We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the
TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter

Vestibular System: Anatomy, Physiology, and Clinical Evaluation

Dmytro Illich Zabolotnyi and Nina Serhiivna Mishchanchuk

IntechOpen

Abstract

Abstract Studies on vestibular system have brought new experimental studies, clinical examinations, and the development of effective treatment for a number of diseases of this system. In particular, vestibular paroxysmal positional disorders of peripheral and central origin have been studied. The main criteria for differential diagnosis of these disorders have been determined. Vestibular dysfunction in canalolithiasis and cupololithiasis has been investigated clinically and histologically. Effective therapeutic and prophylactic positional maneuvers of three types have been introduced into clinical practice. They were developed taking into account the anatomical and physiological features of the vestibular system. Currently only 20% of vestibular reactions, in particular, using electronystagmography test (ENG), are estimated in the horizontal plane. Videonystagmography (VNG) gives the possibility of video recording of nystagmus in the directions of semicircular channels (vertical, diagonal, horizontal). The vestibular evoked myogenic potential test (VEMP) is being widely used in clinical practice. Magnetic coils and scanning laser ophthalmoscopes are gaining increasing significance in examining patients. A brief information on vestibular disorders after the Chornobyl nuclear power plant accident is also given.

Keywords: vestibular dysfunction, vertigo, postural balance and control, spontaneous, positional, and experimental nystagmus

IntechOpen

1. Introduction

Sensory functions, in particular, vestibular and auditory ones, represent a reliable criterion for assessing human health, social adequacy, professional suitability, and working capacity.

Symmetry of the anatomical-topographical localization of these systems and proper space orientation provided by them are important regarding all social life aspects. The vestibular system plays a crucial role in space orientation, both at rest and in movement, as well as in professional activity of the person. Its effect onto the motor memory mechanisms, underlying all human motor activity forms, including the professional ones, is extremely important. The vestibular system, with its extremely keen sensitivity, dynamism, and high informativeness of symptoms of the ear labyrinth diseases, as well as different parts of the brain, significantly exceeds the informativeness of all other analyzers. It is the first system to respond to any disorders in the body.

Auditory system provides for social communication function. Binaural hearing impairment leads to spatial orientation disorders. Vestibular and auditory sensory systems stimulate cortical processes, being responsible for various activities, postural balance and control, emotions, and creative thought. Therefore, the need for a comprehensive clinical study of vestibular and auditory disorders in order to increase the effectiveness of prevention and treatment, correction and rehabilitation, identification of issues of professional suitability, and work capacity is very important.

2. Overview and anatomy of the vestibular system

Vestibular system (VS) is the most mysterious biological system. It was the first to develop during the embryogenesis. The vestibular system consists of the peripheral and central components, which have a complex structure that has not been fully understood. Its peripheral components are located in the paired ear labyrinth of the pyramid of the temporal bone. Its central components are composed of the conductive part, vestibular nuclei in the brain stem and cortical representation [1, 2].

Bony labyrinth is located in the temporal bone. The membranous labyrinth is located in the middle of the bony labyrinth, resembling the shape of its small cavities. Membranous labyrinth is fixed to the inner wall of the bony labyrinth by means of helical formations acting as shock absorbers. Due to this, it is held in relation to the bony labyrinth, being suspended. Membranous labyrinth consists of the peripheral acoustic section of the cochlea, where the auditory receptor organ of Corti is located, as well as the peripheral component of the vestibular system. The peripheral component of the vestibular system is represented by the vestibulum containing spherical (saccule) and elliptical (utricle) sacs that form the receptor otolith organ. Another three semicircular canals of the peripheral vestibular system are located in the membranous labyrinth [3].

Each canal is thickened and enlarged at one side, resembling ampoules by shape (ampullary receptor organ), and it has a smooth terminal region that connects to the vestibulum on the other side. The three semicircular canals are located approximately at straight angle to each other. Therefore, they may sense angular motion, conducted in any plane or direction. One canal is horizontal and the other two (front and back) are vertical. The perception of head movement is provided by activation of the right and left semicircular canals, which are located within the movement plane, thus forming functional pairs.

The membranous labyrinth is washed by perilymph fluid, which in chemical composition is similar to the cerebrospinal fluid. The middle of membranous labyrinth contains endolymph. It is intracellular fluid that provides the helix, otolith, and ampullar apparatus with oxygen, nutrients, and hormones. The potassium concentration in it is high (144 mmol/L), and the concentration of sodium is low (5 mmol/L). The mechanisms of endolymph formation and its circulation in the membranous labyrinth have not been yet well understood. The membranous labyrinth is elastic, and its size can increase by 2–3 times, filling all the "cavities" of the bony labyrinth, for example, in the case of ascites and other pathological conditions [4].

In the receptor otolithic apparatus, spherical (saccule) and elliptic (utricle) sacs contain hairy receptor cells covered by supporting dense layers of cells called overhead covers. These receptor cells are sensitive to linear acceleration. They flex in response to appropriate irritation. The clusters of the neuroepithelial receptor cells of the otolith apparatus, which are located between the supporting cells in elliptical and spherical sacs, interweave, forming loops. Calcium salt microcrystals are located in these loops; they are called otoliths [5].

The receptor structures of the ampullar apparatus, three semicircular canals (anterior, posterior, and horizontal), are located in mutually perpendicular planes. The smooth terminal parts of two semicircular canals (anterior and posterior) are joined into a single canal that enters the utricle. It is connected to the receptive auditory structures of the Corti organ. Endolymph, which is produced by the vascular strip of the helix, passes through this canal into the vestibular endolymphatic canals. This important fact, as the authors emphasize [4], is significant for various ear diseases and pathological changes of the temporal bone, as well as the brain, accompanied by vestibular disorders.

The hair cells of the vestibulum and the ampoules of three semicircular canals generate a receptor potential, which through the synapses (by production of acetylcholine) transmits signals to the terminal regions of the vestibular nerve fibers.

The vestibular nerve fibers originate in the vestibular ganglion. It is located deep in the internal auditory canal. This node consists of bipolar cells. The dendrites of these cells penetrate into the bony labyrinth through the internal auditory canal opening, approaching the saccule and utricle receptor structures, as well as the ampullar semicircular canal receptor structures. Axons of these cells, joining the helix nerve, represent the vestibulocochlear (auditory vestibular) nerve—the VIII cranial nerve. In the internal auditory canal, this nerve meets facial nerve—the VII cranial nerve—proceeding into the cavity of the skull; then in the thickness of the rhombic fossa of the medulla oblongata, four-paired vestibular nuclei enter: upper and lower and lateral and medial [6].

Reflex pathways originate in the vestibular nuclei, and these pathways are in various ways related to different systems and organs in the body. There are five pathways:

1. Tractus vestibulo-spinalis, through which impulses from the vestibular nuclei reach the voluntary muscles of the spinal cord anterior horns.

2. Tractus vestibulo-longitudinalis joins vestibular nuclei with nuclei of the III, IV, and VI cranial nerves, resulting in responses produced by the oculomotor nerves—varieties of nystagmus.

3. Tractus vestibulo-cerebellaris joins the nuclei with the cerebellum.

4. Tractus vestibulo-reticularis joins vestibular nuclei with the vagus nerve nuclei in the reticular formation, producing reflexes in the internal organ smooth muscles.

5. Tractus vestibulo-cortikalis joins the vestibular nuclei with the temporal lobes of the cerebral cortex through multisynaptic connections, with the midbrain crossway.

It should be noted that disorders of the vestibular system occur at any of its levels from the receptor structures of the ear maze to the cortical representation. When leaving the internal auditory canal, V, VI, and VII pairs of cranial nerves are located near the VIII pair of cranial nerve as well as a group of pairs of caudal (IX–XII) cranial nerves. They reflect the lesions of structures located near the vestibular system.

It should be emphasized that in the cases of disorders in the area of the labyrinth, temporal bone, and cerebellar angle, vestibular disorders are often accompanied by unilateral auditory disorders. Central vestibular disorders are less often combined with auditory disorders. In the brain stem, four pairs of vestibular nuclei are located in a relatively small anatomical space. The presence of these nuclei indicates the great importance of the vestibular system in evolutionary terms [2, 3, 5].

Vestibular disorders very often occur in patients with brainstem pathology. The nuclei of the III, IV, and VI cranial nerves are located with the vestibular conduction pathways, the damage of which is accompanied by diplopia. Pathology of the V cranial nerve is manifested by a decrease in the sensitivity of the skin of the face. Facial (VII) nerve disorders lead to facial distortion, speech disorders, pathology of the IX–X cranial nerves, and disorders of swallowing and articulation. Vestibular disorders through close anatomical connection with the cerebellum can contribute to the development of cerebellar ataxia [4].

3. Physiology of the vestibular system

Researchers have been studying functions of the ear labyrinth for centuries. Describing the feelings during self-spinning, the symptoms of responses occurring in this case were reported: vertigo, balance problems, sweating, nausea, vomiting, changes in heart rate and blood pressure, and respiratory disorders. In the study on birds, destroying semicircular canal of the ear labyrinth, it was first found that sensory perception is based on stimulation of ampullary receptors. In further experiments it was reported that semicircular canals are receptor organs that perceive rotational motions. These movements cause shifting of the endolymph, which causes irritation of receptor neuroepithelial cells in the semicircular canal ampoules, producing nerve impulse [6].

Purkyně [7], reporting on his feelings in the rotation, first described the symptoms of the reactions that occur in this case: vertigo, imbalance, sweating, nausea, vomiting, changes in heart rate and blood pressure, and breathing.

Florens [8] in the experiment on birds, destroying the semicircular canals of the ear labyrinth, first established that the stimulation described by J. Purkiunje was based on the irritation of the ampullary receptors of these canals. These observations initiated the experimental study of the vestibular labyrinth. It was defined that semicircular canals are receptive organs that perceive rotational movements. These movements cause displacement of the endolymph, leading to irritation of receptor neuroepithelial cells in ampoules of semicircular canals, resulting in a nerve impulse.

Evald [9] conducted unique experimental studies and discovered the patterns of functioning of vestibular semicircular canals, which are known as the three laws of Evald:

1. Nystagmus always occurs in the plane of the semicircular canal irritation.

2. Ampullopetal (toward the canal ampulla) movement of the endolymph causes richer response than the ampullofugal (toward the smooth terminal part of the canal) one.

3. Nystagmus is always directed toward more active semicircular canal.

4. Prominent scientists of the last century presented clinical and experimental evidence of the vestibular system connection with other body systems and organs, the dependence of response on both strength of the stimulus and functional state of the CNS (cited by [6]).

If vestibular system is affected, three types of pathological responses may occur: vestibular sensory, vestibular somatic, and vestibular vegetative, with different levels of manifestation.

I. The vestibulo-sensory subjective pathological responses are caused by the processes that occur in the cerebral cortex. These structures analyze and synthesize obtained stimuli. The disorder here may be manifested as a pathological subjective sensation of continuous or periodic vertigo of different direction and intensity, as well as orientation disorders with the reflex action. Vertigo is the most widespread specific sensation after pain, which indicates a disease. The vestibulo-sensory subjective pathological responses originate in the vestibulo-cortical tract.

II. The vestibulo-somatic objective pathological responses are manifested as muscle reflexes, accompanied by objective spontaneous static and kinetic equilibrium disturbance, as well as pathological objective vestibulo-oculomotor reflexes: spontaneous or positional nystagmus of various direction and intensity (horizontal, rotating, vertical, diagonal, multiple). They are an objective feature of the vestibulo-sensory subjective sensation vertigo of appropriate orientation. These reflexes are provided via tractus vestibulo-spinalis, tractus vestibulo-longitudinalis, and tractus vestibulo-cerebellaris.

III. The vestibulo-vegetative objective pathological responses arise in the receptor vestibular apparatus, as a response onto the smooth muscle of the internal organs' irritation (overpronounced response, hyperreflexia; suppressed response, hyporeflexia) with symmetric or asymmetric sensitivity due to vestibular pathologies, as well as intense and prolonged vestibular loads. These responses occur via tractus vestibulo-reticularis. They often lead to, combined with other vestibular responses, the development of various symptom complexes, including various forms of kinetosis, formerly called motion sickness (marine, air) [6, 10, 11].

These responses are differently significant for human life. As for professional activity, the vestibular vegetative and vestibular sensory responses are the most important. The first ones cause vegetative discomfort, in which a person feels bad and his/her workability is reduced. Others disorient a person in space and can cause serious danger when performing work that involves precise and coordinated movements.

According to the literature [12], up to 20% of the professionals whose jobs are related to the effect of prolonged or elevated vestibular system stimuli may become disabled due to vestibular disorders. Such professionals, as a result of movement discoordination or space disorientation, can make professional mistakes, which may cause man-made accidents or even catastrophes.

In anatomical, physiological, and functional relationship between the vestibular and auditory systems, the relation between the nuclear areas and different central nervous system formations and cerebral circulation contributed to the development of otoneurology. Progress in otosurgery and neurosurgery has identified a separate medical specialty: otoneurosurgery.

Pressure changes and various pathological changes associated with purulent and non-purulent processes in the tympanic cavity cause impaired middle-ear sounding function. These changes reach the window of the helix and vestibulum, causing sensory and neural hearing loss and vestibular dysfunction.

The structural, vascular, toxic, allergic disorders of the labyrinth may lead to hyperfunction of the endolymph and various vestibulopathies and labyrinthopathies.

Vestibular system, as a system consisting of paired organs, functions by the lever principle. The receptor hairy cells in each of the semicircular canals are located so that shift of the cupula into one side increases afferent input along the vestibular nerve directed toward that side and decreases toward the opposite side.

For example, turning the head to the right will increase afferent input of the right lateral semicircular canal and decrease afferent input of the left one. As a result, two conclusions can be made, based on the above mentioned: (1) vertigo may develop at unilateral hypofunction state, even at rest; (2) in the case of complete dysfunction of the semicircular canal on one side, the functioning semicircular canal on the opposite side may perceive head movements in both directions of appropriate plane (by decreased or increased afferent input perception). This ability of the preserved labyrinth to perceive head movements represents the basis of vestibular compensation, providing for restored vestibular functions with unilateral vestibular dysfunction (VD) [12].

The adequate stimulus of the three semicircular canal ampulla apparatus receptor structures is acceleration and slowing during rotation movements. The receptor cells may shift due to the endolymph inertia shift. At the movement acceleration stage, it will be the maximum one. While rotating the head with steady speed, the endolymph shift gradually decreases, and in 15–20 s of rotation it attains the background properties. If to stop movement, the cupula shift turns the cupula toward the opposite side. This phenomenon represents the "stop-stimulus" while conducting classical rotation test using Barany rotational chair. If to compare duration of the caloric test, or the bilateral caloric cold and heat stimulation as well as the post-rotation nystagmus after rotating to the left and right, we should assess the symmetry or asymmetry of vestibular functions [1].

An adequate stimulus of the otolith organ results in acceleration or slowing down at the straight-line movements. As the gravity force is a linear acceleration, the otolith receptors perceive head inclination movements regarding the earth gravity force vector. Absent action of the gravity force onto the otolith organ at null gravity causes significant disturbance in the body, which are thoroughly studied by cosmic medicine. The sensitivity of otolith hairy cells to linear acceleration is determined by the mass of heavy calcium crystals—otoliths. Elliptic sacs of the otolith organ, situated close to horizontal plane, are more sensitive to acceleration within this plane. Spheric sacs are located in almost vertical plane, so they are more sensitive to acceleration and slowing down within a vertical plane. It is necessary to stress that the head movements are the combined ones, i.e., they are accompanied with linear and angular acceleration within various planes and directions. Due to joint functioning of four otolith organs and six semicircular canals, it is possible to perceive complex movements in space [11, 13, 14].

The nystagmus subtypes are the most valuable specific and objective characteristics of acute peripheral, chronic, or acute progressing central VD. The nature of these nystagmuses has not been understood completely. It is supposed that the standard tone of the eye-moving muscles is supported by the impulses of similar symmetric force which derive from the both labyrinths. When we irritate the labyrinth, there appears reflex asymmetry from the eye-moving muscles, expressed as a gradual turning away of the eyes toward the muscle hypertonia side, with gradual nystagmus component developing. Gradual turning away of the eyes causes instant response from the central (cortex) parts, so the eyes turn to the previous position. This is how a quick component of the spontaneous or other nystagmus may appear. The confirmation of cortex genesis of quick nystagmus component is its absence in the case of unconsciousness or narcosis. The slow nystagmus component is preserved in these cases. The nystagmus direction is determined by its quick component [12].

There are three stages of spontaneous nystagmus: in the first phase, when the nystagmus is manifested when the eyes turn away toward the quick component side; in the second phase, when the eyes move toward the quick component or when a person looks straightforward; in the third phase, when the eyes look toward the quick component, straightforward and to the opposite side [13].

The studies established that the peripheral or labyrinth-borne spontaneous nystagmus, as a rule, by its intensity is a small- or medium-swinging; by its direction the nystagmus may be horizontal or horizontal-rotating and rhythmical, with distinctly changing quick and slow phases [12].

Peripheral nystagmus in the acute stage lasts from the first 2–3 hours to 2–3 days, being directed toward acute stimulation of the labyrinth receptor structures. With gradual labyrinth depression, the nystagmus changes its direction toward the healthy side. In the case of the VD acute stage of peripheral syndrome type, the spontaneous horizontal or horizontal-rotating nystagmus is accompanied with sensory subjective sensation, horizontal vertigo toward labyrinth hyperreflexia side and, in the case of depression, toward the opposite intact side. So, shifts in statics and movement coordination, keeping to the vector laws, are observed the same, directed toward stimulation side or toward the healthy side in depression.

The specific acute vestibular symptoms are accompanied by considerable general discomfort, manifested dually; its first manifestation is characterized by nausea, vomiting, and vascular disorders associated with sympatho-adrenergic crisis. Here we may observe increased arterial pressure, tachycardia, hyperemia, and skin dryness, as well as dry oral mucosa. Its second manifestation is characterized by decreased arterial pressure, bradycardia, pale skin and mucosa, extreme sweating, and salivation [13, 14].

The acute vestibular syndrome requires urgent medical aid. As the authors observe [14–16], the peripheral vestibular syndrome is characterized by high capacity for compensating the affected functions due to central regulating mechanisms. In 2–4 weeks the spontaneous nystagmus decreases in intensity and then disappears completely. At the same time, vertigo decreases; kinetic and then static equilibrium functions are restored.

The pressure changes and pathological disorders in purulent and non-purulent processes in the external ear and tympanic membranes cause problems with the sound-conducting function of the middle ear. These pathological changes through the helix window and vestibule may migrate onto the ear labyrinth. In the labyrinth, under the effect of these conditions, the content and shift of endolymph movement may be changed. These endolymph changes lead to the VS receptor structure impairment, and finally they result in sensorineural deafness and vestibular dysfunction.

In the case of the acute central vestibular syndrome (pathology of the cerebellopontine angle or the pons bodies), there may be other characteristics of spontaneous nystagmus observed. It may be large-swinging or medium-swinging. It may develop within various planes: the vertical, diagonal, horizontal, or multiple. In some cases, spontaneous nystagmus is defined as a tonic-clonic or tonic (with prolonged average angular speed of the slow stage of nystagmus or decrease of its frequency). Spontaneous nystagmus in the case of the central vestibular syndrome is continuous and may progress in intensity [12].

4. Clinical disorders of the vestibular system

4.1 Benign paroxysmal positional vertigo (BPPV)

Benign paroxysmal positional vertigo (BPPV) is the most frequent cause of light-headedness. Its treatment has become possible due to application of the original correction methods. The main sign of the BPPV is short-lasting vertigo attacks, which appear when a person abruptly changes his head position related to the gravity vector, for example, changing from the vertical onto the horizontal position, when a person lies down, or vice versa, when he gets up, or upturns in the bed, or abruptly throws his head back. These attacks of vertigo more often appear in the morning after sleep. They are mostly manifested when the person first changes body position after sleep. They are weakened with repeated head movements. The patients' complaints are very characteristics, quite often basing on the complaints it is possible to diagnose the condition and define the affected side. The patient quite often shows himself, from what side vertigo appears [1, 4, 10, 12].

If the vertigo and nystagmus are horizontally or horizontally rotating directed, this shows us that the horizontal (lateral) semicircular canal is affected. The provoking moment may be when a patient inclines his head toward the affected ear side. The vertigo may be accompanied with nausea and vomiting. The attack appears after a person moves his head, in 1–2 s and lasts for 30–60 s.Vertigo and nystagmus depend on the head movement. If a person looks upward, vertigo and nystagmus are vertical. Vertical nystagmus in this case evidences about excitement of receptors of the posterior semicircular canal. BPPV may develop at any age, most often from 50 to 70 years, affecting women twice as often as men. It may develop after prolonged bed stay, particularly after craniocerebral traumas [11, 14, 16, 17].

The diagnosis is established due to position tests. The position tests should be conducted with all patients complaining of the vertigo even if a patient's complaint is typical for the other vestibular disorders (Meniere's disease, vestibular neuronitis, migraine, and various etiology labyrinth diseases). When there are no effective method of the primary disease treatment, it is always possible to relieve the vertigo, related to the BPPV [12, 15].

According to the cupulolothiasis theory, which was histologically confirmed, in the ampulla of the posterior canal, which is located lower than the other canals, otoliths may deposit more frequently. They, due to various reasons, leave the otolith membrane and stick to the cupula walls. The cupula walls with otoliths become heavy. They become a sensor of linear acceleration instead of the sensor of the angular one though this theory cannot explain many peculiarities of nystagmus [4].

The canalolithiasis theory explains the positional nystagmus signs. Otoliths, according to this theory, do not stick but freely float in the endolymph. As they narrow or obstruct the canal diameter, they cause positional vertigo. As they travel along the canal, otoliths disrupt free shift of the endolymph from the utricle or to the utricle. This theory allows predicting the direction, latent period, and duration of the nystagmus, as well as the changes of its characteristics at various positional maneuvers [4].

In 10–20% of patients suffering from BPPV, lateral semicircular canals have been affected. There are two types of them: related to canalolithiasis (more widespread) and a rarer one, cupulolithiasis. Identification of the lateral semicircular canal BPPV is characterized by some features which were earlier considered to be characteristics of the central positional vertigo. In the case of the lateral semicircular canal canalolithiasis, the patient experiences vertigo when he turns his head to sides, being supine. Changing the position from the supine onto the sitting one and vice versa is not accompanied with significant symptoms. Exacerbations with the lateral canal BPPV are less prolonged than those with the posterior canal affected. The cause of lateral canal BPPV as a canalithiasis type is the invasion of aggressive otoliths in this canal. Remissions are often observed in patients with lateral canal BPPV as otoliths can easily leave the lateral canal during head movements. On the contrary, otoliths do not move from the posterior canal independently due to the anatomical position (it is located below all other canals). A quick result from the maneuvers testifies to the lateral canal BPPV. BPPV anterior canal is used very rarely [4, 6, 17].

The Dix-Hallpike test is the technique used to diagnose posterior semicircular canal BPPV. A patient is brought from sitting to a supine position, with the head turned 45° to one side and extended over the end of the stretcher. In the case of left posterior semicircular canal dysfunction, the test will first cause an increased and then decreased nystagmus that occurs after a short latent period. After returning to the starting position, the nystagmus will change the direction [15–17].

A number of positional maneuvers have been developed to treat BPPV. They are aimed at removing conglomerates of otoliths from semicircular canals. At present, maneuvers developed by Brandt and Daroff and Semont and Epley maneuvers are used. Within the theory of canalolithiasis, Brandt and Daroff were the first to come up with a set of exercises, including head movements that destroy the otolith conglomerates. Their fragments move to the other sections of the labyrinth, where they may be stationary. Therefore, they do not affect the function of semicircular canals [4].

These maneuvers, when applied correctly, are always effective but 50% relapse. In case of relapses, it is recommended to repeat the maneuver that was more effective at the first attack [12, 14].

4.2 Vestibular neuronitis

Vestibular neuronitis is a common cause after BPPV peripheral vestibular disease. Clinically, it is manifested by vertigo in the direction of a healthy ear, by spontaneous nystagmus of a horizontally rotary direction to a healthy ear. Functional tests check various degrees of hyporeflexia to the affected ear and postural abnormalities toward a healthy ear. It is considered that vestibular neuronitis is of viral etiology. It is recommended to prescribe glucocorticoids at first as they effectively reduce functional disorders and have a strong anti-inflammatory effect. In addition, they accelerate the central mechanisms of vestibular compensation for postural disorders. Antiviral drugs are less effective [10].

4.3 Meniere's disease

Meniere's disease refers to the peripheral diseases of both vestibular and auditory systems. During an acute attack in the excitation phase in the affected labyrinth, there occurs a strong vertigo of the horizontal direction with horizontal nystagmus, postural disorders, and significant vestibulo-vegetative pathological reactions. At the same time, there is a strong noise in the affected ear, hearing loss, feeling of pawning and fullness in it, and the phenomena of sound discomfort on enhanced sound stimuli. In the phase of inhibition of the labyrinth, vertigo and nystagmus change the direction toward a healthy labyrinth. Postural disorders gradually settle, and vestibulo-vegetative pathological reactions disappear. Within functional stimulation, hyporeflection of the nystagmus is fixed from the side of the affected labyrinth. At the same time, noise, stuffiness, and fullness in the ear decrease, and the effects of sound discomfort are reduced. These facts indicate a common mechanism of the processes of excitation and inhibition in both sensory systems in this disease [6, 10, 18, 19].

It was histologically confirmed that the basis for Meniere's disease is the periodic accumulation of endolymphatic dropsy (endolymphatic hydrops). An acute attack of vestibular dysfunction lasts from 30 minutes to 3–4 hours and recurs at different intervals. One of the effective treatment methods for Meniere's disease is shunting of a damaged labyrinth, vestibular gymnastics, and salt restriction. Long-term betahistine treatment is often prescribed to prevent attacks and reduce their manifestation. However, the causes of its occurrence have not been fully understood [11, 12, 18].

4.4 Migrainous vertigo

Migrainous vertigo is the most common form of spontaneous recurrent systemic vertigo. It occurs at any age, from preschoolers to older adults. Family history is often noted, indicating the contribution of genetic factors. It occurs with an aura less often than without an aura. During the attack, transient symptoms occur, such as atrial fibrillation, unilateral paresthesia, and aphasia. These symptoms are often preceded by headaches. Migraine-associated vertigo increases when the position of the head changes. The duration of symptomatic episodes when positional nystagmus can be detected may take several days. Relapses occur more frequently than BPPV. Migrainous vertigo is referred to as central positional vertigo [2, 3, 5, 19].

4.5 Central positional vertigo

Central positional vertigo occurs not frequently, in less than 5% of patients with vertigo. But it is a sign of a serious disease that is associated with structural damage of central divisions of the vestibular system and lobes of the cerebellum. Therefore, central lesion should be excluded first of all in patients with positional vertigo. The most reliable differential feature of BPPV and central positional vertigo is the direction of positional nystagmus. In the case of BPPV, by stimulation in the plane of a certain canal, positional nystagmus characteristic for this canal is typical. When stimulating horizontal (lateral) canalis semicircularis, horizontal positional nystagmus always occurs. The direction of the central positional nystagmus is often not correlated with the stimulating canal. Pure vertical or rotary nystagmus is a sign of central vestibular disorder. In patients with central vertigo, in the absence of changes in MRI, it is possible to suspect a migrainous or other vertigo [14, 16, 19].

4.6 The effect of Chornobyl nuclear power plant accident on vestibular system

Our own experience [20, 21] of vestibular examinations for more than three decades of 8136 participants of Chornobyl nuclear power plant accident indicates that the patients had vestibular and sensorineural dysfunction. These two dysfunctions are characterized by a predominant disorder in the central (brain stem and subcortical) structures. The priority of changes (preclinical and early clinical) in the central departments of the vestibular and auditory systems, the dependence of the degree of manifestation on the dose, and duration of radiation exposure indicate the parallelism of the common mechanism under the influence of the radiation factor.

The occurrence of deterministic radiation effects of these dysfunctions by the type of central syndrome in radiation doses greater than 0.20 Gy has been investigated. Mathematical modeling determined the dependence of these effects on the age, magnitude of the dose, and duration of stay in the exclusion zone of the Chornobyl power plant, both by clinical electrophysiological and audiometric psychoacoustic and electroacoustic methods. Elongation of magnitudes of the latent periods of the components P-2 and N-2 of auditory evoked long latency or cortical potentials (AEP) in patients with progressive sensorineural hearing loss (SHL) is characterized by slowing the intelligibility of speech and its paradoxical decrease in the conditions of high loads of noise. These features alongside with presbyacuzis praecox indicate common inhibitory processes of subcortical and cortical structures of the auditory system [20, 21].

At the same time, there was a decrease in the parameters of the induced nystagmus reaction and a decrease in the postural balance, as well as changes in the manifestation of pathological vestibulo-vegetative reflexes inpatients with VD in late post-accident period. It has been proven on the basis of epidemiological studies that the inhibition processes in these systems can be regarded as a symptomo-complex of premature aging, with the development of cognitive, emotional, and volitional responses. They require regular treatment and prevention and rehabilitation measures to improve quality and life expectancy [21].

5. Clinical tests for the vestibular system

Determination of vestibular dysfunction of peripheral, central, or combined (mixed) character requires timely vestibulometric examination for differential diagnosis. This is necessary for the clinical needs of ENT specialists in the treatment of ear diseases (non-purulent and purulent otitis media, otosclerosis, sensory and neural deafness of different genesis, Meniere's disease, neoplasms of the ear).

Varieties of vestibular and acoustic dysfunctions may be detected by the physicians of other specialties to provide optimal medical care for neoplasms and traumas of the skull (including the temporal bone, brain), cardiovascular, neuro-psychic, infectious, noise-vibrating, radiation-induced, endocrine, toxic, and other diseases [12, 14].

According to the clinical data [13, 15–17], vestibular test methods should be economical, informative, and adequate to the patient's condition and the task of diagnostics and include the study of the functional state of other cranial nerves which may be required to provide a qualified advisory opinion. ENT examination, as well as voice and speech audiometry, is mandatory for vestibular examination.

In the case of unilateral or asymmetric bilateral disorder of sound-conducting or sound processing functions, or their combined disorder, it is necessary to carry out one of the following procedures: pure tone audiometry, impedancemetry, oto-acoustic emission, registration of short-latent (brain stem) and long-latent (cortex) auditory evoked potentials. The results of the state of auditory function permit making certain focuses during vestibular examination and determining directions for further study of a sick person.

Schemes of vestibular surveys which include vestibular card surveys and a certain sequence of procedures were developed [6]. Scheme of vestibular examination includes:

1. The study of complaints, medical history, and past diseases using a standardized card or survey.

2. Investigation of spontaneous vestibular reactions (equilibrium functions, varieties of spontaneous, positional and pressor nystagmuses) and their registration.

3. Conducting vestibular experimental loads (functional stimulations) and their registration.

4. Analysis and evaluation of vestibular test results, making conclusions about the status of vestibular function and recommendations.

Special vestibular test cards or surveys include a list of general and specific complaints. The sensory subjective reaction—vertigo (the nature of the rotation of objects or their floating or self-rotation, the sense of failing, etc.)—is explained in detail. The direction of vertigo (left, right, up, down, chaotic) and postural disorders (while walking, in the darkness, in fatigue, during transport loads) should be determined as well as the presence of autonomic disorders (nausea, vomiting, changes in heart rhythm, changes in skin color, sweating). In cases of complaints about vertigo and postural disorders, attention is focused on the possibility of detecting specific objective spontaneous symptoms—registration of types of nystagmus and posturographic control of these complaints. Some patients pay attention to the fact that they have impaired vision fixation in vertigo. Visual performance is reduced, and fatigue occurs when using a personal computer or mobile phone. In the inter-onset, when there is no vertigo, vision fixation and visual acuity are restored.

The history of the disease is collected in detail: the sequence of its development and the combination with signs of disorders in other systems and organs (cardiovascular, neuro-psychiatric, endocrine, digestive, and musculoskeletal) and past diseases. Attention is paid to the presence of noise, its nature, the acuity, and asymmetry of hearing. Also the asymmetry of the pair of cranial nerves of V, VII, IX, and XII must be examined. Allergic or toxic manifestations are recorded during the survey.

In the course of clinical vestibular test, a large number of trials and tests have been accumulated for postural control. Some of them are of historical importance, and some are still in use, particularly, walking in a straight line, flank walking by steps to the right and left—for differential diagnosis of vestibular and cerebellar disorders.

Romberg's test (classical and sensitized) is the basis for determining the static and kinetic equilibrium in modern types of postural test techniques (in particular, stabilography—a mobile platform with processing of the center of "gravity" and Fourier oscillation analysis.). The speed of movement of the center of gravity in three directions (back and forth, left-right, up-down) is calculated quickly and accurately by a computer. Deviations in the performance of these methods are taken into account when assessing the degree of manifestation of disturbances of the equilibrium function. Postural tests are widely used in the differential diagnosis of peripheral and central balance disorders, for postural control during rehabilitation measures, for postural balance before and after cochlear implantation, for expert and prognostic purposes.

The next step in vestibular examination is the detection of spontaneous, positional, and pressor nystagmuses and registration of their characteristics [13, 14]. At first, nystagmuses can be evaluated visually as well as using Frenzel glasses (+10–12 diopters, which have the backlight inside). A type of spontaneous nystagmus is a positional nystagmus that occurs in one of the head positions and can change its parameters depending on its change. The positional nystagmus is of peripheral or central origin.

Applying pressure, fistula test is of great importance in vestibular field in cases when fistula, prefistula, or dyskinesia in the bony labyrinth is suspected. As a rule, its presence is associated with the destruction of the capsule of bony labyrinth in the purulent process in the middle ear and in the temporal bone. Pressor nystagmus occurs most frequently in the lateral semicircular canal but can often occur in the anterior and posterior semicircular canals. In the presence of a fistula, the pressor nystagmus is directed in the direction of thickening of the air, and in the case of rarefaction (decompression)—in the opposite direction. Tullio phenomenon is characterized by under acoustic loads with vertigo and nystagmus. The Tullio phenomenon is often a barrier to the use of sound-enhancing equipment and hearing aids. The presence of a fistula in the dynamics of clinical observation and surgery is specified at the MSCT.

Barany tests [22] continue to be the most common methods of functional stimulation in clinical practice for the study of the characteristics of induced nystagmus. They are called classic caloric and rotating. The essence of the induced nystagmus reaction in caloric stimulation according to Barany is explained by the different movements of the endolymph during its cooling or heating of the liquid. In the caloric test, the patient bends his head back at 60°. In this location, the lateral and semicircular canals occupy a position when their ampoules are on top and the smooth end is below [22].

The caloric test is generally well tolerated. It can be performed in the case of the integrity of the eardrum, even in the state of unconsciousness, but in the absence of other obstacles. Temperature regimes can be changed depending on the tasks of the examinations and the accepted schemes in certain clinics.

Barany rotary test causes angular acceleration. In this test, the subject with the eyes closed and the head tilted forward 30° rotates according to the program in a chair 10 times for 20 s. in the lateral plane of the semicircular canals. These channels are of particular importance in people's life, because most frequently they make movements in the horizontal plane [22].

During the rotating test to the right, after stopping the chair the movement of the endolymph in the left semicircular duct will be ampullopetal, that is, the post-lateral nystagmus reaction will be directed to the left according to Ewald's laws, and during the rotating test to the left, it will be directed to the right. The disadvantage of the probe is that each labyrinth cannot be inspected separately in isolation.

The Fitzgerald-Hallpike caloric test estimates the function of each of the lateral semicircular canals separately [1, 2]. Before examination, the pathology of the tympanic membrane is excluded, and the head is raised up to 30° forward, so that the lateral semicircular canals take a strictly vertical position, which will maximize the sensitivity of canals to thermal stimulation. Water at a temperature of 30 and 44°C is infused bilaterally (after 5–10 minutes) to the external auditory canal each time for 40 s. Electronystagmography (ENG) records horizontal and vertical nystagmus, which occurs during cold calorization toward irritation and during hot calorization, in the opposite direction. A difference of more than 25% indicates an asymmetric lesion.

When infused with hot water 44°C in the same amount, the endolymph molecules rise up, causing the ampullopetal movement of the endolymph, which causes a caloric nystagmus reaction toward the irritated ear. The main advantage of caloric stimulation is monaurality, which allows surveying each labyrinth separately. This advantage is especially important for otoneurology. The disadvantages are limited possibilities for perforated ear drums, traumas, and neoplasms of the outer, middle ear, and ear labyrinth.

Electronystagmography (ENG) and videonystagmography (VNG) record varieties of spontaneous nystagmus and experimental nystagmus reaction to functional stimulation using special mass-produced instruments, with computer-aided analysis of their quantitative and qualitative characteristics [1, 6, 10].

ENG is the first noninvasive quantitative and qualitative method of recording the difference of the corneo-retinal potential for the evaluation of spontaneous and induced nystagmuses in cold and warm caloric stimulation, as well as in rotational and optokinetic tests in the horizontal plane. ENG ensures accurate recording of results in patients with known vestibular disorders not only for clinical but for forensic and insurance medicine.

In caloric and rotational tests, the induced nystagmus reaction in the case of central vestibular syndrome is arrhythmic or dysrhythmic, with the presence of "silent fields," which indicates a violation of the central regulatory mechanisms of nystagmus (see dysrhythmic nystagmus in **Figure 1**).

At the same time, illusory sensory sensations—vertigo and autonomic reactions—arise, the degree of manifestation of which is taken into account when assessing the reactivity of the vestibular system. The more excitable it is, the greater and longer the illusory reactions will be.

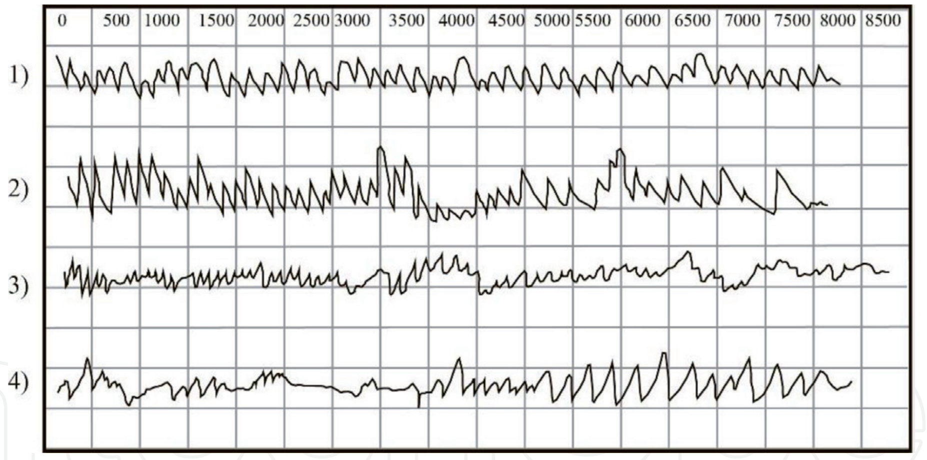

Figure 1.
ENG in caloric stimulation: (1) normoreflexia, (2) hyperreflexia, (3) hyporeflexia, and (4) dysrhythmia (obtained with permission from [6]).

Computer analysis of induced nystagmus responses to calorific and rotational stimulations can be performed every 10 s from the onset to attenuation, as also the duration of the induced and sensory responses can be determined and their changes tracked in the dynamics of the process and control of the treatment.

We would like to emphasize that caloric and rotational stimulations are based on the study of the functions of horizontal semicircular canal. It is considered that this is only an estimation of 20% of the functions of the vestibular system. However, the ability to capture the functions of horizontal semicircular canal is clinically important for otology and labyrinthology [2, 4].

The following variants of the state of the induced nystagmus reaction to functional loads are distinguished by ENG:

1. Normoreflexia.

2. Hyperreflexia, characterized by an increase in the qualitative and quantitative parameters of the induced nystagmus reaction on one side or on two sides. It indicates unilateral asymmetric or bilateral symmetric state of excitement of vestibular function; the symmetrical state of excitement of vestibular function is often registered at congenital and acquired kinetoses.

3. Hyporeflexia, which is characterized by a decrease in the qualitative and quantitative parameters of the induced nystagmus reaction on one side or on two sides. It indicates a one-way asymmetric or two-way symmetrical state of decrease in sensitivity of vestibular function. Symmetrical state of decrease in sensitivity in the absence of disturbances of the functions of equilibrium occurs in trained people of certain professions (pilots, athletes).

4. Areflexia is the complete absence of experimental nystagmus reaction on one side or two sides. It is confirmed by two stimuli—caloric and rotational.

5. Dissociated vestibular reactions are marked by dysrhythmia of experimental nystagmus with disharmony of all constituent reactions (vestibulo-sensory, vestibulo-vegetative, and vestibulo-somatic). This condition is observed in the central disorders of the vestibular function [6].

In addition to assessment of the condition of the vestibular function, the type of lesion, the degree of its manifestation, and stage of development will be determined.

There are three types of vestibular dysfunction: (1) peripheral, (2) central, and (3) mixed.

There are three stages of manifestation of vestibular dysfunction and three stages of development—compensation, subcompensation, and decompensation [6, 11].

ENG has some limitations. It is important to emphasize that ENG records the function of the lateral semicircular canals and does not capture information about the anterior and posterior semicircular canals and spherical and elliptical sacs. ENG testing is not sensitive to rotary, vertical, and other types of spontaneous and induced nystagmuses.

These examinations are now possible with the help of videonystagmography (VNG). VNG is the second noninvasive method which is increasingly used in clinical practice. On VNG, which is based on the principle of video telemetry of the eyeball movements, a video photo of spontaneous or positional nystagmuses is performed in different directions (vertical, horizontal, diagonal). It quickly and accurately captures horizontal and vertical eye movements, without artifacts (motion blinks or electrical noise when recording). VNG is performed with the eyes wide open. Eye movement is recorded with a camera recorder using a monocular and binocular mask. The resolution of the method is limited by the speed of the camera recorder shot (the most common currently available is the camcorder capacity of 100 frames per second).

Computer processing of video of pupil movements and light reflexes on the cornea are carried out, and two-dimensional image of eye movements is obtained. VNG registers Fitzgerald-Hallpike bithermal caloric stimulation with graphical image and digital computer analysis of its indices in relation to each other, which is important for clear determination of asymmetries in otoneurology (**Figure 2**).

Vestibular evoked myogenic potential (VEMP) testing has been studied in recent decades. In conducting this test, intense sound is used to stimulate one of the receptor otolith organs, the spherical sac. This stimulus elicits an electrophysiological response through the lower branch of the vestibular nerve.

The vestibulospinal reaction with relaxation in the ipsilateral sternocleidomastoid (SCM) muscle is measured by changing its activity. It is recorded using electromyography (EMG). SCM muscle is used because the response to this muscle is considered reliable due to the availability of EMG technology with electrodes on the skin surface. Initially, VEMP is recorded with a background muscle contraction and

A) B)

Figure 2.
(A) Equipment for videonystagmography. (B) Examination of a patient with a videonystagmograph (from our own archive).

then with a 90–100 dB acoustic click stimulation for 30 s from the ear to which the acoustic stimulus is applied. The VEMP test is considered promising for the assessment of labyrinth in norm and pathology [23].

Recently, methods of examination with the use of magnetic coils and scanning laser ophthalmoscopes have become increasingly important. The main purpose of these methods is differential diagnosis of peripheral and central vestibular and oculomotor disorders.

In patients with acute pathology of the external, middle, and inner ears of inflammatory nature and other genesis, functional loads at vestibulometry are performed with the implementation of rotational stimulation. Caloric stimulation is limited. With purulent chronic otitis media, complicated by cholesteatoma, retraction pockets, and other pathology, fistula (pressor) tests and rotational stimulation with mandatory appointment of MSCT with contrast are required.

In bilateral or asymmetric sensorineural hearing loss of different genesis, vestibulometric examination is performed using caloric and rotational stimulations, with consultations of psycho-neurologists, hematologists, vertebrologists, endocrinologists, and toxicologists.

The otoneurologic examination should necessarily include the studies which make it possible to detect structural changes in the state of the auditory and vestibular systems in the ear labyrinth, temporal bone, cervical spine, skull, and brain. They are performed using multispiral computed tomography (MSCT) and magnetic resonance imaging (MRI) with contrast.

Data on the functional status of sensory systems are needed for clinical physicians to obtain expanded information on diseases with consideration of morphological, etiological, and pathogenetic factors for nosological diagnosis.

To make conclusions the most commonly used classification of vestibular syndromes is used according to the syndromotopic scheme:

Peripheral and central syndromes are distinguished by this scheme. The peripheral syndrome includes labyrinthine and radicular ones. Central syndromes are divided into subtentorial and supratentorial. Subtentorial syndromes are subdivided into subnuclear, nuclear, and super-nuclear. Supratentorial syndromes include diencephalic-hypothalamic, subcortical, and cortical. Often combined vestibular syndromes are identified.

This classification is not universal. However, in the creation of a universal one, as emphasized by researchers [3–5], the obstacle is the "ubiquity" of the vestibular representation in the CNS. In addition, the subtle sensitivity to various changes in the internal and external environment and the globality of the vestibular symptom complex with similar symptoms, known as "vestibular triad," complicate the development of the principle of classifications of vestibular disorders according to the nosological principle.

Due to the anatomical, physiological, and functional closeness of the receptor structures of the auditory and vestibular systems, given the specificity of their disorders in the ear labyrinth, it is rational to isolate the peripheral cochleovestibular syndrome. Specific changes in the central departments of the vestibular and auditory systems are the bases for the formation of the central audio-vestibular syndrome and their combination—for mixed audio-vestibular syndrome.

6. Conclusions

1. The presented anatomical and physiological bases of the vestibular system indicate the structural and functional interrelation of its peripheral and central departments in normal and pathological conditions.

2. The parity and symmetry of the anatomical and physiological localizations of the vestibular and auditory systems play a crucial role in the spatial orientation in the state of motion and rest, in the formation of motor, sensory memory, and cortical stimulation of their activity.

3. The vestibular system is closely linked to the departments of the central nervous system, cerebral circulation, organs, and other systems of the body, so before others, it responds to the smallest changes in the internal and external environment.

4. The priority of changes in the central departments of the vestibular system under the influence of radiation has been proven.

5. It is established that the inhibitory processes in the vestibular and auditory systems as a result of radiation from the Chornobyl accident can be regarded as a symptomocomplex of premature aging of the organism with a decrease in cognitive and emotional-volitional reactions.

6. Along with the widespread use of objective electrophysiological methods of registration, in particular, electronystagmography, new diagnostic tests have been developed. The method of videonystagmography, scanning laser ophthalmoscopes, and magnetic coil examinations are gaining popularity. They contributed to the study of vestibular dysfunction in the positional paroxysmal vertigo of peripheral and central origins.

7. Three types of effective therapeutic and prophylactic positional provocative maneuvers have been implemented in clinical practice. They were developed by taking into account the anatomical and physiological features of vestibular system peripheral and central components.

Further experimental and clinical studies are needed to explore regarding the receptor functions of three semicircular canals and the otolith apparatus of the vestibular system. Developing new and refining existing objective methods for examining and recording varieties of spontaneous and experimental nystagmus not only in horizontal but also in other planes are necessary to enhance the assessment of vestibular functions in normal and pathological conditions.

The solutions to the important problems of vocational guidance; professional selection and career aptitude in sports, arts, maritime, aviation, and space technologies; and jobs related to ground and underground transportations are extremely needed. These professions are associated with heavy loads on the vestibular system. Particularly high demands are placed not only on vestibulo-vegetative and postural stability but also on vestibulo-sensory reactions. The development of preventive measures for safety and high endurance of the vestibular system, along with modern technological advancements, is of high priority.

Author details

Dmytro Illich Zabolotnyi and Nina Serhiivna Mishchanchuk*
O.S. Kolomiychenko Institute of Otolaryngology, National Academy of Medical Sciences of Ukraine, Kyiv, Ukraine

*Address all correspondence to: nsmisch@i.ua; nsmishch@gmail.com

IntechOpen

© 2020 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Gulya AJ, Minor LB, Poe D, editors. Glasscock-Shambaugh Surgery of the Ear. Trans. from English; Karpichenko SA, Editor. 6th ed. PH Panfilov: Moscow; 2015. 864p

[2] Bronstein A, Lempert T. Dizziness (A Practical Approach Diagnosis Management). Trans. from English; Parfenova VA, Editor. GEOTAR-media: Moscow; 2010. 216p

[3] Veber P, editor. Vertigo and Disequilibrium: A Practical Guide to Diagnosis and Management. 2nd ed. New York: Thieme; 2017. 232p

[4] Brandt T, Dieterich M, Strupp M. Vertigo and Dizziness. Common Complaints. Trans. from English; Timonina N, Editor. Moscow: Practica; 2009. 200p

[5] Jáuregui-Renaud K, Gutierrez-Marquez A, Viveros-Rentería L, Ramos-Toledo V, Gómez-Alvarez F. Neurotology symptoms at referral to vestibular evaluation. Journal of Otolaryngology - Head & Neck Surgery. 2013;**42**(1):55. DOI: 10.1186/1916-0216-42-55

[6] Babiyak VI, Lantsov AA, Bazarov VG. Clinical Vestibulology: A Guide for Doctors. St. Petersburg: Gippokrat; 1996. 332p

[7] Purkyně E. On the forms of the cells of the anthers, with fibrous and also on the grains, pollinarium: commentary on phytochemical. J.D. costs Grusonii; 1830. 112p

[8] Flourens P, Flourens P-M-J, Rolando L. Recherches Expérimentales Sur Les Propriétés Et Les Fonctions Du Système. Chez Crevot; 1824. 384p

[9] Evald JR. Physiologische Untersuchungen Bber Das Endorgan Des Nervus Octavus Wiesbaden. Germany: Bergman; 1892

[10] Babiyak VI, Hoffman VR, Nakatis YK. Neurootorinolaryngology: A Guide for Doctors. Gippokrat: St. Petersburg; 2002. 726p

[11] Babiyak VI, Yanov YK. Vestibular Functional System.St. Gippokrat: Petersburg; 2007. 426p

[12] Blakley BW, Chan L. Methods considerations for nystagmography. Journal of Otolaryngology - Head & Neck Surgery. 2015;**44**(25). DOI: 10.1186/s40463-015-0078-2

[13] Kim HA, Bisdorff A, Bronstein AM, Lempert T, et al. Hemodynamic orthostatic dizziness/vertigo. Diagnostic Criteria. 2019;**29**(2-3):45-56. DOI: 10.3233/VES-190655

[14] Cohen HS. A review on screening tests for vestibular disorders. Journal of Neurophysiology. 2019;**122**(1):81-92. DOI: 10.1152/jn.00819.2018

[15] Zhou YF, Wang ZL, Zheng HZ, Zhang HW, et al. Application of modified Dix-Hallpike maneuver in the diagnosis of posterior semicircular canal benign paroxysmal positional vertigo. Lin Chung Er Bi Yan Hou Tou Jing Wai Ke Za Zhi. 2019;**33**(6):512-514. DOI: 10.13201/j.issn.1001-1781.2019.06.009

[16] Imai T, Okumura T, Sato T, Takeda N, et al. Effects of interval time of the Epley maneuver on immediate reduction of positional Nystagmus: A randomized, controlled, non-blinded clinical trial. Frontiers in Neurology. 2019;**10**:304. DOI: 10.3389/fneur.2019.00304

[17] Gupta AK, Sharma KG, Sharma P. Effect of Epley, Semont maneuvers and Brandt-Daroff exercise on quality of life in patients with posterior semicircular

canal benign paroxysmal positional vertigo (PSCBPPV). Indian Journal of Otolaryngology and Head & Neck Surgery. 2019 Mar;**71**(1):99-103. DOI: 10.1007/s12070-018-1322-7

[18] Tavartkiladze GA. Guidelines for clinical audiology. Moskva: Meditsina; 2013. 676p

[19] Lopez-Escamez JA, Dlugaiczyk J, Jacobs J, Lempert T, et al. Accompanying symptoms overlap during attacks in Menière's disease and vestibular migraine. Frontiers in Neurology. 2014;**5**:265. DOI: 10.3389/fneur.2014.00265

[20] Mischanchuk N, Sushro Y, Buzunov V, Fedirko PH. Sensory organs. In: Cerdiuk A, Bebeshko V, Bazyra D, Yamashita S, editors. Chapter 18. Health Effects of the Chornobyl Accident-A Quarter of Century Aftermath. Kyiv-Nagasaki: DIA; 2011. pp. 491-532

[21] Zabolotnyi DI, Mishchanchuk NS. Vestibular and acoustic dysfunctions in clean-up workers of Chornobyl accident (30 years of follow-up). Problemy Radiacijnoyi Medytsynyi Radiobiologii. 2016;**21**:218-237. (in Ukrainian)

[22] Barany R, Ibershoff AE. Physiology and Pathology of the Semicircular Canals; Being an Excerpt of the Clinical Studies of Dr. Robert Barany with Notes and Addenda Gathered from the Vienna Clinics. New York: P. B. Hoeber; 1910. 66p

[23] Semmanaselvan K, Vignesh SS, Muthukumar R, Jaya V. Vestibular evoked myogenic potentials after Epleys manoeuvre among individuals with benign paroxysmal positional vertigo. Indian Journal of Otolaryngology and Head & Neck Surgery. 2019 Jun;**71**(2):195-200. DOI: 10.1007/s12070-019-01581-6