Heliyon 10 (2024) e29770

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Lateral rectus pulley concerning the orbital wall. Area of a stereotyped bony insertion

Paulo Freitas-da-Costa [a,b,c,*], Pedro A. Pereira [c,d], Hélio Alves [c], M. Dulce Madeira [c,d]

[a] Department of Ophthalmology, São João University Hospital Center, Porto, Portugal
[b] Department of Surgery and Physiology, Faculty of Medicine, University of Porto, Portugal
[c] Anatomy Unit, Department of Biomedicine, Faculty of Medicine, University of Porto, Portugal
[d] Center for Health Technology and Services Research (CINTESIS), Porto, Portugal

ARTICLE INFO

Keywords:
Rectus muscle pulleys
Anatomy
Regional
Connective tissue
Oculomotor muscles
Eye movements
Orbit
Strabismus

ABSTRACT

Purpose: To examine the lateral rectus muscle pulley and its bony insertion concerning the orbital rim and periorbita.

Design: Prospective. An observational anatomic study.

Methods: Study population: Twenty postmortem orbits (10 right, 10 left) of 10 Caucasian cadavers (8 females, 2 males; age range at death, 57–100 years; median age, 79.5 years) fixed by the Thiel method.

Intervention: The floor of the temporal fossa was exposed, and a bone window on the lateral wall of the orbit, posterior to the sphenozygomatic suture, was created, keeping the periorbita intact. The lateral canthus and lateral palpebral ligament were isolated and opened, and the eyelids were folded back. The frontozygomatic suture was identified, and the orbital septum opened adjacent to the orbital rim. The conjunctiva was opened at the limbus, and the lateral rectus insertion was isolated. The bone pillar containing the frontozygomatic suture and the insertion of the periorbita and the pulley was isolated and removed en bloc. The lateral rectus muscle was isolated and excised.

Main outcome measures: Position of the pulley ring on the lateral rectus muscle belly and its bony attachment area in the lateral wall of the orbit.

Results: The pulley bony attachment was roughly quadrilateral with an approximate area of 90 mm^2, 3 mm (mean, range 1–5 mm) posteroinferior to the frontozygomatic suture and 1 mm posterior to the orbital rim. The anterior margin of the pulley sleeve was found at 21.0 mm (median, p25-75 20.0–22.8) from the scleral insertion.

Conclusions: The lateral rectus pulley is stereotyped in its position in the muscle belly and its bony insertion, coinciding with the point of greatest adhesion of the periorbita to the anterior part of the lateral wall of the orbit.

1. Introduction

Diagnosis and surgical correction of strabismus requires precise anatomic knowledge of the extraocular muscles (EOM) and their

---

* Corresponding author. Anatomy Unit, Department of Biomedicine. Faculty of Medicine, University of Porto. Portugal. Alameda Prof. Hernâni Monteiro, 4200-319, Porto, Portugal.

E-mail addresses: paulofreitascosta@gmail.com, paulofreitascosta@med.up.pt (P. Freitas-da-Costa).

https://doi.org/10.1016/j.heliyon.2024.e29770
Received 30 May 2023; Received in revised form 14 April 2024; Accepted 15 April 2024

relationships with orbital tissues. The correlation of high-resolution magnetic resonance imaging (MRI) with modern orbital histology has provided valuable new insights into the role of orbital mechanics in ocular motility. Connective tissue structures, which reportedly restrain EOM sideslip and function as pulleys, are composed of collagen, elastin, and smooth muscle and are coupled to the orbital walls in sleeves that envelop each rectus EOM [1–4]. The pulleys are important mechanical structures that determine the pulling directions of the rectus muscles, serving as their functional mechanical origins [4–7]. They have highly stereotypic positions in normal individuals [5,8], while abnormal pulley positions are responsible and associated with patterns of incomitant strabismus [9–12].

Since the pulleys are close to the globe center, describing their precise location concerning the eye is essential to the kinematic behavior. For that, a coordinate reference has been defined. MRI three-dimensional models have been used to predict the globe center. They are remarkably accurate, with the analysis of serial quasi-coronal images, in determining the functional location of the pulleys [5, 8]. However, its suspension points on the orbital bony rim must still be characterized and can be dissected and exposed reliably. The present study aims to describe the relationship between the bony anchor of the lateral rectus pulley and the periorbita.

2. Material and methods

2.1. Human cadaveric material

Twenty postmortem orbits (10 right, 10 left) of 10 Thiel-embalmed [13] Caucasian cadavers (8 females, two males; age range at death, 57–100 years; median age, 79.5 years) were analyzed. The orbits were studied bilaterally from the ten cadavers. Additionally, four orbits (3 right, one left) from 4 Caucasian formalin-fixed cadavers (1 female, three males; age ranges at death, 59–88 years) were studied. None of the cadavers had clinical evidence of a previous eyelid or orbital trauma, surgery, tumor, Graves' orbitopathy, cerebral nerve palsy, strabismus, or another periocular pathologic feature. Consent and approval to use all cadavers for educational purposes and scientific research by the Portuguese Act n° 274/99 were obtained. All cadavers were registered within the Unit of Anatomy of the Department of Biomedicine, Faculty of Medicine of the University of Porto—the methods for securing human tissue

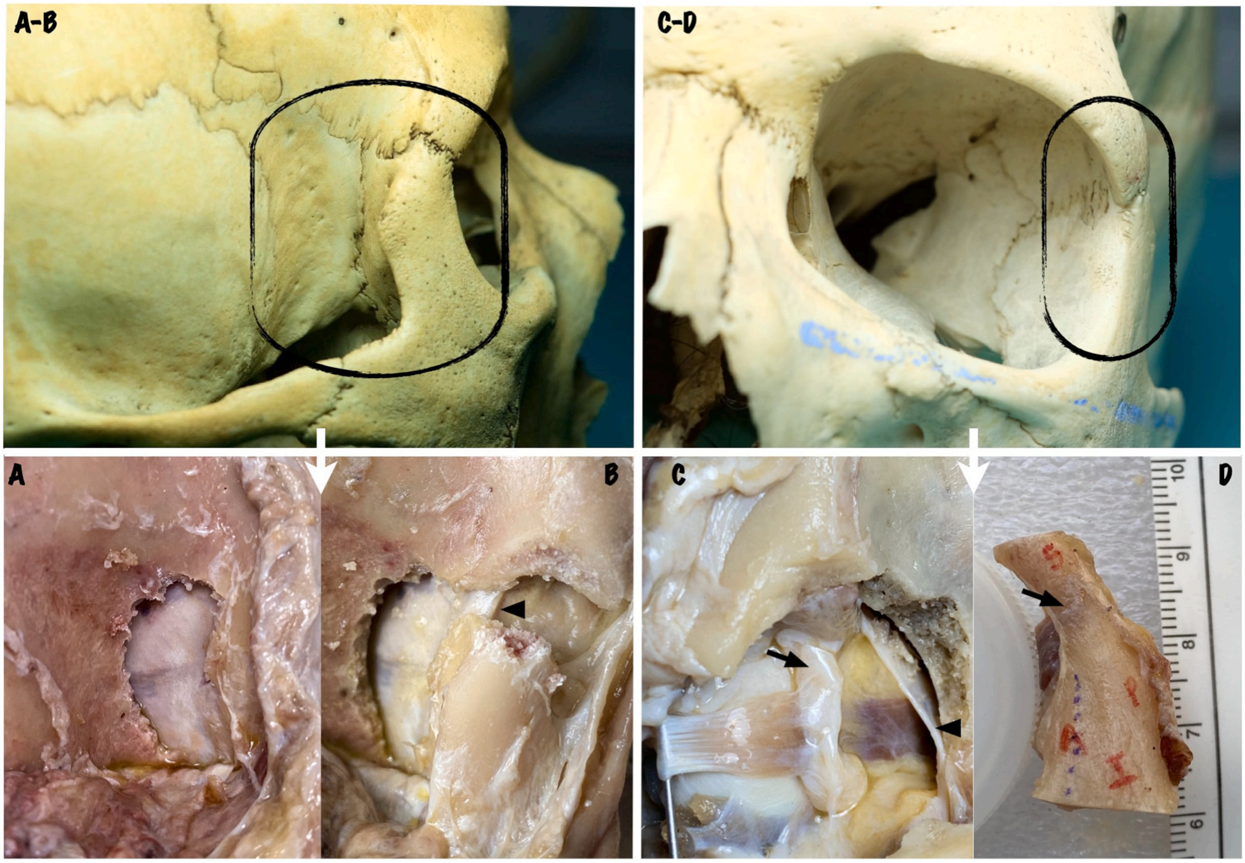

Fig. 1. Thiel-embalmed cadaver dissection. **A,** right side – bone window on the lateral wall of the orbit keeps the periorbita intact. **B,** right side -individualization of the lateral bone pillar by the zygomatic process of the frontal bone. Note the suspension of the anterior periorbita (black arrowhead). **C,** left side – exposure of the lateral rectus muscle path after opening the periorbita (black arrowhead) and removing the lateral bone pillar. Note the ring pulley of the lateral rectus muscle (black arrow). **D,** left side – lateral bone pillar after removal. Note the frontozygomatic suture (black arrow). S, superior; A, anterior; I, inferior; P, posterior.

adhered to the tenets of the Declaration of Helsinki.

2.2. Dissectional approach

In the 10 Thiel-embalmed cadavers, we aimed the anatomical characterization of the bony insertion of the connective tissue apparatus containing the lateral rectus pulley. All the cadavers were supine on the dissection table to perform the dissection work. When necessary, to restore the original spherical shape of the eyeballs, 4 % agar (Bacto Agar; Becton, Dickinson and Company, Sparks, MD, USA) dissolved in hot distilled water was carefully injected into the eyeballs with a needle attached to a syringe, via pars plana at 3–4 mm posterior to the surgical limbus nasally. The agar was allowed to solidify before starting dissection. Two incisions were made with a scalpel through the entire thickness of the soft tissues. One along the frontal process of the zygomatic bone and superior temporal line until the level of the auricle (pinna) and another along the superior border of the zygomatic arch. Using a Farabeuf periosteal raspatory, the temporal muscle was released from its skull attachment, and all soft tissues were reflected posteriorly to expose the floor of the temporal fossa. The remaining dissection work was carried out through the following steps.

i. A small square block of bone was carefully removed, with a surgical mallet and an osteotome, just posterior to the spheno-zygomatic suture, creating a small window in the lateral wall of the orbit to expose the periorbita, which was left intact (Fig. 1A). Using a Kerrison rongeur, the window was enlarged. Anteriorly, it was extended to identify the point where the periorbita firmly adheres to the bone at the orbital rim (the lateral pillar formed by the frontal process of the zygomatic bone and the zygomatic process of the frontal bone).
ii. The region of the lateral canthus was carefully dissected to identify, through an anterior approach, the lateral palpebral ligament. This ligament was opened, and the upper and lower eyelids reflected. The lateral margin of the orbital opening and the lateral third of the supraorbital and infraorbital margins were entirely exposed by reflecting the soft tissues in a superior and inferior direction, and the zygomaticofacial foramen was identified. This foramen was not found in all cadavers (see Results).
iii. The orbital septum associated with each eyelid was cut and opened.
iv. Three measurements were taken: a) the distance between the anterior limit of the frontozygomatic suture and the point of intersection of a line drawn along the long axis of the infraorbital margin and a line along the central axis of the lateral margin of the orbital opening (FZS_Angle); b) the distance between the anterior limit of the frontozygomatic suture and the zygomaticofacial foramen (FZS_ZFf); c) the distance between the anterior limit of the frontozygomatic suture and the superolateral limit of the superior orbital fissure, using a probe placed externally to the periorbita (FZS_SOF).
v. A temporal limbal conjunctiva incision with a trapezoid flap with its base in the fornix and a blunt subconjunctival debridement was performed. The lateral rectus muscle attachment into the sclera was identified with a surgical hook.
vi. An electric bone saw was used to cut halfway through the frontal process of the zygomatic bone and the zygomatic process of the frontal bone. Then, a surgical mallet and an osteotome were used to break the bone along the scored lines. The solo piece of bone (lateral pillar) remained suspended by the periorbita and the lateral rectus pulley (Fig. 1B).
vii. The posterior part of the lateral periorbita was opened to identify the lateral rectus muscle belly. Then, two curved radial incisions were made in the periorbita in an anteroposterior direction. One of the incisions started at the anterosuperior limit and the other at the anteroinferior limit of the exposed periorbita and conjunctiva. These two incisions converge to meet posteriorly. These incisions were carefully made to circle and avoid the lateral rectus muscle and its pulley ring. Thus, the bony lateral pillar containing both the periorbita and pulley attachment was isolated and removed (Fig. 1C and D). The bony attachment of the pulley was observed and measured with a caliper (Fig. 2A–C).
viii. Finally, almost all the lateral rectus muscle was excised. The tendon was sectioned at its scleral origin, and its muscular belly was cut posteriorly to the pulley ring. The length of the muscle between its attachment to the sclera and the anterior limit of the pulley ring was measured (Fig. 2D).

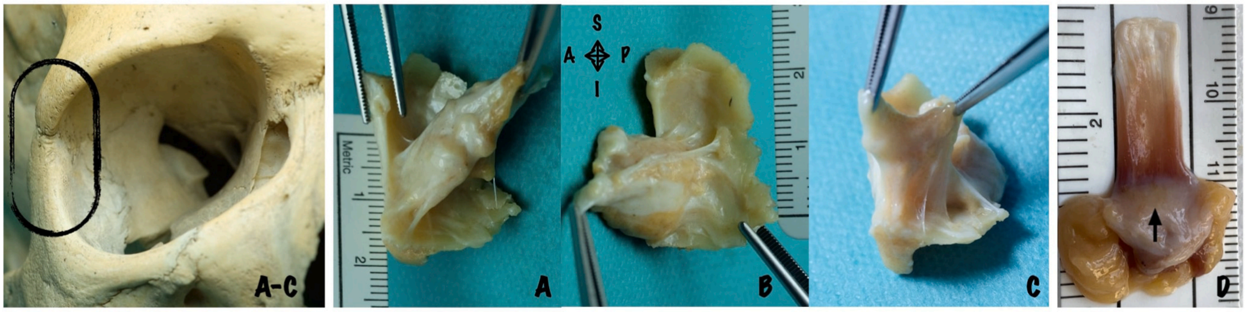

Fig. 2. Thiel-embalmed cadaver. **A-C,** Internal surface of the right bone lateral pillar. The lateral rectus pulley attachment was measured with a caliper. **A,** anterior border. **B,** posterior border. **C,** inferior border. **D,** lateral rectus muscle after removal. Note the pulley ring (black arrow) whose distance from insertion was measured. S, superior; A, anterior; I, inferior; P, posterior coordinates.

The four formalin-fixed orbits were used for gross anatomy study and description of the relationship between the lateral rectus muscle and its pulley, periorbita, and the lateral palpebral ligament. Orbital dissection was performed through the superior wall. After opening the orbital lamina of the frontal bone, the periorbita was opened. The nervous, vascular, adipose, and connective tissue structures and the lacrimal gland were successively and meticulously retracted to expose the trajectory of the lateral rectus muscle.

Descriptive statistics are presented with absolute counts and proportions or with median and percentile 25–75 values, as appropriate. All data were analyzed using SPSS version 26 (SPSS Inc, Chicago, IL).

3. Results

All measurements of the distances described are summarized in Table 1. In all specimens, the lateral rectus pulley bony attachment was roughly quadrilateral in shape, and thus anterior, posterior, superior, and inferior borders could be defined, and their linear length measured. With an approximate area of 90 mm^2, it was distant from the anterior limit of the frontozygomatic suture by an average of 3 mm (range 1–5 mm) in a posteroinferior direction and 1 mm posterior to the orbital rim. The anterior margin of the pulley sleeve was found at 21.0 mm (median, p25-75 20.0–22.8) from the scleral insertion of the muscle.

The periorbita is firmly attached to the bone at the orbital margin and the suture lines, such as the sphenozygomatic suture (Fig. 1B). Otherwise, it is loosely attached. It is easily dissected to enter the relatively bloodless subperiosteal space, especially in its lateral and superior aspects. The lateral rectus muscle course anteriorly with its global belly surface molded by the retrobulbar fat and its enveloping connective-tissue sheet. The septa that lie posteriorly between the orbital surface of the muscle belly and the periorbita are made of loose connective tissue of low resistance and elasticity. As it penetrates the posterior Tenon's fascia, it is ensheathed in its pulley and firmly anchored to the periorbita (Fig. 3A–C). The lateral rectus pulley relates anteriorly and is contiguous with the posterior limb of the lateral palpebral ligament and the lateral conjunctival fornix (Fig. 3A).

The zygomaticofacial foramen presented the greatest variability in its position, with a range of 11.0 mm (16.0–27.0 mm) in its distance to the frontozygomatic suture, being present in only 75 % of the samples and bilaterally in 60 % of the cadavers. The absence was bilateral in one cadaver, and in the remaining three cadavers, the absence was unilateral (two cases on the left and one on the right side).

4. Discussion

The histological description of the stereotypic occurrence of connective tissue septa within the orbit recognized that it might have significance for normal EOM actions [1,2]. These connective-tissue bands or fascia with a presumed pulley effect were initially described back in the 19th century, anatomically stating the ability of these tissues to bend and change the direction of the horizontal rectus tendon on the way to its insertion. The term pulley was first used at the time [14]. The location near the globe equator where these rectus muscles penetrate the posterior Tenon's fascia is of a high standard in ordinary people [4]. We found a median distance for the lateral rectus pulley ring (the dense collagen sleeve) of 21.0 mm from the lateral rectus muscle scleral insertion. It should be noted that this measurement was linear, carried out in a straight line after the excision of the muscle, and did not consider the radius of curvature of the globe. This result aligns with previous histological [4] and MRI studies [5,8], showing a more posterior positioning of the pulley sleeves in the lateral rectus muscle than in the medial rectus muscle. Both are 0.3 mm inferior, but the lateral rectus muscle at 9 mm and the medial rectus muscle at 3 mm posterior to the globe center [5,8]. Likewise, when performing posterior fixation sutures

Table 1

Measurements of the different orbital distances. In millimeters (mm).

	FZS_Angle	FZS_ZFf	FZS_SOF	FZS_LRPb	LRPb				LRPr_LRs
					ANT	POST	SUP	INF	
N	20	15	20	20	20	20	20	20	20
Mean	24.4	22.9	34.5	3.0	9.9	9.6	9.3	9.2	21.6
Median	24.0	25.0	35.0	3.0	10.0	10.0	9.0	9.0	21.0
Sd-Dev	2.4	3.3	2.3	1.1	0.8	1.0	1.0	1.0	2.0
Min-Max	20.0–28.0	16.0–27.0	26.0–37.0	1.0–5.0	9.0–12.0	8.0–12.0	8.0–11.0	7.0–11	19.0–27.0
P25–P75	23.0–27.0	20.0–25.0	34.0–35.8	2.0–4.0	9.0–10.0	9.0–10.0	8.3–10.0	8.0–10.0	20.0–22.8

ZFS_Angle, distance between the anterior limit of the frontozygomatic suture and the point of intersection of a line drawn along the long axis of the infraorbital margin and a line along the central axis of the lateral margin of the orbital opening.
FZS_ZFf, the distance between the anterior limit of the frontozygomatic suture and the zygomaticofacial foramen.
FZS_SOF, the distance between the anterior limit of the frontozygomatic suture and the superolateral limit of the superior orbital fissure.
LRPb, lateral rectus pulley bony insertion.
ANT, anterior border.
POST, posterior border.
SUP, superior border.
INF, inferior border.
LRPr_LRs, the distance between the lateral rectus scleral insertion and its pulley anterior limit.
Min-Max, the minimum-maximum interval of values.
P25–P75, percentile 25–75.

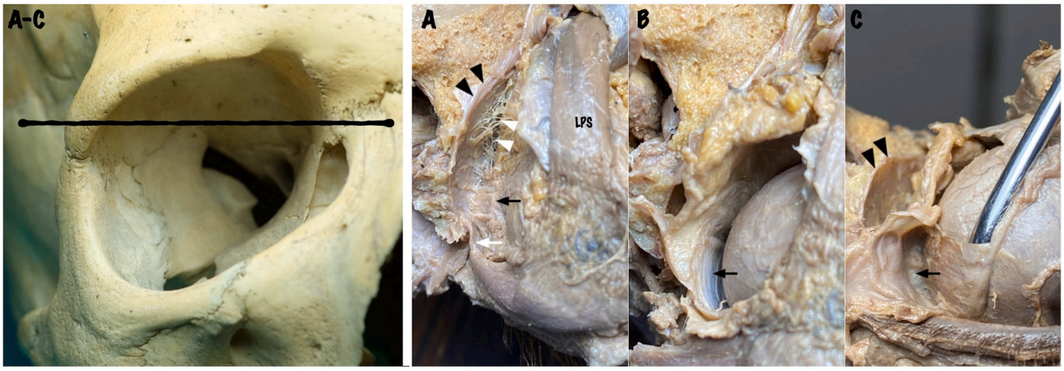

Fig. 3. The right orbit of a formalin-fixed cadaver in a superior approach dissection. **A-C,** the black line, defines the horizontal dissection plane. **A,** Path of the lateral rectus muscle concerning the periorbita (black arrowheads). Posteriorly loose connective tissue septa (white arrowheads), anteriorly the dense pulley attachment (black arrow). Note its relationship with the posterior limb of the lateral palpebral ligament (white arrow). LPS, levator palpebrae superioris muscle. **B,** Tenon's capsule was opened, and after its penetration, the lateral rectus muscle tendon path was exposed (black arrow). **C,** Anterior view of the insertion of the lateral rectus muscle and the anterior limit of its pulley (black arrow). The periorbita is also visible (black arrowhead).

of the medial rectus muscle, strabismus surgeons can see its pulley ring at 12 mm (cord length) from the insertion (equivalent to 14 mm of arc length).

Moreover, MRI demonstrated that the extraocular muscle orbital layers dynamically regulate anteroposterior pulley locations to modulate pulling directions systematically with gaze direction [7,8]. For that, it's fundamental that the path and direction of the lateral rectus capsulopalpebral fascia remain stable. This fascia, also known as lateral check ligament, is the solid triangular fibroelastic tissue that bridges the pulley ring to the lateral orbital bony pillar, the lateral palpebral ligament, and the conjunctival fornix reaching the lateral aspect of the upper and lower tarsal plates [15,16]. In this study cohort, the bony attachment area seems to have a standard dimension and a coordinate position, horizontal and vertical. Certain pattern strabismus, congenital and acquired, are associated with heterotopic rectus pulleys and unstable pulleys shifting abnormally with the gaze [9–12]. Interesting adnexal signs, like blepharoptosis or floppy lower lids, are also noticed in these patients. New findings indicated that Müller's muscle is not an independent structure in the upper eyelid but rather a component of the peribulbar smooth muscle network, continuous with the capsulopalpebral fascia and the pulleys, which might explain this association [17].

Our results corroborate the data found in the literature regarding the variability of the presence and location of the zygomaticofacial foramen [18–20]. The extrinsic ocular muscles may vary lightly in origin, position, and insertion. However, anatomical anomalies of EOMs are rarely described in the literature and include the absence of specific muscles [21,22], duplication or occurrence of additional bellies or tendons [23,24], and accessory or supernumerary rectus muscles [25,26]. Such variations may cause several changes in structure morphology and spatial organization within the orbit. That may be important for orbital imaging or surgical procedures performed on EOMs [27,28]. Accessory rectus muscles seem to be a homogeneous group, as the common feature of this group is an origin at the annular tendon (annulus of Zinn), localization lateral to the optic nerve bridging the superior and inferior rectus, and innervation by the inferior branch of the oculomotor nerve [26]. Although these anatomical variations could be theoretically implicated in eye movement disorders, this was not the case in the published cases. In none of the cadavers in the present study were there any variations in the macroscopic anatomy of the EOMs, which could influence the results.

Three-dimensional reconstruction with specific model-derived predictions demonstrated the stability of rectus EOM belly paths throughout the oculomotor range without side-slip in eccentric gazes [3]. However, which structures or tissues keep the muscle's belly in place in their retrobulbar path is subject to debate. The retrobulbar fat and its enveloping connective-tissue sheets limit the sideways shift of rectus muscle bellies in eye movements out of the plane of the muscle. They are well capable of keeping it in place [29]. It was clear from these specimens that the connective septa between the lateral rectus muscle belly and the posterior periorbita are loose and not very dense, so it seems unlikely that they will significantly affect this issue.

Formalin was traditionally used to preserve human material to study and teach gross anatomy. However, it has been considered that embalmed cadavers do not exhibit many of the qualities of living organs, among which are color, softness, and pliability [30]. At the same time, the composition of Thiel embalming solution [31] accounts for the color realism of tissues, tissue pliability, and enhanced joint motion, making this method particularly suitable as a tissue substitute for surgical intervention training [24]. The predominant surgical disciplines using the Thiel method are musculoskeletal, otolaryngology, general & visceral, and vascular surgery [32]. We found no reports of this method's use in dissection or orbit surgery. The appearance and flexibility of the peribulbar fascial tissue, the periorbita, the EOM, and the consistency of the retrobulbar fat, behaving almost like a fluid, remain more "lifelike."

5. Conclusion

The lateral rectus pulley has a solid anterolateral attachment to the anterior part of the lateral wall of the orbit, adjacent to the posterior limb of the lateral palpebral ligament at the orbital margin, with an approximate area of 90 mm^2. Its anterior edge is found at

21.0 mm from its scleral insertion. In its superior and lateral surfaces, the posterior periorbita is only loosely attached to the periosteum. Anteriorly to the sphenozygomatic suture, it is continuous and firmly coupled with the orbital margin. Due to tissue morphology being more similar to in vivo, the Thiel embalming method would be preferred for postgraduate anatomical study and surgical education, with applicability in the practical training of ophthalmologists, especially for the strabismus and orbit subspecialties.

Funding

None.

Institutional review board statement

Consent and approval to use all cadavers for educational purposes and scientific research by the Portuguese Act n° 274/99 were obtained, and all cadavers were registered within the Unit of Anatomy of the Department of Biomedicine, Faculty of Medicine of the University of Porto—the methods for securing human tissue adhered to the tenets of the Declaration of Helsinki. Research approved by the Ethics Committee of the Faculty of Medicine of the University of Porto – approval ID number 30/21, 05-04-2021.

Informed consent statement

Consent and approval to use all cadavers for educational purposes and scientific research by the Portuguese Act n° 274/99 were obtained.

Data availability statement

Raw data for datasets are not publicly available to preserve individuals' privacy under the European (and Portuguese) General Data Protection Regulation but are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Paulo Freitas-da-Costa: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Pedro A. Pereira:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Hélio Alves:** Writing – review & editing, Formal analysis. **M. Dulce Madeira:** Writing – review & editing, Validation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors sincerely thank those who donated their bodies to science so that anatomical research can be performed. Results from such a study can potentially improve patient care and increase humankind's overall knowledge. Therefore, these donors and their families deserve our highest gratitude.

References

[1] L. Koornneef, New insights in the human orbital connective tissue. Result of a new anatomical approach, Arch. Ophthalmol. 95 (7) (1977 Jul) 1269–1273, https://doi.org/10.1001/archopht.1977.04450070167018.

[2] L. Koornneef, Orbital septa: anatomy and function, Ophthalmology 86 (5) (1979 May) 876–880, https://doi.org/10.1016/s0161-6420(79)35444-6.

[3] J.M. Miller, Functional anatomy of normal human rectus muscles, Vision Res. 29 (2) (1989) 223–240, https://doi.org/10.1016/0042-6989(89)90126-0.

[4] J.L. Demer, J.M. Miller, V. Poukens, H.V. Vinters, B.J. Glasgow, Evidence for fibromuscular pulleys of the recti extraocular muscles, Invest. Ophthalmol. Vis. Sci. 36 (6) (1995 May) 1125–1136.

[5] R.A. Clark, J.M. Miller, J.L. Demer, Location and stability of rectus muscle pulleys. Muscle paths as a function of gaze, Invest. Ophthalmol. Vis. Sci. 38 (1) (1997 Jan) 227–240.

[6] R.A. Clark, A.L. Rosenbaum, J.L. Demer, Magnetic resonance imaging after surgical transposition defines the anteroposterior location of the rectus muscle pulleys, J AAPOS 3 (1) (1999 Feb) 9–14, https://doi.org/10.1016/s1091-8531(99)70088-1.

[7] J.L. Demer, S.Y. Oh, V. Poukens, Evidence for active control of rectus extraocular muscle pulleys, Invest. Ophthalmol. Vis. Sci. 41 (6) (2000 May) 1280–1290.

[8] R.A. Clark, J.M. Miller, J.L. Demer, Three-dimensional location of human rectus pulleys by path inflections in secondary gaze positions, Invest. Ophthalmol. Vis. Sci. 41 (12) (2000 Nov) 3787–3797.

[9] R.A. Clark, J.M. Miller, A.L. Rosenbaum, J.L. Demer, Heterotopic muscle pulleys or oblique muscle dysfunction? J AAPOS 2 (1) (1998 Feb) 17–25, https://doi.org/10.1016/s1091-8531(98)90105-7.

[10] S.Y. Oh, R.A. Clark, F. Velez, A.L. Rosenbaum, J.L. Demer, Incomitant strabismus associated with instability of rectus pulleys, Invest. Ophthalmol. Vis. Sci. 43 (7) (2002 Jul) 2169–2178.

[11] Z. Chaudhuri, J.L. Demer, Sagging eye syndrome: connective tissue involution as a cause of horizontal and vertical strabismus in older patients, JAMA Ophthalmol 131 (5) (2013 May) 619–625, https://doi.org/10.1001/jamaophthalmol.2013.783.

[12] J.L. Demer, The Apt Lecture. Connective tissues reflect different mechanisms of strabismus over the life span, J AAPOS 18 (4) (2014 Aug) 309–315, https://doi.org/10.1016/j.jaapos.2014.01.019.

[13] R. Eisma, C. Lamb, R.W. Soames, From formalin to Thiel embalming: what changes? One anatomy department's experiences, Clin. Anat. 26 (5) (2013 Jul) 564–571, https://doi.org/10.1002/ca.22222.

[14] J.R. Tenon, J. Naus, R. Blanken, Anatomical observations on some parts of the eye and eyelids, 1805. Strabismus 11 (1) (2003 Mar) 63–68, https://doi.org/10.1076/stra.11.1.63.14089.

[15] G.L. Ruskell, I.B. Kjellevold Haugen, J.R. Bruenech, F. van der Werf, Double insertions of extraocular rectus muscles in humans and the pulley theory, J. Anat. 206 (3) (2005 Mar) 295–306, https://doi.org/10.1111/j.1469-7580.2005.00383.x.

[16] H. Kang, Y. Takahashi, A. Ichinose, T. Nakano, K. Asamoto, H. Ikeda, M. Iwaki, H. Kakizaki, Lateral canthal anatomy: a review, Orbit 31 (4) (2012 Aug) 279–285, https://doi.org/10.3109/01676830.2012.694957.

[17] H. Kakizaki, Y. Takahashi, T. Nakano, K. Asamoto, H. Ikeda, D. Selva, I. Leibovitch, Müller's muscle: a component of the peribulbar smooth muscle network, Ophthalmology 117 (11) (2010 Nov) 2229–2232, https://doi.org/10.1016/j.ophtha.2010.02.018.

[18] F. Aksu, N.G. Ceri, C. Arman, F.G. Zeybek, S. Tetik, Location and incidence of the zygomaticofacial foramen: an anatomic study, Clin. Anat. 22 (5) (2009) 559–562, https://doi.org/10.1002/ca.20805.

[19] S. Khalid, J. Iwanaga, M. Loukas, R.S. Tubbs, Bilateral absence of the zygomatic nerve and zygomaticofacial nerve and foramina, Cureus 9 (7) (2017) e1505, https://doi.org/10.7759/cureus.1505.

[20] M. Loukas, D.G. Owens, R.S. Tubbs, G. Spentzouris, A. Elochukwu, R. Jordan, Zygomaticofacial, zygomaticoorbital and zygomaticotemporal foramina: anatomical study, Anat. Sci. Int. 83 (2) (2008) 77–82, https://doi.org/10.1111/j.1447-073X.2007.00207.x.

[21] J.M. Cuttone, P.T. Brazis, M.T. Miller, E.R. Folk, Absence of the superior rectus muscle in Apert's syndrome, J. Pediatr. Ophthalmol. Strabismus 16 (6) (1979 Nov-Dec) 349–354, https://doi.org/10.3928/0191-3913-19791101-04.

[22] F.J. Weinstock, H.H. Hardesty, Absence of superior recti in craniofacial dysostosis, Arch. Ophthalmol. 74 (1965 Aug) 152–153, https://doi.org/10.1001/archopht.1965.00970040154003.

[23] S.B. Nayak, S.D. Shetty, N. Kumar, A.P. Aithal, Double-bellied superior rectus muscle, Surg. Radiol. Anat. 41 (6) (2019 Jun) 713–715, https://doi.org/10.1007/s00276-019-02211-0.

[24] R. Verma, R.W. Hertle, An interesting case of bilateral bifid insertion of superior rectus muscle as an intra-operative finding in a patient with oculocutaneous albinism, Surg. Radiol. Anat. 36 (6) (2014 Aug) 605–606, https://doi.org/10.1007/s00276-013-1187-0.

[25] M. von Lüdinghausen, Bilateral supernumerary rectus muscles of the orbit, Clin. Anat. 11 (4) (1998) 271–277, https://doi.org/10.1002/(SICI)1098-2353(1998)11:4<271::AID-CA8>3.0.CO;2-U.

[26] R. Haładaj, G. Wysiadecki, M. Polguj, M. Topol, Bilateral muscular slips between superior and inferior rectus muscles: case report with discussion on classification of accessory rectus muscles within the orbit, Surg. Radiol. Anat. 40 (7) (2018 Jul) 855–862, https://doi.org/10.1007/s00276-018-1976-6.

[27] M.R. Khitri, J.L. Demer, Magnetic resonance imaging of tissues compatible with supernumerary extraocular muscles, Am. J. Ophthalmol. 150 (6) (2010 Dec) 925–931, https://doi.org/10.1016/j.ajo.2010.06.007.

[28] M. von Lüdinghausen, M. Miura, N. Würzler, Variations and anomalies of the human orbital muscles, Surg. Radiol. Anat. 21 (1) (1999) 69–76, https://doi.org/10.1007/BF01635057.

[29] H.J. Simonsz, Instead of pulley bands, does retrobulbar fat keep the eye muscle bellies in place and thereby act like a pulley? Strabismus 28 (2) (2020 Jun) 109–113, https://doi.org/10.1080/09273972.2020.1767480.

[30] D.S. Hubbell, J.J. Dwornik, S.E. Alway, R. Eliason, R.E. Norenberg, Teaching gross anatomy using living tissue, Clin. Anat. 15 (2) (2002 Mar) 157–159, https://doi.org/10.1002/ca.1113.

[31] W. Thiel, Die Konservierung ganzer Leichen in natürlichen Farben [The preservation of the whole corpse with natural color], Ann. Anat. 174 (3) (1992 Jun) 185–195. German.

[32] H. Niels, Thirty years of Thiel embalming-A systematic review on its utility in medical research, Clin. Anat. 35 (7) (2022 Oct) 987–997, https://doi.org/10.1002/ca.23936.