Part I  Surgical Management of Strabismus
A clear grasp of the relevant anatomy and an understanding of important anatomical variations are obvious prerequisites for the strabismus surgeon. The strabismus surgeon must not only be familiar with the anatomy of the extraocular muscles, but must also be cognizant of adjacent structures in the orbit and the ocular adnexa. Much of the anatomy that the strabismus surgeon must be familiar with is covered routinely during the normal course of training in an ophthalmology residency program. This standard training should be considered as an introduction. The strabismus surgeon needs to understand many intricacies of the ocular anatomy as they relate to cause and surgical treatment in order to both effectively plan and execute surgery to correct strabismus.

A clear understanding of the implications of the palpebral fissures and orbital shape, for example, is important not only because it may affect surgical access to the extraocular muscles, but because anatomical clues may also provide insight about the etiology of the ocular motility disturbance. Indeed, many patients who present with concerns about ocular misalignment actually have pseudostrabismus because of an illusion created by normal and abnormal ocular adnexa. Additionally, unwanted lid fissure changes induced by strabismus surgery are not uncommon because of the close anatomical relationship between the extraocular muscles and eyelid structures. The implications for changes in eyelid shape and/or position following strabismus surgery should be clearly understood, and reviewed with patients preoperatively, when applicable.

While the conjunctiva is often inappropriately considered to be little more than a structure that must be incised to gain surgical access to the extraocular muscles, an understanding and recognition of key features of the conjunctival anatomy, especially nasally, is necessary to devise and carry out appropriate conjunctival incisions to optimize access to the extraocular muscles, to assure proper conjunctival closure and good cosmesis following surgery, and to avoid scarring and contracture of the conjunctiva which can produce unanticipated restrictive strabismus postoperatively. We have encountered many patients who have obtained good alignment following strabismus surgery but who were unhappy with the results of surgery because of the appearance of their conjunctiva afterwards.

Tenon’s fascia and other orbital tissues have a direct impact on the function of the extraocular muscles and on ocular alignment, both by helping to direct and alter the paths of the extraocular muscles through the formation of soft tissue pulleys, and by transmitting forces generated by contraction of the extraocular muscles indirectly to the sclera. Even a “lost” rectus muscle may continue to have a minor to moderate ability to move the eye through these secondary attachments with the globe, despite complete disruption of the normal anatomical insertion.

This chapter will highlight key elements of ocular and orbital anatomy that are important for the strabismus surgeon to understand. Major structures of anatomical importance involving the eyelids, conjunctiva, Tenon’s fascia, and other orbital tissues will be reviewed, concluding with an assessment and review of key elements of the ocular and orbital anatomy that the strabismus surgeon may encounter during surgery on individual extraocular muscles. Cross-referencing to chapters on the recognition, prevention, and treatment of strabismus surgery complications is made throughout the chapter as appropriate.

1.1 The Ocular Adnexa

1.1.1 Surgical Access

Rarely does the shape or size of the palpebral fissures significantly alter the surgical approach for strabismus surgery. However, small palpebral fissures and deeply set eyes can make surgical access more difficult. Recognition of these features prior to surgery can be important in helping the surgeon to estimate the amount of time the procedure will take and in determining the skill level of the surgical assistant that is needed during surgery. Surgical access is most likely to be compromised when performing large recessions on the medial rectus muscles of small infants and when operating on elderly patients with significant lid fissure abnormalities and deeply set eyes as a result of orbital fat atrophy. While these anatomical issues should not deter the surgeon from performing surgery, they may impact the surgical plan. A limbal incision, which provides broad, unimpeded access to the extraocular muscles for example, may be a good option to facilitate surgery in the two examples cited. Just as small palpebral fissures and deeply set eyes may limit surgical access, prominent eyes, and wide palpebral fissures may facilitate access. Proptosis in a patient with thyroid-re-
lated ophthalmopathy may be associated with greater ocular discomfort and a greater risk for exposure keratopathy following surgery.

1.1.2 Eyelid Fissure Orientation

Careful analysis of the ocular adnexa can provide import clues as to the etiology of strabismus in some patients and may help guide preoperative evaluation and surgical management. For example, strabismus is not only common in patients with craniofacial syndromes, but it is often atypical, involving both horizontal and/or vertical deviations and is commonly associated with marked overaction and/or underaction of the oblique muscles that may be secondary to incyclorotation or excyclorotation of the globe in these cases or due to the absence of one or more oblique muscles and/or tendons, most commonly the superior oblique tendon. A combination of several different factors may lead to the development of strabismus in patients with craniofacial syndromes. Recognizing that the patient has strabismus due to a craniofacial skeletal abnormality should prompt the surgeon to carefully evaluate for an A- or V-pattern, oblique muscle dysfunction, and other disturbances.

Often the facial features of a patient with a craniofacial abnormality will be subtle, but may still have an important impact on both the etiology and treatment of strabismus. In general, patients with significant down-slanting palpebral fissures tend to demonstrate apparent inferior oblique overaction during adduction and may have V-pattern strabismus (Fig. 1.1), while those with up-slanting palpebral fissures tend to demonstrate apparent superior oblique overaction during adduction and may have A-pattern strabismus. Patients with spina bifida, for example, commonly have A-pattern horizontal strabismus in association with up-slanting palpebral fissures [1] (Fig. 1.1). Anatomical variation in paths of the extraocular muscle through the orbit have been shown to be altered and heterotopia of rectus muscle pulleys has been implicated as the cause of A-pattern horizontal strabismus in these patients [1].

The recognition of atypical strabismus in a patient with a craniofacial abnormality may prompt consideration of neuroimaging studies to evaluate for abnormalities in muscle positions within the orbit, absent muscles, and other abnormalities [2] (Chap. 27).

1.1.3 Facial Asymmetry

Facial asymmetry has been reported in association with congenital superior oblique palsy [3, 4]. It is manifested as midfacial hemihypoplasia on the side of the face in the direction of the head tilt. Thus it most commonly is seen on the side of the face opposite the superior oblique palsy. The nose and mouth are typically deviated toward the hypoplastic side of the face (Fig. 1.2). This facial asymmetry is thought to be associated with congenital and early-onset superior oblique palsies. This facial asymmetry has been postulated to occur as a result of a chronic head tilt from a young age [5] though others have questioned its association at all [6]. Many strabismus surgeons believe that the presence of facial asymmetry as characterized above and/or the presence of a chronic head tilt in a patient with a recently diagnosed superior oblique palsy is sufficient evidence to warrant a diagnosis of congenital or early-onset superior oblique palsy, negating the need for neurologic evaluation. Patients with congenital superior oblique palsy are often found to have a “floppy” or otherwise abnormal superior oblique tendon at surgery [7]. This finding may help to dictate the surgical approach used in these patients.

Patients with unilateral coronal synostosis (plagiocephaly) often present with an ocular motility condition that clinically resembles superior oblique muscle palsy. The apparent “palsy” is due to asymmetric orbital growth. The trochlea on the involved side does not advance anteriorly as would occur in a normal orbit where it ultimately is located anterior to the equator of the globe. The resulting position of the trochlea more posterior than normal relative to the equator of the globe results in a reduction of depressing action during contraction.

Fig. 1.1a,b. Lid fissure anatomy may provide initial clues in evaluating a patient with strabismus. a V-pattern strabismus and apparent inferior oblique overaction in a patient with down-slanting palpebral fissures. b A-pattern strabismus is common in patients with up-slanting palpebral fissures.
of the superior oblique muscle (Fig. 1.3). This mechanical disadvantage can result clinically in an ocular motility disturbance that resembles a superior oblique palsy [8]. Patients will usually present with a head tilt and frequently will have facial asymmetry that subtly resembles the facial asymmetry that has been reported with early-onset superior oblique palsy. It is important to recognize the difference in presentation of patients with unilateral coronal synostosis because the ophthalmologist may be the first physician to recognize the presence of the condition, prompting referral to a neurosurgeon for surgical treatment. Flattening of the forehead and mild to moderate prominence of the eye resulting from the presence of a shallow orbit on the involved side, and skull asymmetry are noteworthy findings in these patients.

Neurosurgical treatment of coronal synostosis may alter ocular alignment, changing the ultimate surgical plan, or even eliminating the need for strabismus surgery altogether.

1.1.4 Pseudostrabismus

Both normal and pathologic variations in eyelid fissure anatomy can produce the appearance of strabismus, despite normal alignment of the visual axis of the two eyes. In a pediatric ophthalmology practice, diagnosis of pseudoesotropia in infants with large epicanthal folds is probably the most common example (Fig. 1.4a). Family members and primary care physicians alike may believe that strabismus is present because they do not see much “white” on the nasal aspect of the eye compared to the temporal aspect of the eye. Good advice to parents in this setting is to “ignore the white and look at the light,” pointing out the need to assess the corneal light reflex. After careful explanation, most parents can often recognize that the position and shape of the eyelids and other ocular adnexal structures can produce the appearance of strabismus, when in fact the eyes are aligned. It is sometimes difficult, however, to convince
doubting parents that the eyes are straight. A simple demonstration of tightening the epicanthal folds by pinching the bridge of the nose can be an effective tool in convincing parents that the crossing that they see is an illusion (Fig. 1.4b).

In the same way that prominent epicanthal folds can create the illusion of esotropia, abnormalities involving the lateral canthal area can create the illusion of exotropia. Temporal ptosis and dermatochalasis with prominent temporal hooding are just two examples of conditions that may produce the illusion of exotropia. An example of lid fissure asymmetry causing pseudoexotropia is shown in Fig. 1.4c. The illusion of vertical strabismus can be created by asymmetric ptosis and/or upper or lower eyelid retraction (Fig. 1.4d). Similarly, changes in the lid fissures induced by strabismus surgery, especially when asymmetric, can be distressing to patients postoperatively (Chap. 26), both because of the presence of the eyelid asymmetry itself and because the patient may continue to believe that strabismus is still present, when in fact the eyes are actually well aligned.

1.1.5 Strabismus-Induced Eyelid Changes

One of the hallmarks of thyroid-related ophthalmopathy is retraction of one or more of the eyelids (Fig. 1.5). While stra-
bismus due to thyroid-related ophthalmopathy is generally obvious, subtle ocular motility disturbances can present. The presence of eyelid retraction may be the initial clue that the problem is due to thyroid-related ophthalmopathy, and can significantly alter key aspects of treatment including preoperative evaluation, timing of surgery, and the surgical plan itself.

### 1.1.6 Pseudoptosis

Patients with a large hypotropia, particularly those with a restrictive hypotropia, often present with a concurrent ptosis or pseudoptosis. An infant with a monocular elevator deficiency, for example, may appear to have concurrent, severe ptosis. When the child is made to fixate with the hypotropic eye, the apparent ptosis will resolve if the child can bring the hypotropic eye to the primary position, confirming the diagnosis of pseudoptosis in such cases. On the other hand, correction of the strabismus with surgery is often required to confirm a diagnosis of pseudoptosis in such cases. When malpositioned or accidentally incised during strabismus surgery, an incision through the caruncle may occasionally be used in the treatment of complex strabismus, such as the creation of a periosteal flap (Chap. 15) or repair of a lost muscle (Chap. 23).

### 1.2 The Conjunctiva

The conjunctiva is a mucous membrane that covers the posterior surface of the eyelids and the anterior surface of the globe with the exception of the cornea. The bulbar conjunctiva merges with the stroma and epithelium of the cornea. Histologically, the conjunctiva is covered by nonkeratinized stratified squamous epithelial cells and has an underlying substantia propria. The bulbar conjunctiva overlies Tenon’s capsule. The conjunctiva contains numerous mucin-producing goblet cells, particularly in the fornix. The stroma consists of fragile connective tissue that contains lymphoid tissues. Accessory lacrimal glands are found in the conjunctiva of the upper and lower fornix. Though it is a single, continuous membrane, conceptually it is useful to divide the conjunctiva into two parts, namely the palpebral and bulbar conjunctivae. In general, the strabismus surgeon should never enter the palpebral conjunctiva, though an understanding of the anatomy and function of the palpebral conjunctiva as it relates to strabismus surgery remains important.

The palpebral conjunctiva begins on the lid margin at the mucocutaneous junction. The conjunctiva is tightly adherent to the underlying tarsus as it progresses into the fornix. The conjunctiva in the fornices is loose and is reflected into several folds, allowing movement of the globe not to be inhibited by connections between the palpebral and bulbar conjunctivae. The upper fornix is typically much deeper than the inferior fornix. A fat pad present in the inferior fornix should be identified and avoided during strabismus surgery (Fig. 1.6; Chap. 25). Finally, from the fornices, the conjunctiva is reflected upon the globe where it is loosely adherent to the underlying Tenon’s fascia shadowing the sclera, finally ending at the limbus.

There is some redundancy of the conjunctiva so that excision of small parts of the conjunctiva is well tolerated without altering its function and without significantly reducing its secretory capacity. Only the bulbar conjunctiva is routinely incised during strabismus surgery. Except for a small segment of conjunctiva immediately adjacent to the limbus, Tenon’s fascia will always be found deep to the bulbar conjunctiva. The lateral angle of the conjunctiva is rather nondescript and featureless compared to the medial angle of the conjunctiva. A fold of conjunctiva known as the plica semilunaris conjunctivae (referred to simply as plica here) is present in the medial angle of the conjunctiva and represents a fold in the bulbar conjunctiva. It serves no particular function in the human eye but corresponds to the nictitating membrane of some animal species. When malpositioned or accidentally incised during strabismus surgery, it can produce serious cosmetic and/or functional problems (Chap. 19). Another fold of conjunctiva near the medial canthus forms the caruncle, a transition zone between the conjunctiva and skin. It contains elements of skin and mucous membrane. Small lanugo hairs can often be seen growing out of its head. While the plica is essentially never intentionally incised or surgically altered during strabismus surgery, an incision through the caruncle may occasionally be used in the treatment of complex strabismus, such as the creation of a periosteal flap (Chap. 15) or repair of a lost muscle (Chap. 23).

### 1.3 The Sclera

The sclera is composed of densely packed collagen lamellae. It is continuous with the dura mater of the optic nerve. It also continues across the optic nerve head to form the lamina cribrosa. The sclera is penetrated by a variety of vascular and neural structures anteriorly and posteriorly. The thickness of the sclera also varies with age. It is typically thinnest in a newborn. The thickness of the sclera varies depending on its location on the globe. The sclera is thinnest behind the insertions of the rectus muscles, where its thickness is approximately 0.45 mm [9], a fact that is important to the strabismus surgeon since sutures may need to be passed into this thin sclera to correct a rectus muscle (Fig. 1.7). The sclera is approximately 0.6–0.7 mm thick at the corneal limbus and 1.1–1.3 mm thick at the posterior pole [9] (Fig. 1.8).
Fig. 1.6. Relationship of orbital fat to Tenon's capsule and other structures. Violation of the posterior portions of Tenon's capsule can result in intrusion of orbital fat into the surgical space.

Fig. 1.7. Thin sclera posterior to the rectus muscle insertions, highlighted area.
1.4 Fascial System

1.4.1 Tenon’s Fascia

The globe is suspended within the bony orbit by a fascial system, the bulk of which is represented by Tenon’s capsule. Tenon’s capsule is a condensation of fibrous tissue that covers the globe from the entrance of the optic nerve into the posterior aspect of the globe extending to within 1 mm of the corneal limbus, where it becomes fused with the overlying conjunctiva. Tenon’s capsule is thick and readily manipulated surgically in young patients, but becomes thin and fragile in older patients. Potential spaces exist both deep and external to Tenon’s capsule, known as the episcleral (sub-Tenon’s space) and the subconjunctival spaces, respectively. We will generally utilize the term episcleral space in this textbook to refer to the potential space deep to Tenon’s capsule. These spaces are important during strabismus surgery as they must be entered in order to gain access to the extraocular muscles. The anterior aspect of Tenon’s capsule is better formed than its posterior aspect. Several large and small structures penetrate Tenon’s capsule including the optic nerve, the extraocular muscles, the vortex veins, and numerous other small neurovascular structures. Strabismus surgery is performed in the episcleral space, on the distal aspect of the extraocular muscles and/or tendons after they have penetrated Tenon’s capsule approximately midway along their lengths. The rectus muscles penetrate Tenon’s capsule to enter the episcleral space posterior to the equator, while the oblique muscles enter the episcleral space anterior to the equator.

1.4.2 Function of Tenon’s Capsule and Orbital Connective Tissues

Tenon’s capsule and the fascial and ligament system of the orbit are critical to normal control of eye movements. They reduce or check movement of the globe and help to smooth eye movements through their elastic properties, among other functions. Abnormalities of some of these structures, notably the rectus muscle pulleys (see below), have been shown to be associated with anomalous eye movements including some cases of incomitant strabismus [10]. Brown syndrome represents another possible abnormality of the orbital connective tissue structures that may produce unwanted alteration of eye movements.

Tenon’s capsule, as with all orbital tissues, should be handled with care. Tenon’s capsule acts as a barrier to orbital fat, and violation of the posterior aspects of the capsule can result in unwanted intrusion of orbital fat into the surgical space (Fig. 1.6). This surgical complication can cause significant difficulties in completing planned surgery and can also lead to fat adherence and restrictive strabismus postoperatively (Chap. 25).

The strabismus surgeon must become very familiar with Tenon’s capsule, as it must be manipulated during all strabismus operations. The extraocular muscles penetrate Tenon’s capsule to enter the episcleral space, coursing toward their insertions into the sclera (Fig. 1.9). Thus it is in the episcleral space, containing a length of about 7–10 mm of the rectus muscles, where the majority of extraocular muscle surgery is performed. After entering the episcleral space, the muscles have no sheath, but instead are covered by episcleral connective tissues that are loosely fused with the muscle. This tissue expands laterally along the edges of the muscles to form the intermuscular membrane and is present all the way to the muscle insertion. These tissues fuse with Tenon’s capsule posteriorly where the muscles penetrate Tenon’s capsule.

The orbital aspect of the sheath of the superior rectus muscle is closely adherent to the internal surface of the sheath of the levator palpebrae superioris muscle of the upper eyelid. The close association of these two muscles through their fascial sheaths accounts, in part, for the cooperative action seen during contraction of these two muscles, such as depression of the upper eyelid with downward gaze. The surgeon must be aware of these connections because they can have important implications for the patient following strabismus surgery on the vertical rectus muscles (Chap. 26). The global portion of the sheath is tenuously associated with the sheath of the superior oblique tendon (Fig. 1.10).

The fascial sheath surrounding the inferior rectus muscle is complex. It tends to be thicker and more readily apparent than the fascial sheath surrounding the other rectus muscles, and this is readily apparent during surgery. The global portion of this sheath fuses with and becomes continuous with Tenon’s capsule, while the orbital portion contributes to the formation of Lockwood’s ligament of the lower eyelid, helping to explain why surgery on the inferior rectus muscle can alter the position of the lower eyelid (Chap. 26).

The fascial sheath surrounding the portion of the superior oblique tendon distal to the trochlea is both strong and thick.

Fig. 1.8. Thickness of the sclera varies depending on its position around the globe

Fig. 1.9. Tenon’s capsule is a condensation of fibrous tissue that covers the globe from the entrance of the optic nerve into the posterior aspect of the globe extending to within 1 mm of the corneal limbus, where it becomes fused with the overlying conjunctiva.

Fig. 1.10. The orbital aspect of the sheath of the superior rectus muscle is closely adherent to the internal surface of the sheath of the levator palpebrae superioris muscle of the upper eyelid.
The potential space inside the superior oblique tendon sheath is continuous with the episcleral space. Numerous attachments extend from the sheath to adjacent structures including attachments to the global aspect of the sheath of the superior rectus muscle and attachments to the sheath of the levator palpebrae superioris muscle of the upper eyelid (Fig. 1.10). Abnormalities involving this sheath often play a role in the etiology of Brown syndrome.

The fascial sheath of the inferior oblique muscle surrounds the muscle from its origin to insertion. It becomes thicker as the muscle approaches its insertion and it is usually tightly adherent to the orbital aspect of the sheath of the inferior rectus muscle. Small extensions of the sheath near the inferior oblique muscle insertion are directed to the sheath of the lateral rectus muscle and to the sheath surrounding the optic nerve posteriorly.

### 1.5 The Rectus Muscle Pulley System

A reflection extending from Tenon’s capsule envelops the posterior portion of the extraocular muscles that are extrinsic to the capsule at this position in the orbit. Fibroelastic sleeves consisting of dense bands of collagen, elastin, and smooth muscle surround the rectus muscles. These sleeves are suspended from the orbit and adjacent extraocular muscle sleeves by bands of tissue having similar composition. Often referred to as check ligaments, these sleeves and their connections to the orbital walls have a significantly more complex function than simply to “check” movement of the globe and the term check ligaments should probably be discarded. Condensations and extensions from these muscle sheaths ultimately are associated with connections anteriorly as well. Some consider all of these structures collectively as Tenon’s capsule [11] though for practical purposes while they may all be continuous, with one blending gradually into the other, the rectus muscle pulleys are so specialized in function that they should be considered separate from Tenon’s capsule.

High-resolution computed tomography and magnetic resonance imaging have demonstrated that the paths of the rectus muscles remain stable relative to their adjacent orbital walls throughout most of their course in the orbit, even during eye movements and following large surgical transposition procedures [12, 13]. Only the anterior aspect of the muscles actually moves during normal eye movements into secondary gaze.
positions, while the posterior aspects of the rectus muscles are relatively fixed in position by rectus muscle pulleys which are in part located near the equator of the globe.

The rectus muscle pulleys essentially function as the effective origins of the rectus muscles [14] (Fig. 1.11). These muscle sleeves are continuous with Tenon’s capsule anteriorly and posteriorly. The pulleys are important for altering both the paths of the rectus muscles through the orbit and their function. These sleeves are located near the equator of the globe and are approximately 13–19 mm in anterior–posterior dimension [13]. During muscle contraction, the sleeves act as pulleys, restraining the rectus muscles paths and re-directing the force of contraction toward the globe. The orbital layer of the rectus extraocular muscles has been demonstrated to insert into the corresponding rectus muscle pulley, rather than on the globe [15]. The active-pulley hypothesis proposed by De- mer and coworkers [15] suggests that the global layer of each rectus extraocular muscle rotates the globe while the orbital layer of the muscle inserts on its respective pulley and influences the rotational axis of the rectus muscle through changes in the position of the pulley during movements of the globe (Fig. 1.11c). This arrangement is believed to provide a mechanical explanation of important aspects of eye movements including Listing’s law [15, 16].

Fig. 1.11a–c. Rectus muscle pulleys. a Schematic of rectus muscle pulleys. (GL Global layer, IO inferior oblique, IR inferior rectus, LE lateral enthesis, LG lacrimal gland, LPS levator palpebrae superioris, LR lateral rectus, ME medial enthesis, MR medial rectus, OL orbital layer, SO superior oblique, SR superior rectus)
1.6 Gross Anatomy of the Extraocular Muscles

1.6.1 Rectus Muscles

Each of the four rectus muscles originates in the posterior orbit at the annulus of the Zinn surrounding the optic canal and the inferior portion of the superior orbital fissure. Fascial attachments between the origins of the medial and superior rectus muscles into the dura covering the optic nerve are thought to be the cause of pain with eye movements in patients with acute optic neuritis. The origin of the lateral rectus muscle has a superior and inferior head that are located on opposite sides of the superior orbital fissure [17]. For practical purposes, the rectus muscles can be considered to be approximately 40 mm in length in an adult. Coursing anteriorly from the annulus of Zinn, the medial, lateral, and inferior rectus muscles follow the course of adjacent orbital walls for a good portion of their length, while the superior rectus muscle is separated from the orbital roof by the levator palpebrae superioris muscle of the upper eyelid.

The paths of the rectus muscles in the orbit curve sharply toward the globe starting approximately 7–10 mm from the equator as the connective tissue/muscular pulleys described above alter their paths. The thin rectus muscles eventually penetrate Tenon’s capsule 7–10 mm from their insertions into the sclera. After entering the episcleral space and coursing further anteriorly, each eventually becomes tendinous, ultimately inserting into the sclera as a tendon posterior to the limbus. The tendinous insertions of each of the rectus muscles are roughly 10–11 mm in width [18] (Table 1.1).

The average distance of each rectus muscle insertion from the limbus is shown in Table 1.1 and Fig. 1.12, along with other key anatomical features. The medial rectus muscle insertion is typically located closest to the limbus, followed by the inferior rectus, lateral rectus, and finally the superior rectus muscle, which is typically inserted furthest from the limbus. The insertions, particularly those of the vertical rectus muscles, are curved with their convexity away from the limbus. The temporal corners of the vertical rectus muscles are further from the limbus than are the nasal corners. Variations from the means shown are common. A circular line connecting the center of the rectus muscle insertions is known as the spiral of Tillaux (Fig. 1.13). The spiral of Tillaux has several important implications: (1) helping the surgeon to remain oriented during surgery, and helping to assure surgery is performed on the correct muscle, (2) providing some insight as to the amount and type of previous strabismus surgery performed during reoperations, and (3) providing landmarks to help guide reinsertion of transposed and advanced muscles. It is not uncommon for small bundles of muscle fibers to be re-directed posteriorly near the insertion to insert several millimeters behind the remainder of the rectus muscle insertions (Fig. 1.14).
Fig. 1.12. Important measurements of rectus muscle dimensions. Average width of rectus muscle insertions, distance of insertion to the corneal limbus and length of tendon, in adults. (With permission from Apt L. An anatomical reevaluation of rectus muscle insertions. *Trans Am Ophthalmol Soc* 1980;78:365–375 [18])

Table 1.1. Important measurements of rectus muscle dimensions. Average width of rectus muscle insertions in an adult [18], distance of insertion to the corneal limbus [18], and length of tendon [26]

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Rectus muscle tendon dimensions</th>
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<tbody>
<tr>
<td></td>
<td>Distance from limbus (mm)</td>
</tr>
<tr>
<td>Medial rectus</td>
<td>5.3</td>
</tr>
<tr>
<td>Inferior rectus</td>
<td>6.8</td>
</tr>
<tr>
<td>Lateral rectus</td>
<td>6.9</td>
</tr>
<tr>
<td>Superior rectus</td>
<td>7.9</td>
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Fig. 1.13. The spiral of Tillaux
Fig. 1.14. Muscle “footplates” (left of asterisk) representing muscle bundles redirected posterior to the insertion are common and are probably of no functional significance.

Fig. 1.15. Identifying the rectus muscle insertions by visualizing their anterior ciliary vessels beneath the conjunctiva as the eye is rotated. Note movement of the anterior ciliary vessels relative to the conjunctival vessels.

Fig. 1.16. Palpation of a rectus muscle border. After visual identification of the insertion, a hook is placed adjacent to the muscle border (top left). While depressing the hook toward the globe, the hook is moved toward the muscle (top right). The muscle can be seen to bunch against the hook as it is advanced (bottom).
so-called muscle footplates, once thought to have considerable importance in the etiology of strabismus [19], appear today to be of little functional significance.

The insertions of the rectus muscles can be easily seen through intact conjunctiva. Their locations are often first recognized by visualizing their associated anterior ciliary vessels as they course onto the episclera anterior to the rectus muscle insertions. These vessels are most readily identified as the eye is rotated to and fro at right angles to the path of the muscle (Fig. 1.15) where they can be seen to move with globe rotation asynchronously from the overlying conjunctival vessels. Once identified, the muscles themselves can usually be seen as slightly darkened and slightly raised structures beneath the conjunctiva.

We find the technique of rectus muscle palpation with a blunt instrument to be highly useful when identifying the borders of the rectus muscles intraoperatively, and often find the palpation technique more valuable than visual inspection. To perform this technique, the eye is rotated with fixation forces or bridle sutures into the desired position for surgery (Fig. 1.16). A blunt instrument, such as a muscle hook, is placed on the conjunctiva between two adjacent rectus muscles approximately 10 mm posterior to the corneal limbus. While applying gentle posterior pressure on the globe with the muscle hook, the hook is directed toward the rectus muscle. The border of the muscle can be easily palpated in this manner and readily visualized as the hook makes contact with the border of the muscle, assuring the surgeon that the eye has been properly positioned for surgery and helping to facilitate accurate placement of the conjunctival incision.

**1.7 Innervation of the Extraocular Muscles**

The third cranial nerve (oculomotor nerve) is the most complex of the cranial nerves supplying innervation to the extraocular muscles. It provides the innervation to four of the six extraocular muscles and to the levator palpebrae superioris muscle of the upper eyelid. The inferior division of the third nerve supplies the medial and inferior rectus muscles as well as the inferior oblique muscle. The superior division supplies the superior rectus muscle and levator palpebrae superioris muscle of the upper eyelid. Motor branches of the third nerve enter the medial and inferior rectus muscles at approximately the junction between the posterior one-third and anterior two-thirds of the muscle from the internal or global surface of the muscle. The neurovascular bundle supplying the inferior oblique muscle enters the muscle from its posterior surface near the lateral border of the inferior rectus muscle [20].

The superior oblique muscle is innervated by the fourth cranial nerve (trochlear nerve). It is the only extraocular muscle that receives its innervation from the external or orbital surface of the muscle. The nerve passes superiorly from the medial side of the superior oblique muscle to the orbital side of the muscle prior to entering the muscle as several small branches.

The lateral rectus muscle is innervated by the sixth cranial nerve (abducens nerve). The muscle is innervated from the internal or bulbar surface of the muscle near the junction of the anterior two-thirds and posterior one-third of the muscle.

**1.8 Blood Supply to Extraocular Muscles**

Each of the extraocular muscles receives its blood supply from the medial and lateral muscular branches of the ophthalmic artery. The medial branch supplies the inferior and medial rectus muscles as well as the inferior oblique muscle, while the lateral branch supplies the lateral and superior rectus muscles, the superior oblique muscle, and the levator muscle of the upper eyelid. The inferior rectus muscle and inferior oblique muscle also receive a small contribution of blood supply from other sources.

The arteries of the four rectus muscles enter the muscles on their global surfaces at approximately the junction between the anterior two-thirds and posterior third of the muscle. They course anteriorly, emerging onto the orbital surface of the muscle/tendon approximately 10–12 mm from the insertions of the tendons into the sclera, where they are known as the anterior ciliary arteries. Each rectus muscle characteristically has two anterior ciliary arteries, except for the lateral rectus muscles, which characteristically have only one (Fig. 1.17). The course of the anterior ciliary arteries along the muscles and their tendons is highly variable and this variation is important to recognize when planning surgery on patients who are at risk for anterior segment ischemia (Chap. 20). The anterior ciliary vessels course forward to the episclera, where they supply branches to the sclera, limbus and to the conjunctiva. They enter the sclera near the limbus where they ultimately anastomose with the long ciliary arteries to form the major arterial circle of the iris. Veins corresponding to the muscle’s arteries drain into the superior and inferior orbital veins.

![Fig. 1.17. The anterior ciliary arteries. Except for the lateral rectus muscle, each rectus muscle contains two anterior ciliary arteries](image-url)
1.9 Surgically Important Anatomy of Individual Extraocular Muscles

This section will review key elements of the surgical anatomy of the individual extraocular muscles and surrounding tissues that the strabismus surgeon is likely to encounter frequently during standard strabismus surgery. Information about the basic anatomy, function, and structure of each extraocular muscle and its supporting fascia is found elsewhere in this and subsequent chapters.

1.9.1 Medial Rectus Muscle

The medial rectus muscle insertion is typically closer to the corneal limbus than that of the other rectus muscles. According to Apt [18] in the adult eye, the mean insertion distance from the center of the insertion to the anterior limbus is 5.3 mm (Fig. 1.12). There is a wide range in variation of this distance [18] and this distance is smaller in a child. As a general rule of thumb, the surgeon should expect to find the insertion 1 mm closer to the limbus than the values shown in Table 1.1 for a child between the ages of 6 and 12 months. Helveston believes that variation in the insertion of the medial rectus muscle tendon relative to the limbus is large and common, suggesting a range of 3.5–6 mm from the corneal limbus [21]. He believes that the large variation in distance of the insertion of the medial rectus muscle relative to the corneal limbus makes the muscle insertion a poor landmark for measuring during recession surgery on the medial rectus muscle and prefers to utilize the limbus as the landmark, rather than the muscle insertion.

The medial rectus muscle is the only extraocular muscle that does not have a direct attachment to one of the other extraocular muscles. This increases the likelihood that the medial rectus muscle will retract posteriorly into the orbit if extensive dissection of the medial rectus muscle fascial system is carried out and the surgeon loses control of the muscle after it has been detached from the sclera. The surgeon is not likely to engage other vascular or muscular structures when hooking the medial rectus muscle.

The sclera posterior to the rectus muscle insertions is thinner than the sclera anterior to the rectus muscle insertions. This is particularly true of the region posterior to the medial rectus muscle insertion. Small recisions may require fixation of the muscle to this very thin portion of the sclera, where the risk of scleral perforation is probably higher, and may warrant consideration of a muscle hang-back procedure from the thicker sclera at the insertion in some situations. The underlying uvea can sometimes be seen through the thin sclera posterior to the media rectus muscle insertion and can occasionally be a cause of significant concern to patients postoperatively (Chap. 19). The conjunctival anatomy of the medial aspect of the eye is more complex than the conjunctiva encountered when performing surgery on the other rectus muscles (Fig. 1.18). Care must be taken during the creation of conjunctival incisions at the start of surgery and during closure of conjunctival incisions at the conclusion of surgery to avoid disruption of the key anatomical landmarks of the medial conjunctiva, which can result in very significant cosmetic and functional complications (Chap. 19).

1.9.2 Lateral Rectus Muscle

Surgery on the rectus muscle would be straightforward but for two anatomical issues. First, the tendon of the lateral rectus muscle is both thin and long. This makes the tendon more prone to being split with a muscle hook as the muscle is being isolated and it makes passage of a suture to secure the muscle insertion more difficult. In addition to having a tendon that is longer and thinner than those of the other rectus muscles, the lateral rectus muscle typically has only a single anterior ciliary artery. These features can be helpful in confirming that the correct muscle has been isolated if the surgeon becomes disoriented during surgery. Second, the inferior oblique muscle inserts into the sclera approximately 10 mm posterior to the limbus beneath the inferior aspect of the lateral rectus muscle. Loose attachments between the fascial sheaths of these two muscles are usually present. The inferior oblique muscle is often inadvertently hooked along with the lateral rectus muscle when isolation of the lateral rectus muscle is attempted. This can occur during attempts to isolate the lateral rectus muscle from its superior or inferior border, but is more likely to occur when attempting to isolate the lateral rectus muscle from its inferior border. This complication is more likely to occur when the lateral rectus muscle has been previously retracted. The inferior oblique muscle can occasionally be isolated instead of the lateral rectus muscle when attempting to isolate the muscle from its inferior border. This is more likely to occur in eyes with previous surgery and an extensive amount of scarring. Failure to recognize that the inferior oblique muscle has been inadvertently hooked can result in a significant postoperative motility disturbance that is of a restrictive nature [22] (Chap. 25).

Fig. 1.18. Important conjunctival landmarks
1.9.3 Inferior Rectus Muscle

Surgery on the inferior rectus muscle would be rather straightforward if not for the presence of a number of important surrounding structures. The midpoint of the insertion inserts an average of 6.8 mm posterior to the anterior limbus [18] (Fig. 1.12). The temporal border of the tendon inserts approximately 2.5 mm more posteriorly than the nasal border of the insertion [18], a fact which should be considered when recessing or resecting the muscle. When hooking the inferior rectus muscle, the surgeon should avoid passing the hook too deeply into the orbit. A vortex vein can typically be seen posteriorly near both the medial and lateral borders of the inferior rectus muscle (Fig. 1.19). Disturbance of a vortex vein can result in considerable bleeding, rendering continuation of surgery hazardous (Chap. 24).

The fascial sheath of the inferior rectus muscle is typically thicker than that associated with the other rectus muscles. The inferior rectus muscle is intimately associated with the inferior oblique muscle and Lockwood’s ligament through these fascial attachments. The orbital aspect of the fascial sheath of the inferior rectus muscle forms part of Lockwood’s ligament. Because of these firm attachments to Lockwood’s ligament, large resections or resections of the inferior rectus muscle can produce unwanted retraction and advancement of the lower eyelid, respectively. Techniques to minimize these undesired changes in eyelid position are reviewed in Chap. 26. Many surgeons more generously dissect the fascial attachment associated with the inferior rectus muscle to minimize changes in eyelid position. Intrusion into a large fat pad that is closely associated with the inferior rectus muscle can occur during dissection of these fascial tissues.

The firm attachments of the inferior rectus muscle to Lockwood’s ligament and to the inferior oblique muscle, which crosses inferior to the inferior rectus muscle, limit the tendency of the inferior rectus muscle to retract into the posterior orbit when detached from the sclera. These attachments are invaluable in helping to identify a lost or traumatically detached inferior rectus muscle (Chap. 23).

1.9.4 Superior Rectus Muscle

Surgery on the superior rectus muscle is complicated by the presence of adjacent vascular, muscular, and tendinous structures. If a fornix conjunctival incision is planned to surgically access the muscle, it is generally placed in the superotemporal quadrant, to avoid disturbing the superior oblique tendon and its trochlea. The central portion of the tendon of the superior rectus muscle inserts approximately 7.9 mm from the anterior corneal limbus. The insertion is curved relative to the limbus. The temporal border of the tendon inserts almost 3 mm more posteriorly than the nasal border [18], a fact which should be considered when recessing or resecting the muscle. It is the only rectus extraocular muscle that inserts posterior to the ora serrata. As such, a perforation of the eye wall near the insertion of the superior rectus muscle may enter the retina. A vortex vein can usually be found posteriorly near the border of the superior rectus muscle nasally and temporally. Vortex veins are infrequently damaged during surgery on the superior rectus muscle. Compared to the inferiorly located vortex veins, they are more difficult to inadvertently hook or otherwise manipulate when attempting to isolate the superior rectus muscle because they are somewhat protected by the superior oblique tendon.

The fascial sheath surrounding the superior rectus muscle is thicker on its orbital surface. Here, there are relatively firm attachments between the sheath of the superior rectus muscle and the sheath of the levator muscle of the upper eyelid. These firm attachments between the superior rectus and levator muscles are in large part responsible for upper eyelid retraction and advancement following superior rectus muscle recession and resection, respectively (Chap. 26). These unwanted alterations of upper eyelid position are most likely to occur with resections or resections of greater than 5 mm. The global aspect of the muscle sheath of the superior rectus muscle is attached to the superior oblique tendon through relatively tenuous connections (Fig. 1.20). If the close relationship between these two structures is not recognized, the superior oblique tendon can sometimes be inadvertently hooked, along with the superior rectus muscle tendon. If unrecognized, the superior oblique tendon may be sutured along with the superior rectus tendon and recessed or resected, producing unexpected torsional and vertical misalignment following surgery. Because the insertion of the superior rectus muscle is relatively far from the limbus, there is a tendency to pass the initial muscle hook more posteriorly when attempting to isolate the muscle insertion. This increases the risk of capturing a portion of the superior oblique tendon at the same time. We recommend that the strabismus

![Fig. 1.19. Vortex veins as seen from the posterior aspect of the globe](image)
surgeon who may be less accustomed to operating on the superior rectus muscle inspect the insertion site once the muscle is isolated to make certain that the superior oblique tendon is not engaged on the hook.

### 1.9.5 Superior Oblique Muscle/Tendon

Compared to the frequency of surgery on the other extraocular muscles, surgery is performed relatively infrequently on the superior oblique. Only the tendinous portion of the superior oblique, that portion distal to the trochlea, is manipulated surgically. The tendon runs posteriorly and temporally from the trochlea, which is located in the anteromedial orbit, to insert well behind the equator of the globe. The tendon travels inferior to the superior rectus muscle, crossing under the superior rectus muscle beginning 5–10 mm posterior to the insertion of the superior rectus muscle into the sclera. Adhesions between the sheath of the superior oblique tendon and the sheath of the superior rectus muscle often must be severed to complete surgery on the superior oblique tendon. The capsule of the tendon is continuous with the episcleral space at its insertion and is continuous with Tenon's capsule surrounds the tendon (Fig. 1.10). During surgery, this capsule should be disturbed as little as possible. This is especially true of surgery performed to insert a superior oblique tendon expander [23]. Disruption of the capsule surrounding the superior oblique tendon is a potential cause of secondary restrictive strabismus following superior oblique tendon expander surgery (Chap. 25).

The anterior portion of the superior oblique tendon insertion may underlie the superior rectus muscle temporally. The thin tendinous insertion is broad and the most posterior portion of the tendon lies only 8–10 mm from the sheath of the optic nerve. The thinness, width, and posterior nature of the insertion of the superior oblique tendon combine to make surgical isolation of the tendon difficult (Fig. 1.20). The tendon is easily split with a muscle hook, and isolation of only a portion of the superior oblique tendon can easily occur. If unrecognized, the surgical procedure may have a minimal and/or unpredictable effect on ocular alignment. While it is optimal to isolate the superior oblique tendon under direct visualization, it is often not possible to clearly visualize the more posterior fibers of the tendon during this process. After hooking the tendon, the proximal fibers can be visually inspected to assure that there is not a bundle of remaining tendinous fibers running posteriorly toward the insertion, having been excluded from the hook. Superior oblique traction testing (Chap. 8) can also be useful in confirming that the entire superior oblique tendon has been surgically disinserted. The posterior edge of the superior oblique tendon insertion lies between and slightly anterior to two vortex veins (Fig. 1.19). These vortex veins, particularly the temporal one, can be easily damaged during surgery on the superior oblique tendon.

### 1.9.6 Inferior Oblique Muscle

Surgery on the inferior oblique muscle is generally conducted in the inferotemporal quadrant, though some recently described procedures involve manipulation of the muscle in the inferonasal quadrant [24]. The inferior oblique muscle is the only extraocular muscle that does not have a tendinous portion distally. The muscular insertion of the inferior oblique is located temporally beneath the inferior border of the lateral rectus muscle.

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**Fig. 1.20.** Fine attachments between the sheath of the superior rectus muscle and the sheath of the superior oblique tendon

**Fig. 1.21.** Insertion of the inferior oblique muscle under the lateral rectus muscle
rectus muscle. A dual insertion is said to be present in almost 11% of inferior oblique muscles [25]. Failure to recognize a dual insertion can result in minimal and/or unpredictable effects on ocular alignment following surgery. The capsule of the inferior oblique muscle is relatively thick and fine attachments between its capsule and that of the lateral rectus muscle are generally present near the insertion of the inferior oblique muscle (Fig. 1.21). A large orbital fat pad in the inferotemporal quadrant of the orbit can be easily disturbed during surgery on the inferior oblique muscle. This usually occurs during the isolation and dissection of the belly of the inferior oblique muscle, and can result in intraoperative bleeding and intrusion of orbital fat into the operative field, both of which can hinder the visualization necessary to complete surgery and can result in the development of a restrictive strabismus postoperatively.

The inferior oblique muscle is usually identified surgically as it courses across the inferotemporal quadrant, approximately 15 mm from the limbus. Unlike the other extraocular muscles, it is not surgically identified in its resting position on the globe, but rather is retracted inferiorly and identified as it courses within Tenon’s capsule (Fig. 1.22). The muscle is isolated by passing a hook posterior to the belly of the muscle and retracting the muscle anteriorly. It is during this process, that the surgeon is most likely to encounter surrounding orbital fat and may encounter a vortex vein located in the inferotemporal quadrant near the lateral border of the inferior rectus muscle. These complications can be minimized by attention to careful surgical technique as reviewed in Chap. 11. We recommend that the surgeon directly visualizes the posterior border of the inferior oblique muscle and the nearby vortex vein prior to attempting to isolate the muscle on a hook.

The effective insertion of the inferior oblique muscle is not at the medial orbital wall where the anatomical insertion is located, but instead is at the neurovascular bundle which enters the inferior oblique muscle near the temporal border of the inferior rectus muscle [20]. The neurovascular bundle is usually not visualized or disturbed during standard surgery on the inferior oblique muscle. An exception is denervation and extirpation of the inferior oblique muscle, which requires transection of the neurovascular bundle (Chap. 11). This bundle is generally best palpated with a hemostat, a maneuver that facilitates its visual identification.

References


Fig. 1.22. Identification of the inferior oblique muscle (arrow) in Tenon’s fascia as it is retracted inferiorly. Note the presence of a vortex vein (asterisk) near the posterior border of the muscle


