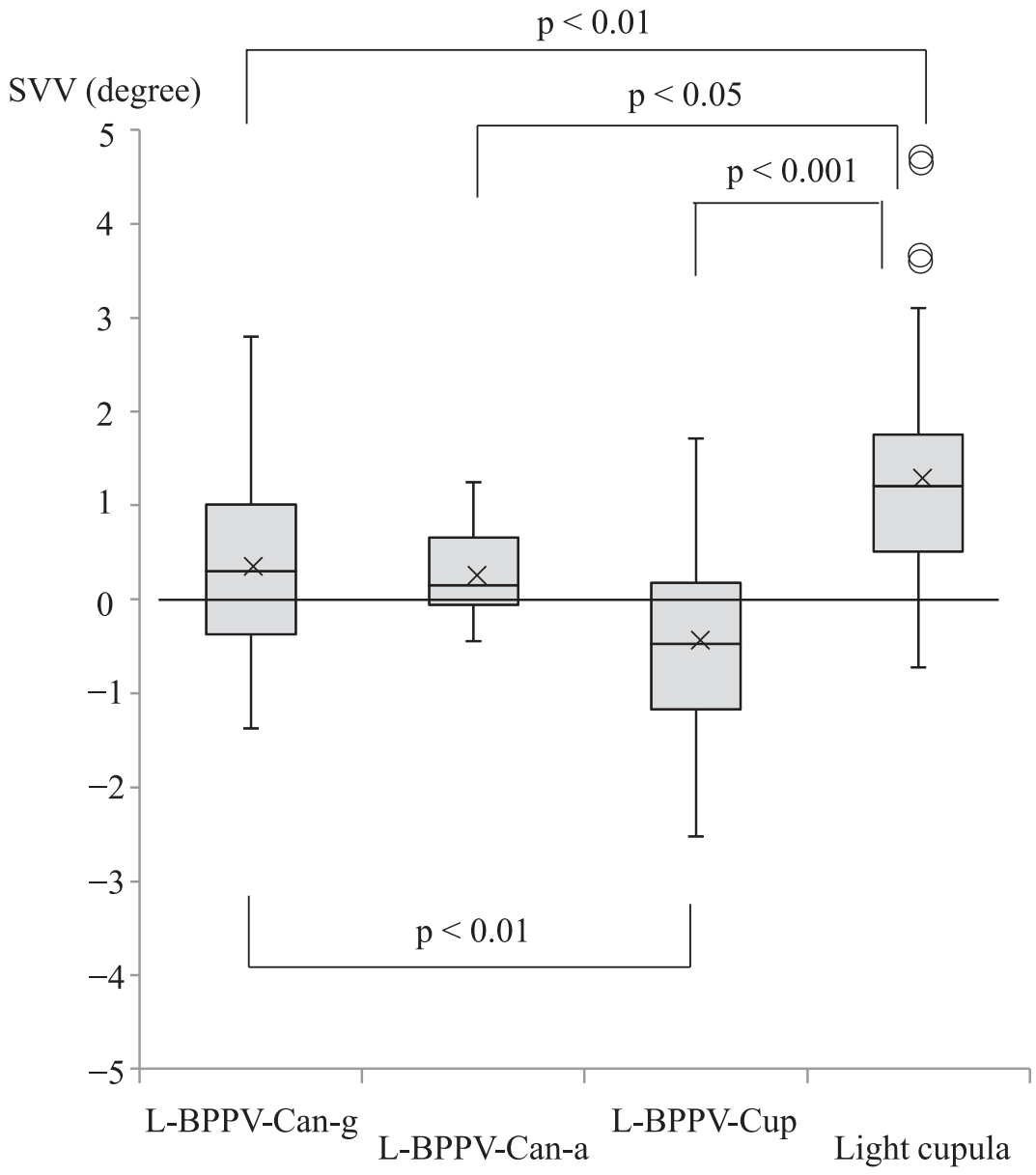

Fig. 2. Comparison of S-SVV deviation according to DCHPNs within 48 h after onset
DCHPN: direction-changing horizontal positional nystagmus, S-SVV+ indicates the direction to the affected side, whereas S-SVV− indicates the direction to the unaffected side. BPPV: Benign paroxysmal positional vertigo, L-BPPV-Can-g: lateral semicircular canal-BPPV-canalolithiasis-geotropic, L-BPPV-Can-a: lateral semicircular canal-BPPV-canalolithiasis-apogeotropic, L-BPPV-Cup: lateral semicircular canal-BPPV-cupulolithiasis. The horizontal bar in the box shows the median value, while X shows the average value. Open cycles represent the mild outlier.

logical conditions, irritation of the otolith organ on the surgical or affected sides was presumed. Therefore, among patients with early-stage L-BPPV-Can-g or L-BPPV-Cup, there could either be hypofunction or irritation of the affected otolith organ. However, in this study, cases of middle ear surgery, sudden deafness, Ménière's disease, and those that underwent repositioning maneuver before the S-SVV test were excluded. Thus, if the underlying cause of BPPV is otolith detachment from the utricular macula, then the utricular function of patients with L-BPPV-Can-g or L-BPPV-Cup is more likely to be hypofunction than irritation.

The utricular macula is divided by the striola into the pars interna and pars externa, and their anatomical polarity are directed to the striola by the positional relationship between the kinocilium and stereocilia. Regarding the functional polarity of the utricular macula, studies have reported contradictory results on whether the pars interna [34,35] or pars externa [36,37] was dominant. However, when considering utricle dysfunction, the imbalance is probably reversed because of the difference in the lesion site between the pars interna and pars externa of the utricular macula.

Fig. 3 presents an illustration demonstrating the positional relationship between the right utricular macula and the opening of each semicircular canal into the utricle in the horizontal plane of the head [37,38]. The cupula of the lateral semicircular canal has been found to be close to the pars externa of the utricular macula, and the gap between them is relatively wide [38]. In contrast, the opening of the lat-

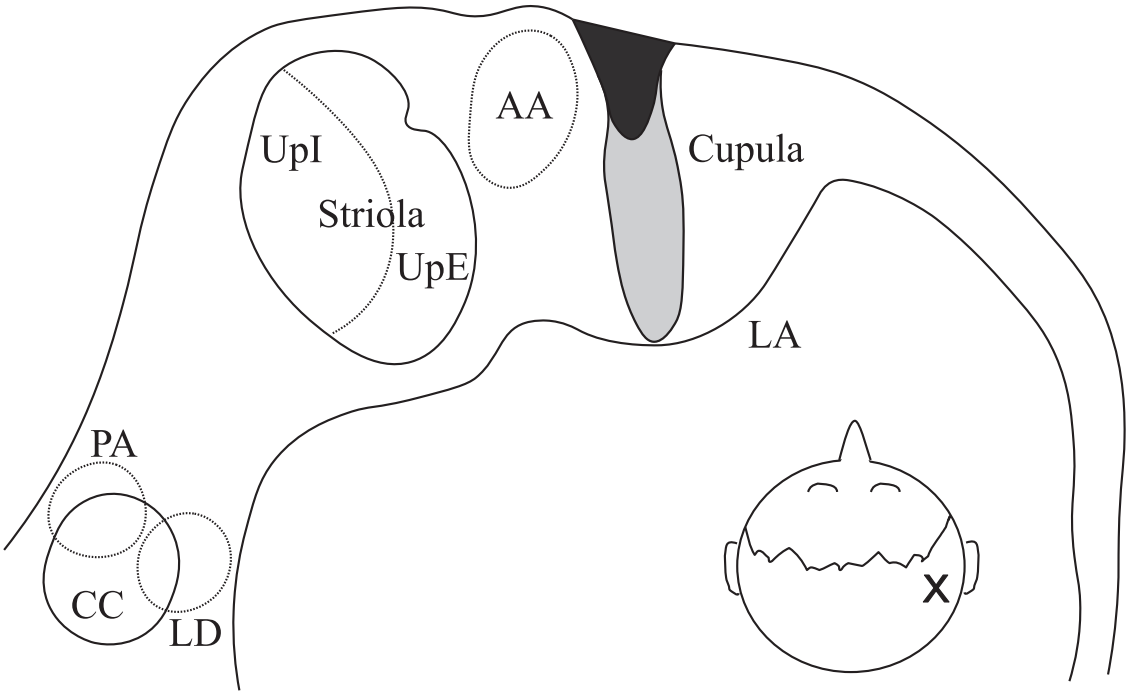

Fig. 3. The positional relationship between the right utricular macula and the opening of each semicircular canal into the utricle in the horizontal plane of the head
UpI, pars interna of the utricle; UpE, pars externa of the utricle; LA, lateral semicircular canal ampulla; AA, anterior semicircular canal ampulla; PA, posterior semicircular canal ampulla; CC, common crus; LD, lateral semicircular canal duct. X is the right labyrinth.

eral semicircular canal on the nonampullary side is located some distance from the pars interna of the utricular macula [38]. Based on a questionnaire survey on head position during sleep in patients with BPPV, Shigeno et al. reported most patients with L-BPPV-Can-g and L-BPPV-Can-a slept in the affected-ear-down head position, whereas those with L-BPPV-Cup showed no relationship between the affected ear and head position during sleep [39]. Therefore, in patients with L-BPPV-Can-g or L-BPPV-Can-a, otoliths detached from the utricular macula probably enter from the non-ampullated end of the lateral semicircular canal, whereas in patients with L-BPPV-Cup, otoliths probably enter from the ampullated end of the lateral semicircular canal and adhere to the utricular side of the cupula rather than the canal side.

Otoliths detached from the pars externa of the utricular macula can easily enter from the ampullated end of the lateral semicircular canal and adhere to the cupula, resulting in L-BPPV-Cup. Therefore, S-SVVs in many patients with L-BPPV-Cup may deviate to the unaffected side. On the other hand, otoliths detached from the pars interna of the utricular macula can easily enter the nonampullary side of the lateral semicircular canal, causing L-BPPV-Can-g. Thus, S-SVVs in many patients with L-BPPV-Can-g can deviate to the affected side.

There have been contradictory reports suggesting that S-SVV in patients with posterior canal-BPPV-Can either deviated to the affected or unaffected side [19,33]. Furthermore, previous studies reported that immediately after the repositioning maneuver performed on some patients with posterior canal-BPPV-Can, the S-SVV deviations to the affected side were reversed to the unaffected side or the absolute S-SVV deviations decreased or increased [19,40,41]. These results may be associated with differences in lesion site between the pars interna and pars externa of the utricular macula or may depend on whether the otoliths return to the pars interna or pars externa of the utricular macula by the repositioning maneuver.

This study has some limitations worth noting. S-SVV has been reported to be unsuitable for screening of vestibular impairments [42]. This is because the absolute S-SVV deviations in most BPPV cases were within 2 degrees, similar to those in healthy subjects. Thus, it was difficult to determine the presence or absence of otolith disorders in individual patients by evaluating S-SVV alone. In this study, the absolute S-SSVV deviation in each patient was also either small or within normal limits. However, S-SVV deviated to the affected side and unaffected side was significantly different among DCHPN cases. S-SVV deviation to the affected or unaffected side, as well as the magnitude of its absolute value, must indicate otolithic (utricular) disorder. Moreover, the significant difference in the S-SVV deviations may be caused by differences in the lesion site between the pars interna and pars externa of the utricular macula. However, it remains unproven whether otolith dysfunction actually changed depending on the lesion site of the pars interna or pars externa of the utricular macula. In the future, an otolith function test for disorders of the pars interna or pars externa of the utricular macula will be needed.

5. Conclusion

Absolute S-SVV values and S-SVV deviation to the affected and unaffected sides were investigated in patients

with L-BPPV-Can-g, L-BPPV-Can-a, L-BPPV-Cup, and Light cupula within 48 h after onset and compared to those in healthy subjects. The size of absolute S-SVVs differed between patients with L-BPPV-Cup and Light cupula versus healthy subjects. Significant differences in S-SVV deviations (+ denotes deviation to the affected side, − denotes deviation to the unaffected side) were also observed among patients with L-BPPV-Can-g, L-BPPV-Can-a, L-BPPV-Cup, and Light cupula. The extent of the otolithic (utricular) disorder in patients with DCHPN is estimated as follows: Light cupula > L-BPPV-Cup > L-BPPV-Can-g and L-BPPV-Can-a. It is likely that many patients with L-BPPV-Cup suffer from disorders of the pars externa of the utricular macula, whereas those with L-BPPV-Can-g suffer from disorders of the pars interna of the utricular macula. BPPV-Can-a and L-BPPV-Can-g must be induced by a common mild utricular disorder.

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