Lisfranc Injury: Imaging Findings for this Important but Often-Missed Diagnosis

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The Lisfranc injury is a popular topic in the radiology, orthopedic surgery, and emergency medicine literature, primarily due to the subtleties of the radiographic findings and potentially dire consequences of missed diagnoses. The purpose of this article is to help readers understand the anatomy of the tarsometatarsal joint, identify a systematic approach for the evaluation of the joint, and demonstrate how a multimodality approach can be used in both straightforward and more complex cases. Specifically, the utility of lateral and weight-bearing radiographs as well as computed tomography and magnetic resonance will be addressed. The dorsoplantar radiograph is often the first radiological examination performed, after initial history and physical examination. An understanding of the anatomy of the normal Lisfranc joint and subtle findings in the abnormal joint is essential in making an accurate diagnosis. Lateral and weight-bearing radiographs can be very useful in evaluating for subtle dislocation and minimizing the effects of overlapping structures at the tarsometatarsal joint. Computed tomography is particularly helpful in the delineation of anatomy and identification of small fractures. The strength of magnetic resonance lies in its ability to show isolated ligamentous injury and bone marrow edema. At the end of the article, the reader should be able to describe the normal anatomy of the tarsometatarsal joint, identify findings of Lisfranc injury on all three modalities, and understand the specific indications for the use of each modality.

Injury to the Lisfranc joint has long been a popular topic in the radiology, orthopedic surgery, and emergency medicine literature. Much of the literature has focused on the injury's frequency and potential long-term complications. The purpose of this article is to describe the mechanism of injury, identify key radiographic findings, and illustrate how computed tomography (CT) and magnetic resonance (MR) can be used as diagnostic aids in complex cases.

The Lisfranc joint bears the name of a field surgeon in Napoleon's army, Jacques Lisfranc, who described a technique for amputation of the forefoot through the tarsometatarsal joint.[1] Multiple authors, including Cassebaum,[2] have noted that fractures or dislocations at the tarsometatarsal joint were never described by Lisfranc. By all accounts, this fracture–dislocation is rare, making up only 0.2% of all fractures (approximately 1 per 55,000 yearly).[1,3,4] Despite its low incidence and prevalence, it has taken on significant importance due to the poor long-term prognosis when treatment is inadequate, inappropriate, or delayed due to initial missed diagnosis.[5] Chronic pain, functional loss due to residual ligamentous instability, arthritis, deformity, and soft-tissue injury are the most significant long-term sequelae of delayed or inappropriate management of a Lisfranc joint injury.[6] It is difficult to quantify the percentage of initial missed diagnoses of Lisfranc fracture–dislocations in the emergency department, but numbers most often quoted in the literature are in the neighborhood of 20%.[7-9] The missed Lisfranc fracture–dislocation is cited as one of the most common reasons for malpractice lawsuits against radiologists and emergency medicine physicians.[10] A recent study showed that over 50% of patients with Lisfranc injuries had pursued legal claims by 2 years after initial injury, with many of these patients having had poor outcomes.[11]

FIG 1. (A) Dorsoplantar radiograph of the right foot. 1, 2, 3 correspond to the first, second, and third cuneiforms. 4 refers to the navicular bone and 5 refers to the cuboid. The thick lines between the first cuneiform and the base of the second metatarsal illustrate the obliquely oriented Lisfranc ligament. The thin double lines between the bases of the second through fifth metatarsals are the intermetatarsal ligaments. No intermetatarsal ligament is present between the first and second metatarsals. The thin vertical double lines between the tarsal bones and metatarsals refer to the dorsal tarsometatarsal (TMT) ligaments. (B) Lateral radiograph of the right foot. An uninterrupted line can be drawn over the dorsal aspect of the tarsometatarsal joint, indicating normal alignment. A step-off at this joint is classic for the Lisfranc fracture–dislocation. (C) Representative sections from T1-weighted axial MR and T2-weighted MR, respectively, of the left foot showing an intact Lisfranc ligament (arrows) between the first cuneiform and the base of the second metatarsal.

Anatomy of the Tarsometatarsal Joint

Knowledge of the anatomy of the tarsometarsal (TMT) joint can be very helpful in making the diagnosis of a Lisfranc fracture–dislocation as well as understanding potential complications of this injury and evaluating posttreatment imaging for adequacy of repair. The TMT joint represents the junction of the midfoot and forefoot and the osseous structures include the five metatarsal bases, three cuneiforms (medial, intermediate, and lateral, respectively), and the cuboid.[6] The cuneiforms are named for their wedge shape, an essential factor in the stability of the TMT joints. In addition to osseous structures, ligaments are essential for stability of the TMT joint. These include the intermetatarsal and tarsometatarsal ligaments, each of which has a strong plantar component and relatively weaker dorsal component.[12,13] Tarsometatarsal ligaments are present across the entire Lisfranc joint, but the transverse tarsometatarsal ligaments connect only the bases of the second through fifth metatarsals. No ligament connects the bases of the first and second metatarsals.[6] The Lisfranc ligament is a particularly strong ligament that traverses the TMT joint, extending obliquely from the medial cuneiform to the base of the second metatarsal[6,12] (Fig 1). The normal transverse arch of the foot, the so-called "Roman arch"

FIG 2. Dorsoplantar radiograph of the left foot with fracture fragment at the lateral aspect of the base of the first metatarsal (arrow) and lateral displacement of the first metatarsal relative to the first cuneiform. Additionally, lateral dislocation of the second through fifth metatarsals is seen. This fracture–dislocation could be classified as a homolateral or Type A subtype.

FIG 3. (A) Dorsoplantar and oblique radiographs of the left foot showing fractures at the bases of the second and third metatarsals with lateral dislocation of the second through fifth metatarsals. Fractures at the lateral aspect of the base of the first metatarsal are visualized, probably representing Lisfranc ligament avulsion. However, the alignment of the first metatarsal with the first cuneiform is maintained. This could be classified as a Type B2, lateral dislocation. Widening of the second–third metatarsal interspace indicates disruption of the intermetatarsal ligament as well as the TMT ligaments. There is likely an additional nondisplaced comminuted medial cuneiform fracture as well. (B) The lateral radiograph shows the step-off at the tarsometatarsal joint (arrow), classic for the Lisfranc fracture–dislocation.

often described in the literature, refers to the combination of the wedge-shaped bones and the ligaments that give the TMT joint its stability.[6,12] Importantly, the base of the second metatarsal is recessed proximally relative to the other metatarsal bases, sits higher in the arch and is the most wedge-shaped, acting as a functional "keystone" for the TMT articulation, which provides additional stability.[5,6,12] A detailed discussion of the synovial spaces and soft-tissue support of the TMT joints is of secondary importance in Lisfranc stability and is beyond the scope of this article.

One model for conceptualizing the TMT joint, as proposed by Myerson and coworkers,[14] divides the

FIG 4. This case shows the value of weight-bearing radiographs in some cases. (A) Non-weight-bearing dorsoplantar and oblique radiographs appear to be within normal limits. (B) On non-weight-bearing lateral radiograph, extensive soft-tissue swelling and a subtle step-off were the only clue to a Lisfranc injury in this patient. (C) On weight-bearing dorsoplantar radiographs, subtle lateral dislocation of the second metatarsal relative to the second cuneiform (arrow) can be easily appreciated.

articulation into three functional columns. This has diagnostic and prognostic significance and is utilized in orthopedic surgery literature. The first column is the medial column and is composed of the medial cunei-form, navicular, and first metatarsal. The next is the middle column and is composed of the intermediate and lateral cuneiforms along with the second and third metatarsals. Finally, the lateral column is composed of the cuboid and fourth/fifth metatarsals.[5,14] Each column is able to tolerate some degree of normal motion, with lateral, medial, and middle columns in descending order of allowable motion. Residual instability in a more mobile column is less likely to result in significant functional impairment and arthritis as a similar degree of residual instability would in a less mobile column.[5]

The significance of the mobility of the columns is also related to the amount of "allowable" offset before a diagnosis of subluxation or dislocation is made.[14] For example, an offset of 2 to 3 millimeters is allowed between the cuboid and the medial margin of the fourth metatarsal in the lateral column.[15,16] This is not the case with the medial and middle columns. In particular, the middle column can have an offset of 1 millimeter and have significant associated symptoms and posttraumatic instability and arthritis.[17]

Knowledge of normal anatomy is also important in assessing posttreatment radiographs following reduc-

tion and/or surgery. There is ongoing debate in the orthopedic literature regarding the appropriate therapy for the majority of Lisfranc injuries. However, there is no question that, whatever treatment is employed, posttreatment alignment *must* be anatomic to best avoid long-term sequelae of a Lisfranc injury.

Mechanism of Injury

The most common mechanisms of the Lisfranc fracture–dislocation involve axial load or forced supination or pronation on a plantar flexed foot. This leads to fractures of the metatarsals and tarsal bones as well as ligamentous injuries.[18] These indirect mechanisms are much more common than direct mechanisms (such as crush injuries) in causing Lisfranc fracture–dislocations.

Examples of the indirect mechanism of injury include the "bunk bed" fracture in which children leaping from the top bunk of a bed bear an axial load on a plantar flexed foot when landing on the toes.[19] Another possible scenario involves falling and twisting with the forefoot fixed as in a horseback rider falling with a foot caught in a stirrup or a windsurfer falling with a foot caught in a footstrap.[1] One of the more common histories is axial load due to floorboard impact sustained during a motor vehicle accident.[9,19-22] An additional mechanism that has been described includes forced plantar flexion and catching the forefoot when stepping off a curb, or what has been called a dorsal fold-over injury.[5]

Another group in which Lisfranc injuries seem to be increasing in frequency is the elite athlete, particularly competitive football players.[23] Multiple players from the National Football League with Lisfranc injuries have recently been described in the popular press. A specific type of injury that has been described in this group is a ligamentous variant that leads to medial column instability.[23] With high-level athletes becoming bigger, faster, and stronger than ever before, mechanical forces at impact and during aggressive planting maneuvers are much greater than in the past. More lightweight footwear and differences in playing surfaces may also increase potential for injury at anatomic "weak points" such as the Lisfranc joint.[23]

Classification of Injury

Classification of the displaced Lisfranc injury was described by Myerson and coworkers[14] based on segmental patterns of injury. Type A describes a completely incon-

FIG 5. Another case demonstrating utility of weight-bearing radiographs as an additional means by which to evaluate for Lisfranc fracture–dislocation. (A, B) Dorsoplantar, oblique, and lateral radiographs of the left foot show no obvious abnormality. However, due to high clinical suspicion, weight-bearing views were obtained. (C) Subtle fracture fragments are identified along the expected course of the Lisfranc ligament on weight-bearing dorsoplantar (arrow) and oblique views of the left foot. Also, subtle lateral dislocation of the second metatarsal relative to the second cuneiform confirmed Lisfranc injury.

FIG 6. (A) Non-weight-bearing dorsoplantar radiograph of the left foot demonstrates a fracture fragment adjacent to the lateral margin of the first tarsometatarsal joint and widening of the first–second interspace. The articulation between the second metatarsal and second cuneiform appears undisturbed on this single view. (B) Stress radiograph of the left foot demonstrates the fracture of the lateral base of the first metatarsal with suggestion of minimal lateral displacement of the first metatarsal relative to the first cuneiform (arrow). (C) Multiple sequential images from an axial CT scan are also shown, for clarification of anatomy and pathology, which clearly confirm the findings on the stress radiograph at the first metatarsal base (arrow) as well as a fracture at the lateral aspect of the base of the first cuneiform (open arrowhead).

gruent tarsometatarsal joint complex with medial or lateral dislocation of the forefoot. Type B characterizes a partially incongruent injury with further subclassifica-tions of B1 and B2, describing medial dislocation of the first metatarsal and lateral dislocation of the second to fifth metatarsals, respectively. Divergent injuries are
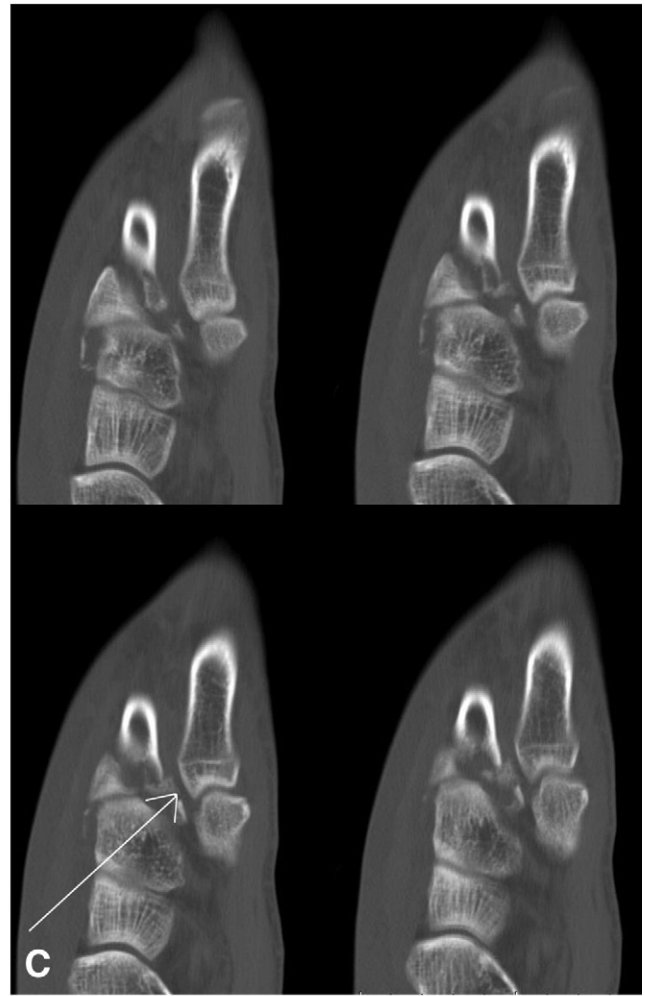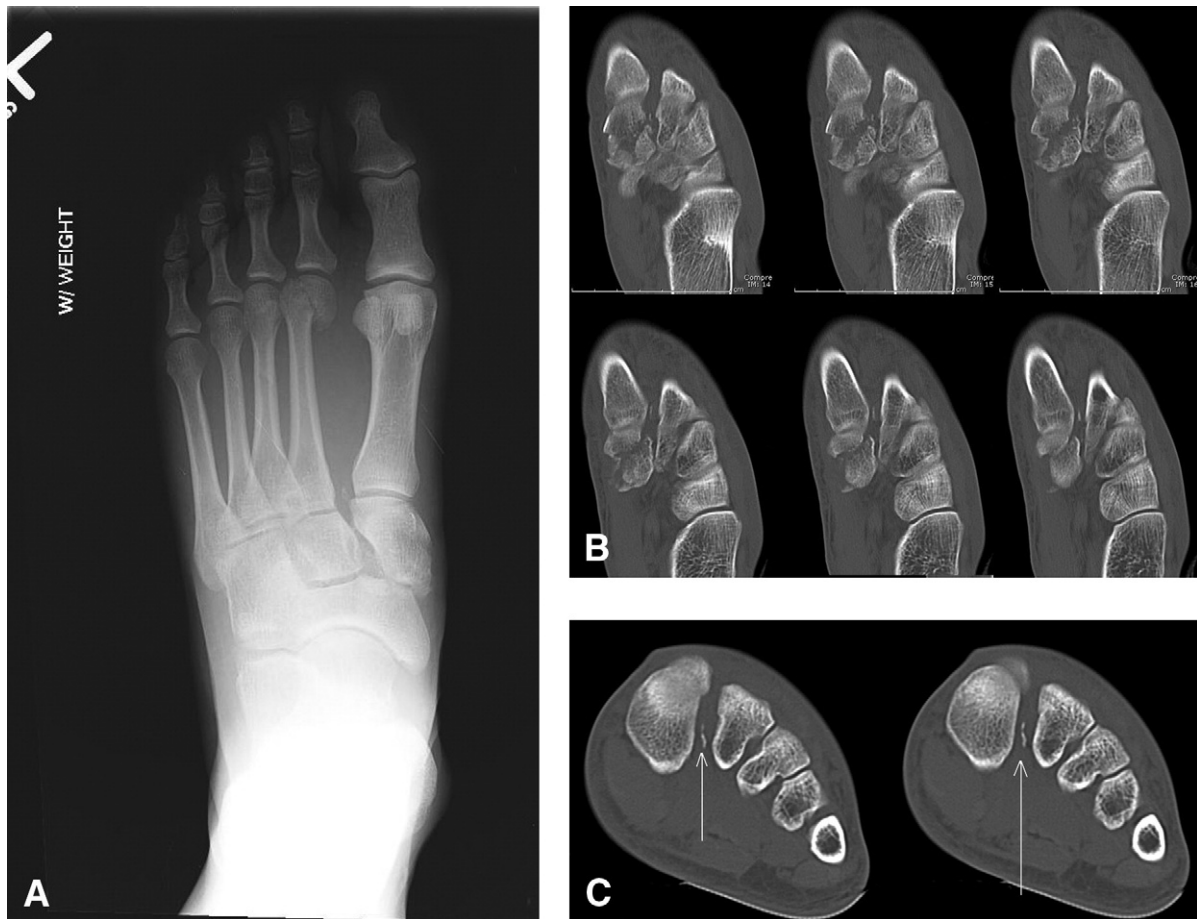
FIG 7. (A) Dorsoplantar radiograph of the right foot demonstrates fractures of the bases of the second through fourth metatarsals including a fragment suspicious for a Lisfranc ligament avulsion at the medial second metatarsal base. The second metatarsal is also displaced laterally relative to the second cuneiform. The alignment of the first metatarsal and first cuneiform appears to be within normal limits. (B) On lateral radiograph, step-off at TMT joints is identified (arrow). (C) Due to persistent pain at the first TMT joint, a CT scan was obtained. Selected images from an axial CT scan show lateral displacement of the first metatarsal relative to the first cuneiform (arrow) in addition to fractures described on conventional radiographs. Based on initial radiographs, this would have been classified as a Type B, lateral dislocation. In combination with CT, classification was changed to Type A, or homolateral.

classified as Type C injuries with C1 for partial and C2 for total displacement. The significance of the divergent injury is the risk of associated fractures of the cuneiform and navicular bones.[24]

Radiographic Findings

As radiographic findings may be subtle and patients frequently present with polytrauma, a systematic approach should be utilized when interpreting conventional radiographs for possible Lisfranc injury. There are three key anatomic relationships to ana-

lyze when examining a dorsoplantar view of the foot. First, the medial margins of the second metatarsal and the middle cuneiform should be well aligned.[24,25] Second, the lateral margin of the first metatarsal should also be aligned with the lateral margin of the medial cuneiform.[24] Third, the medial margins of the fourth metatarsal and cuboid should be well-aligned[24] (Fig 2). The distance between the first two metatarsals should also be evaluated, as it is frequently increased in the Lisfranc fracture–dislocation; however, this is not as reliable as the relationship of the first two metatarsals with their

FIG 8. (A) Weight-bearing dorsoplantar radiographs of the left foot demonstrate comminuted fracture of the first cuneiform with medial displacement of the first metatarsal and first cuneiform. The space between the first and second metatarsals is also widened with tiny fracture fragments between the first and second metatarsal bases. Fracture of the head of the second metatarsal is also identified. (B, C) Representative axial and coronal CT images show the comminuted first cuneiform fracture with clear widening of the first–second intermetatarsal distance, suggesting that the vector of force propagated through the first cuneiform and between the first two metatarsals, disrupting the Lisfranc ligament. The coronal images best display small Lisfranc ligament avulsion fragments (arrows). It is unclear whether the alignment of the second metatarsal and second cuneiform is disrupted. If so, this could be classified as a Type C or divergent injury. If it is not, this could be classified as a Type B1, medial dislocation.

respective cuneiforms.[24,25] The third and fifth metatarsals are usually difficult to analyze directly due to bony overlap.[24]

The lateral radiograph is also important in making the diagnosis of Lisfranc fracture–dislocation. A classic step-off sign is present when an uninterrupted line cannot be drawn along the dorsal surface of the foot at the level of the tarsometatarsal joint[24,25] (Fig 3). This is because there is often some dorsal displacement of the base of the metatarsals with this type of injury due to disruption of relatively weaker dorsal tarsometatarsal ligaments.

Questions have been raised regarding the utility of stress or weight-bearing radiographs in diagnosing this injury. Dorsoplantar and lateral radiographs of the foot

are often sufficient to make this diagnosis; however, with subtle injury, it has been proposed that spontaneous reduction may occur.[24] Arntz and coworkers suggested that up to 10% of tarsometatarsal injuries cannot be detected without performing weight-bearing views.[26] For this reason, stress or weight-bearing radiographs or fluoroscopy can be helpful in cases where suspicion for subtle injury is high and subtle malalignment or ligamentous injury may be present[5,24] (Figs 4 and 5). Findings indicating Lisfranc injury on weight-bearing views such as malalignment across the TMTs are identical to those seen on non-weight-bearing views. Stress or weight-bearing views can be very painful for the patient, and to obtain diagnostic images, adequate pain control is important.[5]

FIG 9. (A) Oblique and dorsoplantar radiographs of the left foot demonstrate fracture at the base of the second metatarsal with lateral displacement of the first metatarsal relative to the first cuneiform and lateral dislocation of the second through fifth metatarsals relative to the tarsal bones. This would be classified as Type A subtype, or homolateral. (B) On lateral radiograph of the left foot, marked step-off is noted at the tarsometatarsal joint, compatible with Lisfranc fracture–dislocation. (C) After attempted closed reduction, repeat oblique and dorsoplantar radiographs demonstrate improved alignment; however, significant lateral displacement at the second tarsometatarsal joint (arrow) can still be appreciated. Fracture fragments are again seen between the bases of the first two metatarsals. (D) Subsequent axial CT images are displayed, showing the fracture fragments (arrow) between the first two metatarsal bases, preventing adequate reduction of the second metatarsal base. This patient subsequently needed open reduction-internal fixation. (MT1 and MT2 refer to the first and second metatarsal bases. C1 and C2 refer to the first and second cuneiforms.)
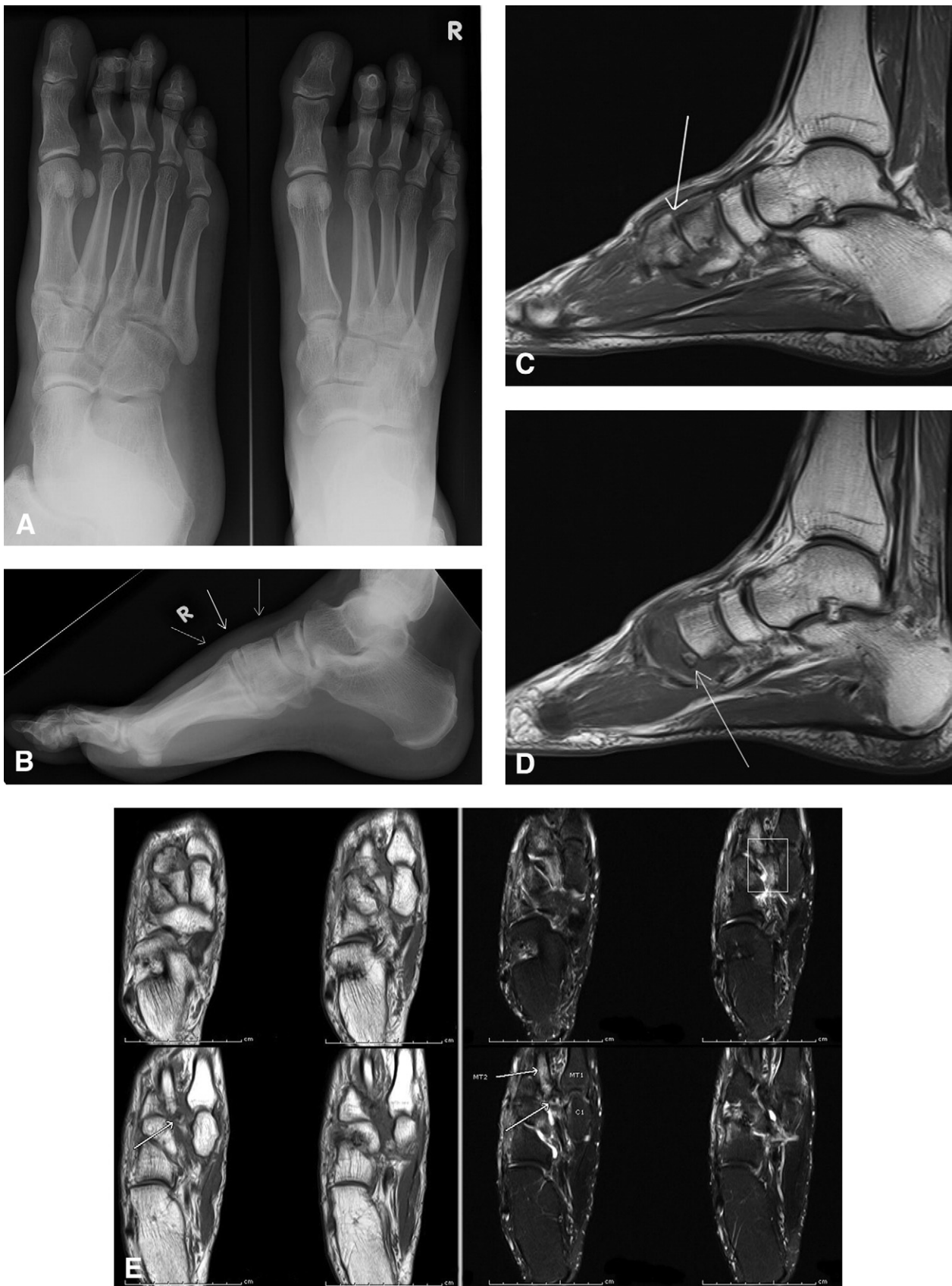
FIG 10. (A) Dorsoplantar and oblique radiographs of the right foot in a patient with a sports injury were initially interpreted as normal. (B) Lateral radiograph does demonstrate dorsal soft-tissue swelling over the metatarsals (arrows) and a subtle step-off at the dorsal margin of the tarsometatarsal joint, although this was also read as normal. Due to persistent pain, MR imaging was performed 3 months later. (C and D) Adjacent sagittal T1-weighted MR images of the right foot demonstrate clear dorsal displacement of the second metatarsal relative to the second cuneiform (arrow pointing down) and a small fracture fragment (arrow pointing up) adjacent to the second MT base. (E) Axial T1 and corresponding fat-suppressed T2-weighted images through the tarsometatarsal joint demonstrate slight lateral displacement of the second metatarsal, edema along the expected course of the Lisfranc ligament (box), and no normal ligament fibers on T1-weighted images. Small fracture fragment (arrows) is seen adjacent to the base of the second metatarsal. Significant edema in the proximal second metatarsal is another strong indicator of Lisfranc injury in this patient. (C1 corresponds to the first cuneiform, MT1 to the first metatarsal, and MT2 to the second metatarsal.)

Role of CT and MRI

CT is useful in the diagnosis of subtle midfoot malalignments and fractures as it allows for imaging in various planes and allows for visualization of unobscured anatomy. Tarsometatarsal malalignment, subtle fractures, and joint space fracture fragments are better appreciated than with conventional radiography (Figs 6-8). CT also allows detection of interposed bone fragments and tendons, which may impede adequate reduction[27] (Fig 9). CT is advantageous as patient positioning is not as critical for optimal anatomical visualization as with conventional radiographic imaging. The ideal imaging plane of the injured foot is with the CT beam angle oriented along the metatarsals as they meet with their corresponding tarsal bones. This can be accomplished by angling the CT gantry or performing multiplanar reconstructions from acquired data. Goiney and coworkers[28] found that satisfactory and diagnostic images could be obtained while the injured extremity was in plantar flexion, thus alleviating significant patient pain and discomfort with positioning. Additionally, CT is also useful in evaluating arthritis and bony deformities in the undiagnosed injury.[6]

Similar to CT, the multiplanar capabilities of MRI allow optimal evaluation of malalignment at the midfoot. MR is superior to all other modalities in its depiction of the ligaments of the midfoot.[13,29] The dorsal intermetatarsal ligaments are best visualized in the coronal plane using thin slices as they are thinner than the plantar ligaments. Tarsometatarsal ligaments are best appreciated in the sagittal plane. In particular, the Lisfranc ligament can be demonstrated in axial, sagittal, or coronal planes using MRI; however, the oblique axial plane may allow visualization of the entire course of the ligament and is often best in visualizing this crucial structure.[13] MR is far superior to other techniques in cases with purely ligamentous injury or in cases with nondisplaced fractures in which bone marrow edema can indicate subtle avulsion[30] (Fig 10).

Conclusions

Although relatively rare injuries, fractures and dislocations at the Lisfranc joint are important to recognize due to the potential for chronic morbidity with missed initial diagnosis or improper treatment. Multiple factors contribute to the relatively high initial miss rate including unfamiliarity with appropriate tarsometatarsal anatomy, difficulty in obtaining adequate radiographs of the midfoot due to suboptimal positioning and bony overlap, as well as low clinical suspicion, especially in patients with polytrauma who may have other immediately life-threatening injuries. Weight-bearing views, CT, and MRI may be extremely helpful in detecting subtle fractures and dislocations, defining the exact nature of the injury for surgical planning, evaluating for additional fractures of the foot and assessing the adequacy of reduction.

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