Simulation study of BPPV fatigability

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Research Article

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Abstract

To analyze the mechanism and clinical significance of BPPV fatigability and discuss how to eliminate BPPV fatigability. A physical simulation model of BPPV was developed to analyze the effects of the Dix-Hallpike test and different angles of bowing maneuver on otolith positions. Dix-Hallpike test can keep the otoliths in the lower arm of the posterior semicircular canal away from the ampulla. The otoliths located in the lower arm of the posterior semicircular canal, slide closed to the ampulla while tilting the head forward more than 30 degrees; slide to the bottom of the crista ampullaris while tilting the head forward more than 60 degrees. The otoliths located in the short arm of the posterior semicircular canal leave the short arm and enter the utricle while tilting the head forward more than 120 degrees. It is recommended that tilting the head forward at least 60° so that the nystagmus induced by repeated Dix-Hallpike tests is consistent with long latency and fatigability is eliminated, which will be an important basis for the diagnosis of BPPV.

Introduction

Fatigability is considered an important characteristic of BPPV, that is, repeated Dix-Hallpike tests can reduce or even eliminate nystagmus. As early as Barany reported the first case of BPPV, the fatigue phenomenon of BPPV has been described\(^1\).

When Dix and Hallpike introduced the Dix-Hallpike test in 1952, the fatigability property was further described: repeated Dix-Hallpike test, nystagmus weakened, and duration shortened. The Dix-Hallpike test was repeated 2–3 times, and it was found that the reaction had been completely eliminated\(^1\). As Barany pointed out, only after a period of rest can the reaction be triggered again\(^1\).

The clinical significance and mechanism of fatigability are controversial. Nystagmus induced by the Dix-Hallpike test is mainly characterized by latency and transience, and fatigability is also considered to be a typical feature of BPPV. However, it is not recommended to repeat the Dix-Hallpike test to prove fatigability, because it will unnecessarily cause the patients to repeat vertigo symptoms, which may cause discomfort and interfere with the immediate bedside treatment of BPPV\(^2,3\).

It is generally believed that the BPPV fatigability is caused by the large otoliths scattered into small pieces in the semicircular canal due to repeated operations. However, previous studies do not support this mechanical explanation of fatigue of BPPV. It is considered that the dispersed particles settling in the semicircular canal will lead to a larger cupula offset than a single particle of the same mass\(^4,5,6\).

Boselli’s model can explain the finite size of particles and their hydrodynamic interactions\(^7\).

In 2014, Boselli quantified fatigability through nystagmus intensity measurement and analyzed fluid-particle dynamics based on the computer model of BPPV. It was believed that fatigability was due to repeated tests, which made the stone located in the lower arm of the posterior semicircular canal far away from the ampulla\(^7\).
It should be pointed out that nystagmus does not always weaken in repeated diagnostic tests, but can also show constant or even enhanced\textsuperscript{7}. Boselli’s explanation of BPPV fatigability is more convincing. In 2019, Imai studied and discussed the immediate effect and fatigability after the Epley maneuver.

After 3 minutes’ rest, the effect of Epley maneuver is worse than that without rest.

It is considered that the direct effect of the Epley maneuver is caused by the BPPV fatigability, not by the established therapeutic effect of the Epley maneuver itself\textsuperscript{8}.

Fatigability can make the nystagmus intensity caused by the same head position change differently, which will interfere with the diagnosis and treatment of BPPV. If the diagnostic test is improved, so that the initial position of the otolith in the semicircular canal is consistent when the diagnostic test is repeated, BPPV fatigability can be eliminated theoretically, and nystagmus will be induced consistently. Therefore, based on the physical simulation model of BPPV, we observed the influence of the Dix-Hallpike test and different angles of head lowering on otolith position, analyzed the mechanism of BPPV fatigability, and explored a reasonable angle of head lowering to eliminate BPPV fatigability.

Results

1. changes of otolith position during the Dix-Hallpike test

When the Dix-Hallpike test was in the supine position, the otolith moved away from the ampulla for a long distance. However, when returned to the sitting position, although the otolith would move towards the ampulla under the action of gravity, it could not reach the initial position but would stay at the position where the lower arm was far away from the ampulla (Fig. 1).

Position change of otolith in Dix-Hallpike test (a) Sit upright and back view. The otolith is located on the short arm side or near the ampulla of the long arm side of the right posterior semicircular canal. (b),(c) lie on back with right ear down and tilt the head 30°back. The otoliths on the long arm side move away from the ampulla. (d) Back to an upright sitting position and side view. The otoliths on the long arm side away from the ampulla move towards the ampulla under the action of gravity and the otoliths on the short arm side are still in situ.

2. The effect of forwarding tilt angle on otolith position.

When the head is tilt 30 degrees forward, the otoliths slide to the lower arm near the ampulla. When the head is tilt 60 degrees forward, the otoliths can enter the ampulla and reach the bottom of the crista ampullaris. The otoliths located in the short arm side of the posterior semicircular canal will break away from the short arm side and enter the utricle when the head is tilt 120 degrees forward.

Effect of bow maneuver on otolith position (a) Sit upright and back view. The otoliths are located on the short-arm and long-arm sides of the posterior semicircular canal. (b) Head forward 30 degrees, medial view, the otolith on the long-arm side slides closer to the ampulla. (c) Head forward 60 degrees, lateral
view, the otolith glided to the bottom of the crista ampullaris. (d) Head forward 120 degrees, the otoliths on the short arm side of the posterior semicircular canal can leave the short arm side and enter the utricle.

**Discussions**

Nystagmus induced by BPPV diagnostic test is an important basis for the diagnosis of BPPV.

The phenomenon that positional nystagmus is generally weaker when the Dix-Hallpike test is repeated and can be observed again when the time has passed is known as BPPV fatigability\(^9\).

Barany first described the fatigue phenomenon of BPPV, as follows: a young women have vertigo nystagmus when lying on the right side, which lasts about 30 seconds; If the head is turned to the right again immediately after the symptoms stop, there is no attack. In order to evoke a new attack in this way, the patient must lie on his back or on his left side for a period of time.

However, if we analyze the case carefully, the case reported by Barany is actually a right-sided posterior semicircular canal BPPV, the reasons are as follows: rotational nystagmus, located in the vertical semicircular canal; right turn over induced rotational nystagmus, located in the right posterior semicircular canal. After vertigo was induced in the right lateral position, the otolith had moved from the ampulla of the right posterior semicircular canal to the posterior arm of the posterior semicircular canal, and at this time, the otolith will no longer move significantly when the patient turns over on the right side, so it will not induce vertigo again. The left lateral position can make the stone from the right posterior semiregular canal posterior arm re-enter the ampulla, and when turning over again, it can induce nystagmus again.

In 1952, Dix and Hallpike described in detail the characteristics of nystagmus induced by BPPV, including latency, rotatory nystagmus, limited duration, change in direction of the induced nystagmus, and fatigability\(^1\).

Although fatigability is considered to be an important feature of BPPV, it is not recommended to repeat Dix Hallpike action to demonstrate fatigability because it unnecessarily subjects patients to repeated symptoms of vertigo that may be discomforting, and repeat performance may interfere with the immediate bedside treatment of BPPV\(^2\).

More importantly, because of BPPV fatigability, nystagmus induced by repeated diagnostic tests may not be consistent, which will affect the diagnosis and curative effect judgment\(^8\).

Previous studies have analyzed nystagmus to locate otoliths through deep learning, but the BPPV fatigability will have a great impact on the effect of deep learning\(^10\).

The intuitive explanation of BPPV fatigability is that repeated operation makes large otoliths become small otoliths, but this is not consistent with the results of BPPV related hydrodynamics research\(^4,5,6\).
Roselli’s study showed that the lower arm of the posterior semicircular canal is straight, and repeated diagnostic tests can keep the otolith away from the ampulla, thus reducing nystagmus when the diagnostic test is conducted again.

Theoretically, if the starting position of otolith motion is consistent, the nystagmus induced by repeated diagnostic tests should be consistent. This enlightens us that if the Dix Hallpike test is improved to keep the starting position of otolith motion consistent, fatigability can be eliminated.

Based on the BPPV physical simulation platform, the influence of the Dix Hallpike test on otolith position was analyzed. The results showed that consistent with Roselli’s study, the otoliths near the ampulla would be far away from the ampulla after the Dix Hallpike test so that when the Dix Hallpike test was repeated, the distance of otolith sliding would be shortened, and nystagmus would be weakened or even disappeared.

When the head is tilted forward, the otolith in the lower arm of the posterior semicircular canal slides toward the ampulla.

The movement of the otolith was analyzed when the head was tilted forward at different angles.

The results showed that when the head was tilted forward 30 degrees, the otolith slid to the entrance of the ampulla, which was enough to ensure that the starting position of the otolith was consistent when the Dix Hallpike test was repeated; when the head was tilted forward more than 60 degrees, the otolith slid to the bottom of the crista ampullaris, which would lead to long latency, because the sliding of the otolith in the ampulla does not cause an obvious hydrodynamic effect during the Dix Hallpike test.

When the head is tilted 120 °forward, the short arm side of the posterior semicircular canal is in a high position, and the otolith inside the posterior semicircular canal will break away from the short arm side and enter the utricle.

In conclusion, in order to make the nystagmus induced by the Dix Hallpike test more characteristic, the head is tilted forward at least 60°to make the otolith enter the ampulla to the bottom of the crista ampullaris.

When the Dix Hallpike test is performed at this time, the starting position of the movement of the otoliths on the long arm side of the posterior semicircular canal is the same, so the sliding path from the ampulla is also the same. The nystagmus induced by the otoliths will have the following obvious characteristics, including long latency, up beating rotatory nystagmus, limited duration, change in direction of the induced nystagmus when sitting up and the otoliths slide backward to the ampulla. In the repeated Dix Hallpike test, nystagmus showed no fatigability.
Therefore, repeated Dix Hallpike test can induce stable and consistent nystagmus, which will be an important basis for the diagnosis of BPPV.

Because the starting position of otolith movement is consistent, the strength of nystagmus is mainly related to the nature of otolith, including the size of otolith and the number of particles, which also has certain clinical significance.

Whether the otolith can be repositioned by tilting the head forward 120 ° can distinguish the long arm side type BPPV and the short arm side type BPPV\textsuperscript{11}. The temporal characteristics of short arm BPPV latency should also be an important identification index, which needs further research and analysis based on video nystagmus records.

The clinical study showed that the modified Dix Hallpike test(tilting the head forward 60°) had the same sensitivity and specificity as the classic Dix Hallpike test. At the same time, we noticed that no fatigue phenomenon was observed when the Dix Hallpike test (the first step of the Epley maneuver) was repeated\textsuperscript{12}.

In the future, we need to collect nystagmus video for further analysis and analyze fatigability by nystagmus parameters\textsuperscript{9}. Through the improved Dix Hallpike test, the BPPV fatigability can be eliminated and the latency time can be prolonged, which is conducive to the diagnosis of BPPV and the location of otolith according to the characteristics of nystagmus, and also conducive to the realization of nystagmus analysis and BPPV diagnosis based on artificial intelligence.

**Methods**

Establish BPPV physical simulation model

Based on the membrane labyrinth model in the standard space coordinate system, the BPPV physical simulation model is established by using a bullet open-source physical engine, and the model rotation is controlled by using Python language\textsuperscript{11,13}.

1. The influence of the Dix-Hallpike test on otolith position
2. In the beginning, the otolith was set close to the ampulla. The changes in otolith position after the Dix-Hallpike test were observed.
3. The effect of forwarding tilt angle on otolith position.

The lower arm of the posterior semicircular canal is straight, and the otolith may be scattered, especially the repeated Dix-Hallpike test will make the otoliths far away from the ampulla. The improved diagnostic test is to make the otolith in the lower arm of the posterior semicircular canal slide close to the ampulla or reach the bottom of the crista ampullaris so that the starting position of the otolith movement is consistent.
Starting from an upright sitting position, the head is gradually tilted forward, observe the position change of the otolith under the action of gravity with the increase of bow inclination, and record the tilt angle when the otolith reaches the key positions, including the otolith on the long arm side entering the ampulla, reaching the bottom of the crista ampullaris, the otolith leaving the short arm side and entering the utricle.

**Declarations**

**Ethical approval**

This study was conducted in accordance with the Helsinki protocol and standard of Good Clinical Practice, and was approved by the Ethics Committee of the Wenzhou People’s Hospital (No.2018143). The Ethics Committee of the Wenzhou People’s Hospital determined that the study was exempt from an informed consent requirement since it was a review of existing clinical data with patient identifiers removed.

**Data availability**

Data files are available on request to the corresponding author.

**References**

1. Dix, M. & Hallpike, C. The pathology, symptomatology and diagnosis of certain common disorders of the vestibular system. (1952).
2. Bhattacharyya, N., et al. Clinical practice guideline: benign paroxysmal positional vertigo. Otolaryngology–Head and Neck Surgery. 139,47-81 (2008).
3. Furman, J. M. & Cass, S. P. Benign paroxysmal positional vertigo. N. Engl. J. Med. 341,1590-1596 (1999).
4. Rajguru, S. M. & Rabbitt, R. D. Afferent responses during experimentally induced semicircular canalithiasis. Journal of neurophysiology. 97,2355-2363 (2007).
5. Obrist, D. & Hegemann, S. Fluid–particle dynamics in canalithiasis. Journal of the Royal Society Interface. 5,1215-1229 (2008).
6. Boselli, F., Kleiser, L., Bockisch, C., Hegemann, S. & Obrist, D. Quantitative analysis of benign paroxysmal positional vertigo fatigue under canalithiasis conditions. Journal of biomechanics. 47,1853-1860 (2014).
7. Squires, T. M., Weidman, M. S., Hain, T. C. & Stone, H. A. A mathematical model for top-shelf vertigo: the role of sedimenting otoconia in BPPV. J. Biomech. 37,1137-1146 (2004).
8. Imai, T., et al. Effects of Interval Time of the Epley Maneuver on Immediate Reduction of Positional Nystagmus: A Randomized, Controlled, Non-blinded Clinical Trial. Frontiers in neurology. 10,304 (2019).
9. Imai, T., et al. Recovery of positional nystagmus after benign paroxysmal positional vertigo fatigue. Eur. Arch. Otorhinolaryngol. 275, 2967-2973 (2018).

10. Lim, E.-C., et al. Developing a diagnostic decision support system for benign paroxysmal positional vertigo using a deep-learning model. Journal of clinical medicine. 8, 633 (2019).

11. Ping, L., Yi-Fei, Z., Shu-Zhi, W., Yan-Yan, Z. & Xiao-Kai, Y. Diagnosis and treatment of the short-arm type posterior semicircular canal BPPV. Brazilian Journal of Otorhinolaryngology. http://dx.doi.org/10.1080/00016489.2021.1876247 (2020).

12. Yifei, Z., Zhaoliang, W., Huizhen, Z., Huwan, Z. & Xiaokai, Y. Application of modified Dix-Hallpike maneuver in the diagnosis of posterior semicircular canal benign paroxysmal positional vertigo. Journal of clinical otolaryngology, head, and neck surgery. 33, 512-514 (2019).

13. Yan-yan, Z., Shu-zhi, W. & Yang, X.-k. Analysis of Dix-Hallpike maneuver induced nystagmus based on virtual simulation. Acta Oto-Laryngologica. http://dx.doi.org/10.1080/00016489.2021.1876247 (2021).