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Research article

Morphological variability of the fibularis longus tendon in human fetuses

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A B S T R A C T

Introduction: The morphological variability of the fibularis longus tendon (FLT) in adults is well understood. However, no comprehensive classification exists in human fetuses. The goal of this study was to prepare the first comprehensive classification of the fibularis longus tendon based on its insertion in human fetuses.
Material and methods: Forty-seven spontaneously-aborted human fetuses were examined: 38 male, 56 female, a total of 94 lower limbs (Central European population). Age ranged from18–38 weeks of gestation at death.
Results: The classification comprised three types of FLT. The most common type was Type I (49%), characterized by the single distal attachment. This type was divided into two subtypes (A-B): A – the tendon inserts to the lateral tubercle of the base of the 1st metatarsal bone, B – the tendon inserts to the head of the 1st metatarsal bone. The second most type was Type II, characterized by a bifurcated distal attachment (24.5%). This type was divided into three subtypes (A–C): A – the main tendon inserts to the lateral tubercle of the base of the 1st metatarsal bone and the accessory band inserts to the medial cuneiform bone; B – the strong, main tendon inserts to both the base of the 1st metatarsal bone and medial cuneiform bone, including the first metatarsal-cuneiform joint, and the accessory bands inserts to the fourth interosseus dorsalis muscle; C – the main tendon inserts to the lateral tubercle of the base of the 1st metatarsal bone and the accessory band inserts to the first interosseus dorsalis muscle. The rarest type was Type III, characterized by a trifurcated distal attachment: the main tendon inserts to the lateral tubercle of the base of the 1st metatarsal bone and the first accessory band inserts to the medial cuneiform bone and the second accessory bands inserts to the first interosseus dorsalis muscle. The anterior frenular ligament was observed in 16% of all cases, and posterior frenular ligament in 6.4%.
Conclusion: The FLT displays high morphological variability. The proposed classification consists of three main types, with Type I and Type II divided into sub-types; it also provides additional data regarding its accessory tendon bands.

1. Introduction

The leg is separated into anterior, lateral, superficial posterior, and deep posterior compartments by intermuscular septa, and is surrounded by the deep fascia of the leg. The lateral compartment of the leg consists of the fibularis longus muscle (FLM) and fibularis brevis muscle (Bergman et al., 2017; Moore and Dalley, 2006a; Olewnik et al., 2019a; Olewnik, 2019a). The muscles within this compartment primarily facilitate ankle and foot eversion (Moore and Dalley, 2006b; Olewnik et al., 2019b; Olewnik, 2019a). The FLM usually originates from the lateral condyle of the tibia, the head and proximal two thirds of the lateral fibula, the intermuscular septa and adjacent fascia. A gap can be seen between its attachment points at the head and body of the fibula; this allows the common peroneal nerve to pass to the front of the leg. The muscle belly becomes the

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fibularis longus tendon (FLT) in the middle of the leg and inserts laterally onto the plantar surface of the medial cuneiform bone and the proximal first metatarsal bone (Moore and Dalley, 2006b).

The fibular muscles are characterized by high morphological variability, characterised by additional bands (fibularis brevis muscle and FLM) (Olewnik et al., 2019c; Olewnik, 2019a), additional tendons, and additional muscles, such as the fibularis digiti quinti, fibularis tertius muscle and fibularis quartus muscle (Chaney et al., 2018; Olewnik et al., 2019c; Olewnik, 2019b; Sookur et al., 2008; Yammine, 2015; Yammine and Erić, 2017).

Although many studies have described the morphological variability of FLT in adults (Drexler, 1958; Le Double, 1897; MacAlister, 1875b; Picou, 1894a, 1894b; Testut, 1884), only one precise systematic classification of FLT insertion exists (Olewnik, 2019a). This classification also indicates the frequency of the occurrence of frenular ligaments (Olewnik, 2019a). At present, however, little information exists about the morphological variability of FLT insertion, or the presence of frenular ligaments, in fetuses.

Few studies have examined the morphological variability of the FLT in adults, and even fewer have studied the FLT in human fetuses. Therefore, the goal of our present work was to classify the types of FLT insertion in human fetuses and compare the findings with the prevailing classification among adults. The results shed greater light on the relationship between the mode of insertion of the FLT and the prevalence of frenular ligaments.

2. Materials and methods

Forty-seven spontaneously-aborted human fetuses (38 male, 56 female, 94 lower limbs) – (Central European population), aged 18–38 weeks of gestation at death were examined. The fetuses were donated to the Chair of Anatomy and Histology before 1998. Permission for the study was given by the Local Bioethics Commission (agreement no. RNN/130/20/KE). The age of the fetuses was determined on the basis of craniosacral measurements as well as head measurements (Karauda et al., 2020, 2021; Olewnik et al., 2018a).

The leg (lateral compartment) and foot (lateral side) were dissected as described previously (Karauda et al., 2020, 2021; Olewnik, 2019a; Olewnik et al., 2021, 2019a). Dissection started from the area of the leg, with the removal of the skin and superficial fascia, to the lateral compartment of the leg, thus allowing the fascia of the fibularis longus muscle (FLM) to be visualized. The FLM was carefully separated from the fibularis brevis muscle. Following this, the skin and subcutaneous tissue of the foot were removed, the fascia was gently removed from the proximal to the distal part, and the dissection was guided along the distal attachment. In the region of the foot, anatomical plantar structures were removed to reveal the exact location of the tendon fibularis longus. 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 (Olewnik et al., 2019c; Olewnik, 2019a, 2019b, 2019c).

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.

An electronic digital calliper was used for all measurements (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan) – Fig. 1. Each measurement was carried out twice with an accuracy of up to 0.01 mm. The individual morphometric measurements are shown in Fig. 2. An exemplary measurement of the length of a muscle belly is shown in Fig. 3.

3. Classification – the principle of creation

The classification is based on the classification proposed by Olewnik (2019a) in adults.

4. Statistical analysis

The statistical analysis was performed using Statistica 13 software [TIBCO Software Inc. (2017). Statistica (data analysis software system), version 13. http://statistica.io.]. Differences in tendon types between genders and bodysides were compared using the Chi^2 test. The normality of continuous data was determined using the Shapiro-Wilk test; as the data was not normally distributed, non-parametric tests were used for the rest of the study. The morphological measurements were compared between the two groups using the Mann-Whitney test. Finally, measurements between FLT types were compared using the Kruskal-Wallis test by ranks with dedicated post hoc test.

A p-value lower than 0.05 was considered significant, with Bonferroni's correction for multiple testing. The results are presented as mean and standard deviation unless otherwise stated.

5. Results

The FLT was found in all tested limbs: 56 female (28 right and 28 left) and 38 male (19 right and 19 left).

Based on morphology it was classified to the following types and subtypes (abbreviations used: F-females, M-males, R-right, L-left):

- Type I – single distal attachment. This type was found in 67 limbs (71.3%) – (43F, 24M, 32R, 35L). Type I includes:

  - o Subtype Ia – the tendon inserts to the lateral tubercle of the base of the 1st metatarsal bone. This subtype was observed in 49 cases. (35F, 14M, 23R, 26L) – Fig. 4a, Fig. 5a.
  - o Subtype Ib – the tendon inserts to the head of the 1st metatarsal bone. This subtype was found in 18 cases. (8F, 10M, 9R, 9L) – Figs. 4b and 5b.

- Type II – bifurcated distal attachment. This type was observed in 23 limbs (24.5%) – (12F, 11M, 12R, 11L). Type II includes:

  - o Subtype IIa – the main tendon inserts to the lateral tubercle of the base of the 1st metatarsal bone and the accessory band inserts to the medial cuneiform bone. This subtype was observed in 17 cases. (9F, 8M, 9R, 8L) – Fig. 6a, Fig. 7a
  - o Subtype IIb – the strong, accessory band inserts to both the base of the 1st metatarsal bone and medial cuneiform bone, including the first metatarsal-cuneiform joint and the accessory bands inserts to the fourth interosseus dorsalis muscle. This subtype was found in four cases. (0F, 4M, 2R, 2L) – Figs. 6b and 7b.
  - o Subtype IIc – the main tendon inserts to the lateral tubercle of the base of the 1st metatarsal bone and the accessory band inserts to the first interosseus dorsalis muscle. This subtype was found in two cases. (2F, 0M, 1R, 1L) – Figs. 6c and 7c.

- Type III – trifurcated distal attachment. This type was observed in four limbs (4.2%). The main tendon inserts to the lateral tubercle of the base of the 1st metatarsal bone; the first accessory band

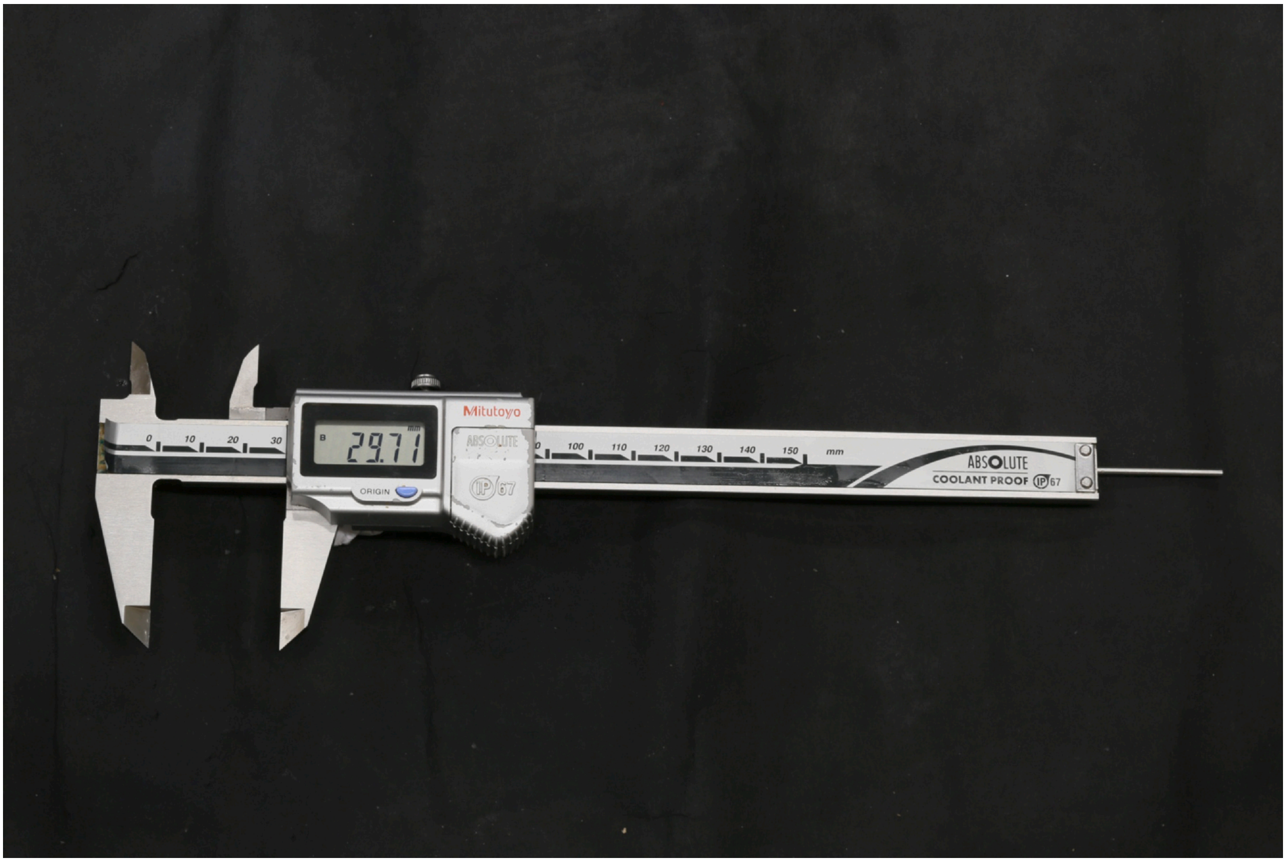

Fig. 1. An electronic digital calliper was used for all measurements (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan).

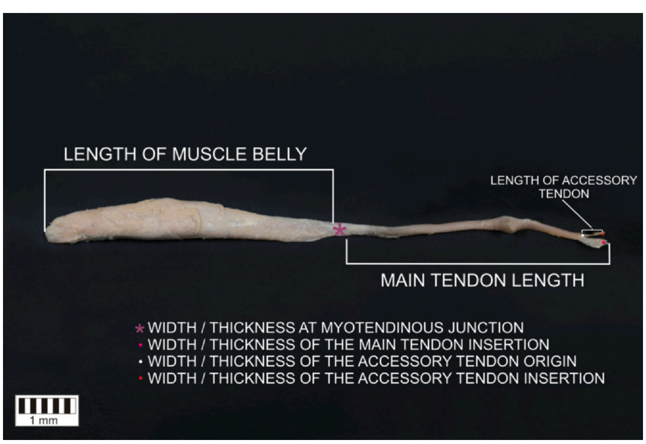

Fig. 2. The individual morphometric measurements of the fibularis longus muscle.

inserts to the medial cuneiform bone and the second accessory bands inserts to the first interosseus dorsalis muscle. (2F, 2M, 2R, 2L) – Figs. 8, 9.

6. Frenular ligaments

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, joining the FLT to the fifth metatarsal bone and to the third plantar interosseus muscle, was present in 15 lower limbs (16%). It was found to coexist with Type Ia and IIa – Fig. 10a.

The posterior frenular ligament, joining the FLT to the long plantar ligament, was present in the six lower limbs (6.4%) and included Type I (subtypes A and B) – Fig. 10b.

The anterior and posterior frenular ligament were observed together on two male limbs (2%) – Fig. 10c.

The distribution of FLT types between sexes and body sides, and with regard to the presence of frenular ligaments, is presented in Table 1.

For the comparison of morphometric parameters, only main muscle types were included; respective data for sex/body side and muscle type are presented in Tables 2 and 3.

7. Discussion

The greatest value of the present paper is that it is the first anatomical study to present a systematic classification of the FLT in human fetuses. Our proposed classification can be used to study the morphological variations occurring in the human body.

A new classification system is needed for foetuses, independent of the adult classification. Olewnik et al. (2018b, 2017) listed five types of plantaris tendon in a classification for adults, while Waśniewska-Włodarczyk et al. (2021) listed eight types for foetuses. A similar situation occurred when examining the proximal attachment of the plantaris muscle (Olewnik et al., 2020a, 2020b; Waśniewska et al., 2022). Considerable variability has also been

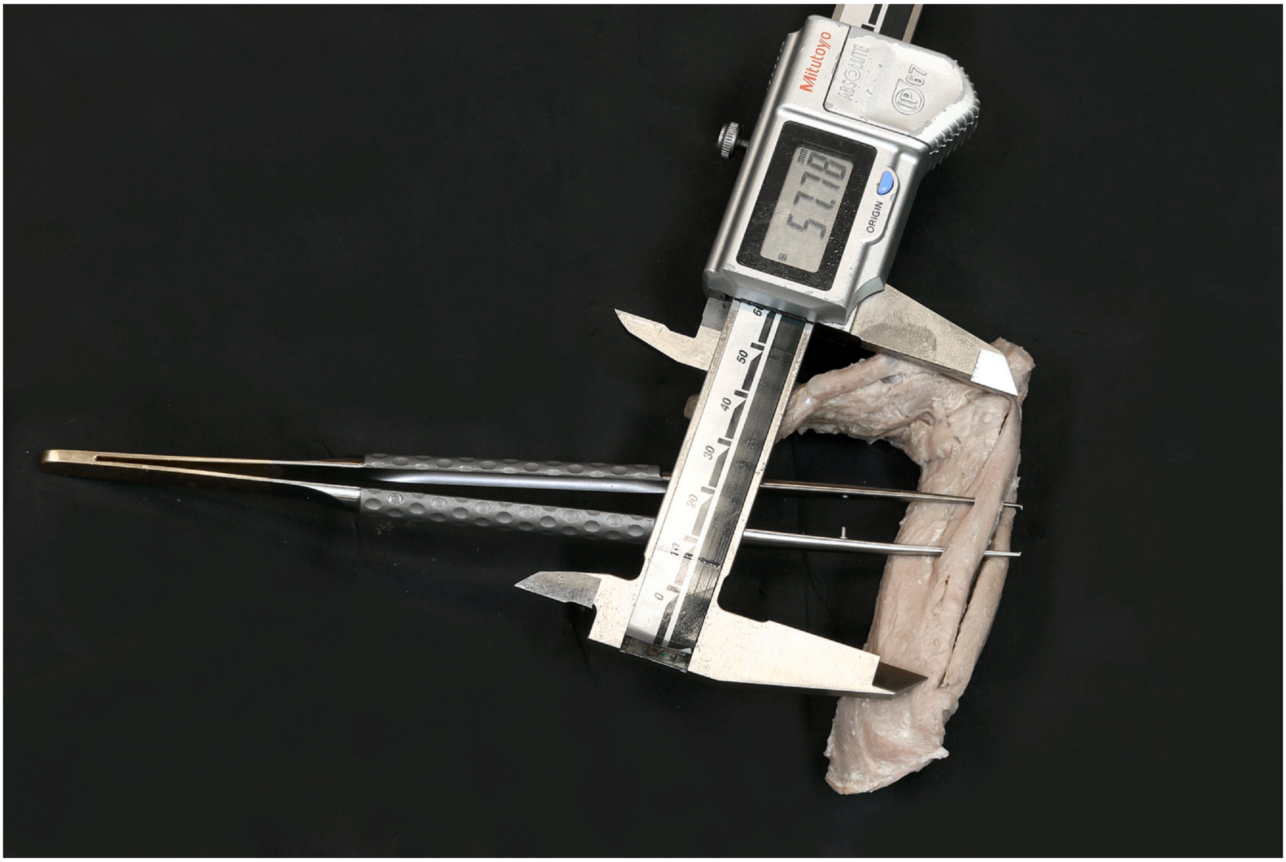

Fig. 3. An exemplary measurement of the length of a muscle belly of the fibularis longus muscle.

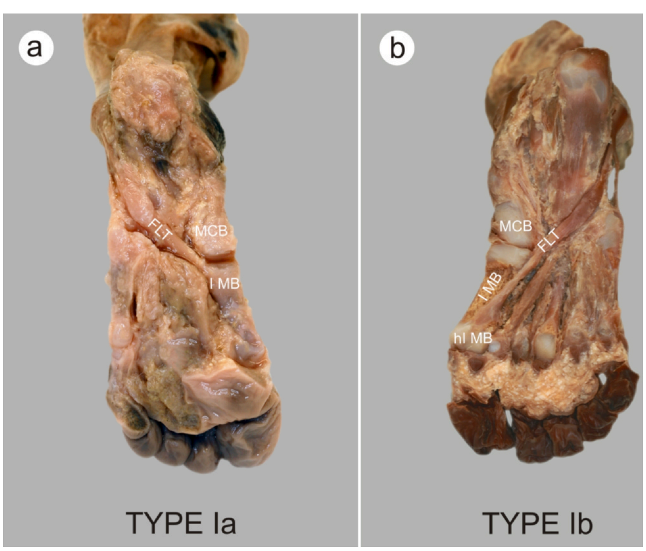

Fig. 4. Type I fibularis longus tendon insertion. a Type Ia fibularis longus tendon (FLT) insertion. FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone. b Type Ib of fibularis longus tendon. FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone; hIMB head of the first metatarsal bone.

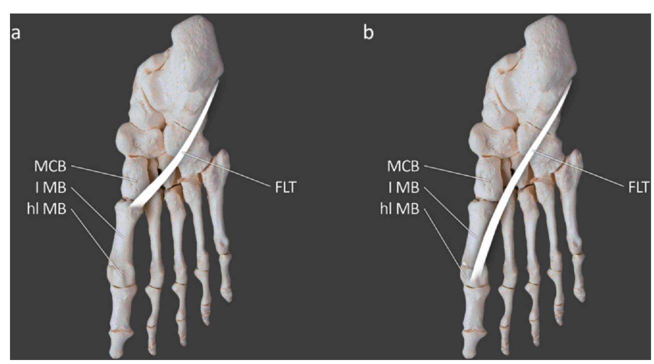

Fig. 5. Scheme of Type I fibularis longus tendon insertion. a Type Ia fibularis longus tendon (FLT) insertion. FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone. b Type Ib of fibularis longus tendon. FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone; hIMB head of the first metatarsal bone.

observed between fetuses and adults for muscles such as the palmaris longus, fibularis tertius, extensor hallucis longus and the tibialis anterior (Karauda et al., 2020, 2021; Olewnik, 2019b; Olewnik et al., 2020c).

The morphological variability of the FLT has its roots in human embryology. During the sixth week, the rudiment of the fibular

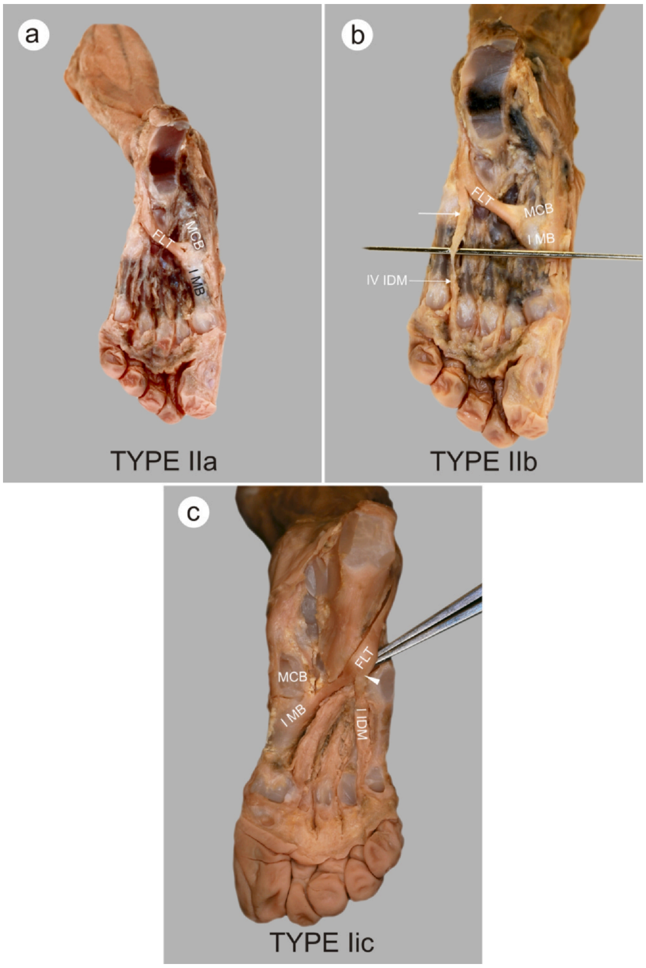

Fig. 6. Type II fibularis longus tendon insertion a Type IIa fibularis longus tendon insertion (FLT); MCB medial cuneiform bone; IMB first metatarsal bone. b Type IIb fibularis longus tendon FLT fibularios longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone; IV IDM fourth interosseous dorsalis muscle; white arrowheads indicate the connection between FLT and fourth interosseous muscle. c Type IIc FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone; I IDM first interosseous dorsalis muscle; white arrowheads show the connection between the FLT and first metatarsal bone.

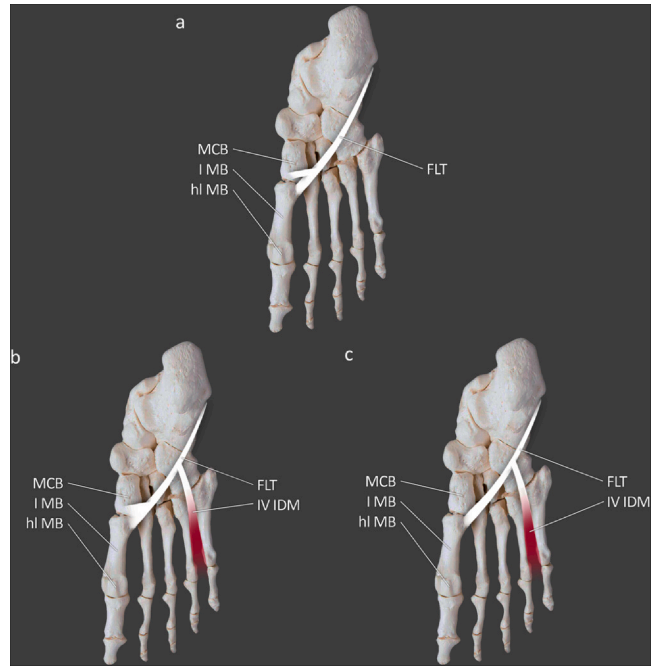

Fig. 7. Scheme of Type II fibularis longus tendon insertion a Type IIa fibularis longus tendon insertion (FLT); MCB medial cuneiform bone; IMB first metatarsal bone. b Type IIb fibularis longus tendon FLT fibularios longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone; IV IDM fourth interosseous dorsalis muscle; white arrowheads indicate the connection between FLT and fourth interosseous muscle. c Type IIc FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone; I IDM first interosseous dorsalis muscle; white arrowheads show the connection between the FLT and first metatarsal bone.

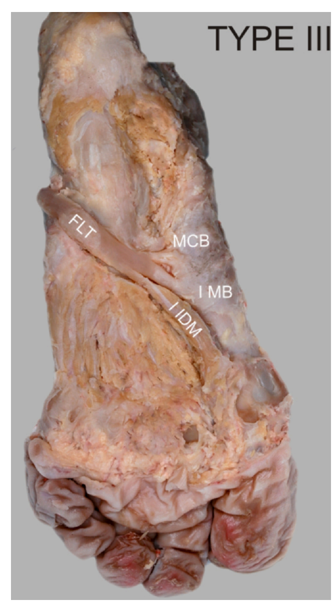

Fig. 8. Type III fibularis longus tendon insertion. FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone; I IDM first interosseous dorsalis muscle.

muscles becomes separated from the long extensors of the toes and the tibialis anterior muscle; at the same time, the rudiment of each fibular muscle begins to become distinct (Bardeen, 1905; 1906a, 1906b). They differentiate in situ, gradually extending from the dorsolateral surface of the proximal end of the fibula. The tendon of insertion of the FLM gradually differentiates during development: it can be traced to the base of the fifth metatarsal in a 14 mm embryo, part way across the sole of the foot in a 20 mm embryo, to the 1st metatarsal and in a 30 mm embryo; however, the tendon only becomes free in its sheath later on (Bardeen, 1905, 1906a, 1906b). The tendon is at first lateral to the rudiment of the malleolus lateralis; later (20 mm) it passes behind it. The muscle also extends proximally to the tibia attachment. The fibularis brevis arises relatively more proximal than in the adult position and its tendon splits off from the FLT (Bardeen, 1906b, 1905, 1906a).

The morphological variations of FLT also have an evolutionary basis (Diogo, 2020; Diogo and Molnar, 2014). The FLM originates from the head of the fibula in all hominoids, and the attachment extends to the lateral aspect of the proximal fibula shaft in all taxa except *Pan*. In the *Hylobates*, an origin has been noted from the anterior aspect of the proximal fibula and from the tibial collateral ligament, which was not described by previous authors. In all

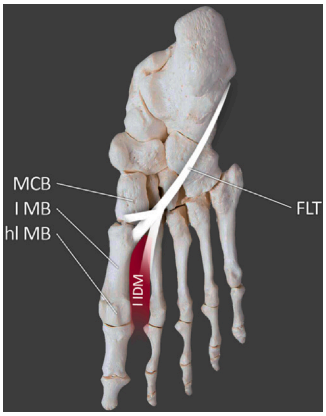

Fig. 9. Scheme of Type III fibularis longus tendon insertion. FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone; I IDM first interosseous dorsalis muscle.

hominoids, the muscle inserts onto the tuberosity of the 1st metatarsal bone (Manners-Smith, 1908; Miller, 1952; Oxnard and Lisowski, 1980); in humans, it also inserts onto the intermediate cuneiform bone. Lewis (1966) reports a fibrous insertion onto the fifth metatarsal bone; Ferrero et al. (2012) note a similar observation in a chimpanzee.

Different types of additional slip insertion of FLT have been described in adults (Drexler, 1958; Le Double, 1897; MacAlister, 1875b; Olewnik, 2019a; Picou, 1894a, 1894b). Macalister (1875a) was one of the first to observe variations regarding FLT insertion; the FLT was characterized by three tendons, which insert to the first, third and fifth metatarsal bone. In addition, the FLT was found to fuse with the fibularis brevis tendon; it also occasionally inserts to the intermediate cuneiform bone or possibly attaches to the fifth metatarsal bone behind it (MacAlister, 1875b). Testut (1884) also reports an insertion to the posterior end of the first metatarsal bone, as well as accessory slips to the metatarsal and cuneiform bones.

A fuller and more recent classification was proposed by Olewnik (2019a). It consists of three main types (I-III), with Type II and Type III being additionally divided into sub-types. Type I (49%) was characterized by a single distal attachment with the tendon inserting into the lateral tubercle of the base of the 1st metatarsal bone. The second most common type was Type II (40%), which was characterized by the bifurcated distal attachment; the main tendon inserts into the lateral tubercle of the base of the 1st metatarsal bone. Three subtypes (A–C) were determined based on the site attachment of the accessory slips: A – the accessory slips inserts into the medial cuneiform bone; B – the strong, accessory slips inserts into both the base of the I metatarsal bone and medial cuneiform bone, including the first metatarsal-cuneiform joint, C – the accessory slips inserts into the first interosseus dorsalis muscle (Olewnik, 2019a). The rarest type was Type III (11%), which was characterized by a single distal attachment which fuses with other adjacent muscle tendons before insertion. This type was divided into two subtypes (A–B): A – fusion with the posterior tibialis tendon, B – fusion with the adductor hallucis longus Olewnik (2019a).

However, very little research has been performed into the morphological variability of FLT insertion in foetuses. Karykowska et al. (2020) present a threefold classification of FLT insertion. Type 1 inserts to the medial cuneiform bone and to the base of the first metatarsal bone (90%); although this was the most common type in the

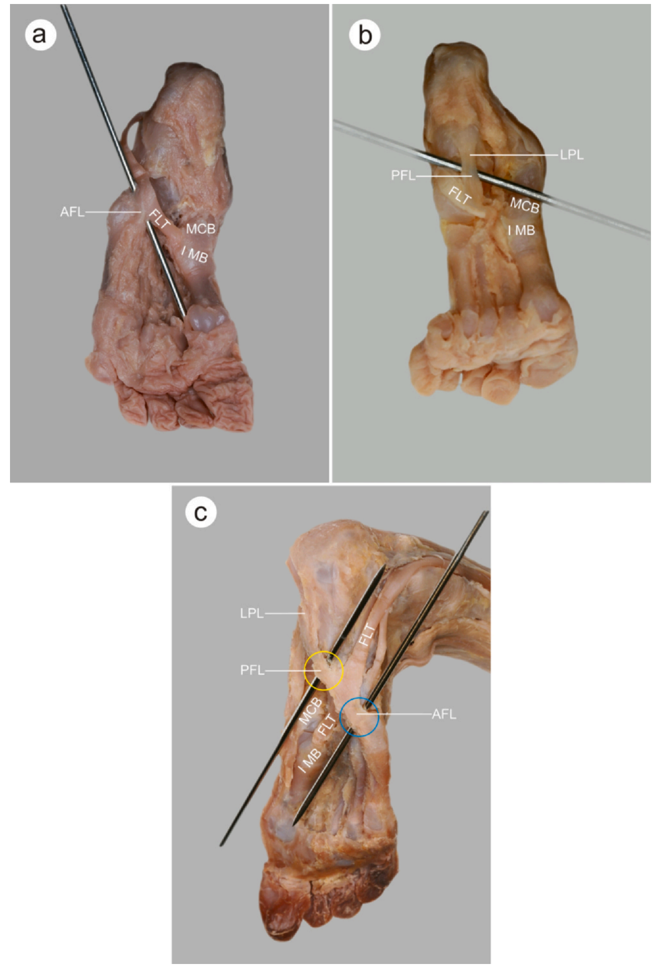

Fig. 10. Anterior and posterior frenular ligaments. a Anterior frenular ligament. White arrowheads shows the anterior frenular ligament. FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone. b Posterior frenular ligament. White arrowheads show the posterior frenular ligament FLT fibularis longus tendon; MCB medial cuneiform bone; IMB first metatarsal bone. **c** Coexistence of anterior and posterior frenular ligament. Yellow circle indicate the posterior frenular ligament, whereas the blue circle indicate the anterior frenular ligament. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

classification, it was only observed on 17 limbs in the present study. Type 2 is characterized by insertion only to the base of the 1st metatarsal bone; this was the most common variant observed in the present study (49 limbs). No examples of Type 3, characterized by an insertion only to the medial cuneiform bone, were observed in the present study. Most importantly, our present findings include types that were not found by Karykowska et al. (2020) The most common is Type IB, which was characterized by the fact that the tendon inserts to the head of the 1st metatarsal bone. It was: type IB; IIB, IIC and III.

Some relationships can be found between the types previously not found in fetuses and those found in adults. For example, Type IB, where the tendon inserts to the head of the 1st metatarsal bone, was described on adults by Testut (1884). Type IIB in the present study is similar to the type described on adults by Olewnik (2019a), a strong accessory band inserts to both the base of the 1st metatarsal bone and medial cuneiform bone, including the first metatarsal-

Table 1
Distribution of FLT types with regard to sex, body side and the presence of frenular ligaments.

FLT		Sex		Sides		Anterior frenular lig.		Posterior frenular lig.	
		Female	Male	Right	Left	Present	Absent	Present	Absent
I	a	35 (62.5)	14 (36.8)	23 (50.0)	26 (54.2)	11 (73.3)	38 (48.1)	4 (66.7)	45 (51.1)
	b	8 (14.3)	10 (26.3)	9 (19.6)	9 (18.8)	0 (0.0)	18 (22.8)	2 (33.3)	16 (18.2)
II	a	9 (16.1)	8 (21.1)	9 (19.6)	8 (16.7)	4 (26.7)	13 (16.5)	0 (0.0)	17 (19.3)
	b	0 (0.0)	4 (10.5)	2 (4.4)	2 (4.2)	0 (0.0)	4 (5.1)	0 (0.0)	4 (4.6)
	c	2 (3.6)	0 (0.0)	1 (2.2)	1 (2.1)	0 (0.0)	2 (2.5)	0 (0.0)	2 (2.3)
III	2 (3.6)	2 (5.3)	2 (4.4)	2 (4.2)	0 (0.0)	4 (5.1)	0 (0.0)	4 (4.6)	

Table 2
Morphometric parameters according to sex and body side (mm).

Parameter	Sex		P-value	Sides		P-value
	Female	Male		Right	Left	
Belly length	41.17 (11.77)	39.01 (14.19)	0.3375	40.19 (12.89)	40.39 (12.80)	0.9067
Width at myotendinous junction	2.51 (1.00)	2.65 (1.05)	0.3967	2.57 (1.04)	2.56 (1.01)	0.9940
Thickness at myotendinous junction	0.81 (0.49)	0.70 (0.45)	0.3512	0.76 (0.48)	0.77 (0.47)	0.8323
Main tendon length	28.43 (14.47)	24.59 (9.08)	0.4549	26.99 (12.89)	26.77 (12.57)	0.9518
Width of the main tendon insertion	1.76 (0.87)	1.54 (0.75)	0.4832	1.68 (0.83)	1.66 (0.84)	0.8205
Thickness of the main tendon insertion	0.58 (0.49)	0.39 (0.31)	0.0257	0.49 (0.43)	0.51 (0.44)	0.8441
Accessory tendon length	2.87 (0.53)	5.32 (6.35)	0.4969	4.10 (4.69)	4.19 (4.86)	0.9806
Accessory tendon thickness	0.13 (0.05)	0.16 (0.12)	0.9034	0.15 (0.09)	0.15 (0.10)	0.9806
Width of the accessory tendon origin	0.57 (0.30)	0.79 (0.37)	0.1985	0.70 (0.37)	0.66 (0.34)	0.7896
Thickness of the accessory tendon origin	0.10 (0.05)	0.18 (0.13)	0.1040	0.14 (0.10)	0.15 (0.11)	0.8843
Width of the accessory tendon insertion	0.61 (0.31)	0.81 (0.38)	0.2345	0.74 (0.38)	0.69 (0.34)	0.6979
3rd tendon length	2.64 (0.06)	3.17 (0.08)	0.2453	2.85 (0.37)	2.96 (0.39)	0.6985
Width of the 3rd tendon origin	0.10 (0.01)	1.04 (0.01)	0.2453	0.57 (0.67)	0.57 (0.65)	0.6985
Thickness of the 3rd tendon origin	0.03 (0.01)	0.07 (0.01)	0.2453	0.05 (0.04)	0.05 (0.01)	0.6985
Width of the 3rd tendon insertion	0.11 (0.01)	1.01 (0.01)	0.2453	0.55 (0.64)	0.57 (0.63)	0.6985
Thickness of the 3rd tendon insertion	0.04 (0.01)	0.04 (0.01)	0.6985	0.04 (0.01)	0.04 (0.01)	0.6985
Anterior frenular ligament origin width	1.41 (1.02)	1.12 (0.95)	0.6374	1.17 (0.99)	1.31 (0.98)	0.7285
Anterior frenular ligament origin thickness	0.34 (0.30)	0.40 (0.38)	0.8137	0.36 (0.36)	0.39 (0.35)	0.9079
Anterior frenular ligament length	2.88 (1.57)	2.79 (1.36)	0.9530	2.71 (1.38)	2.96 (1.50)	0.6025
Anterior frenular ligament insertion width	1.37 (0.93)	1.53 (0.94)	0.9530	1.38 (0.96)	1.56 (0.91)	0.4875
Anterior frenular ligament insertion thickness	0.31 (0.23)	0.68 (0.49)	0.2159	0.48 (0.44)	0.58 (0.47)	0.4875
Posterior frenular ligament origin width	1.19 (-)	0.97 (-)	0.8170	1.02 (0.86)	1.06 (0.89)	0.8273
Posterior frenular ligament origin thickness	0.15 (0.08)	0.91 (0.09)	0.1052	0.68 (0.42)	0.63 (0.48)	1.0000
Posterior frenular ligament length	2.45 (0.24)	2.89 (0.01)	0.1052	2.68 (0.35)	2.80 (0.16)	0.6625
Posterior frenular ligament insertion width	1.22 (0.02)	1.90 (0.06)	0.1052	1.69 (0.41)	1.64 (0.39)	0.6625
Posterior frenular ligament insertion thickness	0.12 (0.01)	0.96 (0.05)	0.1052	0.68 (0.48)	0.68 (0.50)	1.0000

P-value lower than 0.002 is significant with Bonferroni's correction. Values are mean and standard deviation.

cuneiform joint, and accessory bands insert to the fourth interosseus dorsalis muscle; however, no accessory slip was observed until the fourth interosseous dorsalis muscle. Foetal Type IIC in the present study is characterized by the main tendon inserting to the lateral tubercle of the base of the 1st metatarsal bone and the accessory band inserting to the first interosseus dorsalis muscle; this type has also been described in adult studies by Olewnik (2019a) and Patil et al. (2007).

Interestingly, the trifurcated Type III identified in the current study has not been previously described in either adult or foetal studies.

The prevalence of the anterior frenular ligament varies from 29.7% to 80%, and the posterior frenular ligament from 5.4% to 13% (Guimerá et al., 2015; Olewnik, 2019a; Patil et al., 2007; Picou, 1894a, 1894b). In adults, a correlation has been observed between the type of distal attachment and the presence of anterior and posterior frenular ligaments (Olewnik, 2019a). Namely, Type I according to Olewnik (the tendon inserts into the lateral tubercle of the base of the 1st metarsal bone) always occurred with anterior frenular ligament, and Type IIB (the strong accessory slips inserts into both the medial cuneiform bone and the base of the 1st metatarsal bone, including the first metatarsal joint) with the posterior frenular ligament.

Interestingly, while Guimerá et al. (2015) and Picou (1894a, 1894b) report the coexistence of frenular ligaments, Olewnik reports no co-occurrence of anterior and posterior frenular ligaments in adults (Olewnik, 2019a), while Karykowska et al. (2020) do not report any anterior or posterior frenular ligaments. In the present study, both anterior and posterior frenular ligaments were found. The anterior frenular ligament was present in 16% of all examined limbs, the posterior frenular ligament in 6.4%; the two were also found together in two male limbs.

The FLT plays the main role in resisting forces applied to the first metatarsal, and problems with this tendon may cause complete loss of stabilization. It may be associated with metatarsus primus varus (Bohne et al., 1997; Olewnik, 2019a), Charcot Marie Tooth (CMT) (Bohne et al., 1997; Maynou et al., 2017) and most commonly Cavovarus Foot, characterized by a high cavus or arch, an inward turned (varus) heel, and toes contracted like a claw: hence the name *clawed toes* (Maynou et al., 2017). The causes of this latter pathology are varied; however, it could be due to instability between antagonistic muscles, such as the tibialis anterior muscle and the FLM (Bohne

Table 3
Morphometric parameters according to the fibularis longus type (mm).

Parameter	Fibularis longus type			P-value
	I	II	III	
Belly length	40.92 (13.28)	35.59 (9.30)	56.76 (1.28)	0.0113
Width in myotendinous junction	2.53 (1.08)	2.52 (0.82)	3.47 (0.75)	0.0966
Thickness in myotendinous junction	0.73 (0.50)	0.81 (0.41)	1.14 (0.30)	0.1051
Main tendon length	28.30 (14.05)	21.93 (5.49)	31.43 (11.94)	0.1451
Width of the main tendon insertion	1.75 (0.92)	1.37 (0.47)	2.00 (0.03)	0.1285
Thickness of the main tendon insertion	0.56 (0.48)	0.34 (0.22)	0.54 (0.18)	0.2025
Accessory tendon length		4.28 (5.07)	3.36 (0.18)	0.1721
Accessory tendon thickness		0.16 (0.10)	0.09 (0.03)	0.1324
Width of the accessory tendon origin		0.74 (0.35)	0.34 (0.04)	0.0104
Thickness of the accessory tendon origin		0.15 (0.11)	0.08 (0.01)	0.1081
Width of the accessory tendon insertion		0.79 (0.33)	0.30 (0.05)	0.0105
Third tendon length			2.90 (0.31)	-
Width of the third tendon origin			0.57 (0.54)	-
Thickness of the third tendon origin			0.05 (0.02)	-
Width of the third tendon insertion			0.56 (0.52)	-
Thickness of the third tendon insertion			0.04 (0.01)	-
Anterior frenular ligament origin width	1.20 (0.97)	1.32 (1.04)		0.4723
Anterior frenular ligament origin thickness	0.35 (0.34)	0.43 (0.40)		0.5551
Anterior frenular ligament length	2.54 (1.27)	3.63 (1.58)		0.1704
Anterior frenular ligament insertion width	1.20 (0.92)	2.21 (0.10)		0.0777
Anterior frenular ligament insertion thickness	0.40 (0.40)	0.90 (0.35)		0.0666
Posterior frenular ligament origin width	1.04 (0.78)			-
Posterior frenular ligament origin thickness	0.66 (0.40)			-
Posterior frenular ligament length	2.74 (0.25)			-
Posterior frenular ligament insertion width	1.67 (0.35)			-
Posterior frenular ligament insertion thickness	0.68 (0.44)			-

P-value lower than 0.002 is significant according to Bonferroni correction. Values are mean and standard deviation.

et al., 1997; Maynou et al., 2017; Olewnik, 2019a; Olewnik et al., 2020d). Even so, the influence of the additional slips on Cavovarus remains unclear.

This study has some limitations. Due to the great variability of the FLT, the proposed classification is heterogeneous and depends on several morphological details, such as the presence of accessory division and type of insertion. Also, no calculation of the sample size was carried out. Another limitation of the study is that it has not been conducted on foetuses younger than 18 weeks of age. However, this paper is the first of its kind, and our systematic classification can be extremely useful as a basis of foetal anatomical variations and therefore to improve the results of future interventions and as a basis for embryological research on the exact period of formation of additional bands of tendons.

8. Conclusion

The fibularis longus tendon displays high morphological variability. The resulting classification system provides additional data regarding the accessory tendon bands of the FLT. The proposed classification consists of three main types, with Type I and Type II divided into sub-types.

Consent to publish

Not applicable.

Availability of data and materials

Please contact authors for data requests (Łukasz Olewnik PhD – email address: lukasz.olewnik@umed.lodz.pl).

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Authors' contribution

Łukasz Olewnik: Project development, Data collection and management, Data analysis and manuscript writing. **Nicol Zielinska:** Data collection, Data analysis and manuscript editing. **Kacper Ruzik:** Data collection, Data analysis and manuscript editing. **Michał Podgórski:** Statistical analysis, Data analysis and manuscript editing. **Friedrich Paulsen:** Data analysis and manuscript editing. **Rui Diogo:** Data analysis and manuscript editing. **Michał Polguj:** Data analysis, Manuscript editing.

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Declarations.

Ethical approval and consent to participate

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