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КАФЕДРА НОРМАЛЬНОЙ АНАТОМИИ
КАФЕДРА ОПЕРАТИВНОЙ ХИРУРГИИ И ТОПОГРАФИЧЕСКОЙ АНАТОМИИ

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ФУНКЦИОНАЛЬНАЯ АНАТОМИЯ ГЛАЗА И СВЯЗАННЫХ С НИМ СТРУКТУР

FUNCTIONAL ANATOMY OF EYE AND RELATED STRUCTURES

Учебно-методическое пособие

Минск БГМУ 2020

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Описано строение глаза и связанных с ним структур. Отражена функциональная анатомия оптической системы, аккомодационного аппарата, гидродинамики глаза, бинокулярного зрения, слезного аппарата, особенности проводящего зрительного пути и кровоснабжения органа зрения, а также вопросы его развития.

Предназначено для студентов медицинского факультета иностранных учащихся, обучающихся на английском языке.

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INTRODUCTION

Recommended anatomy textbooks set out traditional representations about the structure of the organ of vision. At the same time, the development of new clinical methods of research allows us to clarify and detail current issues of applied anatomy of the eye such as the mechanism of accommodation and additional ways of outflow for the aqueous humor. The factors contributing to the formation of binocular vision are described. Information about the orbital muscle is given. The anatomy of the lacrimal apparatus is presented and features of the tear film structure are explained. The blood supply to the eye, and its age related anatomy is systematized; examples of anomalies of the organ of vision and the mechanisms of their development are given. Anatomical terms are presented taking into account the latest edition of the International Anatomical Nomenclature.

OPTICAL SYSTEM OF THE EYE

The human eye is a complex optical system* consisting of cornea, aqueous humor, lens and vitreous body (fig. 1). The main function of this system is the conduction of light and its refraction to focus an image on the retina.

The condition for conducting light is transparency of cornea, lens, aqueous humor and vitreous body. The transparency of all these structures is provided by the following factors:

– lack of blood vessels;
– specific chemical composition (water and dissolved substances);
– the orderly arrangement of collagen fibrils of cornea.

Nutrients to the avascular **cornea** are delivered with tear, aqueous humor, as well as blood of the vessels of the corneal limbus. In the case of lack of nutrition of the cornea and hypoxia, ingrowth of the vessels into the cornea occurs, which is accompanied by a decrease in its transparency. The violation of corneal transparency can also be caused by a change in its water content, as well as by clouding.

The **aqueous humor** must be completely transparent in order for rays of light to pass through without hindrance. In its composition aqueous humor is similar to blood plasma, because it is formed by filtration from the blood vessels of the ciliary processes of the ciliary body. The appearance of blood, leukocytes or fibrin (for example, in trauma or inflammation of the eye) in aqueous humor leads to a decrease in its transparency.

* By the term optical system of the eye, used in the clinic, in anatomy it means the inner core of the eye.

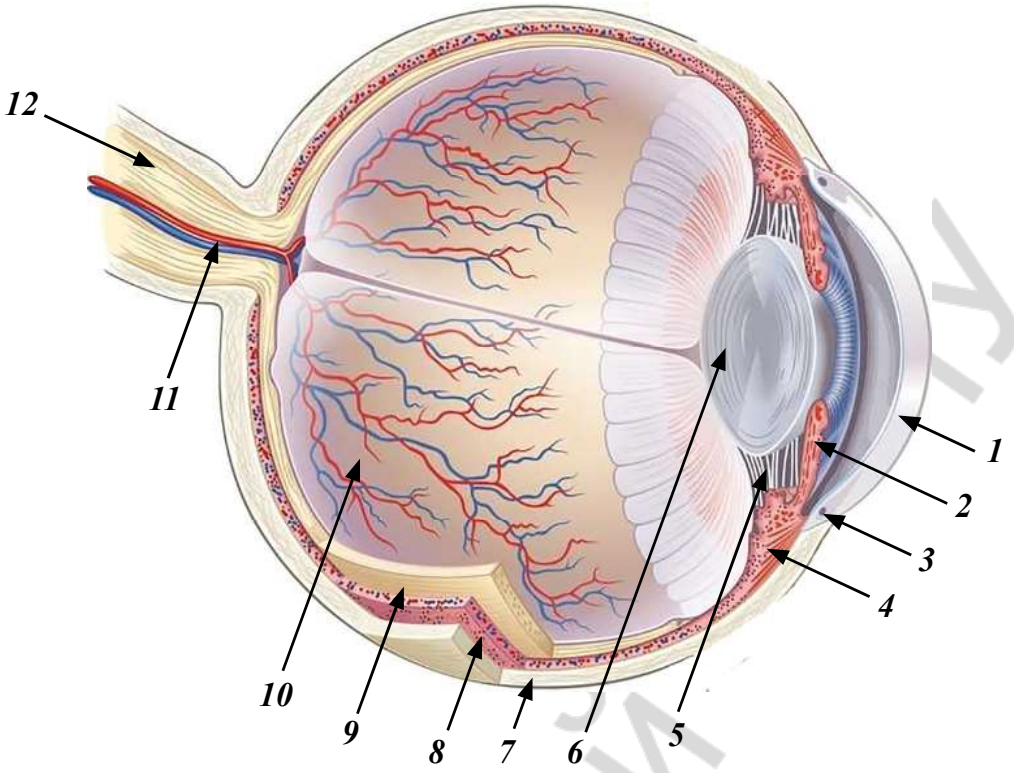

Fig. 1. The eyeball (sagittal cut):
1 — cornea; *2* — iris; *3* — scleral venous sinus; *4* — ciliary body; *5* — zonular fibres; *6* — lens; *7* —sclera; *8* — choroid; *9* — retina; *10* — vitreous body; *11* — central retinal artery and vein; *12* — optic nerve

The **lens** normally remains transparent despite the fact that the formation of lens fibres from the epithelium of the capsule occurs throughout life and the fibres are compacted in the central portion with age. Due to the absence of vessels, inflammatory processes cannot occur in the lens. Most often its transparency decreases due to a clouding — cataract. The latter is caused by the change in the chemical composition of the lens, as well as by the incorrect development of the lens, in particular, by the disruption of the reverse development of the artery of the vitreous body and/or the vascular bag of the lens.

The **vitreous body** is a colourless gelatinous mass that fills the space in the eye between the lens and the retina. 99 % of the vitreous body is water, which determines its transparency. With age, small clouding can develop in the vitreous body, casting a shadow on the retina that is perceived as “flying flies”. The transparency of the vitreous body is impaired by trauma and the appearance of blood or inflammatory discharge in it, as well as by congenital pathology, for example, by the preservation of the artery of the vitreous body.

Light rays are known to be directed in a straight line. Focusing the beams on the retina is necessary to obtain a clear image. This property of the eye is realized through light refraction. The total refractive power of the ocular media (cornea, aqueous humor, lens and vitreous body) is about 60 diopters.

The most refractive power (40 diopters) is in the cornea, because it is located on the boundary of media (air-liquid) and differs in its density and curvature of the surface. Naturally, even small changes in the curvature, density, or relief of the cornea surface can disrupt its ability to refract light rays and significantly reduce visual acuity.

The second most powerful (20 diopters) refracting medium of the optical system of the eye is the lens. However, unlike the cornea, the refracting force of which is constant, the refracting force of the lens can vary and increase upon accommodation to 30 diopters.

The refracting force of aqueous humor and the vitreous body is insignificant — about 3 % of the total refracting force of the eye.

Questions for self-control:

1. List the structures that refer to the optical system of the eye.
2. Name the main properties of the optical system of the eye.
3. What factors provide the transparency of the cornea?
4. List the possible reasons for the decrease in transparency of the cornea, lens, aqueous humor and vitreous body.
5. What is the strongest refracting medium of the eye and why?

ACCOMMODATION OF THE EYE

The refractive power of the optical system of the eye is constantly changing, which is related to accommodation. **Accommodation** is a dynamic adaptation mechanism that provides a clear vision of objects at different distances from the eye.

Until recently, according to Helmholtz‘s classical theory, accommodation was seen as an active process only at the moment the look is directed to closely spaced objects. Now it is established, that accommodation for long distance is also an active process. Accommodation is based on the dynamic balance of the opposing forces of three structures: lens, choroid and ciliary muscle. Of these, only the ciliary muscle is active. It consists mainly of three types of fibres (meridional, circular and radial) that essentially function as separate muscles. During accommodation the power of lens and choroid itself is the result of the elastic properties of these structures.

At the moment of changing focus from distant objects to closely located ones there is a contraction of meridional and circular fibres of the ciliary muscle. As a result, the ciliary body, and with it the base of the zonular fibres, is shifted toward the lens, the tension of the lens capsule is reduced, and the lens becomes more convex due to its elasticity. It increases the refractive power of lens, and the retina focuses the image of closer objects (fig. 2, fig. 3). At the same time, the choroid stretches like a spring.

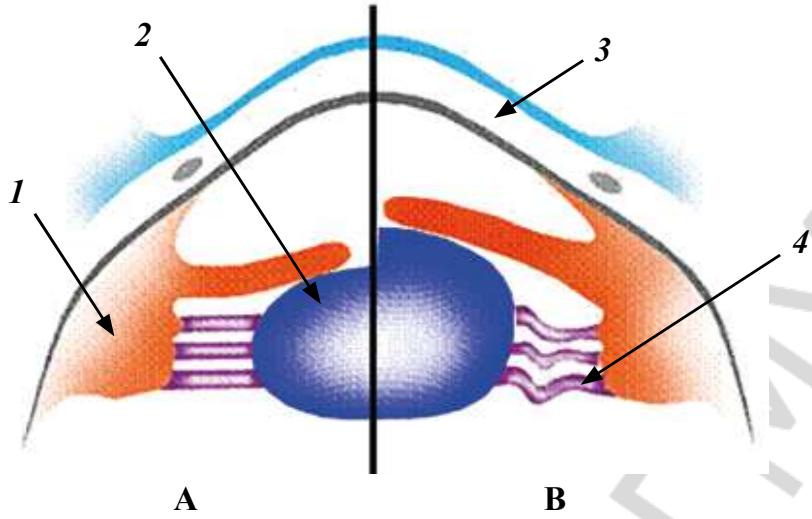

Fig. 2. Accommodation:
A — to a far point; *B* — to a near point;
1 — ciliary muscle; *2* — lens; *3* — cornea; *4* — ciliary zonule

The depth of the anterior chamber decreases due to the lens displacement to the cornea. The pupil narrows, that increases the clarity of the image of close objects.

In order to realize accommodation to focus on distant objects, the radial fibres of the ciliary muscle contract. Therefore, the ciliary body, and the base of the zonular fibres together with it, are moved backward away from the lens. The capsule of the lens is strained by the force of the elastic choroid, and the lens is flattened.

The accommodation capacity of the eye decreases with age due to the reduced elasticity of lens, choroid and the involution of the meridional fibres of the ciliary muscle. For example, if the lens of a newborn extracted from the eye at once takes a spherical shape, the lens of a 60-year-old person remains flat. Reduced accommodation capacity becomes tangible by 40–45 years and requires optical correction.

Questions for self-control:

1. What is accommodation?
2. What is the basis of accommodation?
3. Describe the mechanism of accommodation for a distant point.
4. Describe the mechanism of accommodation for a near point.
5. List the changes in the eye that are caused by the accommodation for a distant point.
6. List the changes in the eye that are caused by the accommodation for the near point.
7. How does the activity of accommodation change with age?

HYDRODYNAMICS OF THE EYE

Aqueous humor fills the chambers of the eye and refracts light. It also performs two other functions: nutrition of the avascular structures of the eye and creation of intraocular pressure, which contributes to the abutment of the layers of the eyeball to each other.

Aqueous humor being constantly produced is formed from blood and returns to blood. Aqueous humor is formed by the ciliary processes of the ciliary body and flows mostly into the scleral venous sinus (Schlemm's canal), located in the iridocorneal angle. This angle is filled with connective tissue in the form of a sponge or mesh and consists of intertwining trabeculae. Through the spaces between trabeculae aqueous humor, under the force of osmotic pressure, seeps into the scleral venous sinus (fig. 3).

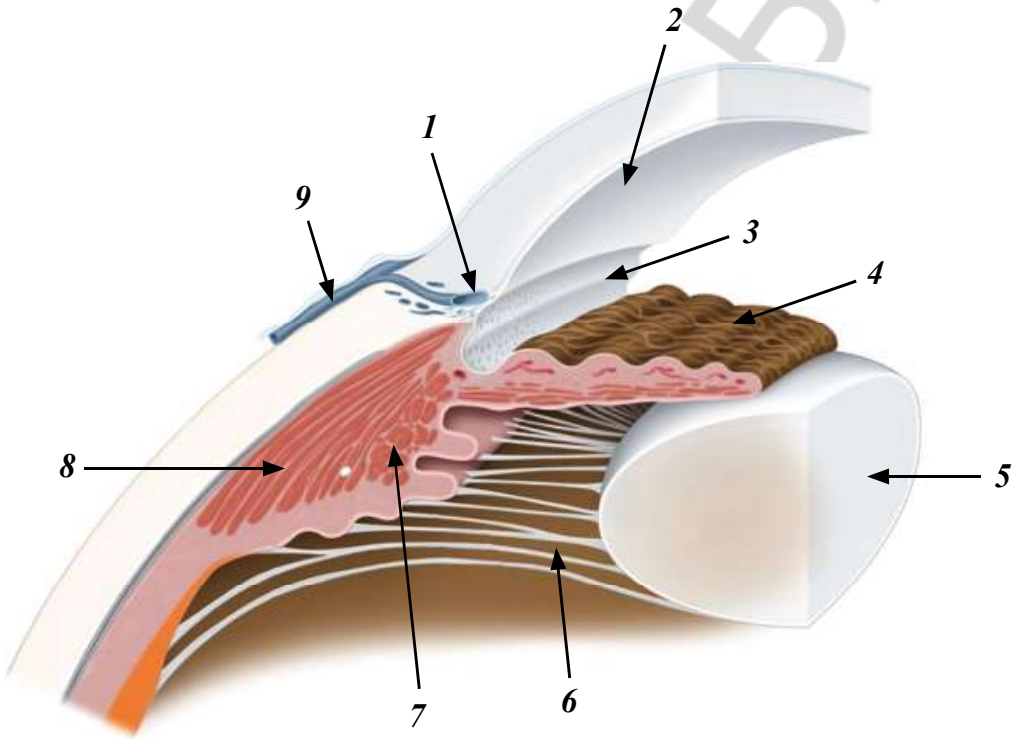

Fig. 3. Iridocoorneal angle:
1 — scleral venous sinus; *2* — cornea; *3* — trabecular network; *4* — iris; *5* — lens; *6* — zonular fibres; *7* — circular fibres of the ciliary muscle; *8* — meridional fibres of the ciliary muscle; *9* — intra-scleral venous plexus

In addition to the main path of aqueous humor outflow to the Schlemm's canal there are two additional return pathways: the uveoscleral pathway and the pathway through the intervaginal spaces of the optic nerve.

The uveoscleral pathway is the outflow of aqueous humor through the spaces of the vascular layer of eyeball and sclera. Knowledge of the uveoscleral outflow

pathway is necessary to understand the mechanism of action of modern eye drops which reduce intraocular pressure by improvement of the uveoscleral outflow. Until recently, eye pressure was reduced only with those drops which narrow the pupil, as well as reduce the production of aqueous humor.

Intervaginal spaces are the spaces between optic nerve sheaths through which the aqueous humor flows into the spaces between the meninges of the brain. Thus, the circulation of the cerebrospinal fluid and aqueous humor is interrelated, as evidenced by the higher intraocular pressure at increased pressure of the cerebrospinal fluid.

Disturbance of the normal conditions of aqueous humor outflow, for example, blockage of the iridocorneal angle by the iris during the dilation of the pupil, pigment, fibrin or remains of the embryonic tissue may lead to the increase of intraocular pressure, i.e. glaucoma development. Glaucoma is a significant problem and one of the main causes of blindness all over the world. A decrease in the intraocular pressure (hypotonia) can lead to the detachment of eyeball layers.

Questions for self-control:

1. Describe the structures of the iridocorneal angle.
2. Name and characterize the ways in which the aqueous humor flows out of the eye.
3. What is the uveoscleral path of aqueous humor outflow?
4. List the possible causes of abnormal outflow of aqueous humor from the eye.

OCULAR MUSCLES

The ocular muscles can be divided into extra- and intra-ocular muscles (fig. 4).

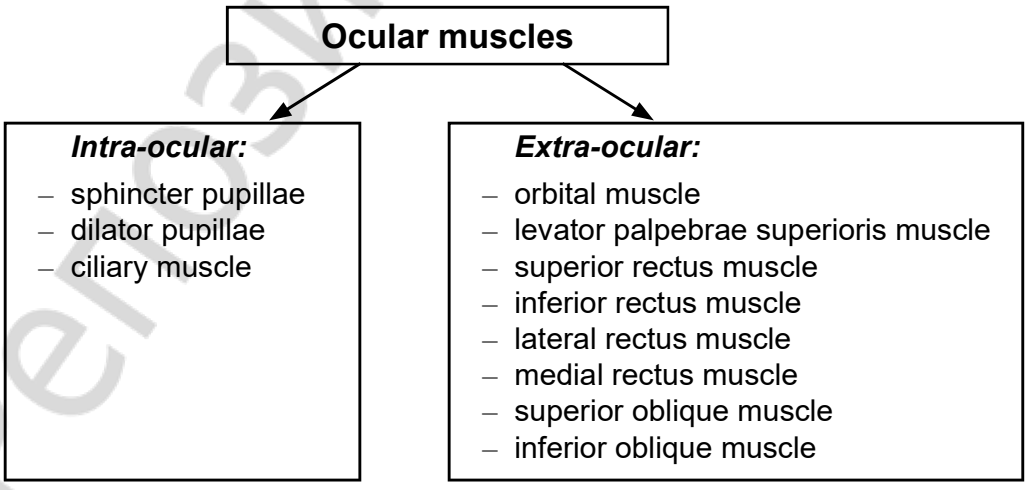

Fig. 4. Classification of the ocular muscles

Intra-ocular muscles include sphincter pupillae, dilator pupillae and ciliary muscles. The extra-ocular muscles are the orbital muscle, levator palpebrae superioris muscle, superior rectus, inferior rectus, lateral rectus, medial rectus, superior oblique and inferior oblique muscles.

All extra-ocular muscles (fig. 5) except the inferior oblique and orbital muscles, originate from a common tendinous ring located in the circumference of the optic canal and are directed forward, forming a «muscular funnel».

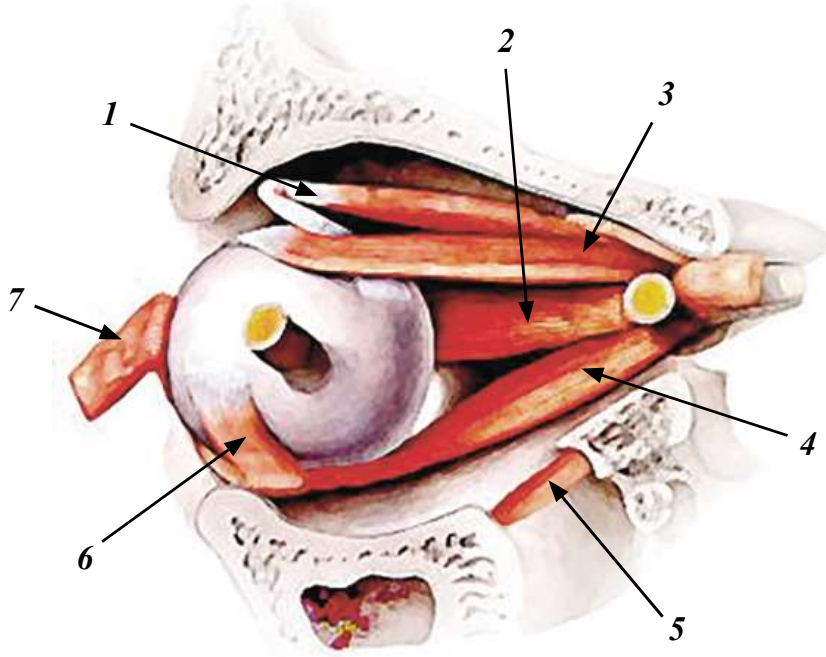

Fig. 5. Muscles of the eye (left eye: the lateral aspect, the optic nerve is dissected, the eyeball is dislocated):
1 — superior oblique muscle; *2* — medial rectus muscle; *3* — superior rectus muscle; *4* — inferior rectus muscle; *5* — orbital muscle; *6* — inferior oblique muscle; *7* — lateral rectus muscle

The line of the rectus muscles' attachment on the surface of the sclera forms something like an unfolding spiral, and the closest to the corneal limbus is the attached tendon of the medial rectus muscle, then – the tendons of the inferior, lateral and superior rectus muscles (fig. 6).

The most powerful is the medial rectus muscle, which is connected with the necessity of constant bringing together (convergence) of both visual axes on the focused object.

The rectus muscles move the eyeball in the direction that corresponds to the name of muscle. Both oblique muscles rotate the eyeball outwards, with the turning it down by the superior rectus muscle and the turning it up by the inferior rectus muscle.

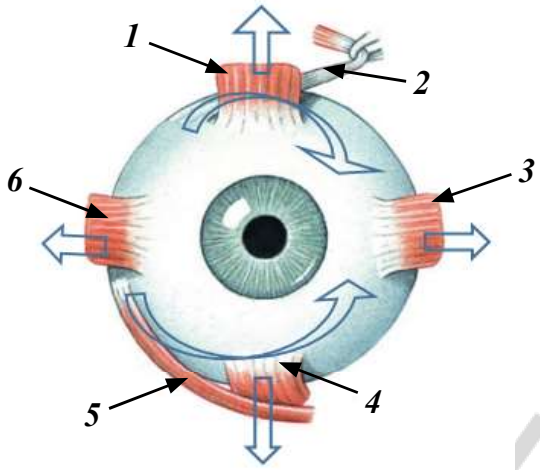

Fig. 6. Right eyeball (anterior view):
1 — superior rectus muscle; *2* — superior oblique muscle; *3* — medial rectus muscle; *4* — inferior rectus muscle; *5* — inferior oblique muscle; *6* — lateral rectus muscle (blue arrows show the direction of movement of eyeball in relation to associated muscle contraction)

The orbital muscle is located in the inferior orbital fissure. It carries out the following functions:

– influences the position of the eyeball: the increased tone of the orbital muscle can cause protrusion of the eye, whereas its functional insufficiency (for example, when the vegetative sympathetic nerves, from which this muscle gets its innervation, are affected) can result in the eyeball retraction;

– affects venous outflow from the eye (the anastomoses connecting the ophthalmic veins with the pterygoid venous plexus pass between the fibres of this muscle).

Questions for self-control:

1. List the ocular muscles.
2. What muscles are referred to extra-ocular muscles?
3. What functions do the extra-ocular muscles perform?
4. What is the orbital muscle? What functions does it perform?

BINOCULAR VISION

Binocular vision (stereoscopic vision) is vision obtained by merging the images of both eyes into a single three-dimensional image. The key characteristic of binocular vision is a more accurate estimation of the depth of space.

You can do the following experiments to understand the idea of the binocularity of vision. Roll a tube from a sheet of paper, put it in front of one eye and look through it. Near the end of the tube, but in front the second eye, place the palm. In binocular vision, images visible through both eyes are superimposed. As a result, you will see

in your palm the hole formed by the tube and there are objects visible through it. The second experiment is with two ordinary pencils. Hold one pencil horizontally in your right hand, the second — in your left hand. Try to get the tip of one pencil into the tip of the second. You can easily do it if both eyes are open. Then close one eye and do the same — you will miss. When looking at an item in front of you, we close one eye, we won't see any difference because the image of the same subject is presented twice (in the right and left eyes), so we perceive it as one visual image.

The prerequisite for binocular vision is the presence of the optic chiasm. Binocular vision requires joint coordinated action of both eyes. In order to provide the movement of the eyeball as a whole in all possible directions it would be enough to have just three muscles working alternately, or in pairs. In fact, there are twice as many muscles — four rectus and two oblique, because it is necessary to provide extremely subtle and accurate sympathetic eye movements. Each eye must «see» the same, otherwise the focused object will be presented as bifurcated, and in the symmetrical areas of the retina the unmatched images will be reflected, as in the case of squint. The function of the ocular muscles to coordinate eye movements is controlled by the central nervous system. In order to form binocular vision, it is necessary to be able to bring together both visual axes on the focused object, i.e. the ability to converge. The correct position of the eyeballs in their orbits plays an important role in the binocularity of vision.

Questions for self-control:

1. What is binocular vision?
2. What conditions are necessary for binocular vision?
3. In what ways can binocular vision be tested?

BLOOD SUPPLY TO THE EYE

Even those people who are unfamiliar with anatomy know something about the blood supply to the eye. Who is not aware of cases of redness of eyes after the sleepless night or cold? Also you can observe the effect of red eyes of «drakula» on photographs taken with a flash.

All parts of the eye, except cornea and lens, are more or less enriched with blood vessels, but they get blood from not one but two systems of vessels. One of them is the system of the **central retinal artery**, and the second is the system of the **ciliary arteries** (fig. 7). Both systems come from the ophthalmic artery, the largest branch of the internal carotid artery, that passes, along with the optic nerve, through the optic canal. These two vascular systems do not anastomose with each other. Therefore, blockage of the central retinal artery or its branches causes ischemic retinal infarction with irreversible changes.

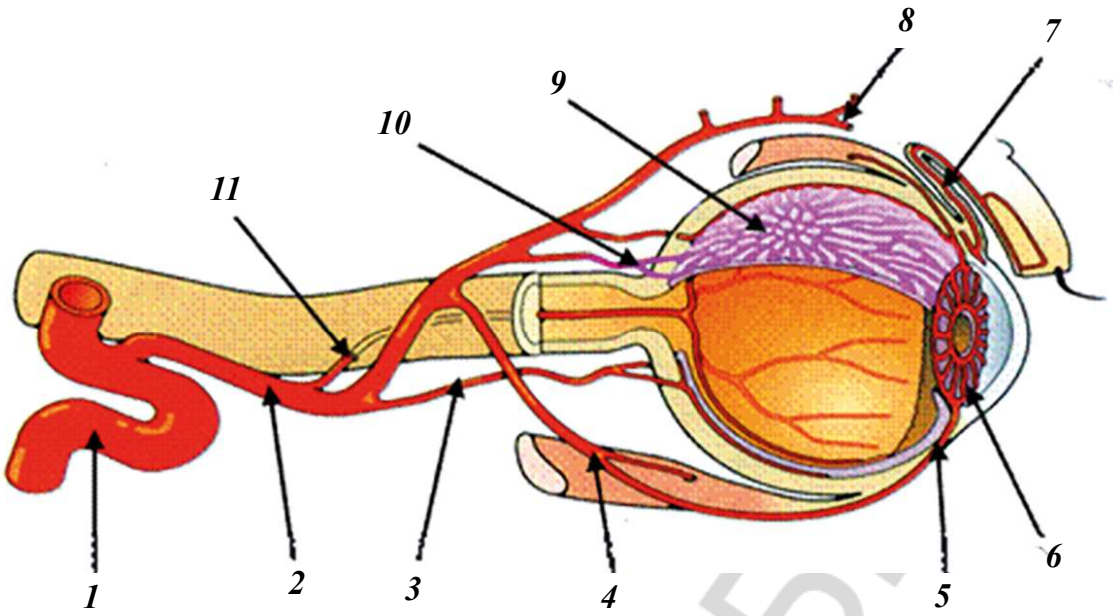

Fig. 7. Arterial blood supply to the eye:
1 — internal carotid artery; *2* — ophthalmic artery; *3* — long posterior ciliary arteries; *4* — muscular arteries; *5* — anterior ciliary arteries; *6* — major circulus arteriosus of iris; *7* — conjunctival arteries; *8* — supraorbital artery; *9* — choroid; *10* — short posterior ciliary arteries; *11* — central retinal artery

The only blood vessels of the human body which are available for life-long non-invasive observation are the central retinal artery and vein. Their assessment during ocular fundus examination is a kind of "monitor" of the health state of the whole organism. In the case of ocular fundus examination (ophthalmoscopy) the pink light reflex is observed. The reflex is formed due to the vessels of the choroid, which are reflected through the transparent retina.

The posterior (short and long) and anterior ciliary arteries start from the ophthalmic artery. The choroid itself receives blood from the short posterior ciliary arteries, and the ciliary body and iris get it from the long posterior and anterior ciliary arteries. Such isolation of the blood supply to the parts of the vascular layer of the eyeball causes a different clinical picture of inflammation of the anterior section of the vascular layer — iris and ciliary body (iridocyclitis) and posterior — choroid (choroiditis). However, the presence of anastomoses between the ciliary arteries do not exclude the possibility of a distinguished lesion of the whole vascular layer (uveitis, from the word "uvea"). The anterior ciliary arteries and the posterior long ciliary arteries form a vascular network around the cornea, being involved in its nutrition. In the case of the inflammation of both cornea and vascular layer, the vessels of this network become expanded, which causes the clinical symptom of pericorneal injection as a continuous pink-purple crown around the cornea.

Veins of the eye accompany arteries but do not correspond to them completely. Blood outflow from the eyeball occurs into the vorticose veins. These veins

begin in the vascular layer of the eyeball with small trunks, which are directed radially to one central point (to the beginning of the vorticose vein). Since these small veins are not straight, but are arched and bent in one direction, their pattern is similar to a whirlpool (vortex), where the name of the vorticose veins comes from. From the vorticose veins blood is directed into the superior and inferior ophthalmic veins. Blood flows out from the ophthalmic veins in three directions:

– cavernous sinus;
– pterygoid venous plexus;
– superficial veins of face.

Facial veins have no valves. They are widely anastomosed with the ophthalmic veins, the veins of the nasal cavity and the ethmoid sinus, which makes it possible for an infection to spread from the facial skin (abscesses, etc.) or from the paranasal sinuses into the ophthalmic veins and then further into the cavernous sinus with the development of its thrombosis. The largest anastomosis between the veins of the face and the ophthalmic veins is the angular vein connecting the facial vein to the superior ophthalmic vein.

In the human embryo the central retinal vessels give branches, which pass forward through the vitreous body to the lens capsule (so called hyaloid vessels), which normally disappear before birth.

Questions for self-control:

1. Name the source of blood supply to the eye.
2. Name the arterial systems in the eye.
3. What arteries provide the nutrition of the retina?
4. What arteries supply to the sclera, the choroid, the ciliary body and the iris?
5. What is the cause of the isolated inflammation of the anterior segment of the vascular layer of the eye (iridocyclitis) and the posterior segment of the vascular layer (choroiditis)?
6. In what directions does blood flow from the eye?
7. What makes infection possible to spread from the skin of the face or from the paranasal sinuses into the eye and then further into the cavity of skull? What clinical significance does it have?

LACRIMAL APPARATUS

Formation of tear. Tear is a complex liquid, that is produced not only by the lacrimal glands (main and accessory), but also other glands (tarsal, conjunctival, etc.) and corneal cells.

The lacrimal gland is a paired organ located in the upper lateral part of the orbit. In the lacrimal gland two parts are distinguished: orbital and palpebral. The

inferior surface of the lacrimal gland can be observed from the side of the conjunctiva at eversion of the upper eyelid and a strong turn of the eyeball inside. The excretory ducts of both parts of the lacrimal gland (20–30 in total) open in the outer part of the superior conjunctival fornix, that creates a similarity to a shower, from which tear enters the conjunctival sac and moisturises the anterior surface of the eyeball. Besides the main lacrimal gland (fig. 8), in the conjunctiva there are accessory lacrimal glands, the secretion of which also comes into the lacrimal sac. The accessory lacrimal glands function constantly, whilst the main lacrimal gland provides mainly reflex lacrimation (crying) under the action of a variety of irritants upon the mucous membrane of the eye or nose.

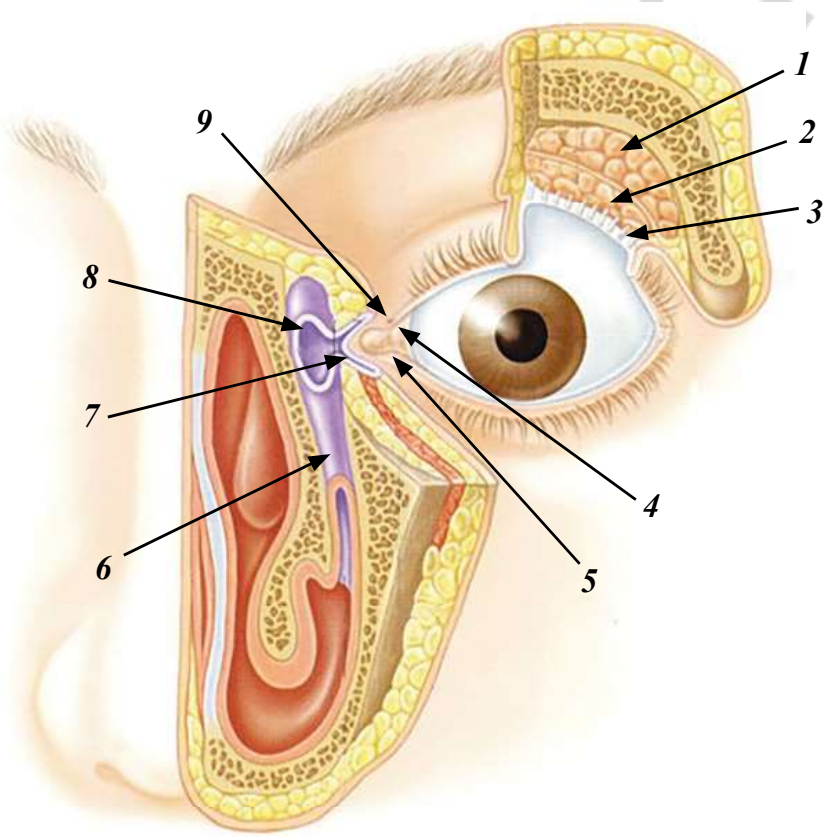

Fig. 8. Lacrimal apparatus:
1 — orbital part of lacrimal gland; *2* — palpebral part of lacrimal gland; *3* — excretory ducts of lacrimal gland; *4* — lacrimal lake; *5* — inferior lacrimal papilla and lacrimal punctum; *6* — nasolacrimal duct; *7* — interior lacrimal canaliculus; *8* — lacrimal sac; *9* — superior lacrimal papilla and lacrimal punctum

Approximately 1 ml of tear in one eye is produced per day under normal conditions. When the palpebral fissure is opened, tear does not pour out of the conjunctival sac, but spreads in the form of a tear film over the surface of the eyeball (fig. 9).

Tear performs protective and trophic functions. Tear film is distributed into three layers: lipid, aqueous and mucin.

The *lipid layer* is formed by the glands of the eyelids (meibomian) and the eyelid glands of Moll and Zeis, opening at the margin of the eyelid.

Properties of the lipid layer:

– slows the evaporation of moisture;

– reduces heat loss by protecting the eye from supercooling;

– increases the surface tension, which helps to stabilize the tear film, since the film prevents the tear from rolling over the margin of the eyelid;

– serves as a lubricant for the eyelids.

The *aqueous layer* is produced by the lacrimal glands — the main and accessory.

Properties of the aqueous layer:

– promotes delivery of oxygen and amino acids to the corneal epithelium;

– serves as a protective medium preventing infection due to presence of lysozyme and immunoglobulins;

– provides smoothness to the corneal surface;

– flushes foreign bodies from the surface of the cornea.

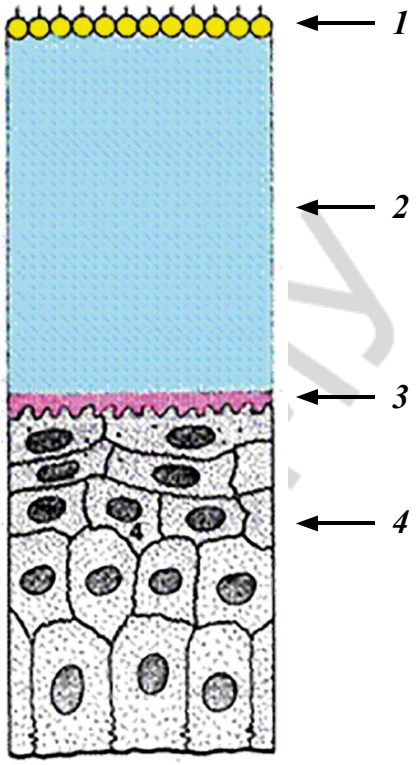

Fig. 9. Structure of the tear film: *1* — lipid layer; *2* — aqueous layer; *3* — mucin layer; *4* — epithelium of cornea

The *mucin layer* is produced by epithelial and bocaloid corneal cells, as well as by glands present in the conjunctiva.

Properties of the mucin layer: promotes tear wetting of the cornea by converting the surface of the cornea from hydrophobic to hydrophilic.

Layers of a tear film do not mix with each other.

Outflow of tears. Approximately 25 % of tears evaporate from the surface of the eye, the rest flow into the nasal cavity through the tear passages. It is believed that at the time of closure of the eyeball, so-called lacrimal streams (pathways) are formed between the margin of the eyelids and the anterior surface of the eyeball. The tear is carried out along superior and inferior conjunctival fornix to the lacrimal lake (lacus lacrimalis), into which the lacrimal puncta are submerged. Lacrimal canaliculi begin with lacrimal puncta, from which tear comes into the lacrimal sac, then — into the nasolacrimal duct, and then — into the nasal cavity, the inferior nasal meatus.

There are the following factors contributing to tear outflow:

– capillary attraction, actively sucking tear into lacrimal canaliculi;

– flashing movements of eyelids (blinking), ensuring further advance of tears.

During the act of closure of the palpebral fissure the eyelids are closed smoothly in the direction from temple to nose, tear is displaced in the same di-

rection and part of which is pushed into lacrimal canaliculi. At the last moment of closing the eyelids, the lacrimal puncta and lacrimal canaliculi flatten and the outer wall of the lacrimal sac is pulled away from the inner wall, whereby a portion of the tear from the lacrimal canaliculus is moved into the lacrimal sac. When the palpebral fissure is opened the walls of the lacrimal sac fall, and the tear from the lacrimal sac is squeezed out through the nasolacrimal duct into the nasal cavity. When the eyelids are opening, the lacrimal puncta and ampullae of the lacrimal canaliculi are also opened and filled with new portions of tears. The next blink — and the cycle of tear outflow will repeat.

Excessive tear formation can be compensated by frequent blinking and increased nasal breathing. The movements of the eyelids play a decisive role in the outflow of tears. Therefore, in the case of paralysis of the facial nerve, which innervates the orbicularis oculi muscle, there is an inability to close the palpebral fissure (lagophthalmos). It can result in disorders of a normal outflow of tear and tear film formation, which predispose to inflammation of the cornea.

The lacrimal sac, according to modern data, plays a passive role in the outflow of tear, as the so-called Horner's muscle (part of the orbicularis oculi muscle) forms the wall of the lacrimal sac but makes no practical contribution to tear outflow.

Questions for self-control:

1. What is a tear?
2. Describe the structure of the lacrimal gland.
3. What are the accessory lacrimal glands?
4. List the layers of a tear film and give a characteristic to each of them.
5. List the tear outflow sequence.
6. What factors contribute to the outflow of tears?
7. Give examples of disruption of the tear outflow.

RETINA AND VISUAL PATHWAY

The retina of the eye consists of two parts: **optic** and **nonvisual**. The posterior two thirds of the retina (from the optic disc until ora serrata) are highly differentiated nervous tissue — the optic part of the retina (fig. 10). The nonvisual retina is represented by the **ciliary** and **irideal** parts. These parts of the retina are formed by a two-layer series of epithelial cells unable to perceive light. The internal layers of the optic part constitute the **neural layer** of the retina, outside of which the **pigmented layer** of the retina is located, which is tightly sealed within the vascular layer of eyeball.

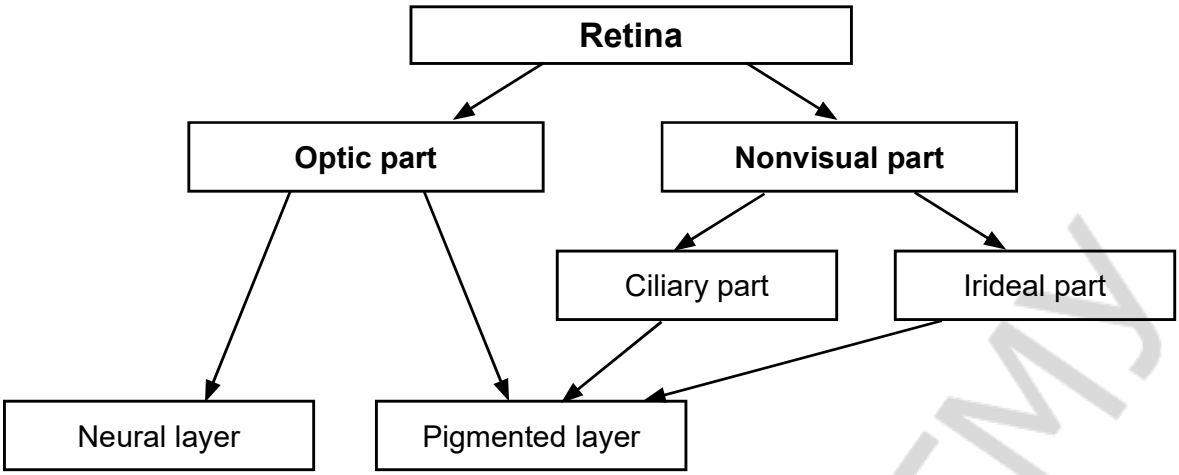

Fig. 10. Scheme of the structure of a retina

When dissecting the eyeball it can be seen that after the vitreous body flows out, the eyeball loses its shape quickly, and the retina, in the form of a thin transparent film, easily collects into the folds and peels off almost throughout. The exposed inner surface of the eyeball has a black colour. The part of the retina that peels off easily represents its neural layer, whereas outside the neural layer of the retina, there is its pigment layer which is tightly attached to the adjacent vascular layer and causes the dark colour of the inner surface of the eyeball.

The neural layer of the retina is connected with the underlying tissues in two places:

– near the ora serrata;
– around the optic disc.

The remaining retina is fixed by the pressure of the vitreous body throughout. In pathological conditions, the close relationship of the retina with the surrounding layers is disrupted and the retina is detached. In most cases, the part of the retina that is detached is its neural part, which is loose-soldered to the pigment layer of the retina, and that, in turn, accreted with the vascular layer of the eyeball. The detached retina loses transparency, accompanied by a decrease in visual acuity until blindness.

In the retina there are photoreceptors — light sensitive cells — rods and cones. Rods (up to 170 million) represent the mesopic (twilight) vision apparatus and cones (up to 8 million) — the central and colour vision apparatus. Within cones and rods there is a process of transformation of light energy into nerve impulses. Photoreceptors are the deepest parts of the retina that can only be reached by light which penetrates through the rest of the retinal layers. The outermost layer of the retina is the pigmented layer, cell bodies of which are filled with pigment — lipofuscin. The pigmented layer absorbs scattered light and prevents reflection from the retina.

The functional **centre** of the retina is located approximately 4 mm from the optic disc to the temple (fig. 11). This area features a yellowish colour, so it is called a yellow spot — **macula lutea**. At the bottom of the macula the retina consists only of cones. Each cone connects with one bipolar nervous cell. Such a precise structural arrangement provides high central vision.

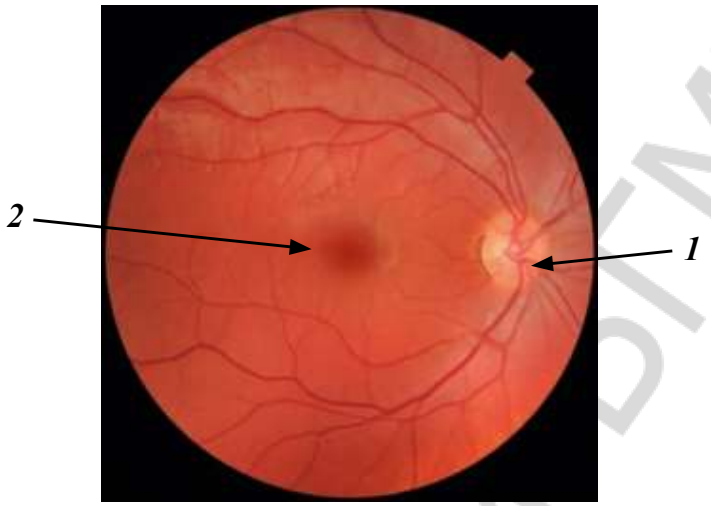

Fig. 11. Ocular fundus:
1 — optic disc; *2* — macula

The **optic disc** is the place where the fibres of the optic nerve leave the eyeball. Because of the absence of photosensitive cells on the optic disc it is also called a blind spot. The optic disc is located in the posterior part of the eyeball asymmetrically displaced towards the nose by 4 mm from the posterior pole of the eyeball.

The **visual pathway** from the retina to the visual centre of the occipital lobe of the brain can be represented by a chain of neurons (fig. 12): the bodies of photoreceptors (cones and rods) — bipolar nervous cells of the retina — multipolar ganglionic cells of the retina — subcortical visual centres — occipital lobe of the brain.

The **subcortical visual centres** include the following structures:

– lateral geniculate body;
– pulvinar of the thalamus;
– superior colliculus of the midbrain.

From **photoreceptors**, which are the peripheral endings of cones and rods, a nervous impulse is transmitted to bipolar nervous cells located in the inner nuclear layer of the retina. The axons of ganglionic cells form the layer of nerve fibres and create the optic nerve.

In the **optic nerve** four parts are determined: intra-ocular, orbital, part in canal and intracranial parts. The optic nerve at the exit of the eyeball acquires membranes (outer and inner sheath) similar to the meninges of brain. The subdural and subarachnoid spaces end blindly behind the site where the sclera is joined to the

dura mater of the brain. This circumstance explains the development of the pattern of the «stagnant disc of the optic nerve» under increased intracranial pressure. The orbital part of the optic nerve is S-shaped, which excludes the risk of tension of its fibres during movements of the eyeball. The optic nerve enters the skull through the optic canal. The part in canal is the most dangerous part of the optic nerve in the terms of possible compression of the optic nerve.

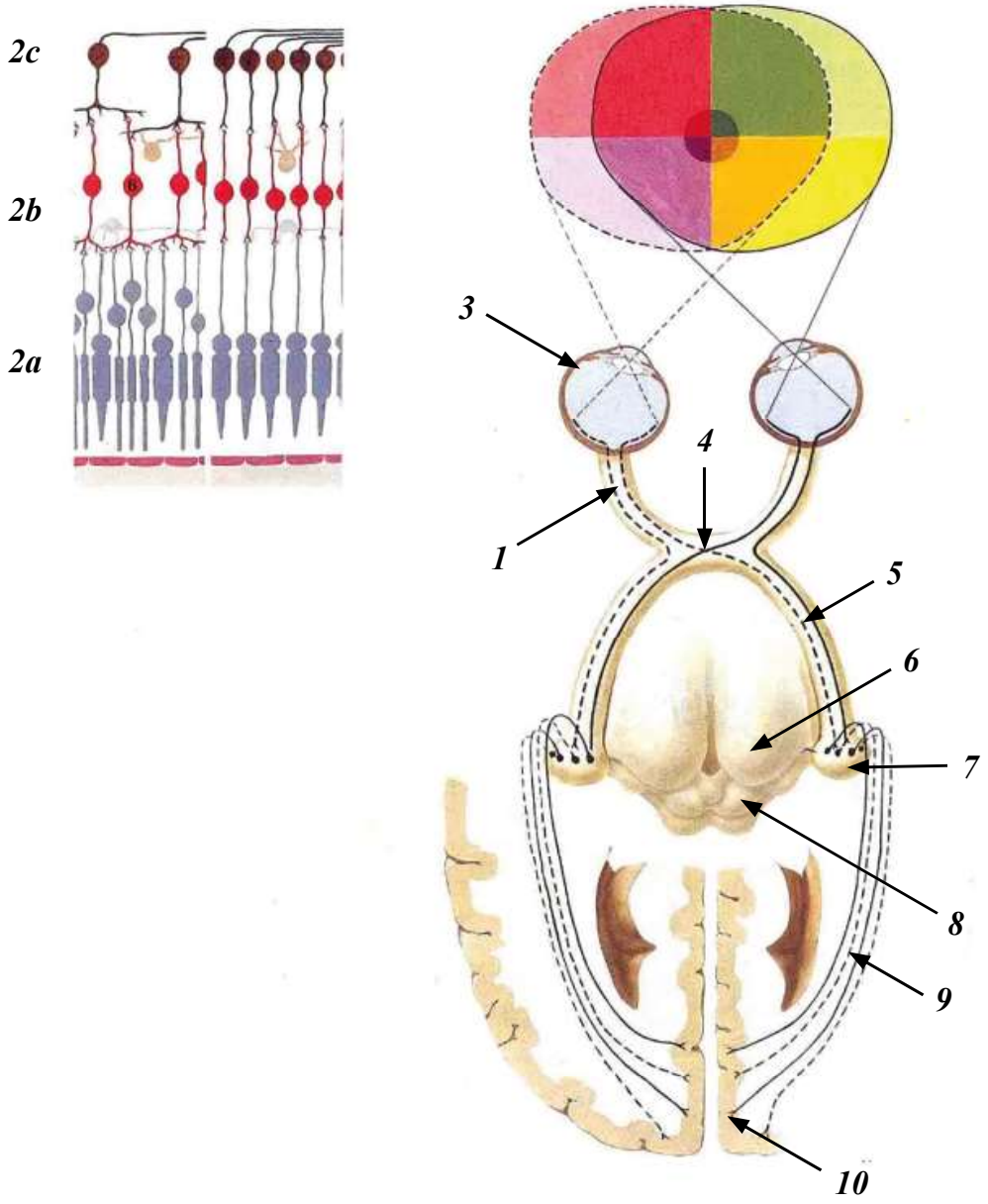

Fig. 12. Visual pathway:
1 — optic nerve; *2* — retinal fragment: *a* — rods, cones; *b* — bipolar nervous cells; *c* — multipolar ganglionic cells; *3* — eyeball; *4* — optic chiasm; *5* — optic tract; *6* — pulvinar of thalamus; *7* — lateral geniculate body; *8* — superior colliculus of midbrain; *9* — optic radiation; *10* — cortical center of vision (calcarine sulcus)

The **optic chiasm** is located in the chiasmatic groove of the superior surface of the body of the sphenoid bone. In the optic chiasm the optic nerve fibres extending from the medial sides of each retina (which correspond to the lateral side of each visual hemifield, because the image is inverted) cross over to the opposite side of the midline of the human body. The partial crossing over of optic nerve fibres at the optic chiasm allows the visual cortex to receive the same visual fields from both eyes to generate binocular vision.

Beyond the optic chiasm, with crossed and uncrossed fibres, the **optic tracts** are formed. They consist of fibres from the lateral retinal regions of the same side and fibres from the medial retinal regions of the opposite side. Fibres from the upper fields of the retina go to the upper parts of the nerve and tract, from the lower fields — to the lower parts, etc.

The optic tract envelops the cerebral peduncle from its lateral side and ends in the subcortical centres of vision.

Functionally, optic tract fibres are divided into **visual** and **reflex**. The main amount of visual fibres ends at the nervous cells of the lateral geniculate body and the pulvinar of the thalamus. Axons of the lateral geniculate body and the pulvinar of the thalamus pass through the posterior limb of the internal capsule, form **optic radiation** and reach the edges of the **calcarine sulcus** — the cortical end of the visual analyzer.

Reflex fibres are directed to the centres of the midbrain. Axons of the cells of the superior colliculus of the tectal plate of the midbrain form the tectospinal tract. The function of this tract is to mediate reflex postural movements of the head in response to unexpected visual (and auditory) stimuli. The axons of the cells of the superior colliculus go to the nuclei of the oculomotor nerve, providing accommodation and convergence.

Questions for self-control:

1. What parts are distinguished in the human retina?
2. What is retinal detachment?
3. Describe photoreceptors.
4. What is the optic disc?
5. What is the central fovea?
6. What are the factors which provide high central vision?
7. List the neurons of the visual pathway.
8. Name the subcortical centres of vision.
9. What is the optic chiasm?
10. Where is the cortical end of the visual analyzer?

DEVELOPMENT OF THE EYE AND ITS ANOMALIES

The eyeball is formed from several sources (table). The retina is a derivative of the neuroectoderm and in the human embryo is represented by a pair of optic vesicles on each side of the forebrain at the end of the 4th week of prenatal development (fig. 13). By invagination of its distal part each optic vesicle is transformed into a two-walled optic cup. The outer wall of the cup is transformed into the pigmented layer and the inner wall - into the nervous layer of the retina. Processes of the retinal ganglionic cells germinate into the leg of the optic cup and form the optic nerve.

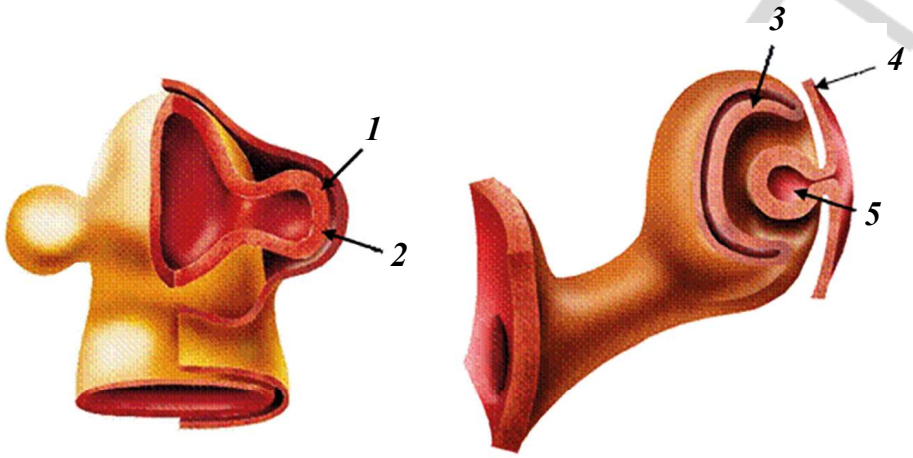

Fig. 13. Development of the eye:
1 — neuroectoderm; *2* — optic vesicle; *3* — optic cup; *4* — surface ectoderm; *5* — lens vesicle

The superficial ectoderm adjacent to the optic cup is pulled into its cavity and forms a lens vesicle. The latter turns into a lens after filling its cavity with growing lens fibres. Through a slit located between the edges of the optic cup and lens, mesenchymal cells penetrate the space inside the optic cup where they participate in the formation of the vitreous body.

Sources of eye development

Sources of development	Structure of the eye
Mesenchyme	Vascular layer Fibrous layer Vitreous body
Neuroectoderm	Retina Smooth muscles of the eye
Surface ectoderm adjacent to the optic cup	Lens
Axons of retinal ganglionic cells	Optic nerve
Myotomes of the head	Striated muscles

The vascular and fibrous layers of the eyeball develop from the mesenchyme. Separation of the corneal mesenchyme from the lens leads to the appearance of the anterior chamber of the eye. Striated muscles are the derivative of myotomes of the head.

Eyelids are represented by folds of skin which grow towards each other and become closed together in front of the cornea. In the thickness of the eyelids the eyelashes and glands are formed.

Abnormalities of the human eye and related structures are the cause of blindness in 50 % of cases. They arise because of hereditary mutations and can be the effects of teratogenic factors.

The pathological formation of the optic vesicles in the first 4 weeks of prenatal development can result in large defects. For example:

– anophthalmos — congenital absence of the eye;

– microphthalmia — a condition in which all structures of the eye are pathologically small because the optic vesicle is formed, but its further normal development does not occur.

Congenital cataract (opacity or clouding of the lens) occupies first place among congenital eye pathology. More often, it develops due to incorrect detachment of the lens vesicle from the ectoderm. In cases of failure of lens vesicle detachment from the ectoderm and weakness of the anterior capsule of the lens, the anterior lenticonus (bulging on the anterior surface of the lens) is formed. Among other types of congenital pathology of the lens it is necessary to note its displacement from its usual location: full (dislocation) and incomplete (subluxation). The cause of such ectopy and displacement of the lens to the anterior chamber or vitreous body is usually an abnormality of the development of the ciliary body and the zolular fibres.

Infringement of the reverse development of the vascular bag of the lens or the remains of it in the form of the pigment deposits and mesh-like structures on the anterior capsule of the lens leads to the formation of pupil membranes. There are also rare cases of congenital absence of the lens (aphakia), which can be primary when the lens was not developed and secondary, as a result of intrauterine resorption of the lens.

The incomplete closure of the embryonic fissure at the stage of the optic cup leads to coloboma formation which is represented by defects in eyelid, iris, optic nerve or choroid.

The partial resorption of mesoderm in the iridocorneal angle results in disruption of intraocular fluid outflow from the anterior chamber of the eye and the development of glaucoma. In the case of an abnormal drainage system of the eye aniridia — absence of iris — may take place.

Corneal abnormalities include microcornea, or small cornea, when its size is reduced compared to the age norm by more than 1 mm (the diameter of the cornea of the newborn is not 9 mm, but 6–7 mm). Megalocornea, or macrocornea is an enlarged cornea, i.e. its size increases against the age norm by more than 1 mm.

Keratoconus is a corneal condition in which the central portion of the cornea is significantly tapered. Keratoglobus is characterized by the excessively convex shape of the surface of the cornea throughout.

One anomaly of the primary vitreous body is hyperplasticity. It occurs in cases of disruption of the reverse development of the artery of the vitreous body, which grows through a vascular slit into the cavity of the optic vesicle.

Ptosis of the upper eyelid is a common anomaly, which arises due to underdevelopment of the levator palpebrae superioris muscle or as a result of disruption of its innervation.

In the case of impaired formation of the palpebral fissure the eyelids remain converged — ankyloblepharon.

The occurrence of optic nerve abnormalities is related to the closure of the ocular fissure during embryogenesis at the stage of the formation of the optic vesicle or optic cup. Any delay in the growth of nerve fibres into the leg of the optic cup may result in the hypoplasia (reduction of diameter) and aplasia (absence) of the optic nerve. The perseverance (delay of development) of the vitreous body is the cause of prepapillary membranes above the optic disk. The abnormal growth of myelin behind the cribriform plate of the sclera inside the eye leads to the formation of myelin fibres of the optic nerve. A lot of eye abnormalities can be diagnosed through ultrasound scanning of foetal facial structures during the 2nd trimester of pregnancy.

DICTIONARY OF ANOMALIES OF THE EYE

Anophthalmos — congenital absence of the eye.
Microphthalmia — pathologically small eye.
Congenital cataract — opacity of lens.
Lenticonus — bulging on the surface of lens.
Ectopy of lens — lens displaces from normal location.
Pupil membranes — mesh-like structures on the anterior capsule of the lens.
Aphakia — absence of lens.
Coloboma — hole in eyelid, iris, optic nerve or choroidea.
Aniridia — absence of iris.
Microcornea — small cornea.
Megalocornea — large cornea.
Keratoconus — cone-shaped extension of the central part of the cornea.
Keratoglobus — the cornea has a convex shape throughout it.
Ptosis — drooping upper eyelid.
Ankyloblepharon — partial or complete fusion of the eyelids.
Optic nerve hypoplasia (aplasia) — optic nerve diameter reduction (underdevelopment of optic nerve).

Questions for self-control:

1. From what sources does the eye develop?
2. What do you know about the anomalies of the lens?
3. What is keratoconus?
4. What is a coloboma?
5. List the abnormalities of the optic nerve.
6. Name the anomalies of the eyelids known to you.

DICTIONARY OF EPONIMS

Meibomian gland — gland of the tarsal plate of eyelids.

Schlemm's canal — scleral venous sinus.

Bowman's membrane — layer of cornea between the superficial epithelium and the stroma.

Bruch's membrane — innermost layer of the choroid.

Brucke's muscle — meridional fibres of the ciliary muscle.

Descemet's membrane — basement membrane between the stroma and the endothelial layer of cornea.

Fontana spaces — spaces between the fibres of the corneoscleral trabecula.

Gorner's muscle — lacrimal part of the orbicular oculi muscle.

Krause's glands — accessory lacrimal glands.

Moll's glands — modified sweat glands on the margin of the eyelid.

Müller's muscle — part of the levator palpebrae superioris muscle.

Tenon capsule — fascial sheath of the eyeball.

Annulus of Zinn — common tendinous ring surrounding the optic nerve.

Zinn's membrane — fibrous strands that connect the ciliary body with the lens.

Glands of Zeis — sebaceous glands located on the margin of the eyelid.

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