



Research Paper

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



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Abstract *Introduction/Objective:* Multiple canal BPPV can be a diagnostic challenge to the clinician. This is due in part to the complex anatomy of the labyrinth but also to complex and often simultaneous ocular responses that result from stimulation of multiple canals during traditional diagnostic testing. Our objective was to analyze the Dix-Hallpike maneuver used in the diagnosis of BPPV to look for patterns of simultaneous canal response and to develop a diagnostic maneuver that will allow separation of canal responses in multiple canal BPPV.

Methods: A previously created and published 3D biomechanical model of the human labyrinths for the study of BPPV was used to analyze and compare the position and movement of otoliths in the Dix-Hallpike maneuver as well as in a proposed expanded version of the traditional Dix-Hallpike maneuver.

Results: The traditional Dix-Hallpike maneuver with the head hanging may promote movement of otoliths in 5 of the six semicircular canals. The Dix-Hallpike maneuver with the head lowered only to the horizontal position allows for otoconia in only the lowermost posterior canal to fall to the most gravity dependent position. This position allows for minimal or no movement of otoconia in the contralateral posterior canal, or in either superior canal. Turning the head

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ninety degrees to the opposite side while still in the horizontal position will provoke otolith movement in only the contralateral posterior canal. The superior canals can then be examined for free otolith debris by extending the neck to a head-hanging position. These positions may be assumed directly from one to the next in the lying position. There seems to be no advantage to sitting up between positions.

Conclusion: The Dix–Hallpike maneuver may cause simultaneous movement of otoliths present in multiple canals and create an obstacle to accurate diagnosis in multi-canal BPPV. An expanded Dix-Hallpike maneuver is described which adds intermediate steps with the head positioned to the right and left in the horizontal position before head-hanging. This expanded maneuver has helped to isolate affected semi-circular canals for individual assessment in multiple canal BPPV.

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Introduction

The Dix-Hallpike maneuver was described in 1952 and has been the pillar of diagnosis for benign paroxysmal positional vertigo ever since.¹

The maneuver involves dropping the patient rapidly from sitting with the head turned 45° to one side, to a head hanging position. The patient is then returned to the sitting position, the head turned 45° to the opposite side of midline, and the patient is again dropped to the head hanging position (Fig. 1). At the time of its introduction the

cause of BPPV was unknown. It was in subsequent decades that the concepts of cupulolithiasis and then canalithiasis were introduced as pathophysiologic mechanisms to explain eye movements observed in the Dix-Hallpike positions, and explanations spread from posterior cupulolithiasis to canalithiasis and then to pathologic involvement of all three canals.²

Correct interpretation of eye movements is crucial for obtaining an accurate diagnosis of the affected canal, the laterality of the disease, and differentiation of cupulo- from canalithiasis. The direction of eye movements, the

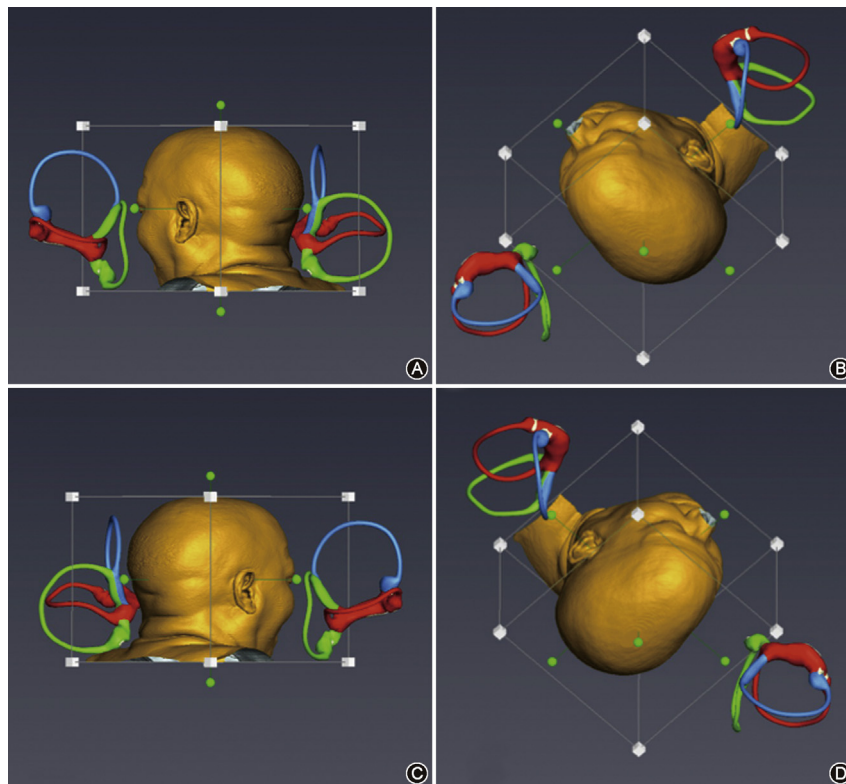


Fig. 1 The traditional Dix-Hallpike maneuver. The traditional maneuver begins with the patient sitting up and the head turned 45° to one side(A). The patient is then dropped to the head hanging position(B). The patient is returned to upright and the head is turned 45° to the opposite side(C). Finally the patient is dropped to head hanging on the second side(D).

fatiguability vs persistence of the response, in addition to finding null positions are all helpful in the clinical setting.

Involvement of multiple canals has been reported in 6.8%–20% of BPPV cases,^{3–8} and is often overlooked and underdiagnosed. In clinical practice the most common multiple canal presentations are bilateral posterior canalithiasis and ipsilateral posterior and horizontal canalithiasis.⁹

Multiple canal BPPV often creates a diagnostic challenge and can be a source of confusion. When multiple canal responses occur simultaneously the ability to visualize the complex anatomy of the labyrinths and knowledge of the ocular responses associated with each canal are of limited use.

To date, no maneuvers have been described that evoke responses exclusively from individual canals. In this paper, we propose a modification of the Dix-Hallpike maneuver that may assist the clinician in separating canal responses in multiple canal BPPV.

Materials and methods

A 3D model developed for the study of otolith disease was used to visualize the positions of the six semicircular ducts during the different phases of the Dix-Hallpike maneuver. The position of the six canals was also examined in the supine position with the head turned 45° to the right and left of midline. Our 3D model of the human membranous labyrinth, as previously reported,¹⁰ was created following the same technique as reported by Wang et al¹¹ for the creation of the Download-able Virtual Model of the Temporal Bone. The model was created from axial histological sections, which were imaged with high resolution scanning and integrated into Amira 5.2.2. The reconstructed labyrinth was cloned for the contralateral side and carefully positioned in relation to the 3D surface map of a human skull and then the skin surface was applied. Moveable markers for otoconia were created to allow known and expected positions of otoconia to be mapped while transitioning from position to position.

As the head was moved into different positions the new gravity-dependent position of the otolith mass in each canal was marked. The standard Dix-Hallpike maneuver sequence was followed with otolith masses present in all six canals. The classic sequence was modified to avoid simultaneous canal activity as much as possible. Numerous trials resulted in identification of a modified sequence, which reduces the simultaneous motion of posterior and superior canal otoliths. Screenshots were taken for the publication of this article.

Results

Analysis of the Dix-Hallpike maneuver

In the most common form of BPPV, posterior canalithiasis,¹² the Dix-Hallpike maneuver positions the posterior canal of the lowermost ear in a plane perpendicular to the earth and allows otoliths to travel to the most gravity-dependent position, causing an up beating and geotropic rotatory

nystagmus. While helpful, this same position can provoke movement in the posterior canal of the uppermost ear resulting in an up beating and apogeotropic rotary nystagmus. The classic Dix-Hallpike can also elicit responses from otolith movement in both superior and in the uppermost horizontal canals (Fig. 2). This simultaneous canal stimulation may complicate the clinical picture and prevent accurate diagnosis in multiple canal BPPV.

Modified Dix-Hallpike maneuver

We propose to start our diagnostic maneuver by moving the patient from sitting upright with the head turned 45° to lying supine with the head turned 45° to the side (to the left in our example, as shown in Fig. 3B). The head is not hanging below horizontal in this position. The plane of the lowermost posterior canal is perpendicular to the earth, potentially eliciting responses from that canal. In this position the uppermost posterior canal is relatively parallel to the earth and no otolith movement or canal response is expected. In this position no movement is expected from otoliths in either superior canal as the lowermost superior canal is parallel to the earth and the segment of the uppermost superior canal near the ampulla where otoliths are expected to be resting is parallel to the earth (Fig. 4).

This initial position of the maneuver will also permit otolith movement from either horizontal canal but because ocular movements resulting from horizontal canal BPPV are in the horizontal plane, nystagmus from posterior canal BPPV and from horizontal canal BPPV can be easily differentiated. Assuming this position (Fig. 3B) from upright, observed lateral canal responses are more likely to originate from the uppermost labyrinth as very little change of dependent otolith position occurs in the lowermost labyrinth (Fig. 2).

The second position of the proposed maneuver requires a 90° turn of the head to the opposite side while lying down (Fig. 3C) In this position the right posterior canal becomes vertical to the earth and otolith movement in the right posterior canal is permitted for the first time. The left posterior canal is not stimulated as its canal plane moves to nearly parallel to the earth. Otoliths in the horizontal canals could be stimulated as described above for position Fig. 3B.

Neither superior canal, if affected with canalithiasis, would be stimulated in positions Fig. 3B or Fig. 3C. The segment of the uppermost superior duct expected to contain otoliths remains parallel to the earth. The lowermost superior canal is parallel to the earth so no movement is provoked (Fig. 4).

The head is then lowered to the 30° head hanging position keeping the head turned to the same side (Fig. 3D). This position will drop the ampullated segment of the superior canal to an angle that allows otolith movement. Otolith movement from the lowermost superior canal can also be provoked in this position.

In the final position, the head is turned 90° directly to the opposite side while head hanging (Fig. 3E). This position will offer maximum fall angle for stimulation of the uppermost superior canal. Because posterior canalithiasis, if present, will have moved around the circumference of the posterior canals in earlier positions in the sequence

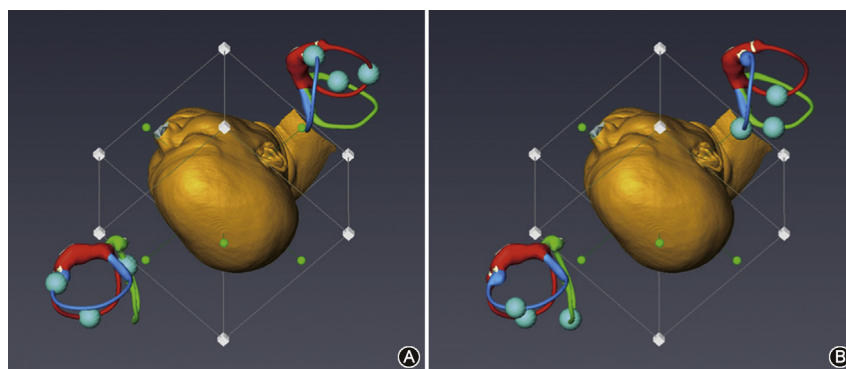


Fig. 2 With the head hanging in the traditional Dix-Hallpike maneuver otolith movement is provoked in all canals except the lowermost lateral canal. Panel A shows otoliths loaded in the dependent positions of all 6 canals before movement provoked by the maneuver. Panel B shows the expected position of otoliths in all 6 canals after otolith movement provoked by the maneuver.

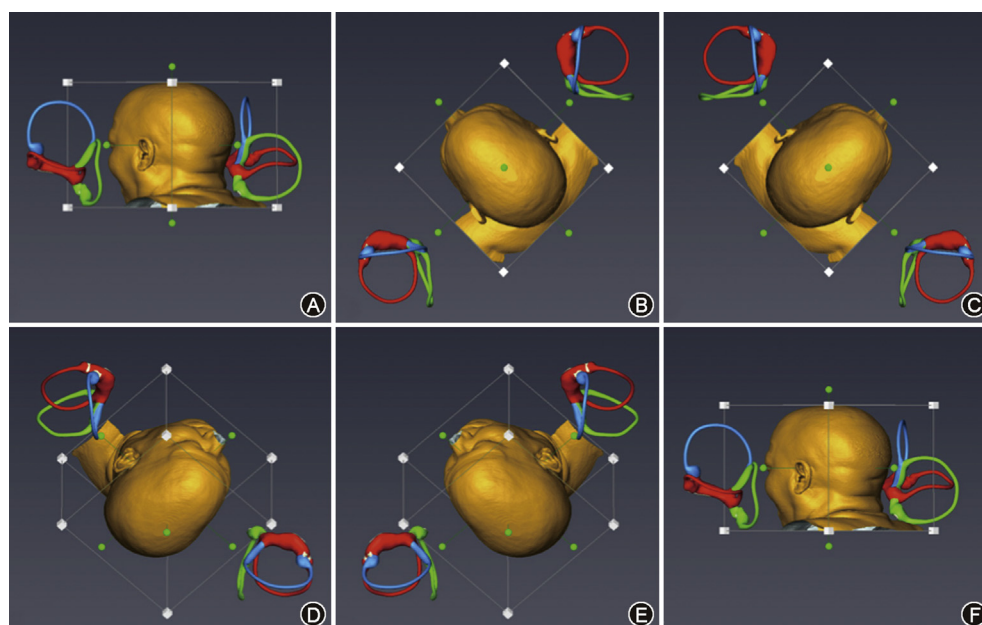


Fig. 3 The expanded Dix-Hallpike maneuver starts with the patient sitting and with the head turned 45° to one side(A). The patient is lowered to the horizontal plane with the head turned to the same side(B). The head is turned 90° to the opposite side(C). The head is lowered from horizontal to a head hanging position on the same side(D). The head is turned 90° while hanging to the opposite head hanging position(E) before sitting up(F).

(Fig. 3B,C), less additional movement occurs in the head hanging positions that could interfere with observation of superior canal responses. At this point the modified maneuver is complete.

As seen above, the expanded maneuver can separate bilateral posterior canal responses, and the co-occurrence of posterior and superior canal responses. It can also separate responses in the common clinical condition of ipsilateral posterior and horizontal canalolithiasis: In the traditional maneuver with the affected ear uppermost in the initial position, both horizontal and posterior canal movement will be present (Fig. 2, uppermost labyrinth). If, however, the patient is positioned with the head only to horizontal, only horizontal canal movement is provoked. Posterior canal responses occur when the head is turned to the opposite side with minimal movement of horizontal canaloliths to complicate interpretation of ocular responses.

If the subject is initially positioned with the affected labyrinth down, no separation of canal responses is seen with the expanded maneuver.

Discussion

Modern advancements in 3D software engineering and technology have made a tremendous impact on our understanding and teaching of human anatomy. 3D models of the labyrinth based on anatomic specimens have been particularly helpful in understanding the anatomy and in teaching physiology of the human inner ear.^{10,11,13} Using a 3D model was found to be more effective in teaching anatomy of the human middle ear in a randomized controlled study.¹⁴ Our qualitative 3D model was developed specifically for the study of BPPV to allow clear

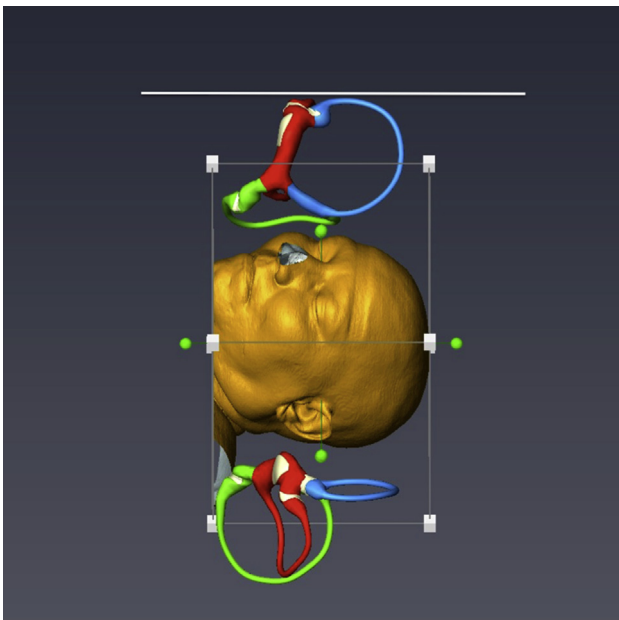


Fig. 4 In the first and second positions of the expanded Dix-Hallpike maneuver no movement is expected from the superior canals. The segment of the uppermost superior duct expected to contain otoliths remains parallel to the earth as indicated by the horizontal line. The lowermost superior canal is parallel to the earth so no movement is provoked.

visualization of expected otolith positions that may occur with changes in head position. It is similar to the model of Rajguru, Ifediba and Rabbitt in which was used for quantitative as well as qualitative biomechanical modeling of BPPV.¹⁵ Other models by House and Honrubia¹⁶ and by Squires et al¹⁷ are quantitative. The use of such models are directly relevant to understanding the positions of displaced particles within the labyrinth, design of provocative maneuvers, and the assessment of existing as well as creation of alternative treatments for variant forms of BPPV.

The only existing model analysis of the Dix-Hallpike maneuver is that of Rajguru et al.¹⁵ It analyzes predicted cupula displacements in the posterior ampulla during the Dix-Hallpike maneuver when dropping from sitting upright to 30° head hanging at up to 60°/sec. This creates an initial inertial response from linear and angular acceleration of the labyrinth and otoliths. The latency that follows is caused by fluid damping. The final gravity dependent ocular responses vary in intensity depending on particle size and number as these variables determine drag that creates cupula displacement.

Our qualitative analysis of the Dix-Hallpike maneuver has revealed several new observations: First, starting the Dix-Hallpike maneuver with the head hanging may offer a disadvantage for the diagnosis of multiple canal BPPV. The head hanging position potentially stimulates all 6 canals affected by otolith disease, and can thereby elicit complex and confusing ocular responses. In addition, because of the rapid fatigability of responses in canalithiasis, it can be difficult to reproduce individual canal responses with further maneuvers. We found with our model and much clinical experience that by having the patient lie supine, with the head turned 45° to the side, responses are elicited

only from the ipsilateral posterior canal or the horizontal canals. Canaliths in neither the contralateral posterior nor either superior canal should cause ocular movements in this position.

Second, having the patient sit up after the Dix-Hallpike maneuver before repeating it for the stimulation of the contralateral posterior canal seems to be unnecessary. In the supine position with the head turned 45° to one side the plane of the uppermost posterior canal is nearly parallel to the earth. Because no otolith movement is provoked in this uppermost posterior canal there is no need to “re-set” the labyrinths by sitting up prior to testing the opposite side. Skipping the step of having the patient sit up before repeating the maneuver again provides a more time-efficient evaluation, and a more comfortable experience for the patient, with no compromise of the sensitivity or accuracy of the maneuver. This is especially true of obese patients or patients with back problems that make body position changes difficult. Placing the head in a head-hanging position as a separate step would then stimulate the superior canals in an isolated manner. If horizontal canal responses are observed and canalithiasis is suspected the completed maneuver can proceed directly to the supine roll test.

Thirdly, our clinical experience with this modified maneuver in the last several years has shown that the almost immediate change in canal position associated with head turning results in robust canal responses that are unrelated to acceleration of otoliths by rapid position change in the Dix-Hallpike maneuver. This is seen clinically in the common complaint of vertigo provoked by turning over in bed. This suggests the Dix-Hallpike maneuver does not need to be performed quickly, as originally described, in order to provoke otolith movement. In canalithiasis, the difference in density between the otoliths and the endolymph is the driving force behind delayed otolith movement following positional change. Both clinical experience and engineering assessments of otolith movement demonstrate that otolith movement is highly damped, accounting for the latency and sometimes long duration of ocular responses. Therefore, it is likely the Dix-Hallpike maneuver can be performed slowly without affecting the accuracy of diagnosis.^{15,17}

Conclusion

A 3D biomechanical model of the inner ear for BPPV has identified some deficiencies in the classic Dix-Hallpike maneuver when used in patients with multi-canal BPPV. We have described an expanded modified Dix-Hallpike maneuver that may be beneficial in isolating canalith responses in multiple canal BPPV. In addition to improving diagnostic accuracy the maneuver does not require rapid movements, is time efficient and minimizes body movements that are sometimes difficult for patients with mobility problems.

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