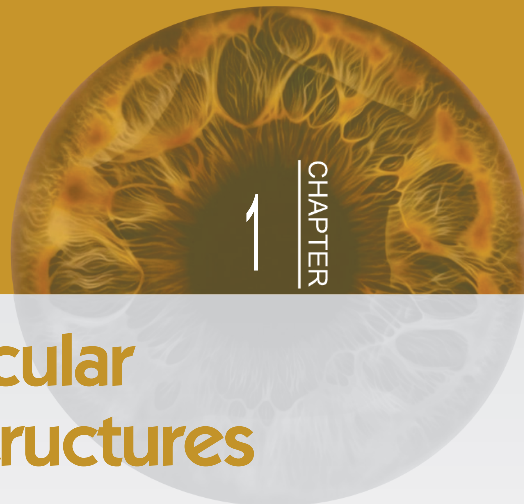

CHAPTER 1

Anatomy of Extraocular Muscles and Related Structures

EXTRAOCULAR MUSCLES AND ORBITAL FASCIA

A set of six extraocular muscles (4 recti and 2 obliques) controls the movements of each eye (Fig. 1.1). Rectus muscles are superior rectus (SR), inferior rectus (IR), medial rectus (MR) and lateral rectus (LR). The oblique muscles include superior oblique (SO) and inferior oblique (IO).

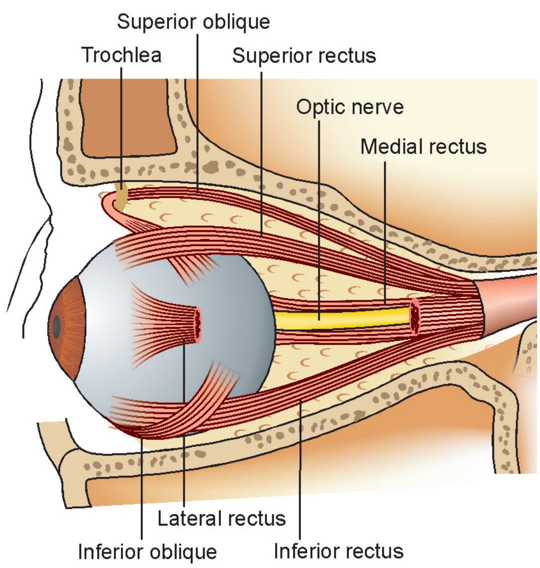

Fig. 1.1 *Extraocular muscles.*

EXTRAOCULAR MUSCLES

RECTUS MUSCLES

Origin

The four rectus muscles originate from a common tendinous ring (the annulus of Zinn), which is attached at the apex of the orbit encircling the optic foramina and medial part of the superior orbital fissure (Fig. 1.2). The *annulus of Zinn* appears oval on cross-section. Medial rectus arises from the medial part of the ring, superior rectus from the superior part, inferior rectus from the inferior part and lateral rectus from the lateral part by two heads which join in a 'V' form. Due to slope of the orbital roof, the origin of the superior rectus and medial rectus is slightly at the anterior plane to others. The superior rectus and medial rectus are closely attached to the dural sheath of the optic nerve at their origin. This attachment accounts for the characteristic pain in a case of retrobulbar neuritis, felt during upward and inward movements of the globe.

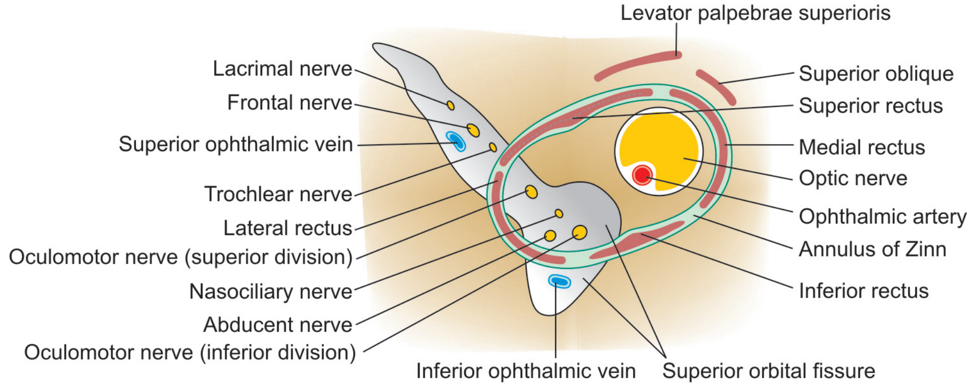

Fig. 1.2 *Origin of the rectus and superior oblique muscles.*

Course

All the four recti from their origin run forward around the eyeball. The medial and lateral recti follow the corresponding walls of the orbit in most of the part of their course, and the inferior rectus remains in contact with the orbital floor for only about half its length. The superior rectus muscle is separated from the orbital roof by the levator palpebrae superioris muscle. The course of the four recti, starting from the apex of the orbit, is diverging, however, somewhat in front of the equator they turn towards the eyeball in a gentle curve to get inserted on the sclera.

Medial rectus (MR) muscle follows the medial wall of the orbit in most part of its course. This proximity to the medial orbital wall accounts for its inadvertent damage during standard or endoscopic ethmoid sinus surgery. Medial rectus muscle is the only rectus muscle that does not have a fascial attachment to an oblique muscle; and because of this fact, it is at the greatest risk of slippage or loss during surgery.

Lateral rectus (LR) muscle, after arising from the lateral part of annulus of Zinn, follows the lateral orbital wall in most of the part of its course. Its inferior border passes just superior to the insertion of inferior oblique (IO) muscle (Fig. 1.1). The facial connections between LR and IO muscles at this point, which is 8–9 mm posterior from the insertion of LR, allow the surgeon to retrieve the, inadvertently lost LR muscle during surgery, at this point.

Superior rectus (SR) muscle after origin from the superior part of annulus of Zinn runs anteriorly, slightly laterally and superiorly in the superior orbit. In most of its course, it is separated from the orbital roof by the levator palpebrae superioris (LPS) muscle. In primary position, SR muscle forms an angle of 23° with the visual axis. This angle determines the secondary and tertiary actions of the SR muscle in primary position. Anteriorly, prior to insertion, the SR muscle courses between the tendon of superior oblique and LPS muscles. Fascial attachments from the SR muscle extend to SO and LPS muscles.

Inferior rectus (IR) muscle, after arising from the inferior part of the annulus of Zinn, runs anteriorly, slightly inferiorly and laterally making an angle of 23° with the visual axis in its primary position. In posterior half of its course, the IR muscle remains in contact with the orbital floor. Anteriorly, the IR muscle courses between the globe and inferior oblique (IO) muscle prior to its insertion (Fig. 1.1). Fascial attachments exist between the IR, IO and lower lid retractors. These connections are useful in retrieving, the inadvertently slipped IR during surgery, in the region of Lockwood's ligament. Further, failure to dissect these connections during IR recession or resection may lead to eyelid fissure widening or narrowing, respectively.

Insertion

At the insertion, the striated muscle fibres of recti muscle with minimal tendinous connective tissue, directly attach to the sclera. All the four rectus muscles are inserted into the sclera just anterior to the equator of globe at different distances from the limbus as under (Fig. 1.3A):

		(Fuchs, 1884)	(Apt, 1980)
Medial rectus	:	5.5 mm	5.3 mm
Inferior rectus	:	6.5 mm	6.8 mm
Lateral rectus	:	6.9 mm	6.9 mm
Superior rectus	:	7.7 mm	7.9 mm

Thus the insertions of the recti, being not equidistant from the limbus, do not form a circle concentric with the limbus; rather form a spiral (*the spiral of Tillaux).*

The *insertion lines* (Fig. 1.3A) of medial and lateral rectus muscles show slight convexity facing the limbus. The lines of insertion of superior and inferior rectus muscles show marked convexity towards the limbus and are obliquely placed in such a way that the lateral end of their insertion line is posteriorly placed as compared to the medial end.

OBLIQUE MUSCLES

Superior oblique muscle

Origin

The superior oblique muscle arises from the bone (body of sphenoid) above and medial to the optic foramen (Fig. 1.2) by a narrow tendon, partially overlapping the origin of levator palpebrae superioris.

Course

The muscle moves forward between the roof and medial wall of the orbit to reach the *trochlea* of the superior oblique muscle. The trochlea is a thick fibrous cartilagenous pulley attached to spina trochlearis on the under aspect of the frontal bone, at the superomedial angle, between the anterior most parts of the superior and medial walls of the orbit. After passing the trochlea, the superior oblique muscle turns posterolaterally. At about distal third of the direct portion (about 10 mm behind the trochlea), the muscle becomes tendinous and remains so in its post-trochlear or reflected part also.

The reflected tendon of the superior oblique (SO) passes under the superior rectus muscle and fans out to get inserted on to the sclera. The fibres of this fan-shaped tendinous part of SO muscle make an angle of 51° with the visual axis in primary position. Functionally, these fibres can be separated into two parts:

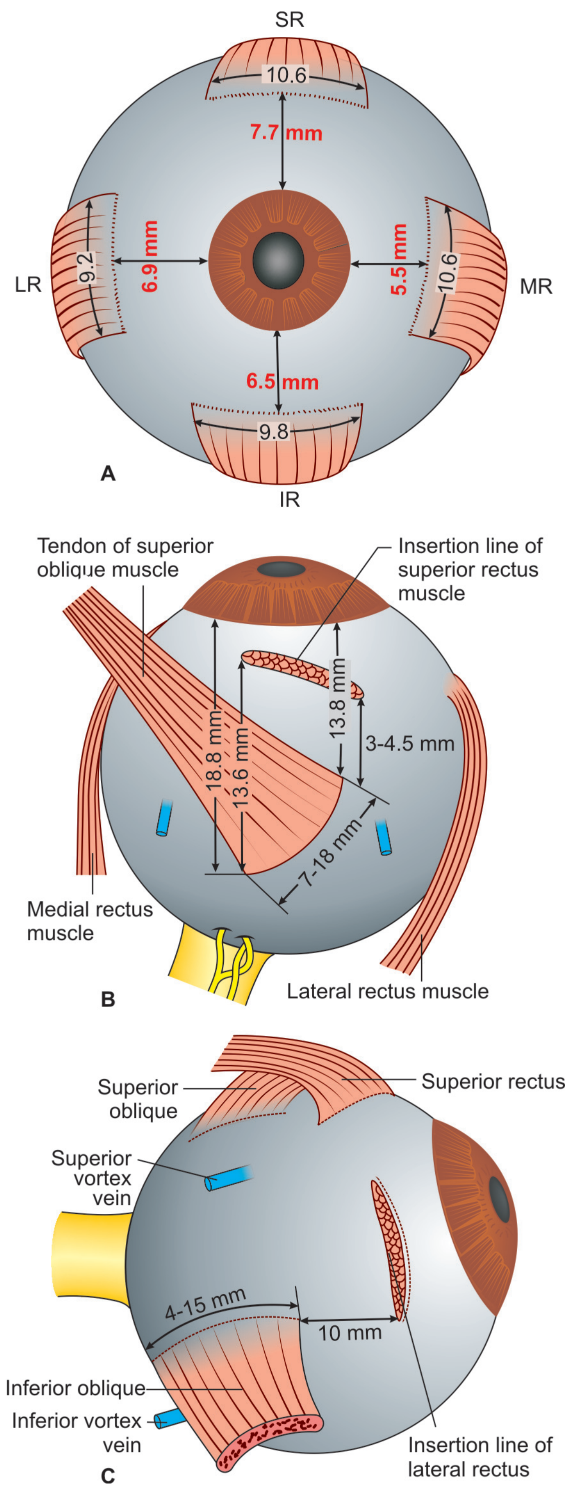

Fig. 1.3 *Insertion lines of the extraocular muscles on the sclera as seen from (A) front; (B) above and (C) lateral side. (SR, superior rectus; MR, medial rectus; IR, inferior rectus; LR, lateral rectus).*

- *Anterior one-third* fibres of the tendon are exclusively responsible for the incyclotorsion of the globe. Therefore, only these fibres of SO muscle are manipulated to enhance incyclotorsion action in Harada-Ito procedure.
- *Posterior two-third* fibres of the fan-shaped tendon of SO function to depress and abduct the globe.

Insertion

The fanned out reflected tendon of the superior oblique is inserted onto the upper and outer part of the sclera behind the equator (Fig. 1.3B).

The insertion line is curved with its concavity facing the trochlea with following landmarks:

- *Anterior end* of insertion lies some 13.8 mm behind the limbus and about 3 to 4.5 mm behind the lateral end of the insertion line of the superior rectus muscle.
- *Posterior end* of the insertion line lies about 18.8 mm behind the limbus and some 13.6 mm behind the medial end of the insertion line of superior rectus muscle.
- *Medial or posterior end of the insertion line* lies about 8 mm from the posterior pole.
- *Width of the insertion* line is about 11 mm, but it varies greatly from 7 to 18 mm.

The superior oblique is the *longest and thinnest* of all the extraocular muscles. The length of its direct part is about 40 mm and that of the reflected tendon is about 19.5 mm (total being 59.5 mm). From a physiologic and kinematic standpoint, the trochlea is the origin of the muscle.

Inferior oblique muscle

Origin

The inferior oblique muscle arises by a rounded tendon from a shallow depression on the orbital plate of maxilla just lateral to the orifice of the nasolacrimal duct (Fig. 1.4). Some fibres arise from the lacrimal fascia. It is the only muscle which takes origin from front of the orbit.

Course

From its origin, the muscle passes laterally and backward, between the inferior rectus muscle and floor of the orbit (Fig. 1.1). It is almost wholly muscular with a short tendon at origin and insertion. It is the *shortest* of the eye muscles, being only 37 mm long. The anterior fibres of the muscle are primarily responsible for extorsion and posterior fibres for the elevation.

Insertion

It is inserted by a short tendon (1 to 2 mm long) in the lower and outer part of the sclera behind the equator (Fig. 1.3C). The insertion line is

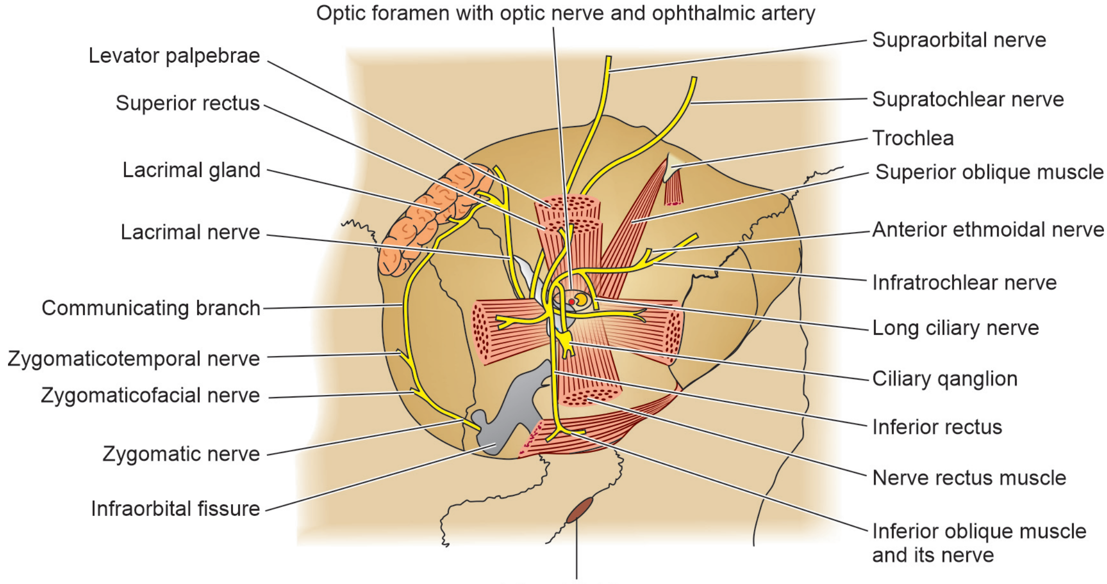

Fig. 1.4 *Origin of inferior oblique muscle and innervation of extraocular muscles.*

curved with a concavity facing the origin, with following landmarks:

- Its average width is around 9 mm. However, it varies widely from 5 to 14 mm.
- Its anterior end is about 10 mm behind the lower edge of the insertion of the lateral rectus muscle.
- Its posterior end is about 1 mm below and 1 to 2 mm in front of a point corresponding with the foveal region.
- Near the insertion, the inferior vortex vein is in relation to its posterior border.

Comparative dimensions

The comparative dimensions of the extraocular muscles are shown in Table 1.1. The table depicts the following:

- Superior oblique is the longest and thinnest muscle.
- Inferior oblique is the shortest muscle.

NERVE SUPPLY OF EXTRAOCULAR MUSCLES

The extraocular muscles are supplied by third, fourth and sixth cranial nerves (Fig. 1.4).

Third cranial nerve *(oculomotor)* supplies the medial, superior and inferior recti and inferior oblique muscles. The branches enter their respective muscles from their bulbar surfaces. The branches from the inferior division of third nerve supply the medial rectus (enters its belly 15 mm from origin), inferior rectus (enters at the junction of the posterior and middle thirds of the belly) and inferior oblique (enters just after the muscle passes lateral to the inferior rectus muscle) muscles. The branches for the superior rectus muscle originate from the upper division of the oculomotor nerve and enter the muscle at the junction of the posterior and middle thirds.

Fourth cranial nerve (*trochlear*) innervates the superior oblique muscle. Unlike other muscles, the nerve to this muscle enters from its outer (orbital) surface near the lateral border. The nerve divides into three or four branches. The most anterior branch enters the belly at the junction of posterior and middle thirds of the muscle and the most posterior at about 8 mm from its origin.

Sixth cranial nerve (*abducent*) innervates the lateral rectus muscle by entering the muscle on the bulbar side 15 mm from its origin.

BLOOD SUPPLY OF EXTRAOCULAR MUSCLES

Muscular arteries, usually two—medial and lateral (with a few fine twigs), are branches of the ophthalmic artery. The *medial muscular* branch, larger of the two, supplies the medial rectus, inferior rectus and inferior oblique muscles. The medial rectus also receives a branch from the lacrimal artery and the inferior rectus and inferior oblique muscles receive branch from the infraorbital artery. The *lateral muscular branch* supplies the lateral rectus, the superior rectus, the levator muscle and the superior oblique muscle.

Table 1.1 *Comparative dimensions of various extraocular muscles in mm and direction of pull in degrees*

Dimension	*Lateral rectus*	*Medial rectus*	*Superior rectus*	*Inferior rectus*	*Superior oblique*	*Inferior oblique*
• Total length	48	40	42	40	60	37
• Tendon length	8.8	3.7	5.8	5.5	20	1 to 2
• Muscle breadth	9	9	9	9	9	9
• Tendon breadth at insertion (insertion line)	9.2	10.3	10.8	9.8	11	9.4
• Distance of mid-point of insertion line from the limbus	6.9	5.5	7.7	6.5	16.3	18.4
• Cross-sectional area in mm						
– Volkmann	16.7	17.4	11.3	14.8	8.4	6.7
– Nakagama	17.5	16	11.4	15.0	7.9	9.5
• Direction of pull	90°	90°	23°	23°	51°	51°
• Arc of contact (mm)	12	7	6.5	6.5	7–8	15

Note: These are average figures and may vary greatly among individuals.

Anterior ciliary arteries arise from the muscular branches. These are usually seven—two each from the superior, inferior and medial recti and one from the lateral rectus muscle.

Veins from the extraocular muscles correspond to the arteries and empty into the superior and inferior ophthalmic veins.

ACTIONS OF EXTRAOCULAR MUSCLES

Detailed actions of each extraocular muscle, along with the mechanics of the ocular movements, are described in the section on physiology of ocular movements (*see* pages 22–30). However, a summary of actions of each extraocular muscle in primary position of gaze (Fig. 1.5) is depicted in Table 1.2.

STRUCTURAL CHARACTERISTICS OF EXTRAOCULAR MUSCLES

Muscle capsule, a thin connective tissue covering of the belly of each extraocular muscle (EOM), extends from its origin to insertion. The smooth avascular surface of the muscle capsule allows the muscle to slide easily over the globe.

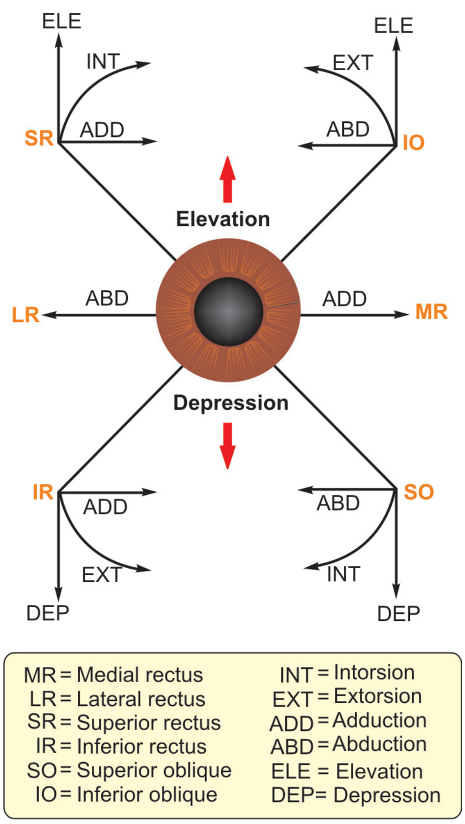

Fig. 1.5 *Actions of extraocular muscles.*

Table 1.2 *Actions of extraocular muscles in primary position of gaze*

Muscle	*Primary action*	*Secondary action*	*Tertiary action*
Medial rectus	Adduction	—	—
Lateral rectus	Abduction	—	—
Superior rectus	Elevation in abduction	Intorsion	Adduction
Inferior rectus	Depression in abduction	Extorsion	Adduction
Superior oblique	Intorsion	Depression	Abduction
Inferior oblique	Extorsion	Elevation	Abduction

Extraocular muscles are voluntary striated muscles. However, the EOMs differ from the *typical skeletal muscle* with the following characteristics:

- Diameter of these fibres is small.
- Contain an enormous amount of fibroelastic tissue
- Contain both slow and fast fibres
- Richly supplied by vessels
- Richly innervated at a ratio of nerve fibre to muscle fibre up to 10 times that of skeletal muscle.

Note: The above characteristics of the EOMs allow quick as well as smooth eye movements. Further the EOMs have high contraction speed and participate in motor acts that are among the fastest (saccadic eye movements) in human body and among the most sustained gaze fixation and vergence movements.

Structural characteristics of EOM, which need to be elaborated are:

- Global and orbital layers of EOMs
- Transverse compartmentalization of EOMs

GLOBAL AND ORBITAL LAYERS OF EOMs

The muscle belly of each EOM can be divided into two distinct portions: the superficial part or the orbital layer (OL) and the deep part or the global layer (GL). Both zones are distinctly separated from each other.

- *In rectus muscles,* the GL is located adjacent to globe (eyeball) and OL on the orbital surface of muscles.
- *In oblique muscles,* the GL is located in the central core and OL forms the concentric outer layer.

Global layer

Global layer of each rectus EOMs passes through its muscle pulley (described on pages 10–11) becomes contiguous with its small terminal tendon and is inserted onto the sclera (Fig. 1.6A). This global layer (GL) is responsible for eye movements. It is mainly (90%) composed of singly innervated fibres (SIFs) with only 10% multiply innervated fibres (MIFs)

- *Singly Innervated fibres (SIFs)* are fast twitch generating and fatigue resistant fibres, and thus allow for large, rapid and precise eye movements. SIFs can be subdivided into three groups (red, intermediate and white), based on the mitochondrial content, with the red fibres being the most fatigue resistant and the white fibres, the least.
- *Multiple innervated fibres (MIFs)*, which constitute only 10% of the GL, are thought to be involved in fine control of fixation and in smooth and fine graded eye movements, particularly the vergence control movements.

Orbital layer

- *In rectus muscles,* the orbital layer (OL) is inserted into their respective muscle pulleys and not the sclera (Fig. 1.6A).
- *Orbital layer (OL) of IO muscle* inserts on the IR and LR pulleys.
- *Orbital layer (OL) of SO muscle* inserts via the SO sheath on the medial aspect of SR pulley.

Types of muscle fibres

OL for each EOM contains 80% SIFs and 20% MIFs.

- *SIFs of OL* are specialized for an intense oxidative metabolism, have a large blood supply and are fatigue resistant. They are considered the major contributor to sustained EOM force in primary and deviated position, by allowing most sustained pulley tension. Of all muscle fibre types, this type is most affected by dennervation from damage to the motor nerves or the end plates, as occurs after botulinum toxin injection.
- *MIFs of OL* are thought to play the same role as that of GL.

TRANSVERSE COMPARTMENTALIZATION OF EXTRAOCULAR MUSCLES

Concept of transverse compartmentalization of EOM fibres and their innervation has been suggested in many studies to explain the different functions being performed by a group of fibres from each EOM.

Anatomical compartmentalization of EOMs and their innervation is reported as below:

- *Lateral rectus (LR) muscle:* The abducent nerve, supplying LR muscle, often divides into two or more trunks. Further, longitudinal LR splitting is evident in several congenital cranial deinnervation disorders (CCDDs).
- *Medial rectus (MR) muscle:* Motor nerve to MR also bifurcates into superior and inferior divisions.
- *Inferior rectus (IR) muscle* has a selective lateral trunk overlapping arborization of another trunk throughout the entire muscle length.
- *Superior rectus (SR) muscle* is, however, reported to lack selective compartmental innervation.
- *Superior oblique (SO) muscle* is reported to be innervated by two (medial and lateral) divisions of trochlear nerve in non-overlapping medial and lateral compartments. The medial compartment of SO muscle is contiguous with tendon fibres which are inserted on the equatorial sclera, and produce incycloduction. While the lateral compartment of SO muscle is contiguous with tendon fibres which are predominantly inserted posterior to equator and produce infracycloduction.
- *Inferior oblique (IO) muscle* is also reported to be innervated in compartmental fashion by separate motor nerve trunks.

Functional anatomical compartmentalization of EOMs has also been demonstrated on MRI studies. A few observations are as below:

Change in posterior partial volume (PPV) is the best contractility index, observed on MRI studies. It robustly correlates with the ductions for horizontal rectus EOMs.

Horizontal rectus EOMs (MR as well as LR) have been divided into superior and inferior halves (compartments) on MRI studies. Inferior compartments are slightly larger than the superior compartments of both MR as well as LR muscles.

In lateral rectus (LR) muscle, MRI studies, the contractility for convergence as well as adduction is reported to be similar in both superior as well as inferior compartments.

In medial rectus (MR) muscle, however, the superior compartment exhibited much greater contractility in adduction than in convergence.

During vertical duction on MRI studies, no differential compartmental changes were noted in vertical recti (SR and IR). However, superior compartments of MR muscles showed changes in maximum cross-section and PPV. But no change was noted in inferior MR compartments and in LR muscle compartments.

During vertical fusional vergence (VFV), induced by a 2 PD base up prism, the LR and SO muscles are reported to exhibit differential compartmental contraction. These observations suggest that the EOM mechanisms that normally compensate for the vertical heterophoria are highly complex.

Compartmental brainstem control for the differential compartmental behaviour of the EOMs has also been reported in the neuroanatomic studies.

Compartmental involvement of extraocular muscles has also been reported in nerve palsies as below:

- *Greater atrophy of superior than inferior compartment of LR muscle* is reported in about 30% cases of abducens palsy. An ipsilesional hypotropia, suggesting preserved inferior compartment function, is also reported in some cases.
- *Hypertropia, that increases in abduction*, reported in many cases of isolated LR palsy, suggests relationship to the residual LR contraction.

ORBITAL FASCIA

The orbital fascia is a thin connective tissue membrane lining the various intraorbital structures. Recent studies have shown that this is a complex interwoven connective tissue joining the various intraorbital contents. Though the orbital fascia is one tissue, for descriptive convenience, it can be described under the heads of (Fig. 1.6):

- Fascia bulbi,
- Sleeves (fascial sheaths) of extraocular muscles,
- Extraocular muscle pulleys,
- Anterior pulley slings (intermuscular septa), and
- Fascial expansions of extraocular muscles.

FASCIA BULBI

Fascia bulbi, or Tenon's capsule, envelops the globe from the limbus to the optic disc. Its inner surface is well defined and lies in close contact with sclera to which it is connected by fine trabeculae. The outer surface of the fascia bulbi lies in contact with orbital fat posteriorly and with subconjunctival tissue anteriorly with which it merges near the limbus. Tenon's capsule is separated from the sclera by episcleral space (Tenon's space), which can be readily injected. Tenon's capsule can be divided into anterior and posterior portions:

- *Anterior Tenon's capsule* is the subconjunctival membrane that extends from the limbus to the level of penetration of the rectus muscles (About 10 mm posterior to the insertion of rectus muscles, i.e. just posterior to the equator).
- Anteriorly, it fuses with the conjunctiva 2 to 3 mm posterior to the limbus. When suturing a muscle during strabismus surgery, it is important to clear anterior Tenon's capsule off the tendon insertion to avoid complication of a slipped muscle.
- *Posterior Tenon's capsule* extends from the penetration of the recti muscles to the optic nerve and thus separates the orbital fat from the sclera.

Around the distal end of optic nerve, the posterior Tenon's capsule is fused with the dural sheath of the optic nerve. Schwalbe, however, considered it to be continuous as a membrane surrounding the dural sheath to form a

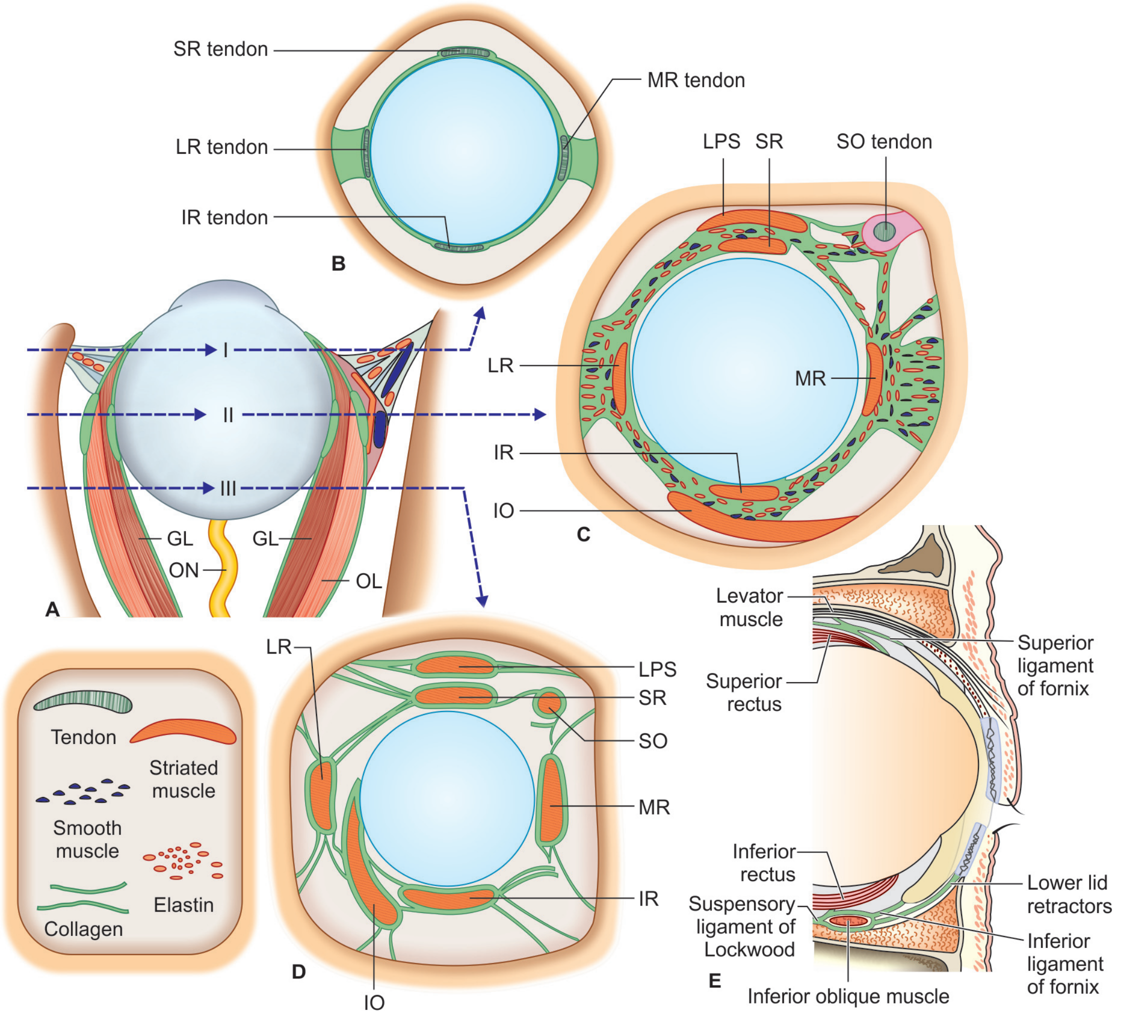

Fig. 1.6 *Schematic depiction of orbital connective tissues: (A) Axial view; (B, C and D) are coronal sections at levels I, II and III, respectively; (E) schematic section of lower eyelid showing suspensory ligament of Lockwood and inferior suspensory ligament of the fornix and upper lid showing superior suspensory ligament of fornix. GL, global layer; OL, orbital layer; ON, optic nerve; SR, superior rectus; MR, medial rectus; LR, lateral rectus; SO, superior oblique; IR, inferior rectus; LPS, levator palpebrae superioris; IO, inferior oblique.*

supravaginal lymph space, a view which is now considered doubtful.

Fascia bulbi is pierced posteriorly by the optic nerve, ciliary nerves and vessels, just behind the equator by venae vorticosae, and near the equator by six extraocular muscles; where it becomes continuous with the fascial sheaths of these muscles.

SLEEVES (FASCIAL SHEATHS) OF EXTRAOCULAR MUSCLES

At the points near the equator, where the fascia bulbi is pierced by an extraocular muscle, it sends a tubular reflection, which clothes the muscles like a glove and are called sleeves or sheaths of extraocular muscles.

Note. The anterior Tenon's capsule, posterior Tenon's capsule, and the muscle sleeves are very important structures, since they form the barriers between the orbital fat and globe and extraocular muscles. When posterior capsule or muscle sleeve is traumatically violated, fat adherence can occur. The fat adherence can occur as a complication of almost any extraocular surgery, e.g. strabismus surgery, buckling procedure for retinal detachment or periocular trauma.

INTERMUSCULAR SEPTA (ANTERIOR PULLEY SLINGS)

The sleeves and pulleys of the four rectus muscles are joined to each other by a fascial membrane called the intermuscular septum *(anterior pulley sling)*, which does not extend up to the apex of orbit (Fig. 1.6A to D). This membrane divides the orbital cavity and orbital fat into a central (conal) and a peripheral (extraconal) part (Fig. 1.6D). Anteriorly the intermuscular septa fuse with the conjunctiva 3 mm posterior to the limbus. ***Posteriorly the intermuscular septa do not extend up to the orbital apex*** and vanish a short distance behind the area of globe–optic nerve junction. This fact has been revealed on high-resolution magnetic resonance imaging (MRI). Thus, the muscle cone does not extend up to the orbital apex and that the conal and extraconal spaces become one continuous space near the apex of the orbit.

SYSTEM OF MUSCLE PULLEYS AND RELATED FACIAL EXPANSIONS

Fascial expansions of extraocular muscles. The muscular sheath of each extraocular muscle sends expansions to the surrounding structures which along with muscle pulleys form a complex system of muscle pulley and related fascial expansions (Fig. 1.6).

Muscle pulleys refer to stiff concentric ring-like structures present around the belly of EOMs. These consist of collagen, elastin and smooth muscle fibres.

Pulleys of rectus EOMs, about 2–3 mm in length, are present close to the equator of globe, i.e. beginning at the points where the rectus muscles penetrate the Tenon's capsule. Thus, the rectus muscle pulleys are co-axial with the underlying collagenous sleeves around the EOMs.

- The rectus muscle pulleys are stiff and are *stabilised by* septa which are attached around the fascial bulbi, intramuscular septa and periorbita.
- Dynamic MRI studies have shown that the pulleys act mechanically as the *functional origins* of the muscles and thus effectively modify the direction of pull of the rectus muscles.
- *Pulleys also serve to stabilise the muscle path*, preventing the sides slipping or movement perpendicular to the muscle axis.
- Anteriorly, the pulleys merge with muscle sleeves.

Pulleys of MR and LR muscles are well developed. Fascial expansions from the pulleys of lateral and medial rectus muscles are strong and are attached to orbital tubercle on the zygomatic bone and to the lacrimal bone, respectively. These are also called lateral and medial **check ligaments**.

Superior rectus muscle pulley is attached to the pulley of levator palpebrae superioris. This attachment ensures synergic action of the two muscles. Thus, when the superior rectus makes the eye look up, the upper lid is also raised. In maximal levator resection for ptosis, hypotropia can be induced, if these connections are not severed. A dense band extends from the lateral border of conjoint SR-LPS pulley to the superior border of LR pulley. This band contains dense collagen and elastin throughout and divides the orbital lobe of lacrimal gland.

Pulleys of inferior rectus (IR) and inferior oblique (IO) muscles are intimately coupled with each other and have main contribution in forming the *suspensory ligament of Lockwood* (Fig. 1.6E).

- This ligament is a thickened sling or hammock of fascial sheath extending from the posterior lacrimal crest to the lateral orbital tubercle, on which rests the eyeball. It is formed by fusion of expansions from the muscular sheaths of the medial rectus, inferior oblique, inferior rectus and lateral rectus muscles joined with the thickened inferior part of Tenon's capsule.
- *Expansion from the inferior rectus muscle* is attached to the capsulopalpebral fascia, a tissue analogous to levator aponeurosis in the lower lid and the sheath of inferior oblique muscle. This relationship is important because an inferior rectus muscle recession can result in lower lid retraction with lid fissure widening while resection results in lid advancement with lid fissure narrowing. Another importance of this relationship is that when the inferior rectus is inadvertently disinserted or lost during surgery, these connections will hold the inferior rectus to the inferior oblique and keep it from retracting posteriorly. Therefore, the lost inferior rectus can usually be found lying between the inferior oblique muscle and the sclera.

Superior oblique (SO) pulley, also known as trochlea, is a thick fibrocartilaginous pulley present at the superomedial angle of the orbital wall. Around it turns the SO tendon. Orbital layer (OL) of the SO muscle is inserted, via the SO sheath, on the medial aspect of SR pulley.

- *Superior transverse ligament of the Whitnall*. It is a thickened band of orbital fascia which extends from the trochlear pulley to the lacrimal gland and its fossa. It is formed by a condensation of the superior sheaths of the levator muscle joined medially by the sheath of the reflected tendon of superior oblique muscle. It forms a true check ligament of the levator muscle.
- *Suspensory ligaments of the fornices* are also well recognized. Superior suspensory ligament of the fornix is formed by the continuation forward of the fibrous tissue between the superior rectus and levator muscles to the upper fornix. During ptosis surgery, if this ligament is cut, fornix conjunctiva can prolapse. Similarly, the *inferior suspensory ligament of the fornix* is formed by the continuation forward up to the inferior fornix of the fibrous tissue of lower lid retractors (Fig. 1.6E).
- *Orbital septa* of elastic and collagenous tissue are well developed in the adults. These septa pass inward from the periorbita to the intermuscular septa (membrane pulleys and muscle sleevs) (Fig. 1.6B). Such septa also pass to and between the extraocular muscles and provide specific supportive channels for the ophthalmic veins.

APPLIED ANATOMICAL ASPECTS

1. *Nerves to the rectus muscles and the superior oblique muscle* enter the muscles about one-third of the distance from the origin to the insertion (or trochlea, in the case of the superior oblique muscle). It is difficult, but possible, to damage these nerves during anterior surgery. However, if an instrument is thrust more than 26 mm posterior to the rectus muscle's insertion, injury to the nerve may occur.

2. *Nerve supplying the inferior oblique muscle* enters the lateral portion of the muscle where the muscle crosses the inferior rectus muscle; it can be damaged by surgery in this area. Since the parasympathetic innervation to the sphincter pupillae and ciliary muscle accompanies the nerve to the inferior oblique muscle, pupillary abnormalities may also result from surgery in this area.

3. *Inferior rectus muscle is distinctly bound to the lower eyelid* by the fascial extension from its sheath. Recession of the inferior rectus muscle tends to widen the palpebral fissure, and resection of the inferior rectus muscle tends to narrow the fissure. Therefore, any alteration of the inferior rectus muscle may be associated with palpebral fissure change.

4. *Superior rectus muscle is loosely bound to the levator palpebrae superioris muscle.* The eyelid may be pulled forward following resection of the superior rectus muscle, thus narrowing the palpebral fissure; also, in hypotropia, a pseudoptosis may be present.

5. *Blood supply to the extraocular muscles* provides almost all of the temporal half of the anterior segment circulation; it provides the majority of the nasal half of the anterior segment circulation, of which some blood is supplied by the long posterior ciliary artery. Therefore, simultaneous surgery on three rectus muscles may induce anterior segment ischaemia, particularly in older patients.

6. *Whenever muscle surgery is performed,* special care must be taken to avoid penetration of Tenon's capsule; if the integrity of Tenon's capsule 10 mm posterior to the limbus is violated, fatty tissue may prolapse through Tenon's capsule and may form a restrictive adhesion and limit ocular motility.

7. *During resection or transposition of extra-ocular muscles,* the intramuscular septal connections and check ligaments attached to the Tenon's capsule should be carefully severed. This prevents the relocation of adjacent muscles and fat compartments. For example, if the attachments between LR and IO are not severed, the IO is moved anteriorly during resection of the LR.

8. *During rectus muscle recessions,* the severing of the intramuscular septal connections is not necessary.

9. *Posterior dissection* during the rectus muscles surgery may result in pulley damage, so special care is required.

10. ***When surgery is performed in the domain of the vortex veins***, accidental severing of a vortex vein is possible. The procedures that present the greatest risk for damaging a vortex vein are inferior rectus and superior rectus muscle recession or resection, inferior oblique muscle weakening and exposure of the superior oblique muscle tendon.

11. ***The sclera is thinnest just posterior to the four rectus muscle insertions.*** This is the site for most muscle surgery, especially for recession procedures. Therefore, the risk of scleral perforation is always present during eye muscle surgery. This risk can be best minimized by using spatulated needles with swedged sutures; working with a clean, dry, and blood-free surgical field; using loupe magnification; and employing a head mounted fibreoptic light source in addition to the overhead operating lights or an operating microscope.

12. ***Surgery on the inferior oblique muscle*** requires careful inspection of the inferolateral quadrant to ensure that all bellies are identified. If, during a weakening or strengthening procedure, the presence of a second or third belly is not recognized, the action of the muscle may not be sufficiently altered, and additional surgery may be required.

13. ***Neurofibrovascular bundle along the lateral border of the inferior rectus*** muscle can become an ancillary insertion site for the inferior oblique muscle when the muscle is anteriorly or medially transposed. Anterior transposition of the inferior oblique creates an anti-elevation effect.

14. ***Maintaining the integrity of the muscle capsules during surgery*** reduces intraoperative bleeding and provides a smooth muscle surface with less risk of adhesion formation. If only the muscle capsule is sutured to the globe, the muscle can retract backward, causing a slipped muscle.

15. ***Intermuscular septa (between the rectus muscles and especially the section between the rectus and oblique muscles)*** play important role as a point of reference in locating a muscle that has been "lost" during surgery or as a result of trauma. Extensive dissections of the intermuscular septum are not necessary for rectus muscle recession surgery. However, during resection surgery, these connections should be severed to prevent unexpected consequences, such as the inferior oblique muscle being advanced with the lateral rectus muscle. Often, there are 2 frenula: one that connects the lateral rectus muscle to the underlying inferior oblique at its insertion and another that connects the superior rectus to the underlying superior oblique tendon. Usually, these must be disconnected during recessions and resections of either of these 2 rectus muscles.

16. ***Medial rectus is the only rectus muscle that does not have an oblique muscle running tangential to it.*** This makes surgery on the medial rectus less complicated but means that there is neither a point of reference if the surgeon becomes disoriented nor a point of attachment if the muscle is lost.

17. ***Intense fibrous connections existing throughout*** the orbit can be evidenced clinically by the consequences of tissue entrapment in blowout fractures and of fibrosis of delicate fibrous septa after retrobulbar hemorrhage.

ANATOMY OF THIRD, FOURTH AND SIXTH CRANIAL NERVES

OCULOMOTOR NERVE

The oculomotor (third cranial) nerve is entirely motor in function. It supplies all the extraocular muscles except lateral rectus and superior oblique.

Oculomotor nuclear complex

The oculomotor nucleus complex has two motor nuclei: (a) *the main motor nucleus* of large multipolar neurons, and (b) *the accessory parasympathetic nucleus* (Edinger-Westphal nucleus) of small multipolar neurons.

a. ***The main motor nucleus*** is composed of the subnuclei (Fig. 1.7A and B) supplying individual extraocular muscles as follows:

1. *Dorsolateral nucleus*: Ipsilateral inferior rectus.
2. *Intermedial nucleus*: Ipsilateral inferior oblique.
3. *Ventromedial nucleus*: Ipsilateral medial rectus.
4. *Paramedial (scattered) nucleus*: Contralateral superior rectus.
5. *Caudal central nucleus*: Bilateral levator palpebrae superioris.

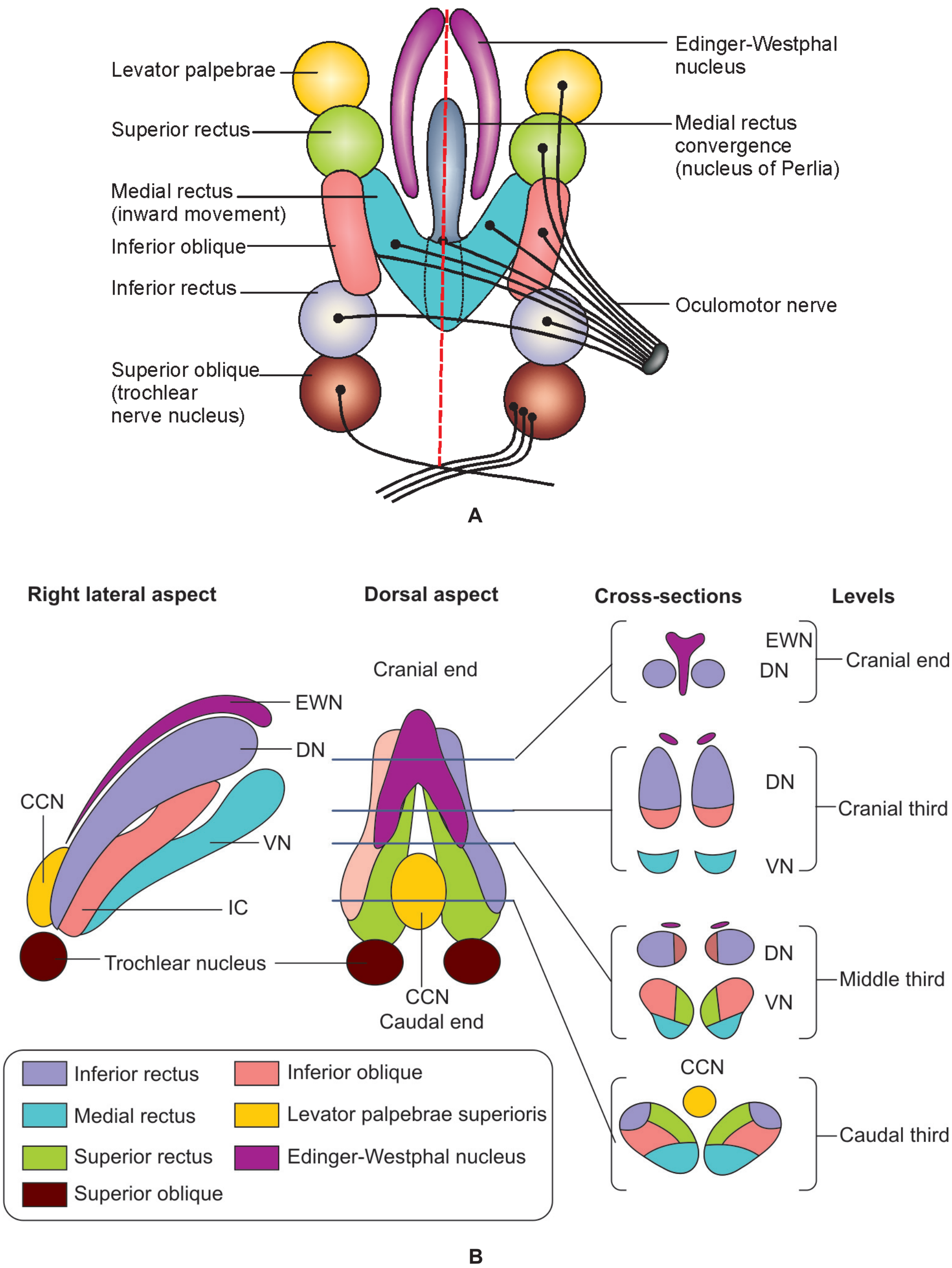

Fig. 1.7 *Scheme to show components of oculomotor nucleus complex. (A) old outdated concept, (B) modern concept (Warwick, 1953) (EWN, Edinger-Westphal nucleus; DN, Dorsal nucleus VN, Ventral nucleus, IC, intermediate column; CCN, caudal central nucleus).*

b. ***The accessory motor nucleus*** (Edinger-Westphal nucleus). It is situated posterior to the main oculomotor nucleus mass. It sends preganglionic parasympathetic fibres along the other oculomotor fibres.

Course and distribution

For the purpose of description, the course of the oculomotor nerve can be divided into: Fascicular, basilar, intracavernous and intra-orbital parts.

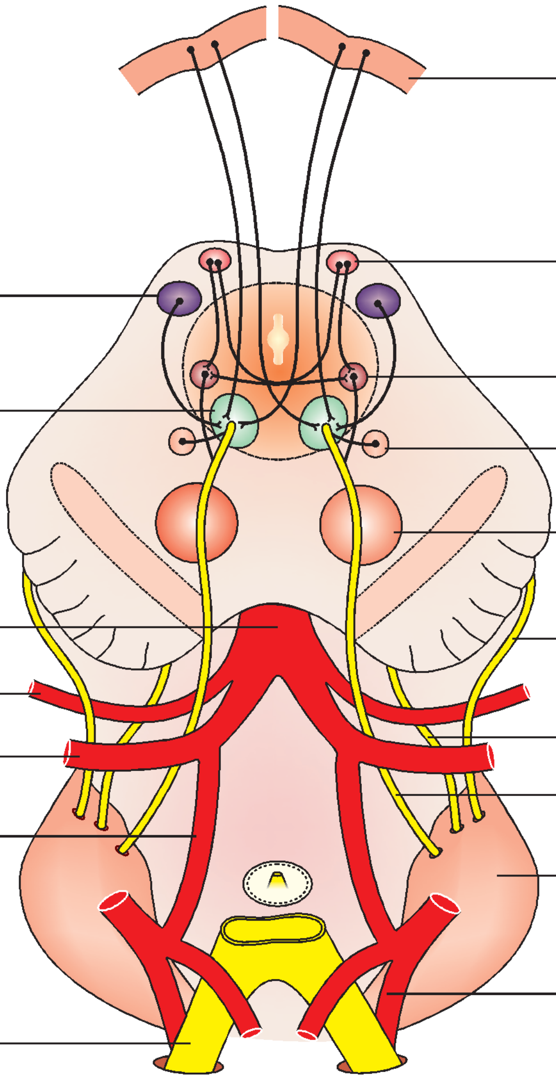

Fig. 1.8 *Oculomotor nerve nuclei, their central connections and course of fascicular and basilar parts of the nerve.*

Fascicular part

The fasciculus consists of efferent fibres which pass from the third nerve nucleus through the red nucleus and the medial aspect of the cerebral peduncle. They then emerge from the midbrain and pass into the interpeduncular space (Fig. 1.8).

Basilar part

The basilar part starts as a series of 15 to 20 rootlets in the interpeduncular fossa. These coalesce to form a large medial root and a small lateral root, which unite to form a flattened nerve, which get twisted bringing the inferior fibres superiorly and superior fibres inferiorly; and thus the nerve becomes a rounded cord. The nerve then runs forwards to reach the cavernous sinus (Fig. 1.9).

Intracavernous part

After entering the cavernous sinus, the nerve descends to the lateral wall of the sinus, where it lies above the trochlear nerve (Fig. 1.10). In the anterior part of the cavernous sinus, the nerve divides into superior and inferior divisions which enter the orbit through the middle part of the superior orbital fissure within the annulus of Zinn (Fig. 1.11). In the fissure, the nasociliary

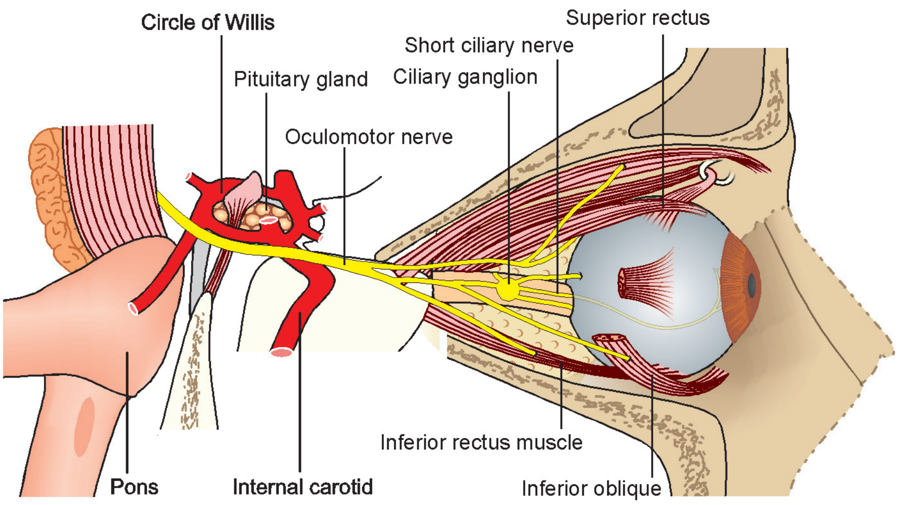

Fig. 1.9 *Showing the course of oculomotor nerve.*

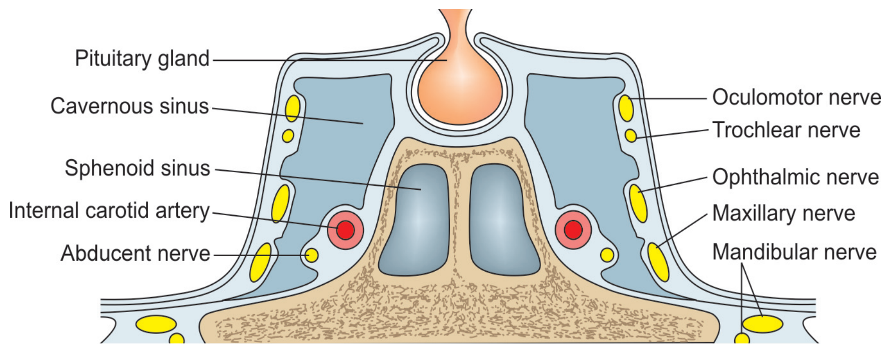

Fig. 1.10 *Coronal section through the middle cranial fossa showing the relations of cranial nerves (3rd, 4th, three divisions of 5th and 6th) with each other in the lateral wall of the cavernous sinus.*

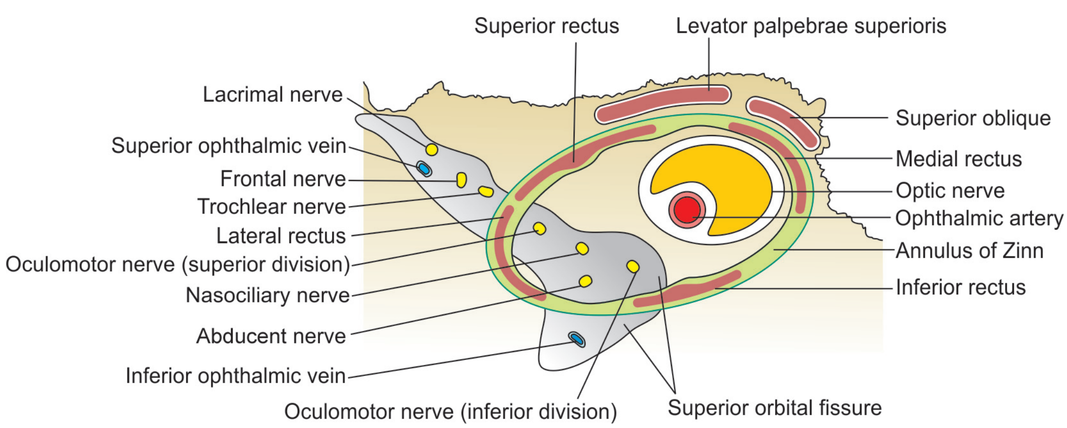

Fig. 1.11 *Apical part of the orbit showing the origin of extraocular muscles, the common tendinous ring and the structures passing through the superior orbital fissure.*

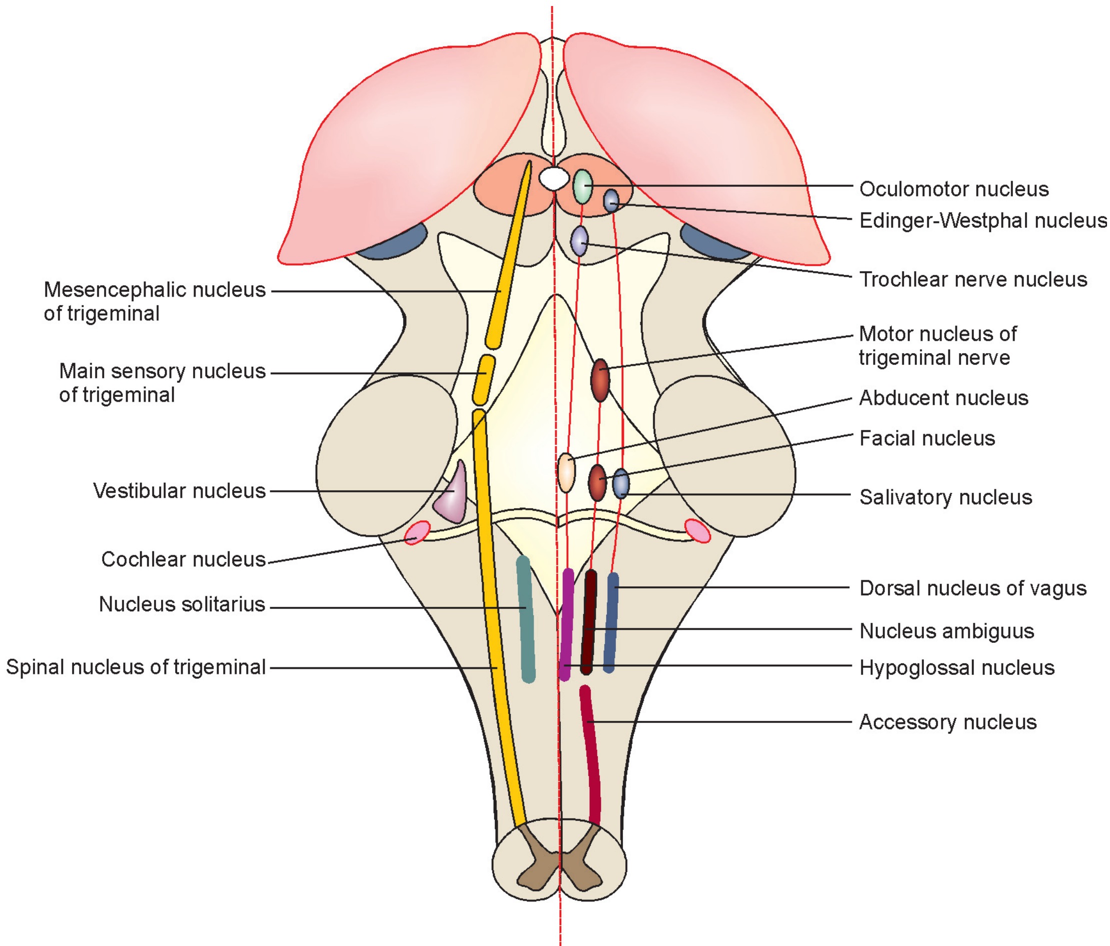

Fig. 1.12 *Scheme to show the cranial nerve nuclei as projected onto the posterior surface of the brainstem.*

nerve lies in between the two divisions, while the abducent nerve lies inferolateral to them.

Intraorbital part

In the orbit (Fig. 1.9), the smaller *superior division* ascends on the lateral side of optic nerve and supplies the superior rectus and the levator palpebrae superioris. The larger, *inferior division* divides into three branches: (1) *nerve to the medial rectus* passes inferior to the optic nerve, (2) *nerve to inferior* rectus passes downward and enters the muscle on its upper aspect and (3) *nerve to inferior oblique* (longest of the three branches) passes in between the inferior rectus and lateral rectus and supplies the inferior oblique from its posterior border. It gives off the motor root to the ciliary ganglion.

TROCHLEAR NERVE

The trochlear (fourth cranial) nerve is entirely motor in function and supplies only the superior oblique muscle of the eyeball.

Nucleus

The trochlear nucleus is situated in the ventromedial part of the central grey matter of the midbrain at the level of inferior colliculus (Figs 1.12 and 1.13). It is caudal to and continuous with the third nerve nucleus complex.

Course and distribution

For the purpose of description, the course of the trochlear nerve can be divided into fascicular, precavernous, intracavernous and intraorbital parts.

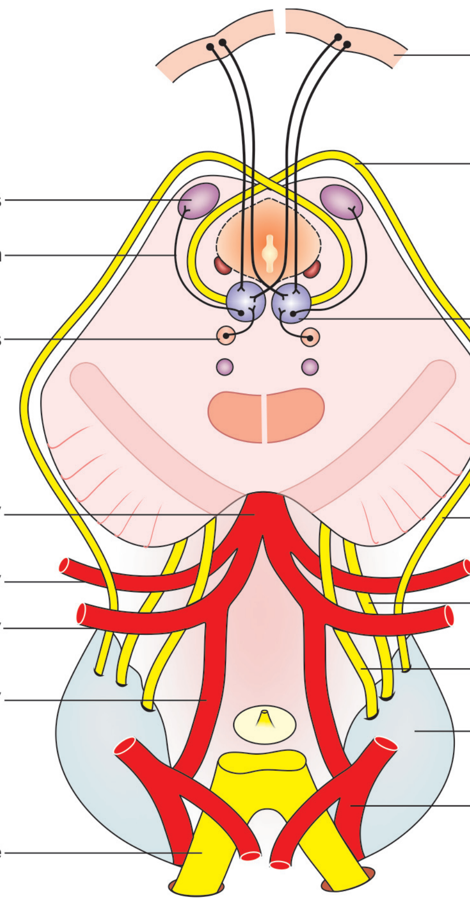

Fig. 1.13 *Trochlear nerve nucleus, its central connections and course of fascicular and basilar parts of the nerve.*

Fascicular part

The fasciculus consists of efferent fibres which after leaving the nucleus, pass posteriorly around the aqueduct in the central grey matter and decussate completely in the anterior medullary velum (Fig. 1.13).

Precavernous part

The trochlear nerve trunk after emerging from the dorsal aspect of midbrain winds round the superior cerebellar peduncle and the cerebral peduncle just above the pons. It then runs forwards and enters into the cavernous sinus.

Intracavernous part

In the cavernous sinus, the nerve runs forwards in its lateral wall lying below the oculomotor nerve and above the first division of the fifth cranial nerve (Fig. 1.10). In the anterior part of the cavernous sinus, it rises, crosses over the 3rd nerve and leaves the sinus to pass through the lateral part of the superior orbital fissure (where it lies superolateral to annulus of Zinn and medial to the frontal nerve) (Fig. 1.11).

Intraorbital part

After entering the orbit through the lateral part of the superior orbital fissure, the nerve passes medially above the origin of levator palpebrae superioris (Fig. 1.14) and ends by supplying the superior oblique muscle through its orbital surface.

ABDUCENT NERVE

The abducent (sixth cranial) nerve is a small, entirely motor nerve that supplies the lateral rectus muscle of the eyeball.

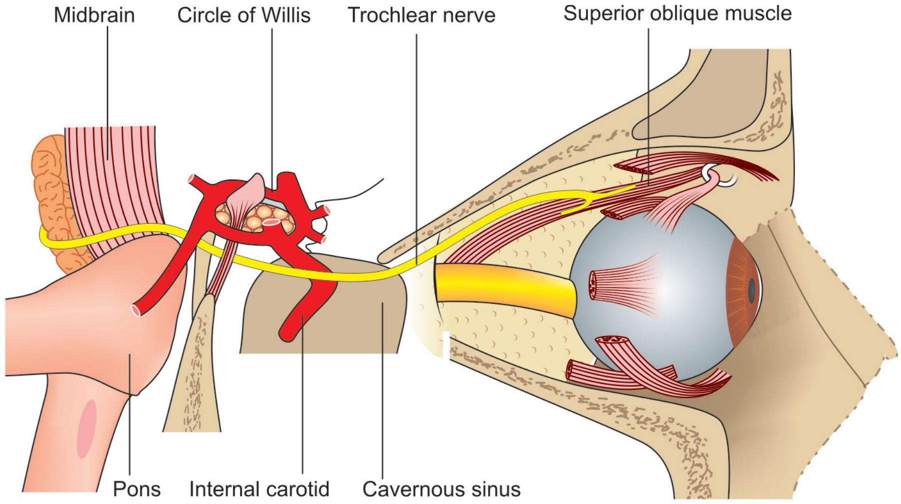

Fig. 1.14 *Showing the course of trochlear nerve.*

Nucleus

The abducent nucleus is situated in the lower part of pons, closely related to the fasciculus of the facial nerve (Fig. 1.15).

Course and distribution

For the purpose of description, the course of the abducent nerve can be divided into: Fascicular, basilar, intracavernous and intra-orbital parts.

Fascicular part

The fasciculus consists of efferent fibres which start from the nucleus, pass forward and emerge by some 7 to 8 rootlets from the junction of pons and medulla which join to form one nerve (Fig. 1.15).

Basilar part

The nerve then runs forwards, upwards on the back of the petrous temporal bone near its apex.

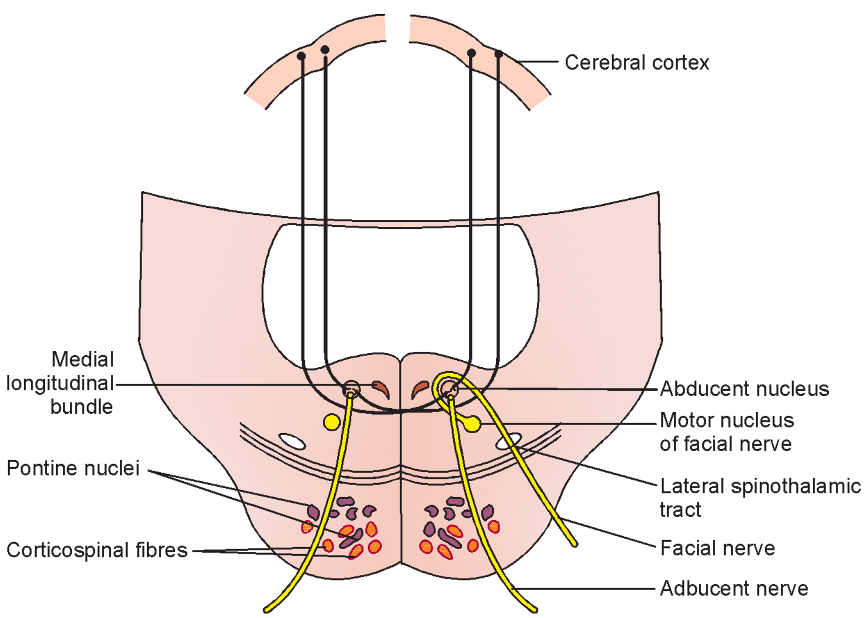

Fig. 1.15 *Abducent nerve nucleus and its central connections.*

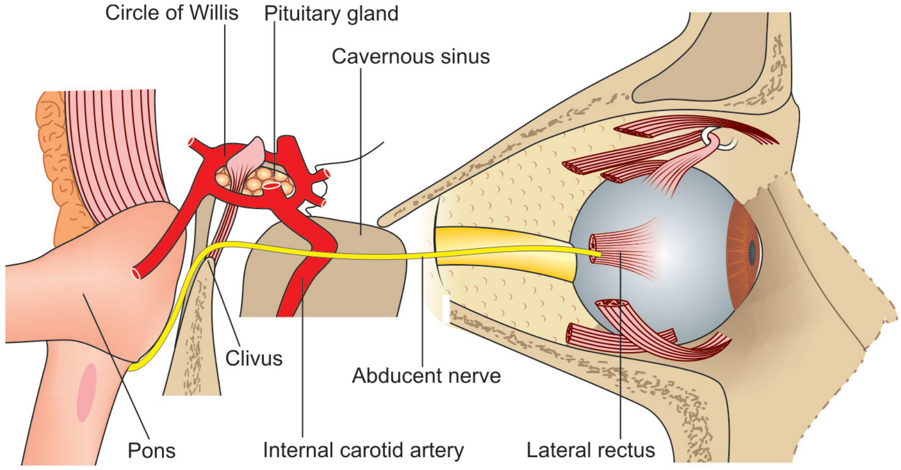

Fig. 1.16 *Course of sixth cranial nerve.*

At the sharp upper border of the petrous bone, the nerve bends forward at right angle and enters the cavernous sinus.

Intracavernous part

In the cavernous sinus, the nerve runs almost horizontally forward, occupying a position below and lateral to the internal carotid artery (Fig. 1.10). The nerve then leaves the cavernous sinus to enter the orbit through the middle part of the superior orbital fissure within the annulus of Zinn (Fig. 1.11). In the superior orbital fissure, the abducent nerve lies inferolateral to the oculomotor and nasociliary nerves.

Intraorbital part

In the orbit, the nerve runs forwards and enters the ocular surface of the lateral rectus muscle just behind its middle portion after dividing into three or four branches (Fig. 1.16).

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