High resolution magnetic resonance imaging anatomy of the orbit
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INTRODUCTION

The preservation of the suspensory connective tissue system of the levator palpebrae superioris muscle (LPS) is regarded to be an important principle in ptosis surgery. According to the literature, the superior transverse ligament (STL) represents the main part of the suspensory system of the LPS.

The superior transverse ligament (Whitnall), is a condensation of the fascial sheath of the LPS on its superior surface which extends from the connective tissue complex of the trochlea medially, to the capsule of the orbital lobe of the lacrimal gland and the orbital wall laterally. The STL has also bilateral connections to the horns of the aponeurosis. The STL is largely located in the transitional zone between muscular levator and the aponeurosis. In some patients with congenital and involutional ptosis, the STL has been observed to be atrophic or dehiscent. It has been suggested that these cases may benefit from repair of Whitnall’s ligament in addition to conventional ptosis surgery.

The function of the STL has been controversially discussed: Whitnall stated that the STL would act as a check ligament of the LPS. However, Lemke et al. noted that the ligament is not under tension during lid closure and Dutton believes that the check function of the STL is not significant under physiological conditions. Anderson and Dixon mentioned that larger amounts of levator resections are required if Whitnall’s ligament is severed and therefore recommended its preservation during ptosis surgery. They suggested that the superior transverse ligament would act as a fulcrum which translates the anteroposterior force of the LPS into a vertical upward motion of the eyelid. Boergen and Scherz, who cut Whitnall’s ligament during large levator resections, stated that „negative consequences” were not observed following this procedure.

The so-called „common sheath” is the intermuscular fascia between the LPS and the SRM. Fink has called its anterior part the „transverse superior fascial expansion (TSFE) of the levator and superior rectus muscles”. Whitnall, Jones, and Dutton briefly mentioned the relation between the STL and the common intermuscular fascia.

The architecture of the connective tissue system of the orbit contributes to the course of the extraocular muscles and therefore may have important functional implications. The present study was undertaken to investigate the course of the LPS muscle and its relationship to the connective tissue system of the superior orbit.

For this purpose, high resolution magnetic resonance imaging (MRI) was performed in vivo in addition to anatomical and histological studies. A series of photographs of macroscopic dissections is shown in order to illustrate the morphological relations for the eyelid surgeon.
MATERIAL AND METHODS

Macroscopic anatomical dissections were performed in 16 orbits from eight unfixed cadavers (age range 40-85 years) via a transconjunctival or a combined transcruceanous and transcranial approach.

En-bloc excised and formalin fixed orbits from six cadavers (age range 26-73 years) which had been decalcified with ethylenediamine tetra-acetic acid, embedded in celloidin, serially sectioned (60 μm) in the frontal plane (n = 3 orbits) and in the sagittal plane (n = 3 orbits), and stained with haematoxylin and azophloxin were analysed microscopically.

MRI of the orbit was performed in five volunteers (age range 29-54 years), after consent had been obtained, on a 1 Tesla scanner (Impact, Siemens, Germany) using a surface coil with a diameter of 10 cm. Oblique sagittal (sections parallel to the optic nerve) and coronal (sections in the frontal plane) T1 weighted images of the orbit were obtained by spin echo sequences with an echo time (TE) of 15 ms and a repetition time (TR) of 440-520 ms. The slice thickness was 2-3 mm and there was no gap between slices. The field of view in the original images ranged between 140 x 140 mm with a 256 x 256 matrix and 230 x 230 mm with a 512 x 512 matrix. The acquisition time was between 2 and 13 minutes. Images were taken with both eyes closed (resting position in slight downgaze).

RESULTS

Anatomy

The STL and the TSFE unite at the medial and lateral margins of the LPS just proximal to the musculotendinous junction thus completely surrounding the LPS muscle (Fig. 1). This fascial sleeve has attachments to the orbital walls medially and laterally: Medially, it joins the connective tissue of the trochlea and superior oblique muscle tendon (Fig. 1). There are also extensions to the medial levator horn, the medial palpebral ligament, and check ligament of the medial rectus muscle. Laterally, there are weak attachments to the superolateral periorbit via the fascia of the lacrimal gland (Fig. 2). More firm extensions insert into the lateral retinacular complex which includes the lateral palpebral ligament, the lateral check ligament, and the adjacent periorbit. The medial attachment of the fascial sleeve of the LPS is much thicker than the lateral attachment. Thin connective tissue septa pass in a more or less radial orientation from the STL through the preaponeurotic fat pad to the periorbit of the orbital roof and margin (Fig. 3). The STL is connected to the LPS with stronger attachments at the medial and lateral borders of the muscle. Loose connective tissue connects the TSFE with the overlying LPS and the underlying SRM. Firm connections exist between the LPS and the SRM at their margins (Fig. 4). The TSFE extends from the fascia of the lacrimal gland (Fig. 2) towards the connective tissue of the superior oblique tendon and the trochlea (Fig. 5). It starts at a level below the STL and extends posteriorly for about 10 mm. The TSFE sends delicate connective tissue fibers into the superior fornice, previously described as the suspensory ligament of the superior fornice (Fig. 4).

If the LPS is reflected and the TSFE is carefully incised, the bare surface of the SRM and the sclera is exposed indicating that the TSFE represents a condensation of Tenon's capsule which blends with the fascial sheath of the muscles in this area (Fig. 6).

Histological sections in the frontal plane (Fig. 7) confirm that the STL and the TSFE unite at the medial and lateral borders of the LPS and extend further laterally to the capsule of the lacrimal gland and medially to the connective tissue of the trochlea. The TSFE blends with Tenon's capsule. Fibres from the TSFE course inferiorly to insert into the connective tissue of the medial and lateral rectus muscle. Posterior to the equator of the globe, the common sheath blends with the superolateral intermuscular septum and with Tenon's capsule medially. Throughout the length of the entire orbit, a network of radial septa connects the fascial sheath of the LPS with the periorbit of the orbital roof. Radial septa are also abundant in the region of the STL. The TSFE is considerably thicker than the STL. Sagittal sections demonstrated that the thickness of the fascia between the LPS and the SRM (common sheath) is continuously increasing from the posterior orbit towards the anterior orbit until it reaches its greatest thickness of about 2-3 mm in the area of the TSFE. Small amounts of adipose tissue are also noted in the space between the LPS and the SRM.

Magnetic resonance imaging

On sagittal images (Fig. 8), the LPS courses upwards from its origin until it reaches a culmination point (most cranial point) from where it courses downwards to the insertion in the upper lid. In resting position (closed lids, eye in slight down gaze), the culmination point is 14-16 mm posterior to the superior orbital margin and 5-7 mm posterior to the equator of the globe (horizontal distances). The culmination point is located 9-11 mm superior to the annulus tendineus and 4-5 mm superior to the globe (vertical distances). The length of the levator aponeurosis between the upper tarsal border and the culmination point measures 22-25 mm. The length of the LPS between its origin and the culmination point measures 36-40 mm. Fine septa are visualized between the upper part of the aponeurosis and the supraorbital margin. The intermuscular space between the anterior third of the SRM and the segment of the LPS, where it changes its course from upwards to downwards, is isointense to orbital fat but also contains hypointense structures corresponding to parts of the TSFE and common sheath respectively.

On coronal slices through the equator of the globe, the TSFE is noted between SRM and LPS. The medial and
Fig. 1. Anterior approach dissection (right upper lid). Following a lid crease incision, the levator palpebrae superioris (LPS) (1) has been cut anteriorly and pulled forwards. The superior transverse ligament (STL) (2) and the transverse superior fascial expansion (TSFE) (3) surround the LPS to form a fascial sleeve around the muscle. The superior rectus muscle (SRM) tendon (4) is under the TSFE. Medially, Whitnall’s ligament inserts into the connective tissue complex (5) of the superior oblique tendon (6) and the trochlea.

Fig. 2. Posterior approach dissection (right upper lid): Following a conjunctival incision, the LPS (1) has been cut anteriorly and pulled upwards. Laterally the STL (2) and the TSFE (3) extend to the capsule of the lacrimal gland (5). SRM insertion (4).

Fig. 3. Posterior approach dissection (right upper lid): The orbital septum (6) has been reflected upwards and the levator muscle (1) has been pulled forwards. The preaponeurotic fat pad (7) has been elevated to show the radial septa (8) running from the STL (2) through the fat pad towards the orbital roof.

Fig. 4. Posterior approach dissection (right upper lid): TSFE (3) between the LPS (1) and the SRM (4): The medial connections between SRM and LPS are thicker than the lateral connections. The suspensory ligament of the superior fornix (9) can be traced from the TSFE towards the conjunctival fornix (10) which is outlined with a piece of paper.

Fig. 5. Posterior approach dissection (right upper lid): The connections between LPS (1) and SRM have been dissected off and the LPS has been reflected upwards to show the TSFE (3) extending from the lacrimal gland (not visible) towards the connective tissue complex (11) of the superior oblique tendon and the trochlea. Tenon’s capsule (12) is overlying the insertion of the SRM.

Fig. 6. Posterior approach dissection (right upper lid): The TSFE (3) has been incised horizontally and reflected upwards: The reflected part of the superior oblique tendon (13), the SRM (4) and the bare surface of the sclera (14) are now exposed. No distinct separation between the TSFE and Tenon’s capsule is found.
lateral main attachments of Whitnall's ligament are visualized extending from the trochlea to the lacrimal gland and the lateral orbital wall (Fig. 9).

**DISCUSSION**

**Anatomy**

The STL and the TSFE, form a fascial sleeve around the LPS which is attached to the medial and lateral orbital wall like an arc (Fig. 10). Since the TSFE is connected to the STL and appears as a firm band-like structure, it has been referred to as the "lower part of Whitnall's ligament" as opposed to the "upper part of Whitnall’s ligament" representing the STL (Priglinger S et al, Anatomie des Lig Whitnall und des oberen Muskelnbindewebssapparates der Orbita. Presented in 1991 at the 25th Strabismus Symposium of the Austrian Ophthalmological Society in St. Poelten, Austria). Lukas et al confirmed that the connective tissue underlying the anterior portion of the LPS has the characteristic anatomical and histological features of a ligament and proposed the name "intermuscular transverse ligament" (ligamentum transversum intermusculare). The attachments of Whitnall's ligament to the orbital wall and the interconnecting fibers between the TSFE and the LPS are more strongly developed medially than laterally whereas the lateral horn of the aponeurosis is much stronger than the more elastic medial horn. Coronal MRI scans confirm these findings. This configuration may contribute to the normal lid contour which has its peak slightly medial to the centre of the pupil.

The LPS can glide within the sling formed by Whitnall's ligament only to a small extent, due to fibroelastic connections between muscle and ligament. Therefore, the ligament must follow the excursions of the LPS which was concluded from a previous MRI study.

The connection between the LPS and the SRM by the common sheath and the common innervation by the superior branch of the third cranial nerve are responsible for the coordinated movement of the LPS and the SRM during vertical saccades. Therefore, contraction of the SRM accounts for up to 2 mm of the entire upper lid elevation. The STL could not be identified with certainty in our MR-images owing to its thinness and the isointensity to aponeurotic tissue. The TSFE is located in the intermuscular space between the anterior third of the SRM and the segment of the LPS where it changes its course from upwards to downwards. This space is largely isointense to orbital fat on
Fig. 9. Coronal MRI scan of a left orbit at the level of the trochlea: The connections between the aponeurosis (1) and the SRM (4) belong to the TSFE (3). Extensions of Whitnall’s ligament to the trochlea (11), to the check ligament of the medial rectus muscle (19) and to the lateral orbital wall under the orbital lobe of the lacrimal gland (5) are visible. Lateral expansions of the common sheath which blends with Tenon’s capsule can be traced to the connective tissue of the lateral rectus muscle (18). Inferior rectus muscle (21), inferior oblique muscle (22).

MRI which is due to fatty infiltration of the connective tissue in this compartment. The function of this adipose tissue might be the reduction of friction between the LPS and the underlying SMR and the globe.

Functional considerations

Lid elevation

Anderson and Dixon and Goldberg et al. suggested that the STL would act as a fulcrum or suspender for the LPS. However, our MR images demonstrate that the STL alone may not be able to act as a suspensory ligament of the LPS muscle for the following reasons:

1. The culmination point of the LPS is situated slightly posterior and superior to the location of the STL. This has recently been demonstrated using high resolution MRI in cadaver specimen where the STL had been marked with synthetic material. The culmination point of the LPS is not exactly overlaying the equator of the globe and the LPS does not follow the shortest path from the origin to the insertion as often depicted in anatomical text books. Such a course would be expected if the globe alone provided the fulcrum for the LPS as suggested by Vistnes and Lemke et al. After removal of the eye, a downwards displacement of the superior muscle complex has been described as part of the post enucleation socket syndrome. This suggests that the globe obviously prevents a partial collapse of the ocular motion compartment by providing additional support for the TSFE and the LPS.

2. The culmination point of the LPS is located superior to the posterior part of the TSFE (Fig. 8) suggesting additional suspensory structures in the retroequatorial part of the orbit.

3. The superomedial and the superolateral main attachments of Whitnall’s ligament are located slightly inferior to the level of the LPS (Fig. 9). Therefore, we argue that the suspension of the LPS muscle may actually be achieved by the radial septal system which connects the fascial sheath of the LPS muscle with the superior periorbit. Whitnall’s ligament itself is suspended from the orbital roof by means of vertical septa and connective tissue strands coursing to the supraorbital notch. Behind the globe, further support for the LPS/SRM complex is provided by hammock-like septa which are anchored to the superior periorbit at the margins of the muscles. The architecture of the connective tissue in the superior orbit could explain the remarkable course of the LPS on sagittal MRI scans: the muscle is ascending from the lesser wing of the sphenoid to a culmination point several millimeters behind the equator and above the globe from where the aponeurosis is descending to the insertion in the eyelid (Fig. 8). The deflection of the LPS leads to a lengthening of the muscle path which may increase the muscle tension due to increased stretch of the muscle. This function is comparable with the rectus muscle pulleys consisting of sleeves in Tenon’s capsule which are coupled to the orbital walls by connective tissue septa.

Fig. 10. Diagrammatic representation of the connective tissue system in the anterior orbit illustrating that Whitnall’s ligament (2, 3) completely surrounds the LPS muscle (1). The nomenclature is explained in the legend to Fig. 9. Medial check ligament (23). (Schematic synthesis of two frontal sections through the trochlea and just posterior to the trochlea)
Lid lowering

We have demonstrated that the TSFE blends with Tenon's capsule. The connections of Whitnall's ligament with tissue structures containing elastic fibers or smooth muscle fibres such as Tenon's capsule, intermuscular septum, radial septa and aponeurosis are responsible for the relatively high elasticity of the upper lid. Furthermore, both parts of Whitnall's ligament contain elastic fibres which are especially abundant in the connections between the STL and the LPS muscle and the TSFE and the SRM allowing for a small amount of movement of the LPS in the sling formed by Whitnall's ligament.2 Loss of elasticity of the suspensory connective tissue system of the eyelid explains the lid lag observed following levator resections and in patients suffering from Graves' disease. The above described fibroelastic attachments may prevent abrupt stops of the lid movements at extreme upgaze and downgaze. In downgaze, the central portion of Whitnall's ligament moves further anteriorly than the medial and lateral attachments producing a bow-shaped configuration of both parts of the stretched ligament so that its convexity is anteriorly directed. Whitnall's ligament may therefore suspend the upper eyelid (but not the LPS muscle) in downgaze.

Based on electromyography and the magnetic search coil technique, it has been suggested that the elastic forces of the eyelid connective tissue system are responsible for the motion pattern of the lid during downward saccades. According to this hypothesis, the LPS must stretch the "connective tissue spring" when elevating the eyelid. Relaxation of the LPS releases the energy stored in the stretched connective tissue and causes a rapid lowering of the eyelid. The present study has described some morphological and radiological details regarding the LPS muscle and its connective tissue system. Similar morphological findings were published by other authors after submission of our study. Further biomechanical considerations and surgical applications are the subject of our ongoing research.

REFERENCES