

Chapter 1

Anatomy

Learning objectives

To learn the anatomy of the eye, orbit and the third, fourth and sixth cranial nerves, to permit an understanding of medical conditions affecting these structures.

Introduction

A knowledge of ocular anatomy and function is important to the understanding of eye diseases. A brief outline is given below.

Gross anatomy

The eye (Fig. 1.1) comprises:

- A tough outer coat which is transparent anteriorly (the *cornea*) and opaque posteriorly (the *sclera*). The junction between the two is called the *limbus*. The extra-ocular muscles attach to the outer sclera while the optic nerve leaves the globe posteriorly.
- A rich vascular coat (the *uvea*) forms the *choroid* posteriorly, which is lined by and firmly attached to the retina. The choroid nourishes the outer two-thirds of the retina. Anteriorly, the uvea forms the ciliary body and the iris.
- The *ciliary body* contains the smooth *ciliary muscle*, whose contraction allows lens shape to alter and the focus of the eye to be changed. The ciliary epithelium secretes *aqueous humour* and maintains the ocular pressure. The ciliary body provides attachment for the *iris*, which forms the pupillary diaphragm.

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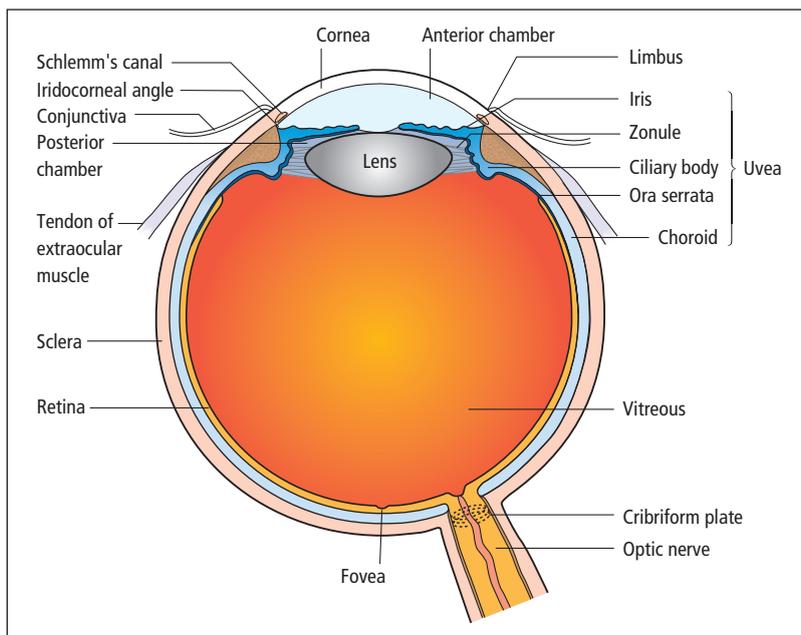


Figure 1.1 The basic anatomy of the eye.

- The *lens* lies behind the iris and is supported by fine fibrils (the *zonule*) running under tension between the lens and the ciliary body.
- The angle formed by the iris and cornea (the *iridocorneal angle*) is lined by a meshwork of cells and collagen beams (the *trabecular meshwork*). In the sclera outside this, *Schlemm's canal* conducts the aqueous humour from the anterior chamber into the venous system, permitting aqueous drainage. This region is thus also termed the *drainage angle*.

The cornea anteriorly and the iris and central lens posteriorly form the *anterior chamber*. Between the iris, the lens and the ciliary body lies the *posterior chamber* (distinct from the *vitreous body*). Both these chambers are filled with aqueous humour. Between the lens and the retina lies the vitreous body, occupying most of the posterior segment of the eye.

Anteriorly, the *bulbar conjunctiva* of the globe is reflected from the sclera onto the underside of the eyelids to form the *tarsal conjunctiva*. A connective tissue layer (*Tenon's capsule*) separates the conjunctiva from the sclera and is prolonged backwards as a sheath around the rectus muscles.

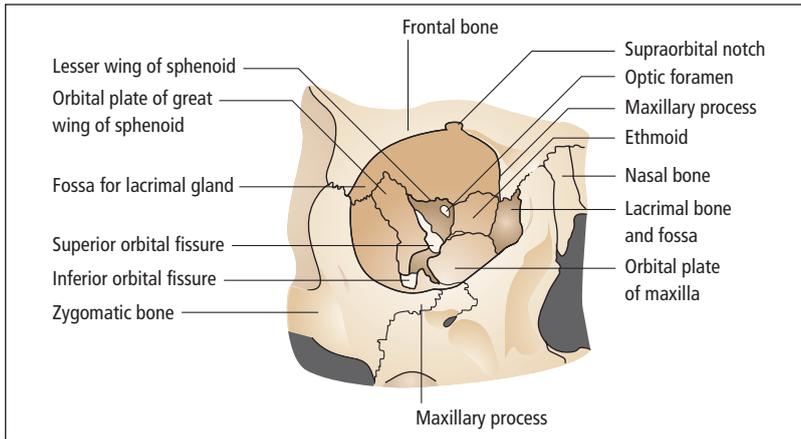


Figure 1.2 The anatomy of the orbit.

The orbit

The eye lies within the bony orbit, which has the shape of a four-sided pyramid (Fig. 1.2). At its posterior apex is the *optic canal*, which transmits the optic nerve to the chiasm, tract and lateral geniculate body. The *superior and inferior orbital fissures* allow the passage of blood vessels and cranial nerves which supply orbital structures. The *lacrimal gland* lies anteriorly in the superolateral aspect of the orbit. On the anterior medial wall lies the fossa for the *lacrimal sac*.

The eyelids (tarsal plates)

The eyelids (Fig. 1.3):

- offer mechanical protection to the anterior globe;
- spread the tear film over the conjunctiva and cornea with each blink;
- contain the *meibomian oil glands*, which provide the lipid component of the tear film;
- prevent drying of the eyes;
- contain the puncta through which the tears flow into the lacrimal drainage system.

They comprise:

- an anterior layer of skin;
- the *orbicularis muscle*, whose contraction results in forced eye closure;
- a tough collagenous layer (the *tarsal plate*) which houses the oil glands;
- an epithelial lining, the tarsal conjunctiva, which is reflected onto the globe via the *forfices*.

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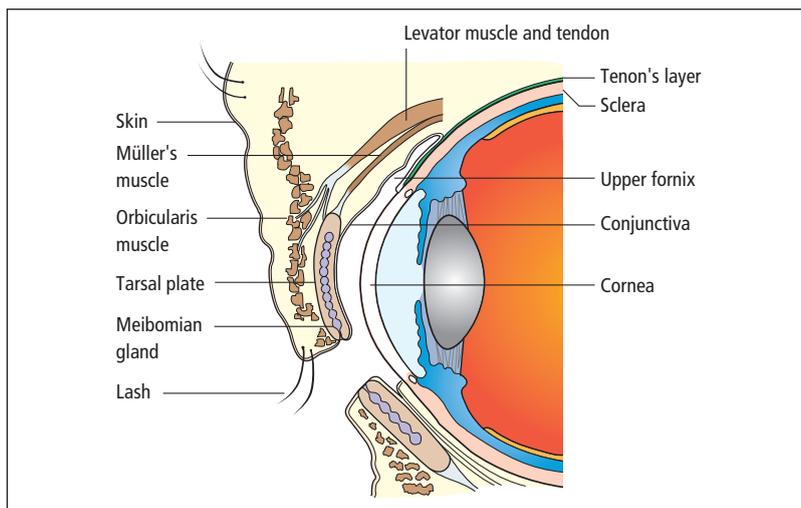


Figure 1.3 The anatomy of the eyelids.

The *levator muscle* passes forwards to the upper lid and inserts into the tarsal plate. It is innervated by the third nerve. Damage to the nerve or lid changes in old age result in drooping of the eyelid (*ptosis*). A flat smooth muscle arising from the deep surface of the levator inserts into the tarsal plate. It is innervated by the sympathetic nervous system. If the sympathetic supply is damaged (as in Horner's syndrome) a slight ptosis results.

The meibomian oil glands deliver their oil to the skin of the lid margin, just anterior to the *mucocutaneous junction*. This oil is layered onto the anterior surface of the tear film with each blink, where it retards evaporation. Far medially on the lid margins, two puncta form the initial part of the lacrimal drainage system.

The lacrimal drainage system

Tears drain into the upper and lower *puncta* and then into the *lacrimal sac* via the upper and lower *canaliculi* (Fig. 1.4). They form a common canaliculus before entering the lacrimal sac. The *nasolacrimal duct* passes from the sac to the nose. Failure of the distal part of the nasolacrimal duct to fully canalize at birth is the usual cause of a watering, sticky eye in a baby. Tear drainage is an active process. Each blink of the lids helps to pump tears through the system.

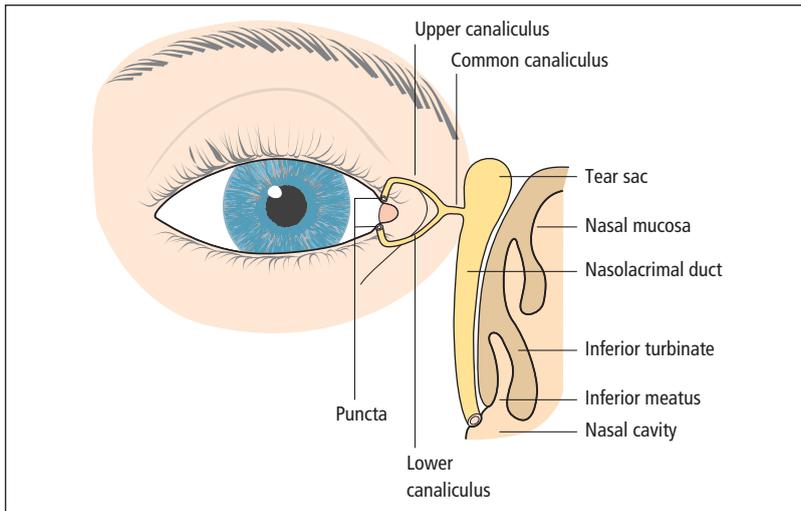


Figure 1.4 The major components of the lacrimal drainage system.

Detailed functional anatomy

The tear film

The ocular surface is bathed constantly by the tears, secreted mainly by the lacrimal gland but supplemented by conjunctival secretions. They drain away via the nasolacrimal system.

The ocular surface cells express a mucin *glycocalyx* which renders the surface wettable. When the eyes are open, the exposed ocular surface (the cornea and nasal and temporal wedges of conjunctiva) are covered by a thin tear film, 3 μm thick, which comprises three layers:

- 1 a thin *mucin layer* in contact with the ocular surface and produced mainly by the conjunctival goblet cells;
- 2 an *aqueous layer* produced by the lacrimal gland;
- 3 a surface *oil layer* produced by the tarsal meibomian glands and delivered to the lid margins.

Functions of the tear film

- It provides a smooth air/tear interface for distortion-free refraction of light at the cornea.
- It provides oxygen anteriorly to the avascular cornea.

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- It removes debris and foreign particles from the ocular surface through the flow of tears.
 - It has antibacterial properties through the action of lysozyme, lactoferrin, defensins and the immunoglobulins, particularly secretory IgA.
- The tear film is replenished with each blink.

The cornea

The cornea (Fig. 1.5) is 0.5 mm thick and comprises:

- The *epithelium*, an anterior non-keratinized squamous layer, thickened peripherally at the *limbus* where it is continuous with the conjunctiva. The limbus houses the germinative *stem cells* of the corneal epithelium.
- An underlying *stroma* of collagen fibrils, ground substance and fibroblasts. The regular packing, small diameter and narrow separation of the collagen fibrils account for corneal transparency. This orderly architecture is maintained by regulating stromal hydration.
- The *endothelium*, a monolayer of non-regenerating cells which actively pump ions and water from the stroma, controlling corneal hydration and hence transparency. The difference between the regenerative capacity of the epithelium and endothelium is important. Damage to the epithelial layer, by an abrasion for example, is rapidly repaired by cell spreading and proliferation. Endothelial damage, by disease or surgery, is repaired by cell spreading alone, with a loss of cell density. A point is reached when loss of its barrier and pumping functions leads to overhydration (oedema), disruption of the regular packing of its stromal collagen and corneal clouding.

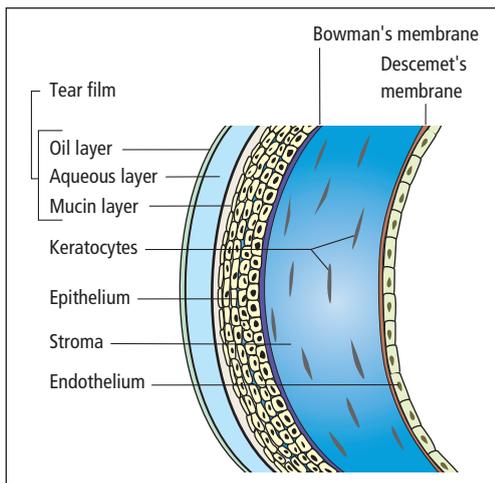


Figure 1.5 The structure of the cornea and precorneal tear film (schematic, not to scale – the stroma accounts for 95% of the corneal thickness).

The nutrition of the cornea is supplied almost entirely by the aqueous humour, which circulates through the anterior chamber and bathes the posterior surface of the cornea. The aqueous also supplies oxygen to the posterior stroma, while the anterior stroma receives its oxygen from the ambient air. The oxygen supply to the anterior cornea is reduced but still sufficient during lid closure, but a too-tightly fitting contact lens may deprive the anterior cornea of oxygen and cause corneal, especially epithelial, oedema.

Functions of the cornea

- It protects the internal ocular structures.
- Together with the lens, it refracts and focuses light onto the retina. The junction between the ambient air and the curved surface of the cornea, covered by its optically smooth tear film, forms a powerful refractive interface.

The sclera

- The sclera is formed from interwoven collagen fibrils of different widths lying within a ground substance and maintained by fibroblasts.
- It is of variable thickness, 1 mm around the optic nerve head and 0.3 mm just posterior to the muscle insertions.

The choroid

- The choroid (Fig. 1.6) is formed of arterioles, venules and a dense fenestrated capillary network.
- It is loosely attached to the sclera.
- It has a remarkably high blood flow.
- It nourishes the deep, outer layers of the retina and may have a role in its temperature homeostasis.
- Its basement membrane, together with that of the retinal pigment epithelium (RPE), forms the acellular Bruch's membrane, which acts as a diffusion barrier between the choroid and the retina.

The retina

The retina (Fig. 1.7) is a highly complex structure derived embryologically from the primitive optic cup.

Its outermost layer is the retinal pigment epithelium (RPE) while its innermost layer forms the neuroretina, consisting of the photoreceptors (*rods* and *cones*), the bipolar nerve layer (and additional nerve cells) and the *ganglion cell* layer, whose axons give rise to the innermost, nerve fibre layer. These nerve fibres converge to the optic nervehead, where they form the optic nerve.

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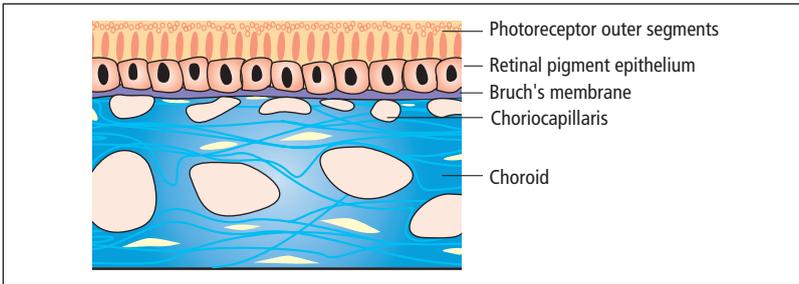


Figure 1.6 The relationship between the choroid, RPE and retina.

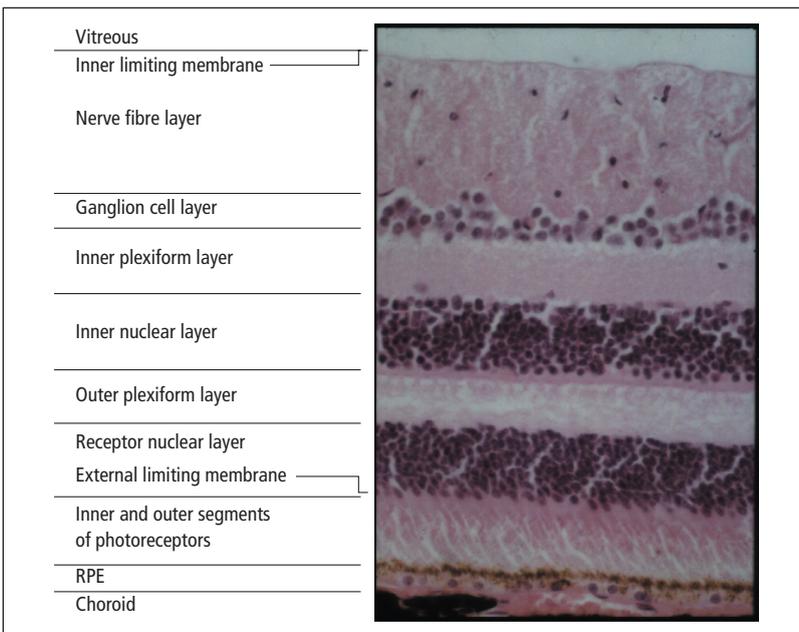


Figure 1.7 The structure of the retina.

The retinal pigment epithelium (RPE)

- is formed from a single layer of cells;
- is loosely attached to the neuro retina except at the periphery (*ora serrata*) and around the optic disc;

- forms microvilli which project between and embrace the outer segment discs of the rods and cones;
- phagocytoses the redundant external segments of the rods and cones;
- facilitates the passage of nutrients and metabolites between the retina and choroid;
- takes part in the regeneration of rhodopsin and cone opsin, the photoreceptor visual pigments and in recycling vitamin A;
- contains melanin granules which absorb light scattered by the sclera thereby enhancing image formation on the retina.

The photoreceptor layer

The photoreceptor layer is responsible for converting light into electrical signals. The initial integration of these signals is also performed by the retina.

- *Cones* (Fig. 1.8) are responsible for daylight and colour vision and have a relatively high threshold to light. Different subgroups of cones are responsive to short, medium and long wavelengths (blue, green, red). They are concentrated at the fovea, which is responsible for detailed vision such as reading fine print.
- *Rods* are responsible for night vision. They have a low light threshold and do not signal wavelength information (colour). They form the large majority of photoreceptors in the remaining retina.

The vitreous

- The vitreous is a clear gel occupying two-thirds of the globe.
- It is 98% water. The remainder is gel-forming hyaluronic acid traversed by a fine collagen network. There are few cells.
- It is firmly attached anteriorly to the peripheral retina, *pars plana* and around the optic disc, and less firmly to the macula and retinal vessels.
- It has a nutritive and supportive role.

Collapse of the vitreous gel (vitreous detachment), which is common in later life, puts traction on points of attachment and may occasionally lead to a peripheral retinal break or hole, where the vitreous pulls off a flap of the underlying retina.

The ciliary body

The ciliary body (Fig. 1.9) is subdivided into three parts:

- 1 the *ciliary muscle*;
- 2 the ciliary processes (*pars plicata*);
- 3 the *pars plana*.

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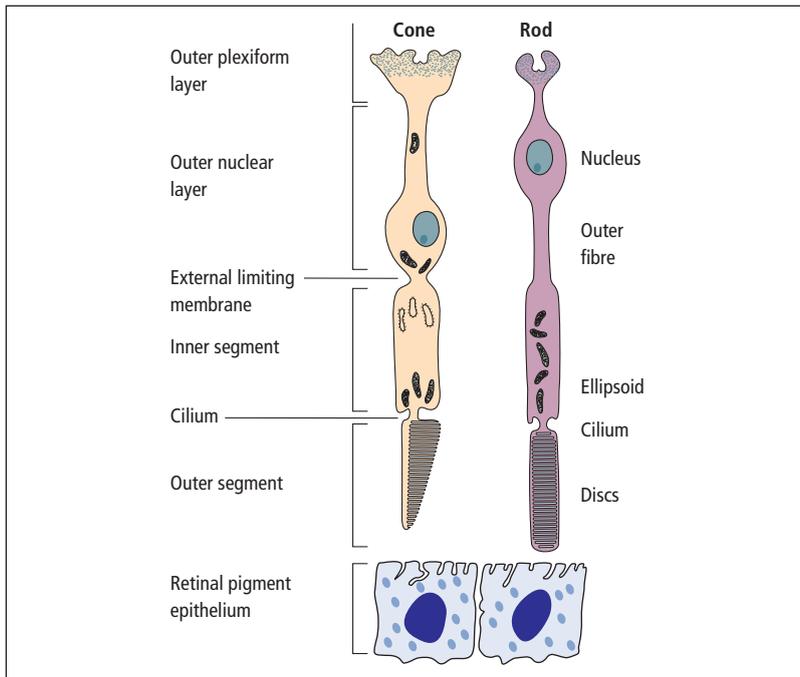


Figure 1.8 The structure of the retinal rods and cones (schematic).

The ciliary muscle

- This comprises smooth muscle arranged in a ring overlying the ciliary processes.
- It is innervated by the parasympathetic system via the third cranial nerve.
- It is responsible for changes in lens thickness and curvature during *accommodation*. The *zonular fibres* supporting the lens are under tension during distant viewing, giving the lens a flattened profile. Contraction of the muscle *relaxes* the zonule and permits the elasticity of the lens to *increase* its curvature and hence its refractive power.

The ciliary processes (pars plicata)

- There are about 70 radial *ciliary processes* arranged in a ring around the posterior chamber. They are responsible for the secretion of aqueous humour.
- Each ciliary process is formed by an epithelium two layers thick (the outer *pigmented* and the inner *non-pigmented*) with a vascular stroma.
- The stromal capillaries are fenestrated, allowing plasma constituents ready access.

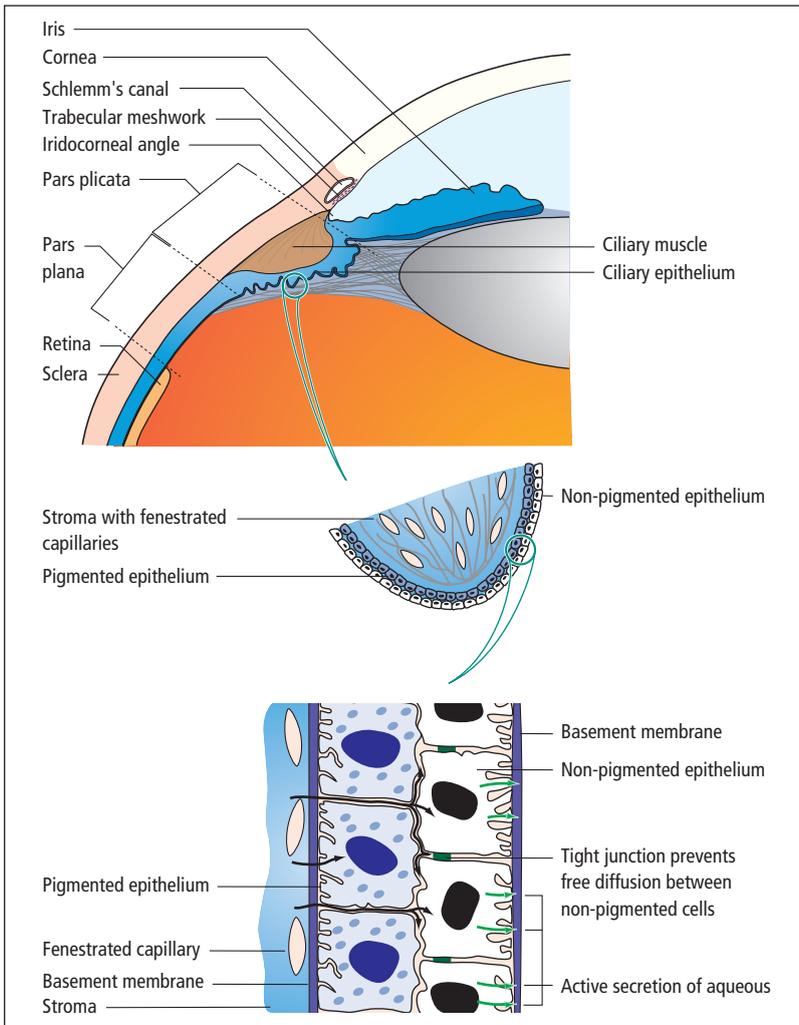


Figure 1.9 The anatomy of the ciliary body.

- The *tight junctions* between the non-pigmented epithelial cells provide a barrier to free diffusion into the posterior chamber. They are essential for the active secretion of aqueous by the non-pigmented cells.
- The epithelial cells show marked infolding, which significantly increases their surface area for fluid and solute transport.

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The pars plana

- This comprises a relatively avascular stroma covered by an epithelial layer two cells thick.
- It is safe to make surgical incisions through the scleral wall here to gain access to the vitreous cavity.

The iris

- The iris is attached peripherally to the anterior part of the ciliary body.
- It forms the *pupil* at its centre, the aperture of which can be varied by the circular *sphincter* and radial *dilator* muscles to control the amount of light entering the eye.
- It has an anterior border layer of fibroblasts and collagen and a cellular stroma in which the sphincter muscle is embedded at the pupil margin.
- The sphincter muscle is innervated by the *parasympathetic* system.
- The smooth dilator muscle extends from the iris periphery towards the sphincter. It is innervated by the *sympathetic* system.
- Posteriorly the iris is lined by a pigmented epithelium two layers thick.

The iridocorneal (drainage) angle

This lies between the iris, the anterior tip of the ciliary body and the cornea. It is the site of aqueous drainage from the eye via the trabecular meshwork (Fig. 1.10).

The trabecular meshwork

This overlies Schlemm's canal and is composed of a lattice of collagen beams covered by trabecular cells. The spaces between these beams become increasingly small as Schlemm's canal is approached. The outermost zone of the meshwork accounts for most of the resistance to aqueous outflow. Damage here raises the resistance and increases intraocular pressure in primary open angle glaucoma. Some of the spaces may be blocked and there is a reduction in the number of cells covering the trabecular beams (see Chapter 10).

Fluid passes into Schlemm's canal both through giant vacuoles in its endothelial lining and through intercellular spaces.

The lens

The lens (Fig. 1.11) is the second major refractive element of the eye; the cornea, with its tear film, is the first.

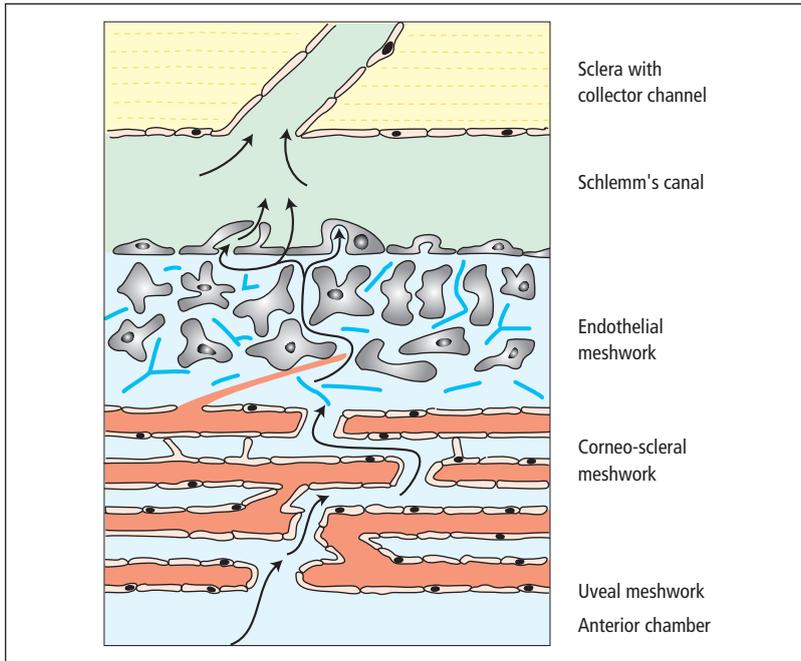


Figure 1.10 The anatomy of the trabecular meshwork.

- It grows throughout life.
- It is supported by zonular fibres running between the ciliary body and the lens capsule.
- It comprises an outer collagenous capsule under whose anterior part lies a monolayer of epithelial cells. Towards the *equator* the epithelium gives rise to the lens fibres.
- The zonular fibres transmit changes in the ciliary muscle, allowing the lens to change its shape and refractive power.
- The lens fibres make up the bulk of the lens. They are elongated cells arranged in layers which arch over the lens equator. Anteriorly and posteriorly they meet to form the lens *sutures*. With age the deeper *fibres* lose their nuclei and intracellular organelles.
- The oldest central fibres represent the fetal lens and form the lens *nucleus*; the peripheral fibres make up the lens *cortex*.
- The high refractive index of the lens arises from the high protein content of its fibres.

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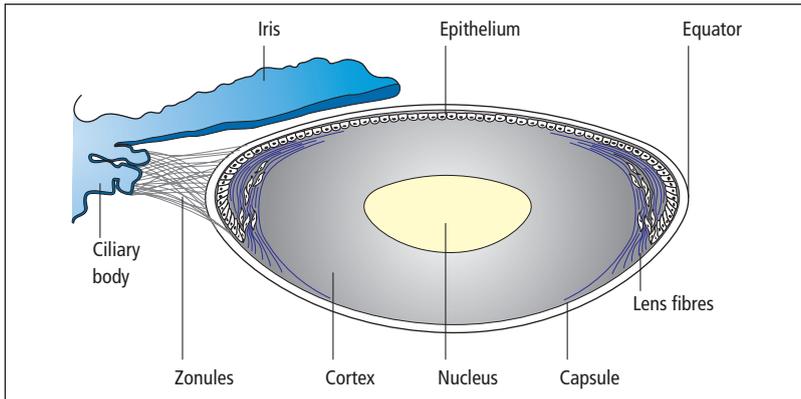


Figure 1.11 The anatomy of the lens.

The optic nerve

- The optic nerve (Fig. 1.12) is formed by the axons arising from the *retinal ganglion cell layer*, which form the *nerve fibre layer* of the retina.
- It passes out of the eye through the cribriform plate of the sclera, a sieve-like structure.
- In the orbit the optic nerve is surrounded by a sheath formed by the dura, arachnoid and pia mater, continuous with that surrounding the brain. It is bathed in cerebrospinal fluid.

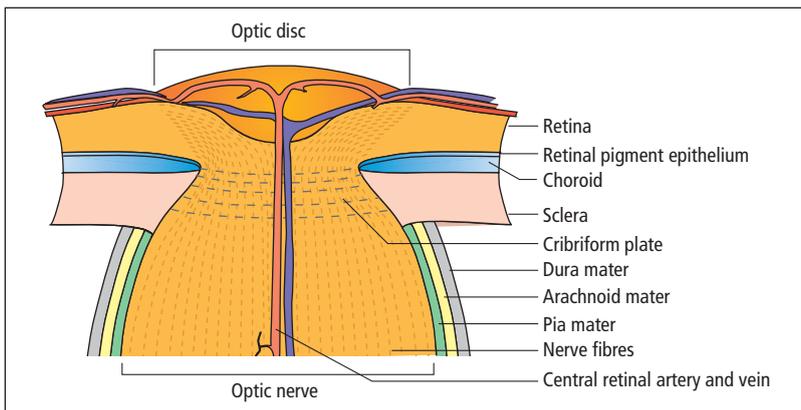


Figure 1.12 The structure of the optic nerve.

The central retinal artery and vein enter the eye in the centre of the optic nerve.

The extraocular nerve fibres are myelinated; those within the eye are not.

The ocular blood supply

The eye receives its blood supply from the ophthalmic artery (a branch of the internal carotid artery) via the retinal artery, ciliary arteries and muscular arteries (Fig. 1.13). The conjunctival circulation anastomoses anteriorly with branches from the external carotid artery.

The anterior optic nerve is supplied by branches from the ciliary arteries. The inner retina is supplied by arterioles branching from the central retinal artery. These arterioles each supply an area of retina, with little overlap. Obstruction results in ischaemia of most of the area supplied by that arteriole. The fovea is so thin that it requires no supply from the retinal circulation. It is supplied indirectly, as are the outer layers of the retina, by diffusion of oxygen and metabolites across the retinal pigment epithelium from the choroid.

The endothelial cells of the retinal capillaries are joined by tight junctions so that the vessels are impermeable to proteins. This forms an '*inner blood-retinal barrier*', with properties similar to that of the blood-brain barrier. The capillaries of the choroid, however, are fenestrated and leaky. The retinal pigment epithelial cells are also joined by tight junctions and present an '*external blood-retinal barrier*' between the leaky choroid and the retina.

The breakdown of these barriers causes the retinal signs seen in many vascular diseases.

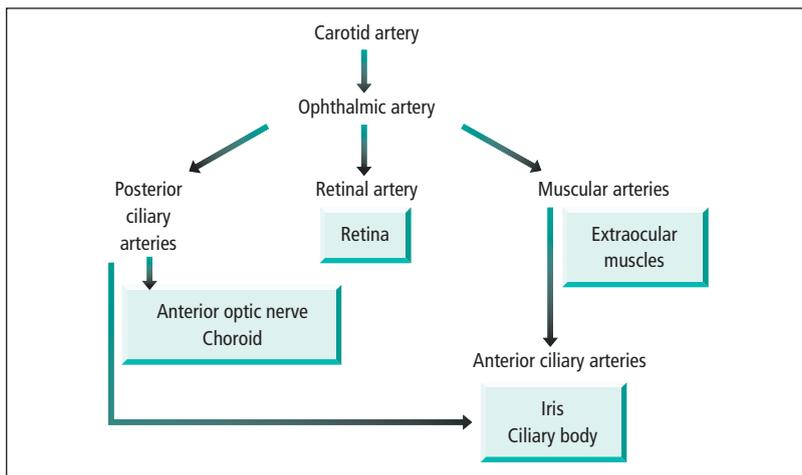


Figure 1.13 Diagrammatic representation of the ocular blood supply.

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Table 1.1 The muscles and tissues supplied by the third, fourth and sixth cranial nerves.

Third (oculomotor)	Fourth (trochlear)	Sixth (abducens)
Medial rectus	Superior oblique	Lateral rectus
Inferior rectus		
Superior rectus (innervated by the contralateral nucleus)		
Inferior oblique		
Levator palpebrae (both levators are innervated by a single midline nucleus)		
Preganglionic parasympathetic fibres end in the ciliary ganglion. Here postganglionic fibres arise and pass in the short ciliary nerves to the sphincter pupillae and the ciliary muscle		

The third, fourth and sixth cranial nerves

The structures supplied by each of these nerves are shown in Table 1.1.

Central origin

The nuclei of the third (oculomotor) and fourth (trochlear) cranial nerves lie in the midbrain; the sixth nerve (abducens) nuclei lie in the pons. Figure 1.14 shows some of the important relations of these nuclei and their fascicles.

Nuclear and fascicular palsies of these nerves are unusual. If they do occur they are associated with other neurological problems. For example if the third nerve fascicles are damaged as they pass through the red nucleus the ipsilateral third nerve palsy will be accompanied by a contralateral tremor. Furthermore a nuclear third nerve lesion results in a *contralateral* palsy of the superior rectus as the fibres from the subnucleus supplying this muscle cross.

Peripheral course

Figure 1.15 shows the intracranial course of the third, fourth and sixth cranial nerves.

Third nerve

The third nerve leaves the midbrain ventrally between the cerebral peduncles. It then passes between the *posterior cerebral* and *superior cerebellar arteries* and then

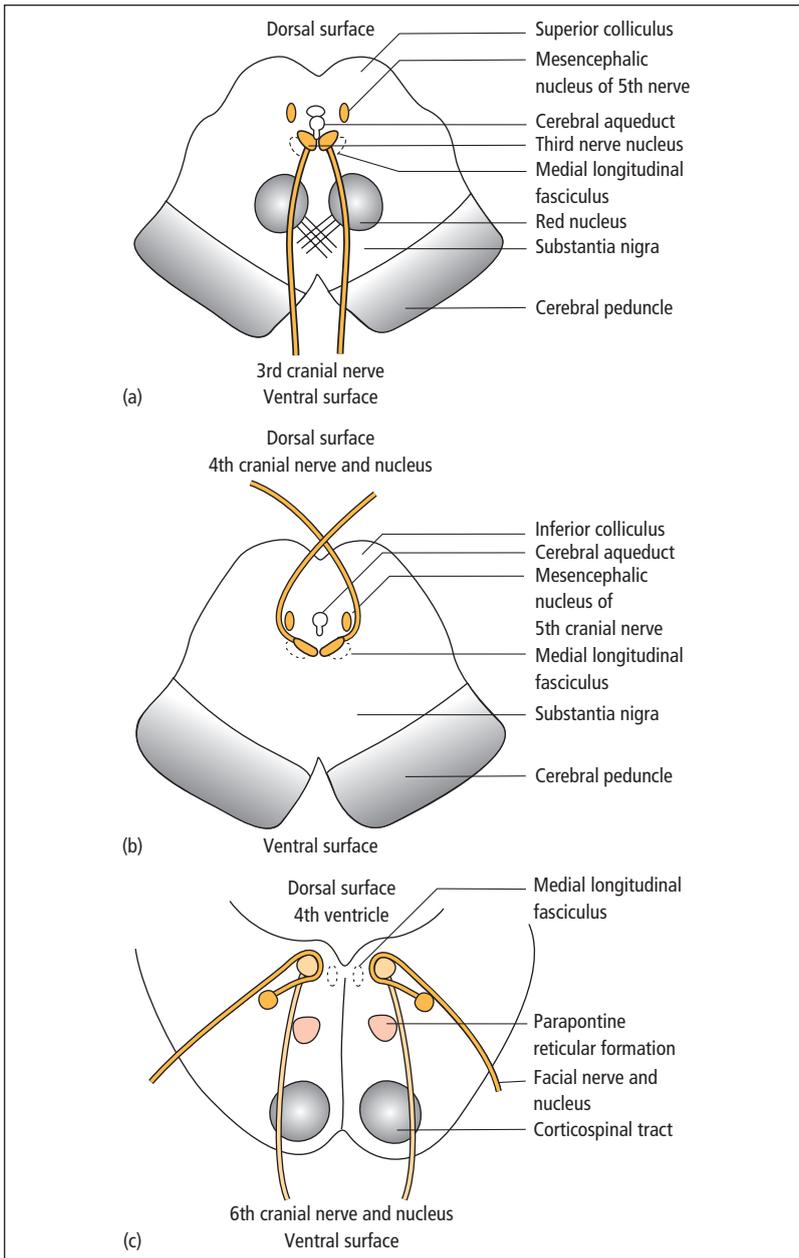


Figure 1.14 Diagrams to show the nuclei and initial course of (a) the third, (b) the fourth and (c) the sixth cranial nerves.

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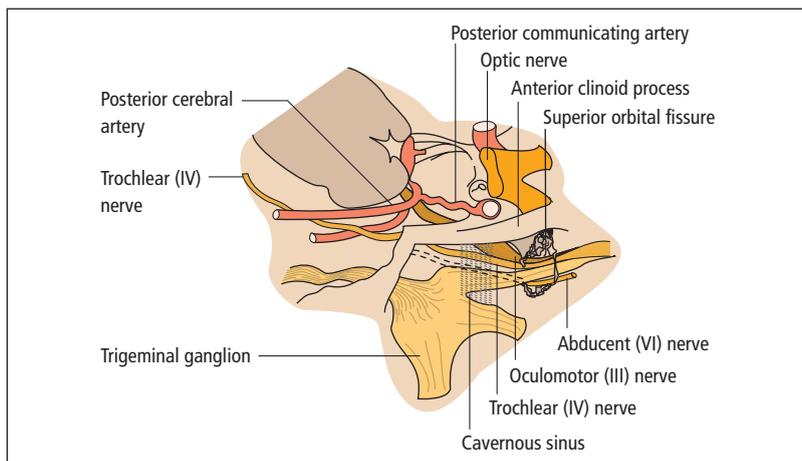


Figure 1.15 The intracranial course of the third, fourth and sixth cranial nerves.

lateral to the *posterior communicating artery*. Aneurysms of this artery may cause a third nerve palsy. The nerve enters the cavernous sinus in its lateral wall and enters the orbit through the superior orbital fissure.

Fourth nerve

The nerve decussates and leaves the *dorsal* aspect of the midbrain below the inferior colliculus. It first curves around the midbrain before passing like the third nerve between the posterior cerebral and superior cerebellar arteries to enter the lateral aspect of the cavernous sinus inferior to the third nerve. It enters the orbit via the superior orbital fissure.

Sixth nerve

Fibres leave from the inferior border of the pons. It has a long intracranial course passing upwards along the pons to angle anteriorly over the petrous bone and into the cavernous sinus where it lies infero-medial to the fourth nerve in proximity to the internal carotid artery. It enters the orbit through the superior orbital fissure. This long course is important because the nerve can be involved in numerous intracranial pathologies including base of skull fractures, invasion by nasopharyngeal tumours and raised intracranial pressure.

Multiple choice questions

1. The cornea

- a Has an endothelial layer that regenerates readily.
- b Comprises three layers.
- c The endothelium actively pumps water from the stroma.
- d Is an important refractive component of the eye.
- e Has a stroma composed of randomly arranged collagen fibrils.

2. The retina

- a Is ten layers thick.
- b Has ganglion cells whose axons form the optic nerve.
- c Has three types of rods responsible for colour vision.
- d The neuroretina is firmly attached to the retinal pigment epithelium.
- e The RPE delivers vitamin A for rhodopsin production.

3. The lens

- a Grows throughout life.
- b Is surrounded by a collagenous capsule.
- c Cortical and nuclear fibres are nucleated.
- d Has a high refractive index owing to its protein content.
- e Changes in shape with accommodation.

4. The suspensory ligament of the lens (the zonule)

- a Attaches the lens to the ciliary body.
- b Is part of the iridocorneal angle.
- c Is composed of smooth muscle.
- d Transmits changes in tension to the lens capsule.

5. The posterior chamber

- a Is another name for the vitreous body.
- b Lies between the iris, lens and ciliary body.
- c Contains aqueous humour, secreted by the ciliary processes.
- d Is in communication with the anterior chamber.

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6. The tear film

- a Is 100 μm thick.
- b Is composed of four layers.
- c The mucin layer is in contact with the cornea.
- d Is important in the refraction of light entering the eye.
- e Contains lysozyme and secretory IgA.

7. The iridocorneal angle

- a Is the site of aqueous production.
- b Lies between the cornea and the ciliary body.
- c In primary open angle glaucoma there is a reduction in the number of cells covering the trabecular meshwork.
- d Fluid passes through the trabecular meshwork to Schlemm's canal.

8. The optic nerve

- a Axons leave the eyeball through the cribriform plate.
- b Is not bathed in CSF until it enters the cranial cavity.
- c Anteriorly is supplied by blood from the ciliary arteries.
- d Axons are not myelinated in its retrobulbar part.
- e Is formed by the nerve fibre layer of the retina.

9. The third, fourth and sixth cranial nerves

- a All originate in the midbrain.
- b A *nuclear* third nerve palsy will cause a contralateral palsy of the superior rectus.
- c The fourth nerve supplies the lateral rectus.
- d The sixth nerve has a long intracranial course.
- e The third nerve may be affected by aneurysms of the posterior communicating artery.

Answers

1. The cornea

- a False. The human endothelium does not regenerate; dead cells are replaced by the spreading of surviving cells.
- b True. The cornea has epithelial, stromal and endothelial layers.

- c True. The endothelial cells pump out ions and the water follows osmotically. Removal of water maintains corneal transparency.
- d True. The cornea is a more powerful refractive element than the natural lens of the eye.
- e False. The fine, equally spaced, stromal collagen fibrils are arranged in parallel and packed in an orderly manner. This is a requirement for transparency.

2. The retina

- a True. See Fig. 1.7.
- b True. The retinal ganglion cell axons form the retinal nerve fibre layer and exit the eye at the optic nerve head.
- c False. The rods are responsible for night vision and three cone types are responsible for daylight and colour vision.
- d False. The attachment is loose; the neuroretina separates in retinal detachment.
- e True. Vitamin A is delivered by the RPE to the photoreceptors and combined with opsin.

3. The lens

- a True.
- b True. This is of great importance in cataract surgery.
- c False. The older, deep cortical and nuclear fibres lose their nuclei and other organelles.
- d True.
- e True.

4. The suspensory ligament of the lens (the zonule)

- a True. Zonular fibres extend from the pars plicata of the ciliary body to the lens equator.
- b False. The zonule lies behind the iris and iridocorneal angle.
- c False. The ciliary muscle contains smooth muscle, not the zonule.
- d True. Contraction of the ciliary muscle relaxes the zonular fibres allowing the lens to increase its curvature and thus its refractive power (this is 'accommodation').

5. The posterior chamber

- a False. The vitreous body is quite separate.
- b True.
- c True.

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d True. Communication is via the pupil, in the gap between iris and lens at the pupil margin. If this gap is narrowed or closed, pressure in the posterior chamber pushes the iris forward and may close the angle (acute closed angle glaucoma).

6. The tear film

- a False. The tear film is 3 μm thick.
- b False. The tear film is composed of mucin, aqueous and oil layers.
- c True.
- d True. It provides a smooth interface for the refraction of light.
- e True.

7. The iridocorneal angle

- a False. It is the site of aqueous drainage.
- b True.
- c True.
- d True. The process is active.

8. The optic nerve

- a True.
- b False. In the orbit, within its sheaths, the optic nerve is surrounded by sub-arachnoid CSF in continuity with that in the intracranial cavity.
- c True. This is a most important blood supply for the anterior optic nerve.
- d False. They are usually not myelinated *within* the eye.
- e True. It is made up from retinal ganglion cell axons.

9. The third, fourth and sixth cranial nerves

- a False. The nucleus of the sixth nerve lies in the pons.
- b True. The superior rectus is innervated by the contralateral nucleus.
- c False. It supplies the superior oblique.
- d True. This makes the sixth nerve susceptible to trauma, which may cause lateral rectus palsy.
- e True. It passes lateral to the artery.