Arşiv Kaynak Tarama Dergisi
Archives Medical Review Journal

DERLEME/REVIEW

Müller's Muscles: Three Different Smooth Muscles of the Eye and Orbit

Müller kasları: Göz ve Orbitanın Üç Farklı Düz Kası

Cansu Kibar Karagöz[1], Hatice Yenigül[1], Özge Coşkun Sağlam[2]

[1]Department of Anatomy, Faculty of Medicine, Istanbul Arel University, Istanbul, Türkiye
[2]Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Istanbul Bilgi University, Istanbul, Türkiye

ABSTRACT

Purpose: The eponym "Müller's muscle" has been used in various textbooks and academic articles to refer collectively to three different smooth muscles: orbital muscle, superior tarsal muscle and the circular fibers of the ciliary muscle. The aim of this review is to highlight the terminological confusion created in the literature by the use of the Müller's muscle eponym as a common name for three different muscles associated with the eye and orbit.
Methods: A comprehensive literature review was conducted in academic databases such as PubMed, Google Scholar, Scopus, and Web of Science to clarify clarify the appropriate usage of the term "Müller's muscle". Additionally, the descriptions of these muscles in leading medical school sources, atlases, and textbooks were examined. The detailed topographical locations, anatomical and morphological characteristics, histological structures, innervation and vascularisation, and clinical syndromes of the muscles were presented in a comparative manner.
Conclusion: We believe that our study will contribute to preventing naming confusion regarding these muscles, collectively referred to as 'Müller's muscle,' in future anatomy atlases, clinical guidebooks, and scientific studies.

Keywords: Müller's muscle, orbit, anatomy, eye

ÖZET

Amaç: "Müller kası" eponimi, çeşitli ders kitaplarında ve akademik makalelerde üç farklı düz kası (m. orbitalis, m. tarsalis superior ve m. ciliaris'in dairesel lifleri) ifade etmek için kullanılmıştır. Bu derlemenin amacı, literatürde Müller kası eponiminin göz ve orbita ile ilişkili üç farklı kas için ortak bir isim olarak kullanılmasıyla oluşan terminolojik karışıklığa dikkat çekmektir.
Yöntem: "Müller kası" teriminin uygun kullanımını netleştirmek için PubMed, Google Akademik, Scopus ve Web of Science gibi akademik veri tabanlarında kapsamlı bir literatür taraması yapıldı. Ayrıca, önde gelen tıp fakültesi kaynakları, atlaslar ve ders kitaplarındaki bu kasların tanımları incelendi. Kasların ayrıntılı topografik konumları, anatomik ve morfolojik özellikleri, histolojik yapıları, innervasyon ve vaskülarizasyonu ve klinik sendromları karşılaştırmalı olarak sunuldu.
Sonuç: Çalışmamızın, gelecekte anatomi atlaslarında, klinik rehberlerde ve bilimsel çalışmalarda topluca 'Müller kası' olarak adlandırılan bu kaslara ilişkin isimlendirme karışıklığının önlenmesine katkıda bulunacağına inanıyoruz.

Anahtar kelimeler: Müller kası, orbita, anatomi, göz

Introduction

The eponymous names of the three smooth muscles located in the orbit are attributed to the German anatomist Heinrich Müller. These muscles are: orbital muscle, superior tarsal muscle, and the ciliary muscle which are characterized by their circular fibers. The use of the term "Müller's muscle" to refer to all three muscles in the literature can lead to confusion. Therefore, a literature review was conducted using academic databases such as PubMed, Google Scholar, Scopus, and Web of Science in order to clarify the use of the term 'Müller's muscle'.

Correspondence Address / Yazışma Adresi
Cansu Kibar Karagöz, Istanbul Arel University, Faculty of Medicine Department of Anatomy, Istanbul, Türkiye e-mail: cansukibar7@gmail.com

2025;34(3):229-236
doi:10.17827/aktd.1612117
Geliş tarihi/ Received: 02.01.2025
Kabul tarihi/Accepted: 16.07.2025

This review will provide literature on these three muscles, all referred to as "Müller's muscles," and will discuss the use of the term "Müller's muscle."

Orbital Muscle

The orbital muscle of Müller is a small extraocular smooth muscle embedded in the periorbita[1]. It is located posteriorly in the orbit and fills the inferior orbital fissure. It separates the periorbital fat from the buccal fat pad[2]. It extends from the sphenoid bone to the zygomatic and maxillary bones and is closely related to the Zinn's ring (Common tendinous ring; Common anular tendon)[3] (Figure 1).

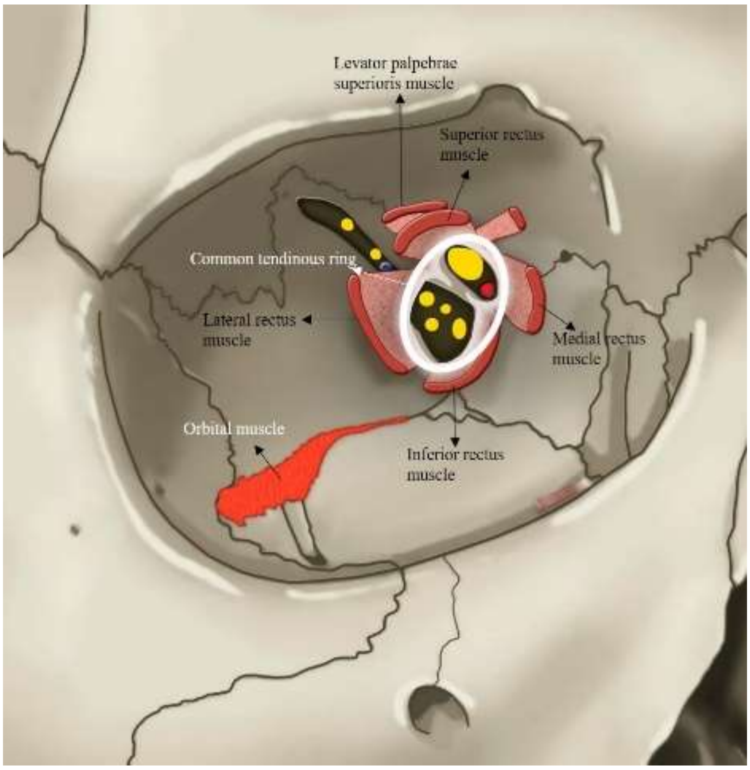

Figure 1. Muscles located in the right orbit, eye removed.

The superior surface of the muscle is adjacent to the rectus inferior muscle, the inferior branch of the oculomotor nerve, and the inferior ophthalmic vein. The inferior surface of the muscle is in proximity to the pterygopalatine fossa and the maxillary, zygomatic, and infraorbital nerves passing through this fossa[4].

The body of the muscle is wider than the inferior orbital fissure. The orbital muscle attaches laterally to the inferior orbital fissure on the ventral side and medially to the inferior orbital fissure on the dorsal side. The average weight of the muscle is 0.22 ± 0.19 g, with an average width of 4 ± 1 mm at its widest point and an average length of 22 ± 5 mm[3].

Sappey defined the orbital muscle as the "lower orbital muscle," while Whitnall referred to it as the "periorbital muscle"[5].

The orbital muscle is composed of smooth muscle cells. The muscle fibers extend from the craniomedial to the caudolateral direction in a slightly oblique plane towards the apex of the orbit. The muscle is largely made up of bundles of fibers that run parallel to each other. The dorsomedial portion of these parallel fibers is complemented and reinforced by vertically oriented muscle fibers[6]. Blood vessels and nerves, including the inferior ophthalmic vein, infraorbital artery, infraorbital nerve, and zygomatic nerve, pass between the muscle fibers[3]. Sympathetic innervation is provided by the superior cervical ganglion via the internal carotid plexus[7].

Its function in humans is not well understood. During embryonic development, it forms approximately 50% of the orbital base[8] and is thought to isolate the orbital contents from surrounding tissues[9]. Additionally, since it is pierced by veins connecting the ophthalmic veins to the pterygoid plexus, it is believed to play a role in regulating venous blood flow[10]. In adults, contraction of this muscle may cause a slight protrusion of the eye globe[7]. Furthermore, it serves as a septum for structures within the orbit, which is crucial for the normal development of extraocular structures[9].

Due to its location covering the inferior orbital fissure, this muscle has clinical and surgical significance as it provides a medical intervention to the orbit[4]. If sympathetic innervation to the orbital muscle is impaired, the muscle cannot function properly. This may lead to collapse of the eye contents and the development of enophthalmos[10].

Superior Tarsal Muscle

Superior tarsal muscle (STM) is another muscle known as Müller's muscle, which was first described by Müller in 1858. STM consists of smooth muscle fibres and is located in the upper eyelid. It originates from the inferior portion of the levator palpebrae superioris muscle (LPSM) and extends alongside it. The muscle inserts into the superior edge of the tarsus via a 1 mm tendon[11] (Figure 2).

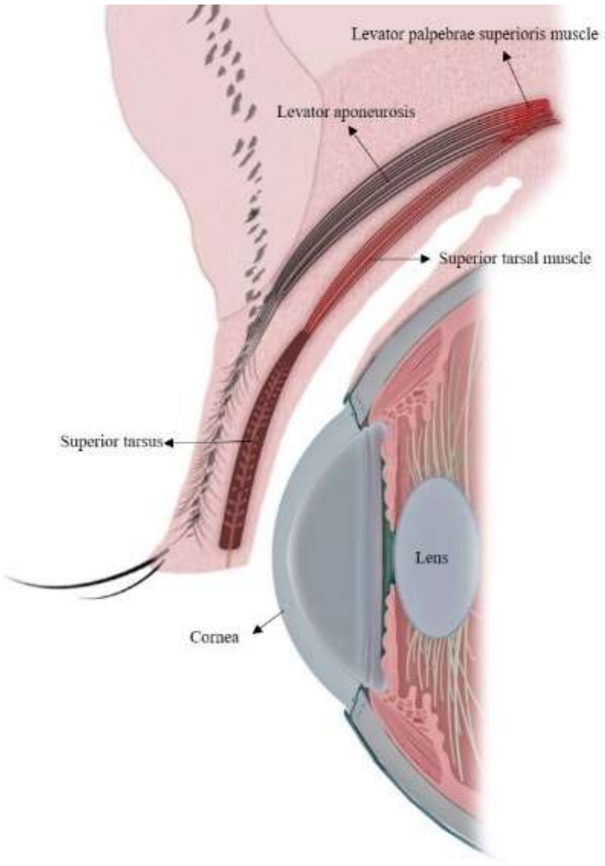

Figure 2. Schematization of the upper eyelid from the lateral view.

The LPSM aponeurosis is located in front of the muscle and the conjunctiva is located behind it. Superior tarsal muscle is approximately 15 mm wide, 10 mm long and 0.1-0.5 mm thick[12]. There is a transition area of loose connective tissue between the LPSM and STM fibres[13].

In some sources, smooth muscle fibres located deep in the LPSM are named as STM[7]. Thin smooth muscle fibres of the STM have differences that distinguish it from other smooth muscles. One of these differences is that STM contains not only smooth muscle fibres but also connective tissue and adipose tissue.

Furthermore, the smooth muscle cells of the muscle are sporadically spread out and not connected to each other[14].

Esperidião et al. classified the muscle into 4 patterns according to the attachment points to the superior tarsus.In Pattern 1, the muscle is observed to attach solely to the central portion of the upper tarsal margin. In Pattern 2M, the muscle is seen to attach to both the central and medial parts of the upper tarsal margin. In Pattern 2L, the muscle is observed to attach to both the central and lateral parts of the upper tarsal margin. In Pattern 3, the muscle is seen to attach to the entire extension of the upper tarsal border, spanning from the medial palpebral ligament to the lateral palpebral ligament. According to the results of the study, 63.27% of the cases were classified as P3, 24.49% as P2M, 8.16% as P2L and 4.08% as P1[13].

The upper eyelid is mainly raised by the LPSM. On the other hand, STM provides an extra 2 mm eyelid elevation in the upper eyelid in case of sympathetic system dominance[11,15]. Furthermore, it plays an active role in maintaining the tone of the elevated eyelid and ensuring the size of the palpebral fissure remains constant[16].

STM is arterial supplied by the lateral muscular branch of the ophthalmic artery. This branch also provides arterial supply to the lateral rectus, superior rectus, superior oblique and levator palpebrae superior muscles. The medial muscular branch of the ophthalmic artery supplies the other extraocular muscles. The venous blood drains into the vorticose veins and superior ophthalmic vein, and finally into the cavernous sinus[7,17].

The muscle is innervated by the sympathetic system. The postganglionic sympathetic fibres, which originate from the superior cervical ganglion, form a plexus around the internal carotid artery. The nerve fibres that leave the plexus enter the cranium and reach the cavernous sinus. The nerve fibres ultimately reach the orbit and then this muscle as a tightly wrapped nerve plexus encircling the ophthalmic artery, a branch of the internal carotid artery[7,17].

In the study reported by Yuzuriha et al., the STM was found to function as a mechanoreceptor via the stimulation of proprioceptive fibres. It also responds to the stimulation of sympathetic fibres[18]. Furthermore, Landau-Prat et al. have indicated that the Müller's muscle contains substantial myelinated sensory fibres that facilitate proprioceptive innervation[19].

Skeletal muscle fibres in the LPSM are intertwined with smooth muscle fibres in the STM. The opening of the upper eyelid with micro-movements or voluntary contractions of fast-twitch fibres in the LPSM stretch the mechanoreceptors in the STM. The resulting stimulus is conveyed to the mesencephalic trigeminal nucleus via the ophthalmic branch of the trigeminal nerve. Activation of the mesencephalic trigeminal nucleus results in the stimulation of the rostral locus coeruleus. The rostral locus coeruleus plays a role in regulating physiological arousal, which increases the microsaccade rate. Stretching of mechanoreceptors in the STM initiates reflex contractions of slow contractile fibres in the ipsilateral LPSM and frontalis muscle via the mesencephalic trigeminal nucleus[20]. It also initiates prolonged reflex contractions of slow-twitch fibres in the bilateral frontalis muscles and orbicularis oculi muscles for coordinated eye-eyelid-brow movements via the rostral locus coeruleus[21].

This muscle plays an active role in the opening of the eyelid and in clinical conditions in which it is affected, partial ptosis (drooping of the upper eyelid) is observed. Horner's syndrome, one of these clinical conditions, is usually caused by trauma to the neck and shoulder regions and consequent damage to the cervical sympathetic ganglia. As a consequence of this lesion, a ptosis of the upper eyelid of 2 to 3 mm is observed, resulting from paralysis of the STM, which has sympathetic innervation[11,22]. Conversely, exophthalmos (protrusion of the eyes forward) is observed in pathologies associated with hyperthyroidism, wherein the upper tarsal muscle displays hyperactivity[13].

Leshno et al. suggested the presence of eyelid-light reflex mediated by STM that occurs with sympathetic stimulation in the transition from light to dark conditions[23]. In their study, an average 8.3% retraction of the upper eyelid was observed with pupil dilation in the transition to the dark environment. Consequently, it has been reported that the STM expands the palpebral opening by adapting to the increase in pupil diameter to allow more light to enter the eye. This response may be referred to as the eyelid-light reflex[23].

In cases with a ptosis of less than 3 mm and a good function of the superior levator palpebrae muscle, a resection of the superior tarsal muscle is performed. Due to the high variability of the superior tarsal muscle, attention should be paid to its morphology in eyelid surgery[24].

Circular Fibers of the Ciliary Muscle

A section of the smooth muscle fibers located in the ciliary body of the eye also has the eponym Müller's muscle[25].

The ciliary body is a ring-shaped structure located in the vascular layer of the eye, between the iris and the choroidea. The width of the ring is approximately 5.9 mm on the nasal side and 6.7 mm on the temporal side[26]. In sagittal section, it has a triangular shape and the base of the triangle faces the anterior chamber. The apex of the triangle is located posteriorly in the ora serrata. While it is attached to the sclera externally, it occupies the posterior chamber and a small part of the vitreous cavity internally. The posterior part of the ciliary body, terminating at the ora serrata, is smooth, while its inner side contains numerous folds or projections extending into the posterior chamber. Lens zonules starting from the inner part connect the ciliary body to the lens (Figure 3). The ciliary body has two main functions: Aqueous humour production and accomodation[25].

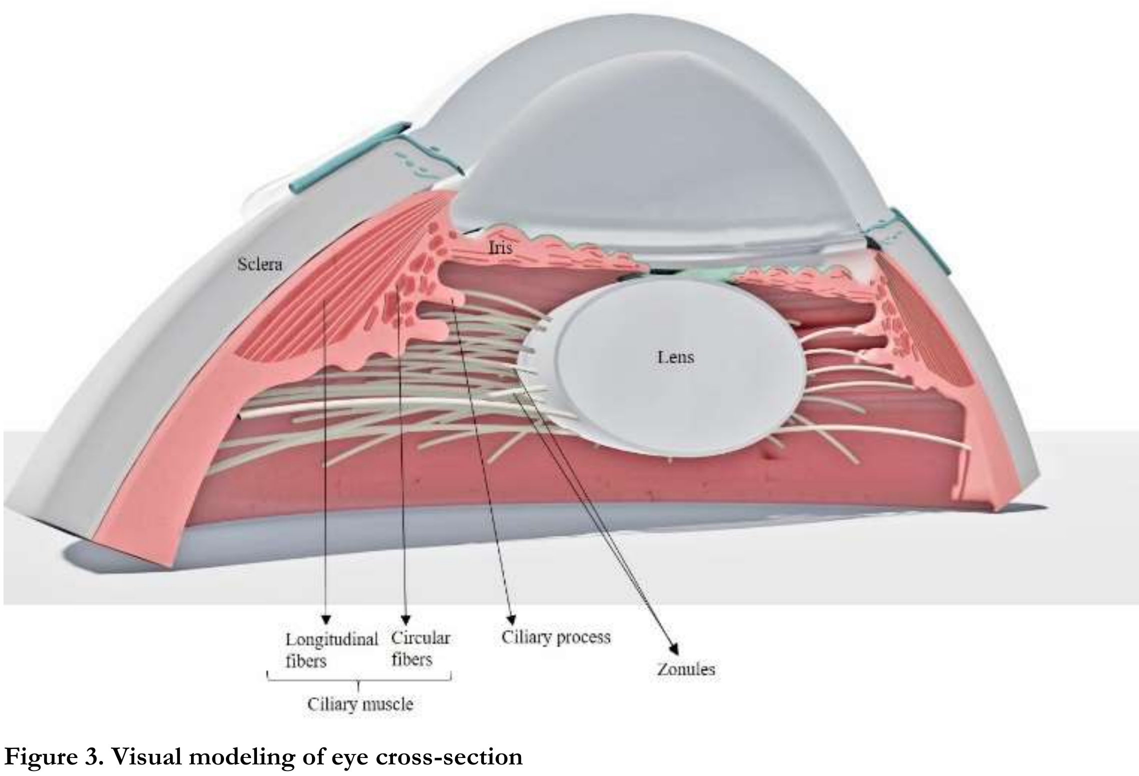

Figure 3. Visual modeling of eye cross-section

The ciliary body consists of the ciliary epithelium, ciliary body stroma, and ciliary muscle layer. The ciliary muscles consist of three bundles of smooth muscle fibers (longitudinal, radial, and circular) located in the anterior two-thirds of the ciliary body. They adjust the tension of the lens zonules to accommodate near and far vision. The fiber bundles embedded in the vascular connective tissue stroma are intertwined. These muscle fibers are named after scientists who described the anatomy of the ciliary body, such as Brücke, Müller and Ivanoff. Brücke described longitudinal muscle fibers; Ivanoff described radial/oblique muscle fibers; Müller described circular smooth muscle fibers[27].

The longitudinal fibers described by Brücke are the outermost layer of the ciliary muscle and run parallel to the sclera in the anterior third of the choroid. It starts from the scleral spur and adjacent corneoscleral trabeculae and attaches posteriorly to the anterior part of the choroid. The fibers are on average 3.4 mm long[27]. The length of the Brücke's muscle increases with increasing axial length of the eye, whereas its cross-sectional area is independent of axial length[27,28].

The middle layer contains radial/oblique fibers, also called Ivanoff's muscle. This layer is the transition from longitudinal fibers to circular fibers[27].

The circular muscle fibers on the inside of the ciliary muscle are another muscle in the orbit called Müller's muscle. It is located in the connective tissue at the base of the ciliary processes. Circular fibers act as a sphincter for the ciliary body[26]. Both Müller's and Ivanoff's muscle fibers are fixed to the muscle elastic tissue to which the iris dilator muscle attaches[29].

Mao et al. measured the maximum thickness of Müller's and Iwanoff's muscles as 245 ± 125 µm and cross-sectional area as 0.19 ± 0.11 mm^2. The cross-sectional area of Müller's and Ivanoff's muscles decreases with increasing axial length[27].

The ciliary muscles are innervated by the autonomic nervous system. Parasympathetic stimulation provides contraction, while sympathetic stimulation produces an inhibitory effect. The cell bodies of the nerve fibers providing parasympathetic innervation are located in the parasympathetic nucleus (Edinger-Westphal) of the oculomotor nerve. Presynaptic fibers travel through the oculomotor nerve and synapse with postsynaptic cell bodies in the ciliary ganglion. Postsynaptic parasympathetic fibers reach the ciliary muscles via the short ciliary nerves. Contraction of Brücke's muscle pulls the choroid forward. Contraction of the Müller's muscle relaxes the lens zonules that lie between the ciliary processes and the lens. The tension of the lens decreases and the lens becomes thicker and more refractive. This allows the eye to focus on nearby objects (accommodation). In addition, contraction of the Brücke's muscle pulls the scleral spur backward, expanding the trabecular meshwork and thus facilitating drainage of the humor aquosus[25,26,30].

Presynaptic sympathetic neuron cell bodies are located in the lateral gray horn of the first thoracic segment of the spinal cord. After synapsing in the superior cervical ganglion, the postsynaptic fibers travel in the plexus around the internal carotid artery. These fibers join branches from the internal carotid plexus or the nasociliary nerve and reach the orbit. Fibers passing through the ciliary ganglion without synapsing reach the muscles. With sympathetic effect, ciliary muscle fibers relax and the eye goes into a resting state and is used for distance vision[25].

While the amount of connective tissue between the ciliary muscle fibers increases over time, the contractile strength of the ciliary muscle does not decrease over time[31].

Problems with the drainage of aqueous humor cause an increase in intraocular pressure and may result in glaucoma. In the presence of glaucoma, the cross-sectional area of the Müller's and Ivanoff's muscles decreases, while the dimensions of the Brücke's muscle are not affected by glaucoma[27].

Conclusion

The eponym "Müller's muscle" has been used in various textbooks, anatomy atlases, and articles across medical and health fields. In Snell's work, the term 'Müller's muscle' refers exclusively to the orbital muscle, while in Sobotta, it refers to the ciliary muscle. The atlases of Netter, Lippincott, and Prometheus use the term solely for the tarsalis superior muscle. Grays' Anatomy uses the term for both the orbital muscle and the tarsalis superior muscle. Additionally, some articles discussing "Müller's muscle" do not specify which muscle is being referred to.

This study provides topographic, clinical, and functional anatomical information about the orbital muscle, tarsalis superior muscle, and circular fibers of the ciliary muscle, all of which are referred to as "Müller's muscle" (Table 1). We believe that the fact that the term 'Müller's muscle' is used for different anatomical structures in the literature is an issue that requires attention from a terminological perspective. Consequently, we believe this study can help prevent confusion regarding the definition of these muscles, collectively known as "Müller's muscle."

Table 1. Comparison of Superior Tarsal Muscle, Orbital Muscle and Circular Fibers of the Ciliary Muscle

	Orbital Muscle	Superior Tarsal Muscle	Circular Fibers of the Ciliary Muscle
Location	Located in the lower part of the orbit, in the infraorbital fissure.	Located on the deep surface of the levator palpebrae superioris muscle in the upper eyelid.	Located in the anterior two-thirds of the ciliare body
Function	Maintains orbital content position and provides structural tone.	Assists in elevating the upper eyelid by a few millimeters.	Provides near vision (accommodation) by changing the tension of the ciliary zonule.
Clinical significance	Enophthalmos may occur due to loss of sympathetic innervation.	Partial ptosis occurs in case of sympathetic denervation (Horner's syndrome).	Accommodation disorders and age-related conditions such as presbyopia

Acknowledgments: The authors would like to thank architect Yiğit Kağan KARAGÖZ for creating the illustrations.

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