UCSF University of California San Francisco

Vestibular Physiology Crash Course

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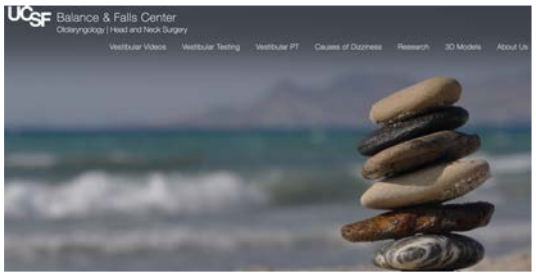
Disclosures

- "Borrowed" some slides/teaching concepts from wonderful teachers I've had over the years
- No other directly relevant disclosures for this talk
- Research support from Advanced Bionics and Eli Lilly

Crash Course: (45 min)

- Plug for website
- Historical Story
- Vestibular Physiology
- Clinical correlation with eye movement videos
- Repeat website plug
- Questions (15 min)

www.ohns.ucsf.edu/balance-falls



Professional produced videos, thanks to a grant from the Mount Zion Health Fund

Vestibular Videos

Benign Paroxysmal Positional Vertigo (BPPV)	Meniere's Disease	Videonystagmography (VNG)
Bilateral Vestibular Loss (BVL)	Vestibular System	Rotary Chair
Vestibular Neuritis (VN)	Vestibular Physical Therapy	Vestibular Evoked Myogenic Potentials (VEMP)
Superior Canal Dehiscence Syndrome (SCDS)	Vestibular Migrane	Video Head Impluse Test (vHIT)

First, some interesting history!

- **Walter E Dandy (1886-1946)**
- NSGY Pioneer
- In 1941 published "The Surgical Treatment of Meniere's Disease" in the *Annals of Surgery, Gynecology, and Obstetrics*.

Dandy's treatment of Meniere's disease

- "*Meniere's disease can be permanently cured by division of the auditory nerve. This procedure carries almost no risk to life. Up to the present time I have performed 401 operations, with 1 death, the 358th case- due to meningitis*"
- "*Total division of the auditory nerve destroys the remaining hearing in that ear, but that is usually of little practical significance*."

Johns Hopkins, circa 1900

The operation

- "*Section of the auditory nerve can be done almost painlessly under local anesthesia*"
- *"A small hook is passed around the 8th nerve, which is elevated, thus exposing the concealed 7th nerve. The handle of the hook is then touched with electrocautery and the nerve is instantly severed*"

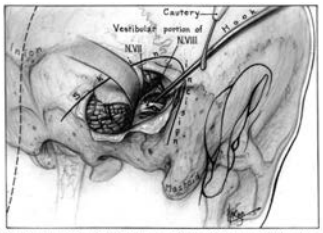


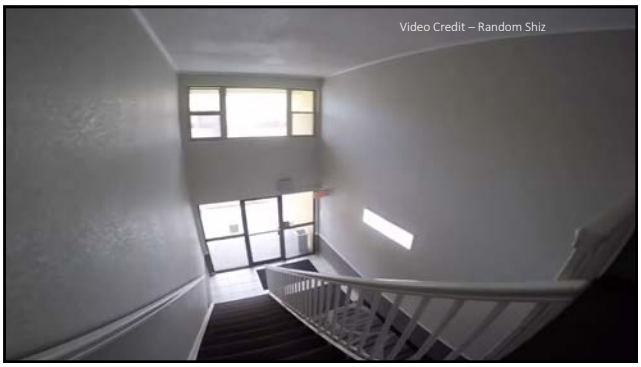
FIG. 5. Intraoperative drawing of vestibular nerve surgery in which Hager Padget uses exquisite detail to reproduce the operative field while leaving peripheral arenas more muted. This illustration appears on p. 196 (Fig. 80) in Dandy WE: **Surgery of the Brain, Lewis' Practice of Surgery; Vol 12.** Hagerstown: W. F. Prior, 1945. The original artwork is housed in the Brödel Archives, Johns Hopkins Department of Art as Applied to Medicine.

Observations on function

- *"If one auditory nerve- or only its vestibular division- is divided there is no permanent loss of vestibular function of any kind"*
- *"Division of both vestibular nerves is attended by one rather surprising after-effect, i.e.* ***jumbling of objects (visual) when the patient is in motion****; as soon as the patient is at rest the objects are again perfectly clear.* ***The other disturbance is uncertainty when the patient is walking in the dark****…These two disturbances indicate the very intimate association between the vestibular and the visual apparatus in human beings. "*

Vestibular physiology

- Why do we have a vestibular system?



Labyrinthectomized cats cannot do this (no video available)
Magnus- 1922- " Wie sich die fallende Katze in der Luft umdreht."

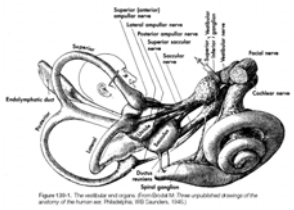
Vestibular System

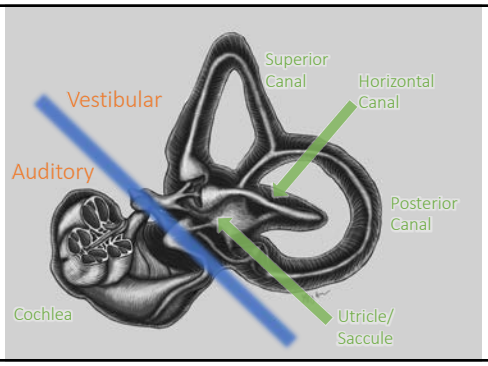
- Image stabilization
  - Important during head and/or body movements
- Postural control/balance
- Higher order
  - Spatial orientation/reasoning
  - Autonomic control

Anatomy of vestibular endorgans

3 semicircular canals at right angles to each other
- sense angular velocity

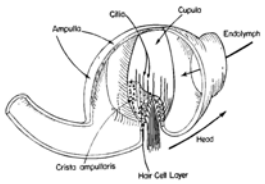
2 otolith organs (utricle & saccule)
- sense translational and gravitational acceleration, and tilt





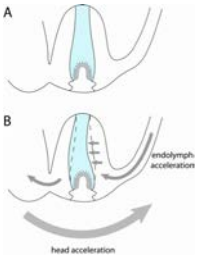
Semicircular canal stimulation

- **Ampulla**
  - swelling where canal joins the vestibule
  - contains the SCC's sensory neuroepithelium
- **Crista**
  - saddle-shaped structure covered by hair cells
- **Cupula**
  - Blocks endolymph flow
  - Deflection of the cupula deflects the stereocilia, indicating rotation of the head.
- **Hair cells**
  - Mechano-neural transducers
  - Similar to cochlear hair cells, but different
- **Stereocilia**
  - project into an overlying gelatinous *cupula*



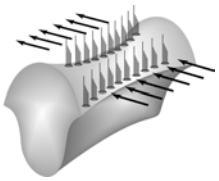
Semicircular canal stimulation

- When head accelerates about the axis of a canal, inertia causes the endolymph in the canal to lag behind the head.
- Relative to the cupula, endolymph effectively moves in direction opposite the head.
- Cupula deflects due to pressure differential across it.
- Stretches/deflects hair cell stereocilia.



Semicircular canal stimulation

- All hair cells on a semicircular canal crista are oriented (*polarized*) in the same direction.
- Their stereocilia bundles all have the kinocilium at the same end.
- Endolymph motion that excites any one hair cell will be excitatory for all hair cells on that crista



Important Caveats

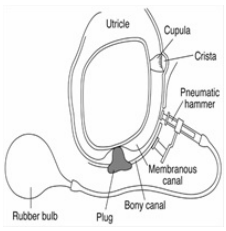
- None of the vestibular reflexes acts entirely alone
- When a labyrinth fails, the CNS adapts to reduce the ill effects, and it shifts to rely on other sensory systems, prediction, and motor efference.
  - Smooth pursuit, optokinetic nystagmus, and cervico-ocular reflex can replace vestibular reflexes at low frequencies and velocities.
  - Anticipatory saccades can help stabilize gaze
- This can mask effects of a labyrinthine lesion.
- If your goal is to examine the labyrinth using VOR responses, you must use stimuli for which the VOR dominates gaze stabilization.
  - Use high-acceleration head rotations to test the VOR

Nystagmus

- The brainstem will interpret any change in firing rate from vestibular afferents as indicating head rotation, tilt, or translation that would normally produce that same change in firing rate.
- Through the vestibulo-ocular reflex, a pathologic asymmetry in input from coplanar canals causes the eyes to turn in an attempt to compensate for the "perceived" head rotation.
- The eyes cannot continue to rotate in the same direction that the canals command for very long. Instead, rapid, re-setting movements occur, taking the eyes back toward their neutral positions in the orbits.
- The result is **nystagmus**, a rhythmic, slowly forward-quickly backward movement of the eyes.

Laws of Ewald

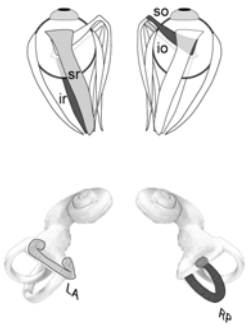
- Stimulation of a canal produces an eye movement in the plane of the canal
- In the horizontal canal, ampullopetal flow causes greater stimulation than ampullofugal flow
- In the vertical canals, the reverse is true



Vertical canals and VOR

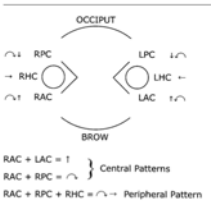
•Note the coplanar arrangement of canals and linked eye muscles.

•This minimizes brainstem processing for the VOR.



Patterns of Nystagmus (from Zee)

- Need both anterior or posterior canals for pure vertical nystagmus.
- Need both vertical canals on one side for pure rotary nystagmus.
- Therefore, both are CENTRAL patterns, where higher level problems occur after information is integrated



Canal Planes

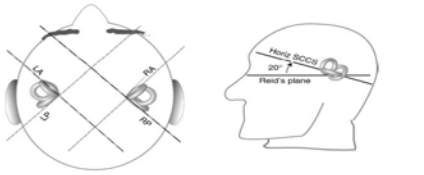


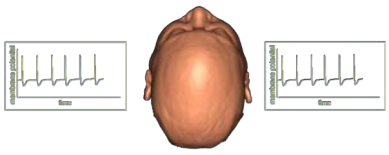
Figure 4-7. Orientation of the semicircular canals. A, The horizontal canal is tilted ~20° upward at its anterior end versus Reid horizontal plane (defined by inferior orbital rims and ear canal centers). B, The vertical canals are oriented in planes ~45° from the midsagittal plane and perpendicular to the horizontal canal plane. The **RA** and **LP** are nearly parallel to each other and an RALP plane. The **LA** and **RP** canals define an LARP plane. LA, left anterior canal; LARP, left anterior, right posterior; LP, left posterior canal; RA,

Implications of the reflexive nature of the vestibular system

- Because labyrinthine input is usually reliable, abnormal input from the labyrinths causes inappropriate reflex responses (nystagmus) and illusion of movement (vertigo).
- Reflexive eye movements and postural changes are the cardinal signs you can use to diagnose the site of the problem.
- To interpret those signs, think of how the brainstem would respond to an illusion of head rotation or tilt (when the head is actually starting still and upright).
- Knowing the effective stimuli for each vestibular endorgan allows you to infer which endorgan(s) must be abnormally excited or inhibited.

Vestibular Physiology

- The nerves of the vestibular endorgans have a baseline firing rate.
- When the head is still, the firing rates on the two sides are equal.

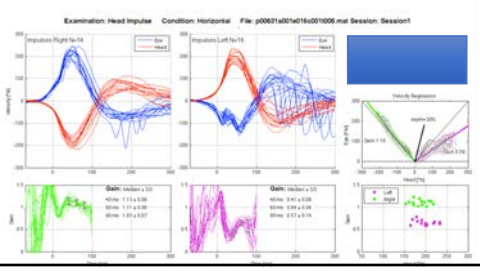


Vestibular physiology

- When the head turns, the firing rate of the horizontal semicircular canal nerve goes up on one side and down on the other.

Head impulse test

Understand and use the head thrust test.



Feel your VOR!

- Close your eyes
- Put your hands over your eyes
- Spin back and forth in your chair

Clinical Correlations

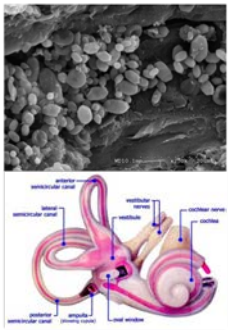
Sleeper slides

Dix-Hallpike Position

- Turn patient's head 45 deg to affected side.
- Place supine with neck extended.
- Particles fall away from the ampulla, which excites the PC.
- Observe PC nystagmus.

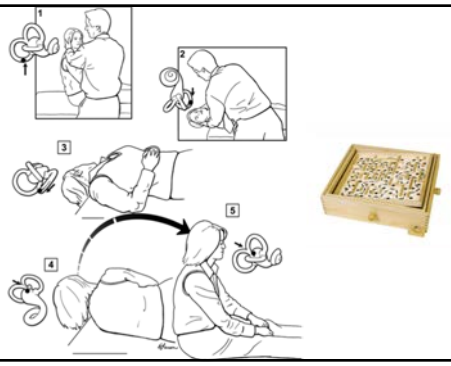
BPPV

- Rick Chole SEM study of material removed from the posterior canal by Lorne Parnes during surgery for BPPV
- PMID: 27726156
- **Found that structurally, the material in the posterior canal was identical otoconia**



Epley!

- Highly effective
- How many diseases can be cured by a five minute maneuver???
- Far outperforms sham maneuvers



Unilateral Loss of Vestibular Function

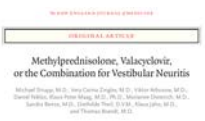
- Acutely, will cause horizontal rotary nystagmus beating towards the healthy ear
  - Superior division of vestibular nerve appears to be more commonly involved
- Needs to be distinguished from posterior fossa stroke
  - HINTS (PMID: 24127701)
    - Head Impulse (should be lost with peripheral lesion)
    - Nystagmus (Direction changing = central)
    - Skew (Refixation with alternate cover test = central lesion)
- It should be treated:
  - Steroids (PMID: 15269315)
  - PT (PMID: 9748036)
- Avoid vestibular suppressant medications (antihistamines, benzos)
- Optimize vision

Vestibular Neuritis

- Selective inflammation of one of the vestibular nerves in vestibular neuritis
- If hearing also affected, labyrinthitis
- Thought to be viral in origin – either new infection or reactivation

Vestibular Neuritis

- Prospective, randomized, double-blind trial of 141 subjects with acute vestibular neuritis.
- Treatments: placebo, methylprednisolone, valacyclovir, or methylprednisolone plus valacyclovir.
- Outcome measure: unilateral caloric weakness
- Analysis of variance showed a significant effect of methylprednisolone (P<0.001) but not of valacyclovir (P=0.43) for recovery of caloric response.


ORIGINAL ARTICLE

Methylprednisolone, Valacyclovir, or the Combination for Vestibular Neuritis

N Engl J Med 2004;351:354-61.

Causes of Dizziness

- Superior Canal Dehiscence

What is SCDS?

ORIGINAL ARTICLE

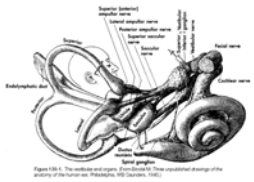
Sound- and/or Pressure-Induced Vertigo Due to Bone Dehiscence of the Superior Semicircular Canal

Lloyd B. Minor, MD; David Solomon, MD, PhD; James S. Zinreich, MD; David S. Zee, MD

- First described by Minor et al. in 1998.
- Cause was described as "**disruption of the bony labyrinth with concomitant development of a third mobile window**"

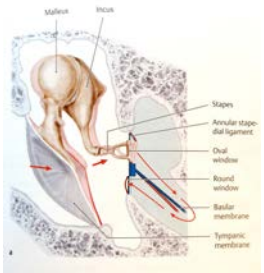
Anatomy of the inner ear

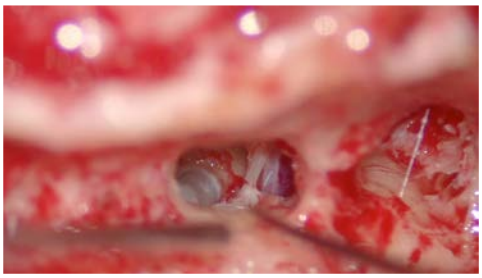
- Fluid filled space
- Enclosed by bone
- All connected!
- So how does sound know to go to the cochlea?



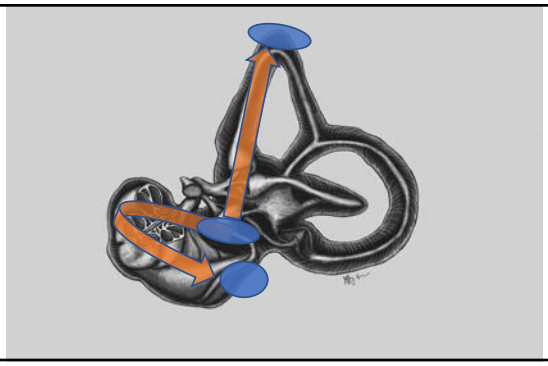
The first two windows

- Bone and fluid are relatively incompressible
- Pressure waves, delivered by stapes displacement, cause displacement of the RW





- Vestibular end organs- despite proximity, are not in the path of least resistance, and therefore don't experience pressure waves, which are shunted between the oval and round windows



Symptoms of SCDS

- **Vestibular**
  - Tullio's (sound induced vertigo)
  - Hennebert's (pressure induced vertigo)
  - Pulsatile Oscillopsia
- **Auditory**
  - Autophony
  - Pulsatile Tinnitus
  - Hyperacusis to bodily sounds (eyes moving, neck creaking)
  - Ear fullness/pressure
- **Other**
  - Headache
  - Brain Fog
  - Generalized dizziness

Causes of Dizziness

- Unilateral Vestibular Hypofunction