Imaging of Sports Injuries in the Foot

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**OBJECTIVE.** This article selectively reviews several areas in which imaging can play a major role in the diagnosis and treatment of sports injuries of the foot.

**CONCLUSION.** Diagnostic imaging provides useful evaluation of capsuloligamentous sports injuries and Morton neuroma in the foot and facilitates appropriate treatment. An understanding of the relevant anatomy, normal imaging appearance, and the spectrum of imaging findings in the setting of injury is important for the practicing radiologist.

The foot is commonly injured at all levels of sport and is particularly vulnerable in agility sports. The overriding concern in sports injuries is early accurate diagnosis, appropriate management, and early return to sport. The complex anatomy in the foot and multiple sites of potential injury can make clinical diagnosis challenging. Early referral for diagnostic imaging can clarify diagnosis and guide treatment. This article reviews several areas where imaging can play a major role in diagnosis and treatment of capsuloligamentous sports injuries and Morton neuroma in the foot.

**First Metatarsophalangeal Joint Capsuloligamentous Injury**

**Clinical Analysis**

Bowers and Martin [1] noted an increasing incidence of first metatarsophalangeal joint capsular injury in sports played on an artificial surface, a condition known as “turf toe.” The term covers a broad spectrum of capsuloligamentous injury, which most commonly involves a valgus-hyperextension mechanism, with disruption of the first metatarsal head insertion of the medial collateral ligament complex and acute hallux valgus deformity [2]. Pure hyperextension injuries may be associated with disruption of the plantar plates and chondral injury at the dorsal aspect of the joint due to a concomitant axial load, with resultant proximal migration of the sesamoids. Less commonly, there may be a varus mechanism with tear of the lateral collateral ligament and hallux varus deformity [3]. Hyperflexion injuries sustained while playing beach volleyball have been termed “sand toe” and are usually associated with dorsal capsular injury to the first metatarsophalangeal joint [4]. Clanton and Ford [5] advocated a 3-point clinical grading system that may be useful in guiding management. Grade 1 injuries are thought to be only a stretch injury, with the athlete often being able to finish the game before presenting with low-grade pain and minimal swelling. Most patients will return to sport early. Grade 2 injuries manifest as swelling, pain, and guarding against dorsiflexion and are thought to be partial tears. Management in a walking boot and graduated return to activity may be required. Grade 3 injuries manifest as severe pain and inability to bear weight on the great toe and are thought to reflect a complete tear. A significant proportion of athletes with first metatarsophalangeal joint capsuloligamentous injury will experience ongoing disabling symptoms that may limit return to competition [6]. Selective early surgical intervention with anatomic primary repair of the torn capsuloligamentous structures would appear to generally result in restoration of plantar stability and return to full athletic activity [7].

**Anatomy**

The first metatarsophalangeal joint experiences significant load with walking (0.4–0.6 times body weight) [8], running (2–3 times body weight), and jumping (8 times body weight) [9]. The presence of a thick plantar capsule with fibrocartilaginous medial and lateral plantar plates and medial...
and lateral sesamoid bones helps to withstand these stresses. The sesamoids articulate with articular facets at the plantar margin of the first metatarsal head and are linked by the thick intersesamoid ligament. The medial collateral ligament complex provides stability to valgus stress, consisting of the medial collateral ligament proper and the medial sesamoid collateral ligament (metatarsosesamoid ligament). The latter is important in providing stability to the medial sesamoid–first metatarsal head articulation during the toe-off phase of walking and running. The lateral collateral ligament complex provides stability during varus stress. The sesamoid insertions of the two heads of flexor hallucis brevis and abductor and adductor hallucis and linkage to the proximal phalanx via the medial and lateral plantar plates (sesamophalangeal ligaments) help provide dynamic stability to dorsiflexion stress, together with the flexor hallucis longus tendon, which inserts into the distal phalanx. The insertion of the extensor hallucis brevis tendon into the dorsal capsule helps provide dynamic stability to planter flexion stress, together with the extensor hallucis longus tendon, which inserts into the distal phalanx.

**Radiographs**

A routine radiographic series of the great toe should consist of weight-bearing anteroposterior and lateral and non–weight-bearing oblique views [3]. In acute trauma, it can be helpful to include both the left and right first metatarsophalangeal joints on the anteroposterior view, because subtle proximal retraction of the sesamoids associated with plantar plate disruption can be made more conspicuous [10]. Radiographs provide assessment for capsular avulsion fractures, impaction fractures of the metatarsal head, sesamoid fractures, and retraction. Commonly, radiographs will be normal [3].

**MRI**

MRI of the first metatarsophalangeal joint is the preferred imaging modality for the assessment of capsuloligamentous trauma, chondral and osteochondral abnormalities, and sesamoid injuries [3, 11, 12]. Dedicated imaging of the first metatarsophalangeal joint with appropriate surface coils facilitates a high-resolution technique, with slice thickness of approximately 2 mm for sagittal and long-axis images and in-plane resolution of approximately 0.3 mm for proton-density sequencing and 0.6 mm for fat-suppressed proton-density sequencing. The orientation of the first metatarsophalangeal joint differs from that of the lesser metatarsophalangeal joints. Sagittal and long-axis (coronal) images of the first metatarsophalangeal joint must be plotted off a short-axis image perpendicular to the intersesamoid axis for the sagittal sequence or parallel to the intersesamoid axis for the long-axis (coronal) sequence. In the acute setting, complete ligament tears are usually of fluid signal intensity (Fig. 1), whereas interstitial tears are of intermediate signal. Sagittal sequencing best depicts tears of the medial and lateral plantar plate (sesamophalangeal ligaments). Short-axis sequencing best reveals tears of the sesamoid collateral (metatarsosesamoid) ligaments. Long-axis sequencing best reveals tears of the medial collateral ligament proper (metatarsophalangeal ligament). In late subacute and chronic cases, scar response may obscure the point of tear, making accurate diagnosis more difficult (Fig. 2).

**Lesser Metatarsophalangeal Joint Plantar Plate Degeneration, Tear, and Synovitis**

**Clinical Analysis**

Second metatarsophalangeal joint synovitis due to plantar plate degeneration and tear is a common cause of forefoot pain that can be easily misdiagnosed as Morton neuroma [13]. Whenever a Morton neuroma is suspected in the second web space, serious consideration should be given to the alternate diagnosis of a second metatarsophalangeal joint synovitis. Athletes typically present with localized pain, subtle dorsal swelling, tenderness localized to the second metatarsophalangeal joint, and pain with forced second metatarsophalangeal joint flexion [13]. There may be pain with the drawer test, which consists of dorsoplantar manipulation of the proximal phalanx while fixing the second metatarsal head. Dorsal subluxation may be elicited with the drawer test if there is a plantar plate tear [14]. There is increased interest in plantar plate tears in the foot and ankle surgical community because of the development of new techniques for plantar plate repair [15–17].

**Anatomy**

The plantar plate of the lesser metatarsophalangeal joints is a fibrocartilaginous thickening of the plantar capsule, thickest at the attachment on the base of the proximal phalanx medial and lateral of midline and relatively attenuated in the midline [18]. Proximally there is a thin synovial attachment to the metatarsal neck [19]. Although not strictly anatomically correct, it can be useful to subdivide the plantar plate into medial and lateral components.
The plantar plate imparts sagittal plane stability to the metatarsophalangeal joint and helps prevent mechanical overload of the metatarsal heads [15].

**Pathologic Analysis**

Attritional mechanical overload of the lateral plantar plate of the second metatarsophalangeal joint at the proximal phalangeal insertion is a common cause of metatarsalgia in athletes. The abnormality seen in this setting encompasses a spectrum from degeneration without tear, to partial thickness tear, to complete tear [15, 20]. In more severe cases, there may be attritional tear of the lateral collateral ligament, varus drift of the second toe, and medial subluxation of the flexor tendon complex. Enthesal bony irregularity and spurring may develop at the proximal phalangeal base adjacent to the plantar plate degeneration [20]. Coughlin et al. [15] proposed a 5-point grading system based on the shape of the plantar plate tear, ranging from attenuation without tear, transverse distal tear (<50% thickness or >50% thickness), transverse and longitudinal tear (with or without collateral ligament), to extensive complete tear.

**Radiographs**

Radiographs should be performed with weight bearing to better assess functional alignment. Attention should be directed to the relative length of the first and second metatarsals and the extent, if any, of protrusion of the second metatarsal head relative to the first metatarsal head. In the setting of tear of the lateral plantar plate of the second metatarsophalangeal joint, there may be varus drift of the second toe.

**Arthrography**

Arthrography can be used to show plantar plate tears [21, 22]. 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 show plantar plate degeneration.

**Ultrasound**

The plantar plate is best evaluated sonographically utilizing an oblique plantar parasagittal approach, directing attention to the lateral plantar plate insertion on the base of the proximal phalanx, the most common site of abnormalities. The plantar plate should also be assessed in the transverse plane [20]. The normal plantar plate is a mildly hyperechoic structure with a somewhat granular echotexture [20]. Dynamic assessment of the integrity of the plantar plate can be performed by applying a dorsiflexion stress. Color or power Doppler ultrasound should be used to assess for hyperemia. Plantar plate degeneration is manifest as hypoechoic echotextural change [20]. Partial tears of the plantar plate may vary in appearance, sometimes seen as a hypoechoic or anechoic cleft and sometimes as a heterogeneous echotexture [20] (Fig. 3A). Complete tears may be seen as a complete defect (Fig. 3B) and may be evident only on dorsiflexion of the metatarsophalangeal joint. Attention should also be directed to the dorsal recess of the second metatarsophalangeal joint to assess for effusion, capsuloligamentous thickening, and hyperemia. Medial subluxation of the flexor tendon complex in the setting of plantar plate tear is best appreciated on short-axis imaging.

**MRI**

In 1994, Yao et al. [21] demonstrated the utility of sagittal high-resolution MRI in visualizing the normal plantar plate and plantar plate degeneration.
degeneration and tear. Uman and Elsinger [23] emphasized the role of short-axis coronal imaging in this context. Plantar plate degeneration manifests on MRI as mild signal hyperintensity on short TE sequences, becoming less conspicuous on long TE sequences (Fig. 4). Plantar plate tears have greater signal hyperintensity on proton-density sequences, becoming more conspicuous on fat-suppressed proton-density and T2-weighted sequences (Fig. 5). Occasionally, bone marrow edema may be seen at the proximal phalanx adjacent to the plantar plate abnormality. Infiltration of the fat plane at the plantar margin of the plantar plate tear can mimic a Morton neuroma. Care should be taken not to misinterpret the normal attenuation of the plantar plate at the proximal phalangeal insertion in the midline at the level of the flexor tendon.

**Morton Neuroma**

**Clinical Analysis**

Symptomatic Morton neuroma is relatively common in athletes and can mimic plantar plate injuries of the lesser metatarsals. Morton neuroma symptoms typically include gradual onset of shooting pain, numbness, and tingling in the third and fourth toes; a burning sensation; cramping; and a sensation of “walking on a lump” in the ball of the foot [24]. The symptoms are often relieved by removal of shoe wear. Mulder click may be elicited by simultaneous dorsoplantar and mediolateral compression of the web space and is thought to be due to plantar displacement of the neuroma [25]. Imaging studies have found a relatively high incidence of asymptomatic Morton neuroma [26, 27].

**Anatomy and Pathologic Analysis**

The common plantar digital nerve normally has a diameter of less than 2 mm and is accompanied by the plantar metatarsal artery. It divides into medial and lateral plantar digital nerves. The intermetatarsal bursa lies predominantly dorsal and proximal to the deep transverse metatarsal ligament, being closely applied to the neurovascular bundle at the distal margin of the ligament. A small amount of fluid is commonly present in the asymptomatic intermetatarsal bursa [27]. Morton neuroma refers to an entrapment neuropathy caused by repetitive compression of the common plantar digital nerve against the transverse metatarsal ligament. This condition most often affects the 3–4 web space and, to a lesser extent, the 2–3 web space. Morton neuroma change virtually never occurs in the 1–2 or 4–5 web space. The disorder is characterized by nonneoplastic swelling, myxoid degeneration, and perineural and endoneural fibrosis and demyelination of the common plantar digital nerve [28].
Ultrasound

Although ultrasound does not have the contrast resolution of MRI in assessing the interface between a Morton neuroma and the adjacent fat plane, it does have the advantage of a virtually unlimited multiplanar capability, which facilitates demonstration of the common plantar digital nerve in long-axis sagittal imaging with a plantar approach using high-quality contemporary ultrasound machines. The normal nerve is seen as a hypoechoic structure adjacent to the common plantar metatarsal artery. Color or power Doppler ultrasound may be required to differentiate the artery from the nerve. The web space can also be assessed in the short-axis coronal plane and with a dorsal approach in the sagittal plane.

Morton neuroma change is typically manifest as fusiform-ovoid hypoechoic thickening along the line of the common plantar digital nerve toward the distal margin of the web space [29, 30] (Fig. 6A). Size criteria for a diagnosis of symptomatic Morton neuroma are of limited utility, given the relatively high incidence of asymptomatic Morton neuromas. Although one study reported a mean diameter of 5.3 mm in symptomatic cases, the mean diameter in asymptomatic cases was 4.1 mm [26]. Vascularity is usually not evident on color power Doppler ultrasound assessment.

MRI

Dedicated high-resolution MRI of the central forefoot (second to fourth metatarsophalangeal joints) provides accurate diagnosis of Morton neuroma. Key points include use of a slice thickness of 2 mm or less in all imaging planes. Optimal MRI assessment of the common plantar digital nerves and the metatarsophalangeal joint is provided by oblique short-axis coronal T1- and T2-weighted sequencing perpendicular to the long axis of the proximal phalangeal shafts (plotted off sagittal images) [31–33]. This is particularly important in the setting of hyperextension deformities of the metatarsophalangeal joints. Oblique sagittal sequencing perpendicular to the transverse axis of the central forefoot (plotted off short-axis-coral images) may allow long axis visualization of the neurovascular bundle. Scanning the patient prone may increase the conspicuity of a Morton neuroma [34]. On MRI, Morton neuroma is often most conspicuous on the short-axis T1-weighted sequence [33], usually of intermediate signal (Fig. 6B). Signal intensity on proton-density and T2-weighted sequencing may be variable, depending on the extent of fibrosis within the lesion, being of low signal if fibrosis predominates (Fig. 7). In lesions with higher water content, the margins may be less conspicuous on T2-weighted images [33] (Fig. 7C). Fat suppression of T2-weighted images may reduce lesion conspicuity because of the similar low signal of a fibrotic Morton neuroma and adjacent suppressed fat. Contrast enhancement is often not present, and routine administration of IV contrast agent is not recommended [32].

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Fig. 6—44-year-old woman training for her first marathon who presented with metatarsalgia.
A. Longitudinal image of second web space using plantar approach shows fusiform hypoechoic thickening (arrows), consistent with Morton neuroma change along line of 2–3 common plantar digital nerve, with normal-appearing nerve (arrowheads) evident more proximally.
B. Short-axis T1-weighted MRI shows intermediate signal (arrow) at plantar aspect of second web space, consistent with Morton neuroma.
C. Short-axis T2-weighted image shows slightly reduced conspicuity of Morton neuroma margins (arrow) compared with T1-weighted image.

Lisfranc Ligament Complex Injury

Clinical Analysis

Lisfranc ligament sprain injuries in the athlete are relatively common, particularly among those who play football, basketball, and gymnastics [35–37], and can be a cause of substantial time off sport [38, 39]. The typical mechanism of injury involves an axial longitudinal force applied to the foot in a plantar-flexed and slightly rotated position [40]. Associated injury to the first tarsometatarsal joint capsule or the medial intercuneiform ligament and navicularcuneiform joint capsule may result in first ray instability [40]. Athletes often describe a “pop” in the foot at the time of injury and midfoot pain aggravated by weight bearing [41]. At times, the clinical findings may be quite subtle, contributing to the relatively high rate of delayed diagnosis. There is some variation in the approach to the imaging assessment and management of subtle Lisfranc ligament complex injuries in which there is no or minimal displacement on weight-bearing radiographs. Some surgeons find stress radiography under anesthesia useful in determining whether to internally fix the midfoot [42]. Others advocate the use of MRI in determining the extent of capsuloligamentous injury and using this to determine whether to proceed to examination under anesthesia. Some surgeons use the increased sensitivity of CT to detect subtle displacement not evident on plain x-rays.

Anatomy

The Lisfranc ligament complex constitutes an oblique linkage between the medial cuneiform and the base of the second metatarsal. It is biomechanically important because of the large axial load transmitted through the second metatarsal during walking and running and
the absence of a transverse ligamentous linkage between the first and second metatarsal bases [43]. The interosseous Lisfranc ligament is the strongest constituent of the Lisfranc ligament complex [44]. The plantar oblique C1–M2,M3 ligament between the medial cuneiform and the bases of the second and third metatarsals is the second strongest constituent of the Lisfranc ligament complex [44]. It is of particular interest because of recent cadaveric and clinical studies showing that injury to the ligament in combination with interosseous Lisfranc ligament injury is the strongest predictor of instability on abduction stress radiographic examination under anesthesia [42, 45]. The plantar oblique ligament consists of a strong superficial band that inserts broadly on the base of the third metatarsal and a less substantial deep band that inserts on the base of the second metatarsal [46]. The dorsal oblique Lisfranc ligament is the least substantial component of the Lisfranc ligament complex [44].

**Radiographs**

Radiographic diagnosis of Lisfranc injury relies on findings of abnormality in midfoot alignment or enthesal Lisfranc ligament flake avulsion fractures (fleck sign). Comparison with an anteroposterior view of the contralateral foot is helpful. Radiographic studies are more sensitive when performed during weight bearing [47]. The ability to bear weight in the acute setting is often limited, potentially explaining the still limited sensitivity of weight-bearing x-rays compared with abduction stress radiography under anesthesia [42, 45]. The key criterion for normal alignment on an anteroposterior view is that the medial borders of the second metatarsal and intermediate cuneiform are colinear [48]. Widening of the interval between the medial cuneiform and second metatarsal base and between the bases of the first and second metatarsals are other criteria [40]. Attention should also be directed to the medial intercuneiform interval on the anteroposterior view and sagittal plane malalignment on the lateral view. A side-to-side difference of greater than 2 mm has been suggested as an indication for surgical midfoot reduction and stabilization [40].

**CT**

CT is more sensitive than radiography at revealing midfoot fractures and subtle abnormalities in alignment associated with Lisfranc ligament injury [49].

**MRI**

Proton-density and fat-suppressed proton-density or STIR sequencing in the long axis of the midfoot will reliably reveal both the interosseous Lisfranc ligament and the plantar oblique ligament between the medial cuneiform and the second and third metatarsal bases [50–52]. Although the entire length of the interosseous ligament will usually be seen on a single image, the plantar oblique C1–M2,M3 ligament often needs to be pieced together on several consecutive long-axis images. In the acute setting, an interstitial strain injury of the interosseous Lisfranc ligament will manifest as mild signal hyperintensity on proton-density and fat-suppressed proton-density MRI sequencing (Fig. 8A). Partial volume artifact associated
with oblique sampling of a bifascicular interosseous Lisfranc ligament may simulate a low-grade strain injury. A complete tear of the interosseous Lisfranc ligament will usually be seen as a fluid signal intensity defect in the ligament, often more conspicuous on fat-suppressed proton-density MRI sequencing (Fig. 8B). Flake avulsion fracture fragments at the medial cuneiform or second metatarsal base are often difficult to perceive. A similar spectrum of findings may be seen in relation to the plantar oblique C1–M2,M3 ligament (Fig. 9). Injury to the dorsal oblique C1–M2 ligament is often best appreciated on short-axis fat-suppressed proton-density MRI sequencing.

**Spring Ligament Injury**

**Clinical Analysis**

Injuries to the spring ligament in the athlete are an uncommon but potentially clinically highly significant injury [53]. Hintermann et al. [53] popularized the concept of medial ligament injury and resultant medial ankle instability characterized by a feeling of giving way, medial ankle pain, and plano-valgus deformity that can be corrected by tibialis posterior activation [54]. Although more commonly associated with injuries to the deltoid ligament complex, 25% of the patients in the study by Hintermann et al. [53] had spring ligament rupture. Untreated medial ankle instability may result in overload of the posterior tibial tendon and tendon degeneration and elongation [53]. Early surgical correction may prevent this progression [53].

**Anatomy**

The spring ligament complex is the major static stabilizer of the arch during midstance [55]. It consists of the superomedial calcaneonavicular ligament, the medioplantar oblique calcaneonavicular ligament, and the interoplantar longitudinal calcaneonavicular ligament [56]. It may be simpler to refer to these ligaments as the superomedial, plantar oblique, and plantar longitudinal fibers of the spring ligament [31].

**Pathologic Analysis**

Isolated spring ligament tears usually involve the superomedial fibers and range from interstitial sprain injury to frank tear, often coronal in orientation, adjacent to the navicular insertion [53], sometimes extending to involve the dorsal talonavicular joint capsule [57].

**Radiographs**

Weight-bearing radiographs may show normal findings or lateral peritalar subluxation of the navicular insertion [58].
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Fig. 11—37-year-old male army officer who sustained eversion sprain to ankle and presented for diagnostic ultrasound for assessment of persistent medial left ankle pain and swelling. Split-screen longitudinal ultrasound image shows thickening, hypoechoic echotextural change, and loss of granular echogenic architecture towards navicular insertion of superomedial spring ligament (long arrow), with hypoechoic thickening at superficial margin (short arrow). Note intact posterior tibial tendon and mildly thickened peritendinous space and normal echogenic well-defined appearance of intact contralateral superomedial spring ligament (round-topped arrow).

MRI

The spring ligament complex is readily seen on MRI [59, 60]. The superomedial fibers are best seen on axial and coronal proton-density images as a uniformly hypointense structure arising from the distal superomedial aspect of the sustentaculum tali and inserting broadly on the plantar medial margin of the navicular [60]. The plantar oblique and plantar longitudinal fibers are best seen on axial images [60]. Most of the imaging and orthopedic literature on MRI of spring ligament tear is in the context of chronic posterior tibial tendon dysfunction, where findings may range from superomedial spring ligament thickening and signal hyperintensity [61–63] to complete tear with a clearly defined ligament defect [63]. Similar findings may be seen in the setting of isolated acute or subacute spring ligament tear. Axial and coronal proton-density or fat-suppressed proton-density MRI shows thickening and signal hyperintensity along the line of the superomedial fibers with ill-defined margins [54]. The site of ligament tear can be difficult to identify [54] (Fig. 10). Adjacent bone marrow edema at the plantar medial aspect of the talar head, although nonspecific, may be present in the setting of spring ligament tear [64].

Ultrasound

The superomedial fibers of the spring ligament can be seen on ultrasound as a mildly echogenic well-defined structure deep to the distal fibers of the posterior tibial tendon [65]. Ligament visualization is facilitated by abducting and pronating the foot, thus placing the ligament under load. An accessory navicular insertion can obscure the superomedial spring ligament [66]. Isolated superomedial spring ligament tears may be seen as ligament thickening, hypoechoic change, and loss of granular echotexture [54, 66] (Fig. 11). Hyperemia may be seen on color power Doppler ultrasound [54]. In the limited published series with surgical correlation, the efficacy of ultrasound in revealing a discrete tear plane has been limited [54]. Extensive tears may be seen as a complete defect in the ligament [66].

Conclusion

Diagnostic imaging provides useful evaluation of capsuloligamentous sports injuries and Morton neuroma in the foot and facilitates appropriate treatment. An understanding of the relevant anatomy, normal imaging appearance, and the spectrum of imaging findings in the setting of injury is important for the practicing radiologist.

References

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