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Imaging of Adult Flatfoot: Correlation of Radiographic Measurements With MRI

Yu-Ching Lin[1]
Jennifer Ni Mhuircheartaigh[2]
Joshua Lamb[3]
Justin W. Kung[2]
Corrie M. Yablon[4]
Jim S. Wu[2]

OBJECTIVE. The purpose of this study is to determine whether radiographic foot measurements can predict injury of the posterior tibial tendon (PTT) and the supporting structures of the medial longitudinal arch as diagnosed on MRI.

MATERIALS AND METHODS. After institutional review board approval, 100 consecutive patients with radiographic and MRI examinations performed within a 2-month period were enrolled. Thirty-one patients had PTT dysfunction clinically, and 69 patients had other causes of ankle pain. Talonavicular uncoverage angle, incongruency angle, calcaneal pitch angle, Meary angle, cuneiform-to-fifth metatarsal height, and talar tilt were calculated on standing foot or ankle radiographs. MRI was used to assess for abnormalities of the PTT (tenosynovitis, tendinosis, and tear) and supporting structures of the medial longitudinal arch (spring ligament, deltoid ligament, and sinus tarsi). Statistical analysis was performed using the chi-square and Fisher exact tests for categoric variables; the Student *t* test was used for continuous variables.

RESULTS. There was a statistically significant association of PTT tear with abnormal talonavicular uncoverage angle, calcaneal pitch angle, Meary angle, and cuneiform-to-fifth metatarsal height. PTT tendinosis and isolated tenosynovitis had a poor association with most radiologic measurements. If both calcaneal pitch and Meary angles were normal, no PTT tear was present. An abnormal calcaneal pitch angle had the best association with injury to the supporting medial longitudinal arch structures.

CONCLUSION. Radiographic measurements, especially calcaneal pitch and Meary angles, can be useful in detecting PTT tears. Calcaneal pitch angle provides the best assessment of injury to the supporting structures of the medial longitudinal arch.

Keywords: adult acquired flatfoot, ankle ligament tear, MRI, pes planus deformity, posterior tibial tendon tear, radiography

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[1]Department of Medical Imaging and Intervention, Chang Gung Memorial Hospital, Keelung and Chang Gung University, 5 Fu-Shin St, Kueishan, Taoyuan 333, Taiwan. Address correspondence to Y. C. Lin (yuching1221@gmail.com).

[2]Department of Radiology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA.

[3]Department of Orthopedics, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA.

[4]Department of Radiology, University of Michigan, Ann Arbor, MI.

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The posterior tibial tendon (PTT) is a powerful invertor of the foot and plays a major role in maintaining the medial longitudinal arch and stabilizing the hindfoot against valgus deformity. Therefore, PTT dysfunction can result in a flatfoot deformity [1, 2]. The PTT can be affected by degenerative tendinosis, tenosynovitis, and partial or complete tear [1, 3]. Moreover, when PTT injury occurs, the weight of the body can distribute abnormally to the secondary supporting structures, which include the spring ligament complex, deltoid ligament complex, and sinus tarsi ligaments. Failure of these supporting structures can result in further flatfoot deformity [4–7]. Thus, early diagnosis of PTT dysfunction and injury to the supporting medial longitudinal arch structures is important in preventing progressive flatfoot deformity.

At present, radiography is the initial imaging study for the evaluation of flatfeet, and there are several radiographic measurements that can indicate the degree of flatfoot deformity [3]. However, correlation of these various radiographic measurements with specific injuries of the PTT and supporting medial longitudinal arch structures has not been fully reported. Currently, evaluation of PTT dysfunction and secondary supporting structure injuries relies heavily on MRI [1, 7–9]. However, MRI is expensive and may not be easily available for all patients. Radiography, on the other hand, is easily accessible. If radiographic foot measurements are able to predict injury of the PTT and supporting medial longitudinal arch structures, then clinicians can better decide who will benefit from MRI evaluation. The purpose of this study is to determine whether radiographic foot measurements can predict injury of the PTT and

supporting structures of the medial longitudinal arch as diagnosed on MRI.

Materials and Methods

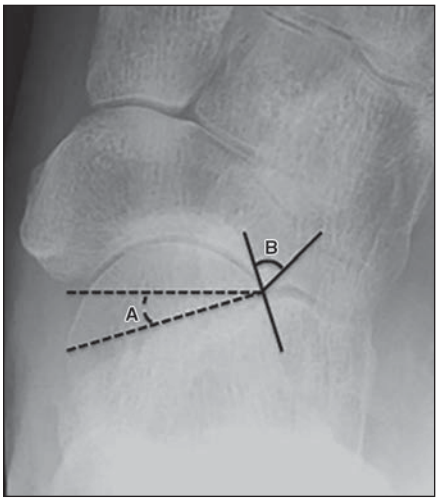
The Beth Israel Deaconess Medical Center institutional review board approved this study. We retrospectively reviewed all patients who underwent an unenhanced ankle MRI and foot-and-ankle standing radiographs within 2 months of each other from January 2009 through December 2012. Patients who had nonstanding radiographic images and patients with previous foot or ankle surgery or displaced ankle fractures were excluded from the study. The musculoskeletal radiologists performing the radiographic measurements and reviewing the MR images were blinded to the clinical history and to the results of the other examination. All the radiographic measurements and MRI evaluations were performed on the same PACS (Centricity, GE Healthcare).

Clinical Assessment

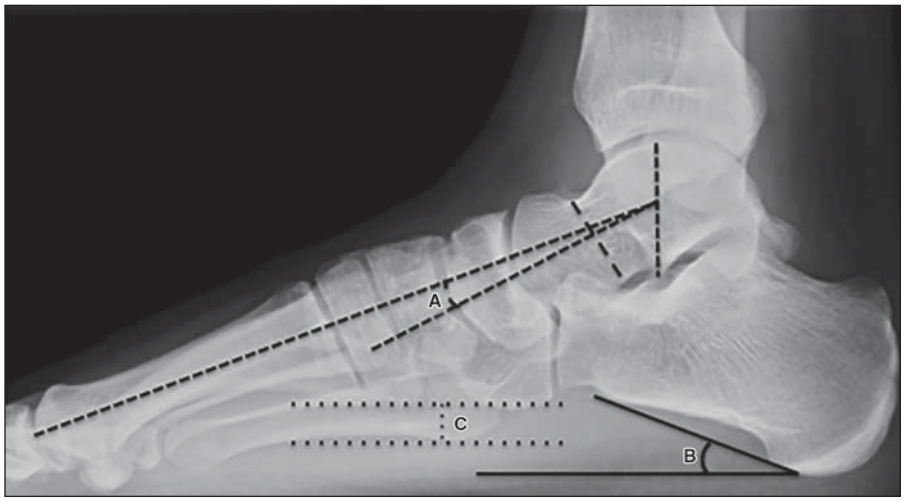
The clinical notes were reviewed for clinical signs and symptoms suggestive of PTT dysfunction, as documented by the referring physician. Patients in the PTT dysfunction group typically had medial ankle or foot pain, focal pain along the course of the PTT, or flatfoot deformity on physical examination. The remaining patients were classified as having other causes of ankle pain. Ankle and foot pain were not assessed separately.

Radiographic Assessment

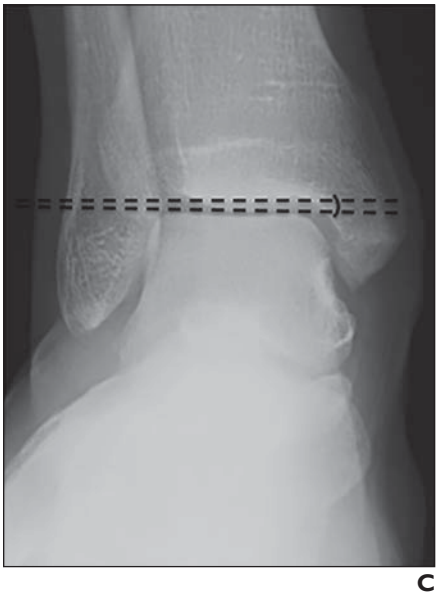
Standing anteroposterior and lateral views of the foot and an anteroposterior view of the ankle were obtained for all patients. All radiographs were obtained in a weight-bearing position with a standardized technique using the same digital radiography system. The digital x-ray detector (film) and the x-ray tube (source) are 35–40 inches apart in both the anteroposterior and lateral views of the foot and ankle. When the anteroposterior view of the foot is taken, the x-ray tube source is angled at 10°. Six foot and ankle radiographic measurements were performed: talonavicular uncoverage angle, incongruency angle, calcaneal pitch angle, Meary angle, cuneiform-to-fifth metatarsal height, and talar tilt. The anteroposterior radiograph of the foot was used for measurement of talonavicular uncoverage [10, 11] and incongruency angles [11] (Fig. 1A), with angles of greater than 26° [10] and greater than 70° [11], respectively, considered abnormal. The lateral radiograph of the ankle (Fig. 1B) was used for measurement of calcaneal pitch angle [10], Meary angle [10, 12], and cuneiform-to-fifth metatarsal height, with less than 19°, greater than 10°, and less than 6 mm, respectively, considered abnormal [10, 12, 13]. The anteroposterior radiograph of the ankle was used for measurement of the talar tilt angle [13] (Fig. 1C), with an angle greater than 5° considered ab-



A



B



C

Fig. 1—46-year-old man with hindfoot pain.
A, Anteroposterior view of foot radiograph. Talonavicular uncoverage angle (angle A) was measured between dotted lines drawn through medial and lateral margins of articular surfaces of navicular and talus. Incongruency angle (angle B) was measured between solid lines drawn through lateral margin of talar articular surface and lateral margin of navicular surface.
B, Lateral view of ankle radiograph. Meary angle (angle A) was measured between longitudinal axis of talus and longitudinal axis of first metatarsal. Longitudinal axis of talus is determined by drawing line through midpoint between superior and inferior surface of talar body and neck. Calcaneal pitch angle (angle B) is formed by intersection of line parallel to floor with line connecting two most inferior points on calcaneus. Cuneiform-to-fifth metatarsal height (distance C) was measured by distance between inferior portion of base of fifth metatarsal and most inferior surface of distal aspect of medial cuneiform.
C, Anteroposterior view of ankle radiograph. Talus tilt angle (*short curved line*) was measured between articular surface of tibial plafond and talar dome (*dashed lines*).

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normal [13]. A single musculoskeletal radiologist, with 4 years of experience, performed all radiographic measurements.

MRI Evaluation

MRI was performed with a 1.5-T system using an ankle coil (eight-channel foot and ankle array, Invivo, GE Healthcare). The following sequences were performed: sagittal T1-weighted spin-echo (TR/TE, 400/10; 3.5-mm section thickness; 160-mm FOV; matrix size, 384 × 257; one acquisition), sagittal fast spin-echo STIR sequence (TR/TE, 5280/57; inversion time, 130 ms; 4-mm section thickness; 160-mm FOV; matrix size, 320 × 214; one acquisition), axial proton density–weighted (TR/TE, 2520/34; 3-mm section thickness; 140-mm FOV; matrix size, 256 × 137; one acquisition), axial T2-weighted fat-saturated fast spin-echo (TR/TE, 5760/56; 3-mm section thickness; 140-mm FOV; matrix size, 384 × 181; one acquisition), and coronal proton density–weighted fat-saturated (TR/TE, 2640/33; 3.5-mm section thickness; 165-mm FOV; matrix size, 384 × 193; one acquisition) MRI.

MRI assessment of the PTT and supporting ankle structures was performed in consensus by two musculoskeletal radiologists with 4 and 8 years of experience, respectively, who were blinded to the results of the radiographs and clinical history. The qualitative features of the PTT, spring ligament complex, deltoid ligament complex, and sinus tarsi ligaments were evaluated. The PTT was evaluated for tendinosis, tenosynovitis, and tear. PTT tendinosis was diagnosed if there was focally increased signal intensity in the tendon with preservation of the normal shape of the tendon. PTT tenosynovitis (isolated) was documented if there was high fluid signal intensity surrounding 50% or more of the PTT circumference with normal size, shape, and intrinsic low signal in the PTT (Fig. 2). A PTT tear was identified if there was increased T2 and T1 signal intensity and enlargement of the tendon, defects in the tendon, linear fluid signal in the tendon (longitudinal split tear) (Fig. 3), or lack of continuous tendon fibers (complete rupture). The spring ligament (superomedial component) was considered torn if there was ligament thickness greater than 4 mm with or without signal intensity change [14]. The deltoid ligament complex was considered torn if there were increased signal intensity and disrupted fibers in either the superficial or deep portions of the deltoid ligament (Fig. 4). Sinus tarsi injury was diagnosed if there was loss of the normal fatty signal (diffuse low T1), inflammation (high T2), or fluid in the sinus tarsi [15].

TABLE 1: Correlation of Clinical Suspicion of Posterior Tibial Tendon (PTT) Dysfunction With MRI Findings

MRI Finding	PTT Dysfunction (n = 31 Patients)	Other Causes of Ankle Pain (n = 69 Patients)	p
PTT tendinosis[a]	4	9	1.00
PTT tear[a]	13	0	0.001[b]
PTT tenosynovitis (isolated)[c]	8	22	0.54
Spring ligament tear[c]	12	11	0.01[b]
Deltoid ligament tear[c]	9	8	0.03[b]
Sinus tarsi syndrome[a]	6	7	0.22

Note—An individual patient may have several MRI findings or none at all.
[a]Fisher exact test.
[b]Statistically significant ($p \leq 0.05$).
[c]Chi-square test.

Statistics

Statistical analysis was performed using SPSS (version 21 for Windows, IBM). Categoric variables were compared using either the chi-square test or Fisher exact test depending on the minimum number of cases in each group. Continuous variables were compared using the Student t test.

Results

From January 2009 to December 2012, 183 patients underwent both an MRI examination and ankle-and-foot radiographs at our institution. We excluded 12 patients with prior foot and ankle surgery, six patients with displaced fractures, and 65 patients who did not have standing radiographs. A total of 100 patients were included in this study (mean [± SD] age, 46.3 ± 14.9 years; range, 20–86 years; 55 women and 45 men). Thirty-one patients had symptoms suspicious for PTT dysfunction (mean age, 51.5 years; 16 women and 15 men), and 69 patients with other causes of ankle pain (mean age, 44.0 years, 39 women and 30 men) served as a comparison group. Injuries of the PTT and supporting structures of the medial longitudinal arch within the two groups are summarized in Table 1. The patients with clinical symptoms of PTT dysfunction had a statistically significant association with PTT tear (p = 0.001), spring ligament complex tear (p = 0.01), and deltoid ligament complex tear (p = 0.03) when compared with the patients with other causes of ankle pain. PTT tendinosis (p = 1.00), tenosynovitis (p = 0.54), and sinus tarsi ligament abnormalities (p = 0.22) were not statistically significantly different between the two clinical groups.

The associations between the radiographic foot measurements and the MRI findings are summarized in Table 2. There was a statisti-

TABLE 2: Relationship of Radiographic Measurements and MRI Findings of Posterior Tibial Tendon (PTT) Dysfunction

MRI Finding	Talonavicular Uncoverage Angle > 26°	Incongruency Angle > 70°	Calcaneal Pitch Angle < 19°	Meary Angle > 10°	Cuneiform-to-Fifth Metatarsal Height < 6 mm	Talar Tilt > 5°
PTT tendinosis	0.71[a]	0.51[a]	0.12[b]	0.54[a]	0.36[a]	0.24[a]
PTT tenosynovitis (isolated)	0.87[b]	0.64[a]	0.76[b]	0.03[b,c]	0.41[b]	0.09[a]
PTT tear	0.02[a,c]	0.13[a]	0.01[b,c]	0.004[a,c]	0.01[a,c]	1.00[a]
Spring ligament tear	0.13[a]	0.08[a]	0.03[b,c]	0.03[b,c]	0.27[b]	0.41[a]
Deltoid ligament tear	0.09[a]	0.03[a,c]	0.05[b,c]	0.14[b]	0.50[b]	1.00[a]
Sinus tarsi syndrome	0.26[a]	0.001[a,c]	0.001[b,c]	0.07[a]	0.03[a,c]	0.24[a]

Note—Data are p values.
[a]Fisher exact test.
[b]Chi-square test.
[c]Statistically significant ($p \leq 0.05$).

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cally significant association with PTT tears (partial or full) and four of the six radiographic measurements (talonavicular uncoverage angle, $p = 0.02$; calcaneal pitch angle, $p = 0.01$; Meary angle, $p = 0.004$; and cuneiform-to-fifth metatarsal height, $p = 0.01$). PTT tenosynovitis had an association with only one of the six radiographic measurements (Meary angle, $p = 0.03$), and PTT tendinosis had no statistically significant correlation with any of the radiographic foot measurements. Moreover, all patients with PTT tears had either an abnormal calcaneal pitch angle or abnormal Meary angle. Thus, if both angles were normal, no PTT tear was present.

As for the supporting structures, calcaneal pitch had a statistically significant association with injury to all three supporting structures of the medial longitudinal arch (spring ligament complex, $p = 0.03$; deltoid ligament complex, $p = 0.05$; and sinus tarsi, $p = 0.001$). Finally, an abnormal talar tilt angle had no correlation with any of the evaluated MRI findings.

Discussion

Acquired adult flatfoot is classified according to clinical symptoms, the severity of the foot deformity, and whether the deformity is flexible or fixed [16, 17]. A classification system proposed by Johnson and Strom in 1989 divides the severity of flatfoot deformity into four different stages [16]. Stage 1 has clinical signs of PTT dysfunction without flatfoot deformity and can be due to PTT tenosynovitis and degeneration, but no tear. Stage 2 has PTT dysfunction with flexible flatfoot deformity, and stages 3 and 4 have fixed flatfoot deformities [3, 17, 18]. These later stages can have tearing and elongation of the PTT as well as injury to the supporting structures of the medial longitudinal arch, causing abnormal values on many foot measurements [3, 17].

In this study, we found that there is a statistically significant association between talonavicular uncoverage angle, calcaneal pitch angle, Meary angle, and cuneiform-to-fifth metatarsal height with PTT tears as diagnosed on MRI; however, radiographic measurements were not helpful in diagnosing PTT tendinosis and isolated tenosynovitis. None of the six radiographic measurements had an association with PTT tendinosis, and only one measurement (Meary angle) was associated with isolated PTT tenosynovitis. Intuitively, this is reasonable, because one would expect PTT tears to cause elongation of the tendon due to disruption of the tendon fibers, which would cause the medial longitudinal arch to fail and lead to the abnormal radiographic measurements. However, with PTT tendinosis and isolated tenosynovitis, the tendon although abnormal would be structurally intact; thus, the medial longitudinal arch would be preserved and radiographic measurement would remain within normal limits [1, 3, 19]. Although radiographs in these patients did not detect anatomic changes caused by PTT tenosynovitis or tendinosis, this information is useful, because negative radiographs can exclude advanced states of flatfoot.

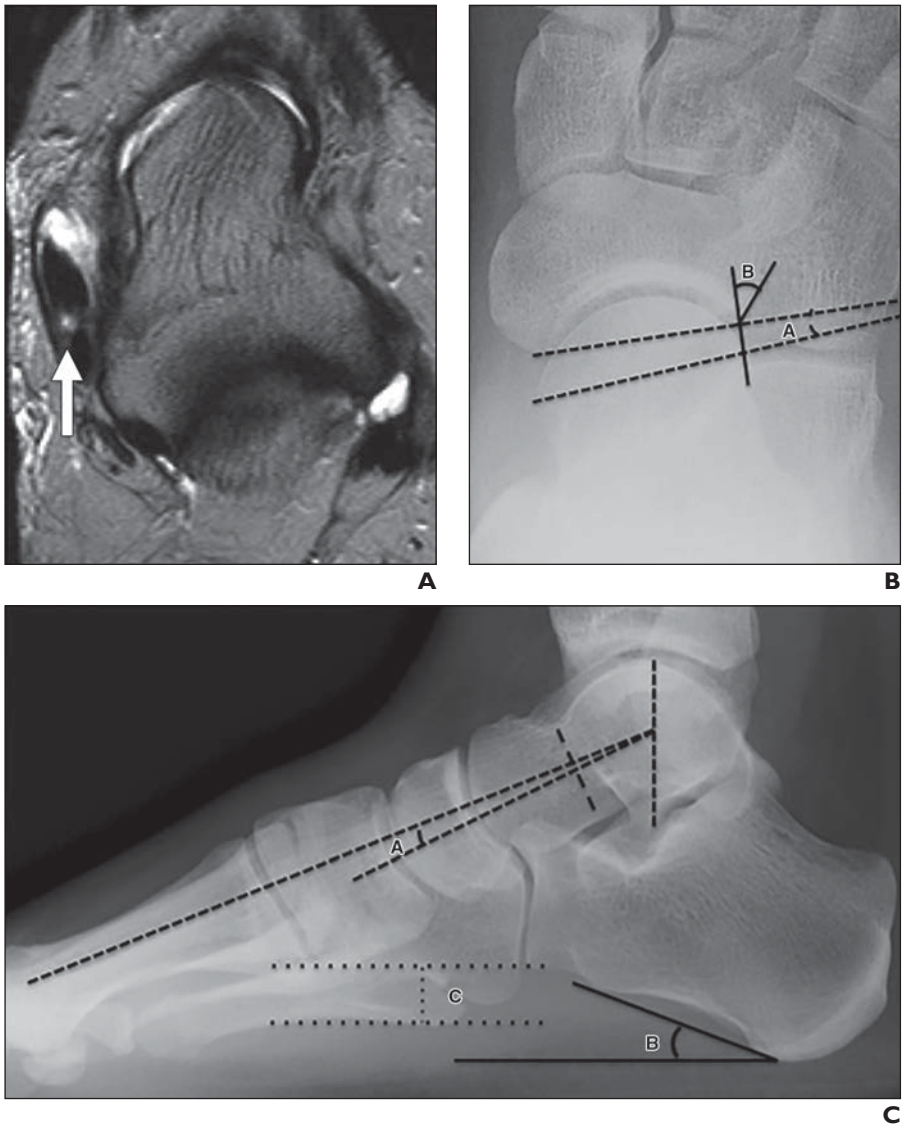


Fig. 2—34-year-old woman with medial foot pain.
A, Axial proton density–weighted MRI shows fluid in distended posterior tibial tendon sheath (*arrow*) representing tenosynovitis. Corresponding standing foot and ankle radiographs show that all radiographic measurements are within normal range.
B, Anteroposterior view of foot with talonavicular uncoverage angle of 3.7° (angle A) and incongruency angle of 19.7° (angle B).
C, Lateral view of ankle shows Meary angle of 3° (angle A), calcaneal pitch angle of 20.7° (angle B), and cuneiform-to-fifth metatarsal height of 12.5 mm (distance C).

Our findings are supported by past studies [9, 20]. Karasick and Schweitzer [20] evaluated 30 patients with surgically proven PTT tears and found that 50% of the patients had a decreased calcaneal pitch angle and 47% had an increased Meary angle. Similarly, we found that these values were abnormal in our series; however, we diagnosed PTT injury on the basis of MRI instead of surgically. Shibuya et al. [9] studied 72 patients for PTT and spring lig-

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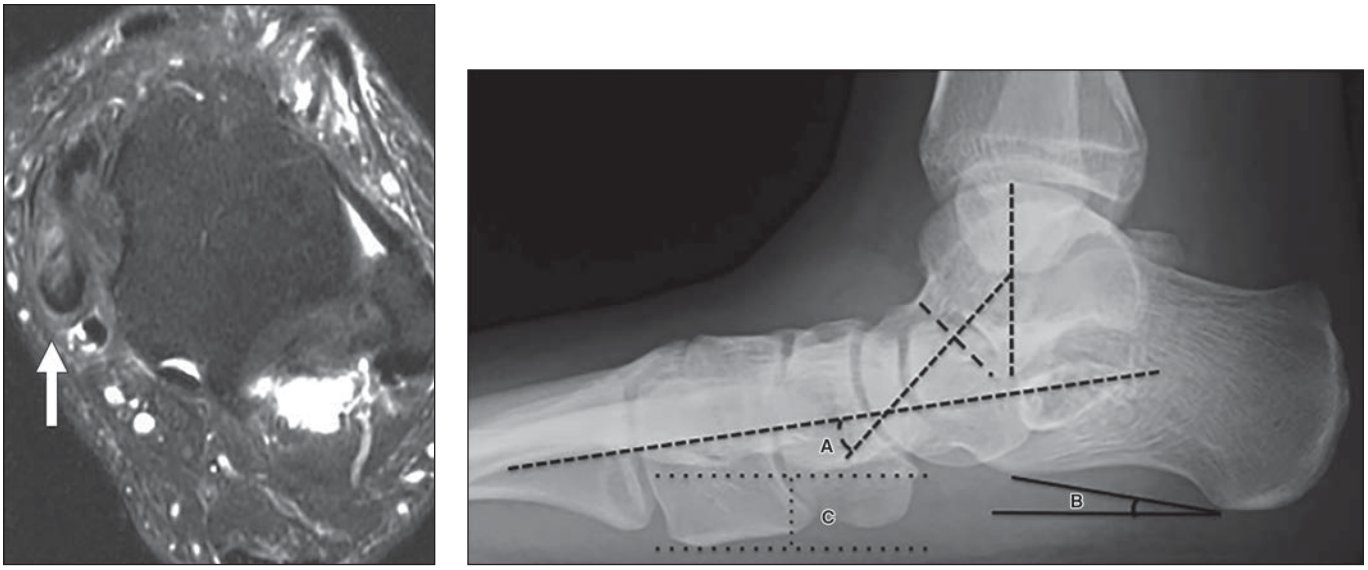


Fig. 3—45-year-old woman with medial ankle pain.
A, Axial fat-saturated T2-weighted MRI of ankle shows enlargement of posterior tibial tendon with hyperintense region in center of tendon, representing split tear (*arrow*).
B, Corresponding lateral radiograph of foot shows abnormal Meary angle of 27.6° (angle A), abnormal calcaneal pitch angle of 9.3° (angle B), and abnormal cuneiform-to-fifth metatarsal height of 12.9 mm (distance C).

ament injury using MRI and radiographs and found that abnormal radiographic measurements and spring ligament injury had a higher association with higher grades of PTT injury. This is similar to our study, where we found more abnormal radiographic measurements in the cases of PTT tears than in cases of PTT tenosynovitis or tendinosis.

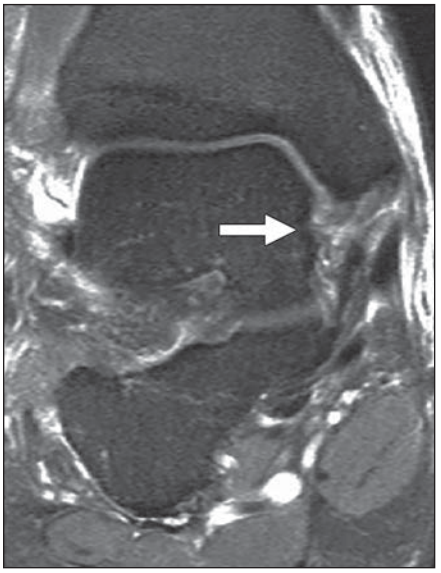


Fig. 4—53-year-old woman with medial ankle pain. Coronal proton density–weighted fat-saturated MRI shows increased signal intensity and discontinuity of posterior tibiotalar portion of deltoid ligament (*arrow*) with edema in adjacent soft tissues consistent with partial tear.

Among all the measurements in our study, Meary angle had the best association with PTT tear as diagnosed on MRI. Meary angle assesses the degree of plantigrade tilt of the head of the talus, which is believed to be one of the earliest findings in the acquired adult flatfoot [21]. Because we had few patients with complete PTT rupture or advanced stage flatfoot deformities in this study, it is not surprising that Meary angle had the highest association with PTT tear. Other studies report similar results [22, 23]. Younger et al. [22] and Coughlin and Kaz [23] evaluated the radiographs of normal patients and those with clinically diagnosed flatfoot and found significant associations between flatfoot and abnormal Meary angle, calcaneal pitch angle, and cuneiform-to-fifth metatarsal height. Meary angle was the best discriminator in both studies.

When the PTT tears, there is an uneven distribution of weight across the secondary ligamentous structures that assist in maintaining the medial longitudinal arch and maintain the talus in normal anatomic alignment [3, 8, 24]. If these secondary supporting structures fail, devastating foot deformities can occur [4–7]. Of the patients with PTT dysfunction in this study, 39% had associated spring ligament injury, 29% had deltoid ligament injury, and 19% had sinus tarsi abnormalities. Previous studies of patients with PTT tears have shown a higher incidence of injury to the spring ligament (74–92%) [8, 9, 19] and sinus tarsi (42–72%) [8, 19] but a lower incidence for the deltoid ligament (19%) [18]. Our lower numbers can likely be attributed to the few cases of PTT rupture (only two cases). Because many of our patients were in the early stages of flatfoot deformity, the supporting structures were still intact. Nonetheless, spring ligament injury was the most common associated injury in patients with PTT tear in this study, similar to other studies [8, 9, 19].

Of the six radiographic foot measurements evaluated in this study, calcaneal pitch angle had the best association with injury to the supporting structures of the medial longitudinal arch (spring ligament, deltoid ligament, and ligaments of the sinus tarsi). It was the only foot measurement with a statistically significant association with all three supporting structure injuries. This may be because of the ease in calculating this measurement. The bony landmarks used to calculate the calcaneal pitch angle are often maintained even in severe cases of foot deformity [25]; therefore, precise measurements can still be acquired. Meary angle, on the other hand, has the highest association with PTT tears; however, if the foot or talus deformity is very severe, then accurate measurements can be difficult to perform [25].

Incongruency angle and talar tilt angle had a very poor association with PTT dysfunction and injury of the secondary structures of the medial longitudinal arch. How-

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ever, incongruency angle has been shown to be excellent in the postoperative evaluation of forefoot abduction in flatfoot deformity, as reported by Ellis et al. [11], but is poor for preoperative evaluation of flatfoot. Talar tilt is an excellent tool for evaluating valgus talar tilt and the integrity of the deltoid ligament; however, this measurement should be performed under valgus stress, which was not performed in this study and likely explains the low diagnostic value of the talar tilt angle in our study [13, 26].

Furthermore, in this study, if the calcaneal pitch and Meary angles were normal, then no PTT tear was seen. However, if either or both of these measurements are abnormal and the patient has symptoms of PTT dysfunction, then further evaluation with MRI may be of benefit. MRI can identify the presence or absence of a PTT tear and whether there is rupture or just a partial tear, because this can affect clinical management. Moreover, MRI would also be useful in identifying injuries to the secondary supporting structures, such as the spring ligament, because these structures would be difficult to assess on radiographs alone [1, 7–9].

A few limitations deserve mention. First, there is a lack of surgical correlation with the MRI findings. However, most of the MRI findings were not surgical issues; thus, this would have been impractical. Next, our comparison group was not entirely normal. These patients had causes of ankle pain unrelated to PTT, such as plantar fasciitis, Achilles tendinitis, or lateral ankle pain. A completely asymptomatic control group would have been ideal but was not feasible because of the cost and the unnecessary exposure of patients to radiation. Finally, although we chose a short imaging time frame of 2 months between the radiographs and MRI examination, it is possible that injuries could have occurred during that interval, which could have affected the results.

In conclusion, radiographic measurements, especially calcaneal pitch and Meary angles, are useful in detecting PTT tears but are not accurate in detecting PTT tendinosis or tenosynovitis. The calcaneal pitch angle provides the best assessment of injury to the supporting structures of the medial longitudinal arch. Knowledge of this information can help guide the clinician and radiologist to determine which patients may benefit from additional clinical and imaging workup.

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