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

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CHAPTER 4

HIGH-RESOLUTION MAGNETIC RESONANCE IMAGING OF THE ORBITAL CONNECTIVE TISSUE SYSTEM

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INTRODUCTION

The complex architecture of the orbital connective tissue system (OCTS) was first described by Koornneef in 1987.¹ The OCTS not only checks the action of the extraocular muscles but also stabilizes their path in the orbit. It is therefore responsible for the stability against sideways displacement of the extraocular muscles during eye movements.³ Knowledge of the OCTS has explained the pathophysiologic characteristics of motility disturbances after orbital fractures and also some features of Graves ophthalmopathy.⁴ Inflammatory orbital pseudotumor, the septa of the OCTS are thickened and become confluent causing severe motility disturbances.⁹ Compared with computed tomography, orbital magnetic resonance imaging (MRI) provides a better soft-tissue contrast resolution and is capable of multiplanar imaging.¹⁰ Because of the lack of ionizing irradiation, high-resolution MRI is a useful tool for functional-anatomical studies in vivo.¹¹ Recent MRI studies confirmed that the course of the recti muscles in the orbit is not straight, but curved.¹² This was attributed to pulley-like structures of the OCTS. The anatomical substrate of the rectus muscle pulleys were found to be sleeves in Tenon capsule that are attached to the orbital walls by means of connective tissue septa containing smooth muscle cells. These fibromuscular rectus muscle pulleys, which are nearly symmetrically arranged, are thought to be the biomechanical basis of Listing’s law.¹³ Knowledge of the normal anatomy of the orbit in MR images is a prerequisite for the analysis of clinical findings. Although a number of publications provide information on the MR imaging anatomy of the orbit¹⁴,¹⁵, details of the OCTS have not previously been described in MR images. In this study, the MRI anatomy of the septa of the OCTS is described. We do not focus on imaging details of neurovascular orbital anatomy because this has recently been described in another study.¹⁷

MATERIAL AND METHODS

Five volunteers, aged 26 to 35 years were examined after informed consent had been obtained (n = 5 orbits). Magnetic resonance imaging of the orbit was performed on a 1 Tesla scanner (Impact, Siemens, Germany) using a surface coil with a diameter of 10 cm. T1-weighted images of the orbit were obtained using spin-echo sequences with an echo time of 15 ms and a repetition time of 440 milliseconds to 520 milliseconds. Contiguous 3 mm slices in the coronal plane were obtained. The field of view in the original images was 140 mm x 140 mm with a 256 x 256 matrix resulting in a pixel size and theoretical spatial resolution of 0.5 mm. The acquisition time was 2 minutes per sequence. The images were taken with closed lids.
The structures in the MR images were identified by comparison with the collection of histologic sections of the orbit from Koornneef which includes hematoxylin-azophloxin-stained 60-µm thin sections and 5-mm-thick cleared sections in the frontal plane.

RESULTS

Bulbar part of the orbit

The aponeurosis of the levator palpebrae superioris muscle and its connections to the trochlea and the lacrimal gland in the region of the superior transverse ligament (Whitnall) are visible. The levator aponeurosis divides the lacrimal gland in an orbital and a palpebral portion. Tenon capsule surrounds the globe and intermuscular septa connect the straight eye muscles. The arcuate expansion of Lockwood ligament toward the lateral orbital floor is clearly visualized (Fig. 1). The "transverse intermuscular ligament" or "inferior portion of Whitnall's ligament" is noted between the superior rectus muscle (SRM) and the levator palpebrae superioris (Fig. 2). The medial and the lateral check-ligaments connect the horizontal recti muscles to the periorbit (Fig. 1-3). Radially orientated septa running towards the periorbit are mainly concentrated at the recti muscles. The lateral border of the superior muscle complex (SRM, levator palpebrae superioris) is suspended to the lateral orbital roof by a septum. Another septum courses from the upper border of the medial rectus muscle toward the medial orbital roof (Fig. 3-5). Posterior to the equator, intermuscular septa are seen between the medial rectus muscle, the inferior rectus muscle and the superior muscle complex (SRM, levator palpebrae superioris). However, a continuous intermuscular membrane connecting all recti muscles is not seen. Around the equator, the intermuscular septum (superolateral intermuscular septum) between the superior muscle complex and the lateral rectus muscle has a similar cross-sectional thickness and signal intensity as the extraocular muscles (Fig. 3). Around the inferior rectus muscle, the septa are orientated parallel to the orbital floor. Branches of the inferior ophthalmic vein are incorporated in these septa. Radial septa connect the inferior rectus muscle with Müller orbital muscle which bridges the inferior orbital fissure (Fig. 3-5).

Retrobulbar part of the orbit

Circular intermuscular septa are not visible in the retrobulbar orbit apart from the superolateral septum. In the midorbit, delicate radial septa pass from the optic nerve toward the medial, lateral and inferior rectus muscles (Fig. 6). Radial septa also connect the margins of the recti muscles, especially the lateral rectus muscle and the SRM to the periorbit. A short radial septum suspends the lateral border of the superior muscle complex to the orbital roof. Other radial septa connect the lateral border of the inferior rectus muscle with Müller orbital muscle. Serial coronal slices show that the superior ophthalmic vein traverses the orbit along a connective tissue septum, called the superior ophthalmic vein hammock, which courses from the superolateral intermuscular septum closely inferior to the SRM toward the supero-medial orbital wall. The superolateral intermuscular septum, which is much thinner in the posterior orbit, blends with the superior ophthalmic vein hammock (Fig. 6).

DISCUSSION

This study demonstrates that surface coil MRI on a clinical MR unit is capable of imaging details of the orbital connective tissue system. The best anatomical detail is obtained by use of T1-weighted pulse sequences. T2-weighted and proton density images were not applied because of a longer acquisition time, which leads to motion artifacts resulting in a poorer image quality. The bright background of the orbital fat on T1-weighted MR images accounts for the excellent soft tissue contrast in the orbit, thus providing visualization of several delicate connective tissue structures that appear hypointense compared with orbital fat. Muscles and major blood vessels are mostly darker than connective tissue septa. Partial volume averaging can lead to errors in the interpretation of structures in MR images. To minimize these mistakes, series of adjacent imaging slices were analysed.

The relations between the vascular and the connective tissue system of the orbit are different for arteries and veins. The orbital arteries which form a radiating system diverging from the orbital apex, traverse through the adipose tissue compartments and perforate the orbital septa. In contrast, the veins are arranged in a ring-like system that reflects their incorporation into the fibrous septa of the orbital connective tissue system. The superior ophthalmic vein traverses the orbit inside the "superior ophthalmic vein hammock," a connective tissue septum that is located just inferior to the superior rectus muscle. Therefore a swollen, inflamed superior rectus muscle may cause venous outflow obstruction. This has been suggested to be the cause of orbital soft-tissue swelling in patients with Graves disease in whom the proptosis is out of proportion to the enlargement of the muscles. Intermuscular septa, especially the superolateral intermuscular septum ("tensor intermuscularis muscle") are visualized on appropriate MR images. Because of the high content of smooth muscle fibres, the superolateral septum showed a similar signal intensity on MRI as the extraocular muscles. The thickness of the tensor intermuscularis has been found to be enlarged in Graves disease.
Fig. 1. Coronal T1-weighted MRI at the level of the trochlea (white arrow; slice position 3-6 mm anterior to the equator of the globe). See appendix for explanation of numbers. Modified and reprinted with permission from Ettl et al.17.

Fig. 2. Coronal T1-weighted MRI at the level of the trochlea (white arrow) and the equator of the globe. See appendix for explanation of numbers. Modified and reprinted with permission from Ettl et al.17 and Ettl et al.20.

Fig. 3. Coronal T1-weighted MRI (slice position 3-6 mm posterior to the equator of the globe). See appendix for explanation of numbers.

Fig. 4. Coronal T1-weighted MRI (slice position 6-9 mm posterior to the equator of the globe). Arrows: septa. See appendix for explanation of numbers. Modified and reprinted with permission from Ettl et al.17.

Fig. 5. Coronal T1-weighted MRI at the level of the posterior pole of globe and optic nerve head (slice position 9-12 mm posterior to the equator). See appendix for explanation of numbers. Arrows: septa. Modified and reprinted with permission from Ettl et al.17.

Fig. 6. Coronal T1-weighted MRI at the level of the optic nerve (slice position 3-6 mm posterior to the hind surface of the globe). See appendix for explanation of numbers. Arrows: septa. Modified and reprinted with permission from Ettl et al.17.
In the past, the existence of a common intermuscular membrane that connects all four recti muscles and divides the orbit into an extra- and an intraconal space has been suggested. However, Koornneef's histological studies did not support this concept of a closed intraconal space and the present MRI study confirmed these findings in vivo. The use of surface-coil technology for orbital MRI allows high-resolution imaging by increasing the signal-to-noise ratio. However, a surface coil is more sensitive to motion artifacts which can represent a considerable problem in orbital MRI. Therefore, high-resolution orbital MRI is currently restricted to cooperative patients who are able to keep their head and eyes still for up to 2 minutes.

In conclusion, this study has demonstrated that major parts of the OCTS can be visualized using high-resolution MRI. A potential clinical application may be its use for the evaluation of restrictive motility disorders such as in Graves disease, ocular fibrosis syndrome, or posttraumatic adhesions of the eye muscles. However, in cases of acute orbital fractures, MRI should not be used because of lack of depiction of bony details. Koornneef suggested that the OCTS may be an important additional locomotor system enabling coordinated movements of eye muscles, globe, optic nerve, and eyelids. Anatomical postmortem studies, however, are of limited value to investigate the role of the OCTS for ocular motility. Here, dynamic high-resolution MRI in vivo could be helpful for improved understanding the mechanical role of the OCTS during ocular movements.

APPENDIX

The following is an explanation of the numbers in the figures.

1. Levator palpebrae superioris muscle
2. Superior rectus muscle
3. Inferior rectus muscle
4. Medial rectus muscle
5. Lateral rectus muscle
6. Superior oblique muscle
7. Superior oblique tendon
8. Inferior oblique muscle
9. Ophthalmic artery
10. Posterior ciliary artery
11. Superior ophthalmic vein
12. Inferior ophthalmic vein
13. Oculomotor nerve (inferior division)
14. Frontal nerve
15. Supraorbital nerve
16. Supratrochlear nerve/artery/vein
17. Infraorbital nerve, dorsal nasal artery/vein
18. Nasociliary nerve
19. Medial check ligament
20. Lateral check ligament
21. Levator aponeurosis
22. Transverse intermuscular ligament/common sheath
23. Anterior Tenon capsule and intermuscular septa
24. Arcuate expansion of Lockwood ligament
25. Suprolateral intermuscular septum (tensor intermuscularis)
26. Superior ophthalmic vein hammock
27. Müllèr orbital muscle
28. Lacrimal gland
REFERENCES
