1

Anatomy of the Eyeball

ANATOMY
- Eyeball
- Tunics of Eyeball
- Segments of the Eye
- Blood Supply of Eyeball
- Blood Supply of Retina
- Blood Supply of Uvea
- Nerve Supply of Eyeball

DEVELOPMENT OF EYE
- Lens
- Optic Stalk and Optic Fissure
- Cornea
- Sclera
- Anterior Chamber
- Uveal Tract
- Optic Nerve
- Vitreous

DEVELOPMENT OF OCULAR ADNEXA
- Eyelids
- Lacrimal Gland
- Lacrimal Passage
- Extraocular Muscles
- Orbit

OVERVIEW

This chapter will:
- Describe anatomy, blood supply and nerve supply of eyeball
- Discuss development of the eye.

Anatomy

Eyeball

The eyeball (Fig. 1.1) lies in a quadrilateral pyramid-shaped bony cavity situated on either side of the root of the nose called *orbit*. Each eyeball is suspended by extraocular muscles and their fascial sheaths. Generally, the eyeball protrudes about 12-14 mm beyond the external orbital rim. The eyeball is protected anteriorly by the eyelids and the eyelashes and posteriorly there lies a pad of fat behind the eyeball to provide a protective cushion.

At birth, the eyeball measures anteroposteriorly about 17.5 mm and reaches 24 mm in adults. The horizontal and vertical diameters of the eyeball are 23.5 and 23 mm, respectively. As it is flattened from above downwards, its shape resembles with an oblate spheroid. Because the eyeball is shaped roughly like the globe of the earth, it is said to have poles.

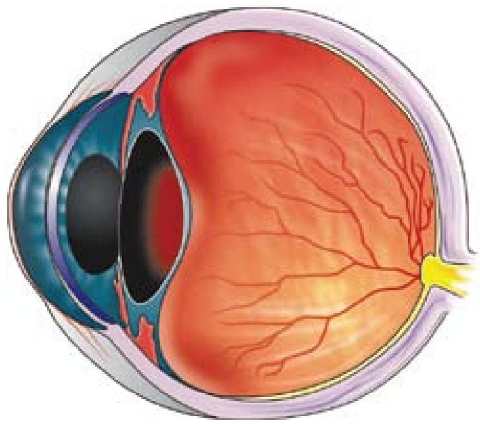

Fig. 1.1: A sagittal section through the eyeball

The central points on maximum convexities of the anterior and posterior curvatures of the eyeball are called *anterior* and *posterior poles* (Fig. 1.2). The axis of the eyeball passes through the poles. The line joining the poles is called *meridian*. The optic nerve leaves the eyeball 3 mm medial to the posterior pole and passes along the axis of the orbit, therefore, the axes of the eyeball and the orbit do not coincide but make an angle between them.

Tunics of Eyeball

The eyeball is composed of three concentric tunics (Fig. 1.3).

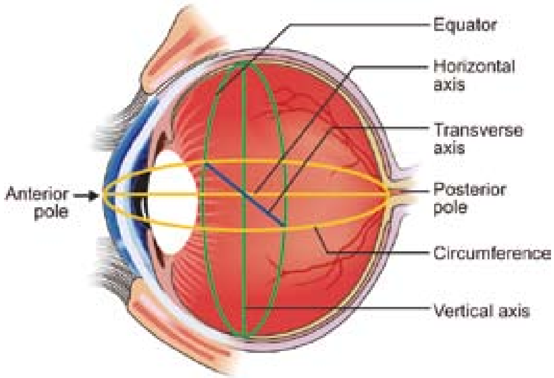

Fig. 1.2: The poles, axes, meridians and equator of the eyeball

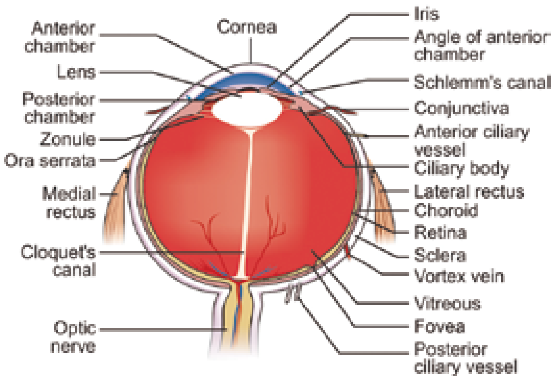

Fig. 1.3: Horizontal section of eyeball

1. The outer tunic consists of anterior one-sixth transparent part, the cornea and the remainder five-sixths opaque part, the sclera. The anterior part of the sclera is covered by a mucous membrane, the conjunctiva, which is reflected over the eyelids and also adhered firmly around the periphery of the cornea, the limbus. With this membrane in place, a conjunctival sac is formed when the eyelids are closed, and the upper and lower extensions of this sac are the superior and inferior conjunctival fornices.
2. The intermediate vascular tunic comprises from behind forward: the choroid, the ciliary body and the iris.
3. The innermost sentient layer, the retina, serving the primary purpose of photoreception and transformation of light energy into electrical impulses, is connected with the central nervous system by a tract of nerve fibers, the optic nerve. At the macular's center lies the fovea, rich in cones and responsible for color vision and the highest visual acuity.

Segments of the Eye

The eyeball can be divided into an anterior and a posterior segments.

Anterior segment of the eyeball consists of the cornea, anterior chamber, iris, posterior chamber, lens and part of ciliary body. The lens is suspended from the ciliary body by fine delicate fibrils called *suspensory ligament of the lens* (zonules).

The anterior chamber is bounded anteriorly by the posterior surface of the cornea and posteriorly by the anterior surface of the iris and the lens. The volume of anterior chamber is about 0.2 ml. It is approximately 2.5 mm deep in the center and contains clear aqueous humor. The anterior chamber has a peripheral recess known as *angle of anterior chamber* through which the drainage of aqueous humor takes place. The anterior wall of anterior chamber angle is corneoscleral coat, from the ending of corneal Descemet's membrane to the scleral spur. The past wall is the anterior end of the ciliary body and iris root.

The posterior chamber is a triangular space lined anteriorly by the posterior surface of the iris, anterolaterally by a part of ciliary body, and posteriorly by the ciliary body, lens and zonules. Its volume is about 0.06 ml.

Both the chambers contain aqueous humor and communicate with each other through the pupil. The aqueous humor filters from the capillaries of the ciliary processes into the posterior chamber and a portion of it freely diffuses through the vitreous humor in the posterior segment while the remainder flows into the anterior segment. After flowing through the pupil into the anterior chamber, it drains into the venous blood via the scleral venous sinus, and unusual venous channel that encircles the eye in the angle at the sclera-cornea junction. Aqueous humor supplies nutrients and oxygen to the lens and cornea and to some cells of retina, and it carries away their metabolic wastes.

Posterior segment of the eyeball includes the vitreous, retina, choroid and optic nerve. This segment is filled with a transparent, gelatinous substance, unlike aqueous humor, cannot be replaced.

Blood Supply of Eyeball

The arteries of the eyeball are derived from the ophthalmic artery, a branch of internal carotid artery. Given off immediately after the internal carotid artery leaves the cavernous sinus. The ophthalmic artery passes into the orbit through the optic canal with the optic nerve.

Blood Supply of Retina

The retina gets its blood supply from the central retinal artery, a branch of ophthalmic artery, which enters the optic nerve about 10 mm behind the eyeball. After running outward and forward, it reaches the optic nerve head and gives superior and inferior papillary branches, from each of which comes off a nasal and a temporal branch. Each branch continues to divide dichotomously spreading over the retina and reaching the ora serrata. The central retinal artery nourishes inner 5 layers of the retina. In few persons, a part of the retina gets nourishment from cilioretinal artery derived from ciliary artery.

The veins of retina do not accurately follow the course of the arteries, except at the disk, where they join to form the central retinal vein, which accompanies the central retina lartery.

Blood Supply of Uvea

The uveal tract is supplied by ciliary arteries arranged into three groups: the short posterior ciliary, the long posterior ciliary and the anterior ciliary arteries (Fig. 1.4).

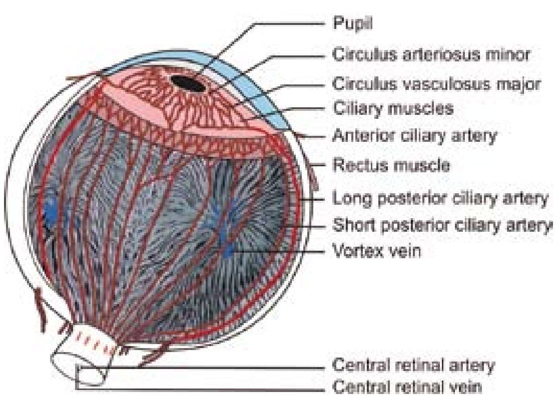

Fig. 1.4: Blood supply of eyeball

The short posterior ciliary arteries (20 in number) pierce the sclera around the optic nerve and supply the choroid. They nourish the choroid and the retinal outer layers.

The long posterior ciliary arteries (two in number) pierce the sclera obliquely in the horizontal meridian on either side of the optic nerve and run anteriorly between the sclera and the choroid without giving off any branch. They divide in the ciliary body and anastomose with the anterior ciliary arteries to form circulus arteriosus major at the root of iris.

The anterior ciliary arteries are derived from the muscular branches of the ophthalmic artery to the four rectus muscles. They pierce the sclera 3 to 4 mm behind the limbus to join the long posterior ciliary artery. Before piercing, they give branches to the conjunctiva, limbus and episclera.

The venous drainage of the uveal tract occurs through the ciliary veins, which form three groups:

1. Short posterior ciliary veins
2. Venae vorticosae, and
3. Anterior ciliary veins.

The short posterior ciliary veins receive blood only from the sclera, and the anterior ciliary veins from the outer part of the ciliary muscles. The bulk of the blood is drained through the venae vorticosae (vortex veins) comprising four large trunks, which open into the ophthalmic vein.

Nerve Supply of Eyeball

The sensory nerve supply to the eyeball is derived from the ophthalmic division of trigeminal nerve (Fig. 1.5). It comes mainly by the nasociliary nerve either directly through

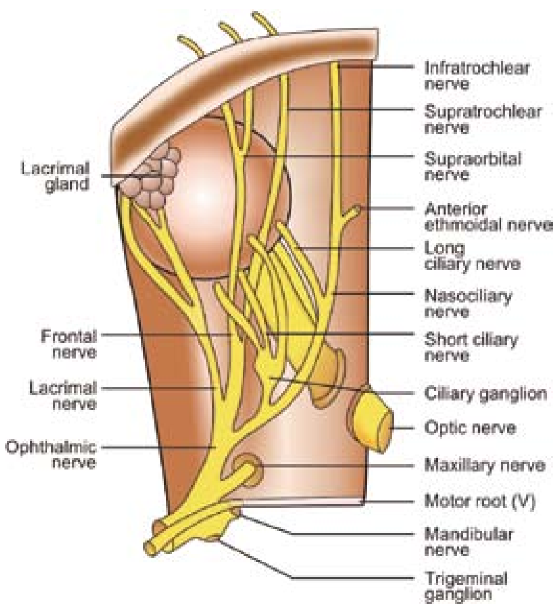

Fig. 1.5: Nerve supply of eyeball

the long ciliary nerve or indirectly through the short ciliary nerves. This branch enters the posterosuperior aspect of the ganglion, and carries sensory fibers, which pass through the ganglion and continue along the short ciliary nerves to the eyeball. These fibers are responsible for sensory innervation to all parts of the eyeball.

The long ciliary nerves (two in number) pierce the sclera in the horizontal meridian on either side of the optic nerve and run forwards between the sclera and the choroid to supply the iris, ciliary body, dilator pupillae and cornea.

The short ciliary nerves (about 10 in number) come from the ciliary ganglion and run a wavy course along with the short ciliary arteries. They give branches to the optic nerve and ophthalmic artery and pierce the sclera around the optic nerve. They run anteriorly between the choroid and the sclera, reach the ciliary muscles where they form a plexus, which innervates the iris, ciliary body and cornea.

The motor root of ciliary ganglion, derived from the branch of the oculomotor nerve to inferior oblique, supplies the sphincter pupillae and ciliary muscles.

Development of Eye

The eyeball develops as a part of the central nervous system. The latter develops from the neural groove, which invaginates to form the neural tube. The tube sinks into the underlying mesoderm and detaches itself from the surface epithelium. A thickening appears on either side of the anterior part of the neural tube that grows to form the primary optic vesicle (Fig. 1.6) at 4 mm human embryo stage.

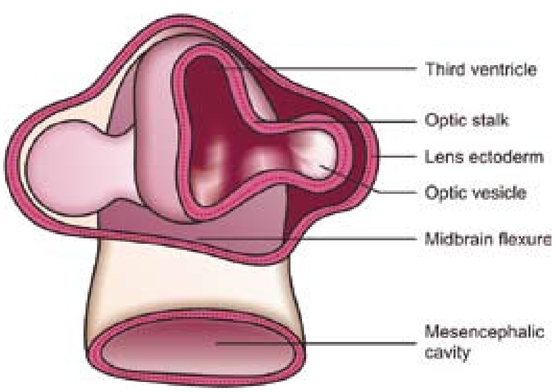

Fig.1.6: Forebrain and optic vesicle in a 4 mm human embryo

The optic vesicle comes in contact with the surface ectoderm and invaginates to form the optic cup. The inner layer of the cup forms the future retina, epithelium of ciliary body and iris, and sphincter and dilator pupillae, while the outer layer forms a single layer of pigment epithelium. At the anterior border of the cup, paraxial mesoderm invades to form the stroma of the ciliary body and the iris.

Lens

The development of the lens begins early in embryogenesis. When optic vesicles enlarge, they come in contact with the surface ectoderm.

Lens Plate

The surface ectoderm overlying optic vesicle thickens at about 27 days of gestation and forms the lens plate or lens placode (Fig. 1.7).

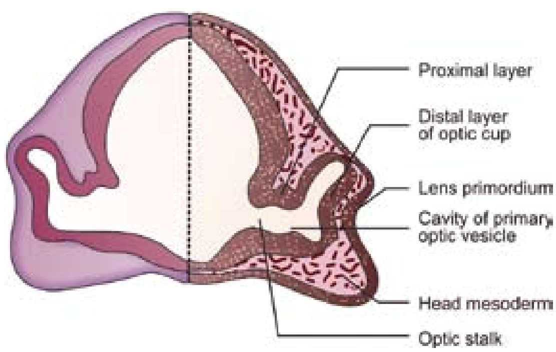

Fig. 1.7: Transverse section through forebrain of a 5 mm human embryo

Lens Pit

A small indentation appears in the lens plate at 29th day of gestation to form the lens pit which deepens and invaginate by cellular multiplication.

Lens Vesicle

At about 33 days of gestation, lens vesicle (Fig. 1.8) is formed due to continued invagination of the lens pit, which later detaches from the surface ectoderm. The lens vesicle is a single layer of cuboidal cells that is encased within a basement membrane, the lens capsule. The vesicle is complete by around day 56 and measures about 400 µm.

Primary Lens Fibers

At about 40 days of gestation, the posterior cells of lens vesicle elongate to form the primary lens fibers.

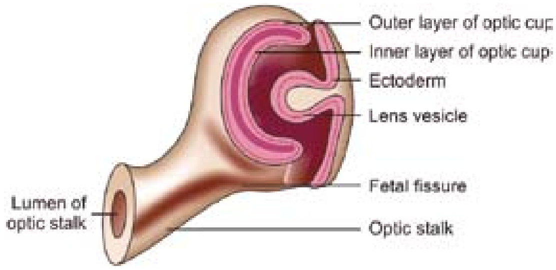

Fig. 1.8: Formation of lens vesicle

They fill up the cavity of the lens vesicle and form the embryonic nucleus. The linear primary fibre cells align parallel to the optic axis. Epithelial cells in the lens germinative zone (anterior to the equator) undergo mitosis and the daughter cells migrate to the transitional zone (posterior to the equator) where they differentiate and elongate into the secondary fibre cells.

Secondary Lens Fibers

The cuboidal cells of the anterior lens vesicle, also known as the lens epithelium, multiply and elongate to form the secondary lens fibers. The mature secondary fibre cells span half the circumference of the lens, meeting in the centre of the anterior and posterior surfaces where their ends overlap to form the sutures (upright Y anteriorly and inverted Y posteriorly). The fibers formed between second and eighth months of gestation form the fetal nucleus. The growth and proliferation of secondary lens fibers continues at a decreasing rate throughout life.

Optic Stalk and Optic Fissure

A deep groove appears of the ventral surface of the optic cup and stalk, called fetal fissure. The mesenchyme enters the optic cup through the optic fissure. The hyaloid system of vessels develops in the mesenchyme to provide nourishment to the developing lens (Fig. 1.9). The vascular system gradually atrophies with the closure of the optic fissure at about sixth week of gestation and is replaced by the vitreous, presumed to be secreted by the surrounding neuroectoderm.

Cornea

The development of the cornea starts at about 33 days of gestation by appearance of two rows of epithelial cells derived from the surface ectoderm. Mesenchymal cells from the edges of optic cup grow

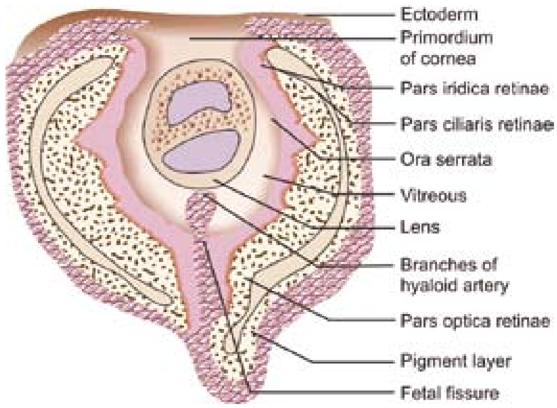

Fig. 1.9: Eye and fetal fissure of a 15 mm human embryo

between these rows to form the corneal endothelium. At about 24 mm stage, mesenchymal cells grow again between the epithelium and the endothelium to form the future stroma of cornea. The condensation of most anterior layer of stroma forms Bowman's membrane. The synthetic activity of the endothelial cells develops Descemet's membrane.

Sclera

The condensation of mesenchyme around the optic cup forms the sclera that differentiates anteriorly into the limbus. The initial scleral part of the lamina cribrosa begins to be formed in the 5 th month fetus. The fibrous tissue originating from the choroid and optic nerve sheath contributes the formation of the lamina cribrosa in the 8th month fetus. At this time, the morphology of lamina cribrosa is similar to that of an adult, but the thickness of the structure is still increasing till one year after birth.

Anterior Chamber

A cleft is formed due to the disappearance of the mesoderm lying between the developing iris and cornea, the anterior chamber (Fig. 1.10). The canal of Schlemm appears as a vascular channel at about fourth month of gestation. The iridocorneal angle is covered by a continuous monolayer of polyhedronal endothelial cells up to about 8 months gestation age.

Uveal Tract

Choroid

The endothelial blood spaces develop very early in the mesenchymal tissues lying close to the outer layer

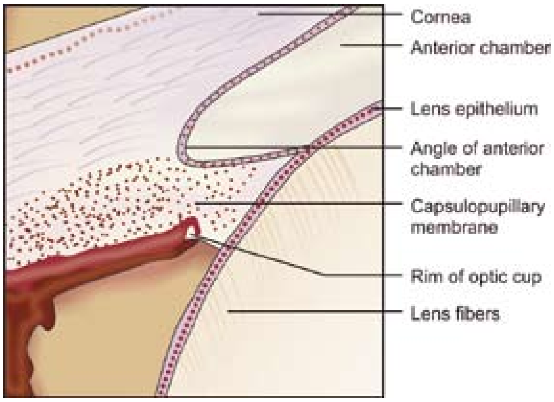

Fig. 1.10: Development of angle of anterior chamber at 75 mm human embryo stage

of optic cup. At about the end of second month, the vascular plexus forms the choriocapillaris. Large and medium sized vessels are formed during fourth to fifth month of gestation.

Ciliary Body

Ciliary body develops from both neuroectoderm and mesenchyme. During the third month, two-layered neuroectodermal optic cup grows and extends in front of the lens and gets differentiated into the ciliary body and the iris. These two parts are nonphotosensitive and are called as pars caeca retinae. At the 65 mm stage, 70 to 75 radial folds appear in the pigmented epithelium, the future ciliary processes. The ciliary muscle develops from the mesoectoderm at about the fourth month of gestation.

Iris

The development of iris begins at the end of third month by the forward extension of both walls of optic cup. The sphincter and dilator papillae are neuroectodermal in origin. The posterior epithelium of iris is a continuation of non-pigmented epithelium of the ciliary body.

Retina

The histogenesis of retina starts very early even before the closure of neural tube (2.2 mm stage). The inner layer of optic vesicle forms the retina and the outer forms the retinal pigment epithelium. The inner layer has an outer nuclear zone and an inner anuclear zone. The neuroepithelial cells actively divide and differentiate into inner and outer neuroblastic layers in the seventh week of gestation.

The ganglion cells, Müller's cells and amacrine cells are derived from the inner neuroblastic layer. The rods and cones, the bipolar cells, and the horizontal cells are derived from the outer neuroblastic layer. The retinal differentiation starts after completion of cell division (120 mm stage). The differentiation of macular area starts relatively late. The macular region is thicker than the rest of the retina until the eighth month, when macular depression begins to develop. Macular development is not complete in anatomic terms until 6 month after birth.

Optic Nerve

The optic stalk forms a connection between the primary optic vesicle and the forebrain. With the closure of optic fissure (19–20 mm stage), the optic stalk becomes a tube. The hollow optic stalk is filled by the axons of ganglion cells of the retina forming the optic nerve. At about two months of gestation, the optic nerve is composed of bundles of nerve fibers divided by parallel rows of glia. The condensation of the mesoderm around the optic cup differentiates to form the outer coats of the eyeball (choroid and sclera) and structures of the orbit. Mesenchymal elements enter the surrounding tissue to form the vascular septa of the nerve. Myelination extends from the brain peripherally down the optic nerve and at birth has reached the lamina cribrosa. Myelination is completed by age 3 month.

Vitreous

The source of development of vitreous body is controversial. Some embryologists think that it is entirely of ectodermal origin, while others believe that all the three layers, ectoderm, mesoderm and neuroectoderm, contribute to the development of vitreous. Like vitreous, the source of origin of zonules is also disputed. Whether they are derived from mesenchyme or ectoderm is not yet resolved. There are three stages in the development of vitreous:

1. Primary vitreous is seen at optic cup-lens vesicle stage. It is partly surface-ectodermal and partly mesenchymal in origin. At about the 4.5 mm stage, mesenchymal cells and fibroblasts derived from the embryonic lens and the inner layer of the optic vesicle, from the vitreous fibrils of the primary vitreous. Ultimately, the primary vitreous comes to lie just behind the posterior pole of the lens in

association with remnants of the hyaloid vessels (Cloquet's canal).

2. The fibrils and cells (hyalocytes) of the secondary vitreous are thought to originate from the vascular primary vitreous. Secondary vitreous is formed by the neuroectoderm of optic cup. Anteriorly, the firm attachment of the secondary vitreous to the internal limiting membrane of the retina constitutes the early stages of formation of the vitreous base. The development of vitreous may continue as late as 65 to 70 mm stage. The hyaloid system develops a set of vitreous vessels as well as vessels on the lens capsule surface (tunica vasculosa lentis). The hyaloid system is at its height at 40 mm and then atrophies from posterior to anterior.
3. Tertiary vitreous is derived from the neuro-ectoderm of the ciliary region at 65 mm stage. During the third month, the marginal bundles is forming. This consists of vitreous fibrillar condensations extending from the future ciliary epithelium of the optic cup to the equator of the lens. Condensations then form the suspensory ligament of the lens, which is well developed by the 100 mm or 4 month stage. The hyaloid system atrophies completely during this stage.

Development of Ocular Adnexa

Eyelids

The eyelids develop from both the surface ectoderm and the mesoderm. The medial and lateral parts of the frontonasal process join to form the upper lid, while the maxillary process forms the lower lid. Cilia develop from the epithelial buds. The ingrowth of inferior canaliculus cuts off a portion of the lid forming the lacrimal caruncle.

Lacrimal Gland

Eight epithelial buds from the superolateral part of the conjunctiva form the lacrimal gland.

Lacrimal Passage

A solid column of cells from the surface ectoderm form the primordium of lacrimal sac. The surface ectodermal growth upward into the lid forms canaliculi, while the growth downward into the nose forms the nasolacrimal duct. The canalization of the cellular columns starts at about the third month and is completed by the seventh month of intrauterine life.

Extraocular Muscles

The extraocular muscles develop from preotic myotomes, which are innervated by the oculomotor, trochlear and abducent nerves. The individual extraocular muscle differentiates at about 20 mm stage of developing embryo excepting the levator palpebrae superioris, which develops from the superior rectus at a later stage.

Orbit

The orbital bones are mostly derived from the neural crest cells, surrounding the eye anlage. The bones of the orbit differentiate during the third month of gestation and later undergo ossification. The eye attains its adult size at about the age of 3 years but orbit attains its adult size around 16th year of life.

Various ocular structures developing from the embryonic germ layers are listed in Table 1.1.

Table 1.1: Development of ocular structures from the embryonic germ layers*

Embryonic germ layer	*Ocular structures*
Surface ectoderm	Lens, epithelium of conjunctiva, cornea, lids and lacrimal passage, lacrimal, tarsal and conjunctival glands, vitreous
Neuroectoderm	Layers of retina, retinal pigment epithelium, nerve fibers and neuroglia of optic nerve, epithelium of iris, ciliary body, sphincter and dilator pupillae muscles, part of vitreous**
Neural crest (mesectoderm)	Stroma and endothelium of cornea, sclera, stroma of uveal tract, ciliary muscles, vascular channels of eye and orbit, optic nerve sheath, connective tissues of lids and orbit, orbital bones and nerves
Paraxial mesoderm	Striated extraocular muscles, blood vessels, sclera, vitreous.

* Table modified from Anatomy of the eye and adnexa. Nema HV, Singh VP, Nema Nitin.

** The surface ectoderm, neuroectoderm and mesoderm all contribute to the development of vitreous.

Key Features

- The eyeball is composed of three concentric layers: the outermost layer consists of cornea in anterior one-sixth which is the transparent part and the sclera in the remainder five-sixth, the opaque part. The intermediate vascular tunic comprises from behind forward: the choroid, the ciliary body and the iris. The innermost layer is the retina
- The main blood vessel supplying the eyeball is derived from the ophthalmic artery, which is a branch of internal carotid artery
- The sensory nerve supply to the eyeball is derived from the ophthalmic division of trigeminal nerve
- The eyeball develops as a part of the central nervous system. A thickening appears on either side of the anterior part of the neural tube that grows to form the primary optic vesicle at 4 mm human embryo stage.

Bibliography

1. Bron AJ, Tripathi RC, Tripathi BJ (Eds). Wolf's Anatomy of the Eye and Orbit, 8th edn. London: Chapman and Hall;1997.
2. Nema HV, Singh VP, Nema Nitin. Anatomy of the Eye and its Adnexa, 3rd edn. New Delhi: Jaypee Brothers Medical Publishers; 1999.

Review Questions

1. What are the dimensions of the eyeball?
2. What are the constituents of the anterior segment of the eyeball?
3. Describe the blood supply of the uvea.
4. Describe the nerve supply of the eyeball.
5. Describe the development of the lens.
6. What are the stages of development of the vitreous?

(MA Xiang)