NERVOUS SYSTEM BLOCK

17th Lecture

Physiology of inner ear

Physiology Team– 430

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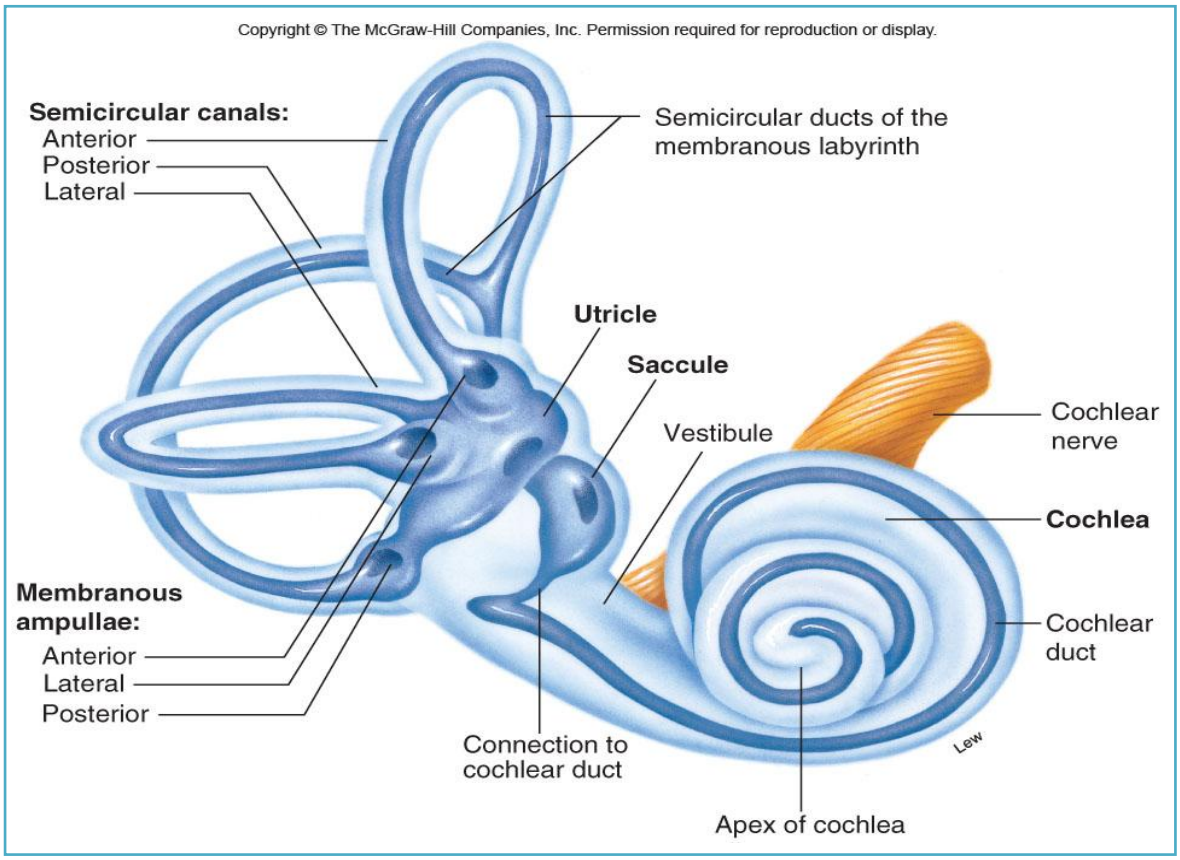
- **Anatomy of inner ear :**



The inner ear consists mainly of two divisions :

A. **Outer bony labyrinth**
B. **Inner Membranous labyrinth**

– The **bony labyrinth** is a series of cavities in the petrous portion of the temporal bone, it is divided into three area :

1- **Semicircular canals**:

There are 3 semicircular canals , named based on their position , anterior , posterior and lateral . At the end of each semicircular canal there is a swollen enlargement called the **ampulla** . Semicircular canals Contain receptors for **equiblirium – non auditory**

2- **The vestibule** :

An oval central portion of the bony labyrinth and contains receptors for **equiblirium – non auditory**

3- The cochlea :

It is a bony spiral canal that resembles a snail's shell and makes almost three turns around a central bony hub. It contains receptors for **hearing – auditory**.

A section of the cochlea shows that it is divided into three channels :

a) Cochlear duct
(which is a continuation of the Membranous labyrinth - consists of **endolymph**)

b) Scala tympani
(which is the channel below the bony partition , it ends at the round windon – contains **perilyphm** because it's a part of the bony labyrinth)

c) Scala vestibule
(which is the channel above the bony partition , it ends in the oval window – contains **perilymph** because it's a part of the bony labyrinth)

– The **bony labyrinth** contains **perilymph** (fluid similar to the cerebrospinal fluid) , surrounds the membranous labyrinth which is a series of sacs and tubes inside the bony labyrinth and the same general shape .
The **membranous labyrinth** contains **endolymph** .

Fluids in the ear:-
1-perilymph : between bony & membranous labyrinth
2-endolymph : inside membranous labyrinth.

– The bony labyrinth encloses the membranous labyrinth for protection.

– **Membranous labyrinth :**

1- Membranous labyrinth **in the vestibule** consists of two sacs :

a) **Utricle**
b) **Saccule**
They have sense organs called **Macula** (otolith organ)

2- Membranous labyrinth in the **semicircular canals** is called **semicircular ducts** and at the end of each semicircular ducts there are swollen enlargements called ampulla.

3- Membranous labyrinth in **the cochlea** is called **Cochlear duct** .

➢ **The utricle , saccule and semicircular ducts are called the vestibular apparatus**.

- **Control of Equilibrium**

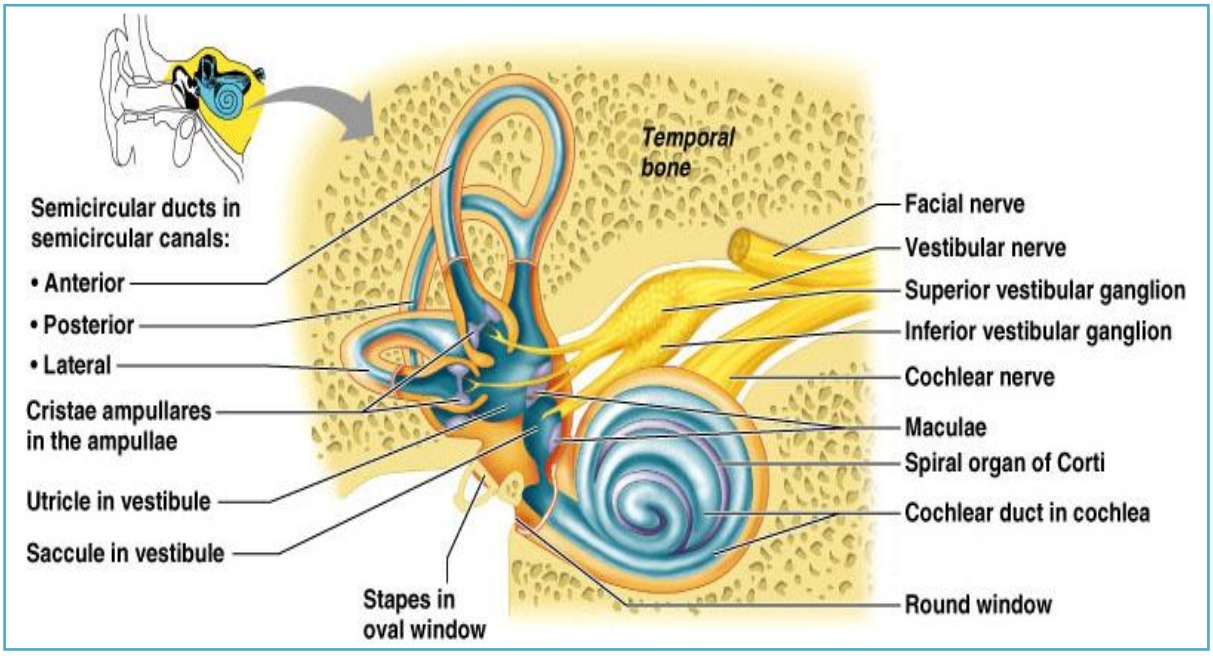
Accurate control requires accurate information

The Sensory inputs:

1) <u>Vestibular system</u>
2) Visual system
3) Proprioceptive system
4) Cutaneous sensations

- **Components of the Vestibular system**

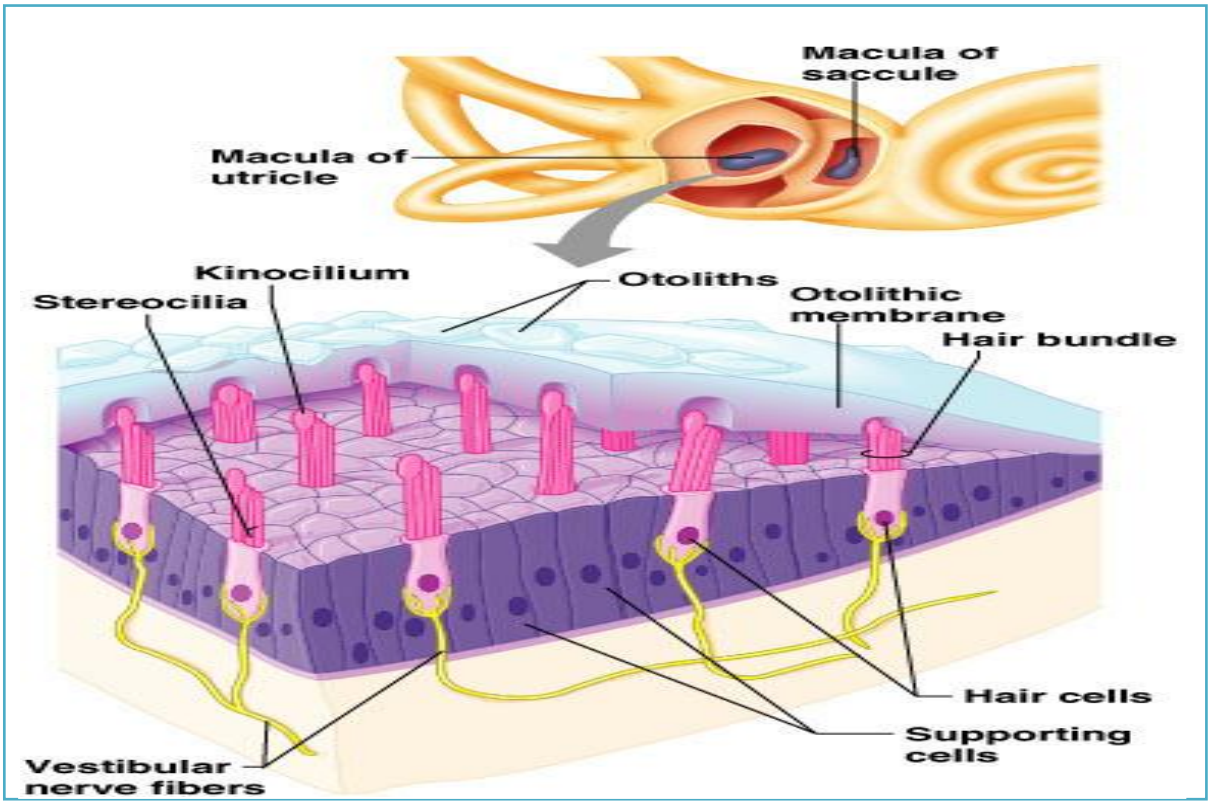
A. Utricle and Saccule
B. Semicircular canals



- **Utricle and Saccule**

– Located on the floor of the utricle and on the wall of the Saccule of each membranous labyrinth are small organs called **Maculae** or **Otolithic organs**.
– Each macula is formed of a ridge of columnar epithelial cells and thousands hair cells (receptors) and is covered by a gelatinous layer.
– Embedded in the gelatinous layer are numerous small calcium carbonate crystals (**otoliths**).

– because of their weight and because they sit on the top of the macula , otolith membrane and the otoliths are pulled by gravity and slide downhill over the hair cells in the direction of the tilt , bending the hairs in the direction of the pull of gravity.



. **Macula** consists of two types of cells :

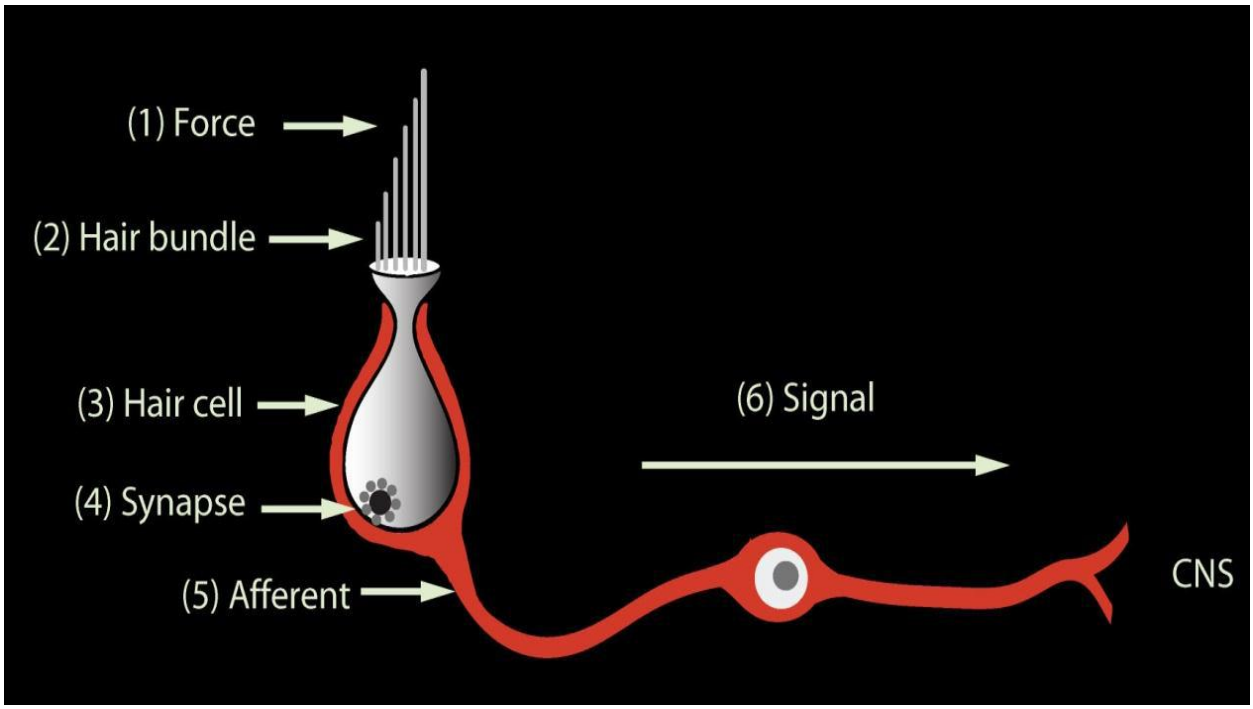
hair cells and supporting cells . Hair cells feature hair bundles that consist of 40-8- microvilli . Scattered among the hair cells are columnar supporting cells that's probably secrete the thick gelatinous layer which is called **otolithic membarane** , that rests on the hair cells. A layer of calcium carbonate crystals called **otoliths** extend over the entire surface of the otolithic membrane.

- **Hair cells**

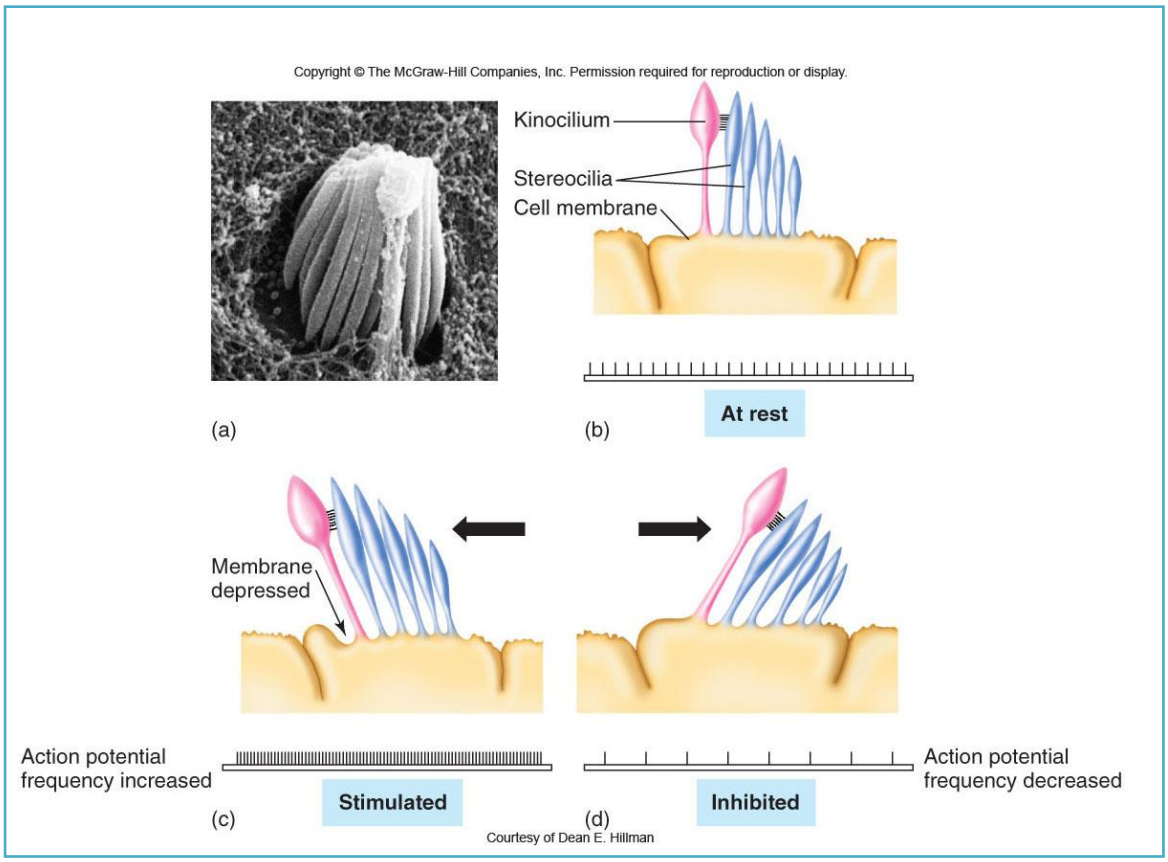
– A single hair cells has on average about 30-150 small hairs called **stereocilia** + one very large cilium called the **kinocilium.**
Note : **Kinocilium not found in the organs of corti because it's sensitive to the direction of movement only.**

– The stereocilia become **progressively shorter** in the axis away from the kinocilium (arranged from shortest to tallest towards the kinocilium)
Note **: A very fine filamentous attachment called *tip links* connect the kinocilium to the nearest longest stereocilium, this to the next shorter stereocilium and so on up to the other end of the cell.**

– Hair cell synapse with endings of the **vestibular nerve.**
– Each cilium membrane has channels for positive potassium ions.
– Stereocilia has otolithes (statoconia) of calcium carbonate susbended in gelatinous material.



- **Mechanism of hair cells**



A. Resting condition:
<u>constant</u> rate of firing of action potentials (basal resting tonic discharge)

Note : **Under resting conditions when the head is upright and vertical, the macula generates action potentials at a constant rate in the afferent fibers..**

B. Stereocilia bent towards kinocilium → **opening** of Potassium channels → Depolarization & Ca entry & neurotransmitter release → ↑discharge rate
(increase rate of impulses to the vestibulocochlear nerve)

C. Stereocilia bent away from kinocilium → **closing** of potassium channels → Hyperpolarization → ↓ discharge rate
(decrease rate of impulses to the vestibulocochlear nerve)

– hair cells are oriented in different direction → tilt of the head in any direction is signaled

<u>Note</u> :**Depolarization is created with each movement of the head, because of the big field that contains hair cells in different direction.**

In the hair cell when the stereocilia bend in the direction of the kinocilium, tip links pull the stereocilia one after the other away from the body of the hair cell. This open ion channels and the cell is depolarized. However, when the stereocilia are bent to the opposite direction the pulling effect of the tip links on the stereocilia is reduced. This closes the ions channels.

- In the Upright position with the head vertical

✓ ***The macula of the Utricle***

Lies in the horizontal plane, the hairs pointing upward. This position allows cells to signal tilting of the head **forward** and other cells signal tilting of the head **backward**.

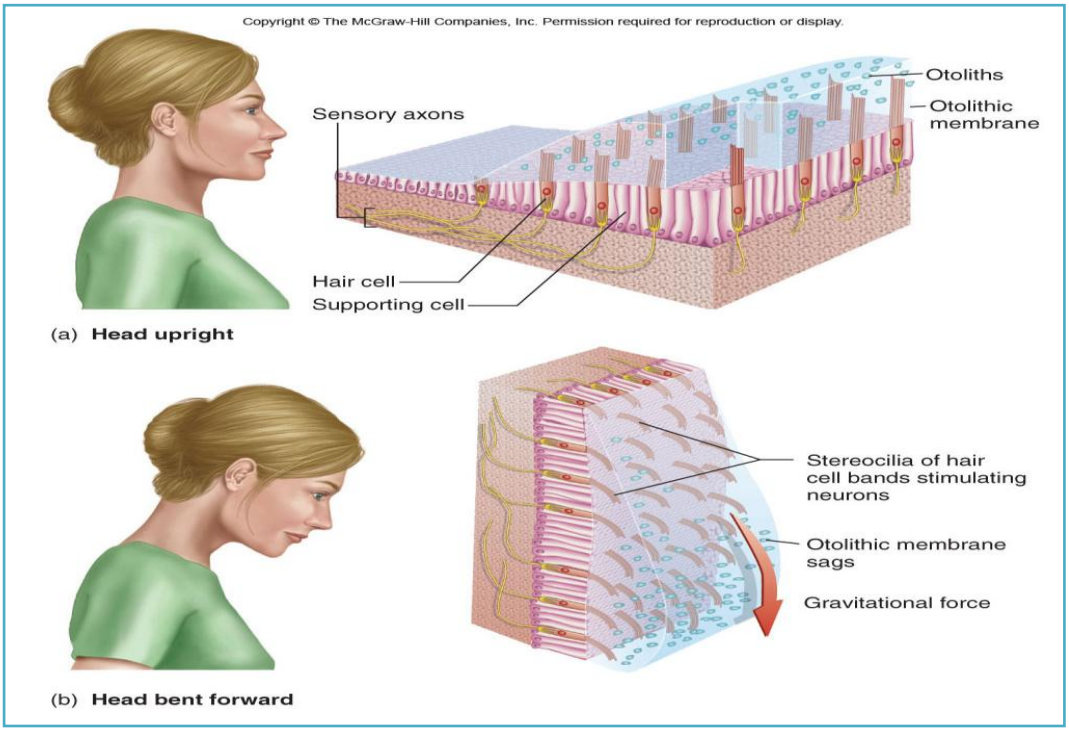
✓ ***The macula of the Saccule***

Lies in vertical plane, the hairs pointing laterally. This allow them to operate only when the head is not on the vertical position**. e.g. When one is lying down**

- The Characteristics of Transducer hair cells:

1. Directional sensitivity
2. **Slow adaptation** (important)
3. Highly sensitive to mechanical stimulation

- **Function of the utricle and saccule**



The macula in the utricle (**and to a lesser extent in the saccule**) **plays two important functions:**

1. **<u>Detection of a static tilt (orientation of head in space & maintenance of static equilibrium):-.</u>**

- In the upright vertical position, impulses from the **right and the left utricles balance each other.** However, if **the body tilts to one side** the utricles on the two sides of the head signal a different pattern, informing the brain about the new position of the head in space.

Statoconia crystals of hair cells fall to that side by their weight → pull steriocilia to move towards kinociliun → depolarization (stimulation) .
Steriocilia of the other side moves away from kinocilium → hyper-polarization (inhibition).
So Tilting to right , stimulate right utricle & inhibit left utricle → sense of imbalance, sensation of tilting to the stimulated side (RIGHT).

- In addition to **giving the sensation of imbalance**, the signals go to the brainstem and the vestibular and cerebellar motor system, which stimulate the appropriate muscles to restore equilibrium.

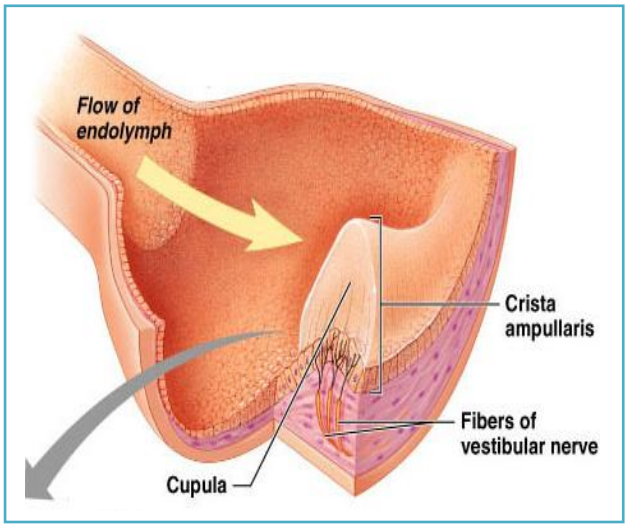
2. **Detection of linear acceleration:**

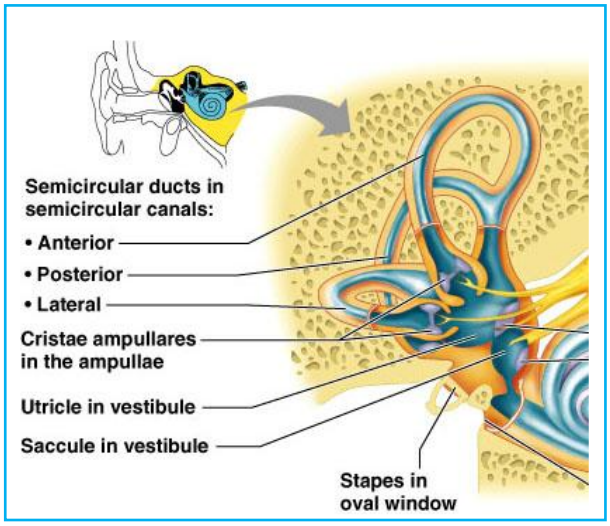
Otoliths are also displaced when the body accelerates forward. E.g. As when a person is running or is standing in a bus which suddenly accelerates causes the otoliths to fall backward on the hair cell's processes. This creates a **sense of malequilibrium.** (the person feels he/she is falling backward), which is correcting by leaning forward so that the otoliths shift anteriorly.

- at beginning of movement statoconia lag behind movement by its inertia → fall backwards → cilia moves backward → person feels he is falling backwards → trys to correct this by leaning forwards to shift statoconia & cillia anteriorly.
- At deceleration (runner try to stop) → statoconia move forwards by its momentum →person feels falling anteriorly → try to correct this by leaning backwards to shift statoconia & cillia posteriorly.

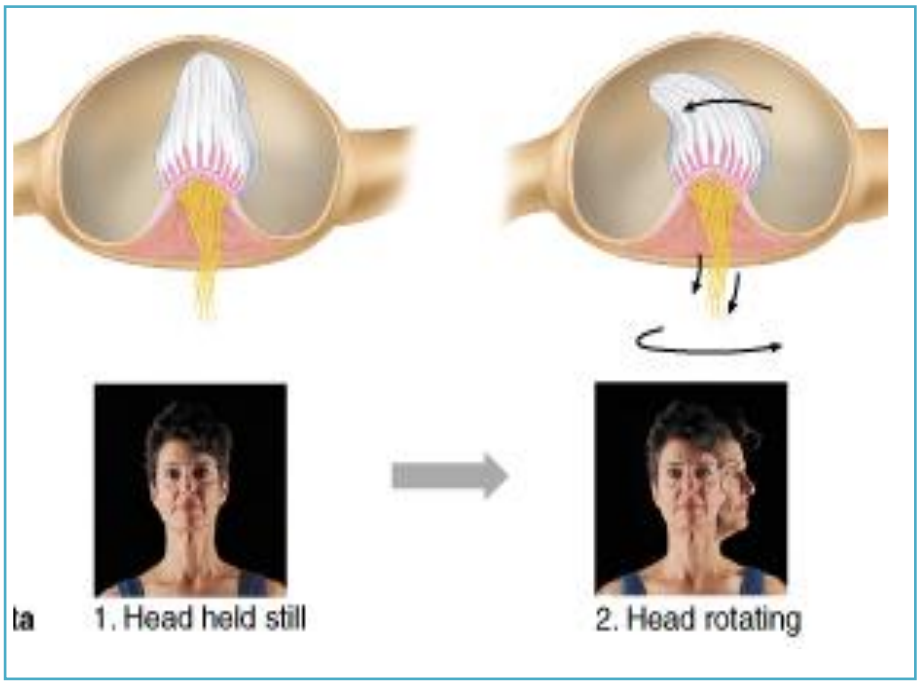
- **Saccular** maculae detect vertical accelerates
- Both **utricle and saccule** horizontal acceleration

- **Semicircular canals**





- There are three semicircular canals on each side, known as external (horizontal), Anterior and posterior (both are vertical).
- They are perpendicular to each other, filled with endolymph**.**
- Each canal open at both ends into the utricle; one of these ends is dilated to form the **Ampulla**, which houses the receptor organ called the **crista ampullaris.**
- The crista is a ridge of hair cells and supporting cells surrounded by gelatinous mass which is called the Capula . The Capula, which extend across the ampulla, Sealing it. Embedded within the capula are the *stereocilia* and *kinocilia*
- The crista is different from macula in that all hair cells in each crista are **orientated in the same direction**.



Rotation of the head → bending of Capula → bending hair cells → Receptor cells fire impulses → Synapse activation → Stimulation of nerve ending → dynamic equilibrium sense.

– Plane of rotation determines which canal will be stimulated:
A. Rotation of head in vertical axis > Horizontal
B. Lateral movement of head (approximate head to shoulder) > posterior
C. Anterolateral or posterolateral head movement > Superior

- **Function of Semicircular canals CCN**

The cristae of the semicircular canals detect head rotation in any direction. This movement called **Angular acceleration.**

1) Under resting conditions, the cristae on both sides of the head transmit a continuous series of impulses as basal tonic discharge , averaging about 200/s.
2) Detect & maintain posture during head rotation in any direction(angular acceleration)= rotation- they are stimulated at beginning& at end& by changing direction or rate of rotation(not stimulated by maintained constant rotation as earth rotation)

- Rotation of canal **from left to right** > Endolymph moves in **opposite direction right to left** > cupula (and hair cells) bent by endolymph > increase discharge from right canal and decrease discharge from left canal

When the head suddenly begins to rotate in any direction, suppose from left to right in the horizontal plane, the horizontal semicircular canal moves in the same plane. The cupula is bent by the endolymph and so are the projecting hairs. Since the kinocilia in the cristae of the horizontal canals are located on the side of the hair cells towards the utricle, the frequency of impulses from the cristae of the right canal is increased, as the stereocilia are bent towards the kinocilium, while that of the left canal is decreased, because of the stereocilia are bent away from the kinocilium. This imbalance discharge from the two sides will give the sensation of rotation to the right.

➢ **Review the steps:**

1. Stimulated by: **angular (rotational) acceleration**
2. Movement of endolymph in SCC
3. Bending of hairs:
– towards ampulla on one side
– Away from ampulla on the other side
4. Unbalanced discharge from two sides (Sensation of rotation in CNS)
5. As rotation continues endolymph will soon rotate in the same direction (& speed) as the SCC
6. Cupula being elastic returns to resting position
7. Discharge from both sides returns to resting level
(**no sensation of rotation so long eyes are closed**)

➢ **Semicircular canals detect only:**

- The beginning of rotation
- The End of rotation
- Changes in rate of rotation

- **Predictive function of SCC**

Predict ahead of time that mal-equilibrium is going to occur → Send impulses to CNS for corrective measures **before** the start of the fall .

- **Effects of stimulation of S.C.C**:

Stimulation by rotation or caloric test May cause :

1- Vertigo: this false sensation of counter-rotation at end of rotation (or angular acceleration)
2- Nystagmus: jerky eye movements at the beginning & end of rotation to fix objects in the eye field.
3- bradycardia& hypotension.
4- increased **muscle tone** on same side of rotation to support the body & decreased muscle tone on the opposite side

Caloric test is (stimulation of SCC by water hotter or colder than body temp in external auditory canal which will cause convection currents in endolymph → motion of cupula)

- **Nervous connections of vestibular apparatus:-**

Nerve fibers from maculae & cristae ampularis → Vestibular nerve → epsilateral vestibular nucleus to :-

1- cerebellum: floculonodular lobe & fastigeal nucleus → thalamus of the opposite side → cortex of the opposite side (motor areas, superior temporal gyrus for vertigo).
2- spinal cord (vestibulospinal tracts)
3- Reticular formation
4- Medial longitudinal bundle(for eye movements)(nystagmus)