PICTORIAL REVIEW

Orbital imaging: Part 1. Normal anatomy

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Advanced imaging techniques enable the radiologist to detect an increasing number of structures within the orbit not previously identifiable. We describe the imaging techniques and orbital anatomy with an emphasis on radiologically identifiable structures. In a second review of orbital pathology we present pathological processes that may involve these structures.

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Introduction

The orbit is amenable to radiological investigation by several methods.\textsuperscript{1,2} Multislice CT and MRI allow multiplanar imaging of both normal anatomy and pathology. Technical advances in MRI allow high-resolution imaging with visualization of small vessels and nerves within the orbit. As images become more refined, an understanding of this detailed anatomy will be increasingly necessary as the demand on radiology to diagnose smaller lesions increases. We provide a detailed account of orbital anatomy, with emphasis on structures visible on current imaging techniques. The anatomy of the globe is not considered in this paper.

Orbital technique

CT technique

The scan plane is planned from a lateral scout to be parallel to the infraorbital-meatal line approximating the orbital nerve plane. An example of an orbital protocol for spiral and multislice CT is given in Table 1. The protocol will differ according to indication. A 2.5–3 mm sectional thickness suffices for most imaging. Where small lesions, fractures or foreign bodies are being considered, the 2.5 mm axial images are reconstructed to 0.63 mm intervals. Slices 3 mm thick are preferred for routine soft tissue visualization on spiral CT because of the increased noise with thinner slices. Sections of 1.0 mm or 1.5 mm will be required for fractures or foreign bodies. Multiplanar reformatting enables further evaluation in the coronal and sagittal planes. Three-dimensional surface-shaded models may be produced when craniofacial surgery is planned providing eloquent demonstration of the bone anatomy in the context of fractures of the orbit and craniofacial abnormalities. The mA should be reduced to ensure the lowest ocular dose; we use an auto mA function to optimize image quality and dose. Increasing the noise index enables a reduction in mA at the expense of reduced signal to noise, but we have found the best compromise between signal to noise and dose to be at an index of 3.8. This usually produces an mAs of 160 that is comparable to a 150 mAs on the spiral scanner.

MR technique

The orbit can be imaged using a quadrangular routine head coil (for which we have provided a protocol: Table 2); however, better image quality can be achieved with a synergy head coil or even with surface coils. A synergy coil offers a combination of different quadrature or linear coils with each coil element independent of the other. The advantage is a larger area of coverage with the same signal to noise ratio (SNR). The aim is to
obtain the highest possible spatial resolution without having signal drop-out near the midline or near the orbital apex. Both these locations constitute a challenge for imaging. The orbital apex requires a high spatial and contrast resolution, owing to the close approximation of the anatomical structures to each other and the optic canal and superior orbital fissure; moreover, the apex is often situated at the edge of the small surface coils where SNR is lower. SNR with small surface coils drops more at the deepest part (medial orbital wall) of the examined structure than when a single larger non-synergy coil is employed, and is also reduced by the square root of the SENSE (sensitivity encoding) factor used.

The highest spatial resolution is achieved with surface coils. In the past these were placed on the orbit like goggles, but this technique often resulted in loss of signal near the orbital apex. Today we place these coils on the lateral wall of the orbit on both sides (Fig. 1). In such a position they still provide enough signal near the orbital apex and they can serve as synergy coils.

Parallel imaging techniques such as SENSE can be used. Individual coil channels receive individual signals per coil element, which are combined in to one image. Unlike conventional phased array or synergy coil reconstructions, the coil elements cover the same anatomical area. Using two coil elements halves the number of phase encoding steps required to measure the same field of view (FOV). Thus one can acquire a higher spatial resolution in the same acquisition time or the same spatial resolution in half the time (when a SENSE factor 2 is used). Moreover, this coil positioning also allows the use of CLEAR (constant level appearance), automatically activated when SENSE is applied. CLEAR is part of SENSE functionality. It uses coil sensitivity maps provided by a reference scan to produce homogeneous signal intensity throughout the image, e.g. from the surface of the orbit to the midline and/or apex. With this technique high quality coronal T1-weighted images, 3.5 mm thick and with a matrix of 605*1024, can be made on a Phillips Intera 1.5T in 6 min 14 (TR = 600 ms, TE = 15 ms, FOV = 260 mm, RFOV = 65%, NSA = 3 with SENSE factor 2).

Figure 1 The best quality on MR is achieved when synergy small loop coils are placed lateral to the orbit. This results in excellent signal intensity near the orbital apex and also allows the use of parallel imaging techniques.

Fluid attenuated inversion recovery (FLAIR), short tau inversion recovery (STIR) and spectral fat saturated inversion or selective partial inversion recovery (SPIR) sequences are useful adjuncts to the orbital examination. STIR increases conspicuity of intraorbital pathology by nulling the hyperintensity of orbital fat. This is achieved by a 180°
radiofrequency (RF) pulse inverting the longitudinal magnetization, followed by a 90° RF pulse at the null point of fat. Optic nerve hyperintensity can best be assessed on STIR and FLAIR, although STIR suffers from distracting CSF hyperintensity within the optic nerve sheath. FLAIR has the advantage of nulling CSF hyperintensity, and the combination of FLAIR and SPIR reduce both orbital fat and CSF hyperintensity. SPIR uses a frequency-specific spectral band of saturation to null fat selectively. Combined with gadolinium it allows assessment of orbital and optic nerve pathology.

Anatomy

The orbital contents are contained within a bony pyramid with the optic foramen at its apex (Fig. 2(a) and (b)). The orbital roof, the floor of the anterior cranial fossa and the frontal sinus are formed by the orbital plate of the frontal bone. The orbital surface of the zygomatic bone and greater wing of the sphenoid constitute the lateral wall. The medial wall is made (from anterior to posterior) from the frontal process of the maxillary bone, the lacrimal bone and the lamina papyracea of the ethmoid bone with a small contribution by the lesser wing of the sphenoid. The floor of the orbit is formed by the orbital surfaces of the zygomatic bone and maxilla and nominally by the palatine bone medially. The zygomatic, frontal and maxillary bones form the orbital margin. Medially the superior orbital rim ends in the spine of the lacrimal bone lying posterior to the infraorbital margin, which ends in the spine of the maxillary bone. The fossa of the lacrimal sac is between these two spines. The lacrimal gland lies in the lacrimal fossa, a recess of the lacrimal sac is between these two spines. The ends in the spine of the maxillary bone. The fossa of the lacrimal bone and the lamina papyracea of the ethmoid bone with a small contribution by the lesser wing of the sphenoid. The floor is formed by the orbital surfaces of the zygomatic bone and maxilla and nominally by the palatine bone medi ally. The zygomatic, frontal and maxillary bones form the orbital margin. Medially the superior orbital rim ends in the spine of the lacrimal bone lying posterior to the infraorbital margin, which ends in the spine of the maxillary bone. The fossa of the lacrimal sac is between these two spines. The lacrimal gland lies in the lacrimal fossa, a recess of the frontal bone anterolaterally in the orbit. For a full discussion of the nasolacrimal apparatus see Russel et al. Superiorly the gland is in contact with peristome and inferiorly it is separated from the lateral rectus and globe by the check ligaments.

The optic foramen is formed by the lesser wing of sphenoid and is separated inferomedially from the superior orbital fissure by the optic strut (Fig. 2). High signal marrow may be seen separating the optic nerve from the oculomotor and other cranial nerves on high resolution T1-weighted MRI of the orbital apex. The superior orbital fissure is limited by the lesser wing of sphenoid superomedially and the greater wing of sphenoid inferolaterally. The fissure provides a large communication between the orbit and the middle cranial fossa via the cavernous sinus. This conduit may transmit tumour and inflammation between the two compartments. The inferior orbital fissure lies between the floor and the greater wing of sphenoid. It communicates with the pterygopalatine fossa and the masticator space (Fig. 3). The two fissures constitute a V-shape with the apex posteriorly within the orbit. The infraorbital groove traverses the orbital floor, ending in the infraorbital canal and foramen. The canal may form more proximally. The infraorbital nerve then becomes vulnerable to damage from sinus surgery or sinus pathology (Fig. 4). Table 3 lists the fissures and foramina associated with the orbit, and the structures they transmit.

Several small foramina may be identified transmitting nerves and vessels from the orbit. Lateral to the superior orbital fissure within the greater wing of sphenoid, the lacrimal foramen or Hyrtl’s canal transmits the lacrimal artery, which arises from the middle meningeal artery in the meningo-lacrimal variant. The meningeal artery then communicates via the superior orbital fissure with the ophthalmic artery via the meningo-ophthalmic artery. This anastomosis, between internal (ICA) and external carotid arteries, may be important in the context of retrograde filling of the ICA via the ophthalmic artery. The zygomatic nerve is a branch of the maxillary nerve within the floor of the orbit, which divides into zygomaticofacial and zygomaticotemporal branches. Both nerves leave the orbit through the zygomatico-orbital foramina on the orbital surface of the zygoma and exit on the external surface through zygomaticofacial and zygomaticotemporal foramina, respectively (Fig. 5(a)). The foramina are occasionally identified on high resolution axial T1-weighted MRI and CT (Fig. 5(b)). The former lies on the anterior surface of the zygomatic bone, and the latter opens into the temporal fossa. Medially the anterior and posterior ethmoidal foramina lie between the frontal bone and the lamina papyracea or within the frontal bone. The ethmoidal nerves and vessels may be seen to leave the orbit through these foramina on high resolution axial and coronal T1-weighted MRI. They are often identifiable on routine axial and coronal sinus imaging (Fig. 6).

There are seven extraocular muscles. The four rectus muscles comprise the muscle cone, the levator palpebrae superioris and the inferior and superior oblique muscles. Normal measurements of extraocular muscles have been described based on the study of a cohort of 100 patients (200 orbits) but are not used in our practice for several reasons. In our experience, morphology is a more important discriminator of abnormality than the muscle size. The measurements need to be made under the precise conditions of the publication (scan thickness and window setting) and vary with age and interzygomatic distance. The extraocular muscles are well demonstrated by axial CT with coronal
reformat and coronal T1-weighted MRI. Contrast administration improves their conspicuity (when combined with fat saturation) as they enhance strongly because of the absence of a blood-tissue barrier, improving SNR. Apart from the inferior oblique muscle, all the muscles arise from a common fibrous ring, the annulus of Zinn, which overlies the optic foramen and the medial end of the superior orbital fissure. The muscle cone divides the orbit into an extraconal, a conal and an intraconal compartment. This has clinical significance in predicting the nature of pathological processes according to their location within the orbit and the tissues that lie within each compartment (See Part 2). The annulus divides the superior orbital fissure into lateral, central and medial sectors. Each sector has predictable contents.6,7

All four rectus muscles insert into the globe behind the limbus or sclerocorneal junction. The superior oblique muscle passes medially along the roof of the orbit to the trochleae, a tendinous sling attached to the orbital roof posterior to the superomedial orbital rim. It then passes postero-laterally between the superior rectus and globe.
where it inserts into the sclera in the middle of the globe. The inferior oblique arises from the medial orbital floor lateral to the lacrimal sac, passing posterolaterally beneath the inferior rectus and between the lateral rectus and globe to insert into the sclera adjacent to the superior oblique. The levator palpebrae superioris is not always identified discretely from the superior rectus on conventional imaging and the two muscles are often referred to as the superior muscle complex. A sagittal T1 SE with 512 matrix elegantly separates the two muscles (Fig. 7).

The trochlear nerve (IV) and two branches (frontal and lacrimal) of the ophthalmic division of the trigeminal nerve (V1) pass through the lateral sector of the superior orbital fissure together with the superior ophthalmic vein. The remaining structures entering the orbit through the superior orbital fissure pass through the annulus of Zinn.\(^8\) The optic nerve sheath complex is formed by the optic nerve and the dural and leptomeningeal coverings. The individual components are not separated on CT, but MRI distinguishes the optic nerve, the dura and the subarachnoid space on T2-weighted and Gd-enhanced T1-weighted MRI. The intracanalicular portion of the optic nerve enters the orbit through the optic foramen with the ophthalmic artery lying inferiorly. Superiorly within the optic canal the

Figure 3  Axial 1 mm CT through inferior orbital fissure. The fissure is bounded laterally by the greater wing of the sphenoid (black arrow) and medially by the orbital plate of the ethmoid bone. It opens into the pterygomaxillary fissure (white asterisk) and thence into the pterygopalatine fossa (white open arrow). Further communication through these spaces is possible through the vidian canal (black arrowheads), sphenopalatine foramen (white O) and masticator space (white arrow).

Figure 4  Sagittal T1-weighted MR image through the orbit and maxillary sinus. The infraorbital nerve sometimes leaves the orbital floor halfway along its course and then runs through the middle of the sinus (white arrows). This should always be mentioned, as these individuals are at risk of having their nerve damaged when future sinus surgery is required.

Figure 5  (a) Axial 1 mm CT section displayed as bone windows through the orbital floor. A linear lucency is present corresponding to the path of the zygomatico-facial nerve through the zygomatic bone (black arrow). (b) Axial T1-weighted MR image showing the zygomatico-facial branch (black arrowhead) medial to the zygomatico-facial canal (white arrow).
leptomeninges, dura, periosteum and optic nerve are fused, fixing the nerve and its coverings. The orbital portion is tortuous and it may not be possible to visualize it in a single axial plane. It runs forward approximately 10 degrees inferior to the orbitomeatal plane: the neuro-ocular plane. Para-axial imaging should be planned off a sagittal localizer to achieve the correct plane as discussed under technique.

The contents of the middle sector of the superior orbital fissure are the oculomotor and abducens nerves and the nasociliary division of V1 together with their parasympathetic and sympathetic contributions. The optic nerve and ophthalmic artery lie medially. The oculomotor nerve (III) divides into superior and inferior divisions within the superior orbital fissure. The superior division supplies the superior rectus and levator palpebrae superioris, lying deep to their respective muscles. The inferior division has three branches supplying the medial and inferior rectus and the inferior oblique. The medial division of the inferior branch crosses below the optic nerve at the same level as that at which the ophthalmic artery and nasociliary nerve cross above. A motor root contributes the parasympathetic supply to the ciliary ganglion. The individual nerves are often identified deep to their respective muscles on high-resolution T1-weighted imaging (Fig. 8).

The ophthalmic division of the trigeminal nerve divides into three branches (frontal, lacrimal and nasociliary) within the distal cavernous sinus before entering the orbit. The branches are sensory with sympathetic supply accompanying the sensory

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Figure 6 Coronal T1-weighted image through the posterior globes. A branch of the infratrochlear artery and nasociliary nerve (black arrow) lies above the medial rectus (m). A branch extends into the ethmoidal foramen on the right consistent with the anterior ethmoidal nerve/artery (white arrow). The supraorbital nerve (white arrowhead) lies between the superior muscle complex (smc) and the periorbita. The lacrimal nerve and artery are seen superiorlaterally (black asterisk). Lateral (1), inferior (i) rectus, superior (so) and inferior oblique (io) muscles are annotated.

Figure 7 Sagittal T1-weighted image through the orbit showing the supraorbital nerve, a branch of the frontal nerve (white arrow) between the orbital roof and the levator palpebrae superioris muscle (black arrow). Black arrowhead superior rectus muscle; white arrowheads infraorbital nerve in the downslping infraorbital canal.
branch of the nasociliary nerve to the ciliary ganglion or the ophthalmic artery. The frontal branches, the supraorbital and supratrochlear nerves pass between the periosteum of the orbital roof (periorbita) and the superior muscle complex (Figs. 6, 8 and 9). The supraorbital nerve lies above the levator muscle together with the supratrochlear artery and nerve (branch of nasociliary nerve) lie above the medial rectus. The optic nerve (ON) is visible surrounded by the subarachnoid space and optic nerve sheath. The superior ophthalmic vein is indicated (white asterisk).

Figure 8  Coronal T1-weighted image through the mid-orbit. The inferior and medial divisions of the oculomotor nerve are seen deep to their respective rectus muscles (white arrows). The IV nerve lies deep to the superior oblique muscle (long white arrow). The infratrochlear artery and nerve (branch of nasociliary nerve) lie above the medial rectus. The optic nerve (ON) is visible surrounded by the subarachnoid space and optic nerve sheath. The superior ophthalmic vein is indicated (white asterisk).

branch of the nasociliary nerve to the ciliary ganglion together with the supratrochlear artery and has similar, although lesser, cutaneous sensory supply. The lacrimal nerve occupies the most lateral position within the lateral superior orbital fissure and passes laterally to lie above the lateral rectus muscle, below the lacrimal gland (which it supplies), supplying the skin over the lateral half of the upper eyelid (Fig. 6). The nasociliary nerve initially lies lateral to the optic nerve and crosses above it to reach the superior surface of the medial rectus, where it can be seen on coronal high resolution T1 weighted MRI (Figs. 6 and 8). There are five branches: (1) the infratrochlear branch, which is sensory to the skin of the root of the nose and upper eyelid; (2) the anterior ethmoidal nerve supplying the mucosa of the nasal septum, lateral nasal wall and the skin over the dorsum of the nose and vestibule; (3) the posterior ethmoidal nerve supplying the mucosa of the sphenoid and posterior ethmoid air cells (imaging can identify the ethmoidal foramina, but cannot resolve both the artery and nerve); (4) the long ciliary nerve, sensory to the globe; and (5) the sensory root to the ciliary ganglion; (4) and (5) are not identifiable with current imaging.

The trochlear nerve (IV) lies above the oculomotor nerve in the orbital apex. It enters the orbit lateral to the annulus of Zinn above the frontal division of V1, runs medially between the superior muscle complex and the orbital periosteum and then along the superior oblique muscle, which it supplies. The latter portion of the trochlear nerve may be identified on coronal T1-weighted MRI (Fig. 8).

The abducens nerve (VI) lies above and medial to the nasociliary nerve. It may be visible along the deep surface of the lateral rectus muscle, which it supplies.

The ciliary ganglion lies between the optic nerve and the lateral rectus muscle, usually lateral to the ophthalmic artery. It receives a sensory branch from the nasociliary branch of the ophthalmic division of the trigeminal nerve, parasympathetic (motor) innervation from the inferior division of the oculomotor nerve and sympathetic innervation from the plexus accompanying the internal carotid artery. It gives off short ciliary branches which accompany the optic nerve, pierce the sclera and supply the ciliary muscles and sphincter of the eye.

The ophthalmic artery lies inferolateral to the intracanalicular optic nerve within the dural sheath. It leaves the dura inferiorly, crossing perpendicularly above the optic nerve from lateral to medial sides. In 15% of cases, the artery may run below the nerve: multiple variations of arterial morphology are possible due to the existence of a

Figure 9  Axial T1-weighted image above the level of the superior muscle complex. The lacrimal artery and nerve course laterally (black arrowheads) within the fat above the lateral rectus muscle (not seen). Similarly, the supraorbital artery (white arrow) and frontal nerve (white arrowheads) is seen above the superior muscle complex (smc).
dorsal and ventral ophthalmic artery embryological supply, which is beyond the scope of this discussion. In contrast, the ophthalmic vein crosses with lesser (20°) obliquity, enabling the distinction from the ophthalmic artery (Fig. 10). The central retinal artery arises from the ophthalmic artery as it winds around the nerve and runs centrally within the optic nerve. The branches of the ophthalmic artery follow those of the nerves and include: ciliary, supraorbital, supratrochlear, infratrochlear, anterior and posterior ethmoidal, and lacrimal arteries (Figs. 6, 9 and 10).

The ophthalmic veins have a superior and inferior division that are connected along the anterior orbital margin by the angular and facial veins. They usually unite within the orbital apex before leaving through the superior and inferior orbital fissures, respectively. The superior vein is larger and more consistently visualized on both coronal and axial imaging. It lies lateral to the superior oblique muscle anteriorly, passing backwards over the optic nerve and beneath the superior muscle complex where it can be seen on coronal imaging (Figs. 8 and 10). It receives supply from the facial vein and drains via the lateral portion of the superior orbital fissures into the cavernous sinus, providing an important route for propagation of thrombosis from the face in the context of orbital cellulitis or facial infection. The inferior ophthalmic vein lies on the orbital floor between the lateral and inferior rectus muscles. It communicates through the inferior orbital fissure with the pterygoid venous plexus and the pterygopalatine fossa. In the presence of carotico-cavernous fistula, these anastomoses are easily identifiable (Fig. 11).

**Conclusion**

We have provided our protocol for standard orbital imaging for CT and MRI and reviewed the radiological anatomy of the orbit, with an emphasis on structures that are detectable with current imaging techniques. We have discussed modern imaging techniques such as SENSE and CLEAR that enable the demonstration of small intraorbital structures with high spatial resolution using synergy surface coils. An understanding of normal anatomy will allow a better appreciation of proximity of normal structures to pathological processes and explain the spread of diseases (infection and neoplasia) beyond the orbit through the various foramina and spaces described. A good understanding will facilitate the compartmental approach to orbital pathology reviewed in part 2 of this review.

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**References**

1. Zonneveld FW, Koorneef L, Hillen B, de Siegtes RGM. Normal


