



Diagnosis strategy and Yacovino maneuver for anterior canal-benign paroxysmal positional vertigo

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Abstract

Objective To investigate the diagnosis strategy of anterior canal-benign paroxysmal positional vertigo (AC-BPPV) and the therapeutic effects of the Yacovino maneuver.

Methods The clinical data of 40 AC-BPPV patients were collected. The nystagmus characteristics induced by the Dix–Hallpike (D–H) and straight head-hanging (SHH) tests, the diagnostic methods used, and the effectiveness of the Yacovino maneuver for the treatment of AC-BPPV were all retrospectively analyzed.

Results Among the 40 cases analyzed, 19 patients had simple AC-BPPV, 11 patients had AC-posterior canal BPPV, and 10 patients had AC-horizontal canal BPPV. D–H and SHH tests showed down-beating nystagmus in 26 and 33 patients, respectively, and showed down-beating and torsional nystagmus in 14 and 7 patients, respectively. AC-BPPV was diagnosed in 15 patients based on the presence of typical BPPV in other canals, in 9 patients based on typical disease history and the results of position tests, in 6 patients based on effectiveness of the treatment with the Yacovino maneuver, in 4 patients based on the treatment effectiveness and the presence of typical BPPV in other canals, in 3 patients based on the treatment effectiveness and the follow-up outcome, in 2 patients based on the typical BPPV in other canals and occurrence of canal conversion, and in 1 patient based on the treatment effectiveness and occurrence of canal conversion. Thirteen patients with canalolithiasis and four patients with cupulolithiasis were cured after the initial Yacovino maneuver treatment. Twenty-one patients with canalolithiasis and seven patients with cupulolithiasis were cured following 1 week of treatment.

Conclusions The effectiveness of the Yacovino maneuver, the follow-up outcome, the presence of typical BPPV in other canals, and the occurrence of canal conversions contribute to AC-BPPV diagnosis. The Yacovino maneuver was found to be more effective in AC-BPPV patients with canalolithiasis than in those with cupulolithiasis.

Keywords Anterior semicircular canal · Benign paroxysmal positional vertigo · Nystagmus · Diagnosis method · Yacovino maneuver

Xu Yang and Xia Ling have contributed equally to this work.

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Introduction

Benign paroxysmal positional vertigo (BPPV) is a transient paroxysmal vertigo triggered by specific head-position changes. BPPV is the most common peripheral vestibular disease and more than 90% of positional vertigo/nystagmus

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cases are caused by BPPV [8]. BPPV was first described by Adler [2] in 1897 and, in 1921, Bárány [6] attributed the characteristic position-change-induced vertigo and nystagmus symptoms to vestibular organ damage. In 1952, based on Bárány's study, Dix and Hallpike [11] first described in detail the clinical manifestations of BPPV, proposed an induction test for diagnosing the disease, and postulated that abnormal otolithic organs likely contributed to the occurrence of BPPV. In 1969, Schuknecht and Rubby [31] proposed the cupulolithiasis theory of BPPV, whereas, in 1979, Hall et al. [14] proposed the canalolithiasis theory, which provides the theoretical foundation underlying the diagnostic criteria for BPPV. In the early 1980s, BPPV was generally considered to originate in the posterior canal (PC). However, in 1985, McClure [22] proposed the existence of a horizontal canal BPPV (HC-BPPV) and described its clinical features. In his study, he found geotropic (downward beating) positional nystagmus in seven patients using the Dix–Hallpike (D–H) test. In 1995, Baloh et al. [5] reported HC-BPPV in three patients who presented with continuous apogeotropic (upward beating) positional nystagmus when the head is turned to the side, while the patient is lying down during a supine roll test. Until recently, the research community has had a relatively poor understanding of the anterior canal form of BPPV (AC-BPPV). To our knowledge, the only reported cases of AC-BPPV have occurred within the last 25 years. In 1994, Herdman et al. [16] analyzed 77 patients with BPPV and found that nine of them had AC-BPPV. In 1999, Honrubia et al. [17] performed a study in 292 patients with BPPV using an infrared camera and a Frenzel mirror, and found that four patients had AC-BPPV.

The previous studies have demonstrated that PC-BPPV is the most common form of BPPV, accounting for 60–90% of cases, followed by HC-BPPV, accounting for 5–30% [23, 28], and by AC-BPPV, accounting for 1–2% [33]. At present, the diagnosis of AC-BPPV mainly depends on the results of the D–H and the straight head-hanging (SHH) tests. These tests can induce a vertical down-beating nystagmus (DBN) with or without a torsional component. There are many manual reduction methods available for treating AC-BPPV, such as the Epley maneuver [28], Kim maneuver [18], Rahko maneuver [30], and Yacovino maneuver [35]. The first three maneuvers are useful for AC-BPPV cases with a clearly lateralized canal, whereas the Yacovino maneuver is useful for AC-BPPV cases with an unclear lateralization. To date, there have been a few studies investigating the diagnosis and treatment of AC-BPPV. In the 2015 BPPV expert consensus document published by the Bárány Society, AC-BPPV is classified as an emerging and controversial syndrome [32]. Therefore, the diagnosis and treatment of AC-BPPV require further study. In the present study, we retrospectively analyzed the nystagmus characteristics induced by the D–H and SHH tests, the diagnosis strategy used, and the effectiveness

of the Yacovino maneuver in 40 patients diagnosed with AC-BPPV.

Patients and methods

Patients

Forty patients with AC-BPPV who received treatment between January 2016 and December 2017 were included in this study. All patients underwent routine neuro-otological examinations including cranial nerve examinations, Romberg's test, Fukuda test, pure tone test, eye movement tests, bithermal caloric tests, and dynamic position tests. The eye movement tests included a gaze test, saccade test, smooth pursuit test, and optokinetic nystagmus test. Dynamic position tests included the D–H, SHH, and supine roll tests. The patients' nystagmus was recorded using a videonystagmograph (VNG) (Micromedical Technologies, Inc., Chatham, IL, USA). Magnetic resonance imaging was performed. This study was approved by the Aerospace Center Hospital Ethics Committee. Written informed consent was obtained from each patient.

Diagnosis methods

The diagnosis of BPPV was performed using the diagnostic criteria established by the Bárány Society in 2015 [32], which include a history of recurrent transient positional dizziness/vertigo and an induced positional nystagmus by the D–H, SHH, and supine roll tests. More specifically, an AC-BPPV diagnosis was given if a vertical DBN with/without a torsional component was observed during the D–H and/or SHH tests, and if the D–H test and/or SHH tests induced a DBN with a torsional component (where the torsion direction of the upper pole of the eyes indicates the affected side). A PC-BPPV diagnosis was given if a vertical up-beating nystagmus (UBN) with a torsional component was observed during the D–H and/or SHH tests, and if the D–H and/or SHH tests induced a UBN with a torsional component (where the torsion direction of the upper pole of the eyes indicates the affected side). Finally, a HC-BPPV diagnosis was given if a geotropic nystagmus was induced on both sides during the supine roll test (where the side of the stronger nystagmus indicates the affected side), or if an apogeotropic nystagmus was induced during the supine roll test (where the side of the weaker nystagmus indicates the affected side). Patients were classified as having cupulolithiasis if the nystagmus lasted ≥ 1 min, whereas they were classified as having canalolithiasis if the nystagmus lasted < 1 min. Finally, to be included in the study, the patient symptoms could not be attributable to other disorders such as

acute cerebrovascular disease, vestibular paroxysmia, and vestibular migraine.

Diagnosis strategy

The preliminary diagnosis of AC-BPPV was made based on disease history and the results of the D–H, SHH, and supine roll tests. (1) Therapeutic diagnosis: the AC-BPPV diagnosis was confirmed if the DBN with/without torsional component induced by the positional tests was effectively treated by manual reduction using the Yacovino maneuver. (2) Accompanying typical nystagmus for other types of BPPV: the combination of a DBN with/without a torsional component and a nystagmus typically associated with other types of BPPV further contributed to the differential diagnosis of AC-BPPV. (3) Follow-up outcome and the occurrence of canal conversion: the AC-BPPV diagnosis was confirmed if otoliths were found to translocate into other semicircular canals during the follow-up period.

Treatments

All patients with a diagnosis of AC-BPPV underwent treatment with the Yacovino maneuver [35]. More specifically, the patient was first placed in a sitting position on the examination bed and was then rapidly laid down with the head hanging at an angle of at least 30° over the end of the bed for a duration of 30 s. The head was then brought up quickly to touch the patient's chest, and 30 s later, the head and body were both brought back to a seated position. The video of the Yacovino manoeuvre is available online at <http://47.93.231.193:8090/Yacovino/YacovinoWithDubbing.mp4> (Online Resource 1).

For patients with a nystagmus duration ≥ 1 min, the holding time of each body position was appropriately prolonged. The maneuver was repeated if symptoms were not alleviated or if the reduction failed. Patients with AC-HC-BPPV underwent both the Barbecue and Yacovino maneuvers. Patients with AC-PC-BPPV underwent the Epley and Yacovino maneuvers. The anterior semicircular canal was first reduced, followed by the horizontal or posterior semicircular canals. The curative effect of the Yacovino maneuver was assessed immediately and at follow-up 1 week after treatment.

After manual reduction using the Yacovino maneuver, the D–H and SHH tests were performed again. If the DBN disappeared, then a complete cure was achieved. The Yacovino maneuver was also considered effective if the DBN was weaker without completely disappearing, whereas it was considered non-effective if the DBN was unchanged or became further aggravated.

Results

A total of 331 patients with BPPV who received treatment between January 2016 and December 2017 were included in the study. Among them, 40 (12.1%) patients had an AC involvement. These 40 patients, aged 61.43 ± 13.14 years (range 27–87 years), consisted of 14 men and 26 women. BPPV symptoms had been presented for < 3 days in 20 (50.0%) patients, 4–7 days in seven (17.5%) patients, 7–14 days in six (15.0%) patients, and > 14 days in seven (17.5%) patients. The previous disease history included hypertension ($n = 20$, 50.0%), diabetes mellitus ($n = 12$, 30%), hyperlipemia ($n = 19$, 47.9%), coronary heart disease ($n = 8$, 20.0%), cerebral infarction ($n = 2$, 5.0%), deafness ($n = 2$, 5.0%), traumatic brain injury ($n = 1$, 2.5%), and previous occurrences of BPPV ($n = 11$, 27.5%).

Eye movement test results were normal in all patients. Thirty-six patients underwent a caloric test and results revealed that 11 of them (30.6%) had a unilateral vestibular dysfunction. Among these 11 patients, six experienced a decrease in function of the right HC and five experienced a decrease in function of the left HC (Table 1).

Among the 40 patients diagnosed with AC-BPPV, 27 (67.5%) were classified as having canalolithiasis and 13 (32.5%) were classified as having cupulolithiasis. The left AC was involved in 16 (40.0%) patients, the right AC was involved in 14 (35.0%) patients, and it was unclear which side was involved in ten (25.0%) patients. Eleven patients were diagnosed PC-BPPV and ten patients were diagnosed with HC-BPPV (Fig. 1, Table 1).

During the D–H test, a DBN was observed in 26 (65.0%) patients, a DBN with a torsional component was observed in 14 (35.0%) patients, and a reversal of nystagmus direction upon sitting up was observed in 11 (27.5%) patients. During the bilateral D–H test, a DBN with/without torsional component was induced in 17 (42.5%) patients, and among these 17 patients, a simple vertical DBN was induced in ten patients. During the SHH test, a DBN was observed in 33 (82.5%) patients, a DBN with a torsional component was observed in seven (17.5%) patients, and a reversal of nystagmus direction upon sitting up was observed in 17 (42.5%) patients (Table 1). There were no significant differences between the D–H and the SHH test results regarding the rate of torsional nystagmus ($P = 0.075 > 0.05$) or the rate of reversal of nystagmus direction upon sitting up ($P = 0.241 > 0.05$) (Figs. 2, 3).

Based on the involvement of different semicircular canals, the nystagmus induced by the D–H and SHH tests in patients with AC-BPPV, AC-PC-BPPV, and AC-HC-BPPV were further analyzed (Figs. 4, 5, 6, 7). Among the 19 patients with simple AC-BPPV, a DBN was induced by a unilateral D–H test in eight patients, a DBN was induced

Table 1 Clinical characteristics of patients with anterior canal-benign paroxysmal positional vertigo

No.	Sex	Age	Duration of disease	Left DH	Sitting up	Right DH	Sitting up	SHH	Sitting up	Canal paresis ^a	Diagnosis	Diagnosis strategy
1	F	54	14	-	-	DBN	UBN	DBN	UBN	L	LAC-ca	Medical history + positional test
2	M	76	90	-	-	DBN	-	DBN	-	L	LAC-ca	Medical history + positional test
3	M	55	7	-	-	DBN	-	DBN	-	N	LAC-ca	Medical history + positional test
4	F	43	1	-	-	DBN	-	DBN	-	N	LAC-ca	Medical history + positional test
5	F	53	2	-	-	DBN	UBN	DBN	UBN	N	LAC-ca	Medical history + positional test
6	M	71	6	-	-	DBN	-	DBN	-	L	LAC-ca	Medical history + positional test
7	F	68	2	CW+DBN	CCW+UBN	CW+DBN	-	DBN	UBN	N	LAC-ca	Therapeutic diagnosis
8	M	52	14	-	-	DBN	-	DBN	-	N	LAC-ca	Medical history + positional test
9	M	64	60	-	-	DBN	-	DBN	UBN	N	LAC-ca	Medical history + positional test
10	F	62	2	CW+DBN	CCW+UBN	CW+DBN	CCW+UBN	CW+DBN	UBN	L	LAC-cu	Therapeutic diagnosis
11	F	65	1	CW+DBN	-	CW+DBN	-	CW+DBN	-	L	LAC-cu	Therapeutic diagnosis
12	F	41	1	CCW+DBN	-	-	-	DBN	-	R	RAC-ca	Medical history + positional test
13	F	63	14	CCW+DBN	CW+UBN	CCW+DBN	CW+UBN	DBN	UBN	N	RAC-cu	Therapeutic diagnosis
14	F	51	3	CCW+DBN	-	DBN	-	CCW+DBN	-	R	RAC-cu	Therapeutic diagnosis
15	F	72	21	CCW+DBN	-	-	-	DBN	-	N	RAC-cu	Therapeutic diagnosis + follow-up diagnosis
16	F	57	5	DBN	-	DBN	-	DBN	-	N	UA-ca	Therapeutic diagnosis + canal conversion
17	F	57	1	DBN	-	DBN	-	DBN	UBN	N	UA-ca	Therapeutic diagnosis
18	F	59	3	DBN	-	DBN	-	DBN	CCW+UBN	N	UA-cu	Therapeutic diagnosis + follow-up diagnosis
19	M	66	25	DBN	CW+UBN	DBN	-	DBN	CW+UBN	N	UA-cu	Therapeutic diagnosis + follow-up diagnosis
20	F	83	20	CW+UBN	-	DBN	UBN	DBN	UBN	N	LAC-ca + LPC-ca	Typical nystagmus for other types of BPPV
21	M	61	3	CW+UBN	-	DBN	-	DBN	UBN	/	LAC-ca + LPC-ca	Typical nystagmus for other types of BPPV
22	F	82	10	-	-	DBN	UBN	DBN	UBN	N	LAC-ca + RHC-ca	Typical nystagmus for other types of BPPV
23	F	43	7	CW+DBN	-	CCW+UBN-DBN	DBN	CW+DBN	UBN	N	LAC-cu + RPC-ca	Therapeutic diagnosis + typical nystagmus for other types of BPPV
24	F	57	14	CW+UBN	-	CW+DBN	CCW+UBN	CW+DBN	CCW+UBN	N	LAC-cu + LPC-cu	Typical nystagmus for other types of BPPV
25	M	69	3	DBN	-	CCW+UNB	-	DBN	-	/	RAC-ca + RPC-ca	Typical nystagmus for other types of BPPV

Table 1 (continued)

No.	Sex	Age	Duration of disease	Left DH	Sitting up	Right DH	Sitting up	SHH	Sitting up	Canal paresis ^a	Diagnosis	Diagnosis strategy
26	F	55	4	DBN	–	CCW + UBN	–	DBN	–	N	RAC-ca + RPC-ca	Typical nystagmus for other types of BPPV
27	F	62	1	CCW + DBN	UBN	CCW + UBN	–	DBN	UBN	/	RAC-ca + RPC-ca	Typical nystagmus for other types of BPPV
28	F	58	14	DBN	–	DBN	–	CCW + DBN	–	R	RAC-ca + RHC-ca	Typical nystagmus for other types of BPPV
29	M	57	3	DBN	–	CCW + DBN	–	DBN	–	R	RA-ca + RH-ca	Typical nystagmus for other types of BPPV
30	F	63	1	CCW + DBN	–	–	–	DBN	–	N	RAC-ca + RHC-cu	Typical nystagmus for other types of BPPV
31	M	82	60	CCW + DBN	UBN	CCW + UBN	–	DBN	–	R	RAC-cu + RPC-ca	Typical nystagmus for other types of BPPV + presence of canal conversion
32	F	49	2	CCW + DBN	–	DBN	–	CCW + DBN	–	N	RAC-cu + RHC-ca	Typical nystagmus for other types of BPPV + presence of canal conversion
33	F	68	2	DBN	–	–	–	DBN	–	R	RAC-cu + RHC-ca	Typical nystagmus for other types of BPPV
34	M	69	1	CCW + DBN	–	–	–	DBN	UBN	N	RAC-cu + RHC-cu	Typical nystagmus for other types of BPPV
35	F	43	1	CW + UBN–DBN	–	–	–	DBN	–	/	UA-ca + LPC-ca	Therapeutic diagnosis + typical nystagmus for other types of BPPV
36	M	87	4	CW + UBN–DBN	CCW + DBN	DBN	–	DBN	–	N	UA-ca + LPC-ca	Therapeutic diagnosis + typical nystagmus for other types of BPPV
37	M	83	3	DBN	–	CCW + UBN–DBN	DBN	DBN	–	N	UA-ca + RPC-ca	Therapeutic diagnosis + typical nystagmus for other types of BPPV
38	M	27	4	DBN	–	DBN	–	DBN	–	N	UA-ca + RHC-ca	Typical nystagmus for other types of BPPV
39	F	52	3	DBN	–	DBN	UBN	DBN	UBN	N	UA-ca + RHC-cu	Typical nystagmus for other types of BPPV
40	F	78	60	DBN	–	DBN	–	DBN	–	N	UA-cu + RHC-cu	Typical nystagmus for other types of BPPV

M male, F female, DBN down-beating nystagmus, UBN up-beating nystagmus, CW clockwise, CCW counterclockwise, R right, L left, N normal, LAC left anterior canal, RAC right anterior canal, LPC left posterior canal, RPC right posterior canal, RHC right horizontal canal, UA unclear side involvement of anterior canal, cu canalolithiasis, ca cupulolithiasis, / not performed

^aOn caloric testing, more than 25%

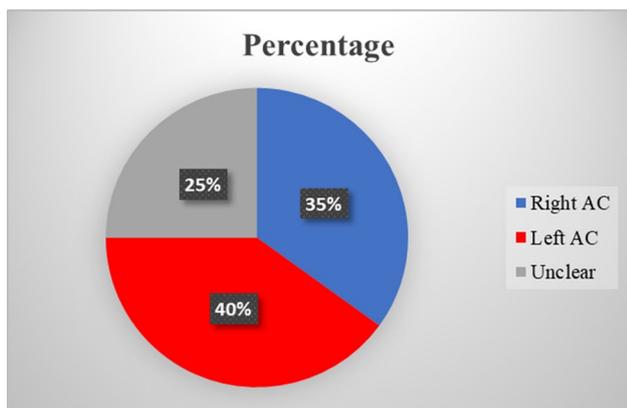


Fig. 1 Distribution of side involvement of anterior canal (AC) benign paroxysmal positional vertigo

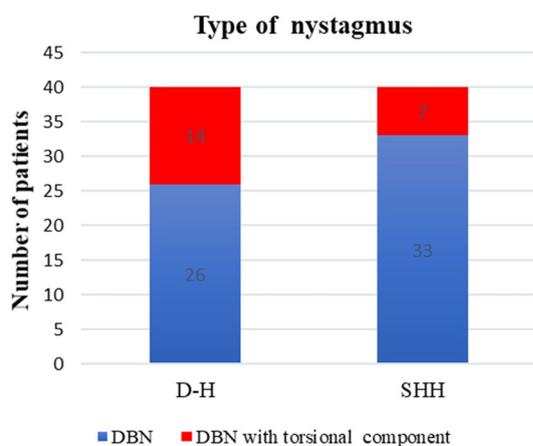


Fig. 2 Comparison of type of nystagmus induced by the Dix–Hallpike (D–H) test and the straight head-hanging (SHH) test. *DBN* down-beating nystagmus

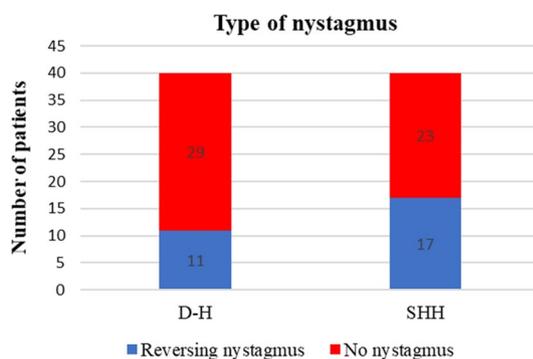


Fig. 3 Comparison of torsional component of nystagmus upon sitting up between the Dix–Hallpike (D–H) test and the straight head-hanging (SHH) test

by bilateral D–H tests in four patients, a DBN with an apogeotropic torsional component was induced by bilateral D–H tests in four patients, a DBN with an apogeotropic torsional component was induced by a unilateral D–H test in two patients, and a DBN with an apogeotropic torsional component on one side in addition to a DBN on the other side were induced by a D–H test in one patient. During the SHH test, a DBN was induced in 16 patients and a DBN with a torsional component was induced in three patients (Fig. 4). During the D–H and SHH tests, a reversal of nystagmus direction upon sitting up was observed in six and nine patients, respectively (Fig. 5). There was no significant difference between the DBN mean slow-phase velocity (SPV) values provided by the D–H and the SHH tests ($8.95^\circ \pm 4.03^\circ/s$ vs. $11.00^\circ \pm 5.81^\circ/s$, $P = 0.24 > 0.05$).

Among the 11 patients with AC-PC-BPPV, the D–H test induced a UBN with a geotropic torsional component on one side and a DBN on the other side in four patients, a UBN with a geotropic torsional component on one side and a DBN with an apogeotropic torsional component on the other side in three patients, a UBN with a geotropic torsional component followed by a DBN on one side and a DBN on the other side in two patients, a UBN with a geotropic torsional component followed by a DBN on one side and a DBN with a geotropic torsional component on the other side in one patient, and a UBN with a geotropic torsional component followed by a DBN on one side in one patient. The SHH test induced a DBN in nine patients and a DBN with a torsional component in two patients (Fig. 6).

Among the ten patients with AC-HC-BPPV, the D–H test induced a DBN on both sides in four patients, a DBN on one side in two patients, a DBN with an apogeotropic torsional component on one side in two patients, a DBN on one side and a DBN with an apogeotropic torsional component on the other side in one patient, and a DBN on one side in addition to a DBN with a geotropic torsional component on the other side in one patient. The SHH test induced a DBN in eight patients and a DBN with a torsional component in two patients (Fig. 7).

Typical BPPV semicircular canal diagnostic criteria were used alone for the diagnosis in 15 patients, a typical disease history and dynamic positional tests were used in nine patients, the success of the Yacovino maneuver was used in six patients, the combined success of the Yacovino maneuver and typical BPPV semicircular canal diagnostic criteria were used in four patients, the success of the Yacovino maneuver and follow-up outcomes were used in three patients, typical BPPV semicircular canal diagnostic criteria and the presence of a canal conversion (otoconial debris moving into the HC and PC after reduction treatment) were used in two patients, and the success of the Yacovino maneuver in addition to the presence of a canal conversion during the follow-up period (otoconial debris

Fig. 4 Type of nystagmus induced by the Dix–Hallpike (D–H) test and the straight head-hanging (SHH) test in 19 patients with simple anterior canal-benign paroxysmal positional vertigo (AC-BPPV). *DBN* down-beating nystagmus, *T* torsional component, *one* D–H test performed on the left or right side, *the other* D–H test performed on the right side or left side, *both* D–H test performed on both the left and right sides

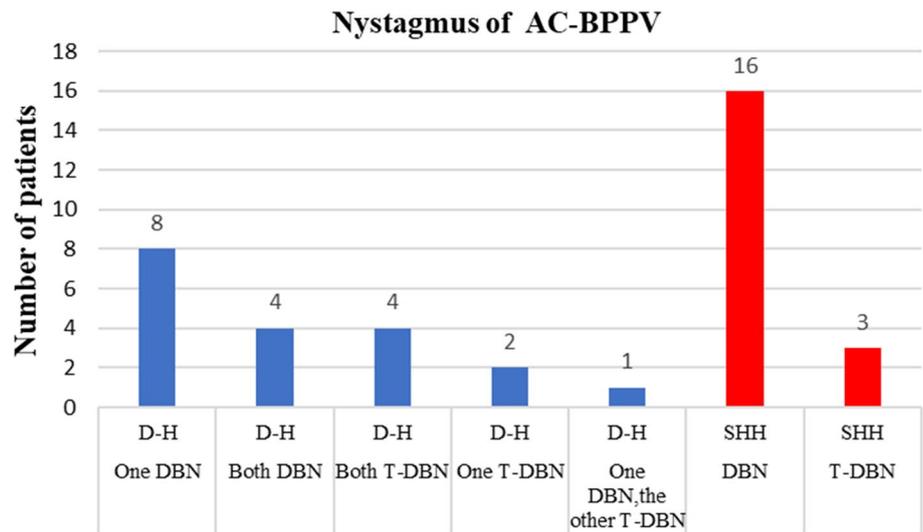


Fig. 5 Comparison of torsional component of nystagmus upon sitting up in patients with simple anterior canal-benign paroxysmal positional vertigo (AC-BPPV) between the Dix–Hallpike (D–H) test and the straight head-hanging (SHH) test

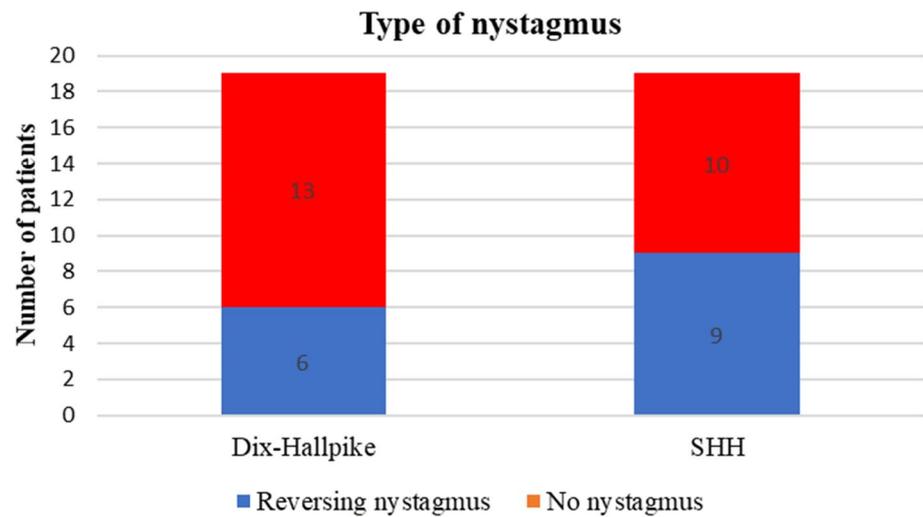


Fig. 6 Type of nystagmus induced by the Dix–Hallpike (D–H) test and the straight head-hanging (SHH) test in 11 patients with anterior canal-posterior canal-benign paroxysmal positional vertigo (AC-PC-BPPV). *DBN* down-beating nystagmus, *UBN* up-beating nystagmus, *T-DBN* DBN with torsional component, *T-UBN-DBN* UBN with torsional component and then turn to DBN without torsional component, *one* D–H test on the left or right sides, *the other* D–H test on the right or left sides

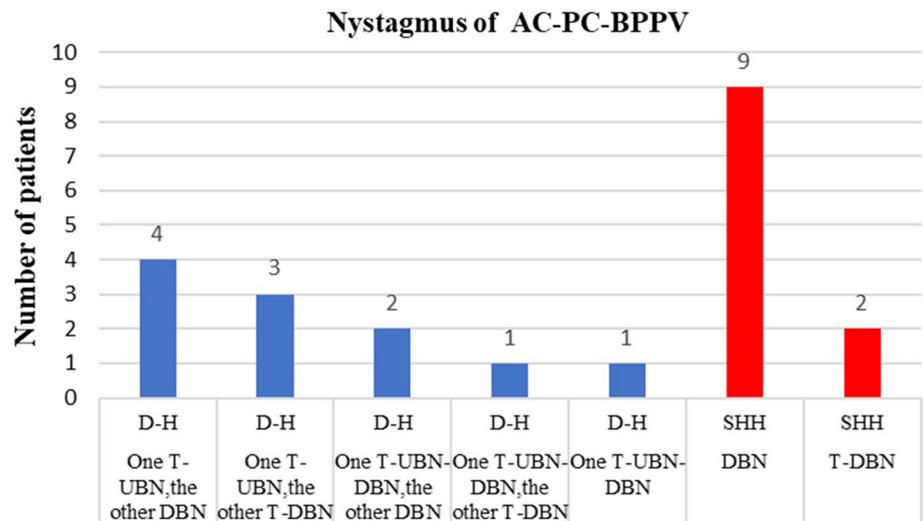
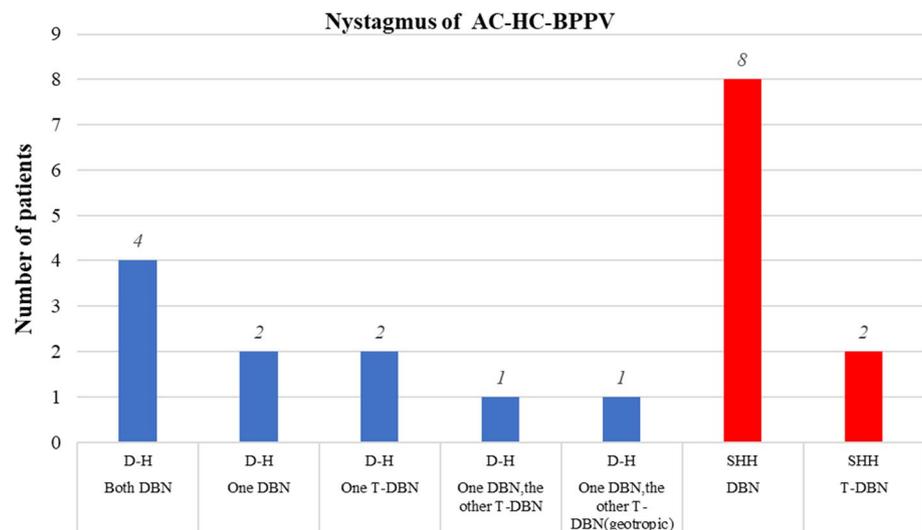


Fig. 7 Type of nystagmus induced by the Dix–Hallpike (D–H) test and the straight head-hanging (SHH) test in ten patients with anterior canal-horizontal canal-benign paroxysmal positional vertigo (AC-HC-BPPV). *DBN* down-beating nystagmus, *UBN* up-beating nystagmus, *T-DBN* DBN with torsional component, *T-UBN-DBN* UBN with torsional component and then turn to DBN without torsional component, *one* D–H test performed on the left or right sides, *the other* D–H test performed on the right or left side, *both* D–H test performed on both left and right sides



moving into HC after reduction treatment) was used in one patient (Table 1).

Among the AC-BPPV patients with canalolithiasis, 13 (48.1%) were cured after the initial manual reduction operations of the Yacovino maneuver. Furthermore, this maneuver was also found to be effective in seven (25.9%) additional patients and not effective in the seven (25.9%) other patients. After 1 week of treatment, 21 (77.7%) patients were cured and this maneuver was found to be effective in another four (14.8%) patients, whereas it was found to be not effective in two (7.4%) patients.

Among the AC-BPPV patients with cupulolithiasis, four (30.8%) were cured after the initial manual reduction operations of the Yacovino maneuver. Furthermore, this maneuver was found to be effective in four (30.8%) additional patients and not effective in the five (38.4%) remaining patients. After 1 week of treatment, seven (53.8%) patients were cured and this maneuver was found to be effective in two (15.4%) additional patients, whereas it was found to be not effective in four (30.8%) patients.

Discussion

Incidence and type of AC-BPPV

The previous studies have shown that AC-BPPV is the least common BPPV subtype, with an incidence of approximately 3% [3]. Its onset is generally caused by the spatial and anatomical position of the anterior semicircular canal. During regular daily activities, the AC is often in an anatomically superior position, which makes it difficult for otolith fragments to retrograde up into the AC. In addition, the posterior arm of the AC opens up into the common crus and the vestibule, which contributes to the easy return of otolith

particles to the utricle following body position changes [13]. In the present study, the incidence of BPPV with anterior semicircular canal involvement was found to be 12.1% (40/331), which is somewhat higher than previously reported estimates. This difference could potentially be explained by several different factors. First, when the D–H and the SHH tests are performed using the Frenzel technique, they can more accurately record nystagmus in patients with BPPV compared with when the Frenzel technique is not used, particularly in patients with weak nystagmus, thus increasing the diagnosis rate of AC-BPPV. Second, in the present study, patients were diagnosed using a variety of different metrics and combinations thereof, such as the curative effects of the Yacovino maneuver, typical semicircular canal BPPV symptoms, the presence of canal conversions during the reduction maneuver or during the follow-up period, the disease history, and the results from the conventional D–H and SHH tests. The use of all these metrics and tests likely greatly increases the diagnosis rate of AC-BPPV. The present study also showed that, in addition to a high incidence of simple AC-BPPV (19/331, 5.7%), the incidence of multi-canal BPPV involving the AC was also high (21/331, 6.3%), suggesting that clinical diagnosis is more difficult for AC-BPPV.

In the present study, 27 (67.5%) AC-BPPV patients were classified as having canalolithiasis and 13 (32.5%) as having cupulolithiasis. At present, there are few studies investigating cases of AC-BPPV-cupulolithiasis. In the latest diagnostic criteria for BPPV established by the Bárány Society in 2015, specific criteria for AC-BPPV-cupulolithiasis were not included [32]. In the present study, 13 patients had a DBN lasting ≥ 1 min, all of which had a typical history of head position-related vertigo episodes. The Yacovino maneuver was found to be effective in nine patients; among whom, seven had a typical nystagmus of their other semicircular canals, and one patient developed a canal conversion during

the follow-up. Therefore, these patients were diagnosed with AC-BPPV cupulolithiasis. Adamec and Habek [1] diagnosed AC-BPPV-cupulolithiasis in one patient based on the curative effect of the Yacovino maneuver and a previous history of PC-BPPV. Dlugaiczy et al. [12] considered that, in patients with BPPV suffering from trauma, a diagnosis of AC-BPPV-cupulolithiasis is likely more common than a diagnosis of AC-BPPV canalolithiasis.

The previous studies have found different findings regarding the lateralization of the affected side in AC-BPPV. Casani et al. [9] performed a study with 18 AC-BPPV patients, and found that the left AC was primarily involved in four patients, the right AC in two patients, and it was uncertain which side was most involved in 12 patients. Lopez-Escamez et al. [21] performed a study with 14 patients and found that the right AC was involved in seven patients, the left AC in four patients, and it was uncertain which side was most involved in three patients. In the present study, among the 40 patients with AC-BPPV, the left AC was involved in 16 patients, the right AC was involved in 14 patients, and it was uncertain in the remaining ten patients.

Diagnosis methods of AC-BPPV

The diagnosis of AC-BPPV mainly depends on the disease history and the presence of a D–H test- or SHH test-induced vertical DBN with or without a torsional component. The coupling between the semicircular canal and the eye muscle determines which side of the semicircular canal is involved, where one side of the AC is affected by the ipsilateral superior rectus muscle and the contralateral inferior oblique muscle. In the D–H and the SHH tests, the otolith fragments in the AC on one side tend to move in the direction away from the ampulla under the action of gravity and causes the flow of lymphatic fluid that leads to the movement of the cupula of the ampullary crest to go in the opposite direction of the utricle. This, in turn, causes an excitatory reaction resulting in the contraction of the ipsilateral superior rectus muscle and of the contralateral oblique muscle, which finally leads to a vertical down-beating quick-phase nystagmus with a torsional component (toward the affected ear) [19, 20]. Therefore, the torsional component of the nystagmus aids in establishing the canal side that is primarily involved in the AC-BPPV.

In clinical practice, a vertical DBN with an apogeotropic torsional component can be induced in most AC-BPPV patients by the D–H test (the affected ear in the superior position). However, a vertical DBN with a geotropic torsional component can only be induced in a few AC-BPPV patients by the D–H test (the affected ear in the inferior position) [19]. However, a vertical DBN with or without a torsional component can be induced in some patients using bilateral D–H tests, which makes determining the

lateralization of the affected side difficult [7, 9, 26]. In the present study, a DBN was induced by the D–H test in 65% of AC-BPPV patients, whereas 25% (10/40) of the patients had a DBN induced by bilateral D–H tests, making it difficult to determine the affected side of AC-BPPV. Casani et al. [9] performed a study with 18 AC-BPPV patients and found that the affected side was difficult to determine in 12 patients. The DBN induced by both bilateral D–H tests and the SHH test should be differentiated from those elicited in other central/peripheral vestibular diseases such as those caused by an impaired posterior semicircular canal, flocculus [29], and cell populations in the paramedian tract [24]. For patients with a simple vertical DBN, the disappearance of the nystagmus after applying the Yacovino maneuver helps clinicians in the differential diagnosis of AC-BPPV. If the outcomes of the Yacovino maneuver are not satisfactory, a follow-up-based diagnosis should be considered. If a canal conversion of otoliths occurs during follow-up, then a diagnosis of AC-BPPV is almost certain.

A canal conversion, can occur in BPPV patients when otoconia move from one semicircular canal to another during spontaneous changes of position and after therapeutic manual reductions. Several studies have reported the incidence rate of PC to HC canal conversions to be approximately 6–8% [4, 15, 36] and the incidence rate of HC to PC canal conversions to be approximately 6% [25]. Park et al. [27] found that the movement of otoliths from the AC to the PC occurred in up to 12.1% of patients after a manual reduction. In the present study, a canal conversion occurred in only 3 (7.5%) of 40 patients. However, because these three patients were diagnosed with a BPPV involving multiple canals, it is difficult to ascertain the directionality of the canal conversion.

In the present study, we analyzed the nystagmus parameters induced by the D–H test in 19 patients with simple AC-BPPV. We found that a DBN in most patients was induced by a unilateral/bilateral D–H test and that a DBN with a torsional component was only found in 36.8% (7/19) patients. In AC-PC-BPPV patients, a UBN with a geotropic torsional component was induced by the D–H test on one side, and a DBN was induced by a D–H test on the other side. However, in a small number of patients, a UBN with a geotropic torsional component, followed by a DBN lasting several dozen seconds, was induced by a D–H test on one side, and a DBN was induced by a D–H test on the other side. This possibly occurs because otoliths exist in both the AC and PC, and thus, a unilateral D–H test can produce otolith movements in both structures, causing a UBN with a geotropic torsional component, followed by a DBN. In patients with AC-HC-BPPV, a DBN was mainly induced by a unilateral or bilateral D–H test, followed by a DBN with an apogeotropic torsional component. However, a DBN with a geotropic torsional component was induced only in a small

number of patients. This possibly occurs as a result of the otolith movement in the horizontal semicircular canal following the D–H test, which produces a geotropic nystagmus that, to a certain degree, interferes with the torsional direction of the nystagmus, thus leading to a geotropic torsion.

In the present study, the SHH test produced more robust DBNs than the D–H test. It is presumed that this is the result of the lower head position in the SHH test, which produces a larger amplitude of otolith movement in the semicircular canals, thus yielding a greater pull on the crista ampullary of the semicircular canals.

Curative effects of Yacovino maneuver for AC-BPPV

The Yacovino maneuver has been previously shown to be effective for treating AC-BPPV with success rates ranging from 44.4 to 100.0% [3, 10, 17]. In 2009, Yacovino et al. [35] used the Yacovino maneuver to treat AC-BPPV in 13 patients and found that the maneuver was effective in all patients, with an initial success rate of 84.6%. Anagnostou et al. [3] found that the average effectiveness rate of the Yacovino maneuver was 78.8%. Chen et al. [10] reported the initial success rate of the Yacovino maneuver for the treatment of AC-BPPV was 22.2%, and that the 2-day cure rate was 44.4%. In the present study, the cure rates after the initial treatment and 1-week treatment with the Yacovino maneuver were 48.1% and 77.7%, respectively, in patients with AC-BPPV canalolithiasis, and were 30.8% and 53.8%, respectively, in patients with AC-BPPV cupulolithiasis. The reduction maneuver did fail in some patients, however, possibly because of: (1) old age, obesity, and severe cervical spondylosis, all of which lead to decreased body flexibility and poor coordination during the reduction process, thereby reducing the success rate of the reduction; (2) excessively large otolith particles or excessively narrow semicircular canals; (3) poor reduction resulting from cupulolithiasis or a BPPV with a multiple canal involvement [34]; (4) a semicircular canal or utricle function impairment leading to a continuous dropping of otoliths into the semicircular canals.

Study limitations

The primary limitation of the present study was the small sample size. We hypothesize that a greater number of statistical differences would have been significant with a larger sample size.

Conclusion

Taken together, our results showed that the types of nystagmus induced by the D–H and SHH tests differ greatly and that they should be comprehensively evaluated using

the D–H, SHH, and supine roll tests. Furthermore, our findings suggest that the differential diagnosis of AC-BPPV is significantly aided by the evaluation of the disease history, the D–H and SHH tests, the reduction produced by the Yacovino maneuver, a follow-up diagnosis, and the assessment of potential canal conversions during the follow-up assessment. Finally, our findings indicate that the Yacovino maneuver is more effective in patients with AC-BPPV canalolithiasis than in those with AC-BPPV cupulolithiasis.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

Ethical approval This study received approval from the Aerospace Center Hospital Ethics Committee and has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Informed consent Written informed consent was obtained from each patient prior to inclusion in the study.

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