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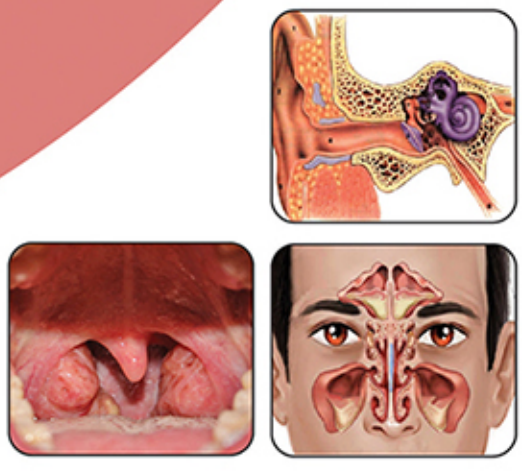

9th Edition

SAKSHI ARORA HANS

JAYPEE

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Chapter 2

Physiology of Ear and Hearing

PHYSIOLOGY OF HEARING

The pinna collects sound signal from the environment. Sound waves pass through external auditory canal (EAC) and vibrates the tympanic membrane (Fig. 2.1) Vibrations of the tympanic membrane are transmitted to the stapes footplate through the chain of ossicles. Vibrations of stapes footplate are transmitted to the oval window → scala vestibuli → helicotrema → scala tympani. This leads to movement of basilar membrane which has organ of Corti. Organ of Corti has hair cells. The hair cells of cochlea act as transducers and convert the mechanical energy into electrical impulses which travel along the auditory nerve.

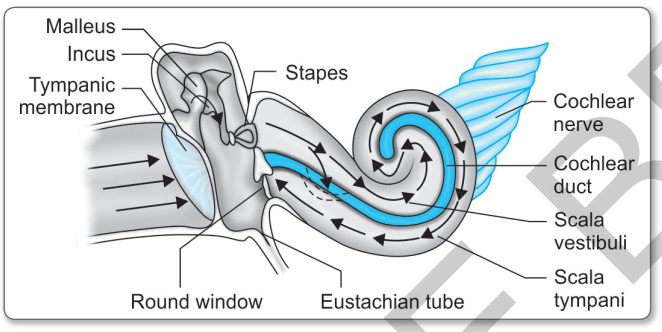

Fig. 2.1: Physiology of hearing. Arrows show sound waves

Source: Essentials of Mohan Bansal, Jaypee Brothers Medical Publishers Pvt. Ltd.

AUDITORY PATHWAY

Inner hair cells → afferent nerves which from cochlear nerve → spinal ganglion (present in Rosenthal canal) → Fibres exit through internal acoustic meatus → Dorsal cochlear nucleus + Ventral cochlear nucleus (Pons) → All fibres of from dorsal and ventral cochlear nucleus synapse to form trapezoid body → Fibres now pass to opposite and same side Superior olivary nucleus → Lateral lemniscus → Inferior colliculus → Medial geniculate body → Auditory cortex (Brodmann area 41)

Mnemonic

ECOLIMA
Mnemonic for auditory pathway

E	–	**E**ighth nerve
C	–	**C**ochlear nuclei
O	–	**S**uperior olivary nucleus
L	–	**L**ateral lemniscus
I	–	**I**nferior colliculus
M	–	**M**edial geniculate body
A	–	**A**uditory cortex.

The auditory fibers travel via the ipsilateral and contralateral routes and have multiple decussation points of which 3 are main.

(a) At the trapezoid body (b) In the commissure between the 2 nuclei of lateral lemniscus (c) In the commissure connecting the two inferior colliculi. Thus, each ear is represented in both cerebral hemispheres.

The area of cortex, concerned with hearing is situated in the transverse temporal gyrus (Brodmann's area 41).

Point to Remember

Higher auditory centres are concerned with sound localisation.

Organ of Corti

It is the sense organ of hearing and is situated on the basilar membrane in scala media.

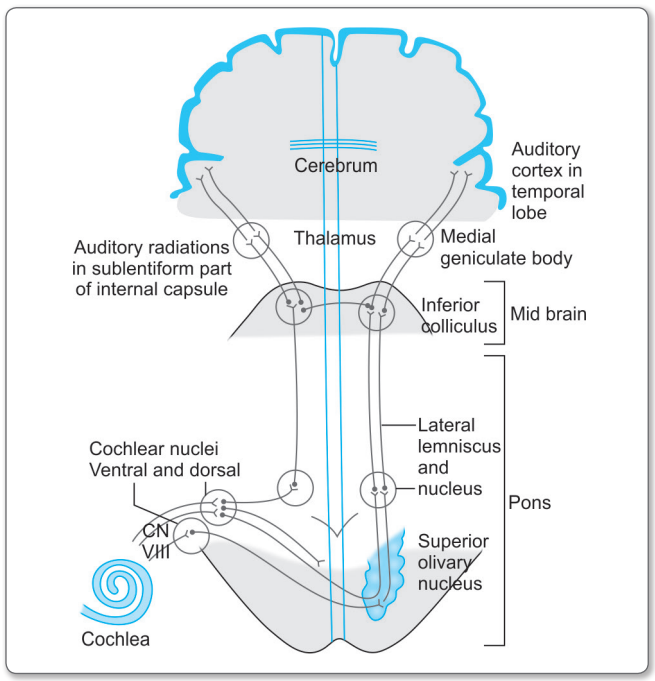

Fig. 2.2: Central auditory pathways

Courtesy: Textbook of Diseases of Ear, Nose and Throat, Mohan Bansal, Jaypee Brothers Medical Publishers Pvt. Ltd., p 21

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Important components of the organ of Corti are:

1. Tunnel of Corti, which is formed by the inner and outer rods. It contains a fluid called *cortilymph*.
2. Cells:

Sensory hair cells		Supporting cells
Inner hair cell	***Outer hair cell***	• **P**illar cells
• Nerve supply primarily afferent	• Nerve supply mainly efferent	• **H**ensen's cells
• Resistant to noise and ototoxicity drugs	• Susceptible to ototoxic drugs and noise	• **D**eiter's cells (PHD).
• Function: To transmit auditory stimulus	• **Function:** To modulate the function of inner hair cells and to generate otoacoustic emission.	

Point to Remember

In cochlea-higher frequencies are represented in the basal turn and progressively lower tones towards the apex of cochlea.

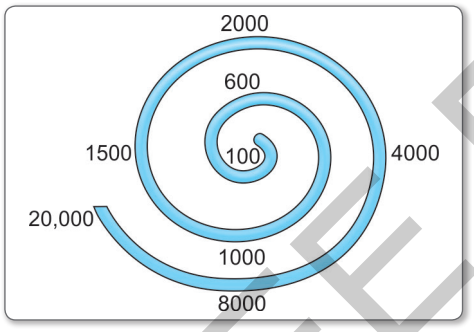

Fig. 2.3: Tonotopic gradient in cochlea. Higher frequency are represented in the basal turn and the progressively lower tones towards the apex of the cochlea

Clinical Correlation

With age, hair cells at base are lost more than at the apex. Significance—so hearing loss is more for higher frequencies than lower with aging. Whereas in Meniere's disease dilatation begins from the apex, hence lower frequencies affected first.

3. **Tectorial Membrane**

It consists of gelatinous matrix with delicate fibers. It overlies the organ of Corti. The shearing force between the hair cells and tectorial membrane produces the stimulus to hair cells.

PHYSIOLOGY OF EQUILIBRIUM

Vestibular System—Peripheral Receptors

They are two types:

- ***Cristae:*** They are located in the ampullated ends of the three semicircular canals.[Q] These receptors respond to **angular[Q] acceleration and deceleration.[Q]**
- ***Maculae:*** They are located in otolith organs (i.e. utricle and saccule).[Q] Macula of the utricle lies in its floor in a horizontal plane. Macula of saccule lies in its medial wall in a vertical plane. They sense position of head in response **to gravity and linear acceleration.[Q]**

Structure of a Crista

It has 2 types of hair cells which project into a gelatinous matrix called as **'cupula'**.

- **Type 1:** Cells are flask-shaped with a single large cup-like nerve terminal, contains bipolar cells.
- **Type 2:** Cell are cylindrical with multiple nerve terminals. From the upper surface of each cell, project a single hair, **the kinocilium** and a number of other cilia.

Structure of Macula

A macula consists mainly of two parts:

a. A sensory neuroepithelium, made up of type I and type II cells, similar to those in the crista.
b. An otolithic membrane, which is made up of a gelatinous mass and on the top, the crystals of calcium carbonate[Q] called ***otoliths* or *otoconia*.**[Q] The linear, gravitational and head tilt movements cause displacement of otolithic membrane and thus stimulate the hair cells which lie in different planes.

Vestibular Nerve

- Vestibular or Scarpa's ganglion is situated in the **lateral part of the internal acoustic meatus.**
- The distal process of bipolar cells innervate the sensory epithelium of the labyrinth while its central process aggregate to form the **vestibular nerve**.
- **The inferior vestibular nerve** supplies the maculae in the saccule.
- A branch of inferior vestibular nerve called as **singular nerve** supplies the hair cells of cristae in the posterior semicircular canal.
- The superior vestibular nerve supplies the hair cells of cristae in the superior and lateral semicircular canal and maculae in the utricle.

Central Vestibular Connections

- The fibers of vestibular nerve end in vestibular nuclei and some go to the cerebellum directly.

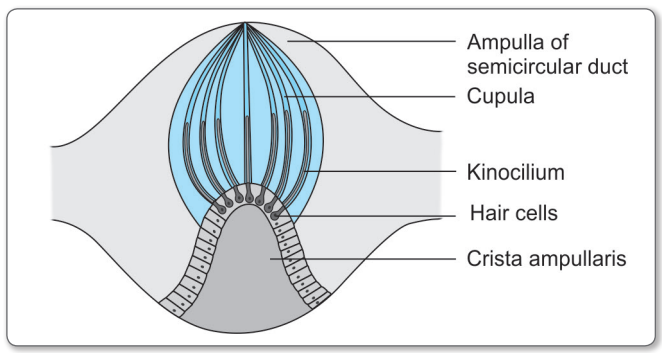

Fig. 2.4: Structure of ampullary end of semicircular duct

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NEW PATTERN QUESTIONS

Q N1. Impedance matching occurs due to:

a. Difference of surface are of tympanic membrane and foot plate
b. Semicircular canal fluid
c. Utricle and saccule
d. None of the above

Q N2. Primary receptor cells of hearing:

a. Supporting cell
b. Tectorial membrane
c. Tunnel of corti
d. Hair cells

Q N3. Otolith organs are concerned with function of:

a. Hearing b. Rotatory nystagmus
c. Linear acceleration d. Angular acceleration

Q N4. Appreciation of sound occurs in:

a. Organ of Corti
b. Basilar membrane
c. Cochlear nuclei
d. Transverse temporal gyrus

Q N5. Trapezoid body is associated with:

a. Auditory pathway
b. Visual pathway
c. Extrapyramidal system
d. Pyramidal system

Q N6. Best discrimination of pitch occurs at _____ frequency:

a. 100-400 Hz
b. 100-1000 Hz
c. 1000-4000 Hz
d. 20-20000 Hz

Q N7. Threshold of hearing in a young normal adult is:

a. 0 dB
b. 10 dB
c. 20 dB
d. 30 dB

Q N8. All of the following are true for organ of Corti *except*:

a. Hensen cell
b. Hensen node
c. Deiters cell
d. Pillar cell

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Explanations and References to New Pattern Questions

N1. Ans. is a i.e. Difference of surface area of tympanic membrane and foot plate *Ref. Dhingra 6/e, p 14*

The area of tympanic membrane is much larger than area of stapes footplate, the average ratio being 21:1. As the effective vibratory area of tympanic membrane is only two thirds, the effectives area ratio is reducted to 14:1 which helps in impedance matching/ transformer action.

N2. Ans. is d i.e. Hair cells *Ref. Dhingra 6/e, p 13*

Hair cells are important receptor cells of hearing and transduce sound energy into electrical energy.

N3. Ans. is c i.e. Linear acceleration *Ref. Dhingra 6/e, p 16*

Otolith organs (present in maculae) are concerned with linear acceleration, gravity and head tilt movements and they also help to maintain static equilibrium.

N4. Ans. is d i.e. Transverse temporal gyrus

Sound localisation and appreciation is a function of higher centres, i.e. auditory cortex located in transverse temporal gyrus (Broadman area 411)

N5. Ans. is a i.e. Auditory pathway *Ref. Dhingra 6/e, p 14, Fig. 2.2*

Trapezoid body is an integral part of auditory pathway.

N6. Ans. is c i.e. 1000-4000 Hz

Human ear can detect sounds ranging in frequency from 20 to 20,000 Hz. Pitch discrimination is best between 1000 to 3000 Hz.

N7. Ans. is a i.e. 0 dB

The hearing threshold is defined as the lowest threshold of acoustic pressure sensation possible to perceive by an organism. It is 0 dB for normal young person.

N8. Ans. is b i.e. Hensen node

See the text for explanation

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QUESTIONS

1. **Hair cell of organ of Corti supported by:** *[PGI Nov 09]*
   a. Onodi cells b. Deiter cell
   c. Hensen cell d. Bullar cell
   e. Heller cell
2. **The centre of stapedial reflex is:** *[AIIMS Nov 2016]*
   a. Superior olivary complex
   b. Medial geniculate body
   c. Superior colliculus
   d. Lateral lemniscus
3. **Stapedial reflex is mediated by:** *[JIPMER 92]*
   a. V and VII nerves b. V and VIII nerves
   c. VII and VI nerves d. VII and VIII nerves
4. **Perilymph contains:**
   a. Na^+ b. K^+
   c. Mg^{++} d. Cl^-
5. **Endolymph in the inner ear:** *[AIIMS May 09]*
   a. Is a filtrate of blood serum
   b. Is secreted by stria vascularis
   c. Is secreted by basilar membrane
   d. Is secreted by hair cells
6. **All of the following are concerned with auditory pathway *except*:** *[AI 95]*
   a. Trapezoid body
   b. Medial geniculate body
   c. Genu of internal capsule
   d. Lateral lemniscus
7. **Higher auditory center determine:** *[AIIMS May 09]*
   a. Sound frequency b. Loudness
   c. Speech discrimination d. Sound localization
8. **Bones of middle ear are responsible for which of the following?** *[MH 03]*
   a. Amplification of sound intensity
   b. Reduction of sound intensity
   c. Protecting the inner ear
   d. Reduction of impedance to sound transmission
9. **Semicircular canals are stimulated by:** *[MP 2000]*
   a. Gravity b. Linear acceleration
   c. Rotation d. Sound
10. **Horizontal semicircular canal responds to:** *[UP 2005]*
    a. Horizontal acceleration
    b. Rotational acceleration
    c. Gravity
    d. Anteroposterior acceleration
11. **Angular movements are sensed by:** *[JIPMER 93]*
    a. Cochlea b. Saccule
    c. Utricle d. Semicircular canals
12. **All are correctly matched *except*:** *[TN 07]*
    a. Otolith—Made up of uric acid crystals
    b. Position of otolith—Changes with head position
    c. Otoliths—Stretch receptors
    d. Otolith organs—Stimulated by gravity and linear acceleration
13. **Singular nerve is a:** *[AP 2007]*
    a. Superior vestibular nerve supplying posterior semicircular canal
    b. Interior vestibular nerve supplying posterior semicircular canal
    c. Superior vestibular nerve supplying anterior semicircular canal
    d. Interior vestibular nerve supplying anterior semicircular canal
14. **Endocochlear potential is:** *[AIIMS Nov 2016]*
    a. +45 mv
    b. -45mv
    c. + 60 mv
    d. +85 mv

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Explanations and References

1. **Ans. is b , and c i.e. Deiter cell and Hensen cell**

Ref. PL Dhingra 5/e, p 16; Logan and Turner 10/e, p 231, 32; Maqbool 11/e, p 18

Supporting cells in organ of corti are PHD i.e. **P**illar cells, **H**ensen cells and **D**ecten cells.

Hellar cells are ethmoidal air cell that extend along the medial roof of the maxillary sinus. They may exist as a discrete cells or the may open into maxillary sinus or infundibulum.[Q] *– Cummings Otolaryngology 4/e, p1162*

"Onodi cells are posterior and lateral extension of posterior ethmoidal cells. These cells can surround the optic nerve tract[Q] ***and put the nerve at risk during surgery"*** *– Cummings Otolaryngology 4/e, p1162*

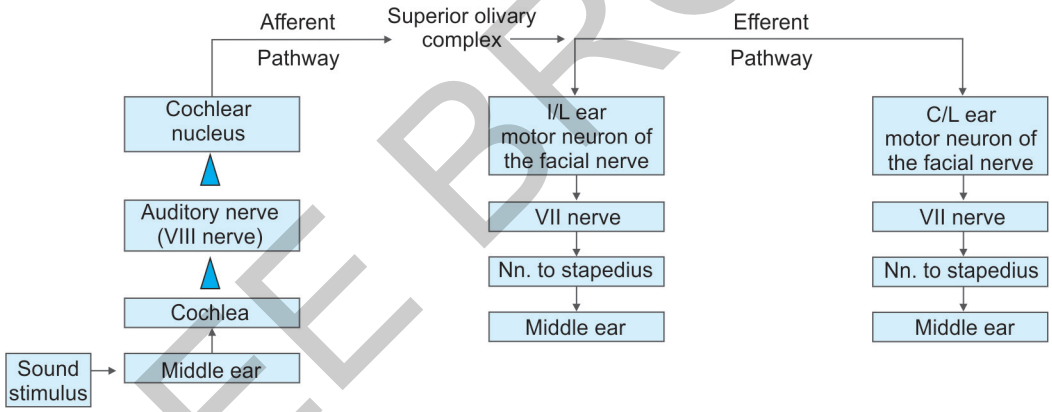
2. **Ans. is a i.e. Superior olivary complex**

3. **Ans. is d i.e. VII and VIII nerves** *Ref. Dhingra 5/e, p 30; 6/e, p 24, 25; Current Otolaryngology 2/e, p 602.*

Acoustic Reflex/Stapedial Reflex

It is based on the fact that a loud sound of 70–100 dB above the threshold of hearing of particular ear, causes bilateral contraction of the stapedial muscle which can be detected by tympanometry. This can be seen both in the stimulating ear (ipsilateral ear) and in the non stimulating ear (contralateral ear).

Note: I/L = Ipsilateral C/L = Contralateral



Also know

Stapedial reflex can be used

- As an objective method to test hearing in infants and young children
- To detect malingers – as stapedial reflex is positive in people faking hearing loss
- To detect

Lesion	Test response
a. Cochlear pathology	Presence of stapedial reflex at lower intensities, i.e. 40–60 dB means recruitment is positive, i.e. cochlear pathology
b. VIII nerve lesion	It eliminates both the contralateral and ipsilateral acoustic reflex when the affected ear is stimulated. But contralateral and ipsilateral reflex are present, if normal side is stimulated
c. VII nerve lesion	Absence of stapedial reflex in presence of normal hearing indicates lesion of VIIth nerve proximal to the nerve of stapedius
d. Brainstem lesion	If ipsilateral reflex is present but contralateral reflex is absent, it indicates lesion in the area of crossed pathway in the brainstem

4. **Ans. is a i.e. Na^+** *Ref. Dhingra 5/e, p12; 6/e, p 10; Current Otolaryngology 2/e, p 583*

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5. Ans. is b. i.e. is secreted by stria vascularis *Ref. Dhingra 5/e, p 12*

There are 2 main fluids in the inner ear.

Perilymph	Endolymph
• Fills the space between the bony and membranous labyrinth, i.e. it is found in scala vestibuli and scala tympani	• Fills the entire membranous labyrinth, i.e. found in scala media
• Resembles extracellular fluid /CSF	• Resembles intracellular fluid
• Rich in Na^+ ions	• Rich in K^+ ions.

6. Ans. is c i.e. Genu of internal capsule *Ref. Guyton Physiology 11/e, p 657, 658; Dhingra 5/e, p 17; 6/e, p 13*

Genu of internal capsule is not a part of auditory pathway. The fibres from medial geniculate body, pass through the posterior limb of internal capsule to reach auditory cortex.

7. Ans. is d i.e. Sound localization *Ref. Scott Brown 7/e, Vol. 3, p 3144; Ganong 23/e, p 213*

Auditory cortex—main function is sound localization[Q]

"Sound localization is markedly disrupted by lesions of the auditory cortex." *– Ganong 23/e, p. 213*

8. Ans. is d i.e. Reduction of impedance to sound transmission

Ref. Scott Brown 7/e, Vol. 3, p 3181; Dhingra 5/e, p 18; 6/e, p 14-16

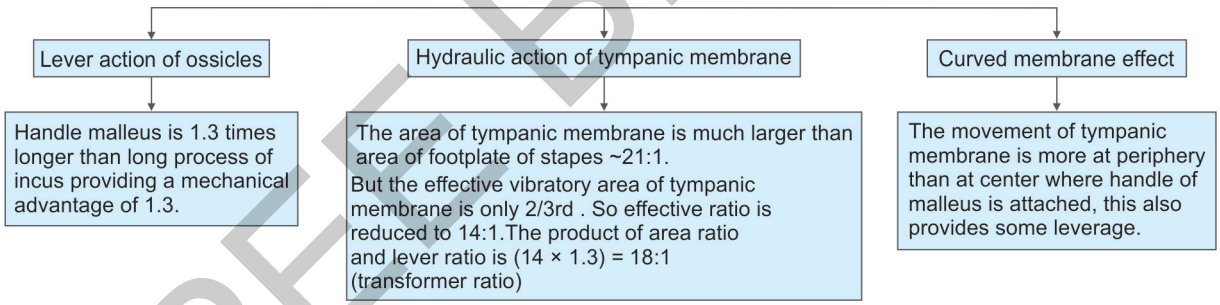
Broadly hearing mechanism can be divided into:
- Mechanical conduction of sound (done by middle ear).
- Transduction of mechanical energy into electrical impulses (done by sensory system of cochlea)
- Conduction of electrical impulse to brain (i.e. auditory pathway)

Detailed Information

i. Conduction of sound:

It is done mainly by middle ear and discussed earlier. Middle ear not just simply conducts the sound but converts sound of great amplitude and less force to that of less amplitude and greater force. This function of the middle ear is called as **impedance matching mechanism or the transformer action**.

- This function of middle ear is accomplished by



ii. Transduction of mechanical energy to electrical impulse:

Movements of the stapes footplate causes vibrations in scala vestibuli followed by scala tympani and is transmitted to the cochlear fluids which brings about movement of the basilar membrane. This sets up shearing force between the tectorial membrane and the hair cells. The distortion of hair cells gives rise to **electrical nerve impulse**.

Note:
- A sound wave, depending on its frequency, reaches maximum amplitude on a particular place on the basilar membrane, and stimulates that segment (traveling wave theory of von Bekesy). Higher frequencies are represented in the basal turn of cochlea and the progressively lower one toward the apex.

iii. Neural pathway/Auditory pathway:

- Hair cells get innervation from bipolar cells of spiral ganglion. Central axons of these cells collect to form the cochlear nerve. (Cochlear division of VIII nerve) and end in the cochlear nuclei (the dorsal and ventral on each side of medulla).
- From cochlear nuclei crossed and uncrossed fibers pass via superior olivary nucleus complex → nucleus of lateral lemniscus → inferior colliculus → Medial geniculate body and finally reach the auditory cortex of the temporal lobe.

9. Ans. is c i.e. Rotation

10. Ans. is b i.e. Rotational acceleration

11. Ans. is d i.e. Semicircular canals *Ref. Scott Brown 7/e, Vol. 3, p 3211; Dhingra 5/e, p 21; 6/e, p 17, 18*

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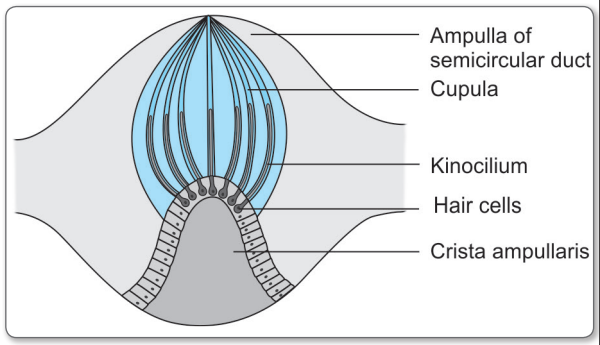
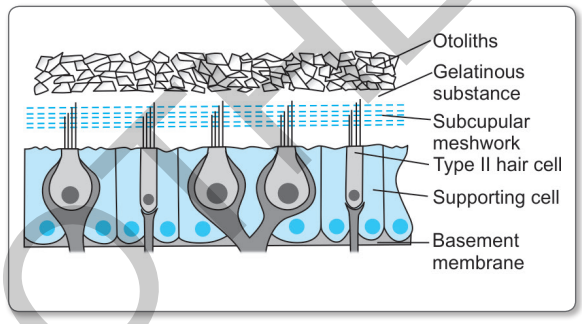
Vestibular systems includes

Semicircular canals/ducts ↓ Cristae	**Peripheral receptors**	**Utricle and saccule (otolith organ)** ↓ Macula
Located in the ampullated end of the semicircular ducts ↓		
Angular/Rotational acceleration and deceleration	**Respond to**	Linear acceleration/gravity/change in position of head
	**Structure**	
It is a crest-like mound of connective tissue on which the sensory epithelial cells lie. Cells are of 2 types, Type I (flask-shaped) Type II (cylindrical) From the upper surface of each cell projects a single hair **k/a kinocilium.** When movement of the endolymph occurs toward **kinocilium discharge increases, and when it occurs away from kinocilium discharge decreases** This stimulates sensory nerve endings which sends impulses upward to the brain giving information about the movement of head		It has 2 parts: • A sensory neuroepithelium made of Type I and Type II cells (similar to crista) • **An otolithic membrane which is** made of gelatinous mass and on the top has crystals of calcium carbonate called as otolith.Q The cilia of the hair cells project into the gelatinous layer The linear, gravitation and head tilt movement causes displacement of the otolithic membrane and thus stimulate the hair cells which lie in different planes.

Extra Edge

Between the utricle and saccule:

Utricle	Senses horizontal linear acceleration
Saccule	Senses vertical linear acceleration
Utricle + saccule	Both sense gravity and position of head in space

- **Coriolis effect**: It is a specific type of angular acceleration (i.e. sensed by semicircular ducts) that causes motion sickness in space craft due to rotation of earth.
- Type I cells correspond to the inner hair cells of organ of Corti and Type II cells correspond to the outer hair cells.

12. Ans. is a i.e. Otolith—Made up of uric acid crystals *Ref. Dhingra 5/e, p 20-22; 6/e, p 16; Tuli 1/e, p 23,24*

As discussed in text: Otolith is made of crystals of calcium carbonate and not uric acid. Rest all options are correct.

13. Ans. b i.e. Interior vestibular nerve supplying posterior semicircular canal *Ref: 5/e, 7/e, Vol 3, p 3120*

As discussed in the preceding text, singular nerve is a branch of inferior vestibular nerve which supplies the posterior semicircular canal.

14. Ans. is d i.e. +85 mv *Ref. Scott Brown Vol 3, pg 3136-3187*

Endocochlear potential is +85 mv- it is the resting potential recorded from scala media. It is generated from stria vascularis by Na^+/K^+AT Pase pump. Endolymph has high K^+ concentration. It acts as a battery and helps in driving the current through the hair cells when they move after exposure to any sound stimulus.

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