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ORIGINAL ARTICLE

Evaluation of the relations between foot & ankle pathologies and anatomic variations with magnetic resonance imaging of 849 study population

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ABSTRACT

Objectives: The aim of the study was to evaluate the relationships between common pathologies and anatomical variations in the foot & ankle using magnetic resonance imaging (MRI).

Patients and methods: Between January 2016 and December 2020, a total of 849 ankle MRIs (427 right foot, 422 left foot) in 738 patients (274 males, 464 females; mean age: 43.4±14.3 years; range, 15 to 70 years) were retrospectively analyzed. Among ankle pathologies, peroneal and flexor hallucis longus (FHL) tendinopathies were evaluated. Among the anatomical variations, retromalleolar fibular groove (RMFG) shape, os peroneum, os trigonum, peroneus quartus (PQ), flexor digitorum accessorius longus (FDAL), low-lying peroneus brevis (PB) and FHL muscles were examined. The distance of the PB and FHL musculotendinous junctions (MTJs) from designated reference points was measured. Cut-off values for PB and FHL musculotendinous junction distances were determined by receiver operating characteristic (ROC) analysis. For the reliability analysis of measurements performed by two researchers, intraclass correlation coefficient (ICC) values were calculated.

Results: Bilateral ankle MRIs of 111 patients were evaluated. The PB, PL, and FHL tenosynovitis were observed in 29.6%, 34.9%, and 38.8% of all ankles, respectively. The PB and PL tendon tears were found in 12.2% and 3.9%, respectively. A total of 47.1% of the RMFG shapes were concave, 36.7% were flat, 12.4% were convex, and 3.8% were irregular. The PQ, FDAL, os peroneum, and os trigonum were detected in 13.8%, 3.1%, 16.6%, and 20.5% of the ankles, respectively. The cut-off value of PB MTJ distance that would cause a PB tendon tear was 4.40 mm distal from reference point. The cut-off value of FHL MTJ distance that would cause FHL tendinopathy was 4.15 mm distal from reference point. The study had a statistically significantly high level of consistency between the experts (ICC=0.85).

Conclusion: The convex and irregular shapes of the RMFG, along with the anatomical variations of the os peroneum and low-lying PB muscle, constitute risk factors for peroneal tendon pathologies. The presence of the os trigonum and low-lying FHL muscle anatomical variations predispose individuals to FHL tendinopathies. The cut-off values that could lead to PB vertical tears and FHL tendinopathy were identified for the low-lying PB and FHL muscles, respectively.

Keywords: Flexor digitorum accessorius longus, flexor hallucis longus, magnetic resonance imaging, os peroneum, os trigonum, peroneal tendons. peroneus quartus.

Foot & ankle pathologies are important public health issues due to their adverse effects on patients' quality of life and their rising incidence.[1] Although these pathologies are mostly associated with activity and trauma, studies have identified anatomical variations which predispose to ankle pathologies.[2-4] These anatomical differences of the ankle and foot are often asymptomatic. However, in some cases, they are critical, as they can be symptomatic and can be confused with pathologies. Understanding of the relationships between this pathology and its variations enables the accurate identification of differential diagnosis, thereby facilitating the determination of the most appropriate treatment

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protocol. Additionally, by identifying the potential pathologies that patients may be at risk for in the future, follow-up processes can be effectively planned.

The meticulous evaluation of anatomical variations such as the shape of the retromalleolar fibular groove (RMFG) shape, os peroneum, peroneus quartus (PQ), os trigonum, flexor digitorum accessorius longus (FDAL) muscle, low-lying peroneus brevis (PB) and flexor hallucis longus (FHL) muscle is essential for foot & ankle pathologies. The RMFG contributes to the stability of the peroneal tendons by providing depth, preventing their subluxation. The shapes of the retro-malleolar fibular groove exhibit various variations, including straight, concave, convex, and irregular forms.[5] Os peroneum is a sesamoid bone located within the peroneus longus (PL) tendon. Although it is often asymptomatic, it can occasionally lead to a pathology known as os peroneum syndrome.[6] The PQ muscle, in some cases, can lead to crowding, which may cause peroneal tendon pathologies and retro-malleolar pain conditions.[7] Os trigonum is an accessory bone located posterior to the talus. It can cause FHL tendon pathologies and contribute to posterior ankle impingement syndrome.[8] The FDAL muscle can cause tarsal tunnel syndrome by creating compressive forces.[9] Low-lying PB and FHL muscle can lead tendon pathologies in foot & ankle (Figure 1).

Magnetic resonance imaging (MRI) has an important place in the diagnosis of foot & ankle pathologies and anatomical variations. It is an indispensable imaging method, since it can distinguish normal and pathological tissue, has high soft tissue resolution, does not utilize radiation, is non-invasive, and provides multiplanes cross-sectional imaging.[10,11] However, MRI has several disadvantages, including its high cost, limited accessibility, long examination duration and the requirement for patient immobility. Additionally, it is contraindicated in cases of claustrophobia or the presence of metal implants in the body.

Many studies have been conducted on ankle pathologies and anatomical variations.[2,4,12] However, no study has been done with many patient populations and comparing many parameters in the ankle at the same time. In the present study, we hypothesized that certain anatomical variations might tend to coexistence and that these variations might serve as predisposing factors for certain ankle pathologies. We, therefore, aimed to reveal the diagnosis of pathologies and anatomical variations of patients undergoing ankle MRI examination and to determine the simultaneous relationship between these factors.

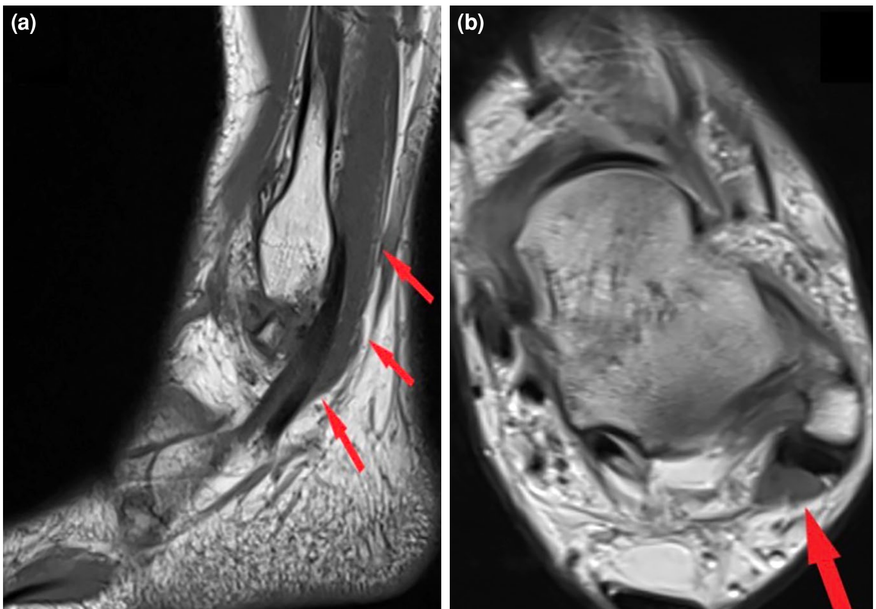

FIGURE 1. Low-lying PB muscle. **(a)** MRI sagittal section (arrows: low-lying PB muscle tract), **(b)** MRI transverse section (arrow: PB muscle bundle extending distally to the fibular tip).

PB: Peroneus brevis; MRI: Magnetic resonance imaging.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Akdeniz University Medical Faculty Hospital, Department of Orthopedics and Traumatology between January 2016 and December 2020. Patients between the ages of 15 and 70 who underwent ankle MRI in our clinic were retrospectively analyzed. In our study, we established the minimum age limit as 15 years, considering the maturation process of soft tissues assessed (i.e., tendons, ligaments and muscle) and the fact that the os peroneum and os trigonum are classified as separate non-ossified bone fragments, if ossification is not completed by the age of 14.[13-16] Those with a history of operation in the foot & ankle, those who had acute trauma in the past month, those with infection and space-occupying tumoral lesions, those with ankle deformation due to systemic diseases, and those with insufficient image quality due to a technical error during MRI or a problem caused by the patient were excluded from the study. In the study, since the MRI images of patients presenting with chronic foot or ankle pathology were retrospectively analyzed, factors such as activity levels, underlying systemic diseases, and body mass index were not considered. Based on these criteria, of the total 1,673 ankles, 849 ankles (427 right foot, 422 left foot) in 738 patients (274 males, 464 females; mean age: 43.4±14.3 years; range, 15 to 70 years) were included in the study. Bilateral ankle MRIs of 111 patients were evaluated. A written informed consent was obtained from each patient. The study protocol was approved by the Akdeniz University Faculty of Medicine Clinical Research Ethics Committee (date: 27.10.2021, No: 70904504/680). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Ankle MRI examinations were carried out using 3T MRI device (Siemens Magnetom Spectra, Erlangen, Germany) or 1.5T MRI device (Siemens Magnetom Aera, Erlangen, Germany) with 16-channel ankle wrap (Siemens Foot/Ankle 16, Tim Coil). Routine ankle MRI scans were performed with the patients in the supine position with the ankle in neutral. For MRI of each ankle, proton density (PD), turbo spin echo (TSE), fat-suppressed (FS) and T1-weighted TSE sequences were obtained in the sagittal plane: PD, TSE, FS sequences in the coronal plane; PD, TSE, FS and PD, TSE sequences in the transverse plane.

Radiological evaluation of images and measurements were made by an orthopedist and a musculoskeletal radiologist in the same session

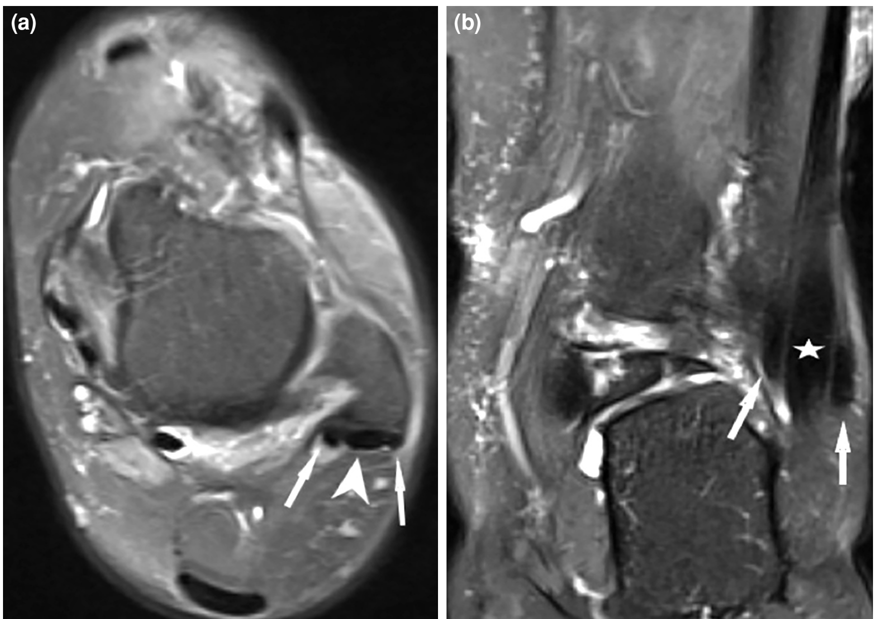

FIGURE 2. (a) MRI transverse section with PB tear (arrowhead: PL tendon, arrows: PB hemitendons formed after the PB tear), **(b)** MRI coronal section with PB tear (star symbol: PL tendon, arrows: PB hemitendons on both sides of the PL formed after the PB tear).

MRI: Magnetic resonance imaging; PB: Peroneus brevis; PL: Peroneus longus.

using the Sectra PACS IDS7 system (Sectra AB, Linköping, Sweden). For the reliability testing of measurements performed by two researchers, the intraclass correlation coefficient (ICC) was calculated for quantitative measurements, while Cohen's Kappa (κ) test was used for qualitative assessments. Quantitative measurements were obtained with a precision of one-tenth of a millimeter.

Peroneal and FHL tendinosis, tendinitis, and tenosynovitis were evaluated in the same group under the name of tenosynovitis. In the tendon sheaths, at least 3-mm intense fluid-induced signal increase in three consecutive sections in PD fat-suppressed sequences of transverse sections was considered pathological. Meanwhile, thickening of the tendons (the condition in which the tendon is 50% thicker than its normal proximal segment or thicker than the tibialis posterior tendon) in sagittal and coronal sections resulted in a diagnosis.[2,10] Peroneal tendon tears were evaluated in three different groups as vertical, partial, and full thickness (Figure 2).

Four shapes were defined for the RMFG as concave, flat, convex, and irregular. First, 1-cm distance from proximal to the apex of the fibula type was determined in the T1 sagittal section.[5] Afterwards, this place was found in the T1 transverse section with the localizer option of the Sectra IDS7 system. By examining this transverse section, the RMFG shapes of the cases were determined (Figure 3).

The os peroneum was examined in all sequences and sections of MRI. Oval-shaped structures at the level of the calcaneocuboid joint and the PL tendon trace, showing the same signal intensity as the normal bone marrow, were evaluated as os peroneum and recorded (Figure 4).

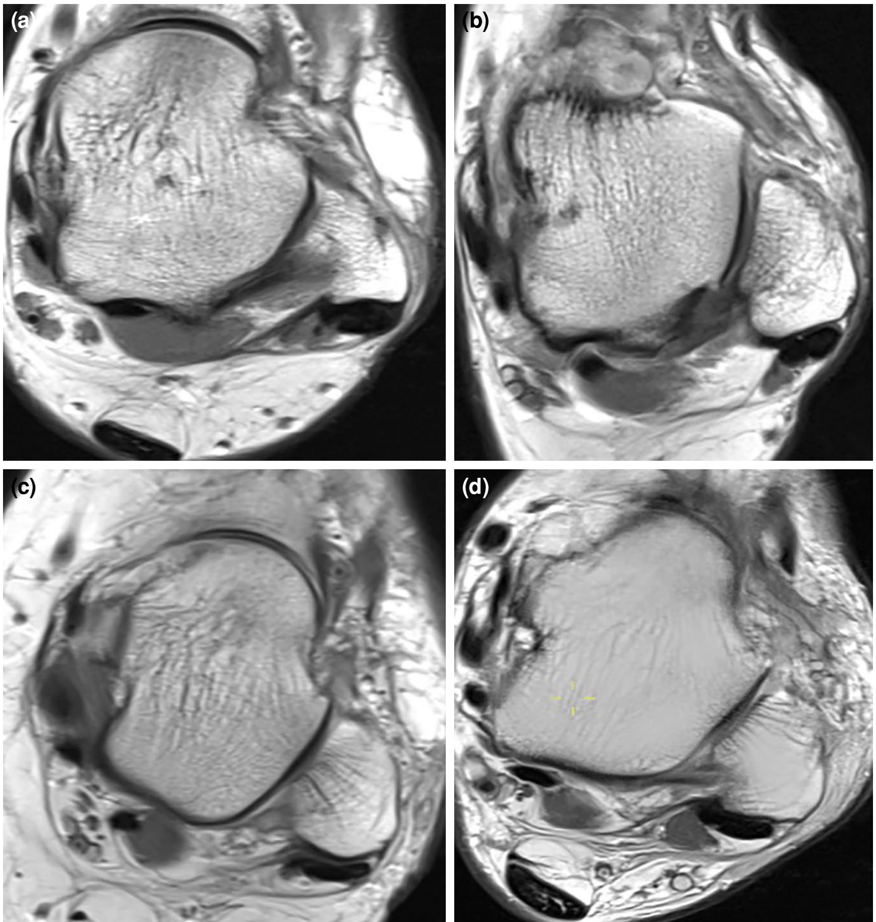

FIGURE 3. RMFG shape variations, MRI T1 transverse sections. **(a)** Concave, **(b)** flat, **(c)** convex, **(d)** irregular.
RMFG: Retromalleolar fibular groove; MRI: Magnetic resonance imaging.

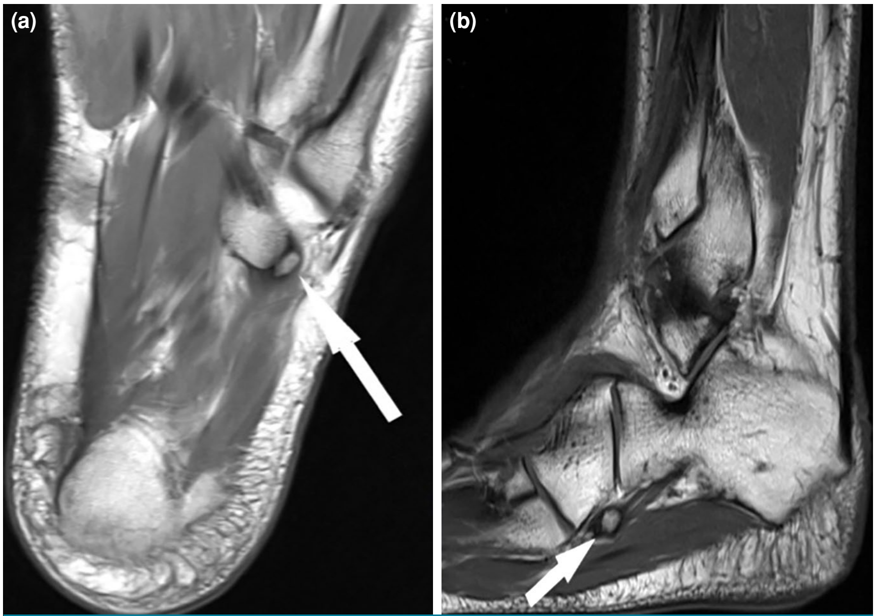

FIGURE 4. Os peroneum **(a)** MRI transverse section, **(b)** MRI sagittal section (arrow: os peroneum).
MRI: Magnetic resonance imaging.

The PQ muscle is a general term used to describe accessory muscles located on the lateral aspect of the ankle which exhibit different origins and insertion sites.[12] The structures which were observed as a separate muscle and tendon in the posteromedial of the PB muscle in transverse sections in MRI and progressing distally as a separate muscle group in sagittal and coronal sections, were recorded as PQ (Figure 5).

A quantitative measurement was performed for both the low-lying PB and FHL muscles. The apex of the fibula was taken as the reference point for the PB

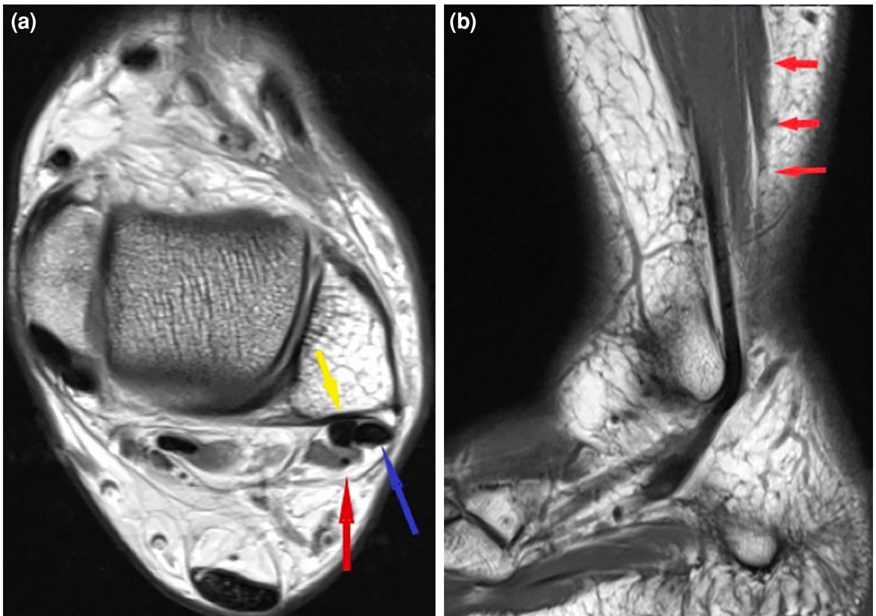

FIGURE 5. Peroneus quartus muscle. **(a)** MRI transverse section (red arrow: peroneus quartus muscle, blue arrow: PL muscle, yellow arrow: PB muscle). **(b)** MRI sagittal section (red arrows: longitudinal tract of peroneus quartus muscle).
MRI: Magnetic resonance imaging; PL: Peroneus longus; PB: Peroneus brevis.

muscle.[10,17] The highest point of the posterior facet of the calcaneus was determined as the reference point for the low-lying FHL muscle. When the muscle extension was located proximal to this reference point, it was recorded as positive, and when located distal, it was recorded as negative. The low-lying PB and FHL muscle was defined as the extension of the muscle distal to the reference point. In the PD TSE transverse sections, the first section without the PB muscle was marked. Using the localizer tool of the Sectra IDS7 system, the corresponding location in the T1 sagittal section was identified, and its distance from the apex of the fibula was measured and recorded (Figure 6). In the T1 transverse sections, the first section without the FHL muscle was marked. The location of this section in the T1 sagittal plane was then identified using the Sectra IDS7 system, and the distance from the highest point of the posterior facet of the calcaneus was measured and recorded (Figure 7).

All sequences, particularly of the sagittal and transverse sections, were analyzed in MRI for os trigonum. The structures in the posterior recess, building joints with the lateral tubercle of the talus and the calcaneus, and having the same signal intensity as the bone marrow in all sequences, were noted as os trigonum.

On MRI, structures with the same signal intensity as the other muscles, which were identified as a separate muscle group in the posteromedial of the FHL muscle in transverse sections and observed in sagittal and coronal sections, were recorded as the FDAL muscle.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 19.0 software (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. The chi-square test was used for qualitative data, while independent sample t-test was used for quantitative data. Adjustments for multiple comparisons were applied using the Bonferroni correction. Statistical correlations between pathologies and anatomical variations with age were analyzed using the Mann-Whitney U test and the Kruskal-Wallis test, while the relationship with sex was assessed using the Pearson chi-square test. Cut-off values of PB and FHL muscle tendon junction (MTJ) distances which may cause pathologies were determined by receiver operating characteristic (ROC) analysis. The ROC cut-off values were determined using the Youden's index to maximize sensitivity and specificity. Sensitivity, specificity, and area under the curve (AUC) values

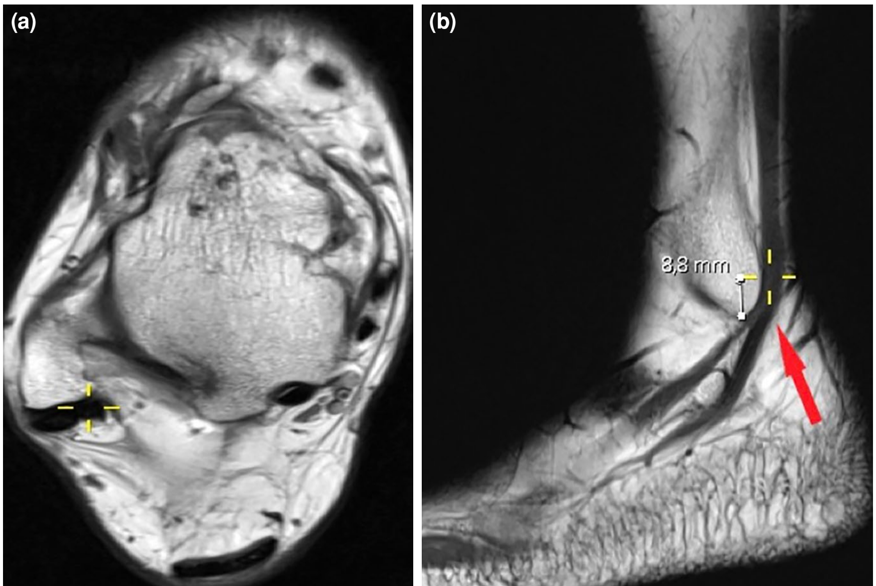

FIGURE 6. (a) First transverse section without PB muscle on MRI, **(b)** T1 sagittal section on MRI (red arrow: measurement based on reference point) (yellow mark: localizer plus sign).

PB: Peroneus brevis; MRI: Magnetic resonance imaging.

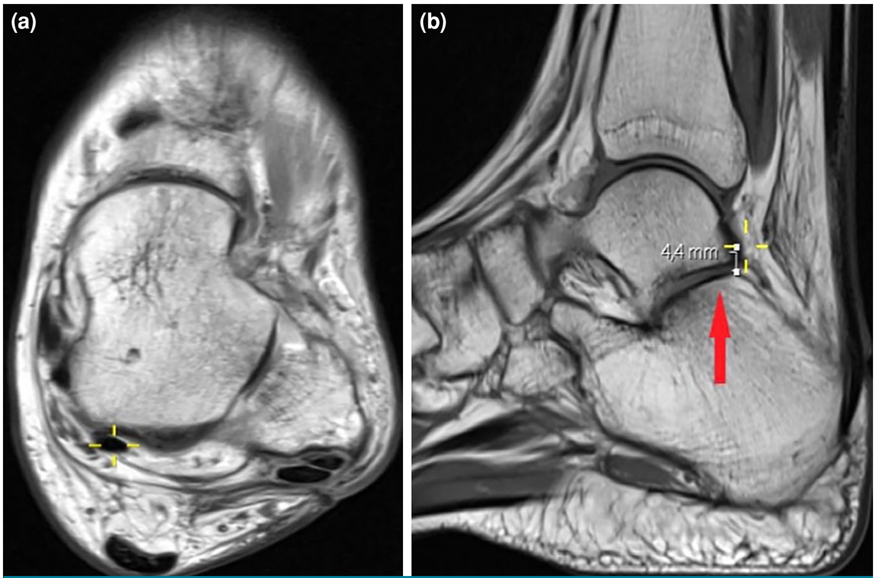

FIGURE 7. (a) MRI PD first transverse section without fat-suppressed FHL muscle, **(b)** MRI T1 sagittal section (red arrow: measurement based on reference point) (yellow mark: localizer mark).
MRI: Magnetic resonance imaging; PD: Proton density; FHL: Flexor hallucis longus.

were calculated. A *p* value of <0.05 was considered statistically significant.

RESULTS

A total of 849 ankles of 738 patients were included in the study. Of these, 427 were right-sided and 422 were left-sided. Bilateral ankle MRI scans were analyzed in 111 patients.

According to the reliability analysis results of measurements performed by two researchers, a statistically very high level of consistency was found between the experts performing quantitative measurements ($p<0.001$), indicating that the measurement methods are highly reliable (ICC=0.85). For qualitative measurements, a statistically high level of consistency was observed between the experts ($p=0.003$ and $p<0.01$), demonstrating that the measurement methods have a high level of reliability ($\kappa=0.78$).

The median age values in cases with peroneal tendon pathology, os peroneum, os trigonum, and FHL tenosynovitis were found to be statistically significantly higher compared to those without these pathologies and anatomical variations ($p<0.05$). In cases with a low-lying PB muscle, however, the median age values were found to be lower. No statistically significant relationship was observed between other anatomical variations and age ($p>0.05$) (Table I).

Low-lying PB muscle, os trigonum, and FHL tenosynovitis cases showed a statistically significant difference between sexes ($p<0.05$). The likelihood of having low-lying PB muscle, os trigonum, and FHL tenosynovitis was 1.4, 1.7, and 1.5 times higher in males than in females, respectively. No significant relationship was found between other pathologies and anatomical variations and sex ($p>0.05$) (Table II).

Peroneus brevis and PL tenosynovitis were seen in 29.6% and 34.9% of cases, respectively. A total of 87.8% of the cases did not have a tear in the PB tendon, 11.1% had a vertical tear, and 1.1% had a partial tear. No full-thickness tear of the PB tendon was observed. There was no tear in the PL tendon in 96.1% of the cases, 2.6% had a vertical tear, 1.2% a partial tear, and 0.1% a full-thickness tear. The RMFG shapes were concave in 47.1%, flat in 36.7%, convex in 12.4%, and irregular in 3.8% of the patients. Os peroneum, PQ, and low-lying PB were detected in 16.6%, 13.8%, and 33.6% of the cases, respectively. Also, FHL tenosynovitis, os trigonum, FDAL, and low-lying FHL muscle variations were observed in 38.8%, 20.5%, 3.1%, and 27% of cases, respectively (Table III).

TABLE I
Analysis of the relationship between pathologies and anatomical variations with demographic characteristics (age)

	Age		
	Median	Range	*p*
RMFG (n=849)			
Concave (n=400)	43	15-70	0.314
Flat (n=312)	43	15-70	
Convex (n=105)	43	16-70	
Irregular (n=32)	50	32-70	
Peroneal tendon pathology (n=348)	48	15-70	**<0.001**
Os peroneum (n=141)	49	17-70	**<0.001**
Peroneus quartus (n=117)	43	16-70	0.869
Low lying PB muscle (n=285)	42	17-70	**0.040**
Os trigonum (n=174)	47	17-70	**0.019**
FHL tenosynovitis (n=329)	47	17-70	**<0.001**
FDAL (n=26)	42	19-67	0.919
Low lying FHL muscle (n=229)	45	17-70	0.513

RMFG: Retromalleolar fibular groove; PB: Peroneus brevis; FHL: Flexor hallucis longus; FDAL: Flexor digitorum accessorius longus; n: The number of cases with observed pathology or anatomical variation

The distance from the PB MTJ site-to-the apex of the fibula was measured as maximum 28.1 mm proximally and 16.3 mm distally. The mean distance was 2.38±5.85 mm. The distance from the FHL MTJ site-to-the highest point of the posterior calcaneus facet was measured as maximum 15.4 mm proximally and 9.2 mm distally. The mean distance was 1.30±2.51 mm (Table IV).

Peroneal tendon pathologies were significantly higher in patients with convex and irregular RMFG

TABLE II
Analysis of the relationship between pathologies and anatomical variations with demographic characteristics (sex)

	Sex				
	Male		Female		
	n	%	n	%	*p*
RMFG (n=849)					
Concave	149	48.1	251	46.6	0.778
Flat	113	36.5	199	36.9	
Convex	39	12.6	66	12.2	
Irregular	9	2.9	23	4.3	
Peroneal tendon pathology (n=348)	130	41.9	218	40.4	0.671
Os peroneum (n=141)	48	15.5	93	17.3	0.505
Peroneus quartus (n=117)	45	14.5	72	13.4	0.637
Low lying PB muscle (n=285)	118	38.1	167	31	0.035
Os trigonum (n=174)	82	26.5	92	17.1	0.001
FHL tenosynovitis (n=329)	139	44.8	190	35.3	0.006
FDAL (n=26)	10	3.2	16	3	0.834
Low lying FHL muscle (n=229)	88	28.5	141	26.2	0.464

RMFG: Retromalleolar fibular groove; PB: Peroneus brevis; FHL: Flexor hallucis longus; FDAL: Flexor digitorum accessorius longus; n: The number of cases with observed pathology or anatomical variation.

shapes ($p<0.05$). Peroneus longus pathologies were significantly higher in patients with os peroneum and PQ muscle ($p<0.05$). There was no significant relationship between PQ muscle and PB tendon pathologies ($p>0.05$).

Low-lying PB were detected in 33.6% of the cases. In addition, PB vertical tears, PB and PL tenosynovitis pathologies were observed more frequently in patients with a more distal PB MTJ ($p<0.05$). There was no significant difference between PL tendon tear and PB MTJ distance measurements ($p>0.05$).

The ROC analysis was performed for the cut-off value of PB MTJ in cases with vertical PB tendon tears (Figure 8). The diagnostic power of the scale was 65%, indicating statistical significance ($p=0.02$ and $p<0.05$). The cut-off value for PB vertical tear was –4.40 mm compared to the PB muscle-tendon junction with 83% sensitivity and 90% specificity. The positive and negative predictive values were 84% and 92%, respectively (Table V).

Flexor hallucis longus tenosynovitis pathology was found at higher rates in patients with os trigonum variation ($p<0.05$). No statistically significant correlation was found between the presence of FDAL muscle and FHL pathologies ($p>0.05$), probably due to its low prevalence among the total cases. However, FHL pathology was observed in 69% (n=18) of 26 patients who had the FDAL muscle. Although this finding was not statistically significant, it is clinically significant.

There was a statistically significant correlation between FHL MTJ distance measurements and FHL tenosynovitis pathologies ($p<0.05$). Pathology of FHL tenosynovitis was observed more frequently in patients whose FHL MTJ ended more distally.

The ROC analysis was performed for the cut-off value of FHL MTJ in cases with FHL tenosynovitis (Figure 9). The diagnostic power of the scale was

TABLE III
Prevalence

	n	%
PB tenosynovitis	251	29.6
PB tendon tear		
Intact	746	87.9
Vertical	94	11.1
Partial	9	1.1
Full-thickness	0	0.0
PL tenosynovitis	296	34.9
PL tendon tear		
Intact	816	96.1
Vertical	22	2.6
Partial	10	1.2
Full-thickness	1	0.1
RMFG shape		
Concave	400	47.1
Flat	312	36.7
Convex	105	12.4
Irregular	32	3.8
Os peroneum	141	16.6
Peroneus quartus	117	13.8
Low lying PB muscle	285	33.6
Os trigonum	174	20.5
FHL tenosynovitis	329	38.8
FDAL	26	3.1
Low lying FHL muscle	229	27.0

PB: Peroneus brevis; PL: Peroneus longus; RMFG: Retromalleolar fibular groove; FHL: Flexor hallucis longus; FDAL: Flexor digitorum accessorius longus.

TABLE IV
Examination of quantitative measures of data

Measurement	Mean±SD	Min-Max
PB MTJ distance (mm)	2.38±5.85	–16.30-28.10
FHL MTJ distance (mm)	1.30±2.51	–9.20-15.40

SD: Standard deviation; PB: Peroneus brevis; MTJ: Musculotendinous junction; FHL: Flexor hallucis longus.

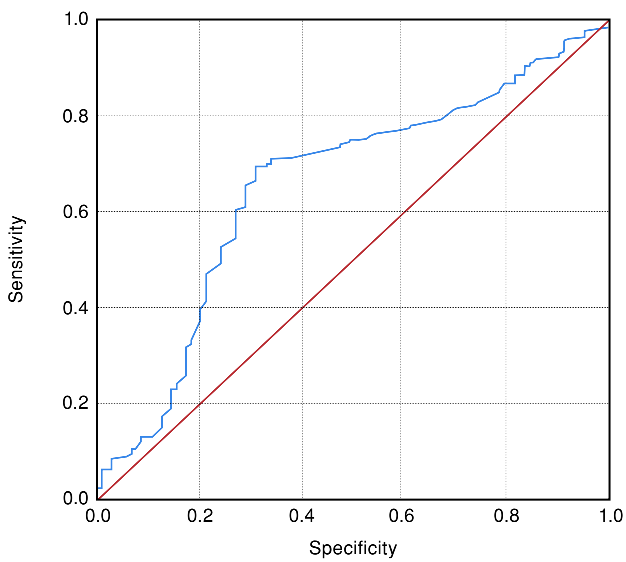

FIGURE 8. ROC curve of PB MTJ distance for PB tendon vertical tears.
ROC: Receiver operating characteristic; PB: Peroneus brevis; MTJ: Musculotendinous junction.

70%, indicating a statistical significance ($p=0.02$ and $p<0.05$). The cut-off value for FHL tenosynovitis was −4.15 mm according to FHL MTJ with 89% sensitivity and 84% specificity. At the same time, positive and negative predictive values were found to be 88% and 84%, respectively (Table VI).

DISCUSSION

Although foot & ankle pathologies and anatomical variations are common, they are difficult to diagnose by clinicians. Therefore, it is of utmost importance to recognize the relationships between the pathologies seen in the ankle and the anatomical variations. Of note, MRI has an important place for both diagnosis and preoperative evaluation.[10,11] In our study of the large patient population, we obtained significant results regarding ankle pathologies and anatomical variations using MRI.

TABLE V
Investigation of the cut-off value of the PB MTJ distance that may cause PB tendon vertical tears

	%	Millimeter	*p*
Cut-off point		−4.40	
Sensitivity	83		
Specificity	90		
Positive predictive value	84		
Negative predictive value	92		
Diagnostic accuracy	65		0.02*

PB: Peroneus brevis; MTJ: Musculotendinous junction; * p<0.05 (ROC analysis applied).

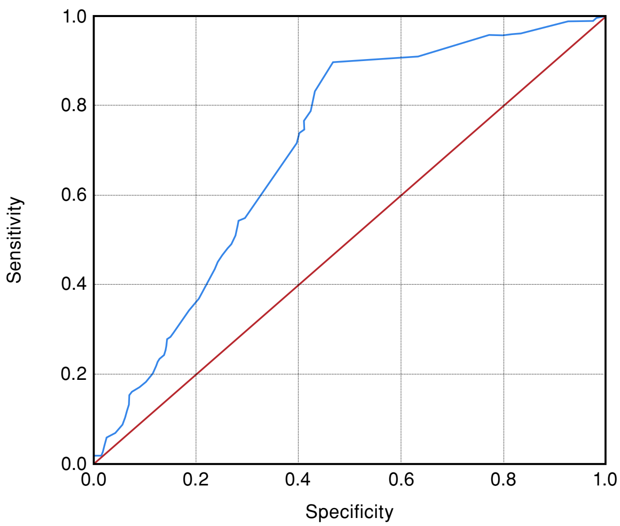

FIGURE 9. ROC curve of FHL MTJ distance for FHL tenosynovitis pathology.
ROC: Receiver operating characteristic; FHL: Flexor hallucis longus; MTJ: Musculotendinous junction.

TABLE VI
Investigation of the cut-off value of the FHL MTJ distance, which may cause FHL tenosynovitis pathology

	%	Millimeter	*p*
Cut-off point		−4.15	
Sensitivity	89		
Specificity	84		
Positive predictive value	88		
Negative predictive value	84		
Diagnostic accuracy	70		0.01*

MTJ: Musculotendinous junction; FHL: Flexor hallucis longus; * p<0.05 (ROC analysis applied).

In the current study, with the increasing age, peroneal tendon pathologies, os peroneum, os trigonum, and FHL tenosynovitis were observed more frequently. This finding is consistent with previous studies in the literature.[8,16] However, there are also studies showing no significant relationship between peroneal tendon pathologies and age.[3] No significant relationship was found between age and other anatomical variations. A review study reported that os trigonum and FHL tenosynovitis were more frequently observed in men compared to women.[8] In our study, consistent with this finding, os trigonum and FHL tenosynovitis were found to be more common in men. Additionally, the frequency of low-lying PB muscle was found to be higher in men. To the best of our knowledge, there is no study available related to this topic in the literature.

Since peroneal tendinopathies are among the most common pathologies of the ankle, they have been investigated extensively in the literature with both radiological and cadaveric studies. The prevalence of PB vertical tears has been shown to vary between 11 and 37% in cadaveric studies.[18-20] In an MRI study conducted by Galli et al.,[3] PB and PL tenosynovitis were reported as 31% and 38%, respectively. In our study, consistent with the literature, PB and PL tenosynovitis were found in 29.6% and 34.9% of cases, respectively, and PB vertical tear was found in 11.1%.

Signal intensity increase in tendons is usually considered an indicator of tendon injury. However, in some cases, this phenomenon may also be attributed to the magic angle effect. When a tendon is positioned at a 55° angle relative to the main magnetic field, the T2 relaxion time increases, leading to a signal intensity increase in sequences with short TE (echo time) values. This effect is most commonly observed in T1-weighted (T1W) sequences. However, when TE value exceeds a certain threshold, the signal intensity increase in the tendon is no longer present in true T2W sequences.[21]

Previous studies have shown that RMFG shape variations should be examined in four groups as concave, flat, convex, and irregular.[3,5] In an ankle MRI study including symptomatic patients, RMFG shapes were 20.3% concave, 58% flat, 18.8% convex, and 2.9% irregular.[2] In our study, RMFG shapes were found to be 47.1% concave, 36.7% flat, 12.4% convex, and 3.8% irregular. In addition, several studies have demonstrated that RMFG shapes can cause peroneal tendon pathologies.[3,5,22] In general, RMFG provides stability during the movement of the peroneal tendons and prevents subluxation. The fibrocartilage tissue on the surface of the RMFG increases the slipperiness, minimizing friction between the peroneal tendons. In cases where the groove shape is convex and irregular, a compression effect on the peroneal tendons is observed due to the narrowing of the groove. As a result, the risk of tenosynovitis and vertical tears in the peroneal tendons increases. In these cases, surgical procedures such as RMFG deepening or shaving may be performed.[23] In our study, consistent with the literature, in cases with convex and irregular RMFG shape, PB and PL tenosynovitis and PB tears were observed more frequently. While PB and PL tenosynovitis were seen in 58.1% and 59% of those with convex RMFG shape, PB and PL tenosynovitis were seen in 53.1% and 68.8% of the irregular ones. Additionally, PB tendon tear was observed in 36.2% of those with convex RMFG shapes, while PB tendon tears were observed in 7.5% of those with concave shapes.

Considering the PB MTJ distance, the PB MTJ level was found to be at a maximum distance of 28.10 mm proximally and 16.30 mm distally from the apex of the fibula, while the average of all measured distances was found to be 2.38 mm proximal to the apex of the fibula. Distally located PB muscle was found in 33.6% of the patients. In an MRI study conducted by Galli et al.,[3] MRIs of the ankles of 108 patients were evaluated, and a low-lying muscle anatomical variation was observed in 36 of the patients (33%). In another study with 50 patients who underwent surgery for peroneal tendon pathologies in the ankle, a low-lying muscle anatomical variation was identified in 31 patients (62%).[17]

Many studies have shown that the low-lying PB muscle may cause peroneal tendon pathologies.[17,24,25] In our study, a significant relationship was found between the low-lying PB muscle and peroneal tendon pathologies. In patients with PB and PL tenosynovitis pathology and PB vertical tear, PB MTJ distance measurements were found to be at lower levels. In patients with PB and PL tenosynovitis, the PB MTJ distances were 0.63 mm and 0.89 mm, respectively, while they were 3.11 mm and 3.17 mm in patients without it. In patients with a PB vertical tear, it was –0.64 mm, while it was 2.72 mm in patients without a PB vertical tear. However, there are studies in the literature showing no significant relationship between peroneal tendon pathologies and low-lying PB muscle.[2,3]

In the current study, the cut-off value of the PB MTJ distance, which could result in a PB vertical tear, was calculated as 4.40 mm distal from the apex of the fibula. The sensitivity of the cut-off value was 83% and the specificity was 90%. At the same time, positive and negative predictive values were determined to be 84% and 92%, respectively. The high sensitivity and specificity of the cut-off value we found indicates its power in diagnosis, while the high level of positive and negative predictive values indicates that it is consistent. To the best of our knowledge, there is no previously published cut-off value indicating an increased risk of a PB vertical tear.

Furthermore, in our study, the PQ muscle was detected in 13.8% of the cases. The prevalence is similar to previous studies.[5,12] Wang et al.[5] reported that the PQ muscle might cause peroneal tendon pathologies. In a cadaveric study, a significant relationship was found between peroneal tendon pathologies and the PQ muscle.[26] On the other hand, there are many studies in the literature that argue the opposite of this idea.[2,18,27] In our study, only PL tenosynovitis among peroneal tendon pathologies was found to have a significant relationship with PQ. While 41.9% of patients with PQ had PL tenosynovitis, 33.7% of patients without PQ had PL tenosynovitis. No significant relationship was found between other peroneal tendon pathologies and PQ.

In the present study, os peroneum was observed in 16.6% of the cases, similar to previous studies.[2,3,13,28] There are many studies in the literature showing a relationship between

PL tendinopathies and os peroneum.[3,28,29] Consistent with the literature, in our study, there was a significant relationship between PL tendon pathologies and the presence of os peroneum. A total of 56% of patients with os peroneum had PL tenosynovitis. Totally 17% of patients with os peroneum had a PL tendon tear, while PL tendon tear was detected in 1.3% of patients without os peroneum.

There are many studies in the literature showing that the prevalence of os trigonum varies between 1 and 30%.[6,30,31] When os trigonum and FHL tendon pathologies are seen together, this situation is called stenosing FHL tenosynovitis.[8] Os trigonum can cause FHL tenosynovitis or impingement syndrome with mechanical effect.[14,32] Consistent with the literature, FHL tenosynovitis and os trigonum variation were significantly associated in our study. In our study, FHL tenosynovitis was found in 83.3% of patients with os trigonum variation, while this rate was 27.3% in patients without os trigonum. Of note, FHL tenosynovitis pathology was observed in 38.8% of all cases. Such tendinopathies are common ankle pathologies and have been documented in many studies.[33,34]

Cadaver study evaluating 62 ankles In a 2021, low-lying FHL muscle was found in 66.13% of cases, with the reference point being the intersection of the most distal tibia and FHL tendon.[35] In our study, low-lying FHL variation was observed in 27% of cases, with the reference point determined as the highest point of the posterior calcaneal facet, ensuring it was in the tarsal tunnel projection and measurable on MRI. The distance from the FHL muscle extension endpoint to the reference point was measured, with results ranging from 15.4 mm proximal to 9.2 mm distal. The mean and standard deviation were 1.30±2.51 mm. A cut-off value of 4.15 mm distal to the reference point was calculated as the threshold for FHL tendinopathies, with a sensitivity of 89%, specificity of 84%, and positive and negative predictive values of 88% and 84%, respectively. ROC curve analysis confirmed that an extension of the FHL muscle bundle more than 4.15 mm distal to the reference point predisposes to FHL pathologies. The cut-off value that could result in FHL tendinopathies was not calculated in the literature before. Our study is the first MRI study of the low-lying FHL muscle.

The mean value of FHL MTJ distance was found to be 0.29 mm in patients with FHL tenosynovitis pathology, while it was 1.94 mm in patients without FHL tenosynovitis. The FHL muscle with FHL tenosynovitis ended more distally anatomically. To the best of our knowledge, our study is the first in the literature to directly compare FHL tendinopathies with the low-lying FHL muscle.

Furthermore, in our study, 3.1% of the cases had FDAL muscle. The FDAL muscle may be a predisposing factor for FHL tendinopathies with its compression effect.[9] In the current study, although 18 (69%) of 26 patients with the FDAL muscle had FHL tenosynovitis, no statistically significant relationship was found. The reason for this is that the FDAL muscle was found at a low rate of 3.1% in total cases.

Nonetheless, there are some limitations to this study. First, the MRI scans of the cases were performed randomly across different MRI devices using 1.5T and 3T scanners. Although the sequence parameters were similar, there was a certain degree of technical heterogeneity. To mitigate this heterogeneity, 16- channel foot & ankle coils were utilized, and motion restriction was ensured during imaging to achieve higher-resolution images. Furthermore, literature studies comparing 3T and 1.5T MRI have shown that 3T MRI provides a significant advantage in cartilage assessment and the diagnosis of specialized pathologies, while there is no significant difference in the detection of tendon pathologies.[36,37] Second, the reliance on two researchers for reliability analysis is another limitation. While efforts were made to ensure consistency through predefined criteria and calibration sessions, inter-rater variability remains a potential concern. Having only two raters limits the robustness of inter-rater reliability measures, as certain statistical tests, such as Cohen's kappa, may be less stable with a small number of evaluators. The absence of a third independent reviewer may also introduce potential confirmation bias. The third limitation is that in our study, since the MRI images of patients presenting with foot or ankle pathology were retrospectively analyzed, factors such as activity levels, underlying systemic diseases, and body mass index were not considered. Further multi-center, large-scale, well-designed, prospective studies are warranted to confirm these findings.

In conclusion, our study results showed significant correlations between peroneal and FHL tendinopathies with anatomical variations in the ankle. In particular, the anatomical variation of the low-lying FHL muscle, of which there is no adequate study in the literature, seems to be related to FHL tendinopathies. Evaluating foot and ankle pathologies and anatomical variations, as well as understanding the simultaneous relationships between these pathologies and anatomical variations, will be guiding for physicians in diagnosis and treatment.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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