High resolution magnetic resonance imaging anatomy of the orbit
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CHAPTER 7

IS WHITNALL’S LIGAMENT RESPONSIBLE FOR THE CURVED COURSE OF THE LEVATOR PALPEBRAE SUPERIORIS MUSCLE?

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INTRODUCTION

Whitnall’s superior transverse ligament (STL) which represents a thickening of the sheath of the levator palpebrae superioris (LPS) on its superior surface, extends from the trochlea to the lateral orbital wall. Similar to the extraocular rectus muscles, the LPS also courses in a curved path and culminates a few millimeters cranial to the surface of the globe (Fig. 1).

The function of the STL is still unclear. Anderson et al. suggested that the STL acts as a fulcrum redirecting the force of the LPS. They believe that a larger amount of surgical levator resection is needed, if the STL is cut and therefore emphasized the importance of preserving the STL. Goldberg et al. concluded that the curved course ("tenting") of the LPS must be a consequence of the force-vector changing action of the STL. In their opinion, the STL represents a mobile pulley which moves posteriorly on up-gaze and anteriorly on down-gaze. However, the STL was not directly visualized in Goldberg’s MRI study.

In contrast to that, other authors suggested that the globe provides the fulcrum for the LPS, a hypothesis which seems to be supported by findings of Smit et al. who described a downwards-displacement of the LPS following enucleations. However, the following observations argue against this hypothesis: The culmination of the LPS is located a few millimeters superior and posterior to the superior pole of the globe and the culmination is hardly displaced anteriorly in the presence of exophthalmus (see Fig. 7.5, 7.7 in Zonneveld). The present study was undertaken to determine whether the location of the STL enables a suspension of the LPS muscle from a mechanical point of view. A suspensory function of the STL would only be possible if it was located near the culmination of the LPS and was attached to the periorbit at the same level as the culmination point or superior to it.

Fig. 1. Oblique-sagittal cryosection (20µm) of the orbit showing the characteristic course of the LPS and the intermuscular space (arrow) between the LPS (1) and the superior rectus muscle (2) which is filled with adipose tissue interspersed with connective tissue lamellae. Magnification x1, Mallory-Cason staining. (Provided by F.W. Zonneveld, from Zonneveld).
An MRI study in living subjects could not answer our question because previous in-vivo experiments showed that it was impossible to visualize the STL in sagittal images due to its thinness and isointensity to aponeurotic tissue. Standard histological techniques have the disadvantage of dislocation artifacts and a reliable identification of the STL in cryosections (Fig. 1) was not possible. Therefore, MRI was performed in human cadaver orbits where the location of the STL was visualized using a synthetic marker.

MATERIAL AND METHODS

Six orbits from 2 male and 1 female human cadavers (range of age = 73-92 years, 1 unpreserved and 2 formalin-preserved specimen) obtained from subjects who donated their bodies to the Department of Functional Anatomy, University of Utrecht, the Netherlands, were investigated.

The STL was identified via a transcutaneous approach. The anterior border of the STL appeared well-defined whereas the posterior portion of the STL blended with the fascia of the LPS muscle. The posterior border of the STL was assumed at the intersection of the nasal and temporal paramuscular expansions of the STL with the longitudinal axis of the muscle.

A band-shaped piece of plastic which gives no signal and therefore appears black on MRimages, was glued onto the STL using cyanacrylate glue with its lateromedial extension at a right angle to the longitudinal axis of the LPS. The anterior border of the plastic piece was flush with the anterior border of the STL. The thickness of the marker was 1.5 mm, the mediolateral extension was 15 mm and the anterioposterior extension varied between 4 and 8 mm according to the anterioposterior dimension of the STL.

T1-weighted MR images in an about 20° oblique-sagittal plane along the optic nerve were obtained using a spinecho sequence (TR = 507 ms, TE =20 ms) and a surface coil with a diameter of 8.5 cm on a 1.5 tesla MR-system (Gyroscan ACS-NT, Philips Medical Systems, Best, the Netherlands). The slice thickness was 1.5 mm, the interslice gap was 0.2 mm and the field of view was 120 x 120 mm with a 205 x 256 matrix. The scan time for 15 slices was 12 minutes.

The length of the LPS segment between the culmination which is defined as the most cranial point of the LPS, and the posterior border of the plastic marker (Fig. 2) was measured in oblique-sagittal MR-images (Fig. 3) which included the eye lens, the vertical rectus muscles, and the optic nerve. The measurements in the MR-images may have several limitations: 1) post-mortem artifacts, dissection artifacts and age-related changes may have altered some anatomical relations. 2) The measurement „points“ are not exactly defined. 3) Air around the plastic marker may have partially obscured its borders. Due to the lack of exact data, a statistical analysis of the findings was not performed.

Fig. 2. Schematic drawing of oblique-sagittal section through the orbit illustrating the location of the superior transverse ligament (STL) [indicated by a marker] in relation to the culminatio (C) of the levator palpebrae superioris muscle (LPS). The distance was measured between the posterior border (P) of the STL and the culminatio (C) of the LPS. Intermuscular transverse ligament (ITL) lies in intermuscular space between levator aponeurosis (A) and muscle (LPS) and superior rectus muscle (SRM).

Fig. 3. A, B Oblique-sagittal T1-weighted MRI scans of two different cadaver orbits: a space which is isointense to fat is noted between the LPS (1) and the SRM (2). This space contains intermuscular adipose tissue and the intermuscular transverse ligament. The LPS ascends from its origin to reach a culmination from where it descends to the tarsal plate. The culmination is located cranial to the posterosuperior surface of the globe. The superior transverse ligament is marked with synthetic material (arrows) which appears black. The images demonstrate that the STL is situated over the descending, distal portion of the LPS.
RESULTS

During gross dissections, the STL appeared to be located inferior to the most cranial region (culmination) of the LPS in all specimens. In order to localize the STL in sagittal MR images, the ligament was marked with a band-shaped piece of plastic which was glued onto the LPS flush with the anterior border of the STL. The anterioposterior extension of the marker varied between 4 and 8 mm according to the anterioposterior dimension of the STL.

In oblique-sagittal MR images, the synthetic marker was located distally (i.e. anteriorly) to the culmination on the descending part of the LPS in all specimens (n = 6, Fig. 3). The length of the LPS segment between the culmination and the posterior border of the marker was measured to range between 5 and 9 mm (Table 1, Fig. 3).

Table 1. Length of the LPS segment between culmination and the posterior border of the plastic marker measured in oblique-sagittal MR-images from the right (R) and left (L) orbits of 3 human cadaver heads.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Side</th>
<th>Length [mm]</th>
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<tbody>
<tr>
<td>9525</td>
<td>R</td>
<td>8</td>
</tr>
<tr>
<td>9525</td>
<td>L</td>
<td>6</td>
</tr>
<tr>
<td>9538</td>
<td>R</td>
<td>6</td>
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<tr>
<td>9538</td>
<td>L</td>
<td>5</td>
</tr>
<tr>
<td>9542</td>
<td>R</td>
<td>8</td>
</tr>
<tr>
<td>9542</td>
<td>L</td>
<td>9</td>
</tr>
</tbody>
</table>

DISCUSSION

The position of the marker in the MR images demonstrates that the STL is located in the anterior descending portion of the LPS, i.e. the position of the STL in dissected cadaver orbits is inferior and distal to the culmination of the LPS (Fig. 2). Therefore, although the STL may suspend the aponeurotic part of the LPS, it is not able to suspend the muscle at its culmination, as previously proposed. This is supported by our own investigations which have demonstrated that the superomedial and superolateral main insertions of the STL are located slightly inferior to the level of the LPS.

If the STL does not determine the course of the LPS, which other causes may contribute to the described curved path of the LPS muscle?

(1) The orbital connective tissue system may determine the course of the LPS in two ways:
(a) the LPS is supported at its culmination by an intermuscular fat pad (Fig. 1) and an intermuscular transverse ligament (Fig. 1) which extends further posteriorly than the STL thus creating a fulcrum for the LPS; (b) the network of radial connective tissue septa extending from the fascial sheath of the LPS to the periorbit may suspend the LPS muscle by mediating a pulley-effect comparable to the one described for the recti muscles.

(2) As for other extraocular muscles, the muscle tension influences the course of the LPS: MRI scans performed in up- and down-gaze, demonstrate that the curvature of the LPS is more obvious during relaxation than during contraction of the muscle. The curvature is even more marked in the presence of IIIa nerve palsies (see Fig. 3.B in Ettl et al. 17).

The definitive function of the STL for upper eyelid mechanics remains unclear. It may check the action of the LPS as previously suggested by Whitnall, it suspends the levator aponeurosis and the upper eyelid, it suspends the lacrimal gland and it seems to play a role for passive upper lid closure.

In conclusion, the STL is unlikely to suspend the culmination of the LPS from a geometrical-mechanical point of view. We suggest that other anatomical structures such as the intermuscular transverse ligament and adipose tissue together with the radial orbital septa contribute to the curved path of the LPS. However, we point out that our investigation refers to dissected cadaver orbits and that the topographical relations may be slightly different in vivo.

In analogy to the recti muscles, the course of the LPS may be important for its normal function. The orbital connective tissue not only determines the course of the extraocular muscles but also contains sensory nerve fibres possibly serving for proprioception, and smooth muscle tissue which may adjust the course of the muscles. Therefore, it is advisable to proceed as conservatively as possible during the dissection of the connective tissue around the LPS in ptosis operations.
REFERENCES