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REVIEW ARTICLE

The peroneus longus muscle and tendon: a review of its anatomy and pathology

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Abstract

This article will review the anatomy and common pathologies affecting the peroneus longus muscle and tendon. The anatomy of the peroneus longus is complex and its long course can result in symptomatology referable to the lower leg, ankle, hindfoot, and plantar foot. Proximally, the peroneus longus muscle lies within the lateral compartment of the lower leg with its distal myotendinous junction arising just above the level of the ankle. The distal peroneus longus tendon has a long course and makes two sharp turns at the lateral ankle and hindfoot before inserting at the medial plantar foot. A spectrum of pathology can occur in these regions. At the lower leg, peroneus longus muscle injuries (e.g., denervation) along with retromalleolar tendon instability/subluxation will be discussed. More distally, along the lateral calcaneus and cuboid tunnel, peroneus longus tendinosis and tears, tenosynovitis, and painful os peroneum syndrome (POPS) will be covered. Pathology of the peroneus longus will be illustrated using clinical case examples along its entire length; these will help the radiologist understand and interpret common peroneus longus disorders.

Keywords Peroneus longus · Os peroneum · Peroneocuboid joint · Retromalleolar groove · Cuboid tunnel · Peroneus longus tendinosis and tears · Tenosynovitis · Painful os peroneum syndrome (POPS) · Peroneus longus muscle injury · Peroneus longus tendon subluxation/instability

Introduction

Peroneal tendon pathology is a common cause of lateral ankle pain. Because of its length and complex anatomy, the peroneus longus can be challenging to evaluate by the radiologist. For the purposes of this article, the anatomy and common pathologies affecting the entire peroneus longus, will be divided into five regions: (1) lower leg, (2) ankle and hindfoot, (3) lateral calcaneus, (4) cuboid tunnel, and (5) plantar foot. While most peroneus longus pathology affects the middle three regions where most of the literature is focused, lesions at the lower leg and plantar foot can be easily overlooked.

The peroneus longus everts and plantar-flexes the foot, while supplementing lateral ankle stability [1, 2]. The muscle lies at the lateral lower leg, with an elongated myotendinous junction giving rise to the distal tendon well above the ankle. The tendon course is long and complex, making two sharp turns at the retromalleolar region and cuboid tunnel before inserting at the medial-plantar forefoot (Fig. 1). At the ankle, the tendon lies in the retro-malleolar groove posterior to the peroneus brevis tendon, with both tendons secured by the superior peroneal retinaculum [3]. Distally, the peroneus longus tendon makes its final turn into the cuboid tunnel, before reaching its primary insertion at the first metatarsal base (Fig. 2). The two turns of the peroneus longus tendon are the most common sites for injuries, likely due to high tensile stresses, particularly at the cuboid tunnel [3].

Imaging modalities

Imaging plays an important role in the diagnosis of peroneus longus pathology as several disorders at the lateral leg, ankle, and hindfoot have overlapping clinical presentations.

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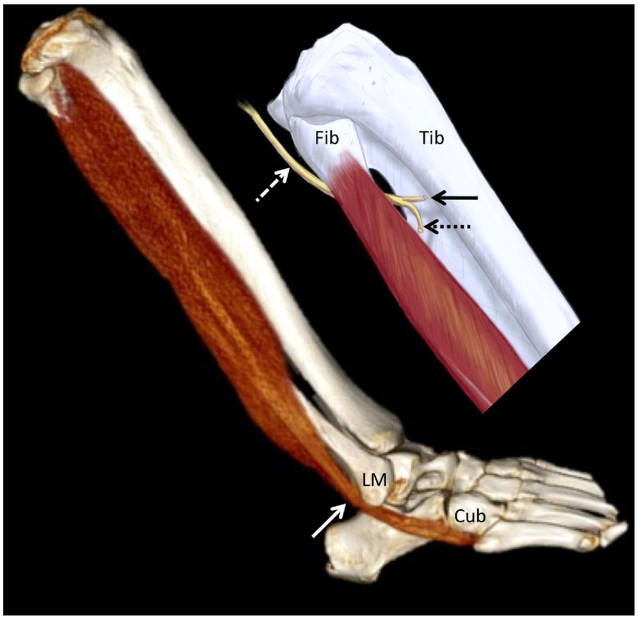

Fig. 1 Normal anatomy of the peroneus longus. The peroneus longus muscle and tendon are shown on a 3D CT reconstruction. The distal tendon has a unique, long course with two turns at the retromalleolar region (*white arrow*) and beneath the cuboid in the cuboid tunnel (not shown) before entering the plantar foot. The inset graphic shows the common peroneal nerve (CPN- *dashed white arrow*) superficial to the fibula before passing between the peroneus longus and fibula neck in the peroneal tunnel. The CPN then divides into the deep (*black arrow*) and superficial (*dashed black arrow*) peroneal nerves along with a small recurrent articular branch (not shown). The superficial peroneal nerve innervates the peroneus longus muscle. *LM* lateral malleolus, *Cub* cuboid, *Fib* fibula head, *Tib* tibula

Peroneus longus pathology is often overlooked, particularly in the setting of concomitant lateral ligament instability, with only 60% of peroneal tendon injuries detected at initial clinical evaluation [4].

Radiography is useful for identifying fibular avulsion fractures of the superior peroneal retinaculum (SPR) insertion, fracture or proximal migration of an os peroneum due to peroneus longus tendon tearing, and peroneal tubercle morphology [3]. More detailed assessment of these osseous structures is afforded by computed tomography (CT), which can also detect tendon entrapment or displacement by fracture fragments [5].

Ultrasonography can detect peroneus longus muscle and tendon tears, and provides dynamic evaluation of tendon motion, including transient dislocation and intrasheath subluxation. Sonography can also be utilized to evaluate for common peroneal nerve lesions [6, 7]. On ultrasound, the normal peroneus longus tendon appears echogenic with a fibrillary architecture. A hypoechoic appearance can signify tendinosis, although non-perpendicular probe positioning can cause artifactual hypoechogenicity from anisotropy [8]. Partial peroneus longus tendon tears may appear as hypoechoic tendon thinning or thickening with a fluid-filled defect, whereas full-thickness tears appear as longitudinal splitting or complete fiber discontinuity with retraction [8, 9].

High-resolution MR imaging using dedicated coils can assess the entire course of the peroneus longus muscle and tendon. Proximally, the common peroneal nerve and branches can be traced, and the peroneus longus muscle assessed for edema and atrophy. More distally, peroneus longus tendinosis, tears and tenosynovitis at the retromalleolar groove and cuboid tunnel can be seen in detail. Importantly, MRI can identify concurrent pathology responsible for lateral hindfoot symptoms, including osteochondral and lateral ligamentous injuries [9, 10].

Artifactual regions of increased signal on short echo time (TE) sequences are common below the fibula due to magic angle artifact, simulating tendinosis (Figure 3); this finding is related to organized collagen fibers within tendons orientated at 55° to the B_0 axis of the main magnetic field. This artifact can be reduced by increasing TE (especially on PD fat-suppressed sequences), using prone positioning or placing the foot in 20° of plantar flexion [9].

Region 1: Lower leg

The peroneus longus muscle lies in the lateral compartment of the lower leg, receiving innervation via the superficial peroneal nerve. It lies superficial to the peroneus brevis and originates from the head and upper two-thirds of the lateral fibula, tibiofibular intermuscular septum and lateral tibial condyle. There is a space between the fibers arising from the fibular head and body through which the common peroneal nerve passes into the anterior compartment of the leg [11, 12]. The longus muscle traverses the lateral compartment of the leg and near the midpoint tapers to form a long tendon [13].

Peroneus longus muscle

Peroneal muscle strains are uncommon and may result from forced ankle inversion and dorsiflexion, or proximal tibiofibular dislocation (Fig. 4) [14]. Peroneal muscle contusions typically result from a direct blow, particularly in athletes involved in kicking or tackling sports. The findings of traumatic muscle injury parallel those seen in more commonly injured muscles like the hamstrings. One potential complication of peroneus longus muscle injury includes lateral compartment syndrome, resulting in pain, ischemia, and foot drop as the deep peroneal nerve can be compressed between the fibula and swollen peroneal muscles [15–17]. Calcific myonecrosis of the

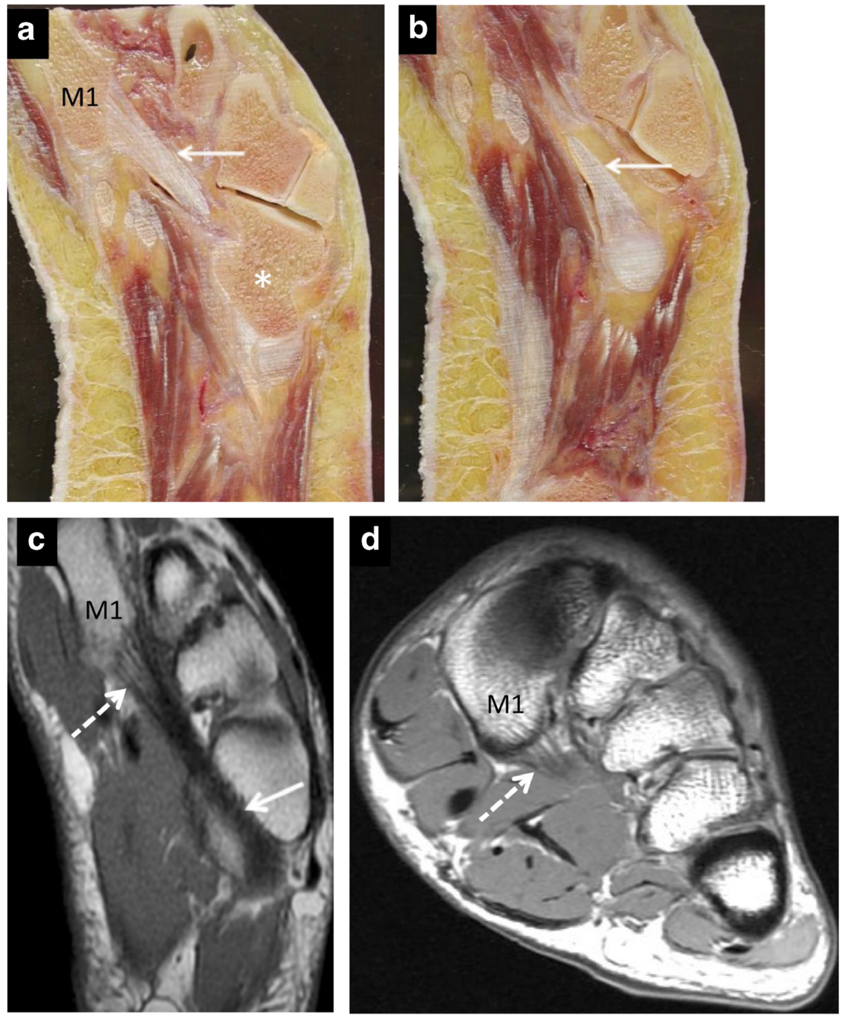

Fig. 2 Distal peroneus longus tendon insertion. Serial axial cadaveric sections of the plantar forefoot with corresponding axial T1-weighted MR images (A-dorsal and B-plantar) show the peroneus longus tendon (*arrows*) in relation to the cuboid (*) and its distal insertion. Axial T1-weighted fat-saturated MR image (**c**) demonstrates the oblique course of the distal tendon (*dashed arrow*) across the plantar forefoot and its insertion at the base of the first metatarsal (M1). Note the tendon traveling through the cuboid tunnel (*arrow*). A coronal T1-weighted MR image (**d**) shows normal heterogeneity and broadening of the tendon near its insertion (*dashed arrow*)

peroneus longus can also develop secondary to lateral compartment syndrome (Figure 5).

Acute trauma or repetitive contusions to the peroneus longus muscle can produce an overlying fascial defect

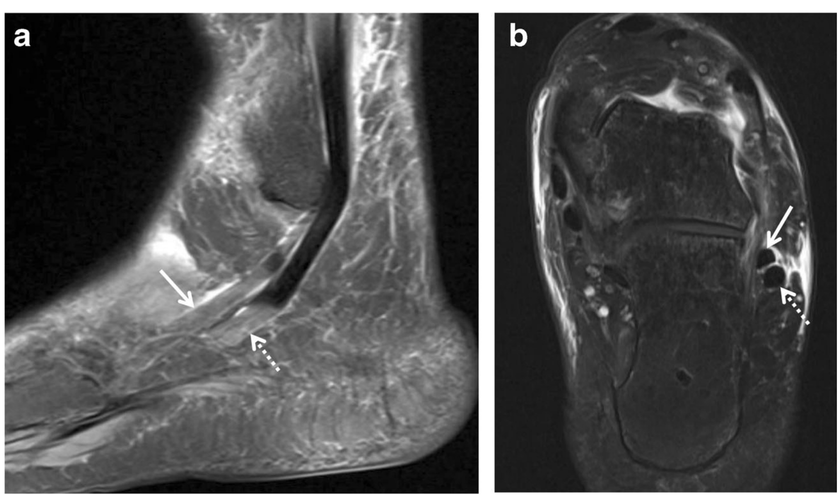

Fig. 3 Pseudotear of the peroneal tendons due to magic angle artifact. The sagittal PD-weighted fat-saturated MR image (**a**) obtained on a 3-Tesla MR system shows focal increased signal within the peroneus longus (*dashed arrow*) and brevis (*arrow*) tendons at the lateral calcaneus that is no longer evident on the T2-weighted fat-saturated oblique axial MR image (**b**). Magic angle artifact, related to organized collagen fibers within the tendon oriented at 55° to the B_0 axis of the magnetic field, is commonly seen below the fibula on short TE sequences

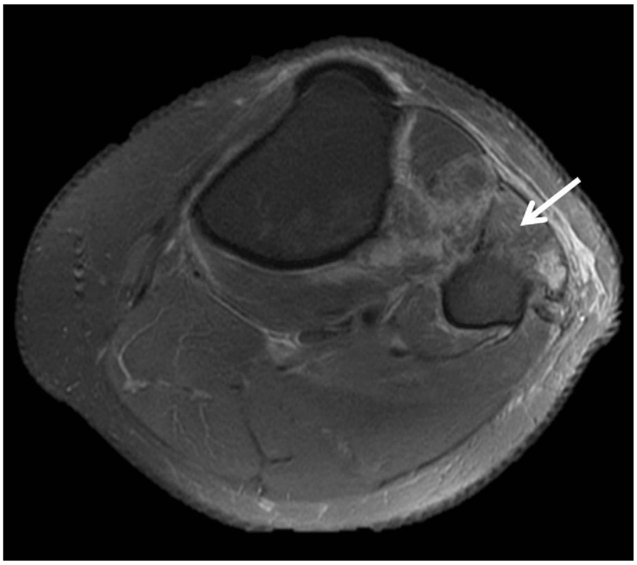

Fig. 4 Strain of the peroneus longus muscle due to proximal tibiofibular joint injury in a 44-year-old female following twisting injury. Axial T2-weighted fat-saturated MR image shows muscle strains at the anterior and lateral compartments, including the peroneus longus muscle (*solid arrow*)

allowing for muscle herniation. This presents as a lateral calf mass, and is most readily assessed using dynamic ultrasound and muscle contraction, as it can be easily overlooked on static MRI (Fig. 6) [18].

Peroneal nerve

The sciatic nerve divides into the common peroneal nerve (CPN) and tibial nerve above the knee. The CPN courses obliquely along the medial biceps femoris muscle then winds around the fibular neck into the peroneal tunnel. The fibular neck is the most common site of CPN pathology as the nerve is superficial and therefore prone to injury. CPN neuropathy can also occur at the posterior knee due to surgery (Fig. 7) or distally as it passes underneath the peroneus longus origin.

Peroneal neuritis may be seen as nerve thickening and edema on MRI and ultrasound in the proximal lower leg. Denervation myopathy is best seen on fluid-sensitive MRI sequences and can progress to fatty atrophy [19]; the precise distribution of muscle changes depends on the level of neuropathy. CPN neuropathy can cause foot drop, lateral leg and dorsal foot numbness, and denervation edema in the anterior and lateral leg muscle compartments. In 80% of patients, the CPN trifurcates at the fibular neck into superficial (SPN) and deep (DPN) peroneal nerves and a smaller recurrent articular branch that is difficult to visualize on imaging [19]. Pathology distal to the trifurcation results in more confined muscle involvement. The DPN innervates the anterior compartment muscles

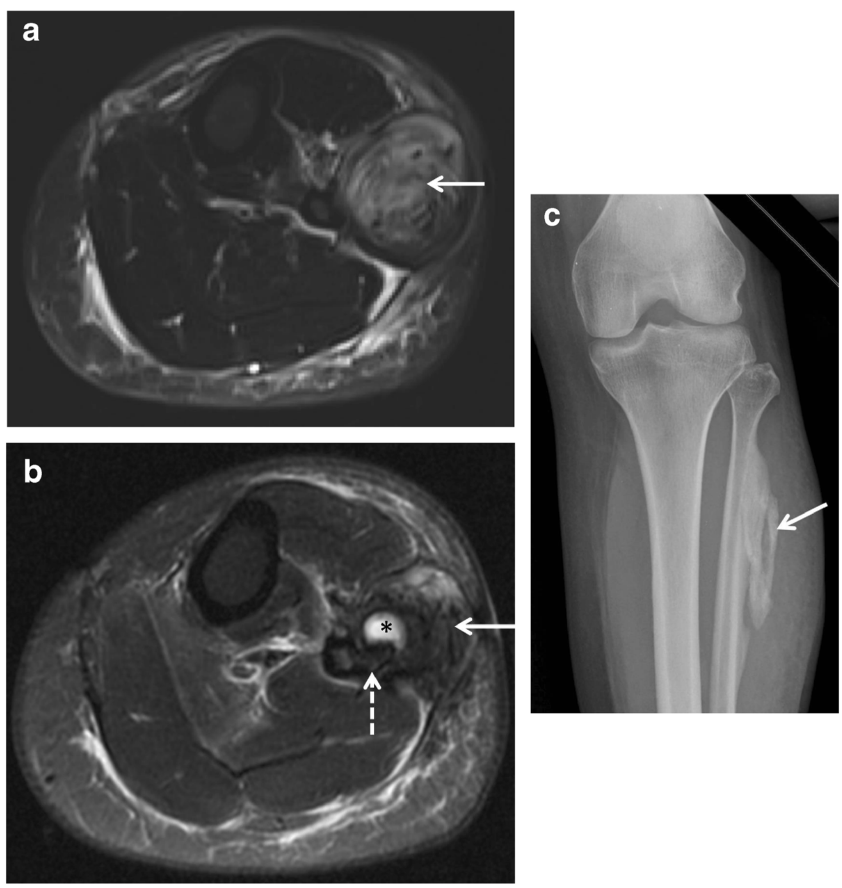

Fig. 5 Acute peroneal compartment syndrome with subsequent calcific myonecrosis in a 50-year-old female with hereditary angioedema. Initial T2W fat-saturated MR image (**a**) obtained for acute calf pain and swelling shows muscle edema and swelling at the lateral compartment (*arrow*), compatible with acute compartment syndrome, subsequently confirmed at urgent fasciotomy. Follow-up T2W, fat-saturated MRI obtained 2 years later (**b**) shows reduced muscle swelling with decreased signal within the peroneus longus muscle (*solid arrow*), ossification along the surface of the fibula (*dashed arrow*), and a small internal fluid collection in the abnormal muscle (*). An AP radiograph (**c**) confirms calcification involving the fibula and peroneal compartment (*arrow*), consistent with calcific myonecrosis

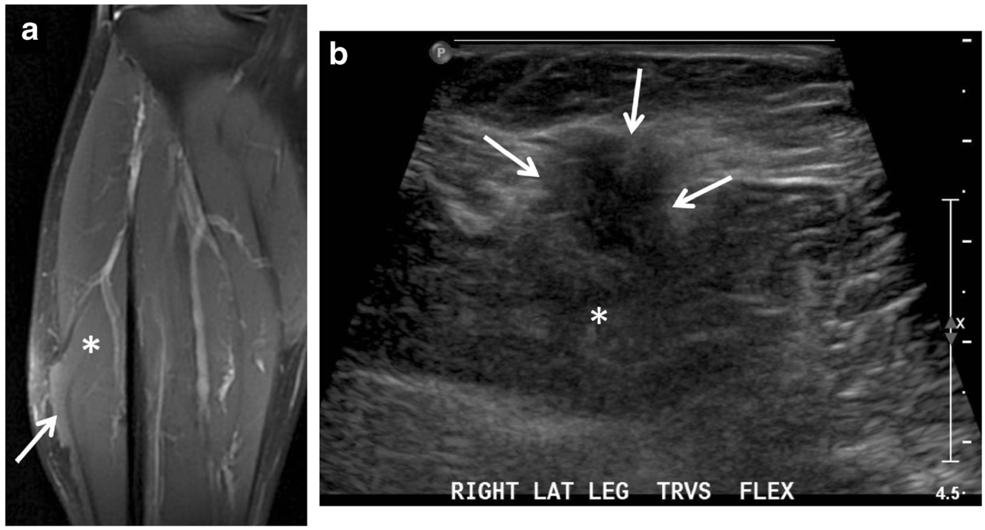

Fig. 6 Peroneus longus muscle herniation in a 42-year-old male soccer player with right calf pain and swelling for 2 months. Coronal T2-weighted fat-saturated MRI (**a**) and transverse ultrasound (**b**) at the lateral leg shows focal herniation (*arrows*) of the peroneus longus muscle (*) into the subcutaneous fat through a fascial defect, presumably related to repetitive injury

and provides sensation to the first web-space. The SPN innervates the peroneus longus and brevis muscles and provides sensation to the distal two-thirds of the leg and dorsal foot.

Region 2: Ankle and hindfoot

At the distal leg, the peroneus longus tapers into a long tendon and lies in a common peroneal synovial sheath with the peroneus brevis tendon. This common tendon sheath spans from 4 cm proximal to 1 cm distal to the lateral malleolus. While peroneus longus tenosynovitis can occur below the ankle to its insertion, it is usually most obvious at the distal fibula and is discussed in this section. At the ankle, both peroneal tendons lie within the retro-malleolar groove where they are secured by the SPR. The retromalleolar region is the most common location for peroneus longus tendon instability.

Peroneus quartus muscle

The peroneus quartus is an accessory muscle seen in 7–22% of patients. It commonly arises from the peroneus brevis muscle and has a variable insertion, typically onto the retrotrochlear eminence of the calcaneus (Fig. 8). This muscle aids in foot pronation, and can be seen on MRI and ultrasound lying posteromedial to the peroneus longus and brevis. Peroneal tendon pathology may occur due to crowding of the retromalleolar groove and stretching of the SPR. Longitudinal tendon splitting (most commonly affecting the peroneus brevis), tendinosis, tenosynovitis, and tendon dislocation are associated with a peroneus quartus or a low-lying peroneus brevis muscle [20, 21]. The incidence of a low-lying (projecting below the SPR) peroneus brevis muscle is controversial as its location is affected by foot position, e.g. dorsiflexion [22]. A low-lying peroneus brevis muscle can be differentiated from an accessory muscle by its normal tendinous insertion at the fifth metatarsal tuberosity.

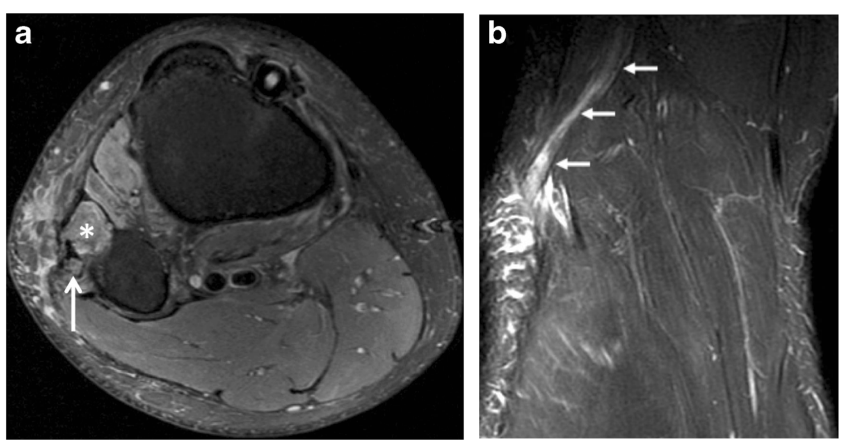

Fig. 7 Common peroneal nerve (CPN) injury with muscle denervation in a 17-year-old male with foot drop after an anterior cruciate ligament tear and recent reconstruction. Axial (**a**) and coronal (**b**) T2-weighted fat-saturated MR images demonstrate a thickened and edematous CPN (*arrows*). Note the denervation edema of the anterior and lateral compartment musculature, including the peroneus longus muscle (*)

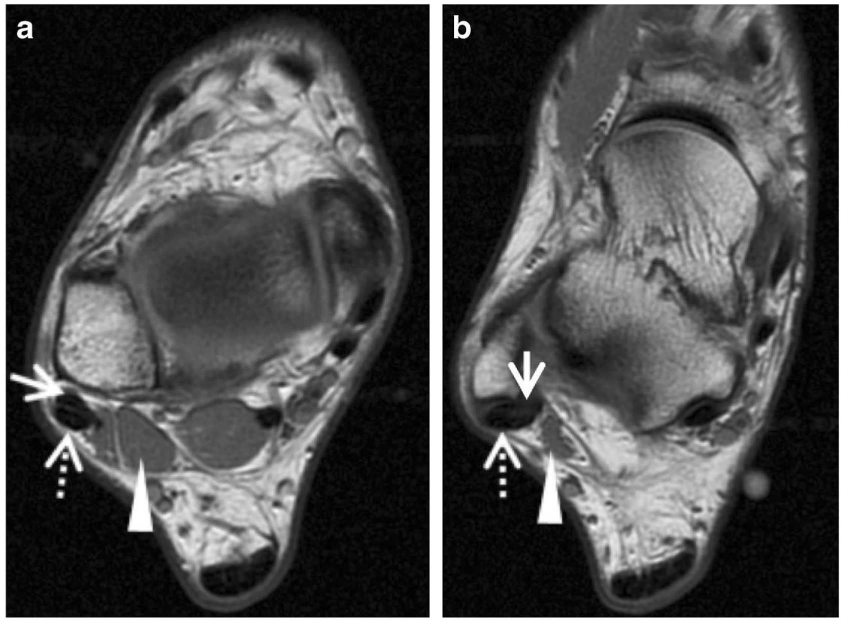

Fig. 8 Peroneus quartus muscle. Axial PD-weighted image (**a**) demonstrates an accessory peroneus quartus muscle (*arrowheads*) posteromedial to the peroneus longus (*dashed arrows*) and brevis (*solid arrows*) tendons. Note the separation of the accessory muscle from the peroneal tendons on a more distal image (**b**), distinguishing it from a low-lying peroneus brevis muscle belly

Peroneus longus tendon instability

Subluxation and dislocation of the peroneal tendons occurs most commonly at the retromalleolar groove and affects the longus more commonly than the brevis. Lateral tendon subluxation is typically related to SPR injuries resulting in incompetent lateral restraining structures. Transient tendon subluxation may present with painful snapping at the lateral ankle with foot dorsiflexion and eversion; dynamic ultrasound, utilizing these motions, is more sensitive than MRI for tendon subluxation (100 vs. 23%) [23, 24].

The morphology of the retromalleolar groove may affect peroneal tendon stability (Fig. 9) [25]. A flat or convex morphology, or groove irregularity, is thought to predispose to tendon instability and tearing [25, 26]; however, the importance of groove morphology has been questioned: a recent study using MR imaging showed no significant difference in the shape of the groove in patients with recurrent dislocation than normal controls [27].

The most common cause of peroneal instability is an incompetent SPR. The SPR originates from the posterolateral margin of the fibula and inserts posteriorly onto the calcaneus and Achilles tendon aponeurosis. SPR abnormalities allow peroneal tendon instability, contributing to tendon friction and tearing [26]. SPR tearing is typically traumatic, due to reflexive peroneal muscle contraction during acute ankle inversion; less common causes include peroneus quartus crowding at the retromalleolar groove.

Traumatic SPR injuries can be categorized into four types using Oden's classification (Fig. 10) [28]. In all four types, the peroneus longus is more likely to exhibit malalignment than the peroneus brevis, though both tendons may be affected. Type I injuries result from periosteal stripping at the SPR insertion, creating a pouch into which the tendons sublux. Type II injuries involve SPR tearing at its fibular attachment, whereas type III injuries consist of an SPR avulsion fracture at the lateral fibula (Fig. 11). Type IV injuries are uncommon, characterized by posterior SPR tearing. SPR injuries are commonly associated with additional injuries including lateral ligamentous complex lesions and calcaneal fractures.

Retromalleolar intrasheath dislocation of the peroneus longus over the peroneus brevis tendon can occur in the presence of an intact SPR. This produces lateral ankle snapping and has been classified into two types: Type A refers to peroneus longus subluxation anterior to an intact brevis tendon; whereas, the less common type B refers to peroneus longus subluxation through a brevis tendon split tear [29]. Dynamic ultrasound, using resisted ankle dorsiflexion, is the diagnostic test of choice (Fig. 12) [7].

Tenosynovial processes

Peroneus longus tenosynovitis is most commonly caused by repetitive mechanical injury, trauma, infection, or inflammatory arthropathies. Other tenosynovial processes can occur along the peroneus longus tendon sheath including synovial osteochondromatosis, lipoma arborescens, and giant cell tumor of the tendon sheath.

Chronic friction resulting in tenosynovitis is typically due to peroneal tubercle hypertrophy, inferior peroneal retinaculum (IPR) thickening, or a peroneus quartus muscle. These factors can also result in peroneus longus tendinosis [30]. The tendon sheath normally contains a thin sliver of fluid [31]. Circumferential and long segments of non-circumferential tendon sheath fluid greater than 3 mm in thickness are highly suggestive of tenosynovitis. On fluid-sensitive MRI tenosynovial fluid is

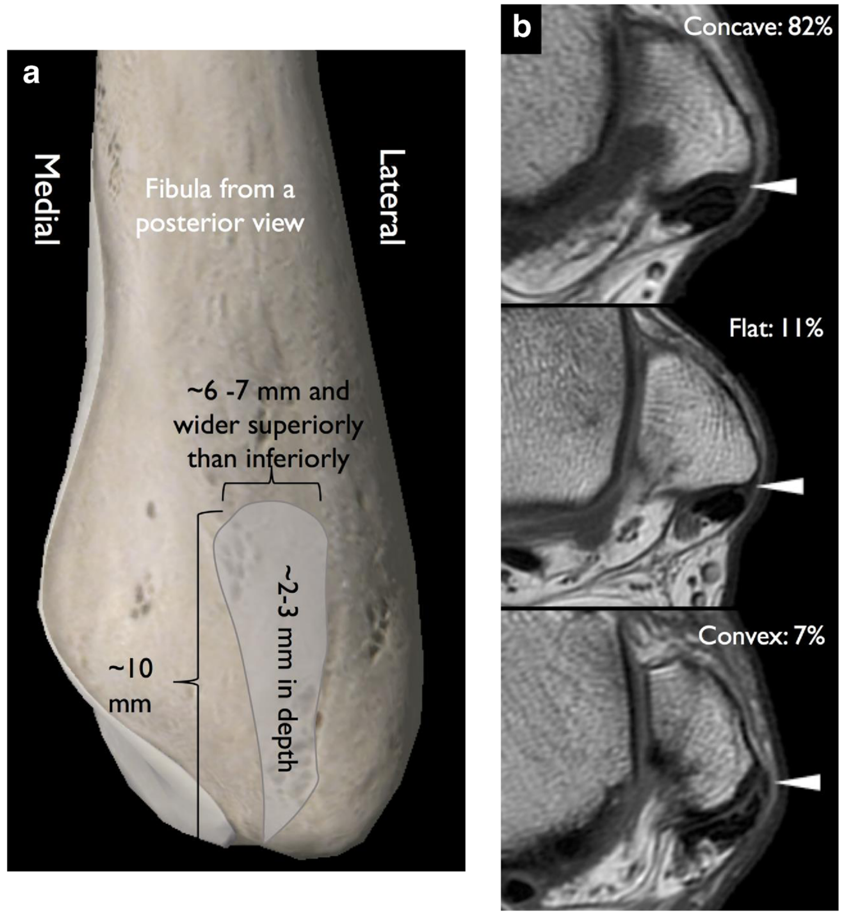

Fig. 9 Retromalleolar groove. Graphic representation of posterior fibula (**a**) illustrates the location and typical dimensions of the retromalleolar groove, which is typically deepened by a lateral fibrocartilaginous ridge (not illustrated). Axial T1W MR images (**b**) illustrate the three typical morphologies of the retromalleolar groove. Flat or convex morphology is believed to predispose to peroneus longus pathology. The fibrocartilaginous ridge can be visualized on MR images (*arrowheads*)

high signal and may be associated with intermediate signal synovial proliferation, tendinosis, and peritendinous edema. Ultrasound demonstrates increased tendon sheath fluid, synovial thickening, and increased vascularity on Doppler imaging [9].

Typical peroneal tenosynovitis is associated with fluid accumulation, while the less common stenosing form results from synovial thickening and fibrous adhesions, limiting fluid accumulation, and preventing free tendon excursion. Typical peroneal tenosynovitis is usually the result of prolonged, repetitive activity. Patients present with lateral ankle pain and swelling without instability [32]. Stenosing tenosynovitis appears as sacculated tendon sheath fluid with synovial thickening on MRI (Fig. 13) and ultrasound. MRI may also reveal low signal intensity within the tenosynovial fluid and gadolinium enhancement. The condition has also been seen in association with an enlarged peroneal tubercle [8, 9].

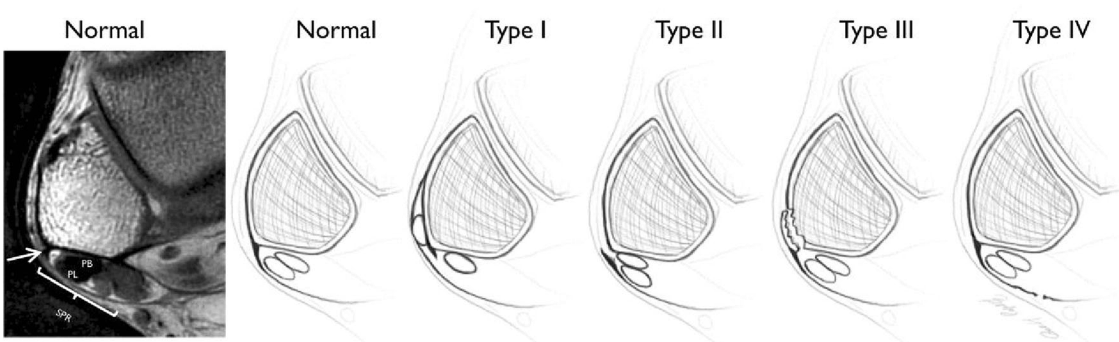

Fig. 10 Schematic of Oden's classification. The peroneus longus (PL) and peroneus brevis (PB) tendons are held in place in the retromalleolar groove by the superior peroneal retinaculum (SPR). A fibrous ridge is present at the fibular attachment of the SPR (*arrow*). Type I injuries result from periosteal stripping at the SPR insertion, creating a pouch into which the tendons sublux. Type II injuries involve SPR tearing at its fibular attachment. Type III injuries consist of an SPR avulsion fracture at the lateral fibula. Type IV injuries are characterized by posterior SPR tearing

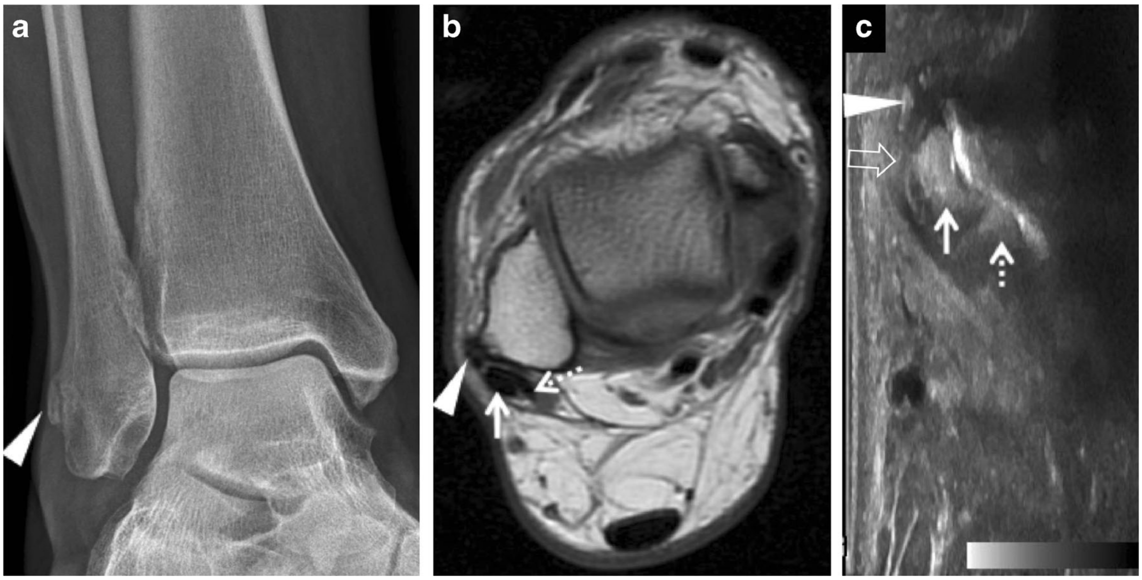

Fig. 11 Superior peroneal retinaculum (SPR) injury and peroneus longus instability in a 46-year-old fitness instructor with chronic lateral ankle pain and snapping. Mortise view (**a**) of the right ankle shows a partially healed SPR avulsion fracture (*arrowhead*). Axial T1-weighted MR image (**b**) shows low signal bony proliferation at the lateral fibula (*arrowhead*), without subluxation of the peroneus longus (*solid arrow*) or brevis (*dashed arrow*) tendons. Transverse ultrasound (**c**) shows anterolateral subluxation of the peroneus longus tendon (*solid arrow*) over the brevis (*dashed arrow*), seen only in dorsiflexion. Note the chronic avulsion fracture (*arrowhead*) and a thickened, indistinct SPR (*open arrow*)

Region 3: Lateral calcaneus

Alongside the lateral calcaneal wall, the common peroneal tendon sheath bifurcates into separate peroneus longus and brevis sheaths at a bony prominence called the peroneal tubercle. This is an important anatomic landmark as the longus tendon passes below and the brevis above the tubercle. A hypertrophied peroneal tubercle protrudes > 5 mm from the calcaneal surface and can cause peroneal tendon impingement, resulting in tendinosis or tenosynovitis (Fig. 14) [30, 33].

At the peroneal tubercle, the tendons are secured by the IPR, which arises from the lateral sinus tarsi and is continuous with the inferior extensor retinaculum (Fig. 15). The IPR

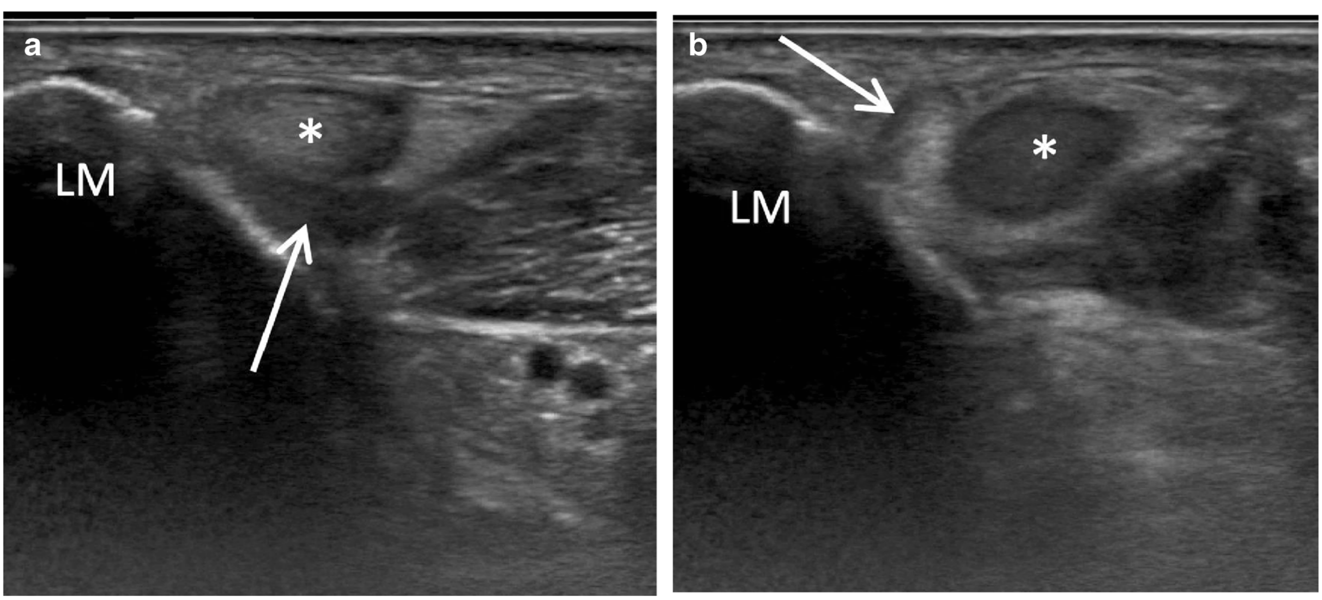

Fig. 12 Intrasheath peroneal tendon subluxation in a 39-year-old female with painless ankle snapping. Peroneus longus (*arrow*) and brevis tendons (*) subluxate over each other with ankle circumduction (A is neutral, B is circumduction). *LM* lateral malleolus. A dynamic ultrasound video is available and has been submitted as a supplementary file

Fig. 13 Stenosing tenosynovitis in a 37-year-old man with lateral ankle pain and swelling. Sagittal T2-weighted fat-saturated MR image shows marked fluid distension and low signal within the common peroneal sheath (*arrow*) extending distally into the separate peroneus longus (*dashed arrow*) and brevis tendon (*) sheaths

courses over the tendons to attach at the lateral calcaneus and retrotrochlear eminence posterior to the peroneal tubercle [3, 9]. Some IPR fibers attach to the peroneal tubercle forming a septum separating the peroneal tendons into two compartments [34]. IPR injuries are rare, resulting from forced foot dorsiflexion and eversion, leading to dislocation of the peroneus longus tendon over, or rarely below, the peroneal tubercle [34, 35].

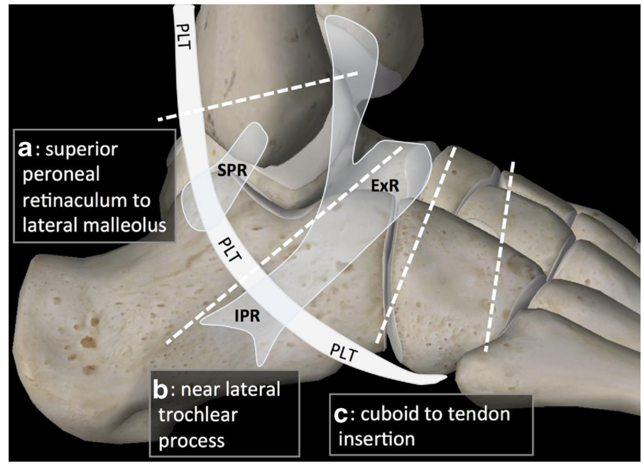

Fig. 15 Three anatomic zones (**a**, **b**, and **c**) of peroneus longus tendon injuries as defined by Brandes and Smith. The zones are defined by their relationships to the osseous structures and supporting retinaculae, as illustrated. The vast majority of peroneus longus tears occur in Zone C. *PLT* peroneus longus tendon, *SPR* superior peroneal retinaculum, *IPR* inferior peroneal retinaculum, *ExR* extensor retinaculum

The calcaneofibular ligament lies deep to the peroneal tendons and rupture of the ligament during an ankle sprain allows tibiotalar joint fluid to enter the peroneal sheath. Less commonly, fractures at the ankle may be accompanied by extrusion of marrow blood and fat into the peroneus longus tendon sheath.

Region 4: Cuboid tunnel and "Peroneocuboid joint"

Distal to the calcaneus, the peroneus longus lies alongside the calcaneocuboid joint. At this region, an os peroneum or fibrocartilaginous nodule (FCN) is variably located within the tendon and can articulate with an ovoid facet at the cuboid tubercle forming the "peroneocuboid joint"

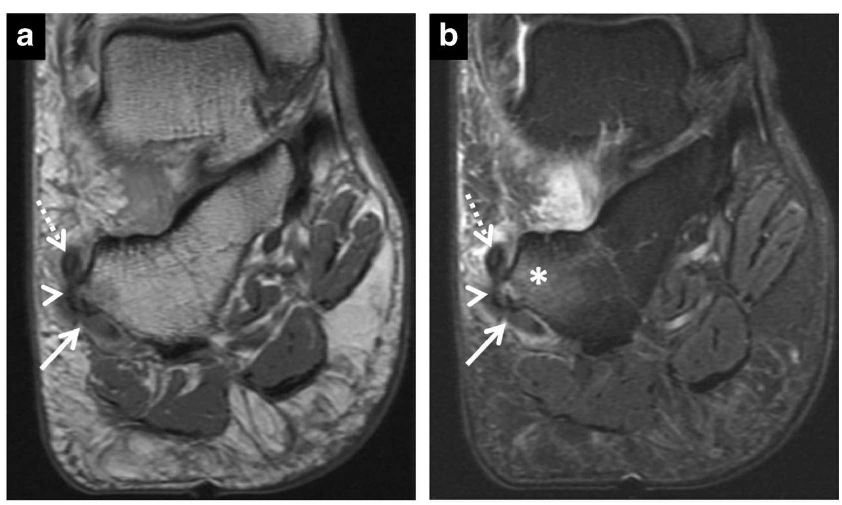

Fig. 14 Peroneus longus tendinosis and tenosynovitis related to an enlarged peroneal tubercle in a 71-year-old male with chronic lateral ankle pain. Axial (**a**) and coronal (**b**) T2-weighted fat-saturated MR images of the ankle show an enlarged peroneal tubercle (*arrowheads*) with underlying calcaneal edema (*). There is associated peroneus longus tendinosis and tenosynovitis (*solid arrows*), with less marked changes at the brevis (*dashed arrows*)

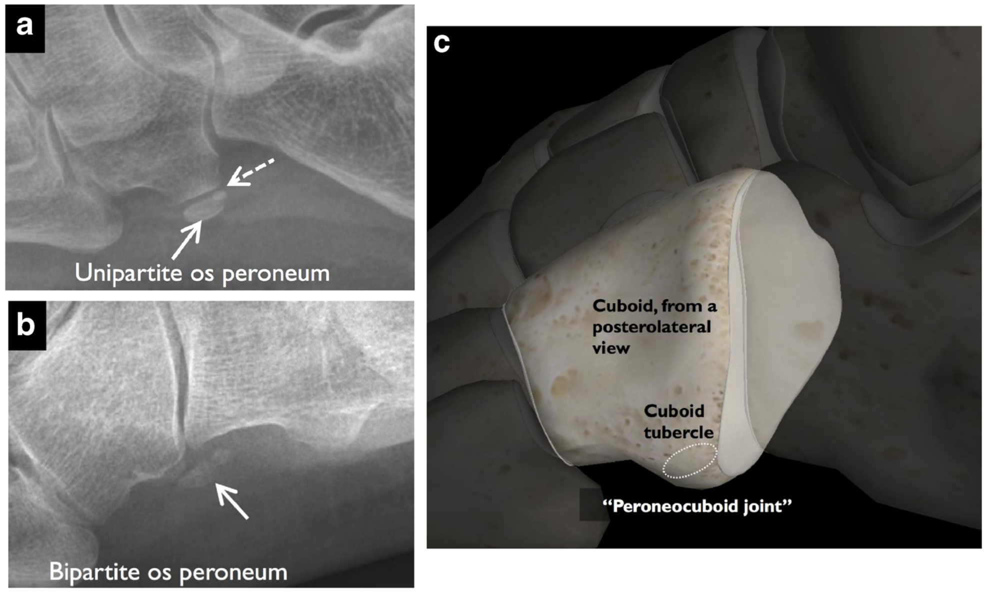

Fig. 16 Os peroneum and the peroneocuboid joint. Lateral radiographs of the os peroneum (*arrows*) demonstrate unipartite (**a**) and bipartite (**b**) morphology. Note an articulating facet at the cuboid in A, forming the "peroneocuboid joint" (*dashed arrow*). The graphic (**c**) illustrates the location of the cuboid tubercle (*dashed oval*), which can form a true articular facet lined by hyaline cartilage that articulates with the os peroneum

(Fig. 16). This articulation has its own synovial cavity and does not communicate with the peroneus longus tendon sheath. Like other articulations, the peroneocuboid joint can undergo degeneration or be involved in inflammatory arthropathies [36, 37].

Distal to the peroneocuboid joint, the peroneus longus tendon makes a second sharp turn, passing between the calcaneal tuberosity and fifth metatarsal base to enter the cuboid tunnel [38]. The tendon travels obliquely and anteromedially through the cuboid tunnel to enter the plantar foot. The cuboid tunnel roof is formed by fibrous tissue lining the cuboid tuberosity and the floor is formed by arciform fibers extending from the cuboid tuberosity to the anterior cuboid ledge, reinforced by the cuboideometatarsal and long plantar ligaments (Fig. 17) [38–40].

The precise position of the tendon within the cuboid tunnel varies with foot position [41]. On both MR imaging and ultrasound, the tendon shows physiological plantar subluxation at the cuboid tunnel during dorsiflexion, potentially relieving tendon stress during ankle motion [42]. One ultrasound study showed dynamic peroneus longus subluxation in 65% of asymptomatic volunteers. In that study, plantar subluxation occurred more often with a narrow cuboid tunnel width, regardless of foot position [39].

Os peroneum and fibrocartilaginous nodule

The os peroneum is a sesamoid bone within the peroneus longus tendon at the level of the calcaneocuboid joint. The origin of the os peroneum is controversial and could be related to a stress response, although cadaveric studies favor a developmental origin with a precursor to the os peroneum identified within embryonic feet [43]. The literature suggests that the embryonic os is chiefly fibrocartilaginous, and this tissue commonly persists without ossifying. This tissue likely forms to counteract the high compressive loads the tendon encounters as it enters the cuboid tunnel.

The os peroneum is ossified in only 20% of individuals. When ossified, it is bilateral in 60% of individuals [43]. It has variable size and morphology and can be bipartite (30% of cases) or multipartite. A partite os peroneum can be difficult to differentiate from a fracture (Fig. 16). A nonossified os peroneum appears as a fibrocartilaginous nodule (FCN) in approximately 17% of MR examinations (Fig. 18). On histology, the FCN contains aggrecan and proteoglycans, which increase T2-weighted signal, simulating focal tendinopathy or a tear [43, 44]. Unlike tendon tear, the FCN signal tends to be less fluid-like and is not associated with tenosynovitis.

Painful os peroneum syndrome (POPS)

The term "painful os peroneum syndrome" (POPS) was coined by Sobel et al. to describe a spectrum of disorders affecting the os peroneum that cause lateral hindfoot pain [45]. POPS incorporates conditions including os peroneum fractures, diastasis of a bipartite or multipartite os peroneum, and os peroneum entrapment secondary to peroneal tubercle hypertrophy. Peroneus longus tendon tears, both proximal and distal to the os peroneum, are also included within the spectrum of POPS [12, 45].

Violent peroneus longus muscle contraction in response to sudden ankle inversion compresses the os peroneum against the cuboid, leading to fracture or diastasis, sometimes with associated peroneus longus tendon tearing.

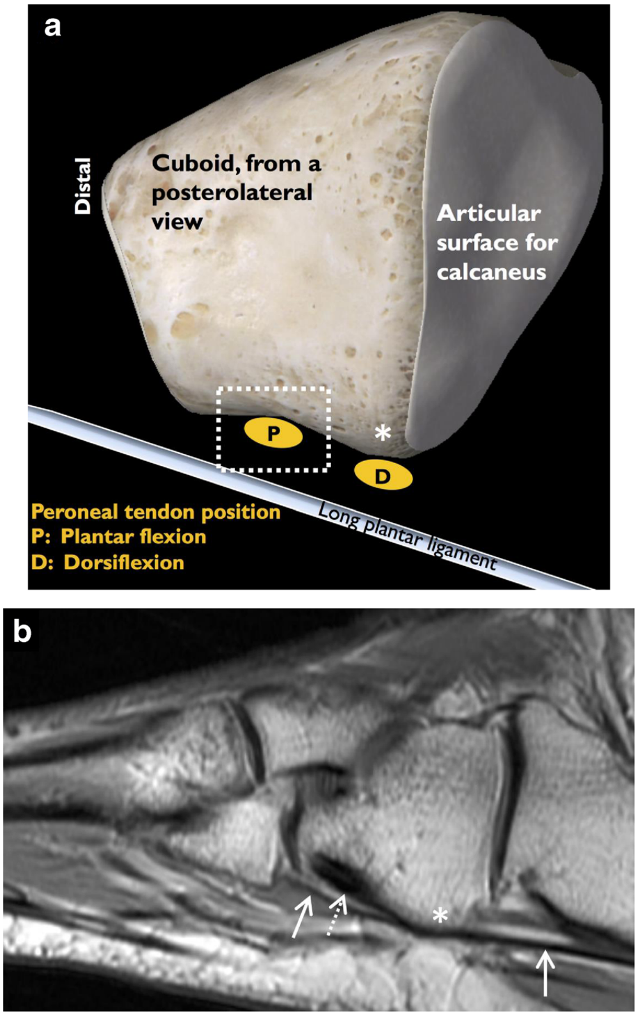

Fig. 17 Cuboid tunnel and long plantar ligament anatomy. The graphic (**a**) and sagittal PD-weighted MR image (**b**) show the cuboid tunnel (*dashed rectangular area*) through which the peroneus longus tendon (*dashed arrow*) travels; the roof is formed by a plantar groove on the cuboid and the floor is formed by the long plantar ligament (*solid arrows*), which has cuboid and metatarsal base insertions. The position of the peroneus longus tendon within the cuboid tunnel varies with foot position, with proximal subluxation onto the cuboid tuberosity (*) in dorsiflexion

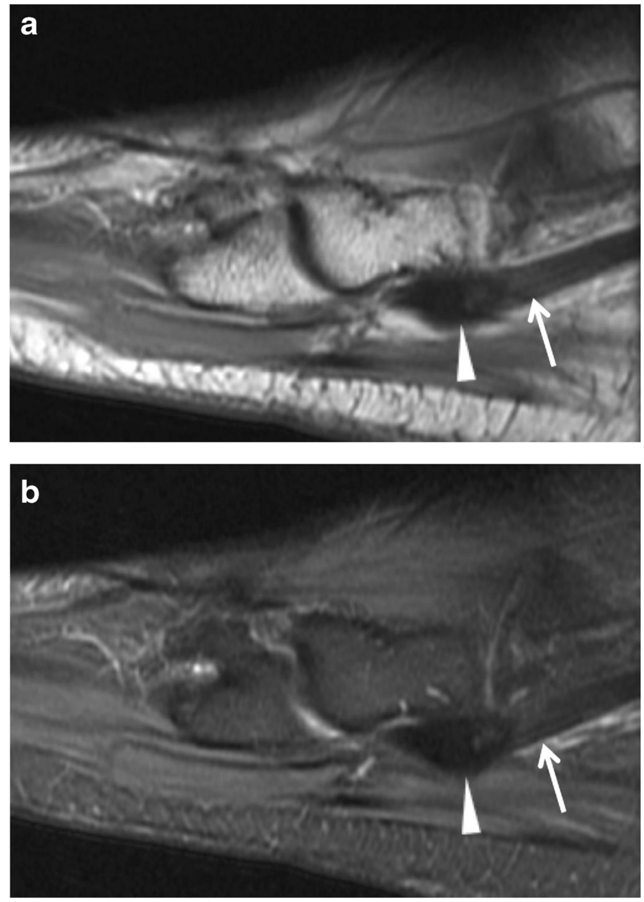

Fig. 18 Fibrocartilaginous nodule within the peroneus longus tendon. Sagittal PD-weighted (**a**) and T2-weighted fat-saturated (**b**) MR images illustrate a fibrocartilaginous nodule (FCN- *arrowheads*) within the peroneus longus tendon (*arrows*). This nodule is analogous to the FCN in the posterior tibialis tendon and develops as a response to high compressive loads on the peroneus longus tendon as it approaches the cuboid tunnel

Differentiating a fracture from a bipartite os peroneum is challenging, with non-sclerotic, irregular margins and a 'puzzle piece' configuration more suggestive of a fracture. MRI is more accurate than ultrasound in making this distinction, affording assessment of marrow and soft tissue edema, synchondrosis instability, and fragment/fracture separation [46]. In the setting of an intact tendon, the fracture fragments are typically separated by less than 2 mm. Fragment separation greater than 6 mm reliably indicates the presence of an injury, either a fracture or diastasis of a partite os. In the setting of a fracture or diastasis, displacement of the proximal os peroneum fragment by ≥ 10 mm proximal to the calcaneocuboid joint on a lateral radiograph or ≥ 20 mm on an oblique radiograph is associated with a complete tendon tear. Marked retraction of an intact os peroneum is an indicator of complete tendon tearing distal to the os (Fig. 19) [47, 48]. The extent of os retraction can also indicate concomitant IPR or SPR injuries. The os normally retracts to the level of the IPR. An IPR tear allows for proximal migration to the lateral malleolus, with additional SPR tearing allowing for retraction into the lower leg [49].

Peroneus longus tendinosis and tears

Peroneus longus tendon disorders can be classified into three main types: (1) tendinopathy and/or tears without tendon instability; (2) tendinopathy and/or tears with instability and (3) tendon sheath irritation with tenosynovitis (discussed previously). Predisposing factors for peroneus longus tendon pathology include peroneal tubercle hypertrophy, cavovarus deformity and a peroneus

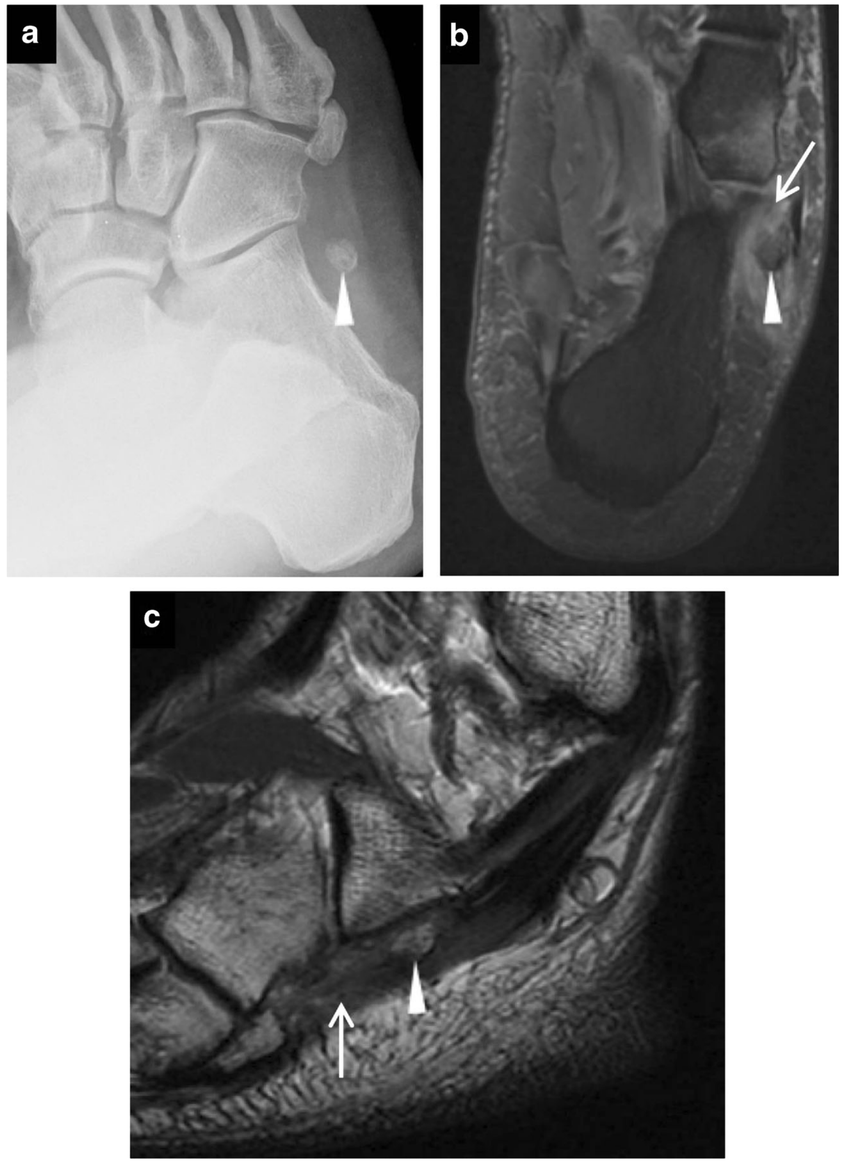

Fig. 19 Painful os peroneum syndrome (POPS) with proximal migration of an os peroneum in a 47-year-old man after an acute injury. On the oblique radiograph (**a**), there is proximal displacement of the os peroneum (*arrowhead*) indicating a complete peroneus longus tendon tear. Note the accessory os vesalianum at the base of the fifth metatarsal. Axial T2-weighted fat-saturated (**b**) and sagittal proton-density (**c**) MR images confirm a complete peroneus longus tear (*arrows* in **b** and **c**) at the level of the cuboid allowing proximal displacement of the os (*arrowheads*). There is associated reactive edema within the cuboid

quartus muscle, which all increase friction upon the tendon [48, 50–52]. Avascular zones at the lateral malleolus and cuboid tunnel have been reported as areas at particular risk for tendinopathy and tears [53, 54]. This remains a topic of debate as other studies report that the peroneus longus is well vascularized along its course [55].

The cuboid tunnel is the most common site for peroneus longus tears due to an acute tendon turn and high shear stresses. Brandes and Smith defined three anatomic zones of peroneus longus tendon injuries (Fig. 15): A) SPR to lateral malleolus, B) near lateral trochlear process of the calcaneus, and C) cuboid to tendon insertion. In their study, the most common site of tendon pathology was zone C (77%); all complete tears of the peroneus longus occurred in zone C (Fig. 20), whereas partial tears were more common in Zone B, near the peroneal tubercle [56]. Based on cadaveric studies the estimated prevalence of peroneal tendon tears is 11–37%, with tears seen in a third of patients undergoing surgery for ankle instability [56]. Peroneus longus tendon tears are less common than those of the peroneus brevis. When the peroneus longus is torn, associated peroneus brevis tearing is present in a third of cases.

Peroneus longus tendinosis and tearing are well depicted with both MRI and ultrasound. The normal tendon exhibits low MRI signal and appears hyperechoic on ultrasound due to its dense collagen and fibrillary architecture. Tendinosis is seen as increased signal intensity and thickening on MRI, with corresponding hypoechogenicity and thickening on ultrasound. Higher-grade peroneus longus tendon tearing may be seen as tendon discontinuity or an empty fluid-filled peroneal tendon sheath. Secondary

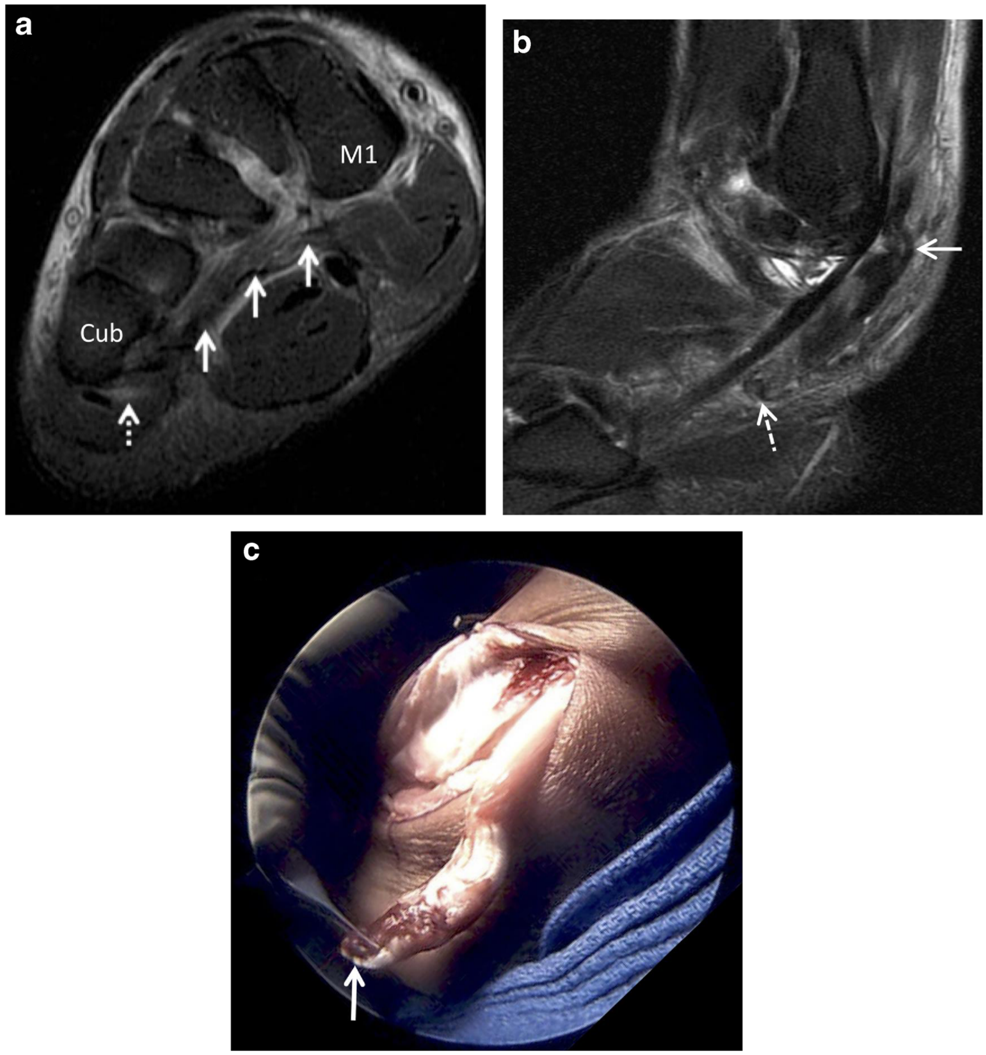

Fig. 20 Complete peroneus longus tendon tear between the cuboid tunnel and plantar midfoot in a 43-year-old male 1 week following inversion injury. Coronal (**a**) T2-weighted fat-saturated MR image shows a high-grade partial peroneus longus tendon tear along the plantar midfoot (*dashed arrow*), distal to the cuboid tunnel (Cub), with torn fibers close to the first metatarsal base insertion (M1-*arrows*). After 1 month of conservative therapy, a repeat sagittal T2-weighted fat-saturated MR (**b**) shows retraction of the torn peroneus longus tendon, with the stump at the lateral calcaneus (*dashed arrow*) and proximal tendon redundancy (*arrow*). These findings were confirmed surgically (*arrow* in **c** shows the tendon stump). Subsequent peroneus longus tenodesis to the peroneus brevis was performed

findings include peroneus brevis tendon or lateral ligamentous complex injuries [3, 9].

Region 5: Plantar foot and distal insertion

The insertion of the distal peroneus longus tendon is highly variable, though the dominant insertion of the tendon is always on the plantar base of the first metatarsal. The synovial sheath of the distal peroneus longus tendon terminates just before its insertion. Cadaveric studies reveal insertional patterns ranging from a single insertion at the first metatarsal base to multiple tendinous slips inserting at the medial cuneiform, plantar 2nd through 5th metatarsals, and the first dorsal interosseous muscle [38, 57, 58]. The distal peroneus longus tendon stabilizes the first tarsometatarsal joint, preventing metatarsus primus varus and hallux valgus. The tendon also aids in plantar flexion of the foot [59, 60]. A strong plantar tendinous slip connecting the peroneus longus and tibialis posterior tendons is variably present; it may act to stabilize the Lisfranc joint and support the tarsometatarsal arch [61].

Even when the insertion is limited to the metatarsal base, the terminal tendon is often enlarged, striated and exhibits increased signal. These findings, along with variable tendinous insertions, are challenging to distinguish from insertional tendon pathology. Disorders at the distal tendon insertion are rare and include tendinosis, tears (Fig. 21), and first metatarsal avulsion fractures. Partial insertional tears are challenging to recognize. When the tear is complete, a fluid-filled gap can be seen created by proximal tendon retraction. Insertional avulsion fractures are caused by forcible dorsiflexion and inversion, which places a high tensile force on the tendon. MRI or CT is typically used to diagnose these fractures, as they may be occult on radiographs. Treatment is usually conservative with operative management reserved for persistent pain or non-union [62].

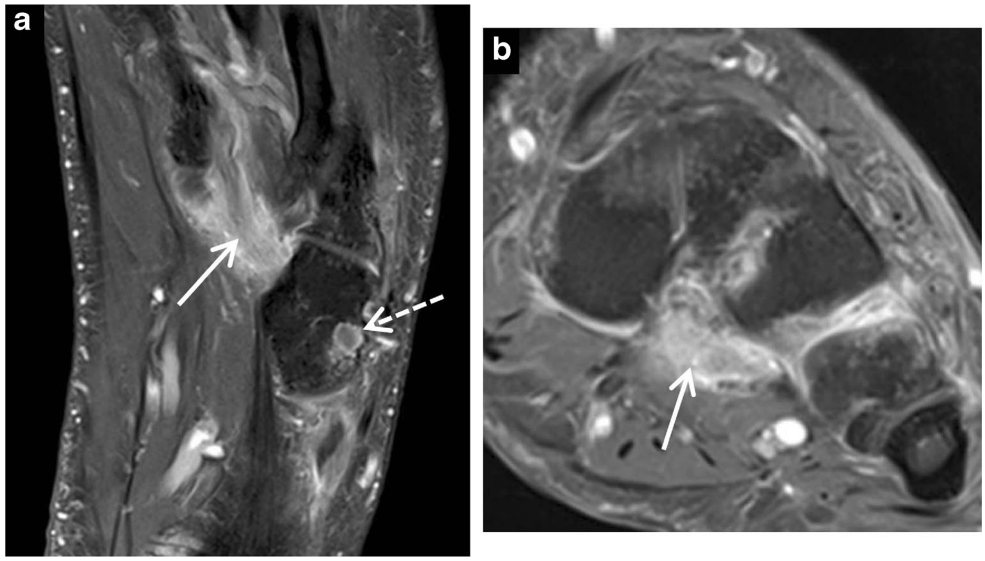

Fig. 21 High-grade tear of the distal peroneus longus tendon in a middle-aged man with plantar and lateral foot pain after an acute eversion injury. Axial (**a**) and coronal (**b**) PD-weighted fat-saturated MR images of the plantar foot show marked thickening and increased signal at the distal peroneus longus tendon compatible with a high-grade tear (*solid arrows* in **a** and **b**). Degenerative change is seen at the plantar cuboid at the level of the cuboid tunnel (*dashed arrow* in **a**) related to chronic friction and tendinopathy

Treatment options

A wide range of treatment options are used for peroneus longus pathology (Table 1). Most patients are treated conservatively with activity modification, anti-inflammatory medications, and physical therapy. Operative management may be required for more recalcitrant symptoms, with the key aim to repair the peroneus longus tendon (primary repair, tenodesis, or tendon grafting) and modify any predisposing anatomic abnormality (SPR repair, peroneal tubercle, or peroneus quartus excision) [10, 23, 48].

Conclusions

The peroneus longus arises within the lateral compartment of the leg and has a unique, long tendinous course making two turns, where it is subjected to high tensile forces. The most common site of tendon injury is at the cuboid tunnel, followed by the retromalleolar region. This article has discussed regional anatomy and pathologies along the entire length of the peroneus longus muscle and tendon.

The radiologist should be aware of the complex anatomy and plethora of peroneus longus muscle and tendon

Table 1 Treatments for peroneus longus tendon pathologies

Peroneal tendon pathology	Non-operative	Operative
Tendinosis	• NSAIDs, rest, ice, compression, activity modification • Physical therapy • Orthotics	• Open tendon debridement and tenosynovectomy • Excision of peroneus quartus or hypertrophied peroneal tubercle, if present
Tear		• Tears < 50%: Excision of affected area followed by tubularization • One tendon torn, other functional: tenodesis between peroneus brevis and peroneus longus tendons • Both tendons nonfunctional: tendon transfer or staged tendon grafts
Painful os peroneum syndrome		• Excision of os peroneum and hypertrophied peroneal tubercle, if present • Primary repair or tenodesis of peroneus longus tendon
Tenosynovitis		• Open debridement and tenosynovectomy • Correction of any associated anatomic or biomechanical abnormalities (e.g., cavovarus hindfoot, hypertrophic peroneal tubercle, or peroneal tendon tear)
Instability	Immobilization in short leg cast with foot in neutral/slight inversion (allows SPR to heal to fibula)	Reattach and/or reinforce retinaculum • Bone-block procedure • Tendon re-routing behind the calcaneofibular ligament • Groove-deepening procedures

pathology in order to provide the appropriate imaging modality and accurate diagnosis. At the proximal lower leg, peroneus longus muscle injury can occur secondary due to denervation, and it is important to carefully assess the peroneal nerves on MRI or ultrasound. At the retromalleolar region peroneus longus tendon instability/subluxation can be transient, and is often better demonstrated using dynamic ultrasound. More distally at the lateral calcaneus and cuboid tunnel, painful os peroneum syndrome, tendinopathy and tendon tears can overlap clinically. A multimodality imaging approach in these regions using radiographs for assessment of the os peroneum morphology, along with MRI or ultrasound for tendon integrity will provide important information for clinical management.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval "All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards."

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