CHAPTER **16**

BIOMECHANICAL AND RADIOGRAPHIC TOOLS IN ASSESSING SUBTLE INJURIES TO LISFRANC JOINT

Michael J. Crawford, DPM
Kent A. Feldman, DPM

INTRODUCTION

The definition of Lisfranc's joint is the articulation between the bases of the metatarsals and the cuneiforms medially and the cuboid laterally. Unlike the lesser metatarsals, the first and second metatarsals are not anchored to each other with an intermetatarsal ligament; rather, they are connected indirectly via Lisfranc's ligament. Lisfranc's ligament connects the lateral aspect of the medial cuneiform to the medial aspect of the base of the second metatarsal. Disruption of this ligament due to low energy mechanisms of injury can result in subtle clinical and radiographic findings often going undiagnosed. Missed diagnosis has tremendous consequences resulting in rapid development of midfoot osteoarthritis and flattening of the medial longitudinal arch of the foot. Accurate, timely diagnosis and appropriate treatment are paramount in successful management of tarsal metatarsal joint injuries.

Anatomy and Biomechanics

The tarsal metatarsal joint consists of the 3 cuneiforms and cuboid and their articulation to the 5 metatarsal bones. Dorsal and interosseus ligaments connect the lesser metatarsals, while strong plantar tarsal metatarsal ligaments provide the most stabilization to the joint (1). Stabilization between the second metatarsal and the first comes from Lisfranc's ligament. It is the strongest of the interosseus tarsal metatarsal joint ligaments (2). It arises from the medial aspect of the medial cuneiform and is directed obliquely and downward, inserting on the lower surface of the medial cuneiform (2). Disruption of either of these ligaments will cause disturbance of the stability between the medial and middle columns of the foot (2).

Peicha and colleagues examined 3 anatomical factors measured on anteroposterior radiographs as possible "risk factors" in the development of a Lisfranc fracture dislocation and compared these to normal cadavers: A) the medial depth of the second tarsal metatarsal joint mortise, B) the lateral depth of the second tarsal metatarsal joint mortise, and C) the length of the second metatarsal. The authors found as the medial mortise depth decreases, the risk of injuring Lisfranc's joint increases (3).

MECHANISM OF INJURY AND CLASSIFICATION

Overt dislocations and fracture dislocations of the tarsal metatarsal joint usually result from high energy trauma (4, 5). A less common form of injury involves an indirect, low energy mechanism of injury. This mechanism is one of an axial force applied to a plantarflexed and inverted foot with or without other rotational forces (6–8). Nunley classified this "midfoot sprain" into 3 categories (9). Stage I injuries are nondisplaced on weightbearing radiographs, stage II injuries have 2-5 mm of lateral displacement of the second metatarsal compared to the intermediate cuneiform without loss of longitudinal arch height, and stage III, which includes a stage II injury with loss of medial longitudinal arch height compared to the contralateral side. Ultimately, these injuries cause disruption of Lisfranc's ligament and can cause considerable disability if they go undiagnosed, or are diagnosed late.

Evaluation of Subtle Injuries

Plain film radiographs are the initial imaging modality of choice when evaluating injuries to the midfoot. The most reliable radiographic abnormality to observe is lateral displacement of the base of the second metatarsal relative to the medial margin of the second cuneiform on weightbearing radiographs (1). In addition, diastasis between the bases of the first and second metatarsal bases and/or diastasis between the medial and intermediate cuneiform are other useful radiographic signs (10). Despite these useful signs, evaluation of subtle injuries to Lisfranc joint using plain film radiographs is unreliable (1, 7, 11-13). One study found that 50% of midfoot sprains can have normal non-weightbearing radiographs (9). Optimizing visualization of Lisfranc's joint and increasing the sensitivity and specificity of plain film radiographs in detecting injuries to Lisfranc's joint can be increased using a craniocaudal angulation of the x-ray beam at 28.9 degrees (14). Despite this, the sensitivity of this technique is only 84.4% and therefore some subtle injuries may be missed.

Computed tomography (CT) examination is a useful tool in evaluating high-energy type injuries to Lisfranc's joint because it can reveal fractures not typically visible on plain film radiographs (6). In a cadaveric study, Lu and colleagues showed that CT examination was more sensitive and specific than plain film radiographs in detecting lateral subluxation of the second metatarsal (12). However, subtle subluxations present in the injured patient are often only visible with weightbearing, and therefore could be missed with a non-weightbearing CT modality (15).

Magnetic resonance imaging (MRI) evaluation of Lisfranc's ligament is another possible valuable imaging modality to help in the diagnosis of subtle injury. The Lisfranc ligament complex can be reliably in the normal foot (11). In 2 small studies, MRI was able to diagnose all Lisfranc fracture/dislocation and Lisfranc ligament tears but all injuries had positive plain film radiograph findings (11, 16). In one case report, a midfoot sprain was diagnosed using MRI when plain film radiographs were negative (17). Thus, there appears to be no significant or controlled studies describing the sensitivity and specificity of MRI imaging of subtle Lisfranc joint injuries compared to plain film radiographs nor do any studies show that MRI has any diagnostic value compared to plain film radiographs. Nunley and colleagues asserted that MRI was not helpful in the diagnosis of subtle Lisfranc joint injuries. It appears that errors in diagnosis using MRI could be due to the small size of the Lisfranc joint complex (15). Also, it can be difficult to distinguish between a partial tear and fluid around the ligament (15).

Isolated Second Tarsal Metatarsal Injuries

Isolated injury to the second tarsal metatarsal joint is rare. There are 3 reports of such injuries in the literature, first by Novotny (18) in 1953, Wilson (19) in 1972, and most recently by Markowitz (20) in 1989. We present a case series of isolated injuries to the second tarsometatarsal joint, to bring the total up to 4. Primarily, it is the largest case series of its kind. Likewise, we demonstrate the utility of the weightbearing CT in the diagnosis of subtle injuries, in the quantification of functional instability with weightbearing, and anatomic risk factors for injury.

MATERIALS AND METHODS

Patient Selection

Patients charts were retrospectively reviewed to be included in this case series by first identifying the presence of Lisfranc joint injury using ICD-9 code (838.03). The patients with isolated second tarsal metatarsal joint injuries were identified by the use of grossly evaluating for fracture, subluxation, or dislocation of any components of the tarsal metatarsal joints on weightbearing CT images. Any patient with injuries in addition to the second tarsal metatarsal joint were excluded. The age, sex, mechanism of injury, and surgical treatment were recorded.

Imaging Technique

All patients were evaluated primarily using a weightbearing CT examination of both feet. The patients were directed to allow for more than 50% of their weight to be biased to their affected side. This helps to unmask any functional instability at the tarsal metatarsal joint. The weightbearing CT images (CurveBeam, LLC, version 2.2.0.2 scanner) were taken in less than 1 minute (approximately 9 seconds of radiation exposure to the patient), with slices of 0.3 mm, and a relatively small radiation dose (~2uSv). Slices were then combined via Cube-Vue software, into a 3-dimensional image that can be manipulated and cut into slices in all 3 planes for accurate anatomical and positional measurements.

Image Measurement Techniques

To evaluate functional joint instability and joint displacement with weightbearing, the position of the second metatarsal base relative to the base of the intermediate cuneiform was measured in the sagittal and transverse planes. Sagittal plane displacement was quantified by measuring the difference between the superior aspect of the second metatarsal base compared to the superior aspect of the intermediate cuneiform on a sagittal CT slice through the center of the joint (Figure 1). We measured transverse plane displacement by comparing the distance between the most medial aspect of the base of the second metatarsal and the medial aspect of the intermediate cuneiform on an axial CT slice through the center of the joint (Figure 2). The adjacent joints and intercunieform joints were grossly evaluated for evidence of misalignment or fracture.

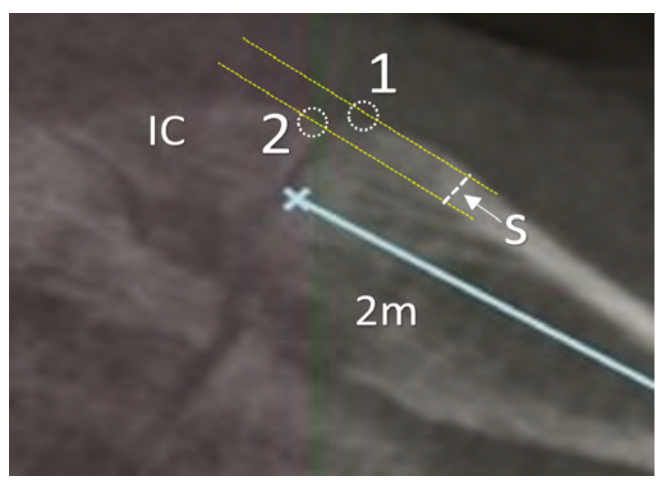


Figure 1. The Second Tarsal Metatarsal Joint Sagittal Plane Displacement. Point 1 corresponding to the most superior aspect of the proximal second metatarsal base (2 m) and Point 2 corresponding to the most superior aspect of the distal intermediate cuneiform (IC). A tangential line was drawn from the first point and a second line parallel to that intersecting with the second point were used to measure the amount of displacement in the sagittal plane in millimeters (S).

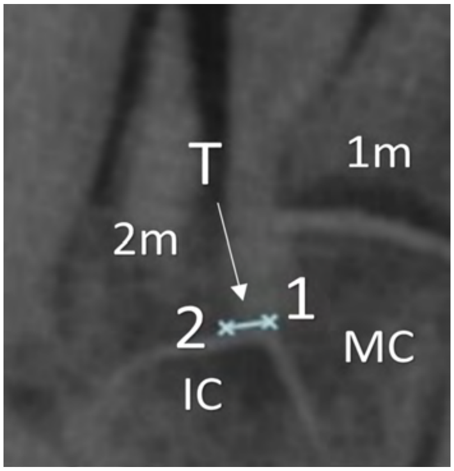


Figure 2. The Transverse Displacement of the Second Tarsal Metatarsal Joint. The most distal medial aspect of the intermediate cuneiform (IC) represented by Point 1 and the most proximal medial aspect of the second metatarsal base (2m) were both found and marked so that the points created a line that was directly parallel to the joint line. The distance between these 2 points (T) was the transverse plane displacement of the second tarsal metatarsal joint in millimeters.

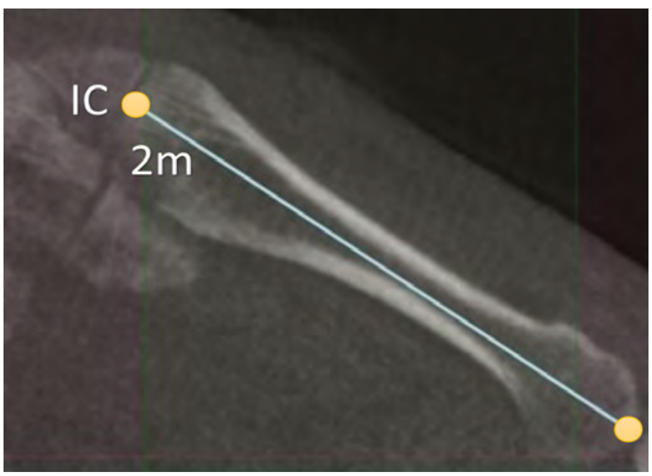


Figure 4. The Length of the Second Metatarsal. The distance between the 2 large circles show landmarks used to measure the length of the second metatarsal from a sagittal cut plane.

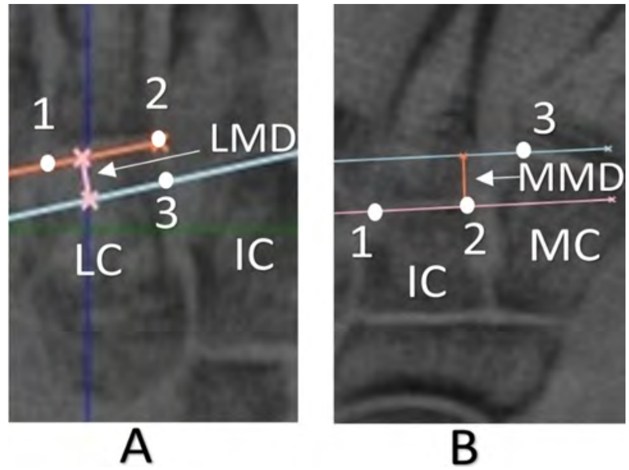


Figure 3A. The Lateral Second Tarsal Metatarsal Joint Mortise Depth. Two landmarks are drawn to identify the distal orientation of the lateral cuneiform (LC) with a line connecting the most distal lateral point (point 1) and distal medial point (point 2). The most distal lateral point of the intermediate cuneiform (IC) is found (point 3). A line is drawn through this point parallel with the line derived from connecting points 1 and 2. The distance between these 2 lines gives the lateral mortise depth (LMD).

Figure 3B. Medial Second Tarsal Metatarsal Joint Mortise Depth. The distal medial (1) and distal lateral (2) points of the IC are found and a line is connected and extended through them. This line should approximate the articular facet of the second tarsal metatarsal joint. A third point is found corresponding to the distal lateral aspect of the medial cuneiform (MC) and a tangential line passing through this point is drawn parallel to the first line that connected points 1 and 2. The distance between these 2 lines gives the medial mortise depth (MMD).

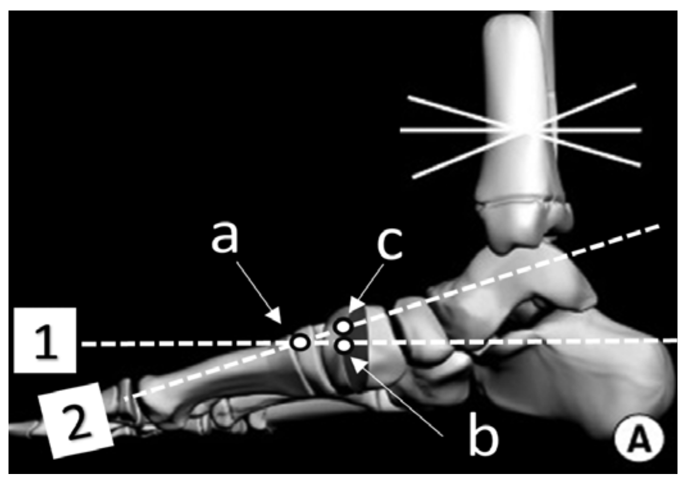
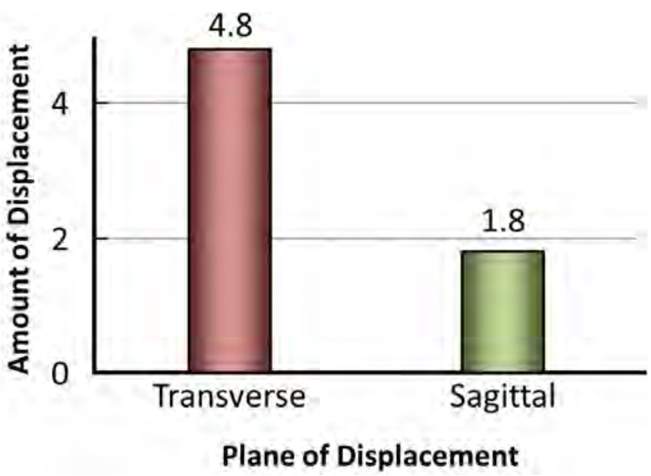


Figure 5. Adjustment of CT Cut Orientation. Line 1 is the traditional axial cut plane, which is not parallel with the declination of the metatarsals but rather parallel with the ground. The axial slice of CT image would render the superior-most portion of the metatarsals and the middle portion of the cuneiform, in the same image slice. This phenomenon could lead to inaccurate measurement of the boney relationships. However, line 2 is more parallel to the declination of the metatarsals, so the points a and c will be shown in the same slice, which accurately reflects true anatomic relationship. The Cube-Vue software allows for complete manipulation of the cut planes in all 3 dimensions. Our axial slices were taken in the orientation of line 2. Care was taken to apply the same principle of cut plane orientation to imaging of other planes.

Table 1. Demographic data

Subject	Age, years	Sex	Laterality	Mechanism	Treatment
1	59	Male	Left	Direct trauma	
2	23	Male	Left	Police altercation, twisted foot	ORIF of medial cuneiform to second metatarsal base
3	22	Male	Right	Fell down a few stairs	4.0 mm partially threaded lag screw
4	31	Female	Right	Twisted foot while dancing	

Table 2. Second Tarsal Metatarsal Joint Displacement. The graph compares the total amount of displacement of the second tarsal metatarsal joint in the transverse and sagittal plane in millimeters. Notice the majority of displacement occurs in the transverse plane by almost a ratio of 4:1.



To evaluate anatomic risk for injury, the medial (A) and lateral (B) depth of the second tarsal metatarsal joint mortise was determined from an axial slice as shown in Figure 3. Likewise the second metatarsal length (C) on a sagittal slice was determined (Figure 4). We then calculated the mean depth of the mortise by adding the medial and lateral mortise depths and dividing by 2. Likewise, we calculated the ratios of the lever arm (second metatarsal length), relative to the medial mortise depth(C/A), lateral mortise depth(C/B), and mean mortise depth(C/[(A+B)/2].

The software allows for 3-D rotation of a 3-D reconstructed image of the osseous structures of the foot. Slices used for measurement were carefully positioned as not to create a tangential slice through the joint but rather a "true" slice perpendicular to the long axis of the second tarsal metatarsal joint (Figure 5).

RESULTS

Patient Population

The demographics of the patients involved in this case series are summarized in Table 1. There was a total of 4 patients (3 males and 1 female) with an average age of 33.75 years. All patients had a low energy mechanism of injury ranging from falling down stairs, to twisting their foot while dancing. All had no evidence of instability of fracture to any of the other tarsal metatarsal joints. All injuries were surgically fixated with a 4.0 mm lag screw from the medial cuneiform to the base of the second metatarsal.

Joint Instability

The mean displacement of the second tarsal metatarsal joint in the transverse plane was 4.405 mm ± 0.95 laterally. The mean displacement in the sagittal plane was 1.8mm ± 0.7. The results are summarized in Table 2. The displacement in the transverse plane was almost 4 times greater than in the sagittal plane

Anatomic Risk Factor Measurements

The mean and standard deviation of the medial mortise depth (A), the lateral mortise depth (B), the mean mortise depth (A+B/2), second metatarsal length (C), and lever arm ratios from our case series as well as the control and injury groups from by Peicha are compared in Table 3. The measurements from our case series appear to match Peicha's study. The only abnormal value in both injury groups appears to be any measurement parameter that includes the medial mortise depth.

DISCUSSION

Midfoot sprains and subtle Lisfranc's joint injuries that are isolated to only the second tarsal metatarsal joint have traditionally been regarded as rare. To our knowledge, there are 3 reports of such injuries in the literature totaling 4 cases. We report a case series of 4 isolated second tarsal metatarsal joint injuries seen within a single decade, by a single practitioner. All were diagnosed with the use of weight bearing CT, a modality not available until recently. We suggest that isolated injuries have been previously underdiagnosed due to insufficient imaging modalities and are more common than previously thought.

Peicha and colleagues examined 3 anatomical factors as possible risk factors for injury to Lisfranc's joint. The authors found that the odds of being in the injury group is 0.52 (approximately half) that of being a control if the medial depth of the mortise is increased by 1 mm (3). Our findings analyzing similar parameters agree with the above study and support the idea that a shallow second tarsal metatarsal joint mortise increases the risk of injury to that joint.

Primarily, compared to traditional imaging modalities, weightbearing CT allows for assessment of anatomic detail and functional instability to improve diagnostic accuracy in equivocal cases. The functional stability of the second tarsal metatarsal joint should be functionally evaluated for instability that may be missed with non-weightbearing examinations such as traditional CT or MRI. Secondly, it has been thought that instability or injury to Lisfranc's ligament often require stabilization of the neighboring tarsal metatarsal joints. Prior to weightbearing CT examination, it was difficult to assess the functional stability of the tarsal metatarsal joints after injury preoperatively or intra-operatively; therefore, additional and possibly unnecessary fixation may be added to stabilize joints that may not be functionally unstable. Our study shows in great detail that it is possible to have functional instability of a single tarsal metatarsal joint while the others remain stable.

The accuracy of plain film radiograph has been shown to be greatly enhanced with weightbearing. However, overlap and poor anatomic detail still can give false negatives (9). CT examination has been shown in a cadaveric model to be more sensitive and specific than plain film radiography but still lacks the functional stability assessment necessary to unmask subtle injuries (15). MRI has not been shown to add any diagnostic value compared to weightbearing radiographs (11, 16).

The weightbearing CT allows for evaluation of anatomic detail like traditional CT and evaluation of the functional stability of the joint with weightbearing. This imaging modality is ideal for evaluating subtle, low energy injuries to the midfoot; especially in the setting of negative results using traditional imaging. With continued use and further academic investigation, the utility of weightbearing CT examination for evaluation of subtle injuries to Lisfranc's joint will likely prove to be an ideal modality for definitive diagnosis of equivocal cases.

Table 3. Mean Values of Anatomic Measurements of the Second Tarsal Metatarsal Joint. Mean values of various measurements derived from the medial (A) and lateral (B) second tarsal metatarsal joint mortise depth, the mean mortise depth (A+B)/2, the second metatarsal length (C), and the relative ratios of the lever arm to the mortise depth; C/A, C/B, and C/[(A+B)/2]. The table compares the control group from Peicha's study (Pc) with the injury group from Peicha's study (Pi) and their relationship to our series data (Ii). The highlighted boxes indicate large but consistent differences between the control group and injury groups.

	Mean			
Coefficient	P_c	P_i	I_i	
A (mm)	11.61	8.95	6.31	*
B (mm)	5.00	4.74	4.38	
(A+B)/2 (mm)	8.31	6.85	5.35	*
C (mm)	73.39	72.23	76.07	
C/A	6.5	8.63	13.26	*
C/B	16.34	17.91	19.39	
C/[(A+B)/2] (mm)	9.08	11.08	14.72	

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