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CHAPTER 6

DYNAMIC MAGNETIC RESONANCE IMAGING
OF THE LEVATOR PALPEBRAE SUPERIORIS MUSCLE

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INTRODUCTION

Knowledge of the functional anatomy of the levator palpebrae superioris (LPS) muscle is essential for ptosis surgery.¹

In eye muscle surgery, the dose-response relationship has been based on biomechanical and physiological principles.²³ Currenty, the amount of surgery on the levator muscle is based on empirically derived values¹ and no biomechanical model of upper eyelid movements has been presented so far. One important aspect of upper lid mechanics which certainly has an influence on the dose-response relationship in levator muscle surgery is the relationship between upper lid elevation (h, clinically known as 'levator function') and shortening (s) of the LPS. A similar problem, the relationship between the lower eyelid margin and the inferior oblique muscle during vertical eye movements, had previously been described: The excursion of the lower lid margin was found to be equal to or slightly larger than the excursion of the inferior muscle complex.⁶

The purpose of the present study was to investigate the physiological relationship between upper lid excursion and the amount of levator muscle contraction in healthy subjects.

MATERIAL AND METHODS

Oblique-sagittal T1-weighted MR images of one orbit were obtained in 4 normal volunteers aged 26 to 34 years in 25-30° down- and about 25° upgaze on a 1-tesla scanner (Magnetom, Siemens, Germany) using the following parameters: surface coil diameter = 10 cm, echo time = 15 ms, repetition time = 440 ms, slice thickness = 3 mm, field of view = 140 x 140 mm, 256 x 256 matrix, acquisition time = 116 s. The images were produced while the subjects were inactivating their frontalis muscle by firm digital pressure onto their eyebrow.

The vertical distance between the upper lid margin and the frontal bone of the superior orbital rim was measured in maximal downgaze and upgaze in the MR images in order to determine the amount of upper lid excursion between down- and upgaze. Additionally, the length (l) of the LPS from its origin to the upper border of the tarsal plate was measured in MR images on down- and upgaze.

RESULTS

The mean (± SD) length of the LPS on downgaze (l₁) was 62 ± 3.0 mm (Fig. 1) and the mean (± SD) length on upgaze (l₂) was 41 ± 2 mm (Fig. 2). For a mean (± SD) lid excursion (h) of 15 ± 1, the mean shortening (s = l₁ - l₂) of the muscle was therefore 21 ± 3 mm. The mean h:s ratio was determined to be 1:1.4 (range 1:1.2-1:1.6, n = 4). In the small age-group investigated, there was no significant age dependence of the above values.

The angle β between the levator aponeurosis in oblique-sagittal MR images and a vertical (cranio-caudal) line through the culmination point of the LPS (most cranial point
oo downgaze: The LPS (1) originate from the lesser wing of the sphenoid and courses superiorly in a curved path to a culmination area superoposteriorly to the equator of the globe from where the LPS aponeurosis (and the superior tarsal muscle) course inferiorly to insert into the upper border of the tarsal plate (arrow) and the posterior surface of the orbicularis muscle (4). The slope of the aponeurosis is steep in this gaze position. Note that the course of the vertical rectus muscles is also curved. The transverse superior fascial expansion embedded in adipose tissue, is situated in the intermuscular space (3) between LPS and superior rectus muscle (SRM) (2). 5 = Orbital septum

Fig. 1. Oblique-sagittal MRI scan in a plane along the optic nerve on downgaze: The LPS (1) and the superior tarsal muscle (2) are contracted and thickened. The curved course of the LPS is less pronounced in this gaze position and the slope of the aponeurosis is flat. Transverse superior fascial expansion in the intermuscular space (3). 4 = Orbicularis muscle. 5 = Orbital septum (modified from Ettl et al. [Ophthalmology 1997;104:869-877] with permission).

oo upgaze: The LPS (1) and the superior rectus muscle (2) are added and therefore a "force-saving" lid elevation is achieved by a deflection of the LPS at its culmination point, which may be due to the unique architecture of the connective tissue system of the superior orbit, i.e. the superior transverse ligament and transverse superior fascial expansion in connection with the radial suspensory septa.

Fig. 2. Oblique-sagittal MRI scan in a plane along the optic nerve on upgaze: The LPS (1) and the superior rectus muscle (2) are contracted and thickened. The curved course of the LPS is less pronounced in this gaze position and the slope of the aponeurosis is flat. Transverse superior fascial expansion in the intermuscular space (3). 4 = Orbicularis muscle. 5 = Orbital septum (modified from Ettl et al. [Ophthalmology 1997;104:869-877] with permission).

of the LPS in the orbit) is estimated to range between 35 and 50° for gaze positions from downgaze to slight upgaze. In maximum upgaze, the angle B is estimated to range between 75 and 80°.

DISCUSSION

Since the lid elevation (h) represents a projection of the LPS shortening (s) along the plane of the aponeurosis onto a vertical (craniocaudal) line intersecting with the upper lid margin, the ratio of s:h depends on the slope of the aponeurosis: If the slope is flat (e.g. in upgaze), less lid elevation for a given LPS shortening is achieved. If the slope is steep (e.g. in downgaze), more lid elevation for a given muscle shortening is achieved. Based on simple trigonometrical principles (Fig. 3), the ratio of s:h can be calculated from 1/cosB and ranges between 1.2 and 1.7 for B = 35-55°. This theoretically calculated s:h ratio is in excellent agreement with the value determined in the MR-images.

If the general equation work = force x distance = weight x height is applied to upper lid elevation, we obtain $F_w \times s = F_{ave} \times h$, where $F_w$ is the lid elevating force vector and $F_{ave}$ is the lid-lowering force vector (composed of orbicularis force and weight of upper lid). If s is larger than h, $F_w$ is smaller than $F_{ave}$. This suggests a physiological mechanism which may save the force of the LPS that is necessary for lid elevation. The following supporting mechanisms may be discussed: (1) The weight of the lid is pulled upwards over an oblique plane provided by the anterosuperior surface of the globe. (2) The superior transverse ligament may suspend the eyelid thus reducing the downwards-directed force vector ($F_{ave}$). The superior transverse ligament (also known as Whitnall's ligament) in connection with the transverse superior fascial expansion of the LPS and the superior rectus muscle forms a sling-like structure around the LPS. The levator muscle contracts by approximately 18-24 mm on up-gaze. Due to the fibroelastic connections between the LPS and the transverse ligaments, the ligaments must follow the excursions of the LPS as suggested in a previous MRI study where the culmination point of the LPS moved posteriorly in the orbit on up-gaze.

A steep slope of the levator muscle aponeurosis and therefore a "force-saving" lid elevation is achieved by a deflection of the LPS at its culmination point, which may be due to the unique architecture of the connective tissue system of the superior orbit, i.e. the superior transverse ligament and transverse superior fascial expansion in connection with the radial suspensory septa.

The curved orbital path of the straight extraocular muscles which had first been described by Simonsz et al. was attributed to fibromuscular pulleys causing a deflection of the muscle bellies, which may increase the elastic force of the muscles. The connective tissue system of the superior
Fig. 3. Schematic drawing of an oblique-sagittal section through the LPS (represented by an angled line through points O, C and U) and the eye ball in primary gaze demonstrating the trigonometrical relation $h = s \times \cos \beta$. If $\beta = 45^\circ$, $h$ is calculated to be $s \times 0.71$. Therefore, the relation between $F_{\text{desn}}$ to $F_{\text{up}}$ is determined as follows: $F_{\text{desn}} : F_{\text{up}} = s : h = 1.41 : 1$. The LPS is suspended and supported around point C by orbital connective tissue structures. LPS = levator palpebrae superioris, TP = tarsal plate, O = origin of LPS, C = culmination point of LPS, U = upper border of TP, L = lower border of TP, $s$ = shortening of LPS projected onto the levator aponeurosis between U and C, $h$ = height of lid elevation, $F_{\text{desn}}$ = lid elevating force vector, $F_{\text{up}}$ = lid lowering force vector.

orbit may have similar „pulley-like“ and supporting functions for the levator muscle.\textsuperscript{a,11} Thus, the connective tissue system of the LPS seems to play an important role for upper lid movements which should be considered during surgical dissection in ptosis patients.

The dose-response relationship in ptosis surgery may depend on the relationship between shortening of the LPS and the achieved elevation of the upper lid. However, as in strabismus surgery, it certainly also depends on many other factors, such as the force and the elasticity of the levator muscle (both may be reduced in congenital ptosis), the course of the levator muscle and the amount of surgical tissue mobilization. Further studies with larger number of cases are needed to investigate these factors in order to establish a dose-response relationship for ptosis surgery which is based on biomechanical principles.

REFERENCES
