Contents lists available at ScienceDirect

Annals of Anatomy

RESEARCH ARTICLE

Is there a relationship between the occurrence of frenular ligaments and the type of fibularis longus tendon insertion?

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ARTICLE INFO

ABSTRACT

Purpose: The fibularis longus muscle (FLM) is located in the lateral compartment of the leg. Although the FLM presents high morphological variability, particularly the tendon, little is known of its insertion. Similarly, little information exists regarding the great diversity of the Frenular ligament. The main aim of the study was hence to characterize the morphology of the fibularis longus tendon (FLT) and its accessory bands, to classify it and to determine the incidence of frenular ligaments. I hypothesize that the presence of anterior/posterior frenular ligament can be closely correlated with a given type of fibularis longus tendon insertion.

Methods: Classical anatomical dissection was performed on 100 lower limbs (50 female, 50 male) fixed in 10% formalin solution. The morphology of the insertion of the FLT and of the frenular ligaments was evaluated.

Results: The FLM was present in all specimens. Three types of insertion were observed, the most common being Type I (49%): a single distal attachment in which the tendon inserts into the lateral tubercle of the base of the I metatarsal bone. The second most common type was Type II (40%): bifurcated distal attachment, the main tendon inserts into the lateral tubercle of the base of the I metatarsal bone. This group was divided into three subtypes (A–C), subtype (A) — the accessory band inserts into the medial cuneiform bone; subtype (B) — a strong, accessory band inserts into both the base of the I metatarsal bone and the medial cuneiform bone, including the first metatarsal-cuneiform joint; subtype (C) — the accessory band inserts into the first interosseus dorsalis muscle. The rarest type was Type III (9%), characterized by a single distal tendon, which fuses with other adjacent muscle tendons before insertion. The main tendon inserts into the lateral tubercle of the base of the I metatarsal bone; this group was divided into two subtypes (IIIA – fusion with the tibialis posterior tendon and IIIB – fusion with the adductor hallucis longus). The anterior frenular ligament was present in 49% of specimens, whereas the posterior frenular ligament joined the FLT to the long calcaneo-cuboid ligament and was present in 9%.

Conclusion: Both the fibularis longus tendon and frenular ligament present high morphological variability. The anterior frenular ligament is closely correlated with Type I of the proposed classification, while the posterior frenular ligament is associated with Type II b. Knowledge of particular types of insertion is essential for both clinicians and anatomists.

Level of evidence: – II basic science research.

1. Introduction

The fibularis longus muscle (FLM) and the fibularis brevis muscle are located in the fibular compartment: one of the four compartments in the leg between the knee and foot, also known as the lateral compartment of the leg. The FLM originates from the lateral condyle of the tibia, the head and proximal two thirds of the lateral fibula, the intermuscular septa and adjacent fascia. The gap between its points of attachment at the head and body of the fibula allows the common peroneal nerve to pass to the front of the leg (Moore and Dalley, 2006). The muscle belly becomes the fibularis longus tendon (FLT) in the middle of the leg and inserts laterally into the plantar surface of the medial cuneiform bone and the proximal first metatarsal bone (Moore and Dalley, 2006).

The main function of the FLM is plantar flexion, where it acts antagonistically to the tibialis anterior muscle. In addition, the FLM also everts the sole of the foot, and the tendon plays a key role in maintaining the transverse arch when passing across the sole of the foot in an oblique direction (Moore and Dalley, 2006).

Although several studies have examined the morphological variability of the muscle (Drexler, 1958; Le Double, 1897; MacAlister, 1875; Patil et al., 2007; Picou, 1894a; Wright et al., 1946), they only describe the different possible arrangements of the insertion, and do not attempt a systematic classification of the FLM (Le Double, 1897; MacAlister, 1875; Patil et al., 2007; Picou, 1894a; Wright et al., 1946). A greater understanding of these morphological variations can clearly help the orthopedist or physiotherapist address the pathologies associated with the FLT, such as transverse arch foot disorder, or traumatic injury, tendinitis, tenosynovitis, acute rupture, dislocation or avulsion fracture (Draghi et al., 2018; Janney et al., 2018; Koh et al., 2019; Lui and Hau, 2018; Patil et al., 2007; Thomas et al., 2019). A further morphological element is represented by the presence of bands associated with the fibularis longus; these are known as frenular ligaments and connect the ligament to surrounding structures (Drexler, 1958; Guimerá et al., 2015; Le Double, 1897; Patil et al., 2007; Picou, 1894b).

Currently, relatively little is known about both the FLT insertion and the presence of the frenular ligament. The main aim of the study was to characterize the morphology of the FLT and its accessory bands, and use this to prepare an initial classification which will help differentiate between different types of FLT and can be used when planning surgical procedures in the area. In addition, the study also aims to clarify the incidence of frenular ligaments, particularly whether the presence of an anterior or posterior ligament can be closely related to the occurrence of a certain type of FLT insertion.

2. Materials and methods

One hundred lower limbs (52 left and 48 right) from equal numbers of female and male adults (Central European Population), fixed in 10% formalin solution, were examined. The mean age "at death" of the cadavers was 62.6 years (35–86). All were the property of the department following donation to the university anatomy program. To allow for complete identification of the tendon insertion, the inclusion criteria comprised sufficient specimen quality and a lack of evidence of surgical intervention in the examined area. Dissection of the lower limb was performed in accordance with a pre-established protocol (Olewnik et al., 2019a, 2019b). The dissection began by revealing the crural fascia of the lateral side of the leg by removing the skin and subcutaneous tissue from the lateral condyle of the femur to the lateral malleolus. A longitudinal cut was made in the crural fascia covering the lateral compartment of the leg, as well as a superior and inferior transverse cut in the fascia to expose the FLM. The fibularis longus muscle was carefully separated from the fibularis brevis muscle. Following this, the skin and subcutaneous tissue of the plantar part of the foot were removed, thus visualizing the plantar aponeurosis. A longitudinal cut across the plantar aponeurosis was made, and then a transverse cut through the plantar aponeurosis at the proximal part, close to the calcaneus bone. The plantar aponeurosis was removed and the first layer of the plantar musculature was visualized: abductor digiti minimi, flexor digitorum brevis and abductor hallucis.

Following this, the abductor digiti minimi, the abductor hallucis and the flexor digitorum brevis were removed to expose the flexor digitorum longus, quadratus plantae and lumbricalis muscle. The removal of the abductor hallucis muscle allowed to see the course of the tendon of tibialis posterior muscle. In addition, very careful removal of the quadratus plantae and flexor digitorum longus muscles with lumbrical allowed the identification of the long plantar ligament, the oblique and transverse heads of the adductor hallucis, medial and lateral heads of the flexor hallucis brevis and plantar interossei muscles. Following this, the tendon was cleansed and checked for additional FLT bands. During the visualization of the tendon, the presence of the anterior and posterior frenular ligament was carefully checked. The tendon was very precisely dissected to the bone attachment itself. The course of each tendon was checked very carefully.

Upon dissection, the morphological features of the TPM were assessed:

- The types of FLT insertion.
- Morphometric measurements of the FLM and FLT.
- The presence of anterior and posterior frenular ligament.

Tips for dissecting the fibularis longus tendon - Special attention should be paid when:

1 removing the abductor digiti minimi: it is possible to remove the posterior frenular ligament by accident,
2 removing the abductor hallucis; there is a chance that an extra band origin of the tendon of the tibialis posterior muscle could be cut (Olewnik, 2019),
3 removing the quadratus plantae and flexor digitorum longus; it is possible to remove the posterior frenular ligament by accident, cut the fusion between the FLT and the tendon of the tibialis posterior muscle, and cut the additional strands originating from the FLT.
4 Finally, particular attention should be paid when identifying the anterior frenular ligament, as it is hard to distinguish it from the surrounding tissue of the foot.

An electronic digital caliper was used for all measurements (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan). Each measurement was carried out twice with an accuracy of up to 0.1 mm. Consent was obtained from the Local Bioethical Commission to perform the anatomical stage (agreement no. RNN/297/17/KE).

2.1. Statistical analysis

Statistical analysis was done with Statistica 12 software (StatSoft Polska, Cracow, Poland). The Chi^2 test with contingency tables were used to evaluate differences between the distribution of FLT types according to gender and body side, and to evaluate the relationship between FLT type and the presence of frenular ligaments.

The normality of the continuous data distribution was checked with the Shapiro–Wilk test. As the data was not normally distributed, the morphological measurements of different FLT types were compared using the Mann–Whitney U-test (two groups) or the Kruskal–Wallis test by ranks with a dedicated *post hoc* test (more than two groups).

A p-value lower than 0.05 was considered significant. The results are presented as mean and standard deviation unless otherwise stated.

3. Results

This section has been divided into two parts. The first presents the proposed types of FLT insertion, while the second examines the incidence of the anterior and posterior frenular ligament.

3.1. Types of insertion

The FLM was present in all specimens. Three key types, with subtypes, were distinguished based on the morphology of the FLT:

1 Type I – single distal attachment. The tendon inserts into the lateral tubercle of the base of the I metatarsal bone. This type was present in 49 lower limbs (49%) -Fig. 1.
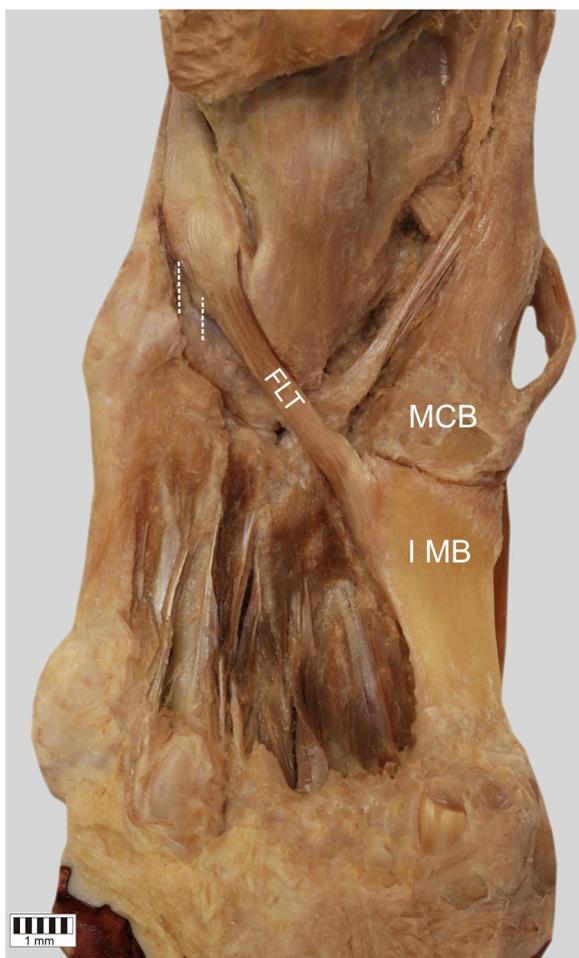
Fig. 1. Type I fibularis longus tendon. Posterior view of the left foot. *FLT* fibularis longus tendon *MCB* medial cuneiform bone *IMB* first metatarsal bone. The dashed line indicates the anterior frenular ligament*. * *Anterior frenular ligament was removed during the dissection.*

2 Type II – bifurcated distal attachment. The main tendon inserts into the lateral tubercle of the base of the I metatarsal bone. This type was observed in 40 lower limbs (40%). Three subtypes were determined based on the site of attachment of the additional slips:

   a subtype A – the accessory slip inserts into the medial cuneiform bone. This subtype was observed in 28 cases – Fig. 2a.

   b subtype B – the strong, accessory slip inserts into both the base of the I metatarsal bone and medial cuneiform bone, including the first metatarsal-cuneiform joint. This subtype was present in nine cases – Fig. 2b.

   c subtype C – the accessory slip inserts into the first interosseus dorsalis muscle. This type was observed in three lower limbs – Fig. 2c.

3 Type III – single distal tendon which fuses with other adjacent muscle tendons before insertion. The main tendon inserts to the lateral tubercle of the base of the I metatarsal bone. This type was present in 11 specimens. Two subtypes were identified:

   a subtype A – characterized by fusion with the posterior tibialis tendon. This subtype was present in eight cases - Fig. 3a.

   b subtype B – characterized by fusion with the adductor hallucis. This subtype was present in three lower limbs – Fig. 3b.

A comparison of morphological measurements between FLT types is presented in Table 1 (supplementary materials).

3.2. Anterior and posterior frenular ligament

At the level of the cuboid bone, the FLT can be fused to surrounding tissues by fibrous/tendinous bands termed frenular ligaments. The anterior frenular ligament (present in 49 cases) joins the FLT to the fifth metatarsal bone and to the third plantar interosseus muscle (Fig. 4a), whereas the posterior frenular ligament (present in nine cases) joins the FLT to the long calcaneo-cuboid ligament (Fig. 4b).

The distribution of FLT tendon types according to gender, body side and presence of frenular ligaments is presented in Table 1.

4. Discussion

The present work provides a systematic classification of the FLT accessory bands and their insertion type. It also highlights the existence of a relationship between the occurrence of the frenular ligament and FLT type. The proposed classification is the first to divide the range of possible FLT insertions into three main types (I–III), with Type II subdivided into three subtypes (A–C), and Type III into two subtypes (A–B).

Different types of accessory slip insertion have been described in the literature (Drexler, 1958; Le Double, 1897; Macalister, 1875; Patil et al., 2007; Picou, 1894b; Wright et al., 1946). Hooper and Ruysch. (1809) were among the first to describe FLT insertions into the outside of the base of the metatarsal bone that sustains the great toe, and into the intermediate cuneiform bone. Macalister. (1875) was one of the first to observe variations regarding FLT insertion: the FLT was characterized by three tendons that attached to the fifth, third and first metatarsal bone, and occasionally to the intermediate cuneiform bone; in addition, the FLT was found to fuse with the fibularis brevis tendon or possibly attach to the fifth metatarsal bone behind it (Macalister, 1875). A second attempt at creating a classification (Testut, 1884) detailed an insertion to the posterior end of the first metatarsal bone, as well as accessory slips to the metatarsals and cuneiform bones. The report recommended distinguishing "among these accessory slips: (a) those which are made on the metatarsals of the medial foot; (b) that which is done on the lateral metatarsal(s); and (c) that which is done on cuneiforms" (Testut, 1884). In contrast, Picou (1894a) report the possibility of insertion to the medial cuneiform bone and base of the I metatarsal bone (95%), to the head of the I metatarsal bone and medial cuneiform bone (89%), or to only the base of the first metatarsal bone (5.5%). In addition, Picou notes the presence of a fusion with the tibialis posterior tendon in 22.2% of samples: an arrangement which has also been described by Lohrmann et al. (1997). Wright et al. (1946) report the presence of an additional band originating from the FLT and inserting to the first interosseus dorsalis muscle in 53.6% of samples, and note that when present, the band gives rise to the muscle.

More recently, Patil et al. (2007) found a basic (strong) insertion to the I metatarsal bone to be present in 30 tested lower limbs. Of these 30 limbs, 26 displayed a slip band to the medial cuneiform bone (86.6%), nine presented an additional band close to the metatarsocuneiform joint (30%). An additional slip to the base of the second, fourth and fifth metatarsal bone and to the neck of the first metatarsal bone was also observed. Similar results were obtained by Shyamsundar et al. (2012) in a study of 26 feet: the basic attachment was located on the I metatarsal bone in all 26 feet; additional bands were inserted to the medial cuneiform bone in 22 feet, the base of the 4/5 metatarsal bone in 12, the base of the II metatarsal bone in eight, the calcaneum in eight and the base of the III metatarsal bone in two. In the present study, a permanent, basic, strong attachment, herein classified as Type I, was also observed on the I metatarsal bone in all 100 feet (100%). While previous studies
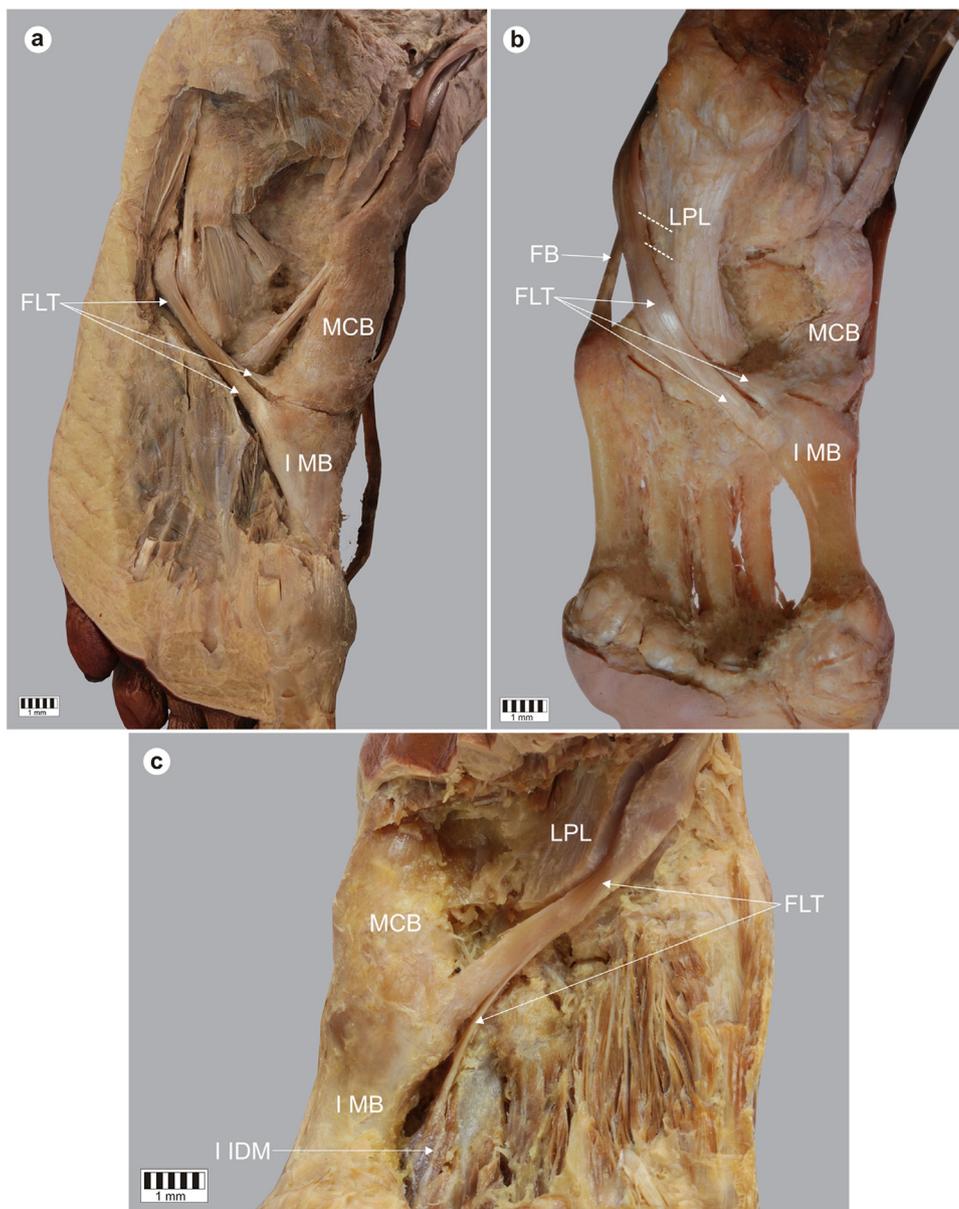
Fig. 2. Type II fibularis longus tendon. (a) Type II A fibularis longus tendon. Posterior view of the left foot. *FLT* fibularis longus tendon *MCB* medial cuneiform bone *IMB* first metatarsal bone. (b) Type II B fibularis longus tendon. Posterior view of the left foot. *FLT* fibularis longus tendon *MCB* medial cuneiform bone *IMB* first metatarsal bone *FB* fibularis brevis *LPL* long plantar ligament. The dashed line indicates the posterior frenular ligament*. *Posterior frenular ligament was removed during the dissection. (c) Type II C fibularis longus tendon. Posterior view of the right foot. *FLT* fibularis longus tendon *MCB* medial cuneiform bone *IMB* first metatarsal bone *LPL* long plantar ligament *I IDM* first interosseus dorsalis muscle.

Table 1
Comparison of distribution of FLT types between genders, body sides and additional morphological features. Percentages are given for columns (determine distribution in a whole given subgroup). The calculation of p-value is based on pure types (without subtypes).

	FLT type	Gender		Body side		Anterior frenular lig.		Posterior frenular lig.	
	Females	Males	Right	Left	Present	Absent	Present	Absent	
I		28 (56%)	21 (42%)	26 (54%)	23 (44%)	49 (100%)	0 (0%)	0 (0%)	49 (54%)
	A	13 (26%)	15 (30%)	11 (23%)	17 (33%)		40	9	31
II	B	4 (8%)	5 (10%)	5 (10%)	4 (8%)	0	(78%)	(100%)	(34%)
	C	0 (0%)	3 (3%)	1 (2%)	2 (4%)	(0%)			
III	A	2 (4%)	6 (12%)	3 (6%)	5 (10%)	0	11	0	11
	B	3 (6%)	0 (0%)	2 (4%)	1 (2%)	(0%)	(22%)	(0%)	(12%)
p-Value		0.3683*		0.6010*		<0.0001*		<0.0001*	

A comparison of morphological measurements between FL tendon types is presented in Table 1 (supplementary materials).
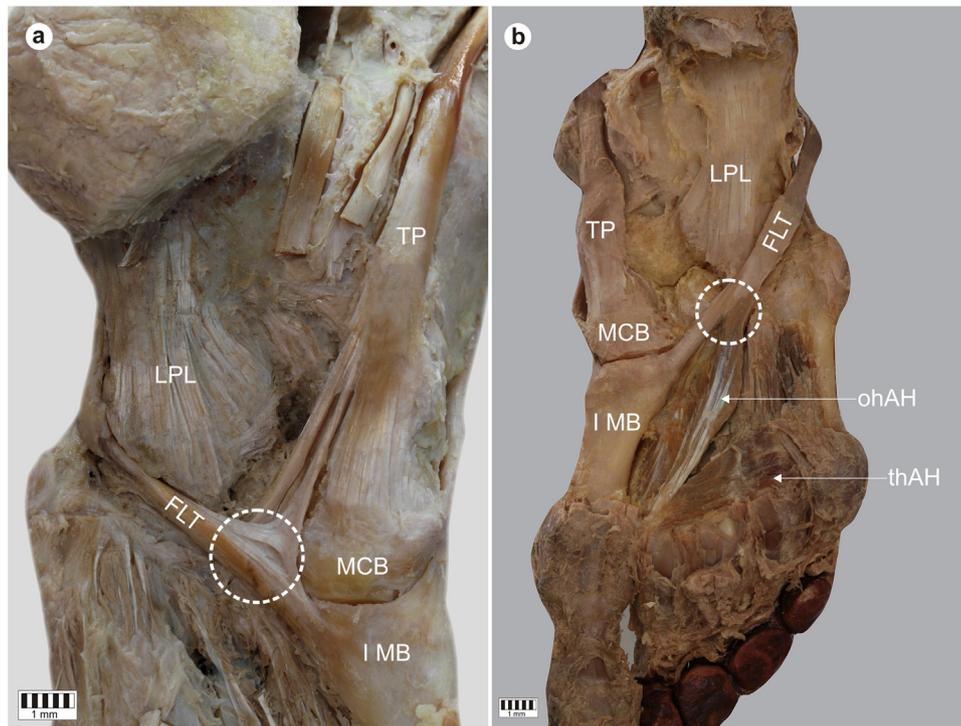 * The Chi² test.

Fig. 3. Type III fibularis longus tendon. (a) Type III A fibularis longus tendon. Postero-medial view of the left foot. *FLT* fibularis longus tendon *MCB* medial cuneiform bone *IMB* first metatarsal bone *LPL* long plantar ligament *TP* tibialis posterior tendon. Dashed circle indicates the fusion between the fibularis longus tendon and tibialis posterior tendon. (b) Type III B fibularis longus tendon. Posterior view of the right foot. *FLT* fibularis longus tendon *MCB* medial cuneiform bone *IMB* first metatarsal bone *LPL* long plantar ligament *TP* tibialis posterior tendon *ohAH* oblique head of the adductor hallucis *thAH* transverse head of the adductor hallucis. Dashed circle indicates the fusion between the fibularis longus tendon and tibialis posterior tendon.
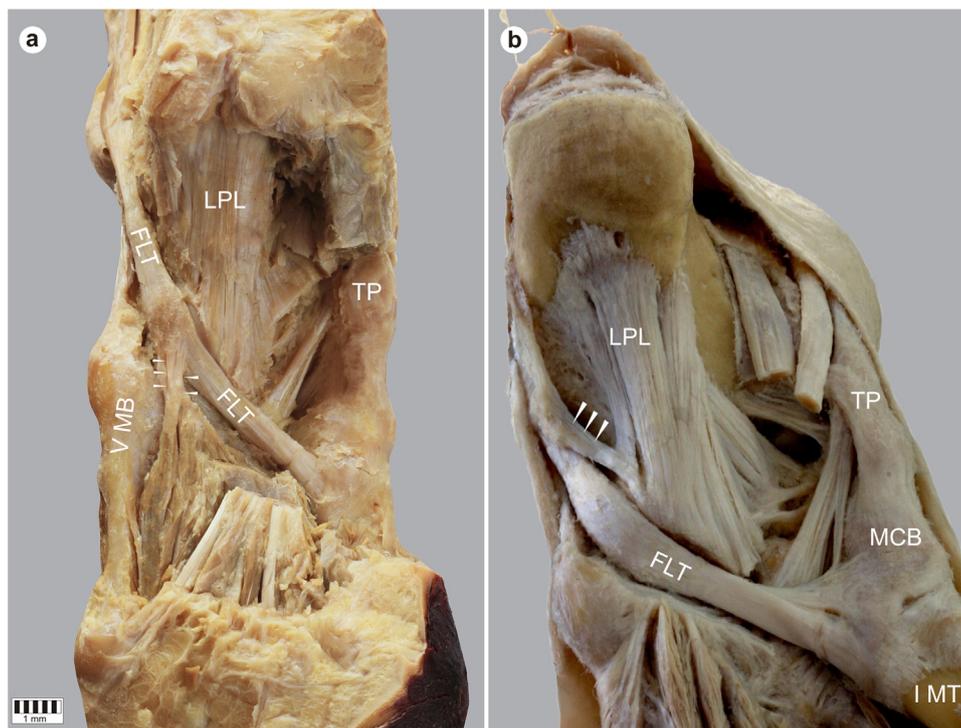

Fig. 4. Frenular ligaments. (a) Coexistence of Type I with anterior frenular ligament. Posterior view of the left foot. *FLT* fibularis longus tendon *MCB* medial cuneiform bone *VMB* fifth metatarsal bone *LPL* long plantar ligament. White arrowheads shows the anterior frenular ligament. (b) Coexistence of Type II B with posterior frenular ligament. Posterior view of the left foot. *FLT* fibularis longus tendon *MCB* medial cuneiform bone *IMB* first metatarsal bone *LPL* long plantar ligament *TP* tibialis posterior tendon. White arrowheads shows the posterior frenular ligament.

do not confirm the possibility of attachment to other metatarsal bones (II—V), our present findings indicate the presence of a fusion with the adductor hallucis in three feet (classified herein as Type 3b). Another new discovery is the presence of two strong bands in nine cases: one main tendon inserting into the lateral tubercle of the base of the I metatarsal bone, and another strong, accessory band inserting into both the base of the I metatarsal bone and the medial cuneiform bone, including the first metatarsal-cuneiform joint (classified as Type 2b).

The FLT plays a much greater and varied role than any other tendon or ligament in resisting forces applied to the first metatarsal due to its variable course and insertion; therefore, partial or total loss of stabilization of the first metatarsal bone due to a problem with the FLT can result in metatarsus primus varus (Bohne et al., 1997; Shyamsundar et al., 2012). It is also believed that the arrangement of the FLT plays a key role in foot deformities occurring in Charcot Marie Tooth (CMT) (Berciano et al., 2011; Bohne et al., 1997; Maynou et al., 2017; Shyamsundar et al., 2012; Tynan et al., 1992), the most common being Cavo-varus foot. It is characterized by a high cavus or arch, an inward turned (varus) heel, and toes that are contracted like a claw, hence the name *clawed toes* (Berciano et al., 2011; Maynou et al., 2017; Tynan et al., 1992). Determining the exact cause of the cavo-varus foot has long been a problem; however, as both internal and external muscle imbalance may play a role in the final deformation, an imbalance between the antagonistic muscles, particularly the tibialis anterior muscle and the FLM, is often mentioned as the cause (Berciano et al., 2011; Bohne et al., 1997; Maynou et al., 2017; Shyamsundar et al., 2012; Tynan et al., 1992), as well as the FLT insertion point. So what effect do the additional slips have on the occurrence of cavo-varus?

The prevalence of the anterior frenular ligament varies from 29.7 to 80%, depending on the study, and the posterior frenular ligament from 5.4 to 13% (Guimerá et al., 2015; Patil et al., 2007; Picou, 1894b). It is noteworthy that our present findings indicate a close correlation of Type I with the presence of the anterior frenular ligament (p = 0.0001), as well as a close correlation between Type II b and that of the posterior frenular ligament (p = 0.0001). No simultaneous occurrence of anterior and posterior frenular ligaments was observed. Interestingly, Guimera et al. (Guimerá et al., 2015) report the simultaneous occurrence of anterior and posterior frenular ligaments in 22 feet (59.5%); however, the insertion types were not specified. Further research on a larger research sample is needed to clarify these differences. A significant novel finding in the present study is that it is possible for the anterior frenular ligament to attach to third plantar interosseus muscle and fifth metatarsal. The results yielded by these aims will shed greater light on the relationship between the mode of insertion of the fibularis longus tendon and the occurrence of frenular ligaments.

The present study does have some limitations, a key one being that no sample size calculation was performed. However, with 100 limbs being tested, the number of samples is considerably greater than other cadaver-based studies of FLT anatomy. In addition, due to the heterogeneous nature of the anatomical area, the proposed classification draws on several morphological details, such as type of insertion or presence of accessory bands; despite the large sample size, considerable disparities remain between the present findings and those of previous studies with regard to distal tendon attachment type and the presence of frenular ligaments. Further studies should address the potential value of ultrasound or MRI for this purpose.

Nonetheless, our findings help raise awareness of "what and where" to look for, and offer a uniform initial classification and terminology to act as a foundation for communication with surgeons. Knowledge of these variants and application of the proposed classification may serve as common practice for specialists if modification of the surgical techniques is introduced. In addition, this work might serve as a segue into studies on diagnostic imaging to determine FLT morphological variations *in vivo* and not to mistake them with pathologies of the FLT. Most importantly, our findings can fuel future biomechanical and physiotherapeutic research based on FLT insertion types.

5. Conclusion

The fibularis longus tendon displays high morphological variability. In addition, both the anterior and posterior frenular ligaments are characterized by high morphological variability; however, the anterior frenular ligament is closely correlated with Type I of the proposed classification, while posterior frenular ligament is associated with type II b. Such knowledge of the appropriate types and places of insertion of accessory bands can help understand the stabilization of the transverse arch of the foot and the mechanism of preventing cavus varus.

Ethical approval and consent to participate

Funding

Authors' contribution

Łukasz Olewnik (D.P.T., PhD) - assistant – project development, data collection and management, data analysis and manuscript writing.

Acknowledgement

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aanat.2019.03.002.

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