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ORIGINAL ARTICLE

Anatomical investigation of levator palpebrae superioris muscle and the distribution pattern of oculomotor nerve

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Abstract

Purpose This study aims to evaluate the morphological features of the levator palpebrae superioris muscle (LPS) and the variations in the distribution of the oculomotor nerve in the muscle.

Methods 100 bilateral orbits from 50 cadavers were included in our study. In our study, the medial, lateral, and middle length, width, and thickness of the LPS were measured from 3 different points and recorded. In addition, the number of branches of the oculomotor nerve entering the LPS muscle was calculated.

Results The medial, lateral, and middle length of LPS were 34.85 ± 5.30 mm, 34.62 ± 5.67 mm, 35.77 ± 5.31 mm on the right side and 33.66 ± 4.74 mm, 33.81 ± 4.83 mm, 34.54 ± 5.14 mm on the left side, respectively. The width of the muscle was seen to expand from proximally to distally. It was noted that the middle 1/3 thickness of the LPS was the thickest part of the muscle compared to the other parts. A total of 239 oculomotor branches entered the LPS. The middle 1/3 of the LPS was reached by 151 oculomotor nerve branches. It was noted that the largest number of oculomotor nerves entered the middle 1/3 part of LPS.

Conclusion The morphometric and morphological findings of LPS and branches of the oculomotor nerve may be useful in surgical planning for the LPS and levator aponeurosis and in preventing complications during surgical interventions.

Keywords Levator palpebrae superioris · Oculomotor nerve · Morphology · Orbit · Anatomy · Cadaver

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Introduction

The levator palpebrae superioris (LPS) muscle is a vital component of the upper eyelid that plays a crucial role in eyelid elevation and control. It is a thin, broad skeletal muscle located in the upper eyelid [20]. Although different variations have been reported about the accessory muscle slips associated with LPS [2, 13, 16, 22], it originates from the lesser wing of the sphenoid bone within the orbit. Its tendon inserts as the levator aponeurosis into the tarsal plate and skin of the upper eyelid. It runs superiorly and slightly medially along the anterior aspect of the superior orbital rim. It has a length of 36–40 mm, a width of 4 mm (proximal part), 18 mm (middle part), and 8 mm (distal part), and a variable thickness of 1.6 ± 0.3 mm [7]. The innervation is provided by the upper division of the oculomotor nerve (CN III), specifically the superior division of the 3rd cranial nerve (CN III). The oculomotor nerve originates from the midbrain and carries motor fibers to various extraocular muscles, including the LPS. The superior division of the 3rd cranial nerve

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innervates the LPS muscle as it passes through the superior orbital fissure. The innervation allows for voluntary control of eyelid elevation and contributes to the involuntary blink reflex [12].

Ptosis occurs in paralysis of the levator palpebrae superioris muscle, which is the main elevator and retractor of the upper eyelid [11]. Different surgical methods and techniques are used to correct ptosis, depending on the degree of ptosis [4, 9, 23]. Therefore, a good knowledge of the anatomy of this muscle by ophthalmologists is very important for safe approaches during eyelid surgery. Since the LPS is exposed to local anesthetics during upper eyelid surgery, understanding the anatomy and morphometry of the LPS muscle is essential for successful surgical interventions and local anesthetics [1, 5, 7, 15, 22].

Based on the hypothesis that postoperative blepharoptosis is caused by transient paralysis of the LPS, besides the anatomy of the LPS, we investigated the distribution of the upper division of the oculomotor nerve in the LPS. Additionally, Ng et al. highlighted that "…the ongoing work of researchers and anatomists will be of great value in ongoing efforts to address the gaps in our knowledge of the anatomy of the LPS" [15]. In this context, our study aimed to demonstrate the anatomical and morphometric features of the LPS and then to examine the nerve distribution of the oculomotor nerve responsible for the innervation of this muscle just before it enters the muscle.

Material and method

Our study was performed in 100 unilaterally fixed (10% formalin) orbits of 50 cadavers (38 male and 12 female) at the Department of Anatomy, Faculty of Medicine, Istanbul University, Istanbul, Turkey (number:155281; date:31/03/2021).

Dissection process

The dissection process of our study was performed from the anterior cranial fossa. After removal of the calvaria and brain tissue, the dura mater on the basis cranii was scraped and dissected. Then, the upper wall of the orbit was broken with a chisel and hammer. The periorbital fascia, fat, and connective tissues surrounding the orbit were removed with toothed pliers and a scalpel. After the dissections were completed, the first morphometric measurements of the LPS were assessed, and then the relationship between the oculomotor nerve, which is responsible for the innervation of this muscle, was evaluated.

Evaluation of the characteristics of the levator palpebrae superioris muscle

Morphometric measurements of 9 parameters at three different points, including lateral, medial, and middle longitudinal lengths, proximal, middle, and distal width, and proximal, middle, and distal thickness of the LPS muscle, were performed. The 9 morphometric measurements of the LPS muscle were performed as follows:

The LPS muscle was divided into three equal parts, and the width was measured from the midpoint of each part. Accordingly, the following widths were measured.

1. The one-third proximal width of LPS (PW-LPS): The width at the midpoint of the 1/3 proximal (PW-LPS) part of the LPS (Fig. 1a).
2. The one-third middle width of LPS (MW-LPS): The width at the midpoint of the 1/3 middle (MW-LPS) part of LPS (Fig. 1b).
3. The one-third distal width of LPS (DW-LPS): The width at the midpoint of the 1/3 distal part (DW-LPS) of the LPS (Fig. 1c).
4. The one-third proximal thickness of LPS (PT-LPS): The thickness at the midpoint of the 1/3 proximal (PT-LPS) part of the LPS.
5. The one-third middle thickness of LPS (MT-LPS): The thickness at the midpoint of the middle 1/3 of the LPS (MT-LPS).
6. The one-third distal thickness of LPS (DT-LPS): The thickness at the midpoint of the 1/3 distal 1/3 of the LPS (DT-LPS).
7. The length of the lateral edge of LPS (LL-LPS): The length between the lateral edge of LPS tendon and the lateral insertion point into levator aponeurosis (Fig. 1d).
8. The length of the medial edge of LPS (ML-LPS): The length between the medial edge of the LPS tendon and the medial insertion point into the levator aponeurosis (Fig. 1d).
9. The length of the middle edge of LPS (ML-LPS): The length between the middle point of the LPS tendon and the middle insertion point into the levator aponeurosis. (Fig. 1d).

We observed that the bulbus oculi collapsed due to the waiting time of the cadavers and the embalming solutions used (Fig. 2a). Therefore, in order to ensure that the morphometric measurements we performed in our study were close to reality, we injected fluid into the bulbus oculi to achieve their normal anatomical shape (Fig. 2b, c).

Morphometric measurements were performed using a digital caliper with 0.01 precision.

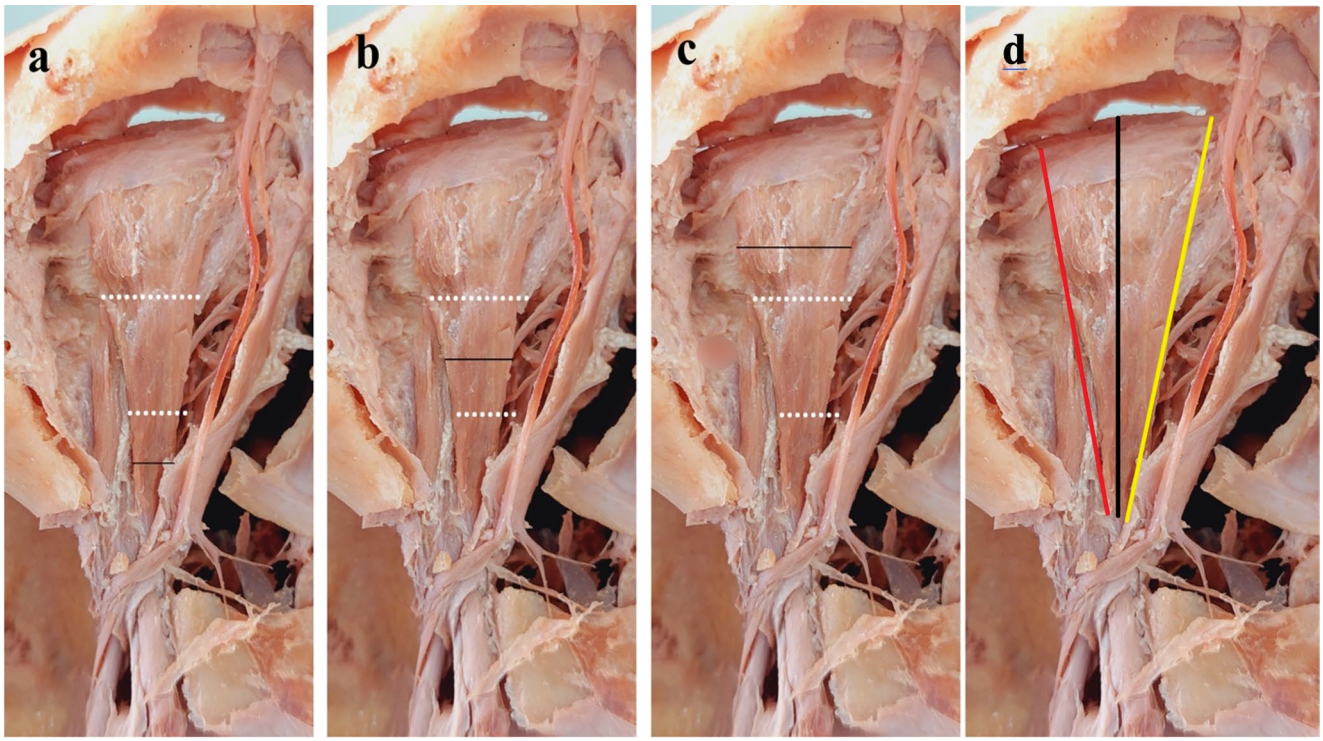

Fig. 1 Morphometric measurements of the levator palpebrae superioris muscle (LPS) by dividing into three parts (dotted white lines). The width of the proximal one-third of LPS (black line) (**a**); the width of the middle one-third of LPS (black line) (**b**); the width of the distal one-third of LPS (black line) (**c**); the length of the medial edge of LPS (yellow line), the length of the middle edge of LPS (black line); the length of the lateral edge of LPS (red line) (d)

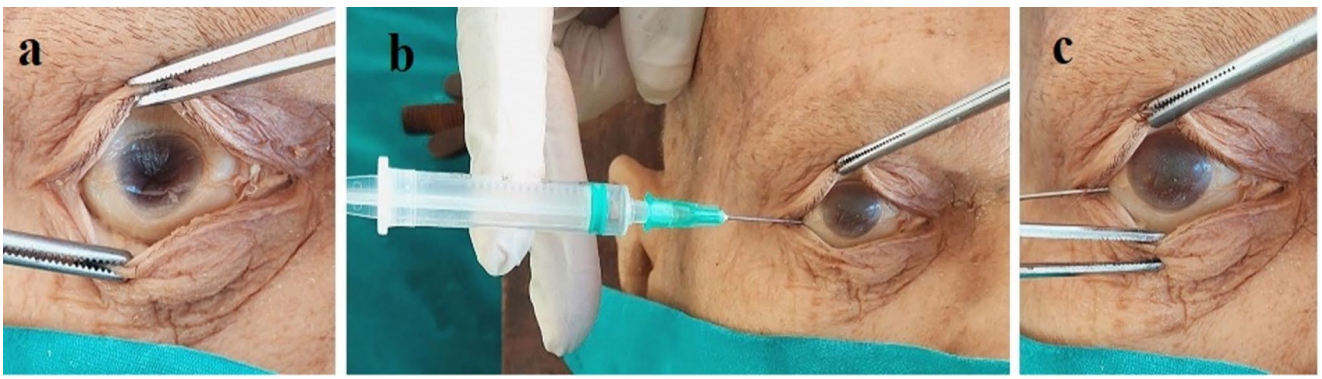

Fig. 2 View of the right bulbus oculi in a cadaver. Collapsed bulbus oculi (**a**); fluid injection into bulbus oculi (**b**); appearance of bulbus oculi after fluid injection (**c**)

Evaluation of the distribution of the oculomotor nerve in the levator palpebrae superioris muscle

After the morphometric measurements of LPS were completed, the muscle was divided into three equal parts (proximal 1/3, middle 1/3, and distal 1/3) and marked with colored pins. The LPS was released from its origin, deviated from proximal to distal, and the number of oculomotor nerve branches entering each part (proximal one-third, middle one-third, and distal one-third) was determined and recorded (Fig. 3).

Statistical analysis

Statistical analyses were performed using Jamovi (Version 2.6), computer software (https://www.jamovi.org). Assumptions of normality were assessed using the Shapiro–Wilk test. Because the data in our study were not normally distributed, non-parametric tests were used. Categorical variables (e.g., the number of branches of the oculomotor nerve [bON] between sexes and sides) were compared using the chi-square test, as appropriate. For continuous variables, the Mann–Whitney U test was used to compare two independent

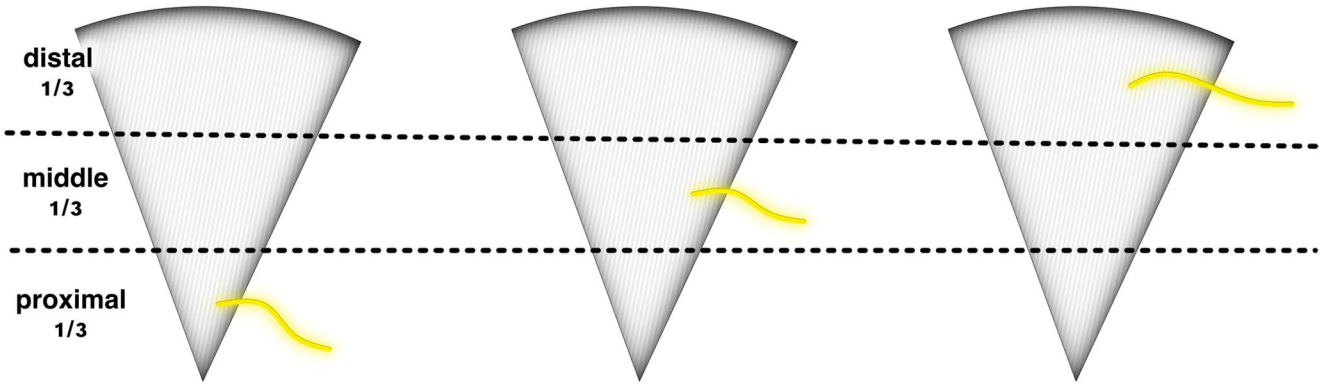

Fig. 3 View of the upper division of the oculomotor nerve entering the levator palpebrae superioris muscle (LPS). Branch entering (yellow line) the proximal 1/3, middle 1/3 and distal 1/3 of the LPS

groups (e.g., male and female, right and left). Corrections for multiple comparisons were applied using the Bonferroni method, where appropriate. Confidence intervals (95%) were calculated for key measurements to improve the interpretation of effect sizes and precision. The significance level was set at $p<0.05$. These tests were chosen to address the nonparametric nature of the data and the categorical comparisons central to the study's objectives.

Results

The anatomical characteristics of the levator palpebrae superioris muscle

The mean length of the LPS muscle of the medial, lateral, and middle edges was 34.85±5.30 mm, 34.62±5.67 mm, 35.77±5.31 mm on the right side and 33.66±4.74 mm, 33.81±4.83 mm, 34.54±5.14 mm on the left side, respectively. There was no statistically significant difference between genders (female–male) and sides (right–left) ($p>0.05$). However, there was a statistically significant difference ($p<0.05$) in the comparison of the same side genders (female–male right side and female–male left side).

The mean width of 1/3 proximal, 1/3 middle, and 1/3 distal of the LPS was 4.30±1.05 mm, 6.12±1.72 mm, and 8.32±2.28 mm, respectively, on the right side and 4.20±1.06 mm, 6.08±1.61 mm, and 8.58±2.38 mm on the left side, respectively. It was noted that the width of the proximal 1/3 of the LPS varied from 2.26 to 8.55 mm, the width of the middle 1/3 of the LPS varied from 3.34 to 12.24 mm, and finally the distal 1/3 width of the LPS varied between 3.76 and 14.77 mm (Fig. 4). Regarding the proximal, middle and distal width of the LPS, there was no statistically significant difference ($p>0.05$) in the comparison of genders, sides and same side genders.

The mean of 1/3 proximal, 1/3 middle, and 1/3 distal thickness of the LPS were 0.71±0.19 mm, 0.74±0.07 mm, 0.64±0.19 mm on the right side and 0.71±0.18 mm, 0.74±0.27 mm, 0.68±0.29 mm on the left side, respectively. There was no statistically significant difference between the proximal and middle thickness of LPS in the comparison of genders (female–male), sides (right–left), and same side genders (female–male right side and female–male left side) ($p>0.05$), while there was a statistically significant difference ($p<0.05$) in the 1/3 distal thickness in the comparison of sides (right–left) and same side genders (female–male right side and female–male left side).

Oculomotor nerve distribution in the levator palpebrae superioris muscle

The number of branches of the upper division of the oculomotor nerve to the parts of LPS (proximal 1/3, middle 1/3, and distal 1/3 parts) varied between 0 and 4. The number of branches to the proximal 1/3 and distal 1/3 parts of the LPS was between 0 and 3, and the number of branches to the middle 1/3 part of the LPS was between 0 and 4. In the 100 orbits examined, the total number of branches entering the proximal 1/3, middle 1/3, and distal 1/3 of the LPS was 49, 151, and 38, respectively. A total of 239 branches reaching the LPS were observed in the 100 orbits examined. Of these branches, 121 belonged to the right side and 118 to the left side, while 179 branches belonged to males and 59 to females (Tables 1 and 2).

The upper division of the oculomotor nerve gave no branches to the proximal 1/3 of the LPS in 58 orbits. In 36 orbits (16 right, 20 left), it gave a single branch, in 5 orbits (2 right, 3 left), it gave 2 branches, and finally, in a single right-sided orbit, it gave 3 branches to the proximal 1/3 of the LPS.

The oculomotor nerve gave no branches to the middle 1/3 of LPS only in 3 orbits (2 right, 1 left). In 53 orbits

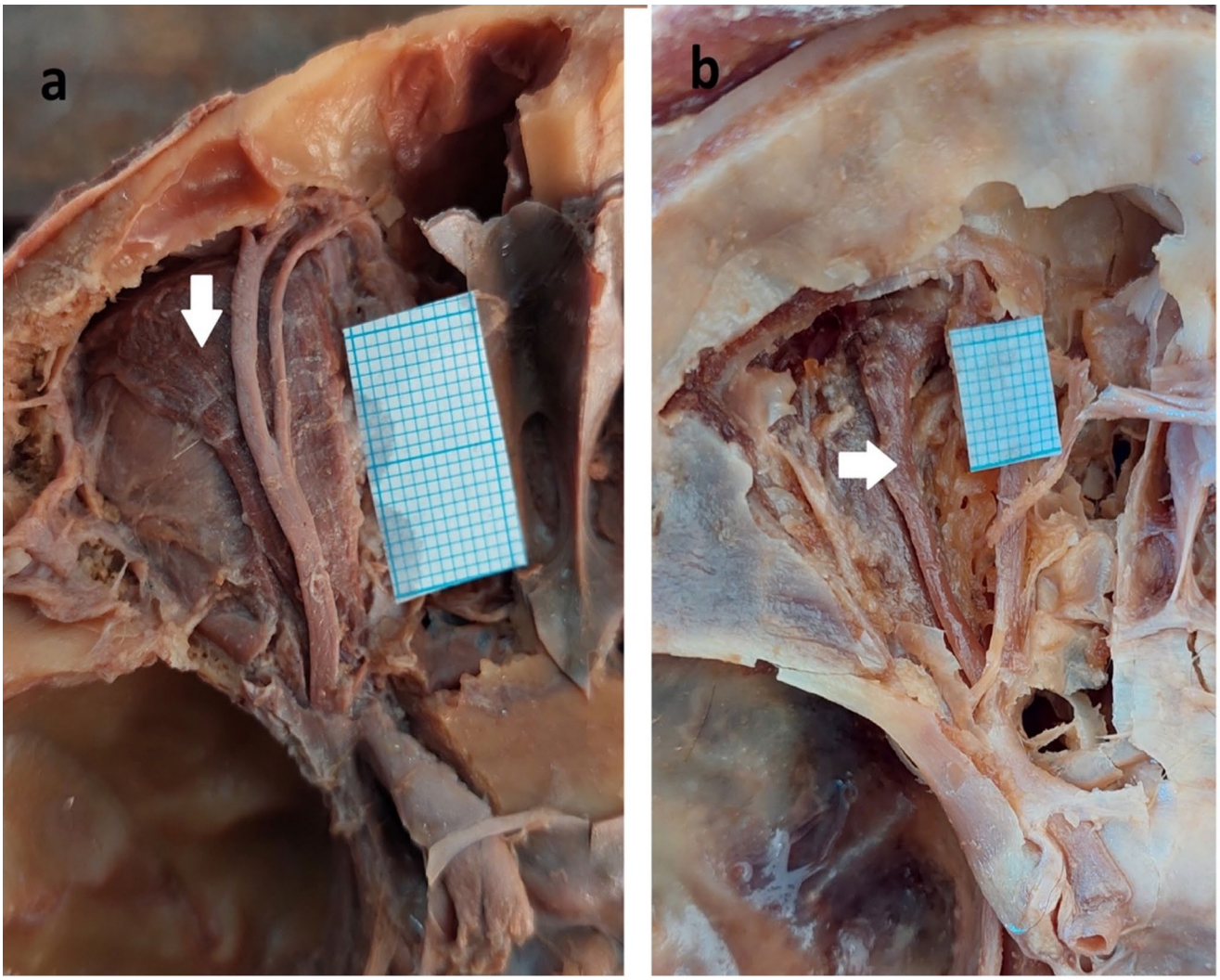

Fig. 4 View of the levator palpebrae superioris muscle (LPS) of the left orbit. The widest LPS (**a**); the narrowest LPS (**b**)

Table 1 Prevalence of upper division oculomotor nerve according to the sides in the orbit with single branch, double branches, three branches, four branches or without (0) reaching the proximal, middle and distal one thirds of the levator palpebrae superioris muscle; bON, branch of oculomotor nerve; LPS, levator palpebrae superioris muscle

Frequency of occurrence according to the sides	Sides	Number of bON					Total number of bON
		0 bON	1 bON	2 bONs	3 bONs	4 bONs	number of bON(s) × frequency of occurrence
Proximal one-third of LPS	Right	31	16	2	1	0	23
	Left	27	20	3	0	0	26
	Total	58	36	5	1	0	49
Middle one-third of LPS	Right	2	25	19	4	0	75
	Left	1	28	16	4	1	76
	Total	3	53	35	8	1	151
Distal one-third of LPS	Right	29	21	1	0	0	23
	Left	35	14	1	0	0	16
	Total	64	34	2	0	0	38

Table 2 Prevalence of upper division oculomotor nerve according to the genders in the orbit with single branch, double branches, three branches, four branches or without (0) reaching the proximal, middle and distal one thirds of the levator palpebrae superioris muscle; bON, branch of oculomotor nerve; LPS, levator palpebrae superioris muscle

Frequency of occurrence according to the genders	Gender	N	Number of bON					Total number of bON
			0 bON	1 bON	2 bONs	3 bONs	4 bONs	number of bON(s) × frequency of occurrence
Proximal one-third of LPS	Male	76	41 (53.95%)	30 (39.50%)	4 (5.25%)	1 (1.30%)	0	41
	Female	24	17 (70.84%)	6 (25%)	1 (4.16%)	0	0	8
	Total	100	58	36	5	1	0	49
Middle one-third of LPS	Male	24	2 (2.64%)	42 (55.27%)	27 (35.53%)	4 (5.26%)	1 (1.30%)	112
	Female	76	1 (4.16%)	11 (45.83%)	8 (33.33%)	4 (16.68%)	0	39
	Total	100	3	53	35	8	1	151
Distal one-third of LPS	Male	76	50 (65.80%)	25 (32.90%)	1 (1.30%)	0	0	27
	Female	24	14 (58.34%)	9 (37.50%)	1 (4.16%)	0	0	12
	Total	100	64	34	2	0	0	39

(25 right, 28 left), 35 orbits (19 right, 16 left), 8 orbits (4 right, 4 left), and a single left orbit, it gave 1 branch, double branches, three branches, and four branches, respectively.

The upper division of the oculomotor nerve gave no branches to the distal 1/3 of the LPS in 64 orbits (29 right, 35 left). In 35 orbits (20 right, 14 left) it gave one branch and finally in 2 orbits (1 right, 1 left) it gave 2 branches to the distal 1/3 of the LPS (Fig. 3). In our study, the upper division of the oculomotor nerve gave maximum 2 branches to the distal 1/3 of the LPS (Fig. 3).

The distribution of the upper division of the oculomotor nerve in the LPS was similar in each gender. However, the frequency of 3 branches reaching the middle 1/3 of the LPS was 16.68% higher in women (Table 2).

Discussion

The length of the levator palpebrae superioris muscle

Ettl et al. reported the length of LPS between 36 and 40 mm [6]. However, they defined the measurement points between its origin and the culmination point. Lemke et al. measured the distance of the length of LPS between the origin of the muscle and the levator aponeurosis and reported this distance as a mean of 36 mm [14]. Haladaj et al. measured the length of the muscle between its origin and the levator aponeurosis' insertion and found it to be 41.3 mm [7]. The aforementioned studies have not pointed out the precise measurement points of the length of LPD. Therefore, if we assume that the studies in the literature were performed by considering the midline of the muscle, the length of the LPS in our study (by measuring the distance from the proximal and midline of the LPS to the superior and midline of the LTS) was found to be 33.66±4.74 mm on the right side, 33.81±4.83 mm, 34.54±5.14 mm on the left side. Although our findings regarding the length of the LTS were similar to the findings in the literature, the length of the LTS was measured from three different points in our study and the measurement points were clearly stated. No study was found in the literature regarding the length of the lateral and medial edges of the LPS. Since the course of the LPS muscle extends obliquely rather than vertically in the orbit, its medial and lateral lengths were measured in parallel with the course of this muscle. We think that an accurate assessment of LPS length during ptosis surgery or related orbital surgeries is important to achieve optimal results. It is worth noting that the study provides valuable information regarding the length of the LPS muscle; however, differences in measurement techniques and sample populations may influence the reported values. Furthermore, individual anatomical differences and ethnic variations may also contribute to small variations in the length of the LPS muscle. Therefore, further research is needed to confirm this observation.

The width of the levator palpebrae superioris muscle

Lemke et al. [14] divided the entire muscle into 3 equal parts for the width of the LPS and measured an average of 4 mm at the origo, 18 mm at the insertio, and 8 mm at the midline between the origo and insertio of the muscle. Haladaj et al. similarly found the width at the origin, midpoint, and distal point of the muscle to be 3.6+0.4 mm, 9.5+1.8 mm, and 21.9±2.9 mm, respectively [7]. In our study, the width of LPS was measured by dividing the muscle from the origin to the LTS into three equal parts. According to this measurement, the proximal one-third, the middle one-third, and the distal one-third of LPS were measured as 4.30±1.05 mm, 6.12±1.72 mm, 8.32±2.28 mm on the right side and 4.20±1.06 mm, 6.08±1.61 mm, 8.58±2.38 mm on the left side, respectively. The width of the LPS at the junction with the levator aponeurosis was 16.01±3.16 mm on the right

and 15.81 ± 3.26 mm on the left side. It is worth noting that individual anatomical differences and ethnic variations can contribute to variations in LPS width. Furthermore, measuring the width of the LPS muscle accurately is essential in surgical procedures that involve the eyelids, and standardized techniques should be employed.

Thickness of the muscle and its relationship with the number of branches of the oculomotor nerve

Haładaj et al. measured the thickness at the midpoint of LPS at a mean of 1.6 ± 0.3 mm [7]. Another anatomical study was conducted by Ohnishi et al. that investigated the LPS muscle in 82 Graves' ophthalmopathy patients with MRI images, 32 patients with Graves' disease but without ophthalmopathy, and 12 controls [17]. The LPS thickness of the control group, patients with Graves' disease and patients with Graves' disease but without ophthalmopathy were 1.74 ± 0.25 mm, 3.08 ± 0.89 mm and 1.72 ± 0.25 mm, respectively. In their study, they recorded a statistically significant difference between the LPS thicknesses of patients with and without Graves' disease ophthalmopathy. In addition, the thickness of the LPS muscle of patients with Graves' disease who showed signs of ophthalmopathy was also very thick. Therefore, the authors argued that there may be a correlation between LPS thickness and upper eyelid retraction, and therefore, the thickness of the muscle may increase in patients with upper eyelid retraction. In this case, it was thought that upper eyelid retraction may be seen in Graves' ophthalmopathy without hyperthyroidism [17].

On the other hand, transient diplopia or blepharoptosis is frequently seen in cases of upper eyelid surgery performed under local anesthesia. Blepharoptosis is also seen as a complication of blepharoplasty. Beyer et al. suggested that the eyelid speculum (blepharoplast) used during intraocular surgeries, or some ocular trauma, may cause separation of the LA, resulting in blepharoptosis [3]. Rainin and Carlos suggested that in some cases of postoperative diplopia and blepharoptosis, the myotoxic effects of local anesthetics on the extraocular muscles and LPS may also cause blepharoptosis [18]. Acquired blepharoptosis is also known to occur in long-term contact lens wearers (because they open their eyelids by separating them with their fingers) and in those who constantly rub their eyes due to allergic conjunctivitis, as a result of thinning and separation of the LA [10, 19]. The LPS is exposed to local anesthetics during upper eyelid surgery and is also vulnerable to local anesthetics. Based on the hypothesis that postoperative blepharoptosis is caused by transient paralysis of the LPS, we investigated the distribution of the upper oculomotor nerve in the LPS.

Hwang Kun et al. recorded the distribution patterns of the upper division of the oculomotor nerve in LPS as Type I (6.7%), Type II (26.7%), and Type III (66.7%) in 30 unilateral orbits [8]. The terminal branches that extend to the proximal third, middle third, and distal third of LPS were classified as Type I, Type II, and Type III, respectively. In our study, we found 2%, 56% and 42% on the right side and 2%, 68% and 30% on the left side, respectively (Fig. 3). We think that the differences between our results and the study reported by Hwang Kun et al. were between the Type I and Type II findings. Since the Type I was observed as the most common type in the study reported by Hwang Kun et al. [8]. The Type II was the most common type in our study. We think that sample size and racial differences may be the reason for this difference.

In our study, 1/3 proximal thickness of LPS (PT-LPS), 1/3 middle thickness of LPS (MT-LPS), and 1/3 distal thickness of the LPS (DT-LPS) were recorded as 0.71 ± 0.19 mm, 0.74 ± 0.07 mm, 0.64 + 0.19 mm on the right side and 0.71 ± 0.18 mm, 0.74 ± 0.27 mm, 0.68 ± 0.29 mm on the left side, respectively. It was found that the 1/3 distal thickness of LPS showed a statistically significant difference between genders and sides ($p < 0.05$). In our study, MT-LPS was thicker than PT-LPS and DT-LPS in both males and females. However, in the literature and in sources such as Gray's Anatomy used for education, it has been reported that the thickness of the LPS decreases as it progresses distally [20]. The number of branches of the upper division of the oculomotor nerve to the 1/3 proximal, 1/3 middle, and 1/3 distal parts of the LPS were 47, 154, and 37, respectively, totaling 238. We think that there may be a relationship between the thickness of the 1/3 middle part of the LPS and the number of nerves entering this part. Since the thickness of the LPS increases in the middle one-third, the number of branches entering the muscle also increases.

Limitations

While cadaveric studies provide invaluable information on anatomical structures, they do have some limitations. Since the morphological structures of cadavers exposed to chemicals are altered [21]. In our study, the use of 10% formalin fixation may have altered tissue elasticity and thickness, which is particularly important for morphometric analysis of small muscles such as the LPS. In addition, structures such as the bulbus oculi (eyeball) in cadaveric studies can be compromised by post-mortem changes. In our study, although the normal anatomical shape of these collapsed bulbus oculi was achieved by injecting fluid into them, the possible morphometric changes of the muscles exposed to chemicals constitute the major limitation of our study. Additionally, cadaveric models cannot replicate functional or dynamic aspects of innervation, such as nerve conduction velocity or LPS contraction during eyelid movement. While

our findings offer detailed anatomical data, they should be interpreted with caution in clinical contexts requiring functional correlation. Furthermore, although the gender and age range of the cadavers are known, the age of each cadaver is not available. Therefore, it cannot provide information about age-related changes in the findings obtained.

Conclusion

In conclusion, in this study, the length, width, and thickness of the LPS were measured and recorded by considering anatomical landmarks. Regarding the thickness of the LPS, it was reported that the middle 1/3 part was the thickest compared to the other parts. This difference may be related to the innervation of the muscle; therefore, as the thickness of the muscle increases, the branches of the oculomotor nerve piercing the muscle may also increase. The variative distribution of the oculomotor nerve, which provides the innervation of the LPS, in the LPS is also crucial clinically. The findings reveal the anatomy and morphology of the LPS, and we think that this may be useful in surgical planning for the LPS and levator aponeurosis and in preventing complications during surgical interventions.

Author contributions G.N.C., A.K. wrote the main manuscript text, and G.N.C. prepared the Figs. 1–4 and Tables 1 and 2. All authors reviewed the manuscript.

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Availability of data and materials No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval Ethics committee approval of our study was received by the Istanbul Medical Faculty Clinical Research Ethics Committee (Number: 155281; date:31/03/2021).

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