Imaging of Lesser Metatarsophalangeal Joint Plantar Plate Degeneration, Tear, and Repair

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Abstract

Plantar plate degeneration and tear is a common cause of forefoot pain, typically involving the second metatarsophalangeal joint at the proximal phalangeal insertion laterally, frequently confused with the second web space Morton neuroma. The condition has received increased attention with the development of surgical techniques that can result in successful repair of the plantar plate and substantial improvement in patient symptoms. High-resolution MRI or ultrasound can confirm a diagnosis of plantar plate degeneration and tear and exclude other pathologies, particularly Morton neuroma. The normal plantar plate is a mildly hyperechoic structure on ultrasound and is hypointense on all conventional MR sequences. Plantar plate degeneration manifests on ultrasound as hypoechoic echotextural change and on MRI as mild signal hyperintensity on short TE sequences, becoming less conspicuous on long TE sequences. Adjacent entheseal bony irregularity is commonly present. Plantar plate tears on ultrasound may be seen as an anechoic cleft defect or area of heterogeneous echotexture, sometimes more conspicuous with dorsiflexion stress. Plantar plate tears demonstrate greater signal hyperintensity on proton-density sequences, becoming more conspicuous on fat-suppressed proton density and T2-weighted sequences. Edema and fibrotic change in the pericapsular fat plane is commonly seen in the setting of an adjacent plantar plate tear and should not be misinterpreted as reflecting a Morton neuroma.

Keywords
- plantar plate
- forefoot
- ultrasound
- MRI
- metatarsalgia

Plantar plate degeneration and tearing is a common and increasingly recognized cause of forefoot pain, typically involving the second metatarsophalangeal (MTP) joint.[1] The condition was originally labeled idiopathic second MTP joint synovitis because in the early stages the joint is swollen and inflamed but no deformity is present. Coughlin in 1993[2] first ascribed the condition to degeneration of the plantar plate. The condition was and still is frequently confused with second web space Morton neuroma, despite the fact that neuroma does not cause deformity.[3] Plantar plate degeneration and tear remain a common cause of a poor outcome following surgical resection of a clinically suspected but not imaging-confirmed second web space Morton neuroma. As plantar plate degeneration and complicating tear progresses, lesser MTP joint instability may develop that is usually clinically obvious, with varus drift of the second toe ultimately leading to crossover toe deformity if there is concurrent hallux valgus. Plantar plate tear is most commonly a degenerative condition of middle-aged and older women, often accompanied by hallux valgus. A swollen lesser MTP joint in a young person is far more likely to be due to an inflammatory arthropathy. Although plantar plate degeneration and tear have also been documented at the third and fourth MTP joint, it is less common compared with the second MTP joint and is uncommonly symptomatic. Diagnostic imaging of the central forefoot (the second to fourth MTP joints and the second and

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third web spaces) can be helpful in confirming a diagnosis of plantar plate degeneration and tear and excluding other pathologies, particularly Morton neuroma, inflammatory arthropathy, metatarsal head bone stress, adventitial bursopathy, and early osteoarthritis. Imaging can also be helpful in planning treatment and assessing patients with a complicated postoperative course following plantar plate repair.

Anatomy and Function

The plantar plate of the lesser MTP joints is a fibrocartilaginous (type 1 collagen) thickening of the plantar capsule, thickest at the attachment on the plantar margin of the base of the proximal phalanx medial and lateral of midline with a mean reported dorsoplantar thickness of 2 mm[4] and range of (2–5 mm).[5] The plantar plate is relatively attenuated in the midline distally[5] where there is a synovial recess that can mimic a tear when seen on MRI or ultrasound.[6] Although not strictly anatomically correct, it can be useful to subdivide the plantar plate into medial and lateral components by virtue of the relationship to this recess, given that most pathology occurs laterally.[4] The plantar plate is relatively thick at the level of the midplantar margin of the metatarsal head, cushioning axial loading of the metatarsal head.[5] Proximally the plantar plate is normally attenuated, with a thin synovial attachment to the metatarsal neck and more substantial fibrous attachment to the plantar fascia-aponeurosis.[4] The plantar plate serves as the point of attachment of the paired accessory collateral ligaments and the deep transverse intermetatarsal ligament. Paired phalangeal collateral ligaments course obliquely to cross the MTP joint and insert bilaterally onto the base of the proximal phalanx, sharing a conjoint insertion with the plantar plate medially and laterally. Capsular sesamoids may occasionally be seen within the plantar plate reflecting normal anatomical variation.

It has been estimated that the load through the second MTP joint plantar plate during weightbearing constitutes 25% of the entire load transmitted through the forefoot during weightbearing.[7] The plantar plate imparts sagittal plane stability to the MTP joint, resisting tensile loads during dorsiflexion and concurrently supporting the windlass mechanism through serving as the major distal insertion of the plantar fascia-aponeurosis.

Pathology

Cadaveric studies of patients with crossover toe deformities (hallux valgus and varus deviation of the second toe) have demonstrated pathology ranging from attenuation of the lateral plantar plate toward the proximal phalangeal insertion without a discrete tear plane,[8] through to cases with discrete tears commencing distally at the lateral insertion in a transverse plane, sometimes progressing to have a longitudinal component that may extend to involve the lateral collateral ligament proper.[9] Histopathologic studies suggest that attritional degeneration of the plantar plate due to overload is the underlying pathologic process in the plantar plate tears that are commonly seen in middle-aged and elderly women and far less commonly in men.[10] Several intrinsic factors have been suggested to predispose to degeneration of the plantar plate of the second MTP joint, including first ray hypermobility, hallux valgus, and a long second metatarsal. Extrinsic factors predisposing to second MTP joint plantar plate degeneration and tear include wearing high-heeled shoes and shoes with a narrow toe box. In contrast, acute traumatic tears of the plantar plate of lesser MTP joints that are occasionally seen in young adult athletes are usually not associated with underlying plantar plate degeneration.

Tear of the plantar plate has several potential biomechanical consequences. First, the interossei tendons become extensors of the MTP joint because they are unopposed by the ruptured plantar plate during the toe-off/MTP joint dorsiflexion phase of the gait cycle. Second, the extensor digitorum longus (EDL) tendon is defunctioned when the MTP joint is in dorsiflexion because the EDL can only extend the proximal interphalangeal joint when the proximal phalanx is flexed or in neutral, predisposing to hammer toe deformity. Third, the lumbrical at the medial margin of the MTP joint imparts a medially deforming/adducting force that is unopposed by the ruptured plantar plate.

Radiographs

Radiographic assessment should constitute the initial imaging investigation in the patient with suspected plantar plate degeneration and tear. Anteroposterior and lateral radiographs should be performed weightbearing to provide assessment of functional alignment. The oblique view should be performed non-weightbearing. The most common pattern of malalignment in the setting of tear of the lateral plantar plate of the second MTP joint consists of varus/medial/tibial angular deviation of the proximal phalanx of the second toe (►**Fig. 1**). Unless there is concomitant varus drift of the third toe, there will be resultant widening of the space between the second and third toes that may be described as splaying (►**Fig. 1**). In more severe cases there may be medial/tibial translation of the proximal phalanx of the second toe in relation to the adjacent second metatarsal head. The degree, if any, of second metatarsal protrusion should be assessed, as calculated by drawing a line between the distal margins of the first and third metatarsal heads and measuring the distance by which the distal margin of the second metatarsal head protrudes beyond this line.[2]

Arthrography

Arthrography can be used to demonstrate plantar plate tears indirectly by documenting leakage of contrast into the flexor tendon sheath.[11,12] However, it has the disadvantage of being invasive, having the potential to increase the extent of a tear by hydraulic distention of the joint and not being able to demonstrate plantar plate degeneration. Although several articles have documented the technique, it is not widely used in clinical practice.

Fig. 1 Anteroposterior weightbearing X-ray in a 62-year-old woman demonstrates varus drift of the proximal phalanx of the second toe relative to the second metatarsal head, with resultant uncovering of the lateral aspect of the second metatarsal head (short white arrow) and splaying of the second and third toes (large white arrow). Note also the moderate noncongruent hallux valgus.

Ultrasound

The examination should begin with a clinical assessment of alignment of the foot with the patient standing, looking for hallux valgus, varus drift of the second toe, splaying of the second and third toes, hammer toe deformity, and assessment of the plantar arch (►**Fig. 2**).

The patient should then be placed on the examination bed and the forefoot palpated for tenderness, particularly over the lateral aspect of the base of the proximal phalanx of the second toe. The Hamilton-Thompson MTP “drawer” test or vertical stress test should be applied to assess for laxity of the plantar plate. The metatarsal neck is stabilized and a dorsal translatory force is applied to the base of the proximal phalanx.[13] The Mulder click test should also be applied to assess for Morton neuroma, consisting of an application of compressive forces across the transverse metatarsal arch, with concurrent dorsoplantar palpation of the relevant web space. The test is considered positive when painful clicking is elicited.

The patient should be positioned supine for the ultrasound examination. Both feet should be exposed to allow comparison assessment where relevant. The plantar aspect of the foot is often a challenging acoustic window, particularly in individuals who spend considerable time walking with bare feet. The combination of thick, callused skin and the plantar fat pad can degrade image quality. The quality of the acoustic window can be improved somewhat by massaging coupling gel into the plantar skin pores for a minute before beginning the diagnostic examination to optimize skin coupling and minimize air trapped in the dermis. Two of the key strengths of ultrasound are the dynamic nature of the modality and the ability to palpate with the probe and precisely determine the site of maximum tenderness, helping clarify the clinical relevance of the demonstrated sonographic abnormalities.

The plantar plate is best evaluated sonographically utilizing a sagittal long-axis plantar approach with a small footprint high-frequency transducer. The lateral plantar plate insertion on the base of the proximal phalanx of the second toe should first be assessed, given that it is the most common site of pathology, scanning incrementally from the lateral through to the medial insertion sites.

Fig. 2 (**a**) Photograph of the foot of a 60-year-old demonstrating normal alignment of the second toe. (**b**) Photograph of the foot of a 62-year-old patient with a tear of the lateral plantar plate of the second MTP joint, with varus drift of the second toe and resultant splaying of the second and third toes and concurrent hammer toe deformity.

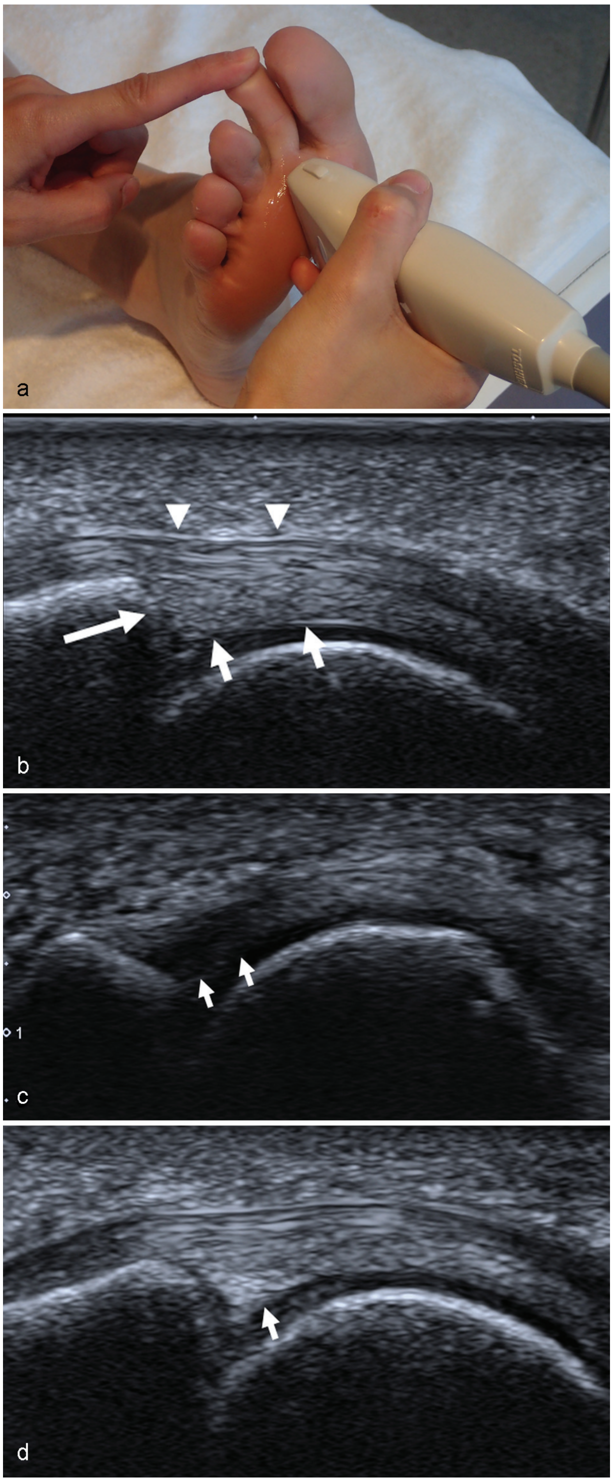


Fig. 3 (**a**) Clinical photograph demonstrating correct transducer placement and orientation. Note the index finger of the operator's left hand is applying dorsiflexion stress to the plantar plate. (**b**) Sagittal ultrasound image of a normal plantar plate when the ultrasound beam is perpendicular to the longitudinal axis of the plantar plate. Note the normal granular mildly hyperechoic appearance (short arrows), contrasting with the fibrillary echotexture of the overlying flexor tendon (arrowheads). Note also the smooth contour of the proximal phalangeal entheses (long arrow). (**c**) Sagittal ultrasound image of a normal plantar plate that appears hypoechoic toward the proximal phalangeal insertion (arrows) due to anisotropy resulting from the plantar plate not being perpendicular to the plantar plate. (**d**) Sagittal ultrasound image demonstrates a triangular-shaped echogenic focus adjacent to the proximal phalangeal insertion (arrow), a normal finding.

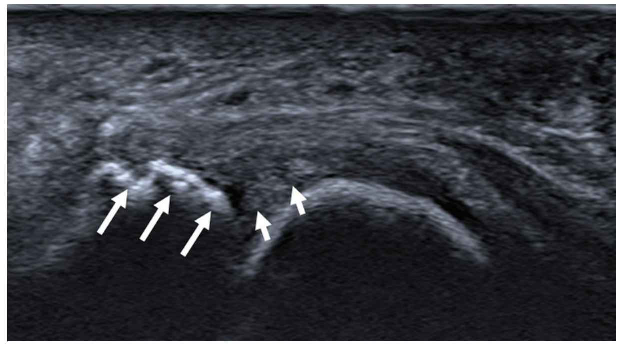


Fig. 4 Sagittal ultrasound image demonstrating second MTP joint lateral plantar plate degeneration manifest as mildly heterogeneous hypoechoic echotextural change toward the proximal phalangeal insertion (short arrows). Note the adjacent entheseal bony irregularity at the base of the proximal phalanx (long arrows) that was only readily appreciable on dorsiflexion of the second MTP joint.

The normal plantar plate is a mildly hyperechoic structure with a somewhat granular echotexture,[10] with an average thickness of 2 mm[4] (►**Fig. 3**). The ultrasound beam must be perpendicular to the area of interest within the curved plantar plate, to avoid anisotropy, analogous to examination of the distal supraspinatus tendon in the shoulder (►**Fig. 3**). A small triangular area of greater echogenicity is often evident toward the phalangeal insertion; although no histologic correlate has been published, this is clearly a normal finding (►**Fig. 3**). The fibrocartilaginous enthesis at the base of the proximal phalanx is normally smooth (►**Fig. 3**).

Plantar plate degeneration manifests on ultrasound as hypoechoic echotextural change, typically occurring at the proximal phalangeal insertion laterally (►**Fig. 4**). Adjacent entheseal bony irregularity is commonly present in the setting of insertional plantar plate degeneration and tear, analogous to similar findings at tendon entheses in the setting of insertional tendinopathy. Occasionally this may be better appreciated on ultrasound with dorsiflexion of the toe (►**Fig. 4**)

Plantar plate tears are usually best appreciated on long-axis sagittal sonographic assessment. Dorsiflexion of the MTP

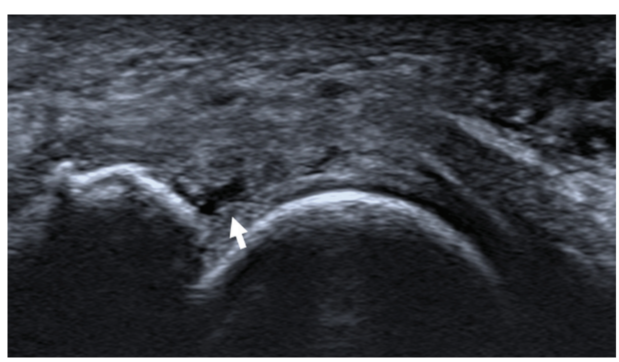


Fig. 5 Sagittal ultrasound image demonstrating a tear of the lateral plantar plate of the second MTP joint at the proximal phalangeal insertion, with an anechoic partial-thickness defect at the deep margin (arrow).

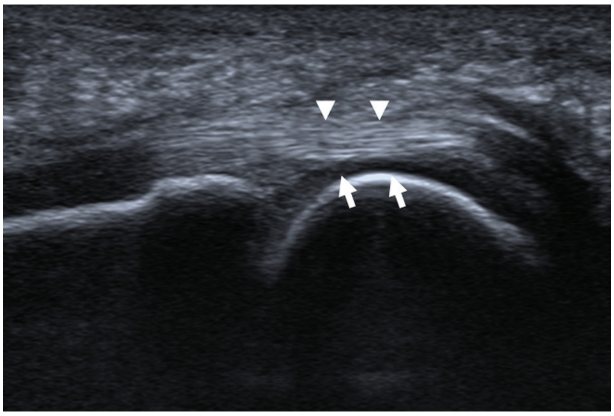


Fig. 6 Sagittal ultrasound image demonstrating an extensive full-thickness tear of the plantar plate of the second MTP joint with retraction and resultant direct abutment between the flexor tendon (arrowheads) and second metatarsal head articular cartilage (short arrows).

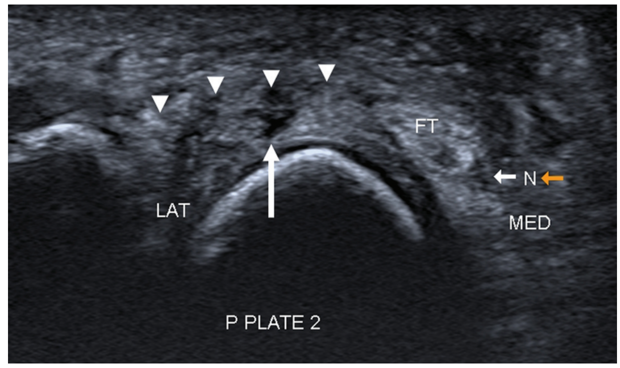


Fig. 7 Short-axis ultrasound image of the plantar plate demonstrating heterogeneity in echotexture of the lateral plantar plate and a discrete anechoic cleft (long arrow) indicating a tear (arrowheads). Note the medial migration of the flexor tendon (FT) and abutment with the lateral plantar hallucal nerve (small arrow).

joint tensions the plantar plate and may make a plantar plate tear, if present, more conspicuous.[14,15] Partial tears of the plantar plate may vary in appearance, sometimes seen as a hypoechoic or anechoic cleft and sometimes as a heterogeneous echotexture or echogenic cleft[10,16] (►**Fig. 5**). Full-thickness tears may be seen as a complete anechoic defect in the plantar plate, extending from the plantar surface to the articular surface.[10,16] Sometimes a full-thickness tear may only be evident on dorsiflexion of the MTP joint, appreciable as an area of altered echotexture or anechoic defect.[17] In addition to demonstrating a tear plane on dorsiflexion stress, it may be appreciated that there is a corresponding loss of congruent motion of the base of the proximal phalanx and the plantar plate at the site of tear as the toe is moved between neutral and dorsiflexion. The geometry of any tear should also be determined with respect to its transverse and, if present, longitudinal extent.[9] If there is an extensive tear, the flexor tendon may directly abut the articular cartilage of the metatarsal head (►**Fig. 6**). The transverse extent of the tear is usually best appreciated on short-axis transverse plane imaging. Transverse plane assessment is significantly less accurate when compared with sagittal plane assessment.[16] Flexor tendon complex subluxation in the setting of plantar plate tear is also best appreciated on short-axis imaging[17] (►**Fig. 7**). Color or power Doppler may be used to assess for hyperemia within any visualized area of plantar plate degeneration or tear, although it is an uncommon finding that is of undocumented clinical significance. A flexor tendon sheath effusion may be seen in the setting of a full-thickness tear of the plantar plate, due to pathologic communication between the MTP joint and the flexor tendon sheath.

Edema and fibrotic change in the pericapsular fat plane is commonly seen in the setting of an adjacent plantar plate tear[6] that can mimic a Morton neuroma and is commonly misinterpreted in this fashion by less experienced radiologists. Often this can be avoided by direct visualization of the plantar digital nerve

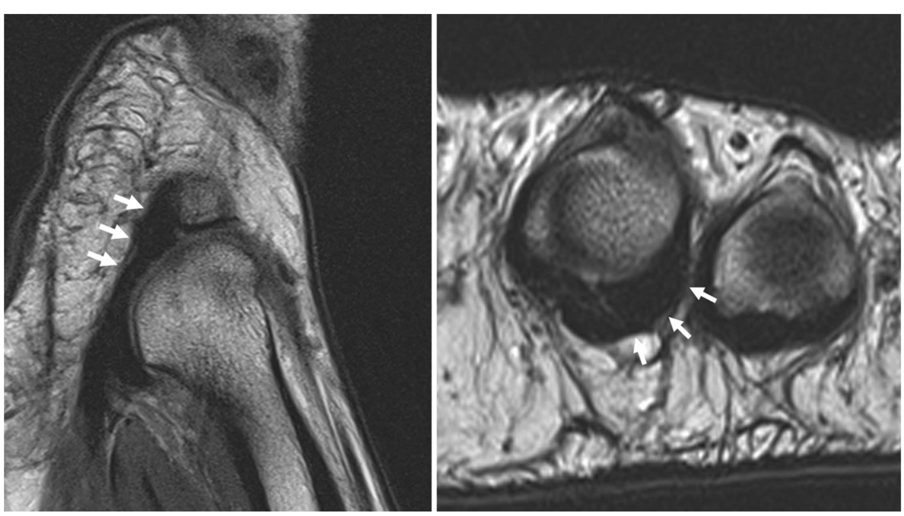
a  b

Fig. 8 Normal lateral plantar plate. (**a**) Sagittal proton-density and (**b**) short-axis T2 MR images demonstrating a normal lateral plantar plate of the second MTP joint (white arrows).

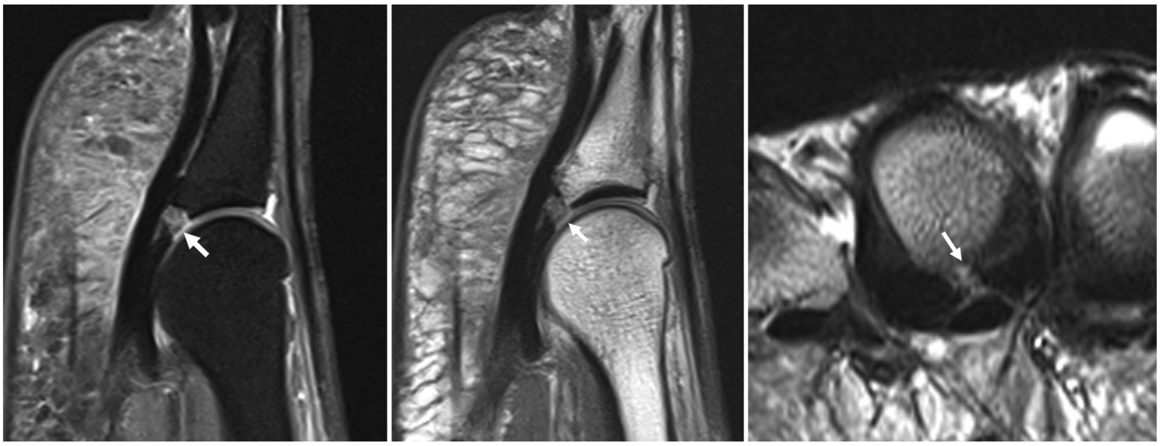


Fig. 9 Normal midline cleft at the proximal phalangeal insertion of the plantar plate on (**a**) sagittal fat-suppressed proton-density (PD), (**b**) sagittal PD and (**c**) short-axis T2 sequencing, demonstrating focal attenuation of the plantar plate and T2 signal hyperintensity (arrows) that should not be misinterpreted as pathologic.

in the long axis and confirming that the nerve is separate to the pericapsular fibrotic change and does not demonstrate the thickening of Morton neuroma formation. On short-axis imaging the pericapsular fibrosis and edema lies eccentrically within the web space, abutting the plantar plate, in contrast to a Morton neuroma that lies centrally within the web space. The pericapsular edema, inflammation, and fibrotic change may be associated with irritation of the adjacent plantar digital nerve and mild

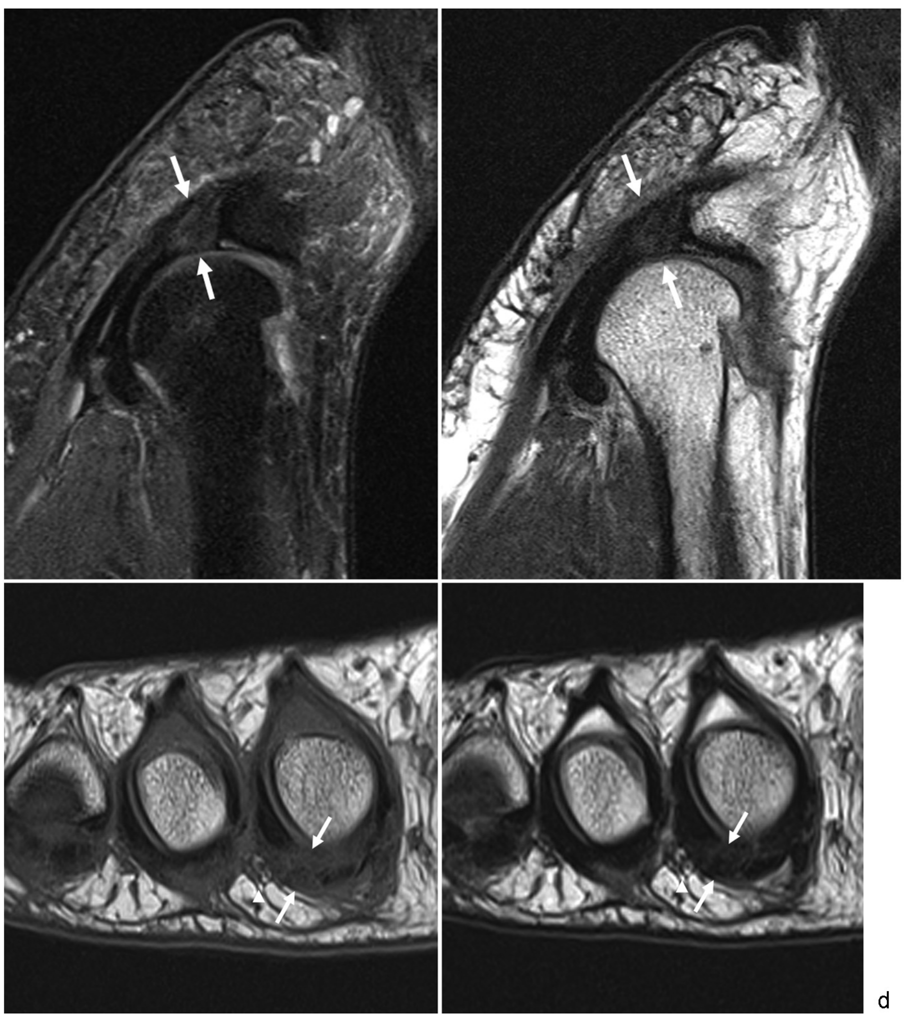


Fig. 10 (**a**) Sagittal fat-suppressed proton-density (PD), (**b**) sagittal PD, (**c**) short-axis T1, and (**d**) short-axis T2 MR images demonstrating myxoid degeneration of the lateral plantar plate of the second MTP joint toward the proximal phalangeal insertion, without tear, (arrows). Note the normal neurovascular bundle in the second web space on short-axis images (arrowheads).

neural thickening to ~ 2 mm that may account for the neuritic symptoms that may be seen in this setting and should not be misinterpreted as indicating Morton neuroma formation.

Several studies have reported on the accuracy of ultrasound in demonstrating plantar plate tears, using cadaveric dissection, MRI, or surgery as the gold standard. There are little data on the negative predictive value of ultrasound. A cadaveric study on 6 cadaveric feet (24 plantar plates) correlated ultrasound and MRI with cadaveric dissection, reporting an excellent correlation between sonographic and MRI findings and findings at dissection.[10] A subsequent study by the same group correlated ultrasound and MRI findings with operative findings during Weil osteotomy in 10 feet (25 plantar plates), reporting moderate to substantial correlation between ultrasound and operative findings. Using MRI as the reference, ultrasound had a sensitivity of 91% and a specificity of 44% for the symptomatic group, and a sensitivity of 73% and specificity of 67% for the asymptomatic group.[15] More recently, Klein et al[16] correlated sonographic and operative findings in 50 patients undergoing plantar plate repair. Ultrasound detected 41 of 45 tears seen at surgery. Three of the four plantar plates reported to be intact on ultrasound were found to be torn at surgery.

Ultrasound arthrography has been advocated as a means of increasing the sensitivity for diagnosis of full-thickness tears of the plantar plate by making the tear plane more conspicuous and by the indirect evidence of fluid decompression in to the flexor tendon sheath. Barrie et al correlated findings at ultrasound and ultrasound arthrography with operative findings in 11 patients. Ultrasound correctly identified four of seven full-thickness plantar plate tears while ultrasound arthrography correctly identified six of seven full-thickness tears.[18] The clinical relevance of this approach is questionable given that many surgeons repair partial-thickness tears of the plantar plate.

MRI

Yao et al in 1994 demonstrated the utility of high-resolution MR imaging in visualizing the normal plantar plate of the lesser MTP joints and plantar plate degeneration and tear.[11] Currently in clinical practice the variability in the quality of MRI studies of the central forefoot often relates to use of inappropriately thick slice selection, inappropriately large field of view (FOV), and inappropriate slice orientation. Use of appropriate high-resolution surface coils is a prerequisite for obtaining small FOV (8–10 cm), thin slice thickness (1.5–2.0 mm) images with adequate signal to noise. Some wrist coils can be adapted to imaging the central forefoot, and if feasible, this often represents the optimal coil choice.[19] Alternative options include small phased array circular or flat surface coils that may be paired so there are dorsal and plantar elements. Some small loop coils offer a maximum FOV of 5 cm, often limiting the examination to cover only a single MTP joint. Although this can provide high-resolution images, such examinations are limited in their ability to exclude other causes of central forefoot pathology involving the remaining MTP joints, metatarsal heads, web spaces, and plantar fat pad. Ski boot–type ankle-foot coils are often limited with respect to their minimum FOV and slice thickness and their ability to deliver homogeneous frequency selective fat suppression (FS). Knee coils can be adapted to imaging the central forefoot by plantar flexing the foot and internally rotating the hip to allow reasonably comfortable positioning within the coil.

It is our preference to image the central forefoot with the patient supine. Imaging the patient prone with the foot in plantar flexion has been reported, however, to reduce involuntary motion and may help reduce the degree of MTP joint dorsiflexion. If the patient is imaged supine, use of small pads within the coil may help reduce the degree of MTP joint dorsiflexion.[19] Some forms of nail polish can result in local distortion of the magnetic field and impair image quality; therefore, nail polish should be removed prior to scanning.

Our standard protocol at 3 T utilizes a wrist coil and includes two-dimensional (2D) long-axis (axial) FS proton-density (PD), 2D sagittal PD, 2D sagittal FS PD, 2D short-axis (coronal) T1, and 2D short-axis T2-weighted sequences. Care is taken in positioning the patient to ensure they are comfortable and that there is no or minimal MTP joint dorsiflexion, with pads being utilized if required to move the proximal phalanges to near neutral flexion. Intravenous contrast administration is generally not required. Long-axis (axial) images are angled to the second to fourth metatarsal heads off a short-axis (coronal) image, utilizing an 8-cm FOV, slice thickness of 1.4 mm, and matrix of 320 × 288 (0.3 × 0.3 mm). Sagittal images are angled along the second metatarsal shaft and the proximal phalanx of the second toe-off long-axis images if there is no second toe malalignment and obliqued off short-axis images to be in the plane of the second MTP joint and the web spaces utilizing a FOV of 8 cm, slice thickness of 1.4 mm, and matrix of 384 × 326 (0.3 × 0.3 mm in plane resolution) for the fat-suppressed sequence and 448 × 381 (0.2 × 0.2 mm) for the non-FS sequence. Short-axis images are angled perpendicular to the proximal phalanx of the second toe-off sagittal images to provide optimal assessment of the neurovascular bundles and plantar plates in the setting of dorsiflexion of the MTP joints utilizing a FOV of 8 cm, slice thickness of 2 mm, and matrix of 384 × 207 (0.3 × 0.3) for the T2 sequence and 448 × 358 (0.2 × 0.2) for the T1 sequence. Short-axis images should cover from 2 cm proximal to the MTP joint level to the midproximal phalangeal level.

Patients with large feet or a severe bunion deformity may not fit in the wrist coil, in which case most are scanned with a phased-array transmit-receive knee coil utilizing the following factors:

Knee Coil Protocol 3 T

Long-axis PD FS, 10 cm FOV, 1.7 mm slice thickness (sl thk), 320 × 288 (0.3 × 0.3 mm)
Sagittal PD, 10 cm FOV, 1.7 mm sl thk, 448 × 358 (0.2 × 0.2 mm)
Sagittal PD FS, 10 cm FOV, 1.7 mm sl thk, 384 × 307 (0.3 × 0.3 mm)
Short-axis T1, 10 cm FOV, 2 mm sl thk, 384 × 307 (0.3 × 0.3 mm)
Short-axis T2, 10 cm FOV, 384 × 224 (0.3 × 0.3 mm)

If patients are scanned on a 1.5-T MRI unit, a wrist coil is usually used with the following parameters:

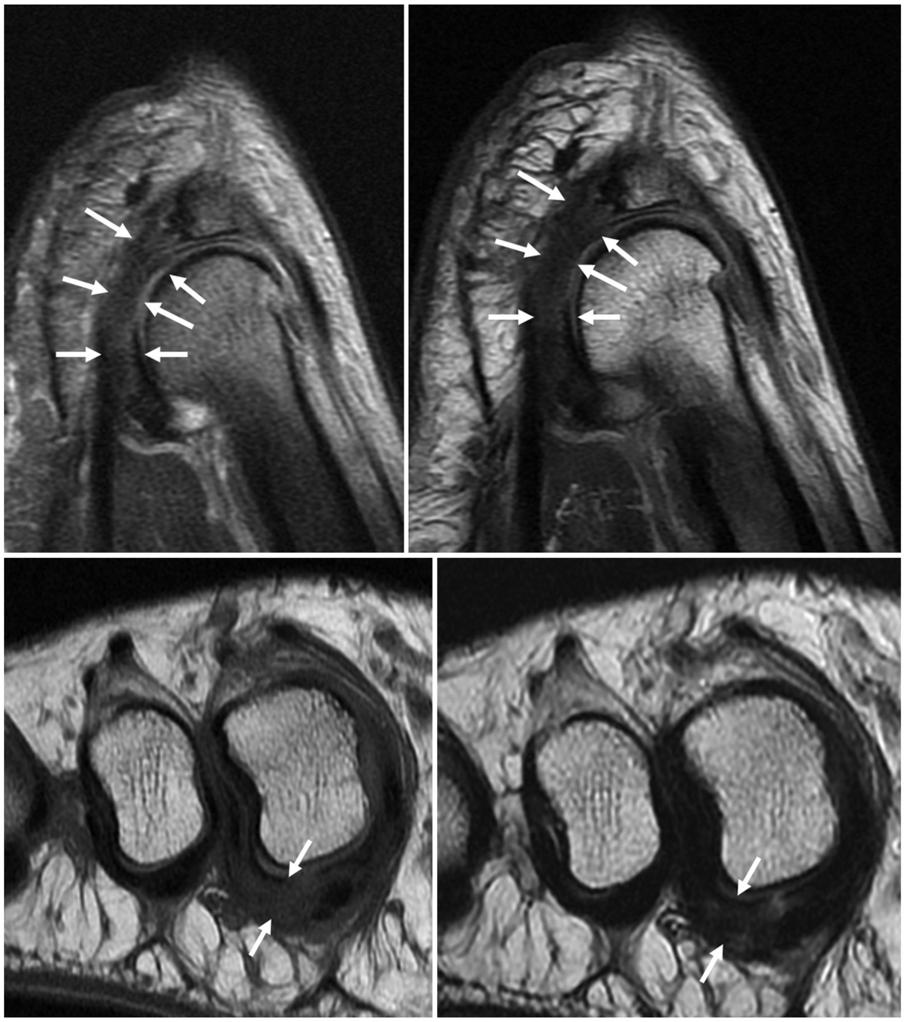


Fig. 11 A 46-year-old man presents with a painful second MTP joint. (**a**) Sagittal fat-suppressed proton-density (PD), (**b**) sagittal PD MR images, (**c**) short-axis T1, and (**d**) short-axis T2 images through the second MTP joint demonstrate severe degeneration of the lateral plantar plate that manifest as signal hyperintensity on PD and fat-suppressed PD sequences (arrows), more marked on T1 sequencing (arrows) and less conspicuous on T2 sequencing (arrows), with elongation of the plantar plate but no discrete tear.

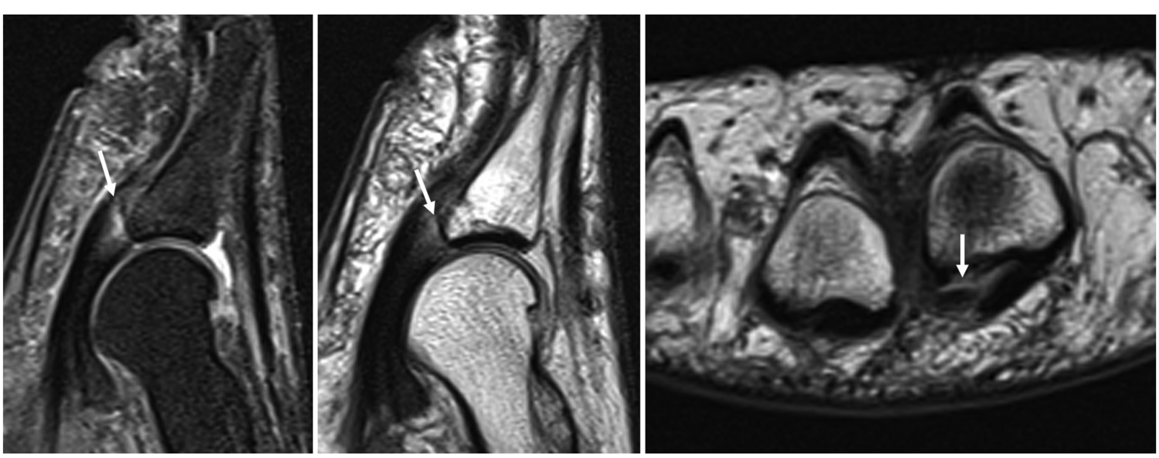


Fig. 12 A 65-year-old woman presents with persistent and unchanged pain 11 months post second web space Morton neuroma excision. (**a**) Sagittal fat-suppressed proton-density (PD), (**b**) sagittal PD, and (**c**) short-axis T2 MR images of the second MTP joint demonstrate nonretracted tear of the lateral plantar plate at the proximal phalangeal insertion (arrows).

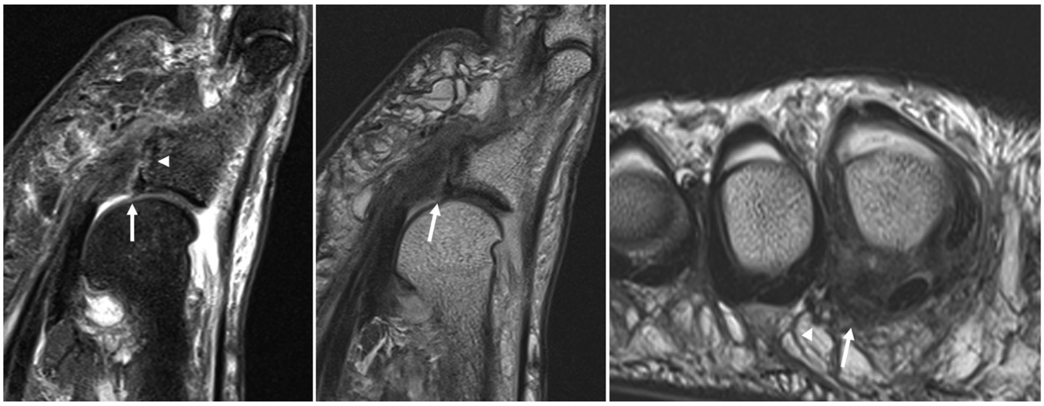


Fig. 13 A 66-year-old woman presents with a 3-month history of pain and swelling at the central forefoot. (**a**) Sagittal fat-suppressed proton-density (PD) and (**b**) PD MR images through the lateral plantar plate of the second MTP joint demonstrate severe degeneration and nonretracted tear at the proximal phalangeal insertion, with adjacent entheseal bony irregularity and mild bone marrow edema at the base of the proximal phalanx. Note the associated joint effusion and mild synovitis. (**c**) Short-axis T2 MR image demonstrates pericapsular fibrosis at the plantar lateral margin of the lateral plantar plate (arrow), displacing the normal-appearing plantar digital nerve (arrowhead).

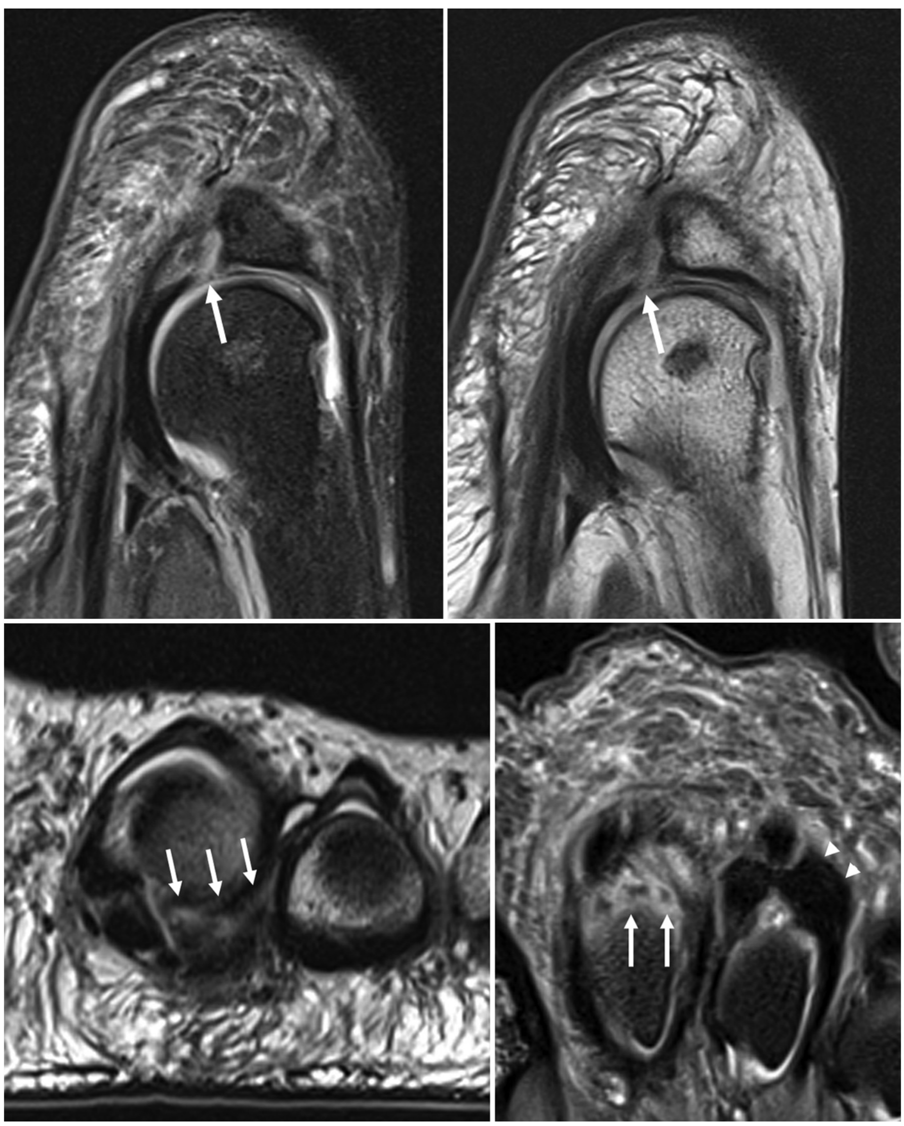


Fig. 14 A 56-year-old woman presents with a 12-month history of second metatarsalgia and hammer toe deformity. (**a**) Sagittal fat-suppressed proton-density (PD) and (**b**) PD MR images demonstrate an extensive tear of the lateral plantar plate of the second MTP joint with transverse and longitudinal components (arrows). (**c**) Short-axis T2 and (**d**) long-axis fat-suppressed PD MR images demonstrate the tear extends transversely over > 50% of the width of the plantar plate complex (arrows). Note the normal lateral plantar plate of the second MTP joint (arrowheads).

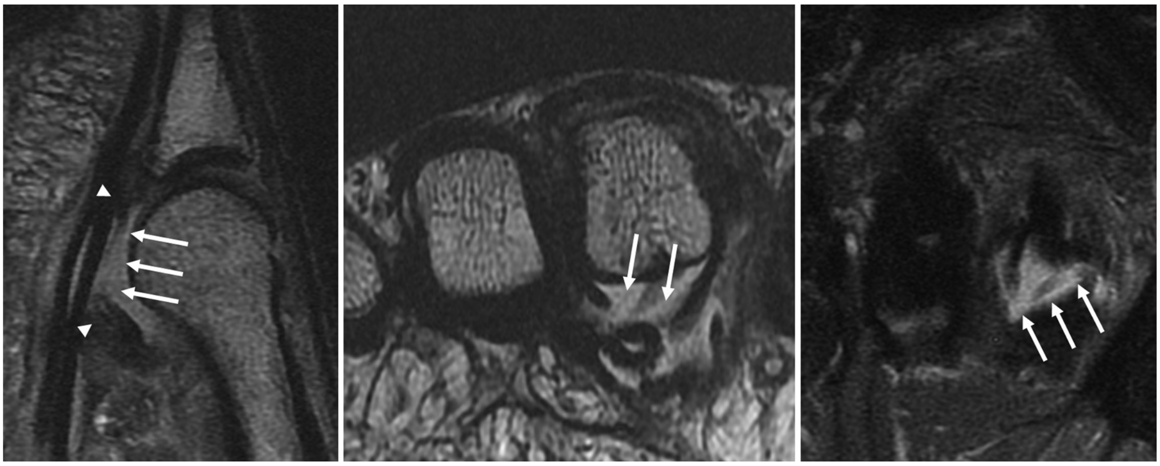
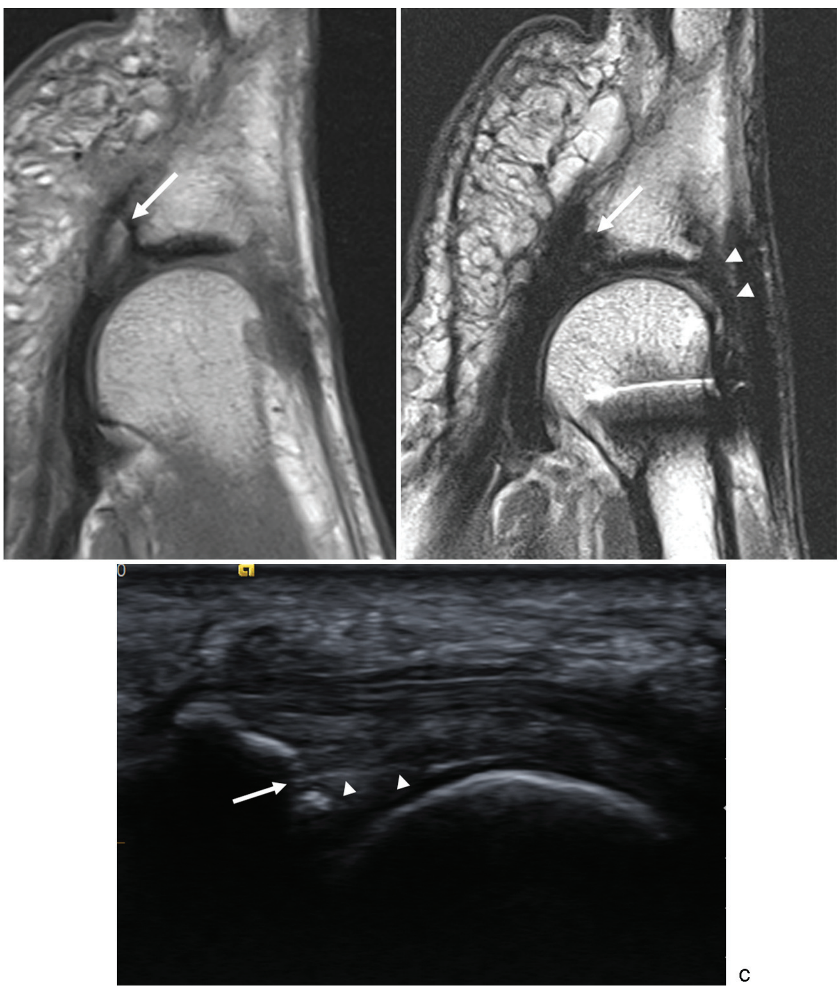
a  b,c

Fig. 15 A 30-year-old professional rugby league player presents with chronic second metatarsalgia. (**a**) Sagittal proton-density (PD) 1.5-T MR image performed in a knee coil demonstrates an extensive longitudinal tear of the plantar plate of the second MTP joint (arrows). Arrowheads indicate the proximal and distal margins of the tear. (**b**) Short-axis T2 MR image demonstrate the extensive transverse component to the defect (arrows). (**c**) Long-axis fat-suppressed PD MR image demonstrates the transverse (arrows) and longitudinal components to the buttonhole-type defect.



a b c

Fig. 16 A 62-year-old woman who initially presented with second metatarsalgia. (**a**) Sagittal preoperative proton-density (PD) MR image demonstrates partial-thickness tear lateral plantar plate second MTP joint at the proximal phalangeal insertion (arrow). The patient underwent Weil osteotomy and plantar plate repair utilizing a dorsal approach with transosseous drill holes in the base of the proximal phalanx for fixation of the repair. (**b**) Sagittal PD postoperative MR image demonstrates an intact plantar plate repair, homogeneously of low signal (arrow). Note the mildly scarred dorsal capsule (arrowheads). (**c**) Sagittal ultrasound image demonstrates intact suture material within the repaired plantar plate (arrowheads), entering the proximal phalanx through the plantar aperture of the drill hole (arrow).

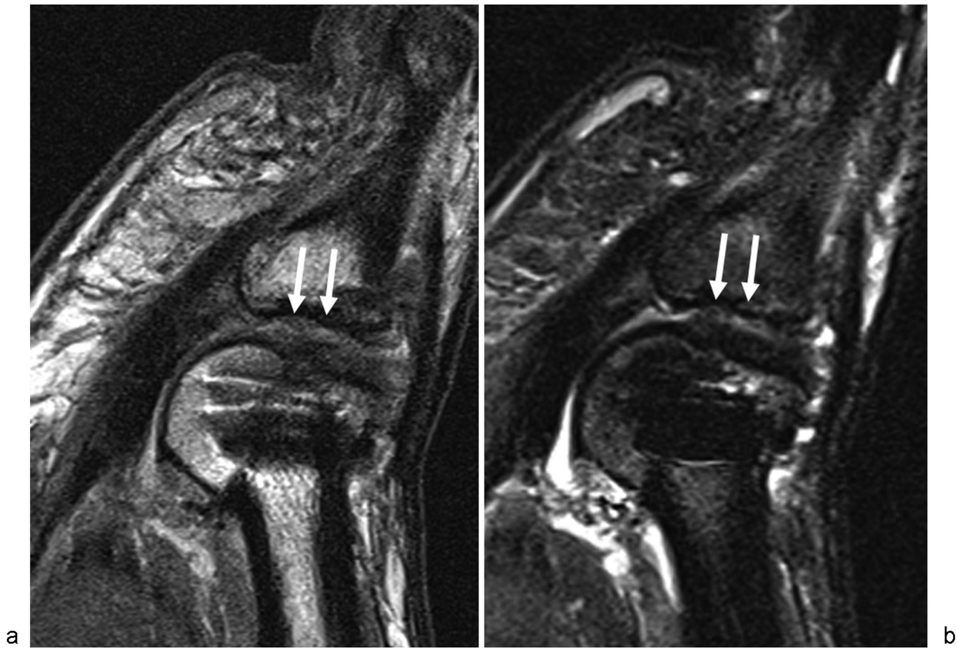


Fig. 17 A 56-year-old woman presents with ongoing pain and swelling 11 months post second MTP joint plantar plate repair. (**a**) Sagittal proton-density and (**b**) sagittal short tau inversion recovery images demonstrate Outerbridge grade 3 chondral wear at the base of the proximal phalanx (arrows), small effusion, and mild synovitis. The plantar plate repair is intact.

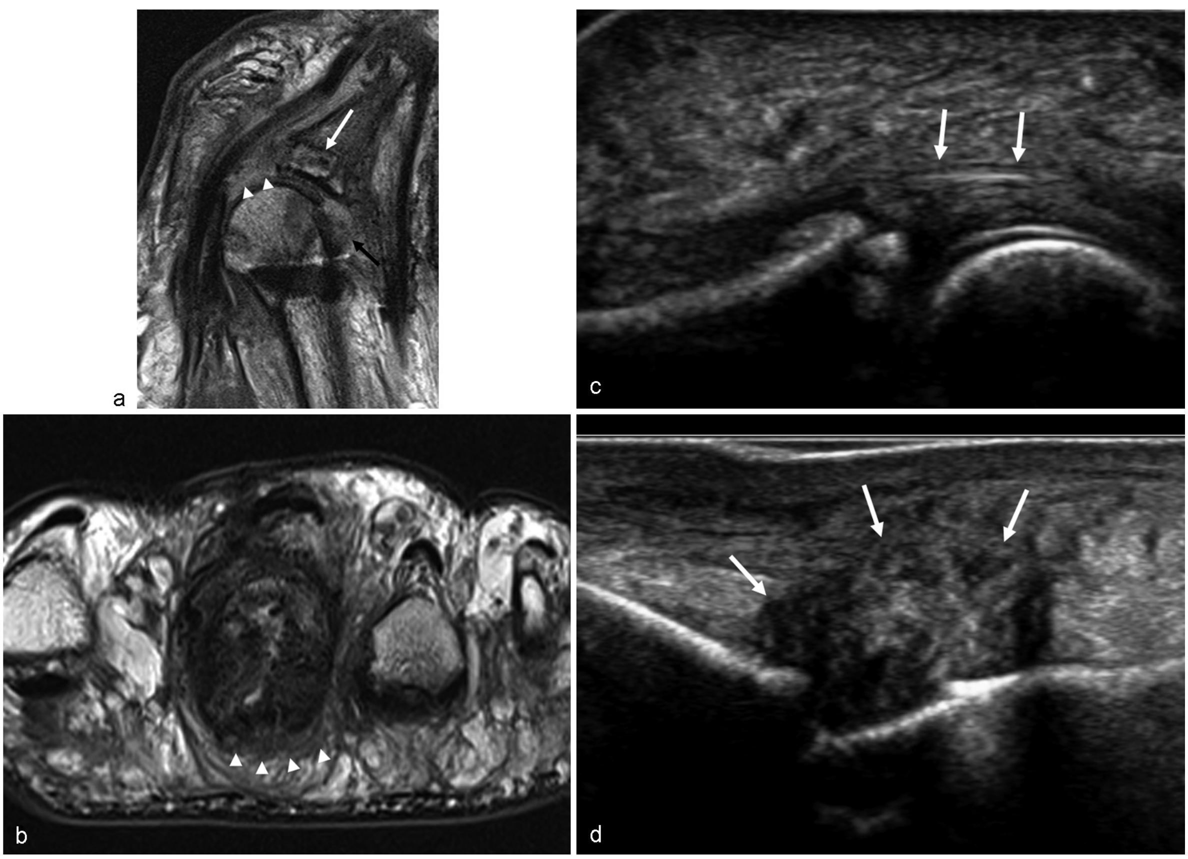


Fig. 18 A 68-year-old woman presents with persistent pain and swelling 1 year post second MTP joint plantar plate repair. (**a**) Sagittal proton-density (PD) MR image demonstrates widening of the drill hole in the base of the proximal phalanx (arrow), an edematous plantar plate (arrowheads), and proximal capsulo-synovial thickening at the dorsal recess (black arrow). (**b**) Short-axis T2 MR image and (**c**) sagittal ultrasound images confirm there is no dehiscence of the plantar plate repair. (**d**) Sagittal ultrasound image confirms the prominent capsulo-synovial thickening in the dorsal recess of the second MTP joint.

Wrist Coil Protocol 1.5 T

Long-axis PD FS, 10 cm FOV, 2 mm sl thk, 256 × 224
Sagittal PD, 10 cm FOV, 2 mm sl thk, 384 × 256
Sagittal PD FS, 10 cm FOV, 2 mm sl thk, 256 × 192
Short-axis T1, 9 cm FOV, 2 mm sl thk, 320 × 224
Short-axis T2, 9 cm FOV, 2 mm sl thk, 320 × 192

MR arthrography has been advocated as a means of increasing the sensitivity of MRI in demonstrating plantar plate tears;[18,20,21] however, it has not been our experience that this is necessary if a high-resolution technique is used. The combination of arthrography and toe traction has also been reported in cadavers, but there are no reports of its use in clinical practice.[22]

The normal plantar plate is usually best evaluated on oblique sagittal PD and fat-suppressed PD and short-axis PD or T2 sequences, demonstrating homogeneously signal hypointensity on all pulse sequences (►**Fig. 8**). Care should be taken not to misinterpret as a tear the normal attenuation of the plantar plate at the proximal phalangeal insertion in the midline at the level of the flexor tendon, manifest on MRI as an area of T2 signal hyperintensity and focal attenuation, measuring up to 2.5 mm (►**Fig. 9**). Plantar plate degeneration is manifest on MRI as mild signal hyperintensity on short TE sequences, becoming less conspicuous on long TE sequences[17] (►**Fig. 10**). Plantar plate degeneration may become sufficiently severe that there is a degree of elongation and defunctioning of the plantar plate, without a discrete tear plane (►**Fig. 11**). This situation is not uncommonly encountered surgically at the time of plantar plate repair. Plantar plate tears demonstrate greater signal hyperintensity on PD sequences, becoming more conspicuous on fat-suppressed PD and T2-weighted sequences[17] (►**Fig. 12**). Entheseal bony irregularity and surrounding bone marrow edema may be seen at the proximal phalanx adjacent to the plantar plate pathology[17] (►**Fig. 13**). Infiltration of the pericapsular fat plane at the plantar margin of a plantar plate tear can mimic a Morton neuroma,[6] probably reflecting a combination of pericapsular edema, inflammation, and fibrosis. It is usually readily appreciated on short-axis T1 and T2 sequencing as separate to the plantar digital nerve without the use of fat suppression[17] (►**Fig. 13**). The pericapsular edema, inflammation, and fibrotic change may be associated with irritation of the adjacent plantar digital nerve and mild neural thickening that may account for the neuritic symptoms that may be seen in this setting and should not be misinterpreted as indicating Morton neuroma formation.

Coughlin and colleagues[23] proposed a classification system for grading the severity of plantar plate tears: grade 0 consists of plantar plate attenuation or degeneration, without discrete tear plane; grade 1 consists of a transverse tear at or adjacent to the insertion on the proximal phalanx involving $< 50\%$ of the width of the insertion; grade 2 consists of a transverse tear at or adjacent to the insertion on the proximal phalanx involving $> 50\%$ of the width of the insertion; grade 3 consists of an extensive tear with transverse and/or longitudinal components and may involve the collateral ligaments (►**Fig. 14**); grade 4 consists of an extensive tear with transverse and longitudinal components and buttonhole deformity (►**Fig. 15**).

Imaging Plantar Plate Repair

Following plantar plate repair, ultrasound can be helpful in confirming integrity of the repair. One of the advantages of ultrasound over MRI is that it allows direct visualization of the sutures within the plantar plate (►**Fig. 16**). A limitation of ultrasound in postoperative evaluation is that it does not provide diagnostic assessment of articular cartilage in the MTP joint. MRI can also be helpful in evaluating the integrity of the repair (►**Fig. 16**), in demonstrating arthrofibrosis and assessing the status of articular cartilage in the MTP joint (►**Fig. 17**). Arthrofibrosis is a common cause of stiffness after plantar plate repair.[24] A synovitic reaction to the suture material used for the plantar plate repair may occur after plantar plate repair, potentially resulting in pain and swelling and sometimes associated with osteolysis involving the drill hole in the base of the proximal phalanx (►**Fig. 18**).

Summary

Plantar plate degeneration and tear is a common cause of forefoot pain, typically involving the second MTP joint at the proximal phalangeal insertion laterally, frequently confused with second web space Morton neuroma. High-resolution MRI or ultrasound can confirm a diagnosis of plantar plate degeneration and tear and exclude other pathologies, particularly Morton neuroma. The normal plantar plate is a mildly hyperechoic structure on ultrasound and is hypointense on all conventional MR sequences. Plantar plate degeneration manifests on ultrasound as hypoechoic echotextural change and on MRI as mild signal hyperintensity on short TE sequences, becoming less conspicuous on long TE sequences. Adjacent entheseal bony irregularity is commonly present. Plantar plate tears on ultrasound may be seen as an anechoic cleft defect or area of heterogeneous echotexture, sometimes more conspicuous with dorsiflexion stress. Plantar plate tears demonstrate greater signal hyperintensity on PD sequences, becoming more conspicuous on fat-suppressed PD and T2-weighted sequences. Edema and fibrotic change in the pericapsular fat plane is commonly seen in the setting of an adjacent plantar plate tear and should not be misdiagnosed as a Morton neuroma. Both ultrasound and MRI can provide assessment of the repaired plantar plate and demonstrate complications including arthrofibrosis, osteoarthritis, and synovitis.

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