MECHANISMS of BPPV

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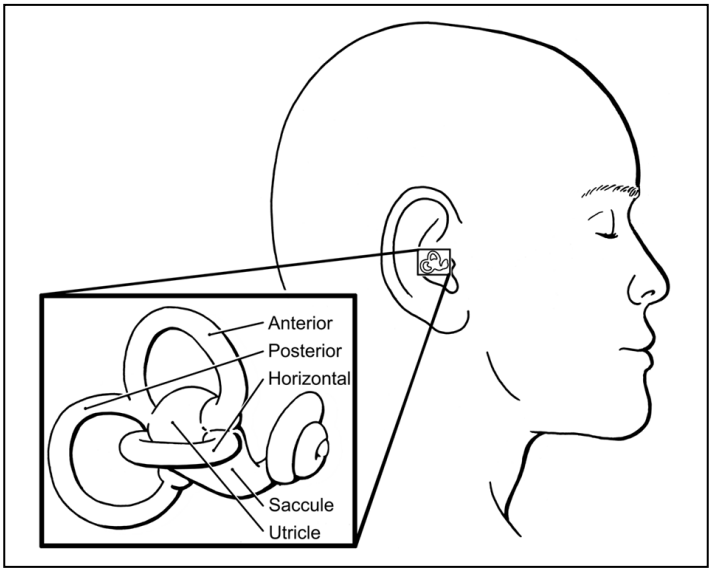
Anatomic Background

The vestibular part of the membranous labyrinth consists of 5 end organs:

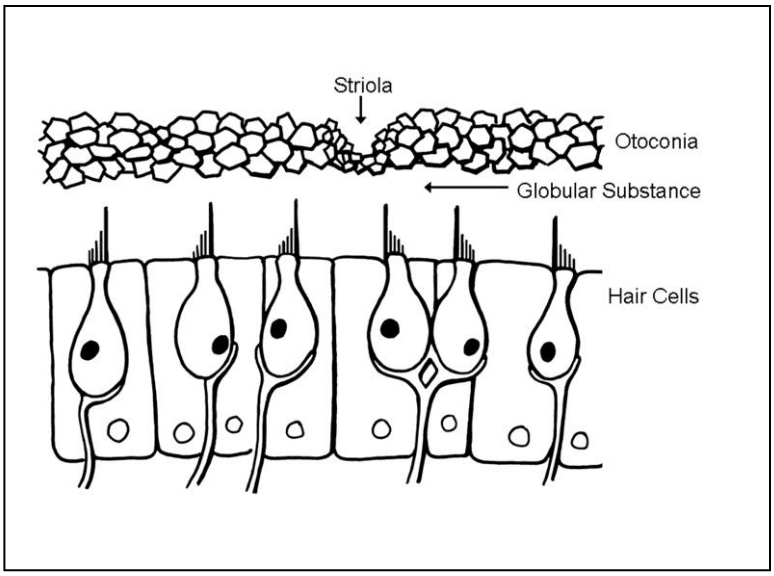
3 semicircular canals:
- Anterior, Posterior, Horizontal
  detect turning (angular) movement of the head.

2 "Otolith" structures:
- Utricle, Saccule
  detect linear acceleration, including gravity.

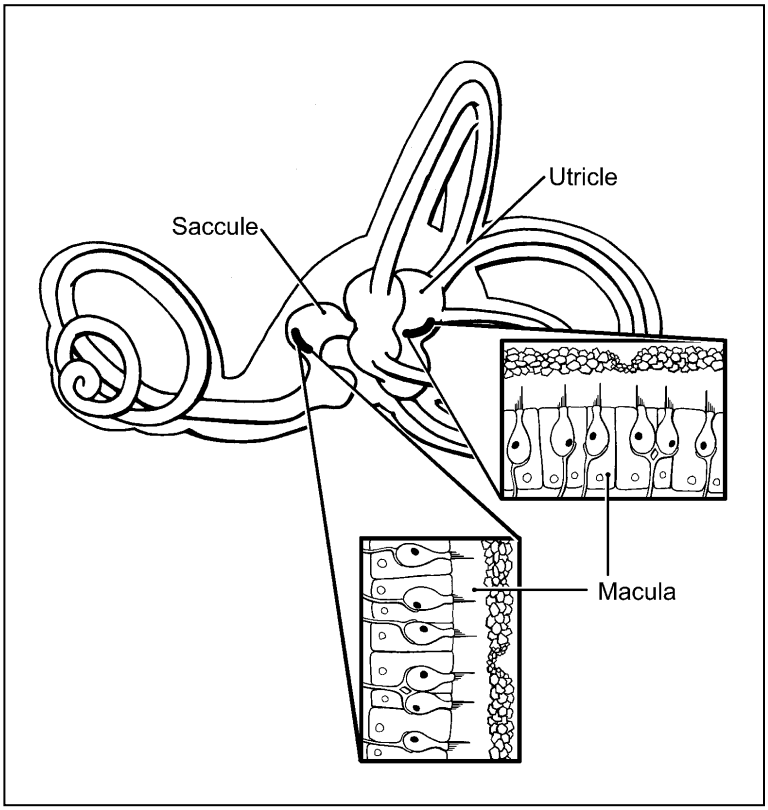


Both the utricle and the saccule contain a sensing structure called the macula. The macula of the utricle is the presumed source of the calcium particles that cause BPPV. The macula consists of calcium carbonate crystals (otoconia) embedded in a gelatinous matrix, into which the stereocilia of hair cells project. Otoconia range in size from 0.5-30 micrometers and are more than twice (density of 2.7 gram/cc) as dense as endolymph, so they move in response to gravity and other accelerative movements.

Otolithic Membrane



Orientation of the Maculae of the Utricle and Saccule



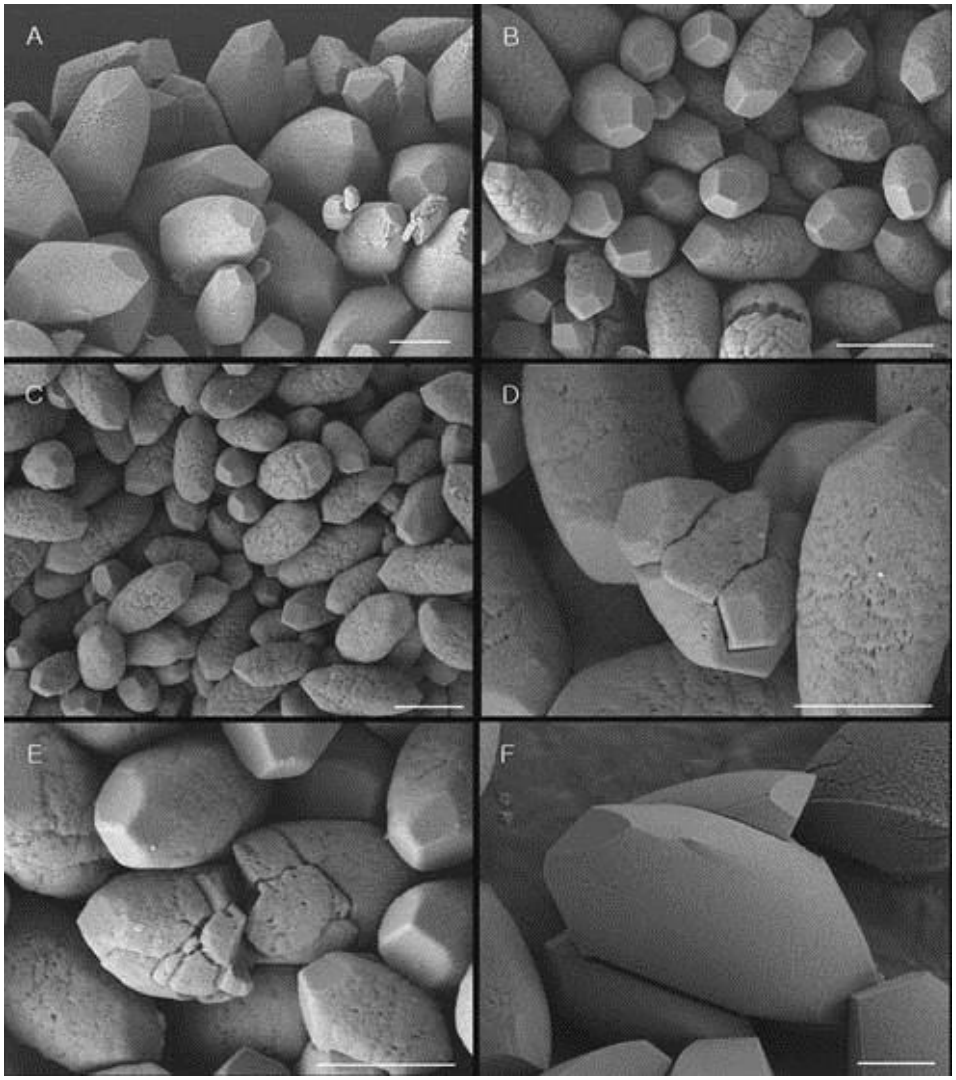
Mechanism of BPPV

Benign paroxysmal positional vertigo is caused when otoliths composed of calcium carbonate that originate from the utricular macula dislodge and move within the lumen of one of the semicircular canals.

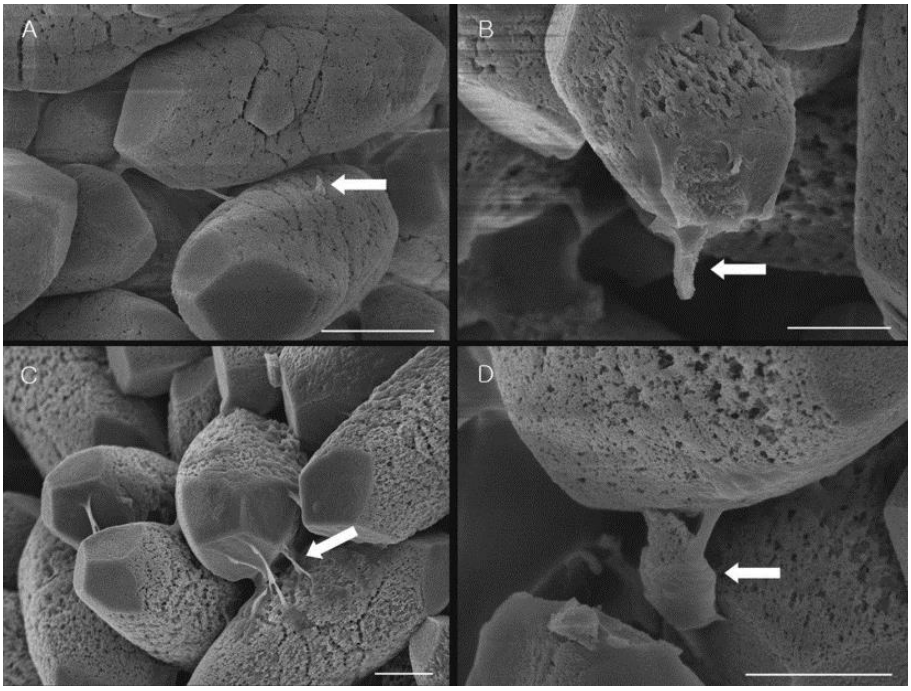
What causes the calcium carbonate material to dislodge?

A: Middle-aged Rat

B-F: Aged rat showing fissured, pitted, broken otoconia.



Field-emission scanning electron microscopy of the utricular otoconia of young, middle-aged, and aged rats (1).



Field-emission scanning electron microscopy of the utricular otoconia of aged rats (1). Bar = 2 μm. Shows weak or broken linking filaments and demineralization of the body of the otoconia.

The reason for this shedding of calcium crystals from the macula is not well understood. The calcium debris may break off following trauma or viral infections, but in many instances it seems to occur without identifiable illness or trauma. It may have to do with age-related changes in the protein and gelatinous matrix of the otolithic membrane. Electron microscopy studies demonstrate evidence of otoconia degeneration with age (2).

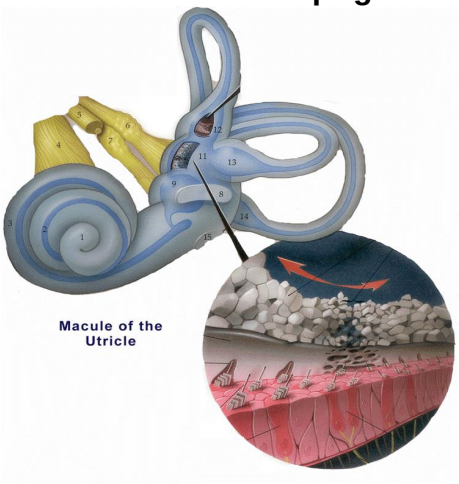
Otoconin 90 is the principal matrix protein in the otoconial membrane of mammals; it may interact with microvesicles of supporting cells to generate formation of calcite crystals (3). Otolithic membrane is composed of a viscoelastic gelatinous material composed of type II collagen, glycoproteins, glycosaminoglycans that maintains the calcium crystal content and holds it to the sensory epithelium. As a result of the aging process, trauma, inflammation and perhaps other causes, calcite crystals may break free of the otolithic membrane and sink in the endolymphatic fluid. This might explain why viral inner ear infections and trauma are associated with BPPV.

Patients with BPPV have been found to have more osteopenia and osteoporosis than matched controls, and those with recurrent BPPV tended to have the lowest bone density scores (4). This observation suggests that the spontaneous release of otoconia may parallel bone demineralization in general. However, recent investigation of an association between BPPV and osteoporosis using biomarkers did not show a strong correlation which may suggest treatment of osteoporosis would not be expected to improve BPPV management (5). Possible relationships with vitamin D deficiency and seasonality have been proposed as well (10,11).

How do the loose calcium carbonate particles cause the clinical features of BPPV?

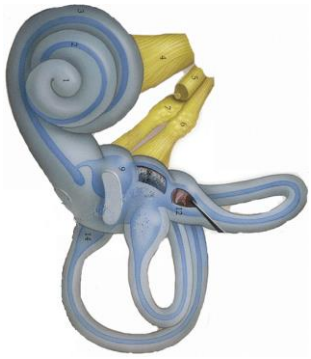
When the calcium carbonate crystals move within the semicircular canal (canalithiasis) they cause endolymph movement that stimulates the ampulla of the affected canal, thereby causing vertigo. The velocity of endolymph increases with addition of otoliths in the canal, which results in nystagmus that begins after a brief latency following head movement.

Upright



Labyrinth in the upright position

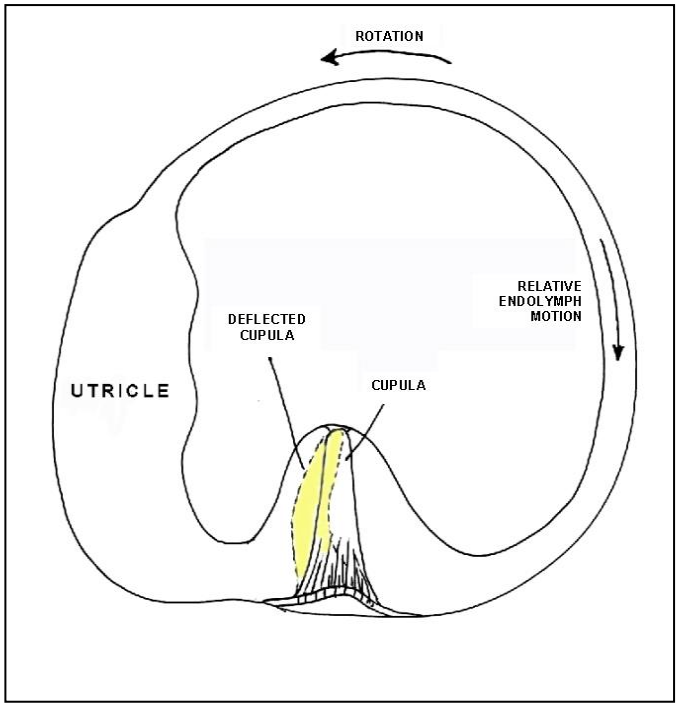
Supine



Labyrinth in the head hanging position

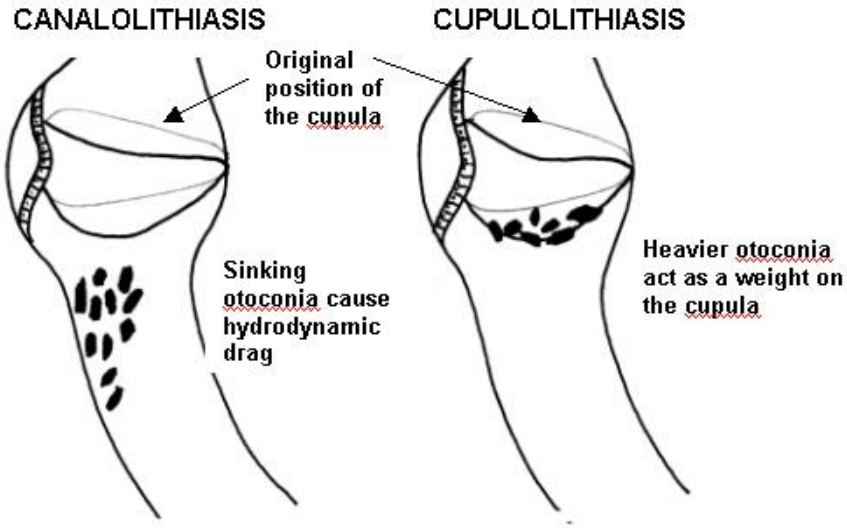
Using a mathematical model assuming calcium carbonate material to be spheres of 7-20 μm, the characteristics of nystagmus and timing were consistent with what is seen in humans. The magnitude of nystagmus in response to Dix Hallpike positioning was mainly due to the total weight of particles. Meanwhile, the latency related to the time it takes for particles to move through the semicircular canal (6,7).

The **cupula** is the motion sensor for the semicircular canal and is located in the ampulla. It is composed of specialized hair cells that have a kinocilium and stereocilia that are imbedded in and covered by a gelatinous material.



The direction of the nystagmus is determined by canal ampullary nerve excitation in the affected canal has its by direct connections to the extraocular muscles. Each canal affected by canalithiasis has its own characteristic nystagmus.

Calcium carbonate material may at times become attached to the cupula itself making it gravity sensitive (**cupulolithiasis**) though most cases are due to freely moving calcium carbonate crystals (**canalolithiasis**)



Canal Variants
Benign paroxysmal positional vertigo may affect the posterior, horizontal, or anterior semicircular canal (8). In some cases it may even involve more than one canal at a time (9). Due to its gravity-dependent position, the most commonly affected semicircular canal is the posterior canal.

Clinical History
- Usually abrupt spinning spells
- Brief duration (10-30 seconds) of spinning
- Often brought on by looking up, rolling in bed or bending then straightening
- Patients may be able to identify the side affected (get it only turning to one side)
- Brief spells of vertigo upon getting out of bed or that awaken the patient suggest BPPV

Examination usually confirms the diagnosis.
- Dix Hallpike maneuver induces nystagmus
- Roll maneuver induces the nystagmus of the lateral canal variant of BPPV
- Observation of characteristic nystagmus
- Nystagmus often fatigues. That is, it lessens each time the maneuver is repeated.
- Responsiveness to particle repositioning maneuvers.

References:

1. Jang YS, Hwang CH, Shin JY, et al. Age-related changes on the morphology of the otoconia. Laryngoscope 2006;116:996-1001.
2. Walther LE, Wenzel A, Buder J, Bloching M, Kniep R, Blodow A. Detection of human utricular otoconia degeneration in vital specimen and implications for benign paroxysmal positional vertigo. Eur Arch Otorhinolaryngol 2013;10.1007/s00405-013-2784-6.
3. Thalmann R, Ignatova E, Kachar B, Ornitz DM, Thalmann I. Development and maintenance of otoconia: biochemical considerations. Ann New York Acad Sci 2001;942:162-78.
4. Jeong SH, Choi SH, Kim JY, Koo JW, Kim HJ, Kim JS. Osteopenia and osteoporosis in idiopathic benign positional vertigo. Neurology 2009;72(12):1069–1076.
5. Sacks D, Parham K. Preliminary report on the investigation of the association between BPPV and osteoporosis using biomarkers. Otology and Neurotology 2015;36:1532-1536.
6. Whitman GT. Seasonality of benign paroxysmal positional vertigo. JAMA Otolaryngol Head Neck Surg 2015;14(2):188-189.
7. Jeong SH, Kim JS, Shin JW, et al. Decreased serum vitamin D in idiopathic benign paroxysmal positional vertigo. J Neurol. 2013;260(3):832-838
8. Squires TM, Weidman MS, Hain TC, Stone HA. A mathematical model for top-shelf vertigo: The role of sedimenting otoconia in BPPV. J Biomech 2004;37(8):1137-46.
9. Rajguru SM, Ifediba MA, Rabbitt RD. Three-dimentional biomechanical model of benign paroxysmal positional vertigo. Ann Biomed Engineer 2004;32(6):831-46.
10. Fife TD. Benign paroxysmal positional vertigo. Semin Neurol 2009;29:500–508..
11. Lopez-Escamez JA, Molina MI, Gamiz M, et al. Multiple positional nystagmus suggests multiple canal involvement in benign paroxysmal vertigo. Acta Otolaryngol 2005;125:954-61.