High resolution magnetic resonance imaging anatomy of the orbit
Ettl, A.

Citation for published version (APA):
Ettl, A. (2000). High resolution magnetic resonance imaging anatomy of the orbit
CHAPTER 8

HIGH-RESOLUTION MRI ANATOMY OF THE ORBIT: 
CORRELATION WITH COMPARATIVE CRYOSECTIONAL ANATOMY

Armin Ettl¹, Erich Salomonowitz², Leo Koornneef³, Frans W. Zonneveld⁴

¹Department of Neuro-Ophthalmology, Oculoplastic and Orbital Surgery, General Hospital, St. Poelten, Austria
²Department of Radiology, General Hospital, St. Poelten, Austria
³Orbit Center, Department of Ophthalmology, Academic Medical Center, Amsterdam, the Netherlands
⁴Department of Diagnostic Radiology, Utrecht, the Netherlands


INTRODUCTION

MR imaging has become an indispensable diagnostic tool in ophthalmology. Since earlier MR imaging studies of ocular and orbital anatomy, MR imaging technology has considerably improved so that we are now able to demonstrate the orbital anatomy including all major vessels and nerves with superb detail. Additionally, biochemical mapping of central visual pathways may be obtained by MR imaging spectroscopy following tomographic MR imaging.

In this article the anatomy of high-resolution MR images of the orbit is described and correlated with anatomic cryosections.

MATERIAL AND METHODS

Healthy, young volunteers were examined after informed consent was obtained. MR images were taken with closed lids and the eyes in resting position (i.e., slight downgaze).

MRI imaging of the orbit was performed on a 1.5-T scanner (Gyroscan ACS NT, Philips, The Netherlands) using surface coils with diameters of 14 and 11 cm. T1-weighted images were obtained using spin-echo (SE) sequences with a TE of 15 milliseconds and a TR of 450 to 475 milliseconds. T2-weighted images were obtained with a TE of 110 milliseconds and a TR of 2500 milliseconds.

Scans were oriented in the following planes: (1) axial (parallel to the optic nerve [i.e., approximately parallel to the neuroophthalmic plane])⁵ (Figs. 1-9); (2) coronal (perpendicular to the transverse plane) (Figs. 10-19); and (3) oblique-sagittal (parallel to the optic nerve [i.e., 20 to 30 degrees to the sagittal plane of the head]) (Figs. 20-25). Three-millimeter slices, a field of view of 140 mm, and a 256 x 256 matrix resulted in a theoretical spatial resolution of 0.5 mm. Acquisition times were 5 minutes for most T1 and 4 minutes for the T2 sequences.

Fig. 1. Scan plane orientation for axial MR images: Parallel to the optic nerve (OM-line minus five degrees). Descending slice order.
The anatomic structures in the MR images were identified and compared with cryosections of the orbit in human cadavers. Furthermore, the MR images were compared with the collection of histological sections of the orbit by Koornneef, including hematoxylin-azophloxin-stained 60-μm thin sections and 5 mm-thick cleared sections in the frontal plane. The cryosectioning technique was as follows: unpreserved normal human orbits, obtained from the Department of Anatomy at Utrecht University Hospital, were mounted on a microtome and embedded in carboxymethyl cellulose. Then, cryosectioning in the transverse, frontal and oblique-sagittal planes was performed at a temperature of -20°C (-4°F); a cutting speed of 4 cm/s; and a thickness of 20 μm on a LKB 2250 PMV microtome (Bromma, Sweden).

IMAGING ANATOMY

**Orbital bones and apertures**

The orbital floor consists of the orbital plates of the maxillary and the zygomatic bone and the orbital process of the palatine bone; the lateral orbital wall of the frontal process of the zygomatic bone and the greater wing of the sphenoid bone; the orbital roof of the orbital plate of the frontal bone and the lesser wing of the sphenoid, which is perforated by the optic canal. The medial orbital wall consists of the frontal process of the maxillary bone, the lacrimal bone, the orbital plate of the ethmoid bone, and part of the body of the sphenoid bone. Due to the signal void of nonmobile protons, cortical bone is not directly visualized on MR imaging but appears black. When cortical bone is adjacent to signal-producing tissue, such as orbital fat, brain (Figs. 11-19), or muscle (Fig. 12-15), its borders can be clearly delineated. When cortical bone is adjacent to areas that do not produce signal, however, such as air-filled parasanal sinuses, the bone may not be clearly defined. Therefore, the extraorbital border of the paper thin medial orbital wall and orbital floor cannot be visualized, unless the parasanal mucosa is swollen or the sinus is filled with mucus or blood. Due to its fat content, the bone marrow of cancellous bone, for instance, at the lateral orbital rim, appears hyperintense (Figs. 2-9, 12).

The inferior orbital fissure, the gap between the posterior orbital floor and the lateral orbital wall, is bridged by the smooth orbital muscle of Müller (Figs. 8-9, 11-13). The superior orbital fissure (Fig. 6) separates the posterior parts of the orbital roof and the lateral orbital wall; it contains the cranial nerves III, IV, and VI; the ophthalmic branch of the trigeminal nerve (V.1), and the superior ophthalmic vein. The anterior ethmoidal foramen (Fig. 4), located 15 to 30 mm from the orbital rim, and the posterior ethmoidal foramen, located 20 to 40 mm from the orbital rim, contain the corresponding neurovascular bundles (anterior and posterior ethmoidal artery, vein, and nerve). The infraorbital neurovascular bundle (infraorbital artery, vein, and nerve) is seen in the infraorbital canal (Figs. 13-18).

**Globe**

The anteroposterior diameter of the eyeball can be estimated on axial and sagittal MR images. Standardized A-scan echography, however, results in more accurate values (the axial length of a normal adult eye, without refractive error, measures 22 to 23 mm). On MRI scans, the following tissue layers of the eye can be distinguished: the cornea and sclera show a medium to low signal intensity on T1-weighted (Figs. 5-7) and T2-weighted (Fig. 25) images. The next layer is hyperintense on T1-weighted images and consists of (1) the triangular-shaped ciliary body and the iris root in the anterior eye segment and (2) the chorioretinal layer in the posterior eye segment (Figs. 5-7). The iris is 0.3 to 0.6 mm thick, and, in most cases, not visualized on clinical MR images. In normal eyes, without retinal detachment, the 0.2- to 0.3-mm-thick retina cannot be differentiated from the highly vascularized choroid using slice thicknesses of 2 to 3 mm.

The meniscus-shaped anterior eye chamber is filled with aqueous humor that is hypointense on T1-weighted (Figs. 5-7) and hyperintense on T2-weighted (Fig. 25) images. The posterior chamber contains the gel-like vitreous body, which consists of 98 % water and less than 2 % collagen and, therefore, appears hypointense on T1-weighted (Figs. 5-7) and hyperintense on T2-weighted (Fig. 25) images. The normal crystalline lens is composed of approximately 65% water and 35 % protein and shows an intermediate signal intensity on T1-weighted (Figs. 5-7) and low intensity on T2-weighted (Fig. 25) images. Relaxation times of the vitreous body and crystalline lens depend on the state of water binding to proteins, which is age-dependent. With vitreous liquefaction, T1 decreases in comparison with normal eyes. In typical age-related nuclear cataract, the nucleus of the lens exhibits a lower signal intensity on T2-weighted images than the cortex.

**Extraocular musculature**

The extraocular muscles show a medium signal intensity on T1-weighted and T2-weighted images. The recti muscles originate from the tendineous annulus of Zinn in the orbital apex (Fig. 23). In axial or sagittal images, the recti muscles take a convex course, bowed away from the retroequatorial surface of the eye (Figs. 7, 23). On coronal images just posterior to the equator, a discrete distance between globe and recti muscles is due to their curved path (Fig. 16). The line of tangency, where the straight muscles start to touch the surface of the globe, is located in the equatorial region, or 1 to 3 mm posterior to the equator (Figs. 7, 25).
Fig. 2. Correlative MR imaging anatomy in the axial plane at the level of the branches of the frontal nerve (74-76) just inferior to the orbital roof. See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.\textsuperscript{55}; with permission.)

Fig. 3. Correlative MR imaging anatomy in the axial plane at the level of the trochlea (17) and the superior muscle complex (8,10). See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.\textsuperscript{66}; with permission.)
Fig. 4. Correlative MR imaging anatomy in the axial plane at the level of the superior ophthalmic vein (56) and lacrimal vein (57). See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.64,65; with permission.)

Fig. 5. Correlative MR imaging anatomy in the axial plane at the level of the ophthalmic artery (43) crossing over the optic nerve (63). See text and appendix for a detailed description.
A, T1-weighted MR scan. Red arrow indicates branch of ophthalmic artery, presumably anastomosis with meningeal circulation.64,65 B, Cryosection (From: Zonneveld et al.64,65; with permission.)
Fig. 6. Correlative MR imaging anatomy in the axial plane at the level of the optic nerve (63) and the horizontal rectus muscles (12,13). The orbital apex communicates with the middle cranial fossa via the superior orbital fissure(89). See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.64-66; with permission.)

Fig. 7. Correlative MR imaging anatomy in the axial plane at the level of the central retinal artery (44) just inferior to the optic nerve. See text and appendix for a detailed description.
A, T1-weighted MR scan. Red arrow labels venous branch exiting medial rectus muscle. B, Cryosection (From: Zonneveld et al.64-66; with permission.)
Fig. 8. Correlative MR imaging anatomy in the axial plane at the level of the inferior ophthalmic vein (58) and the distal portion of the inferior oblique muscle (18). See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.; with permission.)

Fig. 9. Correlative MR imaging anatomy in the axial plane at the level of the proximal portion of the inferior oblique muscle (18) just superior to the anterior orbital floor. See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.; with permission.)
Fig. 10. Scan plane orientation for coronal MR images:
Perpendicular to axial plane. Descending slice order.

Fig. 11. Correlative MR imaging anatomy in the coronal plane at the level just anterior to the orbital apex. See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.1982; with permission.)
Fig. 12. Correlative MR imaging anatomy in the coronal plane at the level of the posterior orbit with central retinal artery (44) entering the dural optic nerve (63) sheath. The inferior orbital fissure communicates with the infratemporal fossa (asterisk). See text and appendix for a detailed description.

A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al. with permission.)

Fig. 13. Correlative MR imaging anatomy in the coronal plane at the level of the anterior part of the inferior orbital fissure. See text and appendix for a detailed description.

A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al. with permission.)
Fig. 14. Correlative MR imaging anatomy in the coronal plane at the level just posterior to the globe. See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.; with permission.)

Fig. 15. Correlative MR imaging anatomy in the coronal plane at the level of the posterior sclera (2) and the optic nerve head (63). See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.; with permission.)
Fig. 16. Correlative MR imaging anatomy in the coronal plane at the level of the distal part of the inferior oblique muscle (18). See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.6465; with permission.)

Fig. 17. Correlative MR imaging anatomy in the coronal plane at the level just posterior to the equator of the globe. See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.6465; with permission.)
Fig. 18. Correlative MR imaging anatomy in the coronal plane at the level of the equator of the globe. See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al., with permission.)

Fig. 19. Correlative MR imaging anatomy in the coronal plane at the level of the trochlea (17), medial palpebral ligament (25) and the lacrimal sac (38). The red arrow indicates the facial vein. See text and appendix for a detailed description. A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al., with permission.)
Fig. 20. Scan plane orientation for oblique-sagittal MR images: parallel to the optic nerve (approximately 20° off to the side).

Fig. 21. Correlative MR imaging anatomy in the oblique-sagittal plane at the level of the middle part of the lateral rectus muscle (13). See text and appendix for a detailed description. A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al., with permission.)
Fig. 22. Correlative MR imaging anatomy in the oblique-sagittal plane at the level of the proximal part of the lateral rectus muscle (13). Note the lesser wing of the sphenoid (87) which separates the anterior from the middle cranial fossa. See text and appendix for a detailed description. A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.; with permission.)

Fig. 23. Correlative MR imaging anatomy in the oblique-sagittal plane at the level of the optic nerve (63) and the vertical rectus muscles (10, 11). Arrows indicate Zinn's annulus tendineus. See text and appendix for a detailed description. A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.; with permission.)
Fig. 24. Correlative MR imaging anatomy in the oblique-sagittal plane at the level of the middle part of the medial rectus muscle (12). See text and appendix for a detailed description.
A, T1-weighted MR scan. B, Cryosection (From: Zonneveld et al.⁶⁴⁸⁵; with permission.)

Fig. 25. T2-weighted oblique-sagittal MRI scan at the level of the optic nerve (63). See text and appendix for a detailed description.
After the line of tangency, the straight muscles run in close contact with the globe towards their insertion (Figs. 7, 25). The superior oblique muscle originates from the lesser wing of the sphenoid (Fig. 11) and courses in close contact with the superomedial orbital wall toward the trochlea (Fig. 4). The fibrocartilaginous trochlea is best visualized in axial and coronal images (Figs. 3, 4, 18, 19). From here, the reflected part of the superior oblique muscle tendon courses postero-laterally in an angle of about 45 to 50 degrees with the sagittal plane to insert in the superolateral quadrant of the globe (Fig. 3).\(^{24}\)

The inferior oblique muscle originates from the maxilla just lateral to the entrance of the nasolacrimal duct into the nasolacrimal canal (Fig. 19). It runs posterolaterally (Fig. 9) and undercrosses the inferior rectus muscle (Fig. 18) to insert in the inferolateral quadrant of the globe (Fig. 8), under the inferior border of the lateral rectus muscle (Figs. 16).\(^{24}\)

The lower lid retractors (capsulopalpebral fascia and inferior tarsal muscle of Müller) originate from the anterior border of the inferior oblique muscle and Lockwood’s ligament and insert in the tarsal plate of the lower lid (Fig. 25). The levator palpebrae superioris muscle courses upward from its origin at the lesser wing of the sphenoid (Fig. 4), until it reaches a point about 3 to 5 mm (craniocaudal distance) superior to the equator of the globe from where it courses downward to its insertion in the upper lid (Figs. 23, 25).\(^{2}\)

Connective tissue system

The T1 hyperintense tarsal plates are demonstrated in the upper and lower lids (Figs. 7, 23) because of the lipid content of the meibomian glands. The fibrous orbital septum appears as T1 hypointense structure (Fig. 3) and courses from the levator aponeurosis (upper lid) and the capsulopalpebral fascia\(^{20}\) (lower lid) to the orbital rim (Figs. 22-25).

In the upper lid, sagittal scans show tissue that is isointense to orbital fat anterior to the orbital septum (brow fat pad) and posterior to it (preaponeurotic fat pad) (Figs. 21-24). If there is sufficient amount of adipose tissue between the levator aponeurosis and Müller’s superior tarsal muscle (postaponeurotic fat pad), Müller’s muscle can be distinguished from aponeurotic tissue.\(^{25}\)

In the lower lid, sagittal scans show fatty tissue posterior to the orbital septum (Fig. 21-24). The levator aponeurosis (Figs. 21-24) and its connections to trochlea and lacrimal gland in the region of Whitnall’s superior transverse ligament\(^{26}\) are visible (Figs. 18-19).

Intermuscular septa (Figs. 13-18) connect the straight eye muscles. In the midorbit, the intermuscular septum between the lateral rectus muscle and the superior muscle complex (superolateral intermuscular septum or tensor intermuscularis\(^{27}\)) has a similar cross-sectional thickness and signal intensity as the extraocular muscles (Fig. 16-18).

The space between the caudal surface of the inferior rectus muscle and the cranial surface of the inferior oblique muscle (Figs. 18, 25) is filled with connective tissue fibers of Lockwood’s ligament. The arcuate expansion of Lockwood’s ligament\(^{4}\) courses toward the lateral orbital floor, and may be visualized as T1 hypointense structure in coronal sections of the anterior orbit.\(^{25}\) A space that is mostly isointense to orbital fat is noted between the culmination point of the levator palpebrae superioris muscle and the cranial surface of the superior rectus muscle (Fig. 18). This intermuscular space also contains hypointense structures that represent strands of the intermuscular transverse ligament\(^{26}\) or inferior portion of Whitnall’s ligament.\(^{2}\)

The medial and lateral check ligaments connect the horizontal recti muscles to the periorbit (Figs. 5-6, 17-18). Radially oriented septa running toward the periorbit are mainly concentrated around the recti muscles and the optic nerve (Fig. 13).

Arteries

The ophthalmic artery originates as a 2- to 3-mm long intracranial vessel from the internal carotid artery that is visible on appropriate oblique-sagittal (Fig. 25) or axial (Fig. 7) MR images. In most individuals, the ophthalmic artery branches off the internal carotid artery following its exit from the cavernous sinus. The intracanalicular portion of the ophthalmic artery courses between optic nerve and inferior wall of the optic canal (Fig. 7). The intraorbital ophthalmic artery appears at the lateral side of the optic nerve, where it gives off the central retinal artery (Fig. 23). Distal to its "knee,"\(^{23}\) the ophthalmic artery overcrosses the optic nerve (Figs. 5, 6), then bends again and runs forward, first at the medial side of the superior oblique muscle and then between the superior oblique muscle and the medial rectus muscle (Fig. 4).

The central retinal artery courses forward inferiorly to the optic nerve and enters its dural sheath approximately 1 cm behind the globe (Fig. 7, 23). Next, at the crossing with the optic nerve, the ophthalmic artery gives off the posterior ciliary arteries on either side of the optic nerve (Fig. 5). The lacrimal artery is visualized near the lacrimal gland (Fig. 4). Axial sections may show the posterior ethmoidal artery coursing nasally or posteriorly toward the posterior ethmoidal foramen (not shown in the present figures). Anastomoses of the ophthalmic artery\(^{24,25}\), such as a recurrent meningeal branch\(^{27}\) (arrow in Fig. 5) may be seen in some individuals. On axial sections inferior to the superior oblique muscle, the curved anterior ethmoidal artery is seen close to the anterior ethmoidal foramen (Fig. 4).
Inferior to the trochlea, the ophthalmic artery terminates in the dorsal nasal artery (Fig. 4). The supraorbital artery (Figs. 3, 19) is located between orbital roof and levator palpebrae superioris muscle inferomedially to the branches of the supraorbital nerve. Cross-sections of the supratrochlear vessels (supratrochlear artery and vein) (Figs. 14-17) and the infratrochlear vessels (dorsal nasal artery and nasofrontal vein) (Figs. 17,19) are visible on coronal images.

**Veins**

The superior ophthalmic vein starts inferiorly to the trochlea at its anastomosis with the angular vein (Fig. 9) as continuation of the nasofrontal vein (Fig. 19). It continues posteriorly to the reflected part of the superior oblique tendon (Fig. 3) and courses from anteromedially to posterolaterally over the optic nerve and over the ophthalmic artery (Fig. 4). Proximal to the junction with the lacrimal vein (Fig. 4), the superior ophthalmic veine courses posteriorly, directing toward the superior orbital fissure (Fig. 4). Serial coronal sections show that the superior ophthalmic vein traverses the orbit closely inferior to the superior rectus muscle along a connective tissue septum that extends from the lateral rectus muscle toward the superomedial orbital wall (Figs. 11-17).

A common variation, the medial ophthalmic vein, is sometimes seen coursing parallel to the medial orbital wall in the extracranial space. Another variant, is the "veine ophthamlique moyenne," a muscular vein that may arise from the medial rectus muscle (Fig. 7, arrow). Branches of the inferior ophthalmic vein, following circular septa of connective tissue, are seen in the inferomedial orbit (Figs. 14-16). The trunk of the inferior ophthalmic vein is visualized laterally to the inferior rectus muscle (Fig. 8).

Vorticose veins can be seen in appropriate image orientations. For example, oblique-sagittal sections temporally to the anterior optic nerve show the temporal vortex veins (Fig. 21). The medial and lateral collateral veins, which connect the superior and inferior ophthalmic veins, are seen in oblique-sagittal sections (Figs. 21, 24) and as cross-sections in axial images (Figs. 5-7).

**Motor nerves**

The superior and inferior branch of the oculomotor nerve (III cranial nerve), the abducens nerve (VI cranial nerve), and possibly the thin trochlear nerve (IV cranial nerve) are visible in posterior coronal images (Fig. 11). Even a tiny nerve structure, the branch of the inferior division of the oculomotor nerve supplying the inferior oblique muscle (Figs. 9, 14-16), may be observed at the lateral border of the inferior rectus muscle.

**Sensory and autonomic nerves**

The ophthalmic division of the trigeminal nerve (V cranial nerve) branches into the frontal, lacrimal, and nasociliary nerves, which are clearly seen on MR images. The frontal nerve with its three branches (supratrochlear nerve and medial and lateral branch of supraorbital nerve) is noted on axial (Fig. 2) and coronal images (Figs. 11-19) superior to the levator palpebrae superioris (LPS) muscle. The lacrimal nerve is best seen in the upper orbit on coronal sections (Fig. 15). High axial sections show the nasociliary nerve as it courses anteriorly and coronal slices show its cross-sections (Figs. 11-14). Its terminal branch, the infratrochlear nerve, can be seen in anterior coronal sections (Fig. 19).

The superior branch of the maxillary division of the trigeminal nerve, the infraorbital nerve, enters the inferior orbital fissure via the foramen rotundum and continues as part of the infraorbital neurovascular bundle inside the infraorbital canal, best seen on coronal images (Figs. 12-18).

A hypointense 2-mm structure anterior to the "knee" of the ophthalmic artery and approximately 1 cm anterior to the superior ophthalmic fissure, situated between optic nerve and lateral rectus muscle, presumably represents the ciliary ganglion (Fig. 6). Parasympathetic fibers enter the orbit with the oculomotor nerve, synapse in the ciliary ganglion, and course to the eye via the short ciliary nerves. The ciliary ganglion also transmits sensory fibers from the eye to the nasociliary nerve via the long ciliary nerves. The tiny short ciliary nerves and posterior short ciliary arteries are arranged around the optic nerve sheath and, in coronal sections, appear as nodular irregularities around the retrobulbar segment of the optic nerve (Figs. 12-14) and on the posterior surface of the globe (Fig. 15).

**Optic nerve**

The optic nerve can be divided into three sections: (1) intracranial, (2) intracanalicular, and (3) intraorbital. The intracranial optic nerve (Figs. 5, 25) is circumferentially surrounded by cerebrospinal fluid. The 5-mm-long intracanalicular part (Figs. 5, 25) passes above the ophthalmic artery through the optic canal, which consists of the wall of the ethmoid and sphenoid sinus (signal void of air) medially; the lesser wing of the sphenoid cranially; the anterior clinoid process laterally; and the optic strut caudally.

After passing through Zinn’s tendinous annulus (Fig. 23), the intraorbital segment of the optic nerve describes an S-shaped course from the optic canal downward and then upward to the globe (Fig. 25). Axial slices in a slightly oblique orientation demonstrate the intracanalicular portion of the optic nerve and its intraorbital portion corresponding to the course of the nerve (Fig. 5). Oblique-sagittal sections parallel to the course of the nerve depict the intraorbital as well as the intracanalicular portion of the nerve (Fig. 25). The
subarachnoid space between pial and dural sheath of the optic nerve is normally 0.5 to 0.6 mm wide, and may be wider at the optic nerve head (Fig. 15), appearing as a T1 hypointense and T2 hyperintense ring around the nerve (Figs. 12-14).

Lacrical System

The lacrical gland is situated superolaterally to the globe and shows a medium signal intensity on T1 (Figs. 3-7, 14-19). It is divided in an orbital and palpebral lobe by the levator aponeurosis, which is best appreciated in coronal images (Figs. 18-19). The lacrical canaliculi are not visible in the presented images (normal lacrical canaliculi are only visible on MR imaging if a paramagnetic contrast medium is injected into the lacrical puncta”). The hypointense lacrical sac and the nasolacrical duct can be seen on anterior coronal MR images (Fig. 19) and their cross-sections in axial images (Figs. 7-9).

DISCUSSION

MR Imaging Technique

High-resolution MR imaging shows surprising details of orbital anatomy. With current technology, best resolution is still obtained using T1-weighted SE pulse sequences. Surface coil technology for orbital MR imaging allows for high-resolution imaging by increasing the signal-to-noise ratio but may be limited by the signal drop-off in the orbital apex and the intracanalicular optic nerve. Also, surface coils may be specifically susceptible to motion artifacts.

A slice thickness of 3 mm was used for the present study, allowing for visualization of relatively long segments of blood vessels and nerves. The high orbital fat content accounts for an excellent contrast, which improves the detection of tiny anatomic structures so that even parts of the orbital connective tissue system can be visualized.

Eye motion and eyelid blinking result in creation of ghost images. Motion artifacts can be minimized by having patients keep their lids open and fixate on a point inside the MR imaging scanner. Reflex blinking may be reduced by instillation of local anesthetic eye drops and artificial tear drops. If a longer acquisition time is needed, however, a good result may also be obtained by having patients close their lids with the eye in resting position. Motion artifacts can represent a considerable problem in high-resolution MR imaging of the orbit. Therefore, this technique is currently restricted to cooperative subjects who are able to lie still in the scanner for about 5 minutes. Recently, it has been possible to perform ocular motion studies using fast MR imaging.

Chemical shift artifacts may be seen at the interface of orbital fat and adjacent tissues. For example, these artifacts may cause areas of hypointensity bordering the optic nerve, which may be confused with its subarachnoid space. By altering the alignment of scanning, using the smallest possible pixel size, the smallest band width, and fat suppression techniques, the chemical shift artifact can be reduced or eliminated.

Foreign bodies, wires, dental appliances, mascara, and palpebral springs (implanted for facial nerve palsy) cause metal artifacts, whereas titanium orbital implants, miniplates and gold eyelid weights (implanted for facial nerve palsy) are seen as signal voids.

Anatomic Comments

The origin and course of the extraocular muscles can be demonstrated on MR images with sufficient detail. Due to the varying arc of contact (region of tangency between muscles and globe), however, and isointensity of tendon and scleral tissue, an exact determination of the insertion of the recti and oblique muscles is not possible. CT and MR images of the orbit demonstrate that the recti muscles do not follow the shortest path from their origin to the insertion but course in a curved path. The most likely explanation for this finding is that the path of the recti muscles is stabilized by special structures of the orbital connective tissue system, the so-called pulleys. They represent sleeves in Tenon’s capsule that are attached to the orbital walls by means of connective tissue septa, the so-called check-ligaments. The supporting framework of connective tissue septa around the extraocular muscles explains their stability against sideways displacement during ocular movements and following surgical transpositions. The course of the oblique eye muscles is also determined by connective tissue structures. The trochlea, as the "pulley" of the superior oblique muscle, translates the anteroposterior muscle force of the superior oblique muscle into a downward movement of the eye. The inferior oblique muscle is also slightly bowed away from the globe near Lockwood's ligament, which represents the "pulley" of the inferior oblique muscle. The levator palpebrae superioris muscle also follows a curved path. Its culmination point is situated a few millimeters superior to the globe, suggesting a suspension of the muscle by radial connective tissue septa and support from the inferiorly situated intermuscular transverse ligament.

The orbital connective tissue system represents an important additional locomotor system enabling coordinated movements of eye muscles, globe, optic nerve, and eyelids. Major parts of the orbital connective tissue system can be visualized using high-resolution MR imaging. According to the direction of their course, orbital septa can be divided in radial septa (e.g., check ligaments) and concentric septa (e.g., intermuscular septa). Blood vessels (especially arteries) appear dark in MR images.

This is because protons of flowing blood that have been excited by a radiofrequency pulse pass outside the
imaging slice before their signal can be detected." Due to this signal void of flowing blood, major vessels in MR images are usually darker than other structures, such as muscles and nerves. A detailed understanding of orbital anatomy allows the identification of various vascular structures on MR images. The vessel diameters, as estimated in the MR images, slightly exceed the real anatomical diameter. This discrepancy can be explained by the fact that the MR imaging system measures not only the blood flow but also minimal motions of the vessel resulting in a larger vessel diameter.

The ophthalmic artery and its branches are subjected to considerable anatomic variations. It overcrosses the optic nerve in 72% to 95% of individuals (Fig. 5) and undercrosse ss it in 5% to 28%. The following anatomic features help to differentiate between arteries and veins in orbital MR images: (1) In general, arteries show a curved course compared with the more straight veins and nerves. (2) The veins of the orbit do not generally follow the orbital arteries but form a separate system. Only the lacrimal, ethmoidal, infraorbital, and angular veins follow their corresponding arterial channels. (3) The topographic relations to the connective tissue system are different for arteries and veins. Arteries form a radiating system diverging from the orbital apex, course through adipose tissue compartments, and perforate the orbital septa. In contrast, veins are arranged in a ringlike system due to their incorporation into septa of the orbital connective tissue system. For example, the superior ophthalmic vein traverses the orbit inside the superior ophthalmic vein hammock, a half-circular connective tissue septum that is situated inferior to the superior rectus muscle. The normal diameter of the superior ophthalmic vein in MR images is estimated to be 1.5 to 3 mm. Disorders with enlargement of the ophthalmic veins include arteriovenous malformations, carotid cavernous fistulae, dural shunts, cavernous sinus thrombosis, and Graves ophthalmopathy. Major branches of the sensory and motor cranial nerves of the orbit are visualized in high resolution orbital MR imaging. All extraocular muscles, except the inferior oblique, are innervated in their posterior third. Therefore, the corresponding nerves are best visualized in posterior coronal images. All motor nerves enter the orbit via the superior orbital fissure, the oculomotor nerve, and the abducens nerve inside Zinn's tendineus annulus and the trochlear nerve above the annulus. Therefore, the recti muscles are innervated from inside the muscle cone.

The optic nerve exhibits MR imaging signal characteristics similar to white matter of the brain because of its myelinated nerve fibers. Due to its S-shaped course, thin axial slices at the level of the optic canal show the intracanalicular portion of the optic nerve, but not the intraorbital and vice versa. Thicker and slightly oblique-axial slices, however, may demonstrate both the intracanalicular and the intraorbital portions of the optic nerve (Fig. 5). If the entire optic nerve is to be visualized in one image, it may be helpful to obtain images in upgaze so that the nerve is stretched, as first proposed for CT scanning.

The thickness of the optic nerve may be determined in oblique-coronal MR images perpendicular to the optic nerve. The mean pial diameter of the intraorbital segment of a normal optic nerve ranges between 3.2 mm (anteriorly) and 2.6 mm (posteriorly), whereas the mean dural diameter measures between 5.2 mm (anteriorly) and 3.9 mm (posteriorly). The major parts of the lacrimal drainage system (lacrimal sac and nasolacrimal duct) are visualized on MR imaging without injection of paramagnetic contrast medium because they are filled with air (signal void!) or fluid (T1 hypointense). The entire lacrimal drainage system including the canaliculi can be depicted on MR imaging after intracanalicular injection of paramagnetic contrast medium (48% gadolinium-pentetic acid diluted 1:100 in liquid tear solution).

Clinical applications

High-resolution MR imaging of the orbit may be used for the following clinical applications:

in general, this technique allows very good delineation of space-occupying orbital lesions in relation to soft tissue structures, thus facilitating surgical planning. The ability of delineate anatomic details in the orbit becomes important for computer-assisted orbital surgery using neuronavigation systems. MR imaging can demonstrate the course of the extraocular muscles following surgical muscle transposition procedures. Peripheral nerve sheath tumors cannot reliably be differentiated from other orbital tumors because of their nonspecific MR imaging signal characteristics. In these cases, high-resolution MR imaging might help to demonstrate a relation of the tumor to a nerve, which suggests a neurogenic tumor. Similarly, a tumor with a connection to the orbital venous system that distends during a Valsalva's maneuver suggests an orbital varix.

High resolution MR imaging can reveal information on the flow in blood vessels. A differentiation between flowing and stagnant blood in orbital vascular lesions is crucial for treatment planning. Therefore, another important application of this technique is the evaluation of orbital vascular lesions. Contrast-enhanced MR imaging with fat supression may reveal an inflammatory lesion (neuritis) of a motor nerve and localize the lesion within the orbit.

Evaluation of restrictive motility disorders, such as Graves' disease, ocular fibrosis syndrome, posttraumatic adhesions, and entrapment of connective tissue in fracture lines are some other applications of orbital MR imaging. In cases of acute orbital fractures, however, direct multiplanar high resolution CT scanning is still the first-choice imaging modality. MR imaging in different gaze positions with subsequent video recording of ocular movements has already been used to analyze motility disorders.
High-resolution MR imaging in different gaze positions may also be helpful for better understanding the mechanical role of the orbital connective tissue system during ocular movements. MR imaging is applied for the analysis of paretic motility disorders. Chronically paretic muscles have a decreased cross-sectional area and are lacking normal contractile changes during different gaze positions. This enables a differentiation between paretic and nonparetic strabismus.

The transverse diameter of extraocular muscles in disorders, such as myositis or Graves' orbitopathy, can be determined. Although standardized echography is a more economic diagnostic technique for this purpose, the variability of muscle diameter values is larger with echography than with high-resolution MR imaging. High-resolution MR imaging with T2-weighted sequences helps in differentiating acute inflammatory muscle changes (long T2 compared to normal muscle) from chronic fibrotic changes, which aids in choosing patients who respond to radiotherapy.

High-resolution MR imaging with and without intracanalicular injection of gadolinium-pentetic acid in lacrimal drainage disorders provides valuable information that affect patient management. In contrast to conventional dacryocystography, MR imaging may directly show the underlying cause of a dacryostenosis.

**CONCLUSION**

High-resolution MR imaging enables visualization of all major blood vessels, muscles, nerves, and connective tissue structures in the orbit. The best anatomic detail is obtained by using surface coils and T1-weighted SE sequences. The article provides the basic morphologic knowledge essential for a successful clinical application of this technique. The previously mentioned applications demonstrate that high-resolution MR imaging may contribute to a specific diagnosis in orbital disease.
APPENDIX

Nomenclature:

The numbers refer to the numbers in the figures.

1 Cornea
2 Sclera
3 Choroid and retina
4 Ciliary body
5 Lens
6 Aqueous humor
7 Vitreous body
8 Levator palpebrae superioris muscle
9 Levator aponeurosis
10 Superior rectus muscle
11 Inferior rectus muscle
12 Medial rectus muscle
13 Lateral rectus muscle
14 Superior oblique muscle
15 Superior oblique tendon (reflected part)
16 Superior oblique tendon (pretrochlear part)
17 Trochlea
18 Inferior oblique muscle
19 Orbicularis muscle
20 Lower lid retractors
21 Müller’s orbital muscle
22 Frontalis muscle
23 Temporalis muscle
24 Temporalis fascia
25 Medial palpebral ligament
26 Lateral palpebral ligament
27 Orbital septum
28 Superior tarsal plate
29 Inferior tarsal plate
30 Medial check ligament
31 Lateral check ligament
32 Intermuscular transverse ligament
33 Intermuscular septum
34 Preaponeurotic fat pad
35 Brow fat pad
36 Retrobulbar fat
37 Lacrimal gland
38 Lacrimal sac
39 Nasolacrimal duct
40 Internal carotid artery
41 Ophthalmic artery (intracranial part)
42 Ophthalmic artery (intracanalicular part)
43 Ophthalmic artery (intraorbital part)
44 Central retinal artery
45 Lateral long posterior ciliary artery
46 Medial long posterior ciliary artery
47 Lacrimal artery
48 Supraorbital artery (presumed)
49 Anterior ethmoidal artery
50 Supratrochlear artery/vein (presumed)
51 Ophthalmic artery (terminal branch) [a. dorsalis nasi]
52 Infraorbital artery/nerve in infraorbital canal
53 Angular artery
54 Angular vein
55 Superior ophthalmic vein (infraorbital branch) [v. nasofrontalis]

56 Superior ophthalmic vein
57 Lacrimal vein
58 Inferior ophthalmic vein
59 Medial collateral vein
60 Lateral collateral vein
61 Optic nerve (intracranial part)
62 Optic nerve (intracanalicular part)
63 Optic nerve (intraorbital part)
64 Dural optic nerve sheath
65 Subarachnoid space/cerebrospinal liquor
66 Oculomotor nerve (sup. division)
67 Oculomotor nerve (inf. division)
68 Oculomotor nerve (inf. division, branch to inf. oblique muscle)
69 Ciliary ganglion
70 Ciliary nerves/posterior ciliary arteries
71 Abducens nerve
72 Trochlear nerve
73 Frontal nerve
74 Supraorbital nerve (medial branch)
75 Supraorbital nerve (lateral branch)
76 Supratrochlear nerve (branch of frontal nerve)
77 Nasociliary nerve
78 Lacrimal nerve
79 Infraorbital nerve
80 Maxillary bone (infraorbital margin)
81 Maxillary bone (frontal process)
82 Zygomatic bone
83 Frontal bone (supraorbital margin)
84 Frontal bone (orbital plate)
85 Frontal bone (zygomatic process)
86 Sphenoid bone (greater wing)
87 Sphenoid bone (lesser wing)
88 Pterygopalatine fossa
89 Superior orbital fissure
90 Inferior orbital fissure
91 Anterior ethmoidal foramen
92 Maxillary sinus
93 Frontal sinus
94 Sphenoidal sinus
95 Ethmoidal sinus
96 Eyelid
97 Frontal lobe of brain
98 Temporal lobe of brain
99 Maxillary artery
100 Vorticose vein
101 Infraorbital nerve
REFERENCES


