Ocular anatomy and physiology relevant to anaesthesia

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Abstract

An understanding of the anatomy of the orbit is essential for performing regional anaesthesia for ophthalmic surgery. This article will discuss ocular anatomy in terms of the orbit and its contents, its associated muscles, nerves and blood supply, as well as basic ocular physiological principles.

Keywords Choroid; cornea; optic nerve; orbit; retina; sclera; Tenon's fascia

Royal College of Anaesthetists CPD Matrix: 1A01

Learning objectives

After reading this article, you should be able to:

- describe and identify the anatomical structures of the bony orbit and eyeball
- describe the muscles, nerve supply and blood supply of the eyeball
- discuss the relevance of the anatomical structures within the orbit in relation to commonly performed eye blocks
- explain the physiological principles of basic optics and how the eye works

Bony orbit

The bony orbit is a protective cavity which contains the eye ball, its associated structures (muscles, nerves and blood vessels), the lacrimal apparatus, as well as fat and connective tissue.

The shape of the orbit resembles a pyramid, with the apex of the pyramid pointing posteriorly and slightly medially to where the optic foramen is found. The medial walls of these orbital pyramids lie parallel to each other (usually 2.5 cm apart and separated by the nasal cavity), while the lateral walls lie approximately 90 degrees to each other. Therefore the angle between the medial and lateral wall of each orbit is 45 degrees (Figure 1).

The volume of the orbit is approximately 30 ml, with the eyeball accounting for 7 ml of this. The depth of the bony orbit is roughly 45–50 mm from the orbital rim to the optic foramen.

A total of seven bones are involved in making up the bony orbit (Figure 2), which are the frontal, zygomatic, maxillary, sphenoid, lacrimal, ethmoid and palatine bones. Three of those bones - the frontal bone, zygomatic bone and maxilla – comprise the rim of the bony orbit. In the middle of the superior margin (frontal bone) of the rim the distinct superior orbital notch can be found, with external application of pressure at this point causing pain due to the presence of the supra-orbital nerve. On the lateral margin a further notch can be palpated which signifies the suture line of the zygomatic and frontal bones.

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Covering these bones within the orbit there is a thin periosteal lining which is loosely attached to the underlying bone and is continuous with the external periosteum of the skull.

Within the bony orbit, blood vessels and nerves pass in to the orbit via several foramina including the superior orbital fissure, inferior orbital fissure and the optic foramen (Figure 3).

The eyeball

Within the orbit, the eyeball sits in a superior, lateral and anterior position. The average length of the eyeball is 25mm with it having a roughly spherical shape. Eyes which are longer than this (i.e. >26mm such as in myopic individuals) have an increased risk of developing staphylomas, which are outpouchings in the sclera often found in the posterior or inferior surfaces of the globe. Presence of these staphylomas increase the risk of globe perforation in performing peribulbar or retrobulbar regional techniques, therefore a sub-Tenon's or general anaesthesia approach is normally preferred in these patients.

The eyeball itself can be thought of as two segments. An anterior segment which is prominent, transparent and forms approximately one sixth of the eyeball, and a posterior segment which is opaque, larger and constitutes the other five sixths of the eyeball.

The structure of the eyeball consists of three main layers which are (Figure 4):

- outer fibrous layer
- middle vascular layer
- inner neural layer.

Outer fibrous layer

This fibrous layer is mostly made up of the sclera ('white of the eye') apart from the anterior component of the eye which is covered by the clear cornea. The sclera is a tough fibrous tissue, mainly made of collagen and some elastin fibres, which helps maintain the shape of the eyeball and is where the extraocular muscles insert. It is approximately 1 mm thick in the posterior eyeball, but thins to 0.6 mm at the equator. The sclera and cornea are a continuation of each other, with the limbus being the junction between these two structures. The sclera is also continuous with the dural sheath that covers the optic nerve. The optic nerve penetrates the sclera in the posterior eye, slightly superior and medial to the posterior pole of the eyeball. The cornea and anterior part of the sclera, as well as the inner aspect

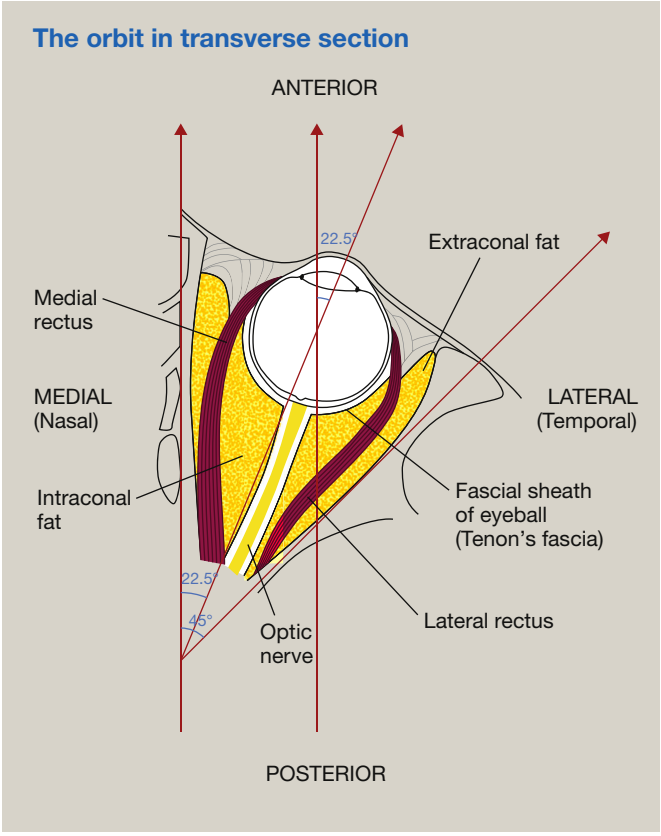

Figure 1

of the eyelids are covered by the conjunctiva, which is the area which becomes inflamed in the condition conjunctivitis.

Middle vascular layer

This vascular layer is made up of the choroid, ciliary body and iris. The choroid provides the blood supply to the retina (which it covers) and at its anterior margin it terminates into the ciliary body. Within the ciliary body there are ciliary processes which are folds which lie between the ciliary ring and the iris and are connected by the suspensory ligament of the lens. These ciliary processes produce aqueous humor (catalysed by carbonic anhydrase) and secrete it into the posterior chamber at the front of the eye. The aqueous humor also fills the anterior chamber (moving between the two chambers from posterior to anterior through the pupil) and drains into venous plexuses from the anterior chamber through the canal of Schlemm in the trabecular meshwork which is located at the angle of the iris and the cornea. If there is a reduction in the drainage of the aqueous humor, the intraocular pressure will rise causing damage to the optic nerve, known as the condition glaucoma. The aqueous humor is in contact with the cornea and lens, which are both avascular, and provides these structures with nutrients. Also within the ciliary body there are the ciliary muscles which are responsible for changes in the lens convexity in accommodation. The iris is a coloured disc which surrounds the pupil and separates the anterior from the posterior chamber. At the edges of the iris disc there are longitudinal smooth muscle fibres (dilator pupillae) supplied by postganglionic sympathetic nerve fibres originating in the cervical plexus. When stimulated, they contract and cause the pupil to dilate. At the innermost part of the iris there are circular muscle fibres (sphincter pupillae) which are supplied by postganglionic parasympathetic nerve fibres from the ciliary ganglion, which when stimulated cause the pupil to constrict.

Inner neural layer

This neural layer of the retina is formed of two layers, an outer pigmented layer and an inner neural layer, and is positioned under the choroid and above the vitreous humor. The retina contains rods and cones which are the light-sensitive photoreceptors which relay impulses to the visual cortex. At the posterior part of the neural layer, the nerve fibres combine together to form the optic nerve. The point where these nerve fibres pass through the retina is the optic disc and signifies the beginning of the optic nerve. At this optic disc there are no rods or cones overlying it, therefore is referred to as the "blind spot".

Other structures in the eyeball

The lens is located between the vitreous and aqueous humor, and is clear with a biconvex shape. A cataract occurs when the lens develops an opacification, which can result in significant deterioration of vision.

The vitreous humor is a transparent gel which is contained within the hyaloid membrane and helps provide support to the eye structure.

Tenon's fascia

The Tenon's fascia is a thin layer which covers the fibrous sclera and separates the eyeball from the surrounding orbital fat, which lies between the eyeball and the extraocular muscles. The fascia starts anteriorly at the junction of the cornea and sclera, with the anterior portion of the eyeball instead being covered by the conjunctiva. The Tenon's fascia ends posteriorly where the sclera meets the optic nerve. The Tenon's fascia layer is penetrated by the extraocular muscles and nerves, with the potential space under the fascia (the sub-Tenon's space) being the site where local anaesthetic can be deposited for a sub-Tenon's block allowing for local anaesthetic to spread to the desired nerves and muscles that supply the eye. With increasing age, the Tenon's fascia generally becomes thinner and less adherent to the sclera.

Blood supply to the eye

The arterial supply to the orbit is from the ophthalmic artery which is a branch of the internal carotid artery, with the ophthalmic artery entering the orbit along the optic canal with the optic nerve before dividing into branches. The central retinal artery is a branch of the ophthalmic artery which supplies the innermost layer of the retina. It travels within the optic nerve, and at the point of the optic disc it emerges before dividing into its branches. The central retinal artery is an end-artery, therefore if occlusion of the artery occurs due to an embolus (central retinal artery occlusion) there will be sudden onset visual loss in the affected eye.

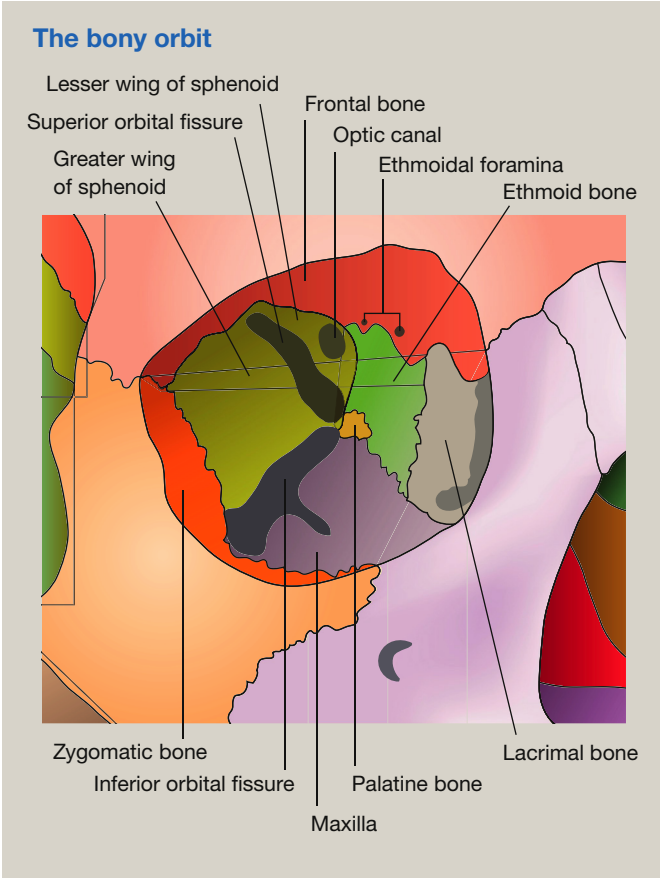

Figure 2

Venous drainage of the eye is via the superior and inferior ophthalmic veins (via the orbital fissures) into the cavernous sinus. If these veins become occluded (central retinal vein occlusion) there will be slower onset painless visual loss (Figure 5).

Muscles of the eye

The muscles involved in movement of the orbit are six extraocular muscles (four rectus muscles and two oblique muscles) and levator palpebrae superioris.

The rectus muscles originate from a tendinous ring (annulus of Zinn) surrounding the optic foramen and medial part of the superior orbital fissure, and insert into the globe posterior to the junction of the sclera and cornea, but anterior to the equator of the eyeball. The four rectus muscles form a muscle cone with each muscle primarily responsible for an action:

- superior rectus – elevation
- inferior rectus – depression
- lateral rectus – abduction
- medial rectus – adduction

In order to achieve elevation and depression in a straight up and down fashion, there also needs to be interaction with the oblique muscles. This is due to the muscle cone axis actually sitting at an angle of 22.5 degrees from the sagittal plane.

When considering ophthalmic regional anaesthetic techniques, the orbit (not including the eyeball) can be divided in to the intraconal and extraconal space. The intraconal space is within an area formed by the rectus muscles. This space encloses most of the nerves. Thus when using a retrobulbar technique whereby local anaesthetic is injected into the intraconal space, only a small volume of local anaesthetic is required. The extraconal space lies outwith the rectus muscles and contains fewer nerves. Therefore if performing a peribulbar technique into the extraconal space, then a larger volume (up to 10–15 ml) is required to allow diffusion into the intraconal space.

The two oblique muscles are superior and inferior oblique. The superior oblique is involved in abduction, depression and medial rotation. It arises close to the origin of the superior and medial rectus on the body of the sphenoid bone and is attached superolaterally to the eyeball. Inferior oblique is involved in

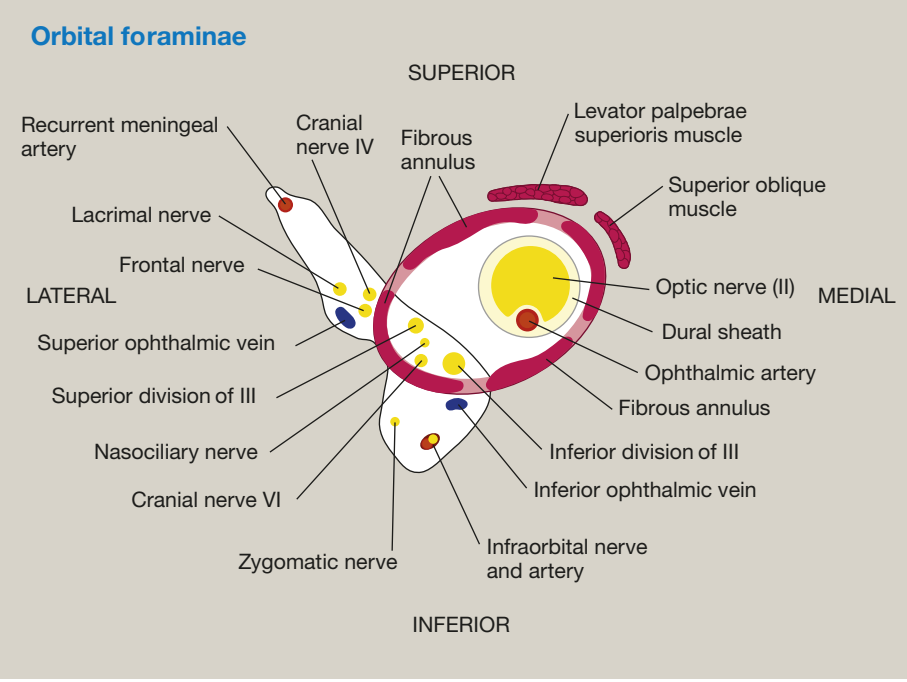

Figure 3

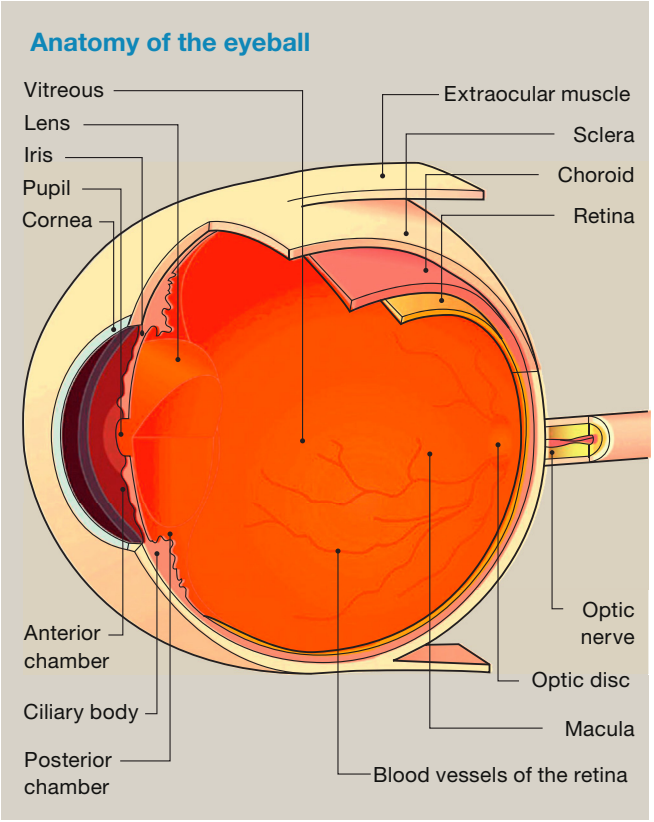

Figure 4

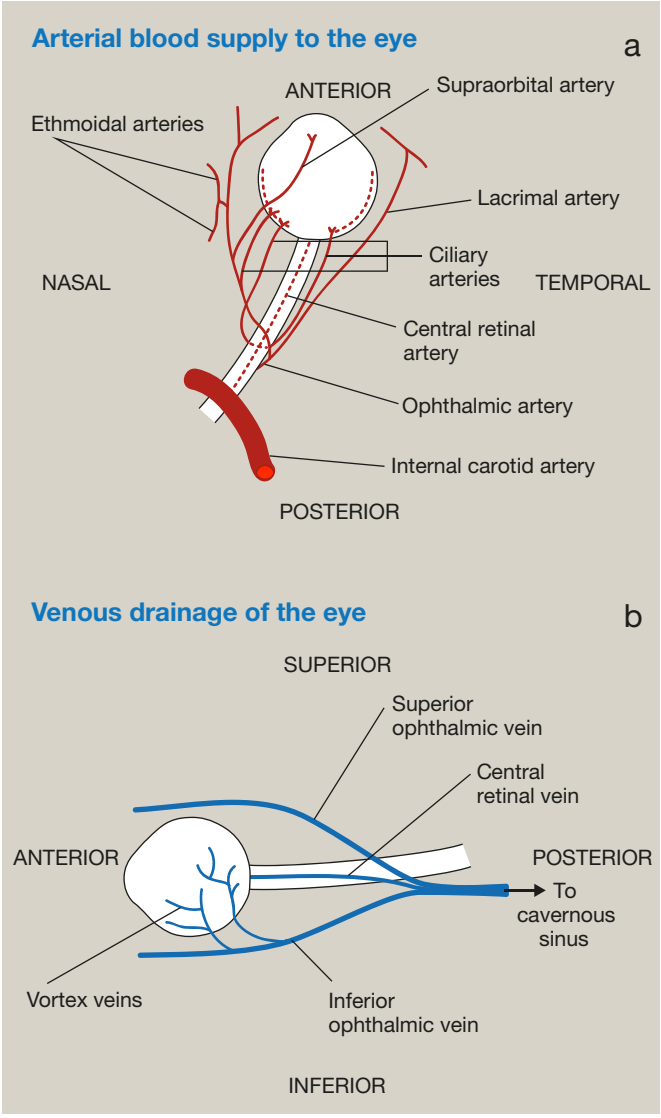

Figure 5

abduction, elevation and lateral rotation and is attached posterolaterally to the eyeball, with its origin anteriorly at the infraorbital rim. Both of the oblique muscles insert onto the eyeball behind the equator of the eyeball.

The levator palpebrae superioris is an extraconal muscle which arises from the sphenoid and inserts into the skin of the upper eyelid and is involved in elevating the eyelid. It has some sympathetic innervation, which gives explanation as to the ptosis associated with Horner's syndrome.

Nerve supply to the eye

There are several cranial nerves which play a role in the nerve supply of structures of the orbit.

The optic nerve (II) conveys vision. Once it has left the globe, the optic nerve passes through the orbit, exiting through the optic foramen into the optic canal.

The motor supply of the orbital muscles (superior, inferior and medial rectus, and inferior oblique) is the oculomotor nerve (III) except for superior oblique by the trochlear nerve (IV) and lateral rectus by the abducens (VI) nerve. The oculomotor and abducens nerve take an intraconal path, whereas the trochlear nerve follows an extraconal path. An intraconal regional technique can therefore result in sparing of the superior oblique muscle, resulting in some ongoing rotational movement of the eyeball.

Sensory innervation to the eye is via the ophthalmic branch of the trigeminal nerve (V_1). It has three branches (lacrimal, fontal, nasociliary) which all pass in to the orbit via the superior orbital fissure. The nasociliary branch provides sensation to the cornea and some areas of the conjunctiva and takes an intraconal path, with the rest of the conjunctiva being supplied by the frontal and lacrimal branches which take an extraconal path.

Ocular physiology

How the eye works

When light enters the eye, before it reaches the retina it must pass through the cornea, aqueous humor, pupil, lens and vitreous humor. In order to produce a focused picture, the light entering the eye must be refracted and directed onto the retina. This refraction occurs when light passes through the cornea and the lens, with the lens having the ability to change its shape with contraction of the ciliary muscles. Contraction of the ciliary muscles causes the lens to become more rounded, increasing its refractive power. This process is called accommodation. Visual defects which affect where the image is focused include:

- Hyperopia (long sighted):
  - Can see far away objects unaided.
  - The eyeball is too short.

- Image focuses behind the retina.
- Corrected with biconvex lenses.

- Myopia (short sighted):
  - Can see near objects unaided.
  - The eyeball is too long.
  - Image focuses in front of the retina.
  - Corrected with biconcave lenses.
- Presbyopia:
  - Can see far away objects, with nearest point able to focus on gradually increasing in distance from the eye with age.
  - Occurs due to lens becoming less elastic with increasing age, resulting in reduced curvature in the lens with accommodation.
  - Corrected with convex lens to improve close vision.

The retina is made up of photoreceptors called rods and cones. The rods are distributed throughout the retina (approximately 120 million) and are responsible for night vision. However, the cones are found in high concentrations in the fovea (approximately 7 million) and are responsible for bright and colour vision.

When light reaches the retina, an electrical potential is generated from the rods and cones and transmitted to the ganglion cells. Axons from these ganglion cells converge at the optic disc to form the optic nerve, with the two optic nerves meeting at the optic chiasm. The axons which come from the medial half of the retina (i.e. closest to the nasal cavity) decussate at the optic chiasm, whereas those from the lateral half continue on the same side. These axons then join together on each side to form the optic tracts, with each optic tract conveying the image of the opposite visual field (i.e. the left optic tract conveying the image of the right visual field, and the right optic tract conveying the image of the left visual field). These optic tracts then synapse at the lateral geniculate nuclei before synapsing through the optic radiation to the primary visual cortex in the occipital lobe. If there are lesions at various stages in this pathway, visual field defects can develop (Figure 6):

- optic nerve: complete loss of vision in affected eye
- optic chiasm: bitemporal hemianopia (loss of temporal vision in both eyes)
- optic tract and optic radiation: homonymous hemianopia (loss of vision from opposite visual field).

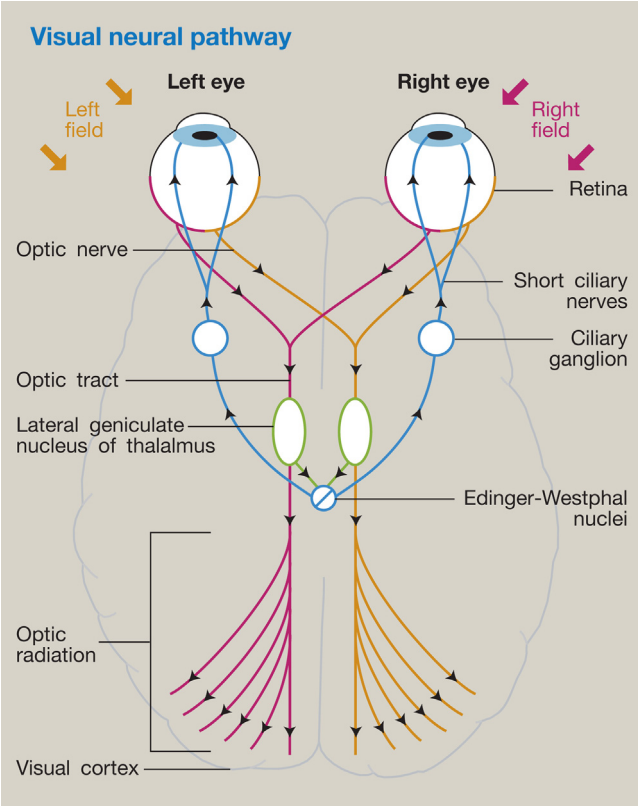

Figure 6

Intraocular pressure

The normal intraocular pressure (IOP) is 10–22 mmHg. It usually increases with age, and it has some diurnal variation of up to 2–3 mmHg with higher pressures in the morning. Transient rises in IOP can occur with coughing or vomiting but these are of little significance to the intact eye. However sustained rises in IOP can result in progressive visual loss. IOP can be affected by changes in intraocular contents (e.g. aqueous humor production and drainage) or external pressure on the eye. IOP can also be affected by other factors:

- Drugs – volatile anaesthetics, opioids and hypnotics all cause a fall in IOP, while ketamine causes a rise in IOP. Depolarizing muscle relaxants can cause a small, transient rise in IOP while non-depolarizing muscle relaxants have no effect on IOP. Mannitol and acetazolamide both decrease IOP by removing fluid from the vitreous and reducing aqueous humor production respectively.
- Arterial blood pressure – due to autoregulation, the blood flow to the eye remains constant over a wide range in blood pressure, but can affect IOP after prolonged hypotension. In addition, a chronic increase in blood pressure is also associated with raised IOP.
- Venous pressure – when patients are tilted head up, venous drainage is encouraged and can decrease venous congestion therefore reducing IOP.

Oculocardiac reflex

The oculocardiac reflex is mediated by the parasympathetic nervous system and results in a bradycardia usually as a result of either compression of the globe or retraction of an extra-ocular muscle. Afferent signals are sent via the ophthalmic division of the trigeminal nerve to the medulla, with efferent signals returning via the vagus nerve to the sino-atrial node. Immediate cessation of the compression or retraction stimulus usually results in reversal of the reflex, however anticholinergics or rarely CPR may be required. Paediatric patients, especially those undergoing strabismus surgery, are especially prone to displaying the oculocardiac reflex. Local anaesthetic blocks help to attenuate the afferent arc of the reflex. There are also oculorespiratory and oculo-emetic reflexes which have afferent pathways similar to the oculocardiac reflex, however demonstrating different efferent effects. These are both also associated with squint surgery. ◆

FURTHER READING

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