ONLINE FIRST

This is a provisional PDF only. Copyedited and fully formatted version will be made available soon.

ISSN: 0015-5659

e-ISSN: 1644-3284

Morphological variability of the leg muscles: potential traps on ultrasound that await clinicians

Authors: Marta Pośnik, Nicol Zielinska, Richard Shane Tubbs, Kacper Ruzik, Łukasz Olewnik

DOI: 10.5603/fm.94290

Article type: Review article

Submitted: 2023-02-19

Accepted: 2023-09-01

Published online: 2023-11-21

Morphological variability of the leg muscles: potential traps on ultrasound that await clinicians

Marta Pośnik et al., Anatomical variations

Marta Pośnik[1], Nicol Zielinska[1], R. Shane Tubbs[2-7], Kacper Ruzik[1], Łukasz Olewnik[1]

[1]Department of Anatomical Dissection and Donation, Medical University of Lodz, Poland

[2]Department of Neurosurgery, Tulane University School of Medicine, New Orleans, LA, United States

[3]Department of Neurosurgery and Ochsner Neuroscience Institute, Ochsner Health System, New Orleans, LA, United States

[4]Department of Anatomical Sciences, St. George's University, Grenada, West Indies

[5]Department of Structural and Cellular Biology, Tulane University School of Medicine, New Orleans, LA, United States

[6]Department of Surgery, Tulane University School of Medicine, New Orleans, LA, United States

[7]University of Queensland, Brisbane, Australia

Address for correspondence: Ł. Olewnik, MD, PhD, Department of Anatomical Dissection and Donation, Chair of Anatomy and Histology, Medical University of Lodz, ul. Żeligowskiego 7/9, 90–410 Łódź, Poland, e-mail: lukasz.olewnik@umed.lodz.pl

ABSTRACT

Background: Although muscles and their tendons are not considered the most morphologically variable structures, they still manifest a substantial diversity of variants. The aim of this study is to increase awareness of some of the many possible variants found during ultrasound imaging of one lower limb compartment, the leg, that could potentially mislead clinicians and lead to misdiagnosis.

Materials and methods: PubMed was used for a comprehensive literature search for morphological variations. Relevant papers were included, and citation tracking was used to identify further publications.

Results: Several morphological variants of muscles of the leg have been described over many years, but this study shows that the occurrence of further variations in ultrasound imaging requires further investigations.

Conclusions: The incidence of additional structures including muscles and tendons during ultrasound examination can cause confusion and lead to misinterpretation of images, misdiagnosis, and the introduction of unnecessary and inappropriate treatments.

Keywords: extensor hallucis longus muscle, tibialis anterior muscle, peroneocalcaneus internus, fibularis quartus muscle, popliteus muscle, plantaris muscle, accessory soleus muscle, gastrocnemius muscle, tibialis posterior muscle, flexor digitorum longus muscle, flexor hallucis longus muscle, ultrasound, morphological variability

INTRODUCTION

As it is commonly known, human anatomy has been explored for many centuries but is still full of surprises. Each year the number of scientific papers about unexpected, unusual variations grows, associated with recognition of their clinical significance. Muscles and their tendons are not considered the most variable structures in humans, but there are numerous papers about atypical muscles; ones with additional tendons or additional bands, others unilateral, and even absences.

A diagnostic method finding increasing use among clinicians around the world is ultrasound imaging (US). This method can be very useful, but accessory and variable structures in an image can lead to confusion; if the person performing the imaging is not aware of the possibility of additional structures, a misdiagnosis can occur. It is therefore important to raise awareness of the morphological variability that can be found during a US examination.

The aim of the present review is to explore and discuss some morphological variations of the leg muscles and their tendons that can be found during US imaging of the lower limb. Since the variants considered could potentially produce pitfalls during US examination, another aim is to raise awareness of them among clinicians in order to preclude confusion.

ANTERIOR COMPARTMENT OF THE LEG

Extensor hallucis longus muscle

The extensor hallucis longus muscle (EHL) is positioned in the anterior compartment of the leg and functions in extension of the great toe, dorsiflexion of the foot, foot eversion and inversion, and stretching of the plantar aponeurosis [56, 75, 80]. A large portion of the EHL is covered by the tibialis anterior muscle (TA) and the extensor digitorum longus muscle (EDL), which also occupy this compartment. The EHL arises from the middle part of the fibula and interosseous membrane deep between the TA and EDL and then forms a long tendon that lies behind the superior and inferior extensor retinacula, crosses the anterior tibial vessels, and inserts on the dorsal part of the base of the distal great toe phalanx [56, 75, 80] However, the EHL has numerous morphological variants in the form of additional bands and their insertions. Structures such as additional tendons associated with the EHL are found in 10% to 81% of cases [80, 116], which leads investigators from different fields of medicine to ask whether such additional tendons should be considered in the classical definition of the EHL [16, 56].

During the long, almost 100 years, history of descriptions of morphological variations of the EHL, the additional tendons have been given different names. An additional tendinous slip from the EHL with insertion on to the proximal big toe phalanx was usually called the extensor primi internodii hallucis. An analogous slip with insertion on to the capsule of the first metatarsophalangeal joint was named the extensor hallucis capsularis. There was also the musculus extensor primi metatarsal of Gruber, with characteristic insertion on to the dorsal aspect of the distal part of the first metatarsal [16, 38, 56, 109]. In order to facilitate recognition of the EHL tendon, Olewnik et al.[80] proposed a three-type classification, which was recently updated by Zielinska et al. [116] based on the number of additional tendons and their positions of insertion on the foot. Type I – single tendon; Type II (Fig. 1) – two distal tendons, one dominant with insertion on the distal phalanx of the hallux, with five subtypes; Type III - three distal tendons, the main one being inserted to the dorsal aspect of the distal part of the distal phalanx, with three subtypes (Table 1).

Table 1. Types of EHL tendon presented in classification proposed by Zielinska et al. [116]

Type	Subtype	Description
I	-	single tendon with insertion on the distal phalanx of the hallux
II	a	additional tendon inserted onto dorsal aspect of the proximal phalanx of the hallux, medial to the insertion of the extensor hallucis brevis muscle (EHB)
	b	additional tendon inserted onto the dorsal aspect of the proximal phalanx of the hallux, just distal to the insertion of the EHB
	c	additional tendon inserted onto dorsal aspect of the proximal phalanx of the hallux, just distal to the insertion of the EHB
	d	additional tendon merged with EHB, with distal attachment onto dorsal aspect of the base of the proximal phalanx of the hallux
	e	additional tendon slip merged with EHB, distal attachment onto dorsal aspect of the base of the proximal phalanx of the hallux
III	a	medial additional tendinous slip inserted on to the distal phalanx proximally and lateral additional tendinous slip fused with EHB and attached distally on to the proximal phalanx
	b	two additional tendons, that arose from the medial side of the main tendon and inserting into the capsule of the joint
	c	two additional tendons, that arose from the medial and lateral sides of the main tendon and inserting into the capsule of the first metatarso-phalangeal joint

In recent years there has been an ongoing discussion about the clinical relevance of the EHL. The relationship between an accessory tendon of the EHL and the development of hallux valgus (HV) deformity has been particularly explored. According to Al-Saggaf [4] the force of extension provided by an additional band on the first MTP joint could counter the EHL at the distal aspect of the distal phalanx and lead to HV deformity. However, it has also been suggested that the additional band prevents HV deformity because the accessory tendon could act contrary to the axis of deforming forces [75]. In order to decide whether additional tendons of the EHL cause or prevent the HV deformity, a detailed biomechanical study is necessary [116].

It is worth mentioning that additional bands are suspected of preventing tendon laceration and maintaining normal muscle function if the main tendon is ruptured, which can happen to all muscles including the EHL [80].

Since recognition of an accessory tendon of the EHL could be significant for proper diagnosis, and since recent developments in radiology make it possible to achieve high resolution imaging of the soft tissues characteristic of the foot, US seems an ideal imaging method. This is especially so since MR can be challenging owing to the complex anatomy of tendons and ligaments in the foot region. Olewnik et al. [81] published a US study in which the morphology of the EHL was evaluated in 100 lower limbs from 50 participants. In terms of the previously mentioned anatomical classifications [80, 116], Type I was observed in 76% of the limbs and type IIa, in which there are accessory tendons, in 24%. In the authors' opinion, no other subtypes of Type II or Type III were noticed during the US examination because the additional bands were small. Because they are very rare, or because anatomical dissection is superior at separating tissue layers, neighboring tissues that travel in different directions separated by blunt dissection could appear in US only as a hidden anisotropy [81].

Further studies of additional bands of the EHL are necessary, not only to clarify their classification and clinical significance, but also to determine whether US is an adequate method for visualizing all types of EHL tendon, not only the most common types.

Tibialis anterior muscle

The TA is the largest component of the anterior compartment of the leg [32]. It is usually described as originating at the lateral condyle of the tibia, the lateral surface of the tibial shaft and the anterior surface of the interosseous membrane, forming a muscle belly that becomes the TA tendon and inserts on to the first metatarsal and the medial cuneiform [49, 79, 115].

Among all the muscles of the anterior compartment of the leg, the TA is the strongest dorsiflexor of the foot, and along with the tibialis posterior muscle (TP) is also an inverter of the foot [115]. Because of the placement of its insertion, contraction of the TA also lifts structures of the medial arch into adduction-supination or inversion [72].

The TA has a wide variety of both proximal and distal attachments, however the distal one was particularly studied. The TA tendon was found as a two-bands structure, trifurcated or as a single band inserted onto the medial cuneiform bone (Fig. 2). The variants of its distal insertion have been described and systematized several times over the course of many years among both adults [8, 17, 74] and fetuses[49]. The most recent classification was by Olewnik et al. [79], based on anatomical dissections performed on one hundred lower limbs and partially confirmed by US findings among fifty volunteers (Table 2).

Table 2. Classification of TA tendon introduced by Olewnik et al. [79]

Type	Description	Occurrence in anatomic study	Occurrence in sonographic study
I	tendon split into two equal-sized bands inserted on the medial cuneiform bone and the base of the first metatarsal, formed by a tendinous slip	31%	20%
II	tendon split into two bands, the larger inserting into the medial cuneiform bone and the smaller on the first metatarsal	24%	35%
III	tendon split into two bands, the larger inserting into the first metatarsal and the smaller on the medial cuneiform bone	11%	13%
IV	trifurcated tendon with one band attached to the medial cuneiform bone and two inserted on the first metatarsal	2%	-
V	single band inserted on the medial cuneiform bone	32%	20%
VI	two equal-sized bands inserted on the medial cuneiform bone	-	12%

There is a growing interest in amateur sports that frequently result in tendinopathies and ruptures [33, 50, 92]. One of the more frequently ruptured tendons is the TA tendon. This usually results from excessive or unpredicted forced plantar flexion that stresses the TA tendon during contraction [65]. Although a complete tendon rupture can be diagnosed by palpation, the diagnosis must be confirmed by some kind of imaging before any kind of procedure, and the gold standard for TA tendon rupture is US [79, 115]. According to Olewnik et al. [79] different types of insertion could cause slight differences in the distribution of forces in the foot and ankle joints, and since the most frequently performed type of reconstruction is tendon transfer, the biomechanics of the foot could potentially modify the reconstructed joint; it could become too tight or too loose.

Therefore, even though interesting and unusual variations of the distal attachment of the TA can surprise, they could have crucial significance in planning a procedure for replacement of a ruptured TA tendon.

LATERAL COMPARTMENT OF THE LEG

Fibularis Quartus muscle

The Fibularis quartus muscle (FQ) used to appear in the literature under many names such as “fibularis accessories”, “fibulocuboid”, “peroneoperoneolongus” or “fibulo-calcaneus externum”, although in current studies it is commonly named the FQ or peroneus quartus muscle [111]. It is an accessory muscle of the lateral compartment of the leg that can also appear in the posterior compartment and accompanies the regular fibularis muscles, fibularis longus muscle (FL) and fibularis brevis muscle (FB) (Fig. 3). Cadaveric dissections have shown that the FQ appears in approximately 12-22% [14, 20, 21, 43, 111]. Although it was stated in 1952 that accessory fibular muscles are present in chimpanzees and other mammals [111], the literature commonly asserted that the FQ is found only in humans [14, 21, 43]. Its absence from other species led Hecker [40] to propose that its appearance is a result of evolutionary development, closely related to assistance in accommodating bipedal posture by its involvement in dorsiflexion and eversion of the foot during walking.

The FQ is frequently described as having an origin on the posterior surface of the fibula or one of the regular peroneal muscles, coursing medially and posteriorly to the peroneal tendons and showing great variability in its distal insertion. It most commonly inserts on the retrotrochlear eminence, more rarely on the cuboid, peroneus longus or inferior retinaculum [14, 21, 111].

A classification of the FQ by shape into six types was presented by Hur et al. [43], who found the muscle in 13 of 80 dissected cadavers (16.3%). Results of Hur et al. [43] study are collected in Table 3. In study by Sobel et al. [99], authors dissected one hundred and twenty-four lower limbs and observed FQ in 27 of those (21,7%). Observations from Sobel et al. [99] study are presented in Table 4.

Table 3. FQ classification presented by Hur et al. [43]

Type	Description	Occurrence
I	FQ with a muscular origin with a tendinous insertion	11,3%
II	FQ with a tendinous origin with a muscular insertion	2,5%
III	FQ characterized by a tendinous origin with muscular and tendinous parts of insertion	1,3%
IV	FQ presented only a tendinous part	1,3%
V	FQ presented only a muscular portion	1,3%
VI	FQ characterized by two tendons connected by an intermediate muscle belly	1,3%

Table 4. Observations on FQ presented by Sobel et al. [99]

Type of FQ	Description	Occurrence
peroneocalcaneus externum	an insertion on the calcaneus	7,4%
peroneus accessorius	an origin from the FB and insertion to the tendinous portion of the FL	3,7%
peroneus digiti minimi	an origin from the FB and insertion into the fifth metatarsal	7,4%
other, unnamed variants	originating from the FL and inserting back to the FL	3,7%
	originating from the FB and inserting on the lateral retinaculum	11,1%
	originating from the FL and inserting on the FB	3,7%

In addition there are reports of more complex variations: a peroneocalcaneocuboideus inserting to the cuboid and calcaneus, or a peroneotalocalcaneus inserting on the talus and calcaneus [23]. Interestingly, it has been suggested that the relatively wide morphological and topographical variability of the FQ resulted from changes in the shank and foot during adoption of the upright position and by forces acting on the lower leg while learning how to walk [26].

As previously mentioned, since the FQ is an accessory fibularis muscle, it cooperates with other fibular muscles throughout dorsiflexion and eversion of the foot during walking. It also serves in foot abduction and as a lateral ankle stabilizer [30, 40, 99].

Regarding to its clinical significance, the FQ can remain asymptomatic, although it can also cause several symptoms in the lateral ankle compartment such as swelling, chronic pain or peroneal tendonitis [14, 43, 93, 111]. It can cause crowding in the retromalleolar groove, leading to degeneration or even tearing in the FB owing to the stenosis it can cause in the lateral compartment [43, 111]. Stenosis in the retromalleolar area can also result from the development of synovial hypertrophy resulting from ankle sprains when an FQ is present [14]. Interestingly, Edwards et al.[30] proposed that a connection between the FQ and the prominence of the peroneal tubercle can explain hypertrophy of the peroneal tubercle, which is suspected of causing stenosing tenovaginitis of the peroneal tendons and lateral ankle pain [30, 99]. Despite all the aforementioned pathologies, the FQ can be also beneficial, as shown by Mick and Lynch [70], who used it to perform a successful reconstruction of the peroneal reticulum.

According to Thomas et al.[105], peroneal tendon pathologies can easily be identified by US, which can provide real-time scanning during active and passive ranges of motion along with observations of foot positioning, dorsiflexion and eversion. During this study, in which the authors focused on intrasheath fibularis tendon subluxations, one of the seven patients examined had a tear of the FQ caused by subluxation. However, Chepuri et al. [20] stated that it can be difficult to identify the FQ by US because of its anatomical variability, which makes it hard to differentiate it from other peroneal muscles, since in the flat plane it ranges from 100% hypoechoic (muscular component) to 100% hyperechoic and fibrillar (tendinous part). This can lead to considering whether the appearance of the FQ on US could be misinterpreted as a longitudinal tear of the fibularis brevis tendon, as happened previously during MRI imaging [96].

There has been a noticeable decline of the number of articles about the FQ and about US imagining of it, which seems rather disturbing since sonography is slowly becoming a common method for evaluating ankle tendon abnormalities [20]. Although the frequency of the FQ ranges from 12 to 22% [14, 20, 21, 43, 111], it should always be considered for patients with symptoms such as chronic ankle pain, swelling, or suspected lateral ankle stenosis.

POSTERIOR COMPARTMENT OF THE LEG

Popliteus muscle

The anatomy of the secondary stabilizers of the knee can be presented in terms of corner-based anatomy, comprising the posterolateral corner (PLC), posteromedial corner and anterolateral corner [34, 39, 45]. The popliteus muscle and its tendon form one component of the PLC, and like other structures in this compartment, including the fibular collateral, arcuate, and fabellofibular ligaments, the posterolateral joint capsule and the popliteofibular ligament, the popliteus muscle has a complex, variable and imperfectly known anatomy. This is often explained by its location: the deepest layer of the posterior knee, its smallness and its complicated anatomy [108].

The popliteus muscle is frequently described as having a wide attachment on the posteromedial surface of the tibia, proximal to the soleal line that forms a long tendon passing through the popliteal hiatus beneath the lateral collateral ligament and inserting mainly posteriorly and distally to the lateral epicondyle of the femur. However, fibers are also attached to the popliteal groove and under the lateral collateral ligament [46, 108, 114]. Nonetheless, the popliteus muscle varies in its proximal attachment. It can occur as a single tendon attached to the popliteal sulcus, with one accessory band – to the oblique popliteal ligament, fibular collateral ligament or to the lateral meniscus (Fig. 4). Variations with more than one accessory band are also present, so various classifications of the popliteus tendon (PLT) have emerged, based on differences in its origin. There are types distinguished by the tendon’s attachments sites: posterior capsule, arcuate popliteal ligament, oblique popliteal ligament, fibula, posterior cruciate ligament, posterior meniscofemoral ligament and lateral meniscus [31]. Other authors have based their classifications on a relationship between the PLT and FCL: inferior, posteroinferior or double by bifurcated bands [48]. Another classification [22] distinguishes four types: I (13.3%) with one attachment, II (34.2%) and III (23.3%) with two attachments, IV (28.8%) with three. The most comprehensive classification is four-fold and based on dissections of one hundred and thirty-four lower limbs: type I has a single tendon; type II has a main band attached to the popliteal sulcus, with five subtypes; type III has two tendons in the popliteal sulcus; and type IV has two main tendons in the popliteal sulcus, with five subtypes [78]. Classification by Olewnik et al. [78] is presented in Table 5.

Table 5. Classification of the PLT introduced by Olewnik et al. [78]

Type	**Subtype**	**Description**	**Occurrence**

I	-	single tendon attached to the popliteal sulcus	34,4%
II	a	main tendon as type I, accessory band attached to the oblique popliteal ligament	30,6%
	b	main tendon as type I, accessory band attached to fibular collateral ligament	
	c	main tendon as type I, accessory band attached to the lateral part of the lateral meniscus	
	d	main tendon as type I, with two accessory bands: the first attached to the posterior articular capsule and the second to the oblique popliteal ligament	
	e	main tendon as type I, with three accessory bands: the first attached to the fibular collateral ligament and the second and third attached to the posterior meniscofemoral ligament	
III	-	two tendons present in the popliteal sulcus	15,7%
IV	a	main tendon as type III, the accessory band attached to the oblique popliteal ligament	19,4%
	b	main tendon as type III, with two accessory bands: the first attached to the fibular collateral ligament and the second attached to the posterior articular capsule	
	c	main tendon as type III, with two additional bands: attaching to the fibular collateral ligament and the lateral meniscus	
	d	main tendon as type III, two additional bands were present: attaching to the lateral part of the lateral meniscus and the posterior articular capsule	
	e	main tendon as type III, with two additional bands: attaching to the lateral part of the lateral meniscus and the medial part of the lateral meniscus	

There is an ongoing discussion about the function of the popliteus muscle. It is well known that together with the FCL and the PFL, it has a key role in the static stabilization of the knee joint with respect to internal rotation, varus angulation and anterior translation.

Because of its ligament-like function about the knee, it is often called the “fifth ligament” of the knee [59]. However, its dynamic function remains unclear. It is suspected that it participates in lateral rotation of the femur on the tibia during the gait cycle and also rotates the tibia medially on the femur when the limb is off the ground [78, 100, 108].

Since any isolated injury of the popliteus muscle is uncommon and is mostly associated with more complex posterolateral corner injuries, it can cause problems during diagnosis. Additionally, it usually manifests itself with lateral knee pain, which can have several causes such as iliotibial band syndrome, lateral meniscal pathology, patella-femoral syndrome or biceps femoris tendinopathies [27].

Popliteus tenosynovitis is an uncommon condition that mostly occurs in athletes. It is usually detected by MRI imaging or during arthroscopic examination [15, 114]. However, Howard et al. [41] presented an interesting study of recurrent tenosynovitis, which after 22 years of misdiagnosis as meniscal pathology was finally recognized by US. During US imaging, swelling around the PLT was noted, extending over the lateral meniscus. It was indicated by increased size of the tendon, loss of homogenicity and a hypoechogenic area around the tendon.

Another interesting condition is a ganglion cyst of the PLT. Again, the symptom is lateral/posterolateral knee pain, so the diagnosis can be troublesome. It is an extremely rare condition; there are three reports in the literature and only one that describes US treatment. A ganglion cyst of the PLT manifests itself in US imaging as a small, anechoic structure within the margin of the PLT. Power Doppler demonstrates no internal flow within the cyst [47].

Interestingly, the PLT has an “incomplete sheath” created by the superior lateral parameniscal recess, which can inflame when the popliteus muscle is over-trained. Unsurprisingly, this causes lateral knee pain. On US imaging it occurs as a remarkable fluid distention around the PLT and synovial hypertrophy of the lateral para-meniscal recess [27].

A snapping PLT is another interesting instance. It is the main differential diagnosis of lateral snapping knee, which affects mostly young patients with active lifestyles. Surprisingly, in several published cases, clinical examination, MRI and even arthroscopy failed during the diagnosis of such lateral snaps, so US imaging could be helpful. Although the PLT and underlying popliteal groove are easily detected in US imaging and dynamic sonography can be crucial for confirming involvement of the PLT in snapping knee, there have been no studies of the use of US imaging for evaluating the connection between a snapping PLT and snapping knee syndrome [53, 66, 68].

It seems rather disturbing that although US imaging and guided interventions of the knee joint are widely used, some structures such as the posterolateral corner of the knee are not routinely scanned. This could prove challenging, since structures such as the popliteus tendon and its additional bands are very morphologically variable, potentially giving rise to unusual US images, a potential pitfall for diagnosis.

Plantaris muscle

The plantaris muscle (PM) causes great confusion in many departments of medicine and anatomy, mainly because of the extreme morphological variability of both its distal and proximal attachments and even its course [83, 84]. The typical description of the PM portrays it as small, short and fusiform, usually originating around the supracondylar line of the femur and around the joint capsule, developing a long slender tendon that lies between the gastrocnemius muscle (GM) and the soleus muscle (SM) and then reaches its distal attachment, the calcaneal tuberosity [54, 55, 83–85]. The morphological variability in both its distal and proximal attachments has led to the creation of several classifications . In 1946, Cummis et al. [24] made one of the first attempts, a fourfold classification based on the dissection of 200 lower limbs. Sterkenburg et al. [102] distinguished nine variants. Olewnik et al. [76] described a sixfold classification based on the insertion of the PM (Table 6).

Table 6. PM classification by Olewnik et al. [76]

Type	**Description**	**Occurrence**
Ia	attachment to the lateral head of the GM, lateral femoral condyle and to the knee joint capsule	39,8%
Ib	an origin to the lateral head of the GM, lateral femoral condyle, knee joint capsule and to the popliteal surface of the femur	8,6%
II	an origin to the knee joint capsule and to the lateral head of the GM, which attached indirectly to the lateral femoral condyle through the lateral head of the GM	25%
III	an attachment to the lateral femoral condyle and to the	10,15%

	knee joint capsule	
IV	origin located on the lateral femoral condyle, the knee joint capsule and to the iliotibial band	6,25%
V	origin on the lateral condyle of the femur	8,6%
VI	,,rare cases” - all unusual and uncommon variants, including all another attachment not classified as types I-V	1,6%

There is an ongoing discussion among the medical community about whether the PM is a developing or a residual structure. Some authors assert that its absence in 7-20% of the population is sufficient evidence for vestigiality [5, 19, 95]. However, the entire type VI in the six-fold classification mentioned before could support the opposite view. Some interesting case studies in the current literature can be classified as type VI; reports of two-headed [55, 76] three- headed [84], and even more complex ones [54]. Olewnik et al. [84] observed three-headed PM variant where the first head originated from the posterior femoral surface and the medial side of the lateral femoral condyle, the second from the lateral femoral condyle and from the lateral head of the GM, and the third from the lateral head of the GM (Fig. 5).

Another confusion surrounding the PM concerns its function. It is a biarticular muscle, particularly active during the plantar flexion of the foot, although its small, fusiform muscle belly and long tendon suggest that its biomechanical role is insignificant. However, its anatomical structure and its high density of muscle spindles could suggest that it is a highly-specialized muscle, which has developed a sensory over the motor function [54, 55].

Discussion of the clinical significance of the PM continues. Rohilla et al. [95] described a rupture of the PM misdiagnosed as deep vein thrombosis (DVT) during a US examination. According to these authors, the resident who performed the US imaging based his diagnosis on the fluid he saw in the muscle planes and on the linear hypoechoic structure in the liquid. A correct diagnosis was made after MRI, which revealed that the fluid was located between the medial head of the GM and the SM. This led to a second US examination with Doppler, which ruled out DVT. As stated by Rohilla et al. [95], a PM rupture can be mistaken not only for a DVT but also for a ruptured Baker’s cyst or calf neoplasm. According to Kurtys et al. [55], a more complex muscle variant, a bifurcated or two-headed PM, could cause greater confusion during US examination; hypotrophy of the additional part of the PM can mislead as easily as confusion of a muscle rupture with a Baker’s cyst or calf neoplasm.

Another clinical condition involving the plantaris is “tennis leg”. Generally, this condition can develop during full extension of the knee joint when the ankle joint is in dorsiflexion. There is disagreement in the medical community about whether a PM injury could be one cause of “tennis leg”, since a rupture or tear of the GM is usually considered responsible [25, 54, 55]. However, Delgado et al. [25] examined 141 patients and conducted an anatomical study of four cadavers using both US and MRI imaging, and showed that even though the most common cause of “tennis leg” is indeed GM injury, rupture of PM can also be responsible [25].

The recent literature indicates noticeable interest in the possible involvement of the PM in mid-portion Achilles tendinopathy [1, 2, 35, 36, 67, 82, 103]. The discussion started when Alfredson revealed that in 58 out of 73 cases of chronic painful midportion Achilles tendinosis, the PM was enlarged [1]. Interestingly, involvement of the PM in the Achilles tendinopathy can be detected during US + color Doppler, which reveals the position of the PM tendon as a focal hypoechogenic area connected with increased blood flow. If ultrasound tissue characterization is used, involvement of the PM in mid-portion Achilles tendinopathy can be confirmed by red and white echopixels that indicate a disorganized matrix [67].

The PM is not only a seriously confusing but also a very interesting structure because of its variability, complexity, and the ongoing debates among scientists trying to clarify some aspects of it. Because it traverses the knee and ankle it is prone to rupture, and this could potentially be a sonographic pitfall. This emphasizes the need to popularize knowledge of the PM and the value of clarifying details of it.

Accessory soleus muscle

The accessory soleus muscle (AS) muscle is a rare supernumerary structure with a 0.7% to 5.6% incidence [89]. It is often described as arising from the anterior surface of the soleus muscle (Fig. 6) or from the fibula and the soleal line of the tibia. It has five documented types of insertion [61, 113] presented in Table 7.

Table 7. Types of AS insertion.

Type	Definition
I	insertion along the Achilles tendon
II	a tendinous structure and a fleshy insertion to the superior calcaneus region

III	a tendinous structure and a fleshy insertion to the superior surface of the calcaneus
IV	a fleshy insertion on the medial surface of the calcaneus
V	a tendinous insertion on the medial part of the calcaneus

The AS usually remains asymptomatic, but it can result in a few conditions reported in the literature. It can be associated with clubfoot deformity in children [37]. When it is connected with this condition it cannot easily be detected since the posteromedial area of the ankle is not swollen. However, identification of it is significant because hindfoot deformity can persist after limited surgery if the AS insertion is not released [37]. The AS can also cause swelling of the posteromedial aspect of the ankle [51], which can be asymptomatic or manifest itself as pain during chronic exertion of the ankle during the second and third decades of life owing to increased muscle mass [98]. The AS can also be connected to tarsal tunnel syndrome; it is located outside the tarsal tunnel, but it could exert extrinsic compression [18]. It is also speculated that the AS is associated with Achilles tendinopathy [62].

The AS is rare and can easily be misdiagnosed by an unaware clinician. During diagnosis it can mimic a soft tissue tumor, DVT, lipoma, ganglion, sarcoma, synovioma or hemangioma [13, 98]. Failure to perform imaging before clubfoot surgery when an AS is present, or even failure to recognize the supernumerary muscle during pre-surgery examination, can lead to persistence of hindfoot deformity [37]. Since US is an excellent imaging technique for evaluating superficial soft tissues, including muscular units and myotendinous junctions, it can demonstrate AS accurately [98]. US can help to differentiate the AS from other soft-tissue masses in the posteromedial region of the ankle and prevent potential pitfalls that could lead to unnecessary actions such as biopsy when swelling in the posteromedial compartment of the ankle is confused with a soft tissue tumor [13].

The AS is not common, but its occurrence is significant in various conditions and it is important to know that it could be found during examination of the posteromedial compartment of the ankle and in diagnosis of any condition caused by swelling of this area.

Gastrocnemius muscle

The GM is usually described as a double-headed component of the posterior thigh that forms the belly of calf muscles [9]. The medial head originates from the upper posterior part of the medial femoral condyle and the lateral head from the upper part of the lateral femoral condyle [44]. The two heads fuse to form a single muscle belly at the lower part of the popliteal fossa and then, as the muscle declines, its fibers fuse with SM fibers and form the tendon that inserts on the calcaneus [44].

The GM seems quite variable. Numerous morphological variations have been described: lack of fusion of the medial and lateral heads, both heads replaced by fibrous bands, absence of the lateral head, lack of fusion between the GM and SM, and a sesamoid bone within the medial head [57]. However, the most common and clinically significant are additional heads of the GM [9, 57]. The most frequent of these is a three-headed variant called gastrocnemius tertius, with a prevalence of 7.5% [6]. This can originate from various locations such as lateral epicondyle of femur (Fig. 7), linea aspera, knee joint capsule, long head of biceps femoris muscle or crural fascia, or more than one location [57]. Its variable and unpredictable origin can make it uncertain whether it is indeed the gastrocnemius tertius or a doubled PM [44].

There are also reports of other multiple heads. Ashaolu et al. [9] reported a four-headed GM and called it quadriceps gastrocnemius. Rodriques et al. [94] presented a unique case of a six-headed GM.

Additional GM heads are clinically significant. Since the heads of the GM form the distal boundaries of the popliteal fossa, additional heads could narrow the distal triangle of the that fossa, which will not necessarily remain asymptomatic [9, 44, 94, 112]. Such narrowing could lead to popliteal vessel or sural nerve entrapment syndromes; arterial stasis and aneurysm, venous stasis and impaired nerve function [9, 44, 57, 94]. A symptomatic additional head of the GM usually manifests itself through aching pain, intermittent claudication, tenderness of the popliteal fossa, history of leg swelling, or diminution of the pulse of the distal arteries in passive dorsiflexion of the ankle [57, 112].

A US specialist can find an additional head of the GM during examination of the popliteal fossa while seeking the cause of the previously-mentioned symptoms [57, 112]. Asymptomatic occurrence of a gastrocnemius tertius has been reported as easily noticeable during standard US examination [10]. However, to check if it causes compression of the popliteal neurovascular bundle, color Doppler examination should be performed [112]. During examination of the dorsiflexion position of the ankle, popliteal neurovascular compression caused by an additional head manifests itself by disappearance of the sound of the posterior tibial or dorsalis pedis arteries [112].

Although an additional head of the GM does not always manifest itself with symptoms, when it compresses the popliteal neurovascular bundle it is significant and should be resected. That is why clinicians should be aware of such structures, especially since it is easily detected during US examination of the popliteal fossa.

Fibulocalcaneus (peroneocalcaneus) internus

The Fibulocalcaneus (peronecalcaneus) internus muscle (PCI), which also appears in the literature under the name “muscle of MacAlister”, is an extremely rare accessory muscle (1% prevalence). Radiologists often declare it the least common of all accessory muscles of the ankle [3, 57, 58]. The PCI was first described by MacAlister [63] in 1872. Its rarity leads to an interesting situation: it is more frequently recognized during MRI imaging than during anatomical dissection. In fact, since this muscle was first described, only one gross anatomical photograph of it has been taken during dissection [58].

The PCI is quite variable as well as infrequent. The most common description of it indicates the medial aspect of lower half/third of the fibular diaphysis as its position of initial attachment, distal to the flexor hallucis longus muscle (FHL) origin and around 2-3 cm above the tibiotalar joint. The tendon can pass the surface of the sustentaculum tali lateral to the FHL tendon and insert into the medial calcaneal surface, inferiorly or directly to the sustantaculum cali [12, 69, 97] (Fig. 8). In a case study by Lambert et al. [97] the PCI was classified on the basis of four features: (1) position of origin, lower part of fibula; (2) alignment in relation to the FHL course, parallel and lateral; (3) positioning relative to the tarsal tunnel, lateral or within; (4) position of insertion, inferior aspect of medial calcaneus.

The function of the PCI was not particularly explored in the literature of the nineteenth or twentieth century, although its actions were described by Perkins et al. [88] in 1914 as assisting during plantar flexion in movement at the ankle joint and in markedly encouraging supination and inversion of the foot.

Even though the PCI is rare, it can be important for MRI and ultrasound imaging, potentially leading to misdiagnosis because its anatomical position can mislead and lack of knowledge of it can cause it to be confused with the FHL or an accessory flexor digitorum longus muscle (AFDL) [21, 28, 42, 58]. The FHL is an important landmark for posterior hindfoot arthroscopy, its tendon serving as a secure margin line, since at this level the tibial neurovascular bundle is located superficially and posteromedially to the FHL, which allows safety to be achieved during lateral and anterior instrumentation of the FHL [42, 90]. The PCI can also be misidentified as the AFDL, during MRI or US searches for the cause of tarsal tunnel syndrome. The confusion can arise because both those muscles travel similar courses, although the key distinguishing feature between them is the position of insertion. While the PCI inserts into the medial calcaneal surface inferiorly or directly to the sustentaculum tali, the AFDL has a muscular insertion on either the flexor digitorum longus muscle (FDL) or the quadratus plantae [42]. The distinction between these two muscles can also be important because the AFDL is more closely applied to the posterior tibial neurovascular bundle than the PCI, so it is more likely to be associated with nerve impingement [21].

According to the literature, the PCI can also cause posterior ankle impingement. Seipel et al.[97] described a case of a 14-year old boy who complained of tenderness in the posterolateral and posteromedial aspects of the hindfoot, while prone examination gave no positive posterior ankle impingement test. The boy had undergone unsuccessful prolonged physiotherapy, which comprised stretching, peroneal strengthening, subtalar stabilization and proprioceptive work. The potential cause of this condition, bilateral PCIs, was revealed only by imaging. In order to relieve the symptoms it was decided to excise the PCI; complete resolution of the symptoms followed. The PCI was reported as a cause of tarsal tunnel syndrome in an US pictorial review by Soares et al.[101] who presented a case of 27-year-old woman with history of pain in the left foot; the PCI was visible during longitudinal and axial imaging. However, according to Howe et al.[42] US imaging of the PCI is limited in respect of accurate identification and depiction of the tendon insertion because its position is relatively deep and the sustentaculum tali causes shadowing.

Although the PCI is extremely rare, it can confuse diagnoses in several ways, leading to misinterpretation not only of US images but also of MRI scans if they are interpreted by someone who is not aware of the possibility of this accessory muscle. This highlights the importance of raising awareness of the PCI among clinicians and of emphasizing that US is not always the best method for portraying it.

Tibialis posterior muscle

The TP originates from upper two-thirds of posterior surface of fibula and upper two-thirds of the posterior surface of tibia and posterior surface of interosseous membrane of the leg and forms tendon, that passes medial malleolus of the tibia posteriorly, trough the tarsal tunnel and that inserts onto plantar surface of tarsal bones, mostly navicular and medial cuneiform bone and onto cuboid, cuneiform bones and second, third and fourth metatarsal bones [72].

Even though several variations of TP were noted, the most significant variability occurs on its distal attachment. TP can be inserted as one tendon, or with additional bands – one onto lateral cuneiform bone, two – to the lateral and medial cuneiform bones (Fig. 9), metatarsal bones or even quadriple insertion can be present [77]. Olewnik et al. [77] proposed four-fold classification based on dissection of 80 lower limbs (Table 8). Interestingly during anatomical dissections of 118 lower limbs carried out by Park et al. [87] other variations than presented by Olewnik et al. [77] were noticed, so the author proposed supplementation of previously introduced classification (Table 9).

Table 8. Classification for the Tendon of Insertion of TP by Olewnik et al. [77]

Type	Description		Occurrence
I	typical insertion with single attachment onto navicular and medial cuneiform bone		16,25%
II	typical insertion like in type I with additional tendinous band to the lateral cuneiform bone		22,5%
III	triple attachment with main tendon that courses like in type I, with additional bands		43,75%
	Subtype IIIA	accessory bands onto medial and lateral cuneiform bones	
	Subtype IIIB	bands onto lateral and intermediate cuneiform bones	
	Subtype IIIC	first accessory band onto second/third/fourth /fifth metatarsal bone and second band with insertion onto the second metatarsal bone	
IV	quadriple attachment with main tendon that courses like in type I, with accessory bands		17,5%
	Subtype IVA	accessory bands onto plantar calcaneocuboid ligament, cuboid bone	

		and flexor hallucis brevis muscle (FHB)	
	Subtype IVB	first and second bands are organized anteriorly to the third	
	Subtype IVC	first and second bands are arranged posteriorly to the third one	

Table 9. Supplementation of Olewnik et al. [77] classification for the Tendon of Insertion of TP, presented by Park et al. [87].

Subtype	**Description**	**Occurrence**
IIIK	first accessory tendon inserts onto lateral cuneiform bone and second accessory tendon inserts onto fibrotendinous origin of the FHB	9,3%
IVK-1	accessory bands attach onto intermediate and lateral cuneiform bones and onto fibrotendinous origin of the FHB	21,2%
IVK-2	accessory bands onto second metatarsal and second/third/fourth/fifth metatarsal and fibrotendinous origin of the FHB	32,2%
IVK-3	accessory bands onto lateral cuneiform, fourth metatarsal and origin of the FHB	11%
IVK-4	additional bands that attaches conjointly onto fibularis longus and first metatarsal bone, cuboid bone and origin of the FHB	1,7%

Posterior tibial tendon disfunction (PTTD) is a pathological condition that affects 5% to 15% of population, that can progress to adult acquired flatfoot deformity (AAFD) [71]. PTTD might be induced owing to overloading the TP tendon during activities such as running, walking or hiking and since such sports are more commonly undertaken by amateur, the incidence of PTTD and resulting AAFD increase [107]. Knowledge and understanding of highly variable anatomy of the TP tendon is extremely important in AAFD treatment, since it might impose the method of treatment and eventual surgical approach [87], therefore performance of imaging study during pre-operational process seems mandatory. Currently MRI is perceived as gold standard for PTTD, however according to Arnoldner et al. [7] 18 Hz HR-US is equally accurate as 3T MRI, moreover comparison to surgical findings shows somewhat higher accuracy towards HR-US. Given this fact, clinicians should be aware not only of the fact that PT tendon shows extraordinary variability, but especially that during imaging accessory tendinous bands might occur and affect decision about further treatment.

Flexor digitorum longus muscle

FDL originates from medial part of posterior surface of the tibia, inferior to soleus and medial to PT, by a brad tendon to fibula and above the ankle joint gives off a tendon that inserts onto the bases of the distal phalanges of the lateral four digits [72].

FDL is mostly variable in tendinous connections that occurs between FDL and FHL. Other variations such as additional slip to the fifth toe were also noted [104]. Although the most frequently observed accessory muscle of the leg – previously mentioned AFDL is also a variation of the FDL [104]. This additional muscle presents variable origin to the tibia, fibula, tibia and fibula, deep muscles of the posterior compartment of the leg and intermuscular septum, muscle belly transforms into tendon, travels through tarsal tunnel and inserts onto FDL and/or quadratus plantae [21, 57] (Fig. 10). Since this muscle lays within the tarsal tunnel its presence might cause compression of the posterior tibial neurovascular bundle and result in tarsal tunnel syndrome development. According to Kinoshita et al. [52] AFDL was found to cause such constriction in 12% of cases. Eberle et al. [29] presented AFDL that passed into the foot and into fibro-osseus tunnel below the same part of the retinaculum as the FHL, what resulted in tethering of the flexor tendons, that resembled flexor hallucis syndrome.

During diagnosis of both tarsal tunnel and flexor hallucis syndrome some kind of imaging study must be undertaken. As previously mentioned AFDL can be easily mistaken for the PCI muscle during both ultrasound imaging and MRI scanning due to the course of both muscles [21, 42]. In order to distinguish the most and the least common accessory muscles of the leg one must look closely at the distal attachments of those variations, since in most cases there can be found the defining feature. AFDL inserts to FDL and/or quadratus plantae whereas PCI into the medial calcaneal surface inferiorly or directly to the sustentaculum tali [42].

Flexor hallucis longus muscle

According to medical textbooks FHL originates from inferior two thirds of posterior surface of fibula and inferior part of interosseous membrane [72]. Its tendon passes through the tarsal tunnel where it crosses the FDL tendon and runs towards its site of insertion – base of the distal phalanx [72].

FHL muscle presents certain variability. Xarchas et al. [110] reported absence of the FHL tendon connected with additional fifth band that arose from the FDL to the great toe. However, previously mentioned connections between FHL and FDL, especially single slip extending from FHL tendon to FDL tendon distally (Fig. 11) are the most frequent [57]. Those communications were assigned into VII types with variable frequency in different studies (Table 10).

Table 10. Types of connections between FHL and FDL

Type	**Description**	**Occurrence**
I	single slip that extends from FHL tendon to FDL tendon distally	Mao H et al. [64] 96,9% LaRue BG et al. [60] 42% Vasudha et al. [106] 61,76% Mulier et al. [73] 58% Beger et al. [11] 75%
II	two connecting slips where one connects the FHL proximally to FDL distally and other that connects the FDL proximally to FHL distally	LaRue BG et al. [60] 42% Mao H et al. [64] 0% Vasudha et al. [106] 2,94% Beger et al. [11] 10%
III	single slip that extends from FDL tendon proximally towards FHL tendon distally	Vasudha et al. [106] 7,35% O'Sullivan et al. [86] 13% Plaass et al. [91] 3% Beger et al. [11] 0%
IV	lack of communication between the FHL and FDL	LaRue BG et al.[60] 17% Vasudha et al. [106] 14,70% Mulier et al. [73] 13% Beger et al. [11] 0%
V	two slips that connects FHL tendon proximally to FDL tendon distally	Vasudha et al. [106] 8,82% Beger et al. [11] 5%
VI	three slips where two connects FHL tendon proximally to FDL distally and the third slip that	Beger et al. [11] 5%

	connects FDL proximally to FHL distally	
VII	three slips where two connect FDL proximally to FHL distally and one that connects FHL tendon proximally to FDL distally	Vasudha et al. [106] 1,47% Beger et al. [11] 5%

Such tendinous connections have great clinical significance. FHL and FDL transfers are commonly used in reconstructive surgeries such as PTTD, chronic Achilles tendon or peroneal tendon rupture [91]. Communication between FHL and FDL will influence the length of the graft that can be harvested for such surgeries. Performance of imaging study before harvesting those tendons especially since their wide variability might surprise clinicians and thwart treatment plans. Another reason for implication of imaging study is that eventual errors during harvesting surgery might imply multiple complications like weakness in the little toes, wound morbidity and neurovascular injury [91].

CONCLUSIONS

The morphological variants presented in this study can potentially cause pitfalls during US imaging. In order to prevent confusion, misinterpretation, misdiagnosis and the introduction of erroneous methods of treatment, research on the use of US for locating morphological variants is required. The importance of US imaging has grown because it has recently become more accessible, so it is more frequently used by clinicians for diagnosis.

Ethical approval and consent to participate

The study protocol was accepted by the Bioethics Committee of the Medical University of Lodz (resolution RNN/297/17/KE). The cadavers were the property of the Department of Anatomical Dissection and Donation, Medical University of Lodz, Informed Consents were obtained from all participants before they died.

Conflict of interest: None declared

REFERENCES

1. Alfredson H. Midportion Achilles tendinosis and the plantaris tendon. Br J Sports Med. 2011; 45(13): 1023–1025, doi: 10.1136/bjsports-2011-090217.

2. Alfredson H, Spang C. Clinical presentation and surgical management of chronic Achilles tendon disorders — A retrospective observation on a set of consecutive patients being operated by the same orthopedic surgeon. Foot Ankle Surg. 2018; 24(6): 490–494, doi: 10.1016/j.fas.2017.05.011.

3. Al-Himdani S, Talbot C, Kurdy N, et al. Accessory muscles around the foot and ankle presenting as chronic undiagnosed pain. An illustrative case report and review of the literature. Foot. 2013; 23(4): 154–161, doi: 10.1016/j.foot.2013.08.002.

4. Al-Saggaf S. Variations in the insertion of the extensor hallucis longus muscle. Folia Morphol (Warsz). 2003; 62(2): 1–9.

5. Aragão JA, Prado Reis F, Guerra DR, et al. The Occurrence of the Plantaris Muscle and its Muscle-Tendon Relationship in Adult Human Cadavers Presencia de Músculos Plantares y su Relación Musculotendinosa en Cadáveres Humanos Adultos. Int J Morphol. 2010; 28(1): 255–258.

6. Arce YV, Almiron YP, Diaz MAR, et al. Anatomical variations of the gastrocnemius muscle. Br J Morphol Sci. 2008; 25: 157–214.

7. Arnoldner MA, Gruber M, Syré S, et al. Imaging of posterior tibial tendon dysfunction - Comparison of high-resolution ultrasound and 3 T MRI. Eur J Radiol. 2015; 84(9): 1777–1781, doi: 10.1016/j.ejrad.2015.05.021.

8. Arthornthurasook A, Gaew Im K. Anterior tibial tendon insertion: an anatomical study. J Med Assoc Thai. 1990; 73: 692–696.

9. Ashaolu JO, Oni-orisan OA, Ukwenya VO, et al. The quadriceps gastrocnemius muscle. Surg Radiol Anat. 2014; 36(10): 1101–1103, doi: 10.1007/s00276-013-1248-4.

10. Ata AM, Kara M, Aydin G, et al. Ultrasound Imaging for Muscle Variations: Digastric Flexor Carpi Ulnaris, Gastrocnemius Tertius, and Supernumerary Fibularis Longus in an Asymptomatic Family. Am J Phys Med Rehabil. 2018; 97(11): e107–e109, doi: 10.1097/PHM.0000000000000945.

11. Beger O, Elvan Ö, Keskinbora M, et al. Anatomy of Master Knot of Henry: a morphometric study on cadavers. Acta Orthop Traumatol Turc. 2018; 52(2): 134–142.

12. Best A, Giza E, Linklater J, et al. Posterior Impingement of the Ankle Caused by Anomalous Muscles. J Bone Joint Surg Am . 2005, 87: 2075–2079.

13. Bianchi S, Abdelwahab IF, Oliveri M, et al. Sonographic Diagnosis of Accessory Soleus Muscle Mimicking a Soft Tissue Tumor. J Ultrasound Med. 1995; 14: 707–709.

14. Bilgili MG, Kaynak G, Botanlıoğlu H, et al. Peroneus quartus: Prevalance and clinical importance. Arch Orthop Trauma Surg. 2014; 134(4): 481–487, doi: 10.1007/s00402-014-1937-4.

15. Blake SM. Popliteus tendon tenosynovitis. Br J Sports Med. 2005; 39(12): e42–e42, doi: 10.1136/bjsm.2005.019349.

16. Boyd N, Brock H, Meier A, et al. Extensor Hallucis Capsularis: Frequency and Identification on MRI. Foot Ankle. 2006; 27(3): 181–184.

17. Brenner E. Insertion of the tendon of the tibialis anterior muscle in feet with and without hallux valgus. Clin Anat. 2002; 15: 217–223.

18. Carrington SC, Stone P, Kruse D. Accessory Soleus: A Case Report of Exertional Compartment and Tarsal Tunnel Syndrome Associated With an Accessory Soleus Muscle. J Foot Ankle Surg. 2016; 55(5): 1076–1078, doi: 10.1053/j.jfas.2015.07.011.

19. Cft SL, Simpson MS, Hertzog RH, et al. The plantaris tendon graft: An ultrasound study. J Hand Surg Am . 1991, 16A: 708–711.

20. Chepuri NB, Jacobson JA, Fessell DP, et al. Sonographic Appearance of the Peroneus Quartus Muscle: Correlation with MR Imaging Appearance in Seven Patients. Radiology. 2001; 218(2): 415–419.

21. Cheung Y. Normal Variants: Accessory Muscles About the Ankle. Magn Reson Imaging Clin N Am. 2017; 25(1): 11–26, doi: 10.1016/j.mric.2016.08.002.

22. Chuncharunee A, Chanthong P, Lucksanasombool P. The patterns of proximal attachments of the popliteus muscle: Form and function. Med Hypotheses. 2012; 78(2): 221–224, doi: 10.1016/j.mehy.2011.10.028.

23. Clarkson MJ, Fox JN, Atsas S, et al. Clinical Implications of Novel Variants of the Fibularis (Peroneus) Quartus Muscle Inserting onto the Cuboid Bone: Peroneocuboideus and

Peroneocalcaneocuboideus. J Foot Ankle Surg. 2013; 52(1): 118–121, doi: 10.1053/j.jfas.2012.10.006.

24. Cummis EJ, Anson BJ. The structure of the calcaneal tendon (of Achilles) in relation to orthopedic surgery, with additional observations on the plantaris muscle. Surg Gynecol Obstet. 1946; 83: 107–116.

25. Delgado GJ, Chung CB, Lektrakul N, et al. Tennis leg: Clinical US study of 141 patients and anatomic investigation of four cadavers with MR imaging and US. Radiology. 2002; 224(1): 112–119, doi: 10.1148/radiol.2241011067.

26. Domagała Z, Gworys B, Kreczyńska B, et al. A contribution to the discussion concerning the variability of the third peroneal muscle: an anatomical analysis on the basis of foetal material. Folia Morphol (Warsz). 2006; 65(4): 329–336.

27. Dregoesc MI, Iancu AC, Lazar AA, et al. Hypereosinophilic syndrome with cardiac involvement in a patient with multiple malignancies. Med Ultrason. 2018; 20(3): 399, doi: 10.11152/mu-1574.

28. Duran-Stanton A, Bui-Mansfield L. Magnetic Resonance Diagnosis of Tarsal Tunnel Syndrome Due to Flexor Digitorum Accessorius Longus and Peroneocalcaneus Internus Muscles. J Comput Assist Tomogr. 2010; 34(2): 270–272.

29. Eberle CF, Moran B, Gleason T. The accessory flexor digitorum longus as a cause of flexor hallucis syndrome. Foot Ankle Int. 2002; 23(1): 51–55.

30. Edwards ME. The relations of the peroneal tendons to the fibula, calcaneus, and cuboideum. Am J Anat. 1928; 42(1): 213–253.

31. Feipel V, Simonnet ML, Rooze M. The proximal attachments of the popliteus muscle: A quantitative study and clinical significance. Surg Radiol Anat. 2003; 25(1): 58–63, doi: 10.1007/s00276-002-0093-7.

32. Fennell CW, Phillips and P, Calgary Md, et al. Redefining the Anatomy of the Anterior Tibialis Tendon. Foot Ankle. 1994; 14: 396–399.

33. Forde MS, Punnett L, Wegman DH. Prevalence of musculoskeletal disorders in union ironworkers. J Occup Environ Hyg. 2005; 2(4): 203–212, doi: 10.1080/15459620590929635.

34. Geiger D, Chang EY, Pathria MN, et al. Posterolateral and Posteromedial Corner Injuries of the Knee. Magn Reson Imaging Clin N Am . 2014. W.B. Saunders, 22: 581–599, doi: 10.1016/j.mric.2014.08.001.

35. Gonera B, Kurtys K, Karauda P, et al. Possible effect of morphological variations of plantaris muscle tendon on harvesting at reconstruction surgery-case report. Surgical and Radiologic Anatomy. 2020; 42(10): 1183–1188, doi: 10.1007/s00276-020-02463-1.

36. Gonera B, Kurtys K, Paulsen F, et al. The plantaris muscle – Anatomical curiosity or a structure with important clinical value? – A comprehensive review of the current literature. Ann Anat. 2021; 235, doi: 10.1016/j.aanat.2021.151681.

37. Gupta P, Singla R, Gupta R, et al. Accessory soleus muscle in clubfoot deformity: a report in four feet. J Pediatr Orthop B. 2007; 106–109.

38. Hallisy SE. The muscular variations in the human foot. A quantitive study. Am J Anat. 1930; 45(3): 411–432.

39. Hansford BG, Yablon CM. Multiligamentous Injury of the Knee: MRI Diagnosis and Injury Patterns. Semin Musculoskelet Radiol. 2017; 21(2): 63–74, doi: 10.1055/s-0037-1599208.

40. Hecker P. Study on the peroneus of the tarsus. Anat Rec. 1923; 26: 79–82.

41. Howard CB, Bonneh DY, Nyska M. Diagnosis of Popliteus Tenosynovitis by Ultrasound. J Orthop Sports Phys Ther. 1992; 16(2): 58–59.

42. Howe BM, Murthy NS. An accessory peroneocalcaneus internus muscle with MRI and US correlation. J Radiol Case Rep . 2012, 6: 20–25, doi: 10.3941/jrcr.v6i10.1063.

43. Hur MS, Won HS, Chung IH. A new morphological classification for the fibularis quartus muscle. Surg Radiol Anat. 2015; 37(1): 27–32, doi: 10.1007/s00276-014-1292-8.

44. Ishii T, Kawagishi K, Hayashi S, et al. A bilateral third head of the gastrocnemius which is morphologically similar to the plantaris. Surg Radiol Anat. 2021; 43(7): 1095–1098, doi: 10.1007/s00276-020-02670-w.

45. Jadhav SP, More SR, Riascos RF, et al. Comprehensive review of the anatomy, function, and imaging of the popliteus and associated pathologic conditions. Radiographics. 2014; 34(2): 496–513, doi: 10.1148/rg.342125082.

46. Jadhav SP, More SR, Riascos RF, et al. Comprehensive review of the anatomy, function, and imaging of the popliteus and associated pathologic conditions. Radiographics. 2014; 34(2): 496–513, doi: 10.1148/rg.342125082.

47. Jose J, Silverman E, Kaplan L. Symptomatic ganglion cyst of the popliteus tendon treated with Ultrasound-guided aspiration and steroid injection: A case report. Sports Health. 2011; 3(4): 393–395, doi: 10.1177/1941738111406223.

48. Jung GH, Kim J do, Kim H. Location and classiffication of popliteus tendon’s origin: Cadaveric study. Arch Orthop Trauma Surg. 2010; 130(8): 1027–1032, doi: 10.1007/s00402-010-1123-2.

49. Karauda P, Podgórski M, Paulsen F, et al. Anatomical variations of the tibialis anterior tendon. Clin Anat. 2021; 34(3): 397–404, doi: 10.1002/ca.23663.

50. Kaux J-F, Forthomme B, le Goff C, et al. Current opinions on tendinopathy. J Sports Sci Med. 2011; 10: 238–253.

51. Kendi TK, Erakar A, Oktay O, et al. Accessory Soleus Muscle. J Am Podiatr Med Assoc. 2004; 96(6): 587–589.

52. Kinoshita M, Okuda R, Morikawa J. Tarsal tunnel syndrome associated with an accessory muscle. Foot Ankle Int. 2003; 24(2): 132–136.

53. Krause DA, Stuart MJ. Snapping popliteus tendon in a 21-year-old female. J Orthop Sports Phys Ther. 2008; 38(4): 191–195, doi: 10.2519/jospt.2008.2698.

54. Kurtys K, Gonera B, Olewnik, et al. A highly complex variant of the plantaris tendon insertion and its potential clinical relevance. Anat Sci Int. 2020; 95(4): 553–558, doi: 10.1007/s12565-020-00540-4.

55. Kurtys K, Gonera B, Olewnik, et al. Is the plantaris muscle the most undefined human skeletal muscle? Anat Sci Int. 2021; 96(3): 471–477, doi: 10.1007/s12565-020-00586-4.

56. Lai KC, Tan HW, Chen LJ, et al. Characteristics of the accessory tendon of the extensor hallucis longus muscle: a Taiwanese study. Surg Radiol Anat. 2021; 43(7): 1053–1059, doi: 10.1007/s00276-020-02648-8.

57. Lambert HW. Leg Muscles. Bergman’s Comprehensive Encyclopedia of Human Anatomic Variation. 2016; 421–437, doi: 10.1002/9781118430309.ch41.

58. Lambert HW, Atsas S, Fox JN. The fibulocalcaneus (peroneocalcaneus) internus muscle of MacAlister: Clinical and surgical implications. Clin Anat. 2011; 24(8): 1000–1004, doi: 10.1002/ca.21289.

59. Laprade RF, Wozniczka JK, Stellmaker MP, et al. Analysis of the Static Function of the Popliteus Tendon and Evaluation of an Anatomic Reconstruction. Am J Sports Med. 2010; 38(3): 543–549, doi: 10.1177/0363546509349493.

60. LaRue BG, Anctil ÉP. Distal anatomical relationship of the fexor hallucis longus and fexor digitorum longus tendons. Foot Ankle Int. 2006; 27(7): 528–532.

61. Lorentzon R, Wirell S. Anatomic variations of the accessory soleus muscle. Acta radiol. 1987; 28: 627–629.

62. Luck MD, Gordon AG, Blebea JS, et al. High association between accessory soleus muscle and Achilles tendonopathy. Skeletal Radiol. 2008; 37(12): 1129–1133, doi: 10.1007/s00256-008-0554-0.

63. Macalister A. Additional observations on muscular anomalies in human anatomy. The Transactions of the Royal Irish Academy. 1871; 25: 1–134.

64. Mao H, Wang L, Dong W, et al. Anatomical feasibility study of fexor hallucis longus transfer in treatment of Achilles tendon and posteromedial portal of ankle arthroscopy. Surg Radiol Anat. 2018; 40(9): 1031–1038.

65. Mao H, Xu G. Soft tissue repair for tibialis anterior tendon ruptures using plate and screw fixation technique in combination with anterolateral thigh flaps transplantation. J Orthop Surg Res. 2015; 10(1), doi: 10.1186/s13018-015-0278-5.

66. Marchand AJ, Proisy M, Ropars M, et al. Snapping knee: Imaging findings with an emphasis on dynamic sonography. AJR Am J Roentgenol . 2012, 199: 142–150, doi: 10.2214/AJR.11.7817.

67. Masci L, Spang C, van Schie HTM, et al. How to diagnose plantaris tendon involvement in midportion Achilles tendinopathy - Clinical and imaging findings. BMC Musculoskelet Disord. 2016; 17(1), doi: 10.1186/s12891-016-0955-5.

68. McAllister DR, Parker RD. Bilateral Subluxating Popliteus Tendons A Case Report. Am J Sports Med. 1999; 27(3): 376–379.

69. Mellado JM, Rosenberg ZS, Colon E. The Peroneocalcaneus Internus Muscle: MR Imaging Features. AJR Am J Roentgenol. 1997; 169: 585–588.

70. Mick CA, Lynch F. Reconstruction of the peroneal retinaculum using the peroneus quartus. A case report. J Bone Joint Surg Am. 1987; 69(2): 296–297.

71. Mills FB, Williams K, Chu CH, et al. Prevalence of Abnormal Ultrasound Findings in Asymptomatic Posterior Tibial Tendons. Foot Ankle Int. 2020; 41(9): 1049–1055, doi: 10.1177/1071100720931085.

72. Moore K, Dalley A. F., Agur A.M.R. Clinically Oriented Anatomy (7th ed.). Wilkins, Lippincott Williams and Wilkins, Philadelphia. 2014.

73. Mulier T, Rummens E, Dereymaeker G. Risk of neurovascular injuries in fexor hallucis longus tendon transfers: an anatomic cadaver study. Foot Ankle Int. 2007; 28(8): 910–915.

74. Musiał W. Variations of the terminal insertions of the anterior and posterior tibial muscles in man. Folia Morphol . 1963; 26: 294–302.

75. Natsis K, Konstantinidis GA, Symeonidis PD, et al. The accessory tendon of extensor hallucis longus muscle and its correlation to hallux valgus deformity: a cadaveric study. Surg Radiol Anat. 2017; 39(12): 1343–1347, doi: 10.1007/s00276-017-1881-4.

76. Olewnik, Kurtys K, Gonera B, et al. Proposal for a new classification of plantaris muscle origin and its potential effect on the knee joint. Ann Anat. 2020; 231, doi: 10.1016/j.aanat.2020.151506.

77. Olewnik Ł. A proposal for a new classification for the tendon of insertion of tibialis posterior. Clin Anat. 2019; 32(4): 557–565, doi: 10.1002/ca.23350.

78. Olewnik Ł, LaPrade RF, Paulsen F, et al. A proposal for a new morphological classification of the popliteus muscle tendon with potential clinical and biomechanical significance. Sci Rep. 2021; 11(1), doi: 10.1038/s41598-021-93778-5.

79. Olewnik Ł, Podgórski M, Polguj M, et al. A cadaveric and sonographic study of the morphology of the tibialis anterior tendon - A proposal for a new classification. J Foot Ankle Res. 2019; 12(1), doi: 10.1186/s13047-019-0319-0.

80. Olewnik Ł, Podgórski M, Polguj M, et al. A cadaveric study of the morphology of the extensor hallucis longus - A proposal for a new classification. BMC Musculoskelet Disord. 2019; 20(1), doi: 10.1186/s12891-019-2688-8.

81. Olewnik Ł, Podgórski M, Polguj M, et al. Is ultrasound effective in determining variation of the insertion of the extensor hallucis longus tendon? Clin Anat. 2020; 33(8): 1235–1239, doi: 10.1002/ca.23572.

82. Olewnik L, Wysiadecki G, Podgórski M, et al. The Plantaris Muscle Tendon and Its Relationship with the Achilles Tendinopathy. Biomed Res Int. 2018; 2018, doi: 10.1155/2018/9623579.

83. Olewnik Ł, Wysiadecki G, Polguj M, et al. Anatomic study suggests that the morphology of the plantaris tendon may be related to Achilles tendonitis. Surg Radiol Anat. 2017; 39(1): 69–75, doi: 10.1007/s00276-016-1682-1.

84. Olewnik Ł, Zielinska N, Karauda P, et al. A three-headed plantaris muscle: evidence that the plantaris is not a vestigial muscle? Surg Radiol Anat. 2020; 42(10): 1189–1193, doi: 10.1007/s00276-020-02478-8.

85. Olewnik, Podgórski M, Polguj M, et al. The plantaris muscle - Rare relations to the neurovascular bundle in the popliteal fossa. Folia Morphologica . 2018; 77(4): 785–788, doi: 10.5603/FM.a2018.0039.

86. O'Sullivan E, Carare-Nnadi R, Greenslade J, et al. Clinical signifcance of variations in the interconnections between fexor digitorum longus and fexor hallucis longus in the region of the knot of Henry. Clin Anat. 2005; 18(2): 121–125.

87. Park JH, Kim D, Kwon HW, et al. A new anatomical classification for tibialis posterior tendon insertion and its clinical implications: A cadaveric study. Diagnostics (Basel). 2021; 11(9), doi: 10.3390/diagnostics11091619.

88. Perkins JD. An anomalous muscle of the leg: Peroneocalcaneus internus. Anat Rec. 1914; 8: 21–25.

89. Peterson DA, Stinson W, Carter J. Bilateral Accessory Soleus: A Report on Four Patients with Partial Fasciectomy. Foot Ankle. 1993; 14(5): 284–288.

90. Phisitkul P, Amendola A. False FHL: A Normal Variant Posing Risks in Posterior Hindfoot Endoscopy. Arthroscopy. 2010; 26(5): 714–718, doi: 10.1016/j.arthro.2009.07.026.

91. Plaass C, Abuharbid G, Waizy H, et al. Anatomical variations of the fexor hallucis longus and fexor digitorum longus in the chiasma plantare. Foot Ankle Int. 2013; 34(11): 1580–1587.

92. Riley G. Tendinopathy - From basic science to treatment. Nat Clin Pract Rheumatol . 2008, 4: 82–89, doi: 10.1038/ncprheum0700.

93. Rios Nascimento SR, Watanabe Costa R, Ruiz CR, et al. Analysis on the Incidence of the Fibularis Quartus Muscle Using Magnetic Resonance Imaging. Anat Res Int. 2012; 2012: 1–6, doi: 10.1155/2012/485149.

94. Rodrigues V, Rao MK, Nayak S. Multiple heads of gastrocnemius with bipennate fiber arrangement-a clinically significant variation. J Clin Diagn Res. 2016; 10(8): AD01–AD02, doi: 10.7860/JCDR/2016/20094.8340.

95. Rohilla S, Jain N, Yadav R. Plantaris rupture: why is it important? Case Reports. 2013; 2013(jan22 1): bcr2012007840–bcr2012007840, doi: 10.1136/bcr-2012-007840.

96. Schweitzer1 ME, Emad M, Deeiy1 D, et al. Using MR Imaging to Differentiate Peroneal Splits from Other Peroneal Disorders. AJR Am J Roentgenol. 1997; 186: 129–133.

97. Seipel R, Linklater J, Pitsis G, et al. The Peroneocalcaneus Internus Muscle: An Unusual Cause of Posterior Ankle Impingement. Foot Ankle Int. 2005; 26(10): 890–893.

98. Simonetti I, Pietto D, Zappia M, et al. Learning Point of the Article: Ultrasound and Magnetic Resonance Imaging Diagnosis of Isolated Tear of the Accessory Soleus Tendon: A Case Report and Review of the Literatures. J Orthop Case Rep. 2020; 10(2): 86–87, doi: 10.13107/jocr.2020.v10.i02.1710.

99. Sobel M, Levy ME, York N. Congenital Variations of the Peroneus Quartus Muscle: An Anatomic Study. Foot Ankle. 1990; 11(2): 81–89.

100. Soda N, FujihaShi Y, Aoki T. In vivo ultrasound imaging of the popliteus muscle: investigation of functional characteristics. J Phys Ther Sci . 2016, 28: 979–982.

101. de Souza Reis Soares O, Duarte ML, Brasseur JL. Tarsal Tunnel Syndrome: An Ultrasound Pictorial Review. J Ultrasound Med. 2021; 41(5): 1247–1272, doi: 10.1002/jum.15793.

102. van Sterkenburg MN, Kerkhoffs GMMJ, Kleipool RP, et al. The plantaris tendon and a potential role in mid-portion Achilles tendinopathy: An observational anatomical study. J Anat. 2011; 218(3): 336–341, doi: 10.1111/j.1469-7580.2011.01335.x.

103. van Sterkenburg MN, Kerkhoffs GMMJ, Kleipool RP, et al. The plantaris tendon and a potential role in mid-portion Achilles tendinopathy: An observational anatomical study. J Anat. 2011; 218(3): 336–341, doi: 10.1111/j.1469-7580.2011.01335.x.

104. Stimec B v., Dash J, Assal M, et al. Additional muscular slip of the flexor digitorum longus muscle to the fifth toe. Surg Radiol Anat. 2018; 40(5): 533–535, doi: 10.1007/s00276-018-1991-7.

105. Thomas JL, Lopez-Ben R, Maddox J. A Preliminary Report on Intra-sheath Peroneal Tendon Subluxation: A Prospective Review of 7 Patients with Ultrasound Verification. J Foot Ankle Surg. 2009; 48(3): 323–329, doi: 10.1053/j.jfas.2009.02.003.

106. Vasudha TK, Vani PC, Sankaranarayanan G, et al. Communications between the tendons of flexor hallucis longus and flexor digitorum longus: a cadaveric study. Surg Radiol Anat. 2019; 41(12): 1411–1419, doi: 10.1007/s00276-019-02311-x.

107. Wilk BR, Fisher KL, Rangelli D. The incidence of musculoskeletal injuries in an amateur triathlete racing club. J Orthop Sports Phys Ther. 1995; 22: 108–112.

108. Wood A, Boren M, Dodgen T, et al. Muscular architecture of the popliteus muscle and the basic science implications. Knee. 2020; 27(2): 308–314, doi: 10.1016/j.knee.2019.12.001.

109. Wood J. Variations in human myology observed during the winter session of 1866–1867 at King's College London. Proceedings of the Royal Society of London. 1867; 15: 518–546.

110. Xarchas KC, Oikonomou L. A Missing Flexor Hallucis Longus Muscle and Tendon in a Young Female Patient: A Case Report of a Rare Anomaly. J Foot Ankle Surg. 2016; 55(1): 181–182, doi: 10.1053/j.jfas.2014.12.005.

111. Yammine K. The accessory peroneal (fibular) muscles: peroneus quartus and peroneus digiti quinti. A systematic review and meta-analysis. Surg Radiol Anat. 2015; 37(6): 617–627, doi: 10.1007/s00276-015-1438-3.

112. Yildirim FB, Sarikcioglu L, Nakajima K. The co-existence of the gastrocnemius tertius and accessory soleus muscles. J Korean Med Sci. 2011; 26(10): 1378–1381, doi: 10.3346/jkms.2011.26.10.1378.

113. Yu JS, Resnick D. Skeletal Radiology MR imaging of the accessory soleus muscle appearance in six patients and a review of the literature. Skeletal Radiol. 1994; 23: 525–528.

114. Zabrzyński J, Huri G, Yataganbaba A, et al. Current concepts on the morphology of popliteus tendon and its clinical implications. Folia Morphologica (Poland) . 2021. Via Medica, 80: 505–513, doi: 10.5603/FM.a2020.0106.

115. Zielinska N, Tubbs RS, Paulsen F, et al. Anatomical variations of the tibialis anterior tendon insertion: An updated and comprehensive review. J Clin Med. 2021; 10(16): 3684, doi: 10.3390/jcm10163684.

116. Zielinska N, Tubbs RS, Ruzik K, et al. Classifications of the extensor hallucis longus tendon variations: Updated and comprehensive narrative review. Ann Anat. 2021; 238, doi: 10.1016/j.aanat.2021.151762.

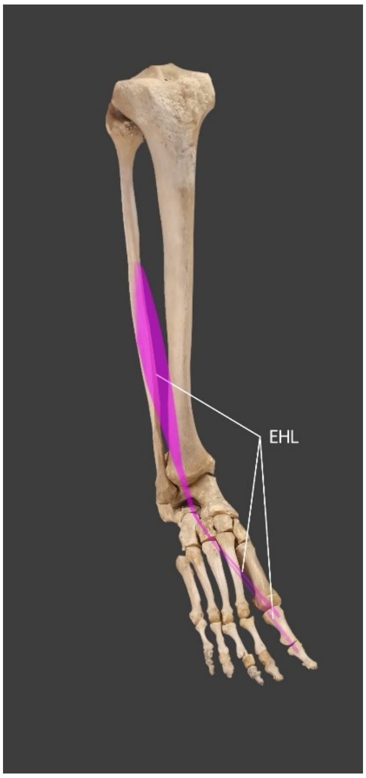

Figure 1. Schematic drawing depicting the extensor hallucis longus muscle variability described as type IIa; EHL — extensor hallucis longus muscle.

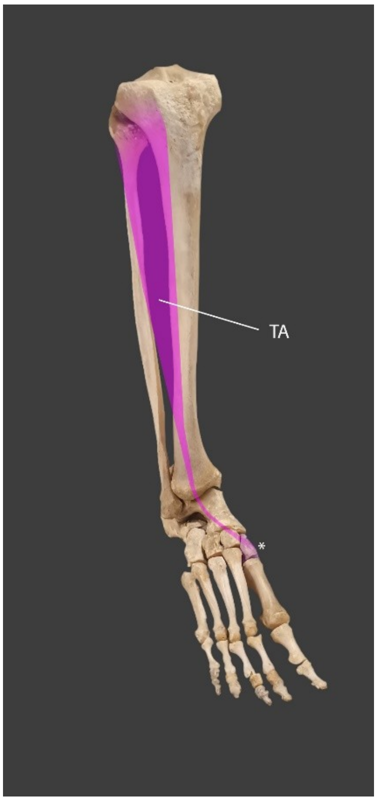

Figure 2. Schematic drawing of the tibialis anterior muscle distal insertion variation. TA — tibialis anterior muscle; *attachment to the medial cuneiform bone.

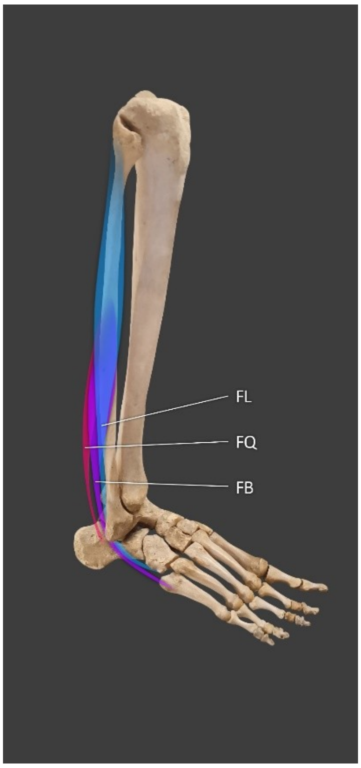

Figure 3. Schematic representation of fibularis quartus muscle position; FL — fibularis longus muscle, FB — fibularis brevis muscle, FQ — fibularis quartus muscle.

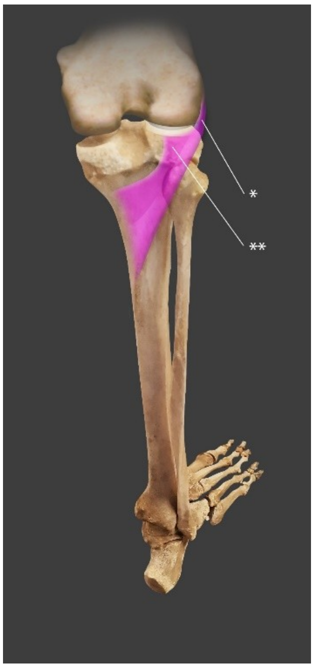

Figure 4. Schematic representation of the popliteus muscle variable origin; *popliteal sulcus, **lateral meniscus.

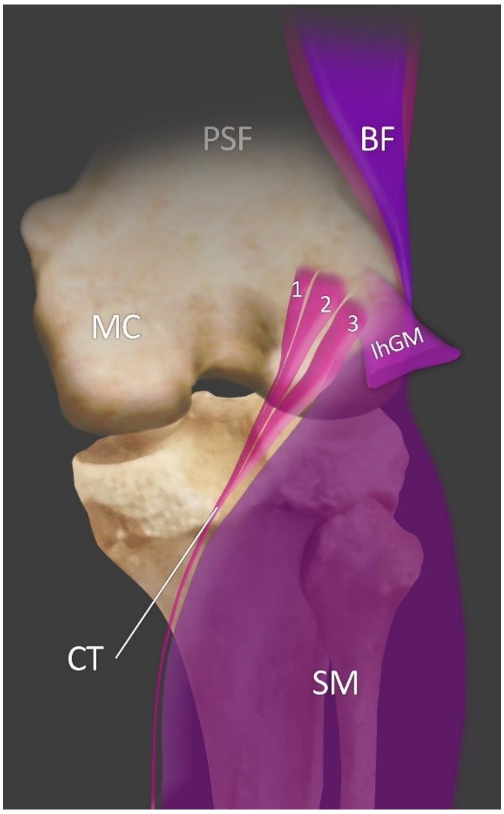

Figure 5. Schematic drawing of the three-headed plantaris muscle; 1 — first head of the plantaris muscle; 2 — second head of the plantaris muscle; 3 — third head of the plantaris muscle; lhGM — lateral head of the gastrocnemius muscle; CT — common tendon; SM — soleus muscle; MC — medial condyle of the femur; PSF — posterior surface of the femur; BF — biceps femoris muscle.

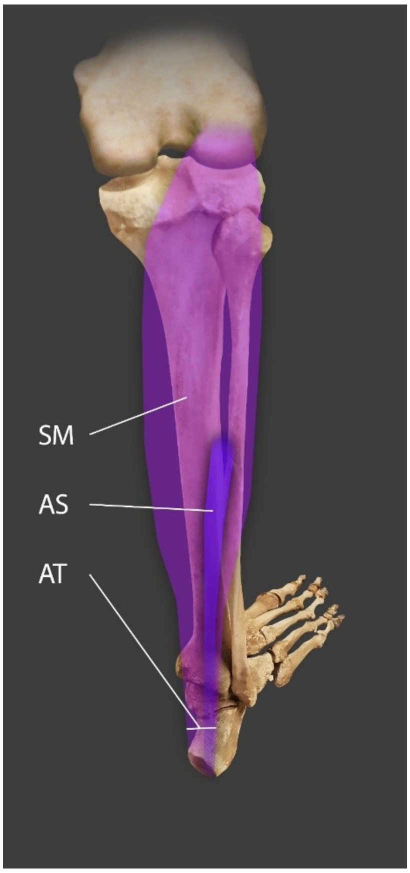

Figure 6. Schematic representation of the accessory soleus muscle position; SM — soleus muscle; AS — accessory soleus muscle; AT — Achilles tendon.

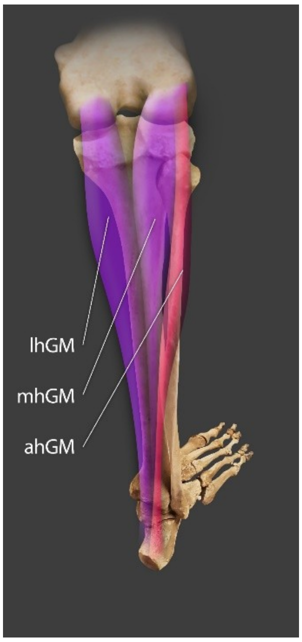

Figure 7. Schematic drawing of the gastrocnemius tertius with additional head origin from the lateral epicondyle of femur; lhGM — lateral head of the gastrocnemius muscle; mhGM — medial head of the gastrocnemius muscle; ahGM — additional head of the gastrocnemius muscle.

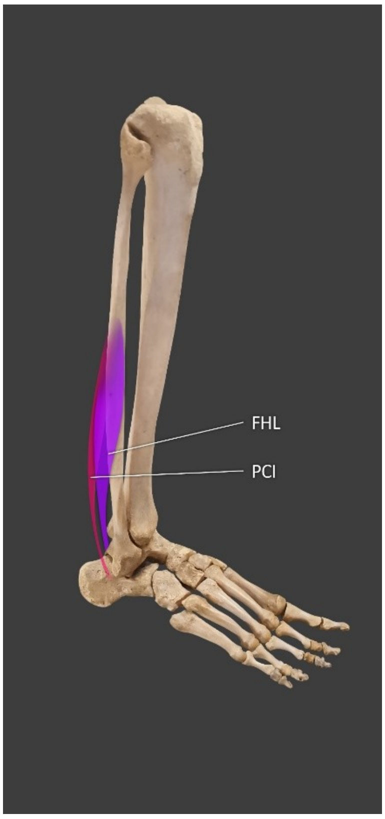

Figure 8. Schematic representation of the peronecalcaneus internus muscle position; FHL — flexor hallucis longus muscle; PCI — peronecalcaneus internus muscle.

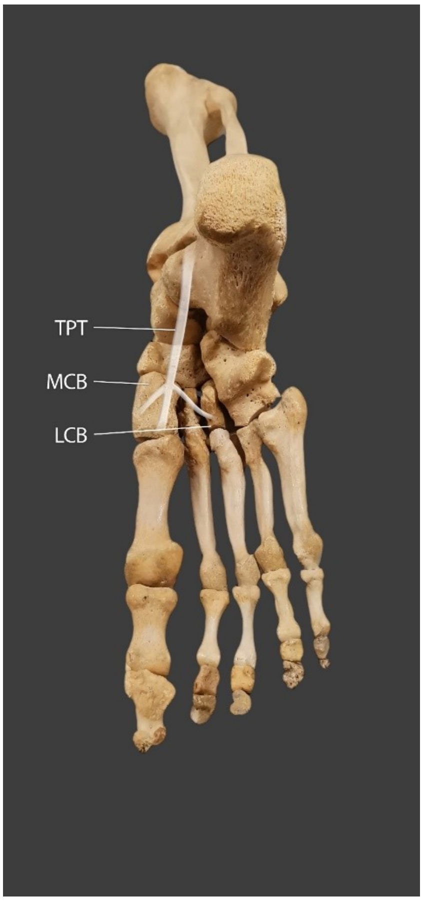

Figure 9. Schematic representation of the triple tibialis posterior muscle distal attachment; TPT — tibialis posterior muscle tendon; MCB — medial cuneiform bone; LCB — lateral cuneiform bone.

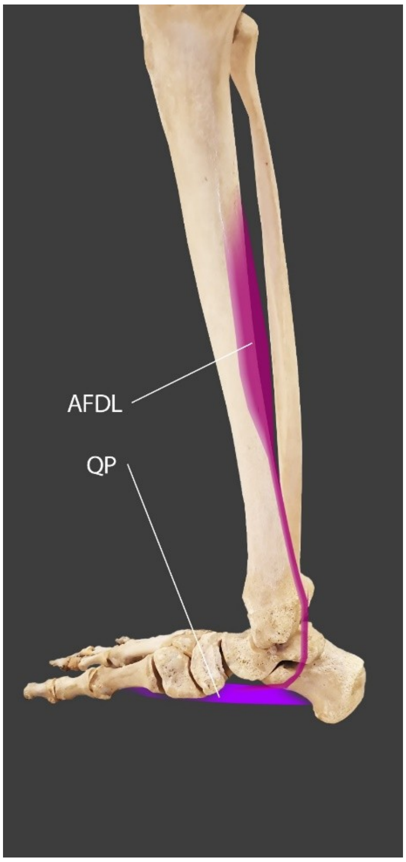

Figure 10. Schematic drawing depicting the accessory flexor digitorum longus muscle position; AFDL — accessory flexor digitorum muscle; QP — quadratus plantae.

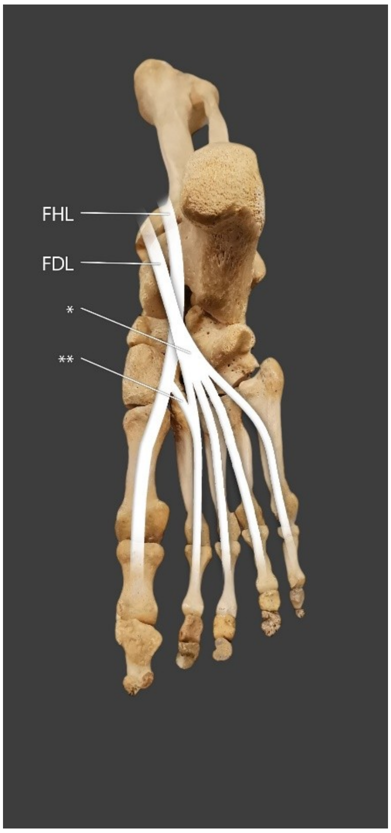

Figure 11. Schematic representation of ,,single slip” type of connection between flexor hallucis longus muscle and flexor digitorum longus muscle tendons; FHL — flexor hallucis longus muscle; FDL — flexor digitorum longus muscle; *master knot of Henry; **slip of intertendinous connection.