Laryngoscope Investigative Otolaryngology

Caloric Testing in Patients With Heavy or Light Cupula of the Lateral Semicircular Canal

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Objective: To clarify whether the dysfunction of the lateral semicircular canal remain or not in patients with heavy or light cupula.

Study Design: Prospective case series.

Methods: The subjects were 19 patients with heavy cupula (3 males, 16 females; mean age, 62.8 years) and 14 patients with light cupula (5 males, 9 females; mean age, 63 years). Caloric testing (iced water) was carried out after complete disappearance of positional nystagmus. We measured maximum slow-phase velocity and calculated asymmetry.

Results: In heavy cupula group, no one revealed canal paresis (CP) and 4 patients (21%) showed inverse CP (affected ear response is greater than healthy ear response). In light cupula group, 3 patients (21%) revealed CP.

Conclusions: Dysfunction of the lateral semicircular canal does not always remain in either heavy cupula or light cupula. The caloric response increases in some cases with heavy cupula. We can explain this phenomenon based on the hydrostatic pressure theory involved in ossicles.

Key Words: semicircular canal, positional nystagmus, maximum slow-phase velocity, hydrostatic pressure theory, Pascal's principle, video-oculography.

Level of Evidence: 4.

INTRODUCTION

The concept of lateral semicircular canal positional vertigo has been generally accepted. Positional nystagmus of the lateral semicircular canal type is classified as direction-changing apogeotropic nystagmus (the horizontal component is toward the sky) and direction-changing geotropic nystagmus (the horizontal component is toward the ground). Apogeotropic nystagmus is always persistent (duration of more than 1 minute) and the pathophysiology is cupulolithiasis (heavy cupula).[1–3] There are two types of geotropic nystagmus, a transient type and a persistent type. Canalolithiasis (moving debris) accounts for the transient type[4,5] and persistent geotropic nystagmus, which lasts for more than 1 minute, is thought to be due to light cupula of the lateral canal.[6–9]

Canalolithiasis can be treated by having a patient sit for several hours after an affected-ear-up 120° maneuver.[5] Although there is no established treatment for heavy cupula and light cupula, the spontaneous remission rate is high. It is controversial as to whether this process is due to central compensation or to functional recovery of the lateral canal.

It has been clear that caloric stimulation does not reach the vertical semicircular canals.[10,11] Namely, caloric nystagmus is a pure lateral canal ocular reflex. We performed caloric testing after complete remission of vertigo in order to clarify whether the dysfunction of the lateral canal remain or not.

MATERIALS AND METHODS

The subjects were 19 patients with heavy cupula (3 males, 16 females; mean age, 62.8 years) and 14 patients with light cupula (5 males, 9 females; mean age, 63 years), who were diagnosed at our institution between January 2014 and November 2015 with a main complaint of positional vertigo.

The heavy cupula patients fulfilled the following criteria:

1. In the right-ear-down position, horizontal nystagmus toward the left occurs and lasts for more than 1 minute.
2. In the left-ear-down position, horizontal nystagmus toward the right occurs and lasts for more than 1 minute.
3. In the supine position, weak horizontal nystagmus continues, and it ceases when the head is turned to the affected ear by 20-60° (neutral position).[12]
4. No nystagmus in the sitting position.
5. Horizontal nystagmus occurs in the nose-down position, and the direction is the opposite to that in the supine position.
6. The prognosis is good. In most cases, vertigo and positional nystagmus disappear within 2 weeks. Severe cases are cured in a total period of 2 months, maximum.
7. No cochlear symptoms related to vertigo, and no central nervous system disorder.

The light cupula patients fulfilled the following criteria:

1. In the right-ear-down position, horizontal nystagmus toward the right occurs and lasts for more than 1 minute.

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2. In the left-ear-down position, horizontal nystagmus toward the left occurs and lasts for more than 1 minute.
3. In the supine position, weak horizontal nystagmus continues, and it ceases when the head is turned to the affected ear by 20-60° (neutral position).[12]
4. No nystagmus in the sitting position.
5. Horizontal nystagmus occurs in the nose-down position, and the direction is the opposite to that in the supine position.
6. The prognosis is good. In most cases, vertigo and positional nystagmus disappear within 2 weeks. Severe cases are cured in a total period of 2 months, maximum.
7. No cochlear symptoms related to vertigo, and no central nervous system disorder.

We did caloric testing after complete disappearance of positional nystagmus. All subjects gave informed consent to participate in the study. We slowly poured 1 ml of iced water (6°C) into the right external auditory canal in a left-ear-down 90° position using a small syringe, taking 20 s. Each subject was rotated to a supine position and stayed there until the nystagmus stopped. The head of the supine subject was tilted forward by 20° because the lateral canal forms an angle of 18.8° (smaller than the conventional measurement) with the Reid horizontal plane.[13]

After a 10-minute rest, we stimulated the left ear in the same way. The testing was performed in the dark, with the patients' eyes open, using an infrared charge-coupled device camera. Caloric nystagmus was recorded and converted to digital data. Using ImageJ 1.36 (a public domain, Java-based image processing program developed at the National Institute of Health) and a Macintosh computer (Mac OS 10.6.2), 2-dimensional video-oculography was performed. For analysis of the horizontal and vertical components, the XY center of the pupil was calculated.[14] Maximum slow-phase velocity of the 2 components was measured by video-oculography. The accuracy of video-oculography is equivalent to that of the scleral search coil system.[15]

Response was defined as the sum of the maximum slow-phase velocity of the horizontal component and that of the vertical component. Both horizontal component and vertical component are vector. Therefore, sum of them is equal to the length of the hypotenuse of a right triangle. According to Pythagorean theorem,

$$\overrightarrow{|Sum|} = \sqrt{MH^2 + MV^2}$$

where MH is maximum slow-phase velocity of the horizontal component, and MV is maximum slow-phase velocity of the vertical component.

Asymmetry was calculated according to the following formula.

$$\text{Asymmetry}(\%) = \frac{(\text{healthy side response}) - (\text{affected side response})}{(\text{healthy side response}) + (\text{affected side response})} \times 100$$

TABLE 1.
Results for heavy cupula patients.

Patient	Age (years)	Sex	Affected side	MSV (°/s) (affected side)			MSV (°/s) (healthy side)			Asymmetry (%)
				H	V	Sum (vector)	H	V	Sum (vector)	
1	64	F	L	28	4	28	42	6	42	20
2	74	F	L	29	7	30	37	10	38	12
3	73	F	L	32	6	33	39	7	40	10
4	58	M	L	34	0	34	36	0	36	3
5	43	F	R	24	3	24	24	7	25	2
6	79	F	R	45	6	45	46	4(D)	46	1
7	73	F	R	26	7	27	27	0	27	0
8	42	F	R	45	0	45	43	0	43	−2
9	23	F	R	47	8	48	40	18	44	−4
10	65	F	L	38	0	38	32	0	32	−9
11	81	M	R	31	7	32	26	4	26	−10
12	62	M	R	48	18	51	37	6	37	−16
13	81	F	R	46	8	47	34	0	34	−16
14	49	F	R	8	6	10	7	0	7	−18
15	66	F	L	20	9	22	14	3	14	−22
16	73	F	R	32	10	34	20	3	20	−26
17	39	F	R	19	0	19	10	0	10	−31
18	72	F	L	49	0	49	22	6	23	−36
19	77	F	L	24	0	24	10	0	10	−41
Mean	62.8					33.7			29.2	−9.6

F = Female, M = Male, R = Right, L = Left, H = Horizontal component, V = Vertical component
MSV = Maximum slow-phase velocity, D = Downward
The direction of vertical component was upward except for patient no. 6.

TABLE 2.
Results for light cupula patients.

Patient	Age (years)	Sex	Affected side	MSV (°/s) (affected side)			MSV (°/s) (healthy side)			Asymmetry (%)
				H	V	Sum (vector)	H	V	Sum (vector)	
20	54	F	L	11	0	11	24	0	24	37
21	73	F	L	13	6	14	28	6	29	35
22	84	F	L	12	0	12	18	9	20	25
23	68	F	L	20	0	20	30	0	30	20
24	41	M	R	14	0	14	19	0	19	15
25	59	M	L	26	3	26	34	0	34	13
26	65	F	L	30	5	30	36	4	36	9
27	62	M	L	22	0	22	26	0	26	8
28	64	M	R	41	0	41	48	4(D)	48	8
29	61	F	L	34	0	34	37	5	37	4
30	46	M	R	28	4	28	27	0	27	−2
31	59	F	L	27	8	28	26	3	26	−4
32	77	F	L	26	11	28	26	5	26	−4
33	68	F	R	39	13	41	37	5	37	−5
Mean	63					24.9			29.9	11.4

F = Female, M = Male, R = Right, L = Left, H = Horizontal component, V = Vertical component
MSV = Maximum slow-phase velocity, D = Downward
The direction of vertical component was upward except for patient no. 28.

Canal paresis (CP) was defined as asymmetry was more than 25%, and inverse CP was defined as asymmetry was less than −25%.

RESULTS

Data are shown in Tables 1 and 2. Video-oculography results for patients no.18 and 29 are shown in Figures 1 and 2.

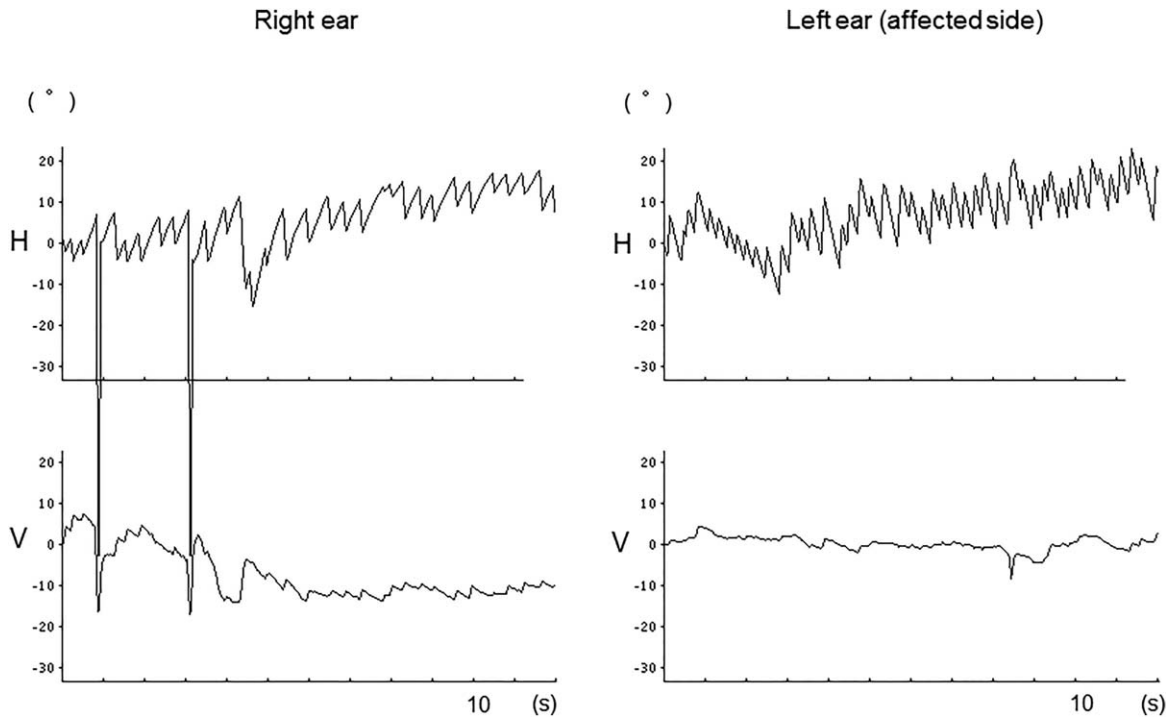

Fig. 1. Video-oculography (position trace) in patient no. 18. The upward deflections in horizontal (H) and vertical (V) eye movements are indicated as being toward the right and upward, respectively. Spikes are blinks.

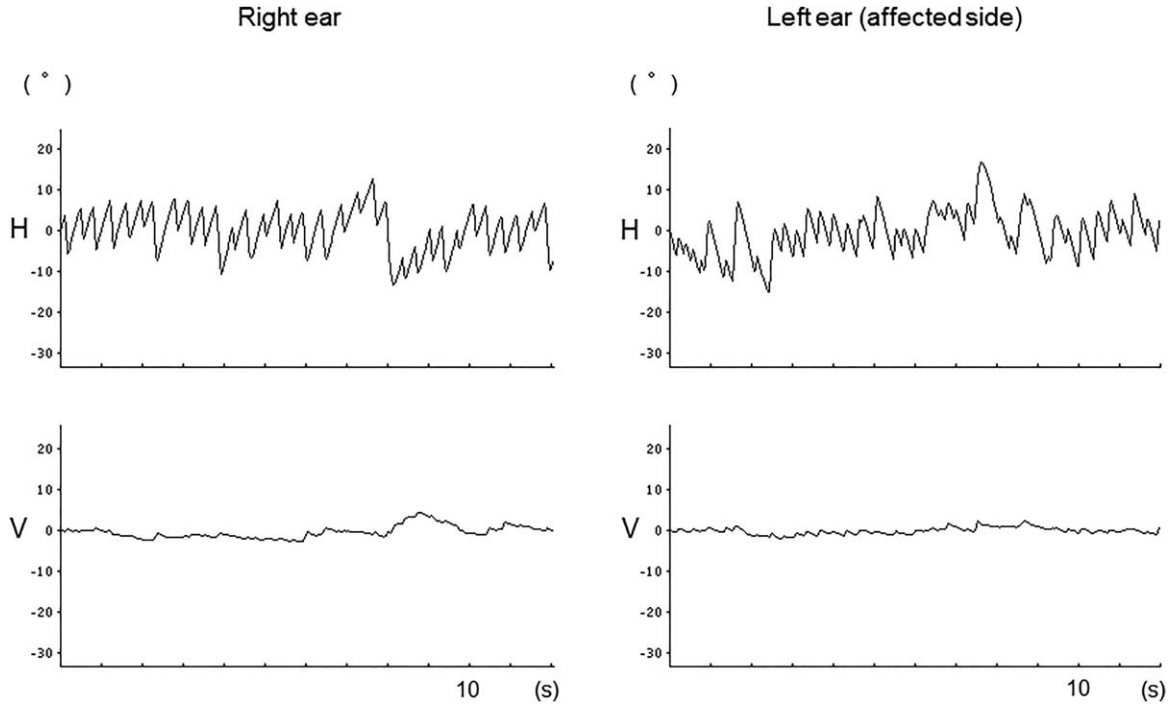

Fig. 2. Video-oculography (position trace) in patient no. 29. The upward deflections in horizontal (H) and vertical (V) eye movements are indicated as being toward the right and upward, respectively.

Maximum slow-phase velocity (°/s)

In heavy cupula patients, the mean value and standard deviation of the affected side was 33.7 ± 11.2, and that of the healthy side was 29.2 ± 12.1. In light cupula patients, the mean value and standard deviation of the affected side was 24.9 ± 9.6, and that of the healthy side was 29.9 ± 7.5.

Asymmetry

In heavy cupula group, no one revealed CP and 4 patients (21%) showed inverse CP (affected ear response is greater than healthy ear response). In light cupula group, 3 patients (21%) revealed CP. (Figures (3 and 4))

DISCUSSION

Traditionally, bithermal caloric irrigation in the supine position is a standard maneuver. However, we adopt 1 ml iced water pouring in the lateral recumbent position because it can chill the tympanic membrane certainly. And monothermal method decreases the burden on patients.

We have been interested in whether the function of pathological cupula (cupulopathy) bounces back or not. Therefore, we examined after the complete disappearance of positional nystagmus. As a result, 11 patients (79%) did not show asymmetry in light cupula group, and 19 patients (100%) had good response in heavy cupula group. Interestingly, affected ear response was greater than healthy ear response in 12 patients (63%) with heavy cupula. These were unexpected results. We had expected that some dysfunction would remain in the lateral canal because the pathophysiology of cupulolithiasis is the attachment of debris to the cupula. Good caloric response even in an affected side indicates that the function of the lateral canal has recovered and hair cells in the crista are intact.

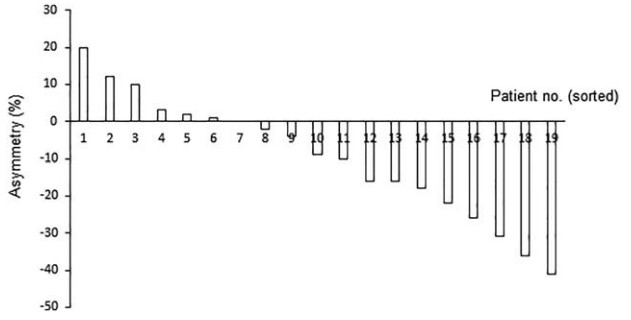

Fig. 3. Asymmetry of heavy cupula patients. No one revealed CP and 4 patients (21%) showed inverse CP (affected ear response is greater than healthy ear response).

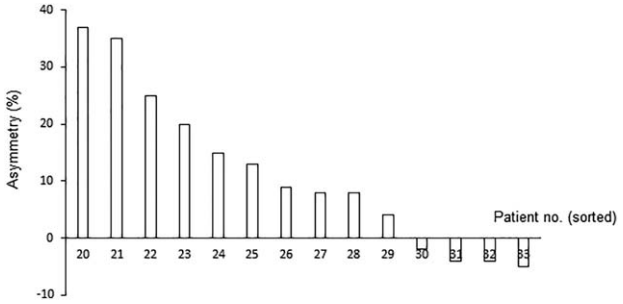

Fig. 4. Asymmetry of light cupula patients. Three patients (21%) revealed CP.

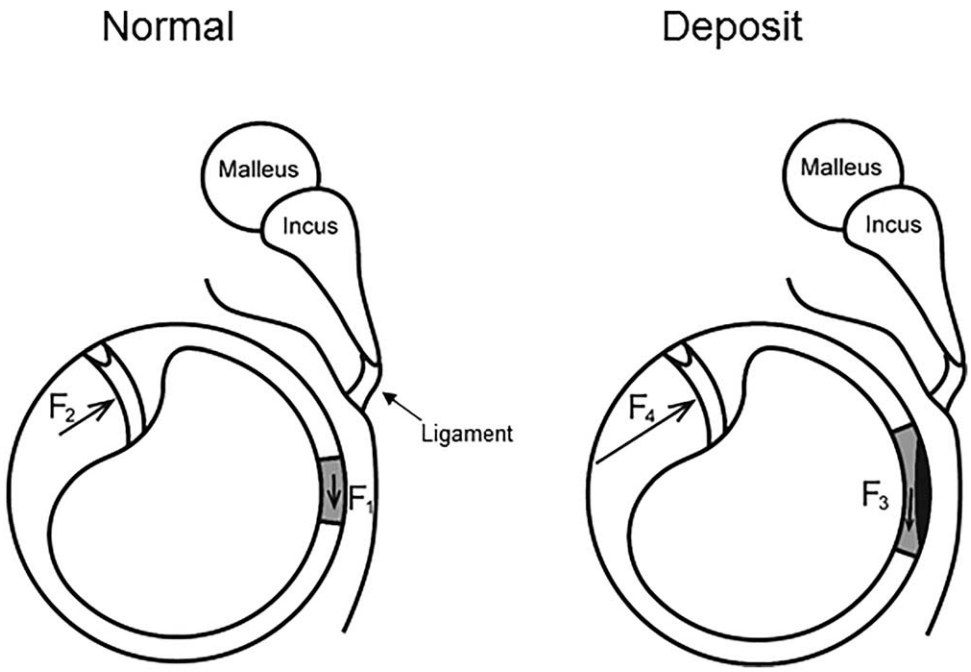

Fig. 5. Hydrostatic pressure theory involved in ossicles. Gray area indicates chilled endolymph, and black area indicates deposit. See text for details.

In both patients with heavy cupula and patients with light cupula, vertigo and positional nystagmus disappear within 2 weeks. Severe cases are cured in a total period of 2 months, maximum. This process is mainly due to the recovery of peripheral function. Small debris is completely absorbed because it is not foreign material.

Why did response increase in heavy cupula patients? We can explain this phenomenon based on the hydrostatic pressure theory involved in ossicles.[10] When the tympanic membrane is chilled, the malleus and incus are chilled first because air has difficulty in conducting heat. The thermal conductivity of bone is much greater than that of the air. Ossicles chill a part of the endolymph in the long arm of the lateral canal via the posterior incudal ligament (Figure 5). The chilled endolymph plays a role, like the piston of a syringe, because the diameter of the long arm is only 0.3 mm.[16] The force (F_1, unit is $N = gm/s^2$) arises in the direction of gravity because objects contract when they cool and increase in density. The cross-sectional area of the ampulla is 15 times as wide as the cross-sectional area of the long arm.[16] According to Pascal's principle (when additional pressure is exerted on a confined liquid, the pressure is transmitted equally to all parts of the liquid), the force pushing the cupula (F_2) is 15 times as strong as the force exerted on the chilled endolymph ($F_2 = 15F_1$). The hydrostatic pressure theory can explain the second and third phases of caloric nystagmus.[17]

Schuknecht showed a thin layer of granular deposit on the membranous wall of the posterior canal in a patient with cupulolithiasis.[18] Assuming that similar deposits occur on the lumen of the lateral canal in heavy cupula patients and the cross-sectional area of the long arm decreases. The chilled volume of the endolymph is the same and the force exerted on the chilled endolymph is the same as F_1 ($F_1 = F_3$), however, pressure (unit is N/m^2) increases and the force pushing the cupula increases ($F_4 > F_2$, Figure 5, right). As a result, the slow-phase velocity of caloric nystagmus increases.

CONCLUSION

Dysfunction of the lateral canal does not always remain in either heavy cupula or light cupula. The caloric response increases in some cases with heavy cupula. We can explain this phenomenon based on the hydrostatic pressure theory involved in ossicles.

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CONFLICT OF INTEREST

None.

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