ETINOSA-OGBAHON OSASENAGA
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PHARMACOLOGY
PHS 212

PHYSIOLOGY OF BALANCE

LABYRINTH

Labyrinth (inner ear) consists of two structures:

1. Bony labyrinth
2. Membranous labyrinth.

BONY LABYRINTH

Bony labyrinth is a series of cavities or channels pre- sent in the petrous part of temporal bone. Membranous labyrinth is situated inside bony labyrinth. The space between bony labyrinth and membranous labyrinth is filled with a fluid called perilymph or periotic fluid. This fluid is similar to ECF in composition with large amount of sodium ions. Bony labyrinth encloses membranous labyrinth

MEMBRANOUS LABYRINTH

Membranous labyrinth is formed by membranous tubules and sacs.

It consists of two portions:

1. Cochlea, which is concerned with sensation of hearing
2. Vestibular apparatus, which is concerned with posture and equilibrium.

Membranous labyrinth is filled with a fluid called endolymph or otic fluid. Endolymph is similar to ICF in composition. It has large quantity of potassium ions.

FUNCTIONAL ANATOMY OF VESTIBULAR APPARATUS

Vestibular apparatus is formed by three semicircular canals and otolith organ (vestibule).

SEMICIRCULAR CANALS

Semicircular canals are the tubular structures placed at right angles to each other. Because of this type of arrangement, semicircular canals represent the three axes of rotation, i.e. vertical, anteroposterior and transverse axes. Semicircular canals are named according to the situation as follows:

1. Anterior or superior canal
2. Posterior canal
3. Lateral or horizontal or external canal.

Anterior and posterior canals are situated vertically and the lateral canal is situated in horizontal plane .

When the head is tilted forward at an angle of 30°, lateral canals of both the sides are at horizontal plane parallel to earth with the convexities directed outward and a little backward. Anterior canals are at vertical plane and directed forward and outward at 45°. Posterior canals are also at vertical plane, but directed backward and outward at 45°.

Therefore, the plane of position of anterior canal of one side is parallel to the plane of posterior canal of opposite side.

Ampulla

There are two ends for each semicircular canal. One end is narrow and the other end is enlarged. The enlarged end is called ampulla. Ampulla contains the receptor organ of semicircular canals known as crista ampullaris. Ampulla of all the three canals and narrow end of horizontal canal open directly into the utricle. The narrow ends of anterior and posterior canals open into utricle jointly, by forming the common crus. Thus, all the three semicircular canals open into utricle by means of five openings. Utricle opens into saccule.

OTOLITH ORGAN OR VESTIBULE

Otolith organ or vestibule is formed by utricle and saccule. Often utricle and saccule are together called otoliths. Utricle communicates with saccule through utriculosaccular duct. Saccule communicates with cochlear duct through ductus reuniens. Another duct called endolymphatic duct arises from utriculosaccular duct. It ends in a bag-like structure called endolymphatic sac, which lies on the cranial surface of petrous bone.

RECEPTOR ORGAN IN VESTIBULAR APPARATUS

Receptor organ in semicircular canal is called crista ampullaris and that in otolith organ is called macula. These receptor organs contain the proprioceptors.

RECEPTOR ORGAN IN SEMICIRCULAR CANAL – CRISTA AMPULLARIS

Crista ampullaris is a crest-like structure situated inside the ampulla of semicircular canals. The crest is formed by a receptor epithelium (neuroepithelium), which consists of hair cells, supporting cells and secreting epithelial cells. The secreting epithelial cells secrete the ground substance, proteoglycan. These cells are arranged in planum semilunatum (group of epithelial cells) around hair cells.

Hair Cells

Hair cells are the receptor cells (proprioceptors) of crista ampullaris. There are two types of hair cells, type I and type II hair cells. Hair cells of semicircular canals, utricle and saccule receive both afferent and efferent nerve terminals.

Type I hair cells

Type I hair cells are flask shaped. Afferent nerve terminates in the form of a calyx that surrounds the cell body. Efferent nerve terminal ends on the surface of calyx.

Type II hair cells

These cells have a cylindrical or test tube shape. Both afferent and efferent nerve fibers terminate on the surface cell body without forming calyx.

Cilia of hair cells

Apex of each hair cell has a cuticular plate. From this plate, about 40 to 60 cilia arise, which are called stereocilia. Each stereocilium is attached at its tip to the neighboring taller one by means of a fine process called tip link. Because of the tip links, all the stereocilia are held together. One of the cilia is very tall, which is named as kinocilium.

Cupula

From crista ampullaris, a dome-shaped gelatinous structure extends up to the roof of the ampulla. It is known as cupula. Cilia of hair cells are projected into cupula.

RECEPTOR ORGAN IN OTOLITH ORGAN – MACULA

Receptor organ in otolith organ is called macula. Like crista ampullaris, macula is also formed by neuro- epithelium and supporting cells. Neuroepithelium of macula also has two types of hair cells, the type I and type II hair cells.

Otolith Membrane

Like crista ampullaris, macula is also covered by a gelatinous membrane called otolith membrane. It is a flat structure and not dome shaped like cupula. The stereocilia and kinocelium of each hair cell are embedded in otolith membrane. Otolith membrane contains some crystals, which are called ear dust, otoconia or statoconia. Otoconia are mainly constituted by calcium carbonate.

Situation of Macula

Situation of macula is different in utricle and saccule.

Macula in utricle

In utricle, the macula is situated in horizontal plane, so that the cilia from hair cells are in vertical direction.

Macula in saccule

In the case of saccule, macula is in vertical plane and the cilia are in horizontal direction.

NERVE SUPPLY TO VESTIBULAR APPARATUS

Impulses from the hair cells of crista ampullaris and maculae are transmitted to medulla oblongata and other parts of central nervous system (CNS) through the fibers of vestibular division of vestibulocochlear (VIII cranial) nerve.

FIRST ORDER NEURON

First order neurons of the sensory pathway are bipolar in nature. The soma of bipolar cells is present in vestibular or Scarpa ganglion, which is situated in the internal auditory meatus. Dendrites of bipolar cells reach the receptor organs, i.e. crista ampullaris and maculae in vestibular apparatus. Branches of the dendrites have close contact with basal part of hair cells. Dendrites terminating on type I hair cells are comparatively larger than those ending on type II hair cells.

Axons of the first order neurons (bipolar cells) form vestibular division of vestibulocochlear nerve. These fibers reach the medulla oblongata and terminate in vestibular nuclei. These nerve fibers are called primary vestibular fibers.

Vestibular Nuclei

There are four vestibular nuclei in the medulla oblongata, viz. superior, inferior, lateral and medial nuclei. Most of the primary vestibular fibers reaching superior and medial nuclei come from crista ampul- laris of semicircular canals. Lateral vestibular nucleus receives fibers mainly from maculae of otolith organ and inferior vestibular nucleus receives fibers from both crista ampullaris and maculae.

Efferent nerve fibers to hair cells

Some neurons in vestibular nuclei send efferent fibers, which run back to the hair cells along with primary vestibular fibers (see above). It is believed that these efferent fibers to hair cells provide tonic inhibition of hair cells.

Fibers to Cerebellum

Fibers from some bipolar cells reach cerebellum directly and terminate in flocculonodular lobe or the fastigial nucleus in cerebellum.

SECOND ORDER NEURON

Second order neurons of this pathway are located in the four vestibular nuclei. Axons from vestibular nuclei form the secondary vestibular fibers. Secondary vestibular fibers form four tracts:

1. Vestibulo-ocular tract
2. Vestibulospinal tract
3. Vestibuloreticular tract
4. Vestibulocerebellar tract.

1. Vestibulo-ocular Tract

Fibers from superior, medial and inferior vestibular nuclei descend downwards for short distance along with vestibulospinal tract. Afterwards, these fibers ascend through the medial longitudinal fasciculus and terminate in the nuclei of III, IV and VI cranial nerves, thus forming vestibulo-ocular tract. This tract is concerned with movements of eyeballs in relation to the position of the head.

2. Vestibulospinal Tract

Fibers from lateral nucleus descend downwards and form the vestibulospinal tract. Some fibers from this nucleus ascend upward and join medial longitudinal fasciculus. Fibers of vestibulospinal tract are involved in reflex movements of head and body during postural changes.

3. Vestibuloreticular Tract

Some fibers from vestibular nuclei reach the reticular formation of brainstem forming reticulospinal tract.

These fibers are concerned with the facilitation of muscle tone.

4. Vestibulocerebellar Tract

Some fibers arising from all four vestibular nuclei form vestibulocerebellar tract and terminate in flocculono- dular lobe and fastigial nuclei of cerebellum. This tract is involved in coordination of movements according to body position.

FUNCTIONS OF VESTIBULAR APPARATUS

Receptors of semicircular canals give response to rotatory movements or angular acceleration of the head. And receptors of utricle and saccule give response to linear acceleration of head.

Thus, the vestibular apparatus is responsible for detecting the position of head during different movements. It also causes reflex adjustments in the position of eyeball, head and body during postural changes.

FUNCTIONS OF SEMICIRCULAR CANALS

Semicircular canals are concerned with angular (rotatory) acceleration. Semicircular canals sense the rotational movement. Each semicircular canal is sensitive to rotation in a particular plane.

Superior Semicircular Canal

Superior semicircular canal gives response to rotation in anteroposterior plane (transverse axis), i.e. front to back movements like nodding the head while saying ‘yes – yes’.

Horizontal Semicircular Canal

Horizontal semicircular canal gives response to rotation in horizontal plane (vertical axis), i.e. side to side movements (left to right or right to left) like shaking the head while saying 'no – no'.

Posterior Semicircular Canal

Posterior semicircular canal gives response to rotation in the vertical plane (anteroposterior axis) by which head is rotated from shoulder to shoulder.

Mechanism of Stimulation of Receptor Cells in Semicircular Canal

At the beginning of rotation, receptor cells are stimulated by movement of endolymph inside the semicircular canals. However, receptors are stimulated only at the beginning and at the stoppage of rotatory movements. And during rotation at a constant speed, these receptors are not stimulated.

When a person rotates in clockwise direction in horizontal plane (vertical axis), horizontal canal moves in clockwise direction. But there is no corresponding movement of endolymph inside the canal at the beginning of rotation. Because of the inertia, endolymph remains static. This phenomenon causes relative dis- placement of endolymph in the direction opposite to that of the rotation of head. That is, the fluid is pushed in anticlockwise direction.

Thus, in the right horizontal semicircular canal, the endolymph flows towards the ampulla and in the left canal, the fluid moves away from the ampulla.

Movement of endolymph in semicircular canal, in turn causes corresponding movement of gelatinous cupula. Thus, in the right horizontal canal, the cupula moves towards the ampulla. Whereas in left canal cupula moves away from ampulla. In any semicircular canal, when cupula moves towards the ampulla, stereocilia of hair cells are pushed towards kinocilium leading to stimulation of hair cells. When cupula moves away from ampulla, the stereocilia are pushed away from kinocilium and hair cells are not stimulated.

Thus, at the commencement of rotation in clockwise direction around vertical axis, hair cells at ampulla of horizontal canal in right ear are stimulated. But, the hair cells in horizontal canal of left ear are not stimulated.

Because of stimulation, the hair cells in right horizontal canal send information (impulses) through sensory nerve fibers to vestibular, cerebellar and reticular centers. Now, these centers send proper instructions to various muscles of the body to maintain equilibrium of the body during angular acceleration (rotation).

On the other hand, rotation in anticlockwise direction causes stimulation of hair cells in ampulla of horizontal canal in left ear only. Hair cells of horizontal canal in right ear are not stimulated. Stimulation of hair cells in left ear is followed by the process as in the case of clockwise rotation.

Electrical Potential in Hair Cells – Mechanotransduction

Mechanotransduction is a type of sensory trans- duction in the hair cell (receptor) by which the mechanical energy (movement of cilia in hair cell) caused by stimulus is converted into action potentials in the vestibular nerve fiber.

Resting membrane potential in hair cells is –60 mV. Movement of stereocilia of hair cells towards kinocilium causes opening of mechanically gated potassium channels. It is followed by influx of potassium ions from endolymph which contains large amount of potassium ions. Potassium ions cause development of mild depolarization in hair cells up to –50 mV. This type of depolarization is called receptor potential. Besides potassium ions, calcium ions also enter the hair cells from endolymph.

Receptor potential in hair cells is non-propagative. But, it causes generation of action potential in nerve fibers distributed to hair cells. Depolarization of hair cells causes them to release a neurotransmitter, which generates the action potential in the nerve fibers. It is believed that the probable neurotransmitter may be glutamate.

Movement of stereocilia in the opposite direction (away from kinocilium) causes hyperpolarization of hair cells. Calcium may play a role in the development of hyperpolarization. Hyperpolarization in hair cells stops generation of action potential in the nerve fibers .

FUNCTION OF OTOLITH ORGAN

Otolith organ is concerned with linear acceleration and detects acceleration in both horizontal and vertical planes. Utricle responds during horizontal acceleration and saccule responds during vertical acceleration.

Function of Utricle

Position of hair cells of macula helps utricle to respond to horizontal acceleration. In utricle, the macula is situated in horizontal plane with the hair cells in vertical plane (Fig. 158.5). While moving horizontally, because of inertia the otoconia move in opposite direction and pull the cilia of hair cells resulting in stimulation of hair cells.

For example, when the body moves forward, the otoconia fall back in otolith membrane and pull the cilia of hair cells backward. Pulling of cilia causes stimulation of hair cells. Hair cells send information (impulses) to vestibular, cerebellar and reticular centers. These centers in turn send instructions to various muscles to maintain equilibrium of the body during the forward movement.

Function of Saccule

Macula of saccule is situated in vertical plane with the cilia of hair cells in horizontal plane. While moving vertically, as in the case of utricle, otoconia of saccule move in opposite direction and pull the cilia resulting in stimulation of hair cells.

For example, while climbing up, the otoconia move down by pulling the cilia downwards. It stimulates the hair cells, which in turn send information to the brain centers. And the action follows as in the case of movement in horizontal plane.

Role of Otolith Organ in Resting Position

During resting conditions (in the absence of head movement), hair cells are stimulated continuously because of the pulling of otoconia by gravitational force. Stimulation of hair cells produces reflex movements of head and limbs for the maintenance of posture in relation to gravity. Because of this function, the receptors of otolith organ are called gravity receptors.