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OTOLOGY

Proposal of a standardized testing protocol for BPPV: Using 3D simulations for insights into movement of otoliths during positional tests

Rajneesh Bhandari[1] · Anita Bhandari[1] · David Samuel Zee[2] · Daniele Nuti[3] · Herman Kingma[4,5] · Raymond van de Berg[5]

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Abstract

Background Benign Paroxysmal Positional Vertigo (BPPV) is a common vestibular disorder caused by displaced otolith debris in the inner ear. This study explored the order effect related to the sequence of performing different diagnostic positional maneuvers.

Methods 3D simulations of the Supine Roll Test (SRT), Dix-Hallpike maneuver (DHM), and Deep head hanging tests, performed in the standardized prescribed way, were used to study various types of horizontal, posterior, and anterior canal BPPV. The simulations allowed visualization of the movement of the otolith debris and the resulting nystagmus patterns. The results of the sequence of tests and the starting side of the tests (from left or right) were observed.

Results Simulations of the SRT on horizontal canal BPPV (hc-BPPV) showed different patterns of nystagmus: direction changing, direction fixed, and unilateral (only elicited in one position) nystagmus. These patterns depended on the position of the debris within the horizontal canal and the side from which the SRT began. Simulations of the DHM showed that the test procedure could displace debris in the horizontal canal. The SRT, however, caused no movement of debris in the vertical canals. The deep head hanging test could displace debris in all canals.

Conclusion An order effect can occur when performing diagnostic maneuvers for BPPV. The maneuvers can displace debris in the semicircular canals into new positions that may influence the findings in subsequent maneuvers and confound interpretation. A standardized testing protocol, starting with the SRT first, can decrease the order effect and simplify the interpretation of test results and in turn improve diagnostic accuracy and outcomes in the management of BPPV.

Keywords BPPV · Supine Roll Test · Maneuvers · Dix Hallpike · Simulations

✉ Anita Bhandari
dranitabhandari@gmail.com

Rajneesh Bhandari
rajneesh.bhandari@maastrichtuniversity.nl

[1] NeuroEquilibrium Diagnostic Systems Pvt Ltd, Jaipur, India

[2] Johns Hopkins University, Baltimore, USA

[3] University of Siena, Siena, Italy

[4] Department of Ear Nose Throat, Aalborg University, Aalborg, Denmark

[5] Department of Otorhinolaryngology, Head and Neck Surgery, Maastricht University Medical Centre, Maastricht, Netherlands

Introduction

Benign Paroxysmal Positional Vertigo (BPPV) is a common condition caused by the displacement of otolith debris from the utricle into the semicircular canals [1]. The movement of otolith debris within the canal causes recurrent episodes of vertigo with a change of head position. The diagnosis of BPPV depends on identifying the affected canal based on the pattern of nystagmus elicited on positional tests [2].

Diagnostic positional tests work on the premise of moving the head in spatial planes aligning with the plane of the tested canal. Thus, it is assumed that the Supine Roll test (SRT) works in the plane of both horizontal canals, Dix Hallpike maneuver (DHM) in the plane of the ipsilateral posterior and contralateral anterior canal, and the deep head hanging test in the summed plane of the vertical canals [3, 4]. Movement of the displaced debris within the canal under the influence of gravity will generate nystagmus. This nystagmus corresponds with the stimulated canal [5]. Careful clinical observation and analysis of the beating direction (i.e. rotation axis) of this nystagmus induced in the provocative position allows one to deduce which canal is being stimulated [6, 7].

The characteristic patterns of nystagmus elicited on these positional tests provide clues to the affected canal, the position of the debris within the canal, and whether the debris is free-floating within the canal (canalithiasis) or adherent to the cupula (cupulolithiasis). In the case of BPPV involving multiple canals and multiple locations of the debris in one canal, the pattern of nystagmus can be a complex sum of all the individual responses and elude interpretation. Furthermore, differences in the density between the endolymph and cupula can also lead to positional vertigo and nystagmus, however these findings differ from BPPV of the canalithiasis type [8].

BPPV is often equated with the long arm canalithiasis type of posterior canal BPPV and treated with Epley's or Semont's maneuver [9–13]. However, various studies have reported a higher incidence of horizontal canal BPPV than previously published [14–17]. Currently, there is no standardized guideline regarding the sequence of performing these diagnostic tests for BPPV. Based on the current understanding that posterior canal BPPV is more prevalent, the Dix Hallpike test is usually performed first for any suspected BPPV case [18].

In this study, simulations were used to infer the movements of the otolith debris in BPPV in various types of canalithiasis affecting the posterior, horizontal and anterior canals. It was hypothesized that the order in which the sequence of diagnostic tests, and the side on which tests were first performed, can lead to different patterns of nystagmus in the same head position even though the initial position of the otolith debris in the offending canal is the same.

Methods

Development of the simulation model

The simulation model was previously described [19]. Simulations of the inner ear were based on a 3D model constructed from DICOM files of the temporal bone, representing the orientation and angles of the canals based on previous studies [19]. The simulations were developed with Unity 3D software and a humanoid figure was animated within Autodesk Maya with the head closely linked to the semicircular canals to mimic head movements. Otolith debris, represented as a sphere, was introduced into the canals through a slender tube [19]. To simulate nystagmus resulting from canal stimulation, the semicircular canals were connected with their respective ocular motor muscles. Ewald's first law [20] was simulated to ensure an accurate representation of the direction of simulated responses. The intensity of nystagmus in the simulation was derived from the distance the debris moved under gravity. Theoretically, many factors can affect the velocity of debris movement, such as size and number of debris, viscosity of endolymph, anatomical variations of the canal, etc. To simplify this issue, some assumptions were included in this model [6]. The otolith debris was considered as a single sphere, and anatomy was standardized. Here, we only considered BPPV of the canalithiasis type in which the otolith debris moved under the effect of gravity.

Simulations of diagnostic maneuvers

The simulation model was used to perform diagnostic positional tests for BPPV and evaluate the resulting nystagmus. The Supine Roll Test (SRT), Dix-Hallpike Maneuver (DHM), and Deep Head Hanging test were simulated.

The SRT included the following steps:

a) The patient was moved to the supine position with the head inclined forward at an angle of 30° (clinically usually done by placing a pillow under the head).
b) The head was turned 90° to the right side and held in this position for 30 s or until the nystagmus subsided.
c) The head was turned back to the central position and held for 30 s.
d) The head was then turned 90° to the left side and held for 30 s or until the nystagmus subsided.
e) The head was turned back to the center position, and then the patient was brought to an upright position.

Simulation of the Dix-Hallpike maneuver (DHM) was performed following the steps below:

a) The patient sat upright, facing forward with legs stretched out.
b) The head was turned by 45° to the right.
c) The patient was brought to the head hanging position with the head 30° below the horizontal. This position was held for 30 s.
d) The patient was brought back to the sitting position, and the head turned to the midline.

Simulation of the Deep Head Hanging test was performed following the steps below:

a) The patient sat upright, facing forward with legs stretched out.
b) The patient was brought to the head hanging position with the head 30° below the horizontal.

c) The patient was brought back to the upright sitting position, facing forward with legs stretched out.

Investigating the order effect when performing diagnostic tests for BPPV

The movement of otolith debris and the resulting nystagmus were observed when performing simulations of different BPPV scenarios. Scenarios differed regarding:

- First diagnostic maneuver performed: DHM, SRT, or Deep Head Hanging test
- Side of first diagnostic maneuver performed: Right or Left
- Location of the otolith debris:

  a)right or left ear
  b)posterior, horizontal or anterior canal
  c)ampullary arm versus non-ampullary arm BPPV (in case of horizontal canal BPPV, see Figure 1)

Results

Simulations of different BPPV scenarios

Effect of the Dix-Hallpike maneuver in horizontal canal BPPV

Simulations of the DHM in horizontal canal BPPV demonstrated that the DHM can displace otolith debris that is located in the ampullary arm of the ipsilateral horizontal canal (Simulations 1–4), generating horizontal nystagmus.

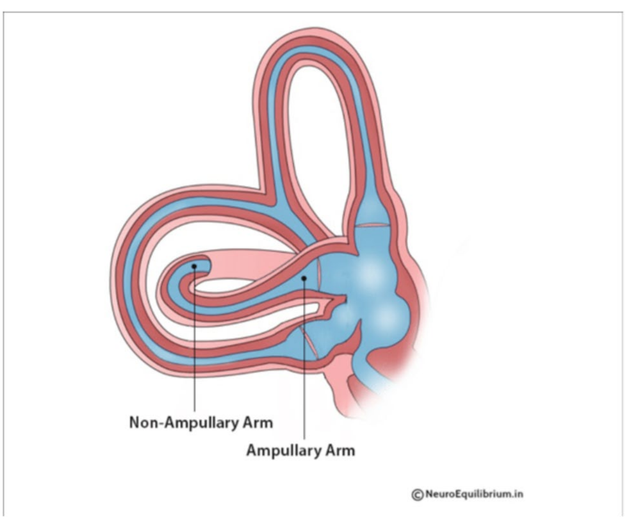

Fig. 1 Depiction of ampullary and non-ampullary arms of horizontal canal. Otolith debris can be located at either of these locations in horizontal canal BPPV

- o Simulation 1 (https://vimeo.com/862607999/b7db86eecc): Dix-Hallpike right in right horizontal canal BPPV (ampullary arm)

If the debris is in the ampullary arm of the right horizontal canal, performing the right DHM will cause the debris to move from the ampullary arm to the non-ampullary arm, resulting in a left beating (apogeotropic) nystagmus.

- o Simulation 2 (https://vimeo.com/862623623/b20e70fd2b): Dix-Hallpike right in right horizontal canal BPPV (non-ampullary arm)

When the debris is in the non-ampullary arm of the right horizontal canal, the right DHM will not induce any nystagmus as the debris does not move.

- o Simulation 3 (https://vimeo.com/862623665/dbe009d669): Dix-Hallpike right in left horizontal canal BPPV (ampullary arm)

In the case of left horizontal canal BPPV, if the debris is in the ampullary arm, performing the right DHM will not cause any movement of debris, and therefore, no nystagmus will be observed.

- o Simulation 4 (https://vimeo.com/862623693/68640a1d78): Dix-Hallpike right in left horizontal canal BPPV (non-ampullary arm)

If the debris is present in the non-ampullary arm of the left horizontal canal, the right DHM will displace the debris farther away from the ampullary arm, producing a right-beating (apogeotropic) nystagmus.

Effect of starting with the SRT in posterior and anterior canal BPPV

Simulations of the SRT in posterior and anterior canal BPPV showed that the position of otolith debris within the affected canal showed little movement before and after the SRT (Simulations 5 and 6).

- o Simulation 5 (https://vimeo.com/862623714/e0c66dad38): SRT in posterior canal BPPV right

When the patient is taken from sitting to supine position, there is some movement of the debris resulting in torsional upbeat nystagmus. However, when the patient's head is turned to the right, the SRT does not induce any debris movement or nystagmus. Similarly, there is no movement of the debris when turning the head to the left.

- o Simulation 6 (https://vimeo.com/862623739/c0817d6850): SRT in anterior canal BPPV

Simulation 6 demonstrates that when the patient's head is moved to the right, the debris in the right anterior canal moves away from the ampulla, resulting in a downbeat nystagmus. However, when the patient's head is turned to the opposite side (left), the debris returns to its original position, resulting in an upbeat nystagmus. However, the final position of otolith debris before and after the SRT does not notably differ.

Effect of starting with the Deep Head Hanging test in horizontal and posterior canal BPPV

It was illustrated that the position of otolith debris within the affected canal showed little movement before and after the Deep Head Hanging test in horizontal canal BPPV (Simulations 7), though upbeat nystagmus with torsion to the same side was elicited in pc-BPPV (Simulation 8).

- o Simulation 7 (https://vimeo.com/862623793/98d3ea7ba3): Deep Head Hanging in horizontal canal BPPV

Little movement of the debris in the horizontal canal is observed.

- o Simulation 8 (https://vimeo.com/862623826/185a45d046): Deep Head Hanging in posterior canal BPPV

The Deep Head Hanging test moves the debris in the posterior canal away from the ampulla, resulting in upbeat nystagmus with torsion beating to the same side (right). When the patient is brought back to the sitting position, the debris falls back towards the ampulla resulting in reversal of the nystagmus. The final position of otolith debris before and after the Deep Head Hanging test does not notably differ.

Effect of starting with the SRT on horizontal canal BPPV findings

Simulations of the SRT in horizontal canal BPPV demonstrated that the pattern of nystagmus is influenced by the side on which the SRT is started and the location of the otolith debris (ampullary or non-ampullary arm). The main findings included:

- Nystagmus does not always change direction in the SRT test, i.e., direction-fixed (e.g. Simulation 9)
- Nystagmus can be present in only one of the head positions in the SRT, since there is negligible movement of the debris on one side and more displacement on the other (Simulation 11)
- Nystagmus can be present in only one of the head positions (right, center, left) in the SRT, since the SRT actually resolved the BPPV. In other words, the diagnostic SRT acted as a therapeutic maneuver (Simulation 12).
- Not stopping at the center, when moving the head from one side to the other during the SRT, can lead to direction-fixed or direction-changing nystagmus, depending on the initial location of the otolith debris (Simulations 13).

These findings will be considered further in the Discussion.

- o Simulation 9 (https://vimeo.com/862623857/9e4d9c2b82): SRT started by turning head to right, in right horizontal canal BPPV (ampullary arm)

As the patient's head is moved to the right, the otolith debris moves from the ampullary arm to the non-ampullary arm of the horizontal canal. This movement induces left beating (apogeotropic) nystagmus. Subsequently, when the patient's head is moved to the center, the left beat nystagmus continues. On turning to the left, the debris continues its displacement in the same direction towards the non-ampullary arm, resulting in left beating (geotropic) nystagmus. Therefore, a consistent and fixed direction of nystagmus is observed during both the right and left SRT, transitioning from apogeotropic to geotropic nystagmus, with the nystagmus beating towards the left.

- o Simulation 10 (https://vimeo.com/862623904/7c1361d66f): SRT started by turning the head to the right, in the right horizontal canal BPPV (non-ampullary arm)

As the head of the patient is moved to the right, the otolith debris moves towards the ampulla, resulting in a (geotropic) nystagmus beating towards the right. Subsequently, when the patient's head is moved to the center the debris move away from the ampulla generating left beat nystagmus. On turning to the left, the debris moves farther away from the ampulla, generating a geotropic nystagmus beating towards the left. Therefore, in this scenario, a direction-changing nystagmus is observed.

- o Simulation 11 (https://vimeo.com/862623941/d6b99c9611): SRT started by turning head to left, in the right horizontal canal BPPV (ampullary arm)

When turning the head to the left, the otolith debris (already close to the ampulla) shows little movement in the direction of the cupula. On coming back to the center, again the debris is not displaced so no nystagmus is generated. On turning to the right, the debris moves from the ampullary to the non-ampullary arm, generating left beating (apogeotropic) nystagmus. When the head is brought back to the center, the debris moves farther away from the ampulla generating left beating nystagmus. Thus, little right-beating or no nystagmus is observed when turning to the left, and left beating apogeotropic nystagmus is observed when turning to the right.

- o Simulation 12 (https://vimeo.com/862623970/ec4860e2c0): SRT started by turning head to left, in right horizontal canal BPPV (non-ampullary arm)

When the head is turned to the left side, the otolith debris from the non-ampullary arm in the right horizontal canal moves out of the canal under the effect of gravity. Left beating (geotropic) nystagmus is observed. When turning the head back to the center and then to the right, no nystagmus is observed as the debris has already moved out of the canal.

- o Simulation 13 (https://vimeo.com/862624004/6d2f2fce3b): SRT started by turning the head to the right and then going directly to the left in right horizontal canal BPPV (non-ampullary arm)

When turning the head to the right, the otolith debris moves towards the ampulla. This generates a right-beating (geotropic) nystagmus. When the head is turned directly to the left without stopping at the center, the debris moves farther away from the ampulla. This generates a stronger (geotropic) nystagmus, which is left beating.

The order effect when performing diagnostic maneuvers for BPPV

The simulations of different BPPV scenarios demonstrated that an order effect is present when performing diagnostic maneuvers for BPPV. This is presented in Table 1 for horizontal canal BPPV. For otolith debris located in the same place (e.g. the ampullary arm of the horizontal canal), different nystagmus patterns were obtained by varying the order of testing (e.g. first SRT to the right, or first SRT to the left).

This table demonstrates that if the SRT is started from the side affected in the horizontal canal BPPV (non-ampullary arm), direction changing nystagmus is seen. However, if the SRT is started from the healthy side in hc-BPPV in ampullary or non-ampullary types, nystagmus on only one side (either the first position or the second position) may be seen. This would create a diagnostic dilemma about the involved side.

Additionally, when performing the Dix-Hallpike maneuver as the first positional test, this can lead to horizontal nystagmus in some cases of horizontal canal BPPV (as described in Simulations 1 and 4). This may also lead to displacement of the otolith debris, confounding the results of further tests.

Discussion

This study demonstrated that an order effect can occur when performing diagnostic maneuvers for BPPV. The maneuvers can displace debris in the semicircular canals into new positions that may influence the findings in subsequent maneuvers. This can confound the interpretation of diagnostic test results. The implication of these findings will now be discussed.

Importance of testing horizontal canal BPPV

It has been a common practice to perform the Dix-Hallpike maneuver as the first positional test [18]. Frequently, the SRT is overlooked, resulting in clinicians only performing the DHM to detect BPPV [21]. If the SRT is not performed, hc-BPPV may not be detected. Thus Bhattacharyya et al., strongly advocated that SRT should be an essential part of evaluating BPPV [18]. Previous literature reported a much lower incidence of hc-BPPV [15]. This could be a reason why clinicians often avoid performing the SRT. However, recent publications [17, 22] reported a much higher incidence of hc-BPPV than previously found. Various explanations were given for this higher incidence. hc-BPPV

Table 1 The order effect when performing diagnostic maneuvers for BPPV

Location of otoliths at start	*Order of testing*	*Nystagmus in first test*	*Nystagmus in second test*
HC right ampullary arm	SRT right—SRT left	Left (apogeotropic)	Left (geotropic)
HC right ampullary arm	SRT left—SRT right	No nystagmus	Left (apogeotropic)
HC right non-ampullary arm	SRT right—SRT left	Right (geotropic)	Left (geotropic)
HC right non-ampullary arm	SRT left—SRT right	Left (geotropic)	No nystagmus

naturally resolves faster, and only clinicians that test patients earlier will be able to detect these cases [18, 23, 24]. Carrying out Video-oculography guided positional tests may also result in better detection of hc-BPPV [22].

Why the Supine Roll test should be the first positional test

In current literature, the displacement of debris in the horizontal canal during the Dix-Hallpike maneuver (DHM) is rarely considered. The simulations showed that the Supine Roll test should actually be performed before the DHM, since the DHM can displace the debris in the horizontal canal (Simulation 1 and Simulation 4). Similar findings were also reported previously [25]. Nevertheless, Simulation 2 and Simulation 3 showed that the DHM does not displace debris in non-ampullary hc-BPPV. Hence, no nystagmus is generated. This implies that the DHM can displace debris in the horizontal canal and generate horizontal nystagmus, but not in all types of hc-BPPV. Therefore, the DHM cannot be used as an absolute diagnostic positional test for hc-BPPV. The BPPV Viewer [25] also highlights that the DHM can displace otolith debris within the horizontal canal, resulting in horizontal nystagmus.

Several papers have described the SRT as elicited by having the patient lie supine with the head pitched upward 30° to bring the horizontal canals into alignment with earth vertical and then moving the head in yaw rotations leftward or rightward [26–30]. But in the real-life scenario, sometimes clinicians do not use a pillow. Simulation 14 and 15 have been included in the supplementary material to show that performing the SRT without the pillow does not bring the horizontal canal into the vertical position and consequently on going from sitting to supine, the debris can move farther down in the dependent position in the posterior and horizontal canals. These findings require further clinical validation but do emphasize the importance of performing the positional maneuvers in the standardized, prescribed way with the head tilted up 30 degrees.

When a patient with posterior canal BPPV is taken from sitting to supine position, there is some movement of the debris resulting in torsional upbeat nystagmus. Simulation 5 shows that SRT may cause some movement of the debris in posterior canal BPPV, but it does not shift the debris from their position in the long arm of the canal. This leads to the conclusion that performing the SRT first does not change the results of DHM.

Simulation 8 showed that the Deep Head Hanging test displaces debris in the posterior canal. It should, therefore, be performed after SRT and DHM. The head hanging position potentially stimulates all six canals in which otolithic debris is present. As a result, it can elicit complex patterns of nystagmus. It is also advised to perform the deep head hanging test at a higher speed to differentiate from Central Positioning Nystagmus where nystagmus intensity increases with head rotation velocity [31]. In addition, because of the rapid fatigability of responses in canalithiasis, it might be difficult to reproduce individual canal responses with additional maneuvers [25]. In contrast to the DHM and Deep Head Hanging test, the correctly performed SRT does not displace debris in the posterior or anterior canals (Simulation 5 and Simulation 6). Therefore, one might perform the SRT first.

Order effect of supine roll test

In current literature, the nystagmus findings observed with the Supine Roll test in hc-BPPV are mainly described as a direction-changing nystagmus. Geotropic nystagmus is found in canalithiasis, and apogeotropic nystagmus is found in cupulolithiasis or periampullary canalithiasis [7] The side with stronger geotropic nystagmus is considered to be the affected side in canalithiasis of the non-ampullary arm. The side with weaker apogeotropic nystagmus is considered to be the affected side in canalithiasis of the ampullary arm. To summarize, in both geotropic and apogeotropic hc-BPPV, in the head position generating the most intense nystagmus, nystagmus will beat towards the affected ear. This study showed that this ‘traditional’ concept is not always applicable because of the order effect that occurs during positional testing (see Table 1). The simulations showed that by starting the SRT from different sides – right or left- different nystagmus patterns were observed. Inadequate knowledge about this variability could lead to an incorrect diagnosis of the affected side. When nystagmus is observed on only one side (the healthy side), the clinician may erroneously label the healthy side as the affected one, as the nystagmus was observed only on the healthy side.

Furthermore, Simulation 9 explained how the transformation of ampullary arm hc-BPPV to non-ampullary hc-BPPV during the SRT can lead to ‘direction-fixed’ nystagmus. Direction-fixed nystagmus is different from direction-changing nystagmus, as hc-BPPV is mainly described in the literature (see above). This direction-fixed phenomenon was also previously described [10, 11, 25, 32].

The importance of equal stimulation on both sides during the Supine Roll test

Simulation 13 illustrated that it would be preferred to perform the SRT by turning the head to one side, bringing the head to the center, and then finally turning the head to the opposite side. In each step, wait until nystagmus subsides or reaches a low intensity. This ensures equally comparable stimulation on both sides.

Table 2 Nystagmus patterns found in horizontal canal BPPV, based on the proposed protocol

Test	HC right ampullary arm	HC right non-ampullary arm	HC left ampullary arm	HC left non-ampullary arm
SRT Right	Left (apogeotropic)	Right (geotropic)—short	No Nystagmus	Right (geotropic)
SRT Left	Left (geotropic)	Left (geotropic)	Right (Apogeotropic)	No Nystagmus

Turning the head to one side and then turning it to the other side without stopping in the midline, might compromise interpretation. **Simulation 13** showed that the nystagmus on the left side (the healthy side) is stronger than on the affected right side. This could be explained by the difference in force applied and the excursion of the otolith debris. The difference in intensity may be due to the difference in excitation and inhibition of afferent nerve firing and/or to the fact that the mass has a different distance to move in the canal [26]. This could also be the reason of varying slow phase velocity (SPV) intensity in different hc-BPPV sub-types. Therefore, it is recommended to perform the SRT by turning the head to one side, bringing the head to the center, waiting until nystagmus subsides or reaches a low intensity, and then finally turning the head to the opposite side.

Proposal for universal testing protocol for BPPV

The simulations in this study have interesting clinical implications. Based on the observations from the simulations, we propose the following testing protocol for the diagnosis of BPPV:

1. Supine Roll Test Right (and turn head back to the midline)
2. Supine Roll Test Left (and turn head back to the midline)
3. Dix Hallpike Right
4. Dix Hallpike Left
5. Deep Head Hanging

This protocol integrates insights gained from the simulations and allows for a systematic assessment of different types of BPPV, ensuring a thorough evaluation of all involved canals. Implementing a universal protocol for BPPV testing can streamline the diagnostic process by proposing a standardized order for testing. This enhances diagnostic accuracy and provides a system to ensure comparable results globally, taking into account the 'order effect'. However, further randomized clinical trials are warranted to validate the proposed testing protocol and evaluate its effectiveness. Table 2 describes the nystagmus patterns that are expected in different horizontal canal BPPV positions by starting the SRT from the right side. This serves as a simple key to interpret the results of SRT and to reach a correct diagnosis.

Minimal stimulus strategy

Minimal Stimulus Strategy and Upright BPPV Protocol are diagnostic approaches to BPPV conducted in the sitting position slowly bending the patient's head along different spatial axes. [33]. The tests aim to move otoliths within the involved semicircular canal under the influence of gravity [4]. The tests are performed under continuous nystagmus monitoring by video-Frenzel goggles.

However, though expert centers may have video-Frenzel/Video-oculography, most doctors do not have this specialized equipment. The protocol advises continuous nystagmus monitoring because given the minimal stimulation, the nystagmus may be less intense and of shorter duration. Without monitoring with the goggles, it may be difficult to observe the nystagmus during all the positional tests like bow and lean. This is an important limitation. Therefore, using SRT is more appropriate as a standard protocol since the nystagmus would be visible to the clinician in all positions.

Limitations

This study was based on the orientation of the semicircular canals obtained from reconstructed CT images. We are aware that these simulations and the underlying physical model cannot precisely represent the in vivo movement of the otolith debris in the canals of each patient, because of variability amongst patients. Our simulations do not consider the impact of different amounts, composition (otoconia and otolithic membrane), and sizes of debris in the canal, and the possibility that the debris can be located in different parts of the canal at the same time. Individual variations in the orientation of the bony and membranous labyrinths in the skull might also influence the results. Furthermore, our simulations were based on carefully controlled orientations of the head (and the lateral semicircular canals) which may not be the case in many examinations performed by medical providers. Only simulations of canalithiasis were demonstrated, and cupulolithiasis was not included. The Upright BPPV Protocol [4] was not included in this study. This diagnostic strategy was beyond the scope of this study but should be considered in future work. Finally, we encourage a clinical validation of our protocol, including its practicality in different clinical settings, e.g., for front-line providers in the emergency department versus neuro-otology specialists in the outpatient setting.

Conclusion

An order effect can occur when performing diagnostic maneuvers for BPPV. The maneuvers can displace debris in the semicircular canals into new positions, that may influence the findings in subsequent maneuvers. This could confound the interpretation of diagnostic test results. A standardized testing protocol, carefully controlling the orientation of the head, and starting with the Supine Roll Test first, can decrease the order effect and should facilitate better interpretation of test results. This would result in a higher diagnostic accuracy and improve outcomes in BPPV management.

Declarations

Conflict of Interest Rajneesh Bhandari and Anita Bhandari are Directors at NeuroEquilibrium Diagnostic Systems Private Limited, India. The authors declare that the research was conducted in the absence of any commercial or financial relationship that could be construed as potential conflict of interest.

References

1. Palmeri R, Kumar A. Benign Paroxysmal Positional Vertigo. [Updated 2022 Dec 26]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan. Available from: https://www.ncbi.nlm.nih.gov/books/NBK470308/
2. Parnes LS, Agrawal SK, Atlas J (2003) Diagnosis and management of benign paroxysmal positional vertigo (BPPV). CMAJ 169(7):681–693
3. You P, Instrum R, Parnes L (2018) Benign paroxysmal positional vertigo. Laryngoscope Investigative Otolaryngol 4(1):116–123. https://doi.org/10.1002/lio2.230
4. Martellucci S, Malara P, Castellucci A, Pecci R, Giannoni B, Marcelli V et al (2020) Upright BPPV protocol: Feasibility of a new diagnostic paradigm for lateral semicircular canal benign paroxysmal positional vertigo compared to standard diagnostic maneuvers. Front Neurol 19:11. https://doi.org/10.3389/fneur.2020.578305
5. Aw ST, Todd MJ, Aw GE, McGarvie LA, Halmagyi GM (2005) Benign positional nystagmus. Neurology 64(11):1897–1905. https://doi.org/10.1212/01.wnl.0000163545.57134.3d
6. Peng Y, Qi J (2020) A dynamic model of otolith for determinants of a BPPV reposition maneuver with its Simulation. J Physics: Conference Series 1631(1):012044. https://doi.org/10.1088/1742-6596/1631/1/012044
7. Young L, Badihian S, Zee DS, Newman-Toker DE, Kerber KA, Bhandari A, et al. (2024) Benign paroxysmal positional vertigo: A case report in which four wrongs made a right. Clinical Case Reports. 12(11). https://doi.org/10.1002/ccr3.9529
8. Kim CH, Kim MB, Ban JH (2014) Persistent geotropic direction-changing positional nystagmus with a null plane: the light cupula. Laryngoscope 124(1):E15–E19. https://doi.org/10.1002/lary.24048
9. Nuti D, Zee DS, Mandalà M (2020) Benign paroxysmal positional vertigo: what we do and do not know. Semin Neurol 40:49–58. https://doi.org/10.1055/s-0039-3402733
10. Nuti D, Vannucchi P, Pagnini P (1996) Benign paroxysmal vertigo of the horizontal canal: a form of canaliithiasis with variable clinical features. J Vestib Res 6:173–184. https://doi.org/10.3233/VES-1996-6303
11. Nuti D, Vannucchi P, Pagnini P (2005) Lateral canal BPPV: which is the affected side? Audiol Med 3:16–20. https://doi.org/10.1080/16513860510028275
12. Asprella LG (2005) Diagnostic and treatment strategy of lateral semicircular canal canalolithiasis. Acta Otorhinolaryngol Ital 25:277–283
13. Martellucci S, Attanasio G, Ralli M, Marcelli V, de Vincentiis M, Greco A et al (2019) Does cervical range of motion affect the outcomes of canalith repositioning procedures for posterior canal benign positional paroxysmal vertigo? Am J Otolaryngol 40:494–498. https://doi.org/10.1016/j.amjoto.2019.04.003
14. Kim HJ, Park J, Kim JS (2021) Update on benign paroxysmal positional vertigo. J Neurol. 268:1995–2000. https://doi.org/10.1007/s00415-020-10314-7
15. Cakir BO, Ercan I, Cakir ZA, Civelek S, Sayin I, Turgut S (2006) What is the true incidence of horizontal semicircular canal benign paroxysmal positional vertigo? Otolaryngol Head Neck Surg 134:451–454. https://doi.org/10.1016/j.otohns.2005.07.045
16. Singh J, Bhardwaj B (2020) Lateral Semicircular Canal BPPV… Are We Still Ignorant? Indian J Otolaryngol Head Neck Surg 72(2):175–183. https://doi.org/10.1007/s12070-019-01737-4
17. Chung KW, Park KN, Ko MH, Jeon HK, Choi JY, Cho YS, Hong SH, Chung WH (2009) Incidence of horizontal canal benign paroxysmal positional vertigo as a function of the duration of symptoms. Otol Neurotol 30(2):202–205. https://doi.org/10.1097/mao.0b013e31818f57da
18. Bhattacharyya N, Gubbels SP, Schwartz SR, et al. (2017) Clinical Practice Guideline: Benign Paroxysmal Positional Vertigo (Update). Otolaryngol Head Neck Surg. 156(3_suppl):S1–S47. https://doi.org/10.1177/0194599816689667.
19. Bhandari A, Kingma H, Bhandari R (2021) BPPV simulation: a powerful tool to understand and optimize the diagnostics and treatment of all possible variants of BPPV. Front Neurol 12:632286. https://doi.org/10.3389/fneur.2021.632286
20. Ewald R (1982) Physiologische Untersuchungen über das Endorgan des Nervous Octavus. Weisbaden: Bergmann.
21. Edlow JA, Carpenter C, Akhter M, Khoujah D, Marcolini E, Meurer WJ, Morrill D, Naples JG, Ohle R, Omron R, Sharif S, Siket M, Upadhye S, E Silva LOJ, Sundberg E, Tartt K, Vanni S,

Newman-Toker DE, Bellolio F (2023) Guidelines for reasonable and appropriate care in the emergency department 3 (GRACE-3): Acute dizziness and vertigo in the emergency department. Acad Emerg Med. 30(5):442-486https://doi.org/10.1111/acem.14728
22. Bhandari R, Bhandari A, Hsieh Y, Edlow J, Omron R (2023) Prevalence of Horizontal Canal Variant in 3,975 Patients With Benign Paroxysmal Positional Vertigo A Cross-sectional Study. Neurol ClinPract. 13(5). https://doi.org/10.1212/CPJ.0000000000200191
23. Kim JS, Oh SY, Lee SH, Kang JH, Kim DU, Jeong SH, Choi KD, Moon IS, Kim BK, Oh HJ, Kim HJ (2012) Randomized clinical trial for apogeotropic horizontal canal benign paroxysmal positional vertigo. Neurology 78:159–166. https://doi.org/10.1212/WNL.0b013e31823fcd26
24. Imai T, Okumura T, Nishiike S, Takeda N, Ohta Y, Osaki Y, Sato T, Inohara H (2018) Recovery of positional nystagmus after benign paroxysmal positional vertigo fatigue. Eur Arch Otorhinolaryngol 275(12):2967–2973. https://doi.org/10.1007/s00405-018-5165-3
25. Traboulsi H, Teixido M (2017) Qualitative analysis of the Dix-Hallpike maneuver in multi-canal BPPV using a biomechanical model: Introduction of an expanded Dix-Hallpike maneuver for enhanced diagnosis of multi-canal BPPV. World J Otorhinolaryngol Head Neck Surg 3(3):163–168. https://doi.org/10.1016/j.wjorl.2017.01.005
26. Baloh RW, Qing Y, Jacobson KM, Honrubia V (1995) Persistent direction-changing positional nystagmus: another variant of benign positional nystagmus? Neurology 45:1297–1301. https://doi.org/10.1212/wnl.45.7.1297
27. Cohen HS (2019) A review on screening tests for vestibular disorders. J Neurophysiol 122(1):81–92. https://doi.org/10.1152/jn.00819.2018
28. McClure JA (1985) Horizontal canal BPV. J Otolaryngol 14:30–35
29. Pagnini P, Nuti D, Vannucchi P (1989) Benign paroxysmal vertigo of the horizontal canal. ORL J Otorhinolaryngol Relat Spec 51(3):161–170. https://doi.org/10.1159/000276052
30. White JA, Coale KD, Catalano PJ, Oas JG (2005) Diagnosis and management of lateral semicircular canal benign paroxysmal positional vertigo. Otolaryngology-Head and Neck Surgery 133(2):278–284. https://doi.org/10.1016/j.otohns.2005.03.080
31. Ling X, Kim H-J, Lee J-H, Choi J-Y, Yang X, Kim J-S (2020) Positioning velocity matters in central paroxysmal positional vertigo: implication for the mechanism. Front Neurol 11:591602. https://doi.org/10.3389/fneur.2020.591602
32. Bhandari A, Bhandari R, Kingma H, Strupp M (2022) Modified interpretations of the supine roll test in horizontal canal BPPV based on simulations: How the initial position of the debris in the canal and the sequence of testing affects the direction of the nystagmus and the diagnosis. Front Neurol 31:13. https://doi.org/10.3389/fneur.2022.881156
33. Libonati GA, Martellucci S, Castellucci A, Malara P (2022) Minimum stimulus strategy: A step-by-step diagnostic approach to BPPV. J Neurol Sci 434:120158. https://doi.org/10.1016/j.jns.2022.120158