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MAIN ARTICLE

Efficacy of physical therapy for intractable cupulolithiasis in an experimental model

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Abstract

Objective: To investigate what kinds of stimuli are effective in detaching otoconia from the cupula in three experimental models of cupulolithiasis.

Methods: Three experimental models of cupulolithiasis were prepared using bullfrog labyrinths. Three kinds of stimuli were applied to the experimental models. In experiment one (gravity), the labyrinth preparation was placed so that the cupula-to-crista axis was in the horizontal plane with the canal side in the downward position. In experiment two (sinusoidal oscillation), the labyrinth preparation was placed 3 cm from the rotational centre of a turntable, which was sinusoidally rotated with a rotational cycle of 1 Hz and a rotational angle of 30°. In experiment three (vibration), mechanical vibration was applied to the surface of the bony capsule around the labyrinth using a surgical drill.

Results: In experiments one, two and three, the otoconial mass was respectively detached in 2 out of 10 labyrinth preparations, none of the labyrinth preparations, and all of the labyrinth preparations.

Conclusion: Vibration was the most effective stimulus for detaching the otoconia from the cupula in these experimental models of cupulolithiasis.

Key words: Benign Paroxysmal Positional Vertigo; Pathology; In Vitro; Bullfrog; Otoconia

Introduction

The cupula consists mainly of mucopolysaccharide and is very adhesive in nature. This adhesiveness facilitates easy attachment of the otoconia, resulting in cupulolithiasis. Schuknecht[1] reported cupulolithiasis in which the otoconia attach to the cupula, making it gravity-sensitive. In our experience, cases of intractable cupulolithiasis need careful treatment. Therefore, physical therapy with maximal efficacy should be developed.

This study aimed to investigate what kinds of stimuli are effective in detaching the otoconial mass from the cupula in experimental models of cupulolithiasis.

Materials and methods

The experimental models of cupulolithiasis were prepared using bullfrogs (*Rana catesbeiana*) weighing 110–220 g. After induction of deep anaesthesia with ether, the bullfrogs were decapitated and the bony labyrinth was removed and placed in Ringer solution according to the method of Suzuki *et al.*[2] The caudal otic capsule was chiselled so that the entire posterior semicircular canal was exposed. The remaining membranous labyrinth was left encapsulated in the bony capsule. The membranous labyrinth was carefully cut at the crus commune to create a tiny, 0.5 mm opening. A small piece of otoconia, removed from the sacculus of the other ear, was introduced through this opening into the canal lumen. The position of the labyrinth preparation was adjusted so that the otoconial mass was fixed onto the cupula.

Three different kinds of stimulus were then used in this experimental model of cupulolithiasis, in order to determine the most effective stimulus for detaching the otoconial mass: gravity, sinusoidal oscillation and vibration.

A dissection microscope (SZX12; Olympus, Tokyo, Japan) was used for observation of the otoconial mass.

All experiments were conducted according to the ethical rules for animal experiments at Tokyo Medical University.

Experiment one: gravity

The first experiment tested the effect of gravity, using 10 membranous labyrinth preparations. The labyrinth preparation was placed in a glass dish filled with

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Ringer solution (100 ml) so that the cupula-to-crista axis was in the horizontal plane with the canal side in the downward position. The labyrinth preparation was maintained in this position for 30 minutes. The otoconial mass attached to the cupula was checked every 10 minutes (Figure 1).

Experiment two: sinusoidal oscillation

The second experimental model assessed the effect of sinusoidal oscillation, using 10 membranous labyrinth preparations. The labyrinth preparation was placed in a glass dish filled with Ringer solution (100 ml), which was magnetically fixed to a turntable (FRA-02; First, Tokyo, Japan). The labyrinth preparation was placed 3 cm from the rotational centre. The cupula-to-crista axis was placed along a line pointing towards the rotational centre. The turntable was sinusoidally rotated with a rotational cycle of 1 Hz and a rotational angle of 30°. The sinusoidal rotation was maintained for 30 minutes. The otoconial mass attached to the cupula was checked every 10 minutes (Figure 2).

Experiment three: vibration

The third experimental model tested the effect of vibration, using 14 membranous labyrinth preparations. The labyrinth preparation was placed in a glass dish (100 ml) in the same position as in experiment one. Mechanical vibration was applied to the top surface of the bony otic capsule of the labyrinth preparation using a surgical drill (BL-F5A; Osada Electric, Tokyo, Japan). A cutting burr with a 5 mm tip diameter was used. The frequency of the vibration, as measured by a vibration analyser (VA-12; Rion, Tokyo, Japan), was 340 Hz. The otoconial mass attached to the cupula was checked during the procedure. Care was taken not to rupture the membranous labyrinth (Figure 3).

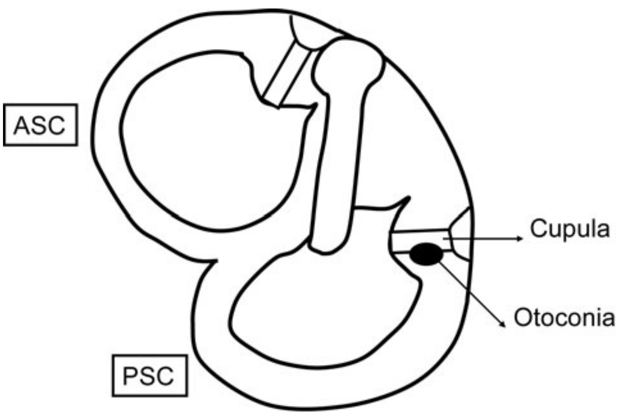

FIG. 1

Diagram representing experiment one (gravity). The labyrinth preparation was placed so that the cupula-to-crista axis was in the horizontal plane with the canal side in the downward position. The otoconial mass was checked every 10 minutes for 30 minutes. ASC = anterior semicircular canal; PSC = posterior semicircular canal.

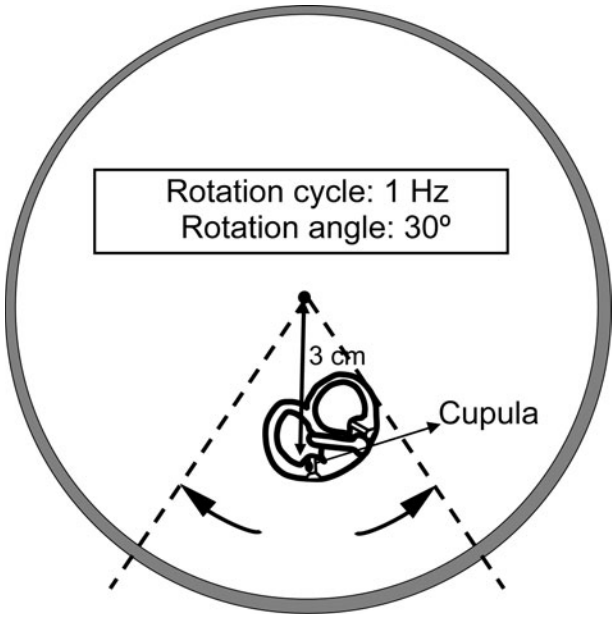

FIG. 2

Diagram representing experiment two (sinusoidal oscillation). The labyrinth preparation was placed 3 cm from the centre of a turntable. The cupula-to-crista axis was placed along a line pointing towards the centre. Oscillation was applied for 30 minutes. The turntable was rotated with a rotational cycle of 1 Hz and a rotational angle of 30°. The otoconial mass was checked every 10 minutes.

Results

Experiment one: gravity

The otoconial mass was detached within 30 minutes in 2 of the 10 labyrinth preparations used in experiment one; in these cases, the detachment times were 10 and 30 minutes.

Experiment two: sinusoidal oscillation

The otoconial mass was not detached from the cupula within 30 minutes in any of the labyrinth preparations in experiment two.

Experiment three: vibration

The otoconial mass was detached from the cupula in all labyrinth preparations in experiment three (Figure 4). The detachment times ranged from 10 seconds to 5 minutes 10 seconds. The mean detachment time was 2 minutes 20 seconds.

Discussion

Benign paroxysmal positional vertigo (BPPV) is mainly caused by movement of detached otoconia within the semicircular canal (canalolithiasis), or by movement of otoconia attached to the cupula (cupulolithiasis). In our group's previous experiments,[3,4] both cupulolithiasis and canalolithiasis effectively stimulated the cupula and were thus potentially valid mechanisms of BPPV. The clinical features of typical BPPV are characterised by brisk, rotatory, dominant nystagmus with a latency of several seconds and a short duration. This feature could be explained more favourably

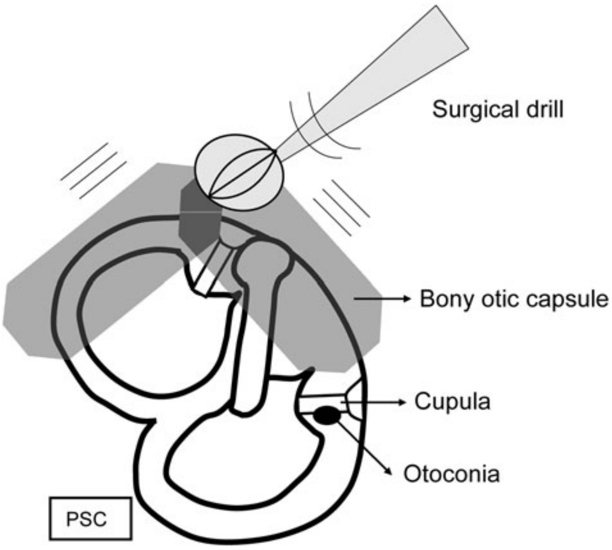

FIG. 3

Diagram representing experiment three (vibration). Mechanical vibration at 340 Hz was applied to the bony capsule near the labyrinth using a surgical drill. The otoconial mass was checked during the procedure.

by the mechanism of canalolithiasis. However, there is another type of positional vertigo with negligible latency and a long duration of more than several minutes. This type of vertigo could be explained by cupulolithiasis. Based on our experience, cases of intractable cupulolithiasis occur and can even require canal plugging surgery.[5] Therefore, the development of physical therapy with maximal efficacy for cupulolithiasis is highly desirable.

Chiou *et al.*[6] have reported the use of a forced prolonged position, wherein patients with cupulolithiasis were required to lie on the side of weaker nystagmus for 12 hours. Symptoms were relieved in all patients after four sessions. However, in our experimental study the otoconial mass was detached in only 2 out of 10 labyrinth preparations following 30 minutes' exposure to gravity. With longer exposure times, it is possible that more otoconia could be detached. The forced prolonged position technique is effective but requires patients to remain in a lying position for a long period, which is uncomfortable for some.

White *et al.*[7] used several types of rolling or brisk deceleration manoeuvres (developed by Lempert and Tiel-Wilck,[8] Gufoni *et al.*,[9] Asprella Libonati *et al.*,[10] and Brandt and Steddin)[11] as well as head-shaking. The Gufoni manoeuvre first places patients in the sitting position, then makes them quickly lie down towards the affected side, and finally makes them rotate their head 45° downward and maintain this position for 2 to 3 minutes.[9] The Vannucchi–Asprella manoeuvre rapidly moves patients from the sitting to the supine position, then turns the head rapidly to the unaffected side, then returns the patient to the sitting position, and finally returns the head to the midline. This manoeuvre is repeated five to eight times.[10] After these manoeuvres, White *et al.*[7] found that the symptoms of all canalolithiasis patients were resolved, but the symptoms of only 50 per cent of cupulolithiasis patients were resolved.

In our experimental study, none of the otoconial masses were detached by sinusoidal oscillation in any of the labyrinth preparations. This result is compatible with the low efficacies noted when the above-mentioned manoeuvres were applied to patients with cupulolithiasis.

Kim *et al.*[12] have reported a new cupulolith repositioning manoeuvre. Beginning with the patient in the supine position, the patient's head is turned 135° toward the affected side. Mastoid oscillation is then applied to the affected side, using a 60-Hz, hand-held vibrator, for 30 seconds. The otoconia at the canal side of the cupula will be detached by this manoeuvre. The patient's head is returned to the supine position. Next, the patient's head is turned 90° towards the unaffected side and mastoid oscillation is repeated once. The otoconia at the utricular side of the cupula will be detached by this manoeuvre. Finally, the patient's head is rotated 90° in the prone position and the patient is slowly brought to a sitting position. Using this manoeuvre, symptoms were resolved in 62 per cent of patients in one session, and in 97 per cent of patients after six sessions.

Our experimental study found that the otoconial mass was detached by mechanical vibration in all labyrinth preparations. This result is compatible with the high efficacy rate of Kim and colleagues' cupulolith repositioning manoeuvre.

- **Cupulolithiasis is intractable because of otoconial adhesion to the cupula**
- **This experimental study tested the effectiveness of various stimuli in resolving cupulolithiasis**
- **The effect of gravity, sinusoidal oscillation and mechanical vibration was tested**
- **Vibration was most effective in detaching an otoconial mass from the cupula**

However, the question remains whether vibration could also dislodge the utricular otoconia. Amir *et al.*[13] reported a case of BPPV which occurred after the use of a whole-body vibration training plate. Similarly, our previous experiments, using bullfrog membranous labyrinth preparations, indicated that otoconia were dislodged from the utricle and moved into the posterior semicircular canal in half of the preparations after 15 minutes of vibration using a surgical drill.[4] It takes longer for vibration to dislodge the otoconia from the utricle than from the cupula. Fine morphological studies show that the utricular otoconia are connected to each other with fine fibrils and are embedded in a gelatinous substance made of mucopolysaccharide.[14,15] The whole otoconial mass is covered by a

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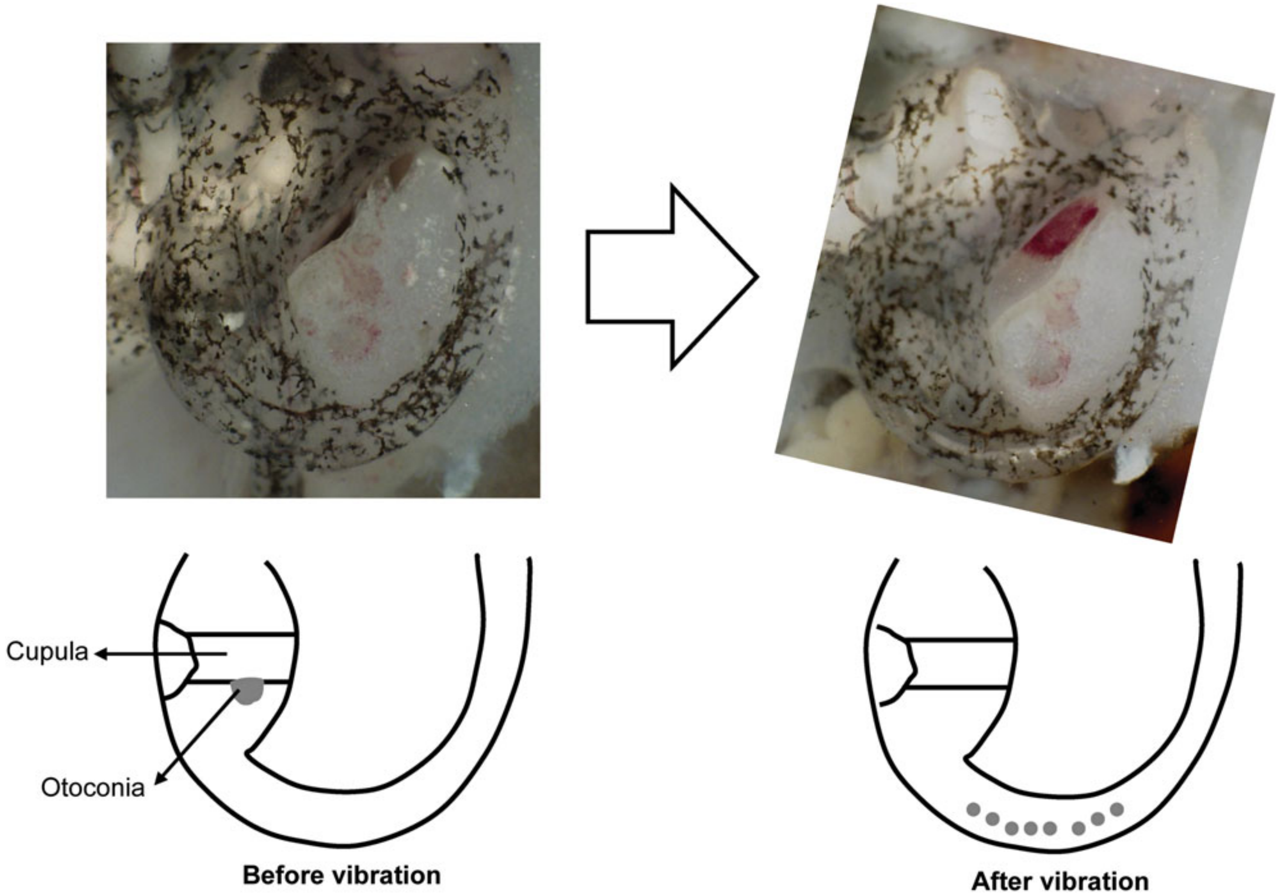

FIG. 4
Magnified photographs and diagrams for experiment three (vibration). Before vibration, the otoconial mass was attached to the cupula. After vibration, the otoconial mass was detached from the cupula and was separated into pieces.

supraotoconial layer.[16] This may be one reason why short-duration vibration can dislodge the otoconia from the cupula without dislodging the utricular otoconia.

Conclusion

In this experimental study of cupulolithiasis in a bull-frog membranous labyrinth model, over 30 minutes, the otoconial mass was detached by gravity in only 2 of 10 labyrinth preparations, and was not detached by sinusoidal oscillation in any preparation. However, the otoconial mass was detached by mechanical vibration in all labyrinth preparations, over the same time period; the mean detachment time was 2 minutes 20 seconds. Thus, mechanical vibration was the most effective stimulus for detaching the otoconia from the cupula in this experimental model.

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