

The Diagnostic Accuracy of MRI to Evaluate Acute Lisfranc Joint Injuries: Comparison With Direct Operative Observations

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Abstract

Background: Early diagnosis is important in patients with Lisfranc joint injury to avoid subsequent complications. As the ligaments in the Lisfranc joint are relatively small and course obliquely, isotropic 3-dimensional (3D) magnetic resonance imaging (MRI) can be beneficial to evaluate ligament injury. The purpose of this study was to investigate the diagnostic accuracy of MRI, including isotropic 3D MRI for acute injury of the Lisfranc joint, especially of the interosseous C1-M2 ligament (Lisfranc ligament), the dorsal C1-M2 ligament (dorsal ligament), and the interosseous C1-C2 ligament, compared with direct operative observations.

Methods: This retrospective review identified 27 patients who had undergone MR examination for acute Lisfranc joint injury followed by surgery. We reviewed the operative reports that described the Lisfranc, dorsal, and interosseous C1-C2 ligaments. All patients underwent an MRI, including a 2D oblique plane image parallel to the Lisfranc ligament and an isotropic 3D MRI. An image analysis of the integrity of the 3 ligaments and other associated injuries was performed. The diagnostic accuracy of MRI was analyzed using operative findings as a reference standard.

Results: Lisfranc and dorsal ligament injuries were identified on MRI in all patients. MRI depicted disruption of the interosseous C1-C2 ligament in 12 patients. MRI diagnostic accuracy for detection of Lisfranc, dorsal, and interosseous C1-C2 ligaments was 100% (95% CI 0.82-1.0), 74% (95% CI 0.54-0.89), and 70% (95% CI 0.50-0.86), respectively.

Conclusion: MRI with oblique planes parallel to the Lisfranc ligament and isotropic 3D MRI was reliable for detecting Lisfranc ligament injury, whereas MRI findings of the dorsal and interosseous C1-C2 ligaments were less consistent with operative observations.

Level of Evidence: Level IV, case series.

Keywords: Lisfranc injury, Lisfranc ligament, magnetic resonance imaging

Introduction

The Lisfranc ligament, the interosseous ligament that connects the medial cuneiform (C1) and the base of the second metatarsal (M2), is important to support the alignment of the Lisfranc joint. There are ligaments on dorsal and plantar aspects that run parallel to the Lisfranc ligament.^{3,26,29} The dorsal C1-M2 ligament (dorsal ligament) connects C1 and the base of M2, and the plantar ligament connects C1 with the base of M2 and the third metatarsal (M3).^{3,9,26,29} Description and naming of these ligaments are not uniform. The interosseous C1-M2 ligament being called the interosseous Lisfranc ligament, dorsal C1-M2 ligament being called the dorsal Lisfranc ligament, and the plantar C1-M2,

M3 ligament being called the plantar Lisfranc ligament.^{28,31} The Lisfranc ligament is strong, consisting of 1 to 4 bundles.⁷ The dorsal ligament is flat and relatively thin.^{3,7,14} The plantar C1-M2, M3 ligament (plantar ligament) is

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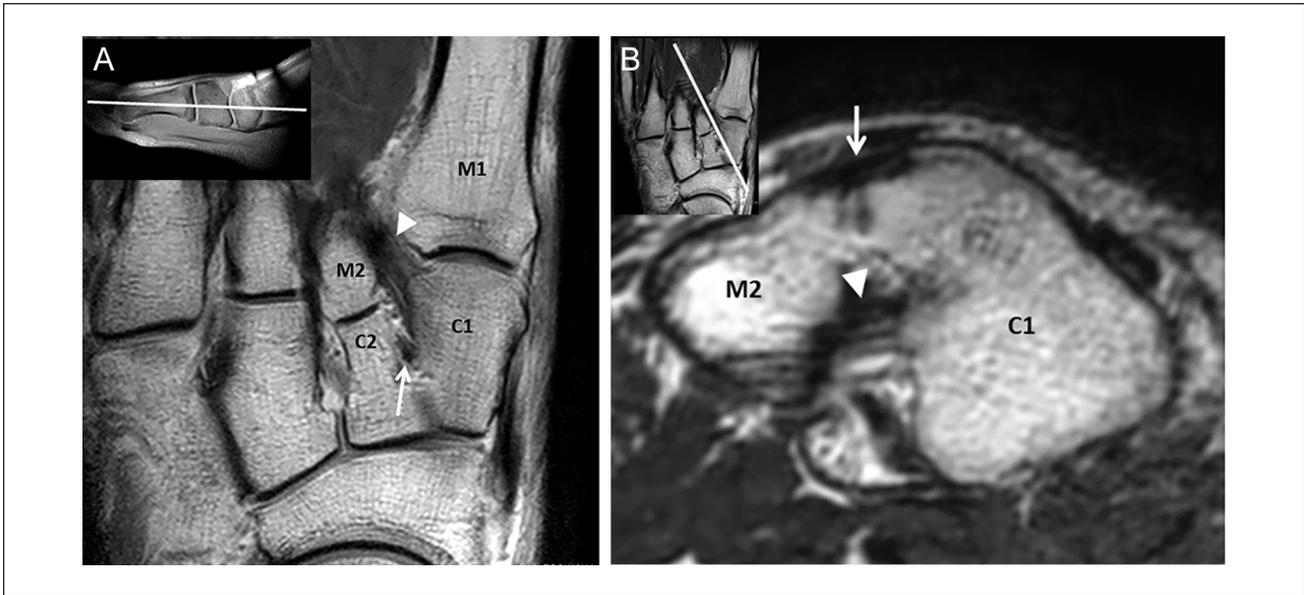


Figure 1. Normal Lisfranc ligament and dorsal ligament. (A) Long axis and (B) oblique sagittal proton density-weighted images show the Lisfranc ligament extending from the lateral surface of C1 to the medial surface of the base of M2 (arrowheads in A and B). The Lisfranc ligament is taut with a striated appearance. The dorsal ligament runs parallel to the Lisfranc ligament and appears homogeneous with low signal intensity (short arrow in B). The interosseous C1-C2 ligament is apparent (long arrow in A). Scout images with reference lines are presented. C1, medial cuneiform; C2, middle cuneiform; M1, first metatarsal; M2, second metatarsal.

strong and variable in shape.^{7,26} Anatomical and biomechanical studies suggest that the Lisfranc ligament is the strongest, the plantar ligament is the second strongest, and the dorsal ligament is the weakest.^{14,29,30}

Lisfranc joint injury causes ligament injury without significant dislocations of the Lisfranc joint.^{2,4,5,15,18,24,27} These injuries may not be detectable on radiographs in the acute phase,^{2,23} which results in prolonged pain, flatfoot deformity, or posttraumatic arthritis.⁶ The intercuneiform ligament between C1 and C2 (interosseous C1-C2 ligament) is a strong and thick ligament,²⁶ which plays an important role in stability of the Lisfranc joint. If the Lisfranc ligament and the interosseous C1-C2 ligament are torn, longitudinal instability of the Lisfranc joint will occur.¹⁰

Magnetic resonance imaging (MRI) is an excellent tool to assess soft tissue injury and is known to be useful to evaluate Lisfranc ligament injury.^{12,16,19,20,22,32} The normal Lisfranc ligament appears as a hypointense bandlike structure on T1-weighted images,²¹ and striated or homogeneous with low to intermediate signal intensity on proton density-weighted images.^{1,12} There can be single or multiple fasciculi. The dorsal ligament appears as a single band with homogeneous low-signal intensity on proton-density weighted image^{1,12} (Figure 1). Because the Lisfranc ligament runs obliquely to the anatomical body axis, a dedicated plane parallel to the Lisfranc ligament, and an isotropic 3-dimensional (3D) MRI, are advantageous to assess injury.^{12,32} There are no reports of MR findings of acute Lisfranc injury using dedicated oblique

planes or isotropic 3D MRI compared to direct operative observations.

Anatomic reduction and stable fixation are the most important factors for treatment of acute unstable Lisfranc injuries. Open reduction and screw fixation or primary arthrodesis are performed frequently.^{13,33} Anatomical reconstruction of the Lisfranc ligament has been developed as an alternative operative procedure for Lisfranc ligament injury.^{8,17,34} Direct observation of the degree of injury of the Lisfranc ligament, the dorsal ligament, and the interosseous C1-C2 ligament is performed during surgery.⁸ Precise diagnosis of these ligament injuries is important to select the best treatment option.

The purpose of this study was to investigate the diagnostic accuracy of MRI using oblique planes and isotropic 3D MRI to detect acute injuries to the Lisfranc ligament, dorsal ligament, and interosseous C1-C2 ligament compared with operative findings as the standard of reference.

Materials and Methods

Patient Selection

This retrospective observational study was approved by our institutional review board with a waiver of informed consent.

We retrospectively searched our radiology reporting system database with keywords of “MRI foot” or “MRI ankle,” and “Lisfranc injury,” “Lisfranc fracture

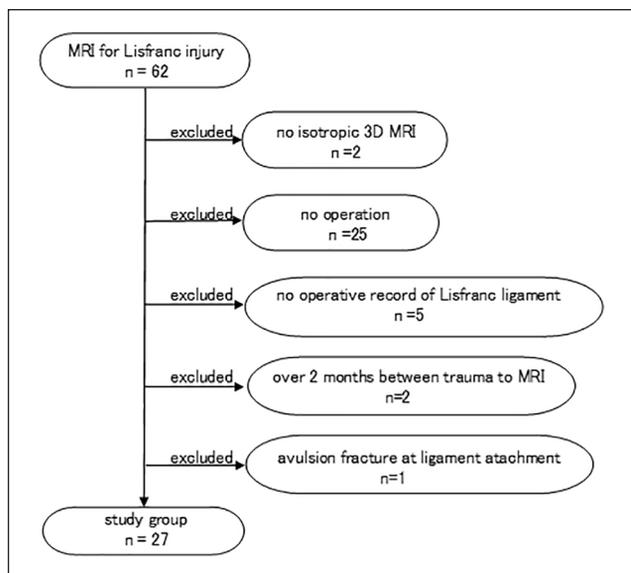


Figure 2. Flow diagram of patient selection.

and dislocation,” or “Lisfranc ligament.” Sixty-two MR examinations were conducted between April 2014 to June 2017. Two MR examinations that did not include an isotropic 3D MRI sequence were excluded. A chart review of these 60 MR examinations revealed that 35 of 60 patients underwent surgery of the foot following MR examination. Findings of the Lisfranc ligament during surgery were not included in the chart for 5 patients. More than 2 months elapsed between trauma and the MRI examination in 2 patients. An avulsion fracture was apparent on MRI at C1 in 1 patient. The remaining 27 patients underwent surgery for Lisfranc joint injury, and the operative record described findings of the Lisfranc ligament, the dorsal ligament, and the interosseous C1-C2 ligament. Thus, 27 examinations from 27 patients were analyzed for this study (Figure 2). There were 13 men and 14 women, mean age 34 years (range, 13-72 years). The interval between trauma and the MR examination was between 2 and 35 days (mean 10.3 days, median 9 days). The interval between MR examination and surgery was between 1 and 181 days (mean 14.6 days, median 6 days).

Operative Records Review

Operative reports were reviewed by one radiologist, and findings of the Lisfranc and dorsal ligaments were recorded. Interpretation of the operative reports was performed in cooperation with an orthopaedic surgeon who specializes in foot and ankle surgery. The dorsal ligament was inspected in the direct-view, and ligament injury was concluded when discontinuity of the ligament was observed. An accompanying hemorrhage at the ligament was recorded. Injuries of the Lisfranc and C1-C2 ligaments were inspected using a dissector. The joint space between C1 and M2 or the C1-C2

intercuneiform joint is tight normally, and the dissector cannot enter into the joint space if the Lisfranc ligament or C1-C2 ligament are intact. When the dissector went into the joint space between C1 and M2 or C1 and C2, the ligament was judged torn and unstable.

MRI Technique

MRI was performed with a 1.5-tesla (T) magnet (Achieva Nova; Philips MRI, Best, The Netherlands) in 16 examinations or a 3.0-T magnet (Ingenua; Philips MRI, Best, The Netherlands) in 11 examinations using a Flex S coil (70 mm of inner diameter, 2 channel). The following images were collected: proton density-weighted images (repetition time, 2000 ms; echo time, 35-40 ms) in the long axis plane parallel to the plantar aspect of the foot and oblique sagittal images parallel to the Lisfranc ligament; T2-weighted long axis and oblique sagittal planes (repetition time, 3300-3600 ms; echo time, 80-85 ms); and STIR (short tau inversion recovery) long axis plane (repetition time, 2200-3500 ms; echo time, 15-30 ms; inversion time 165-230 ms). In each plane, MRI was performed using a 100-mm field of view with a 3-mm slice thickness. Volume data were obtained using a VISTA (Volumetric Isotropic T2-weighted Acquisition, repetition time, 1000-1500 ms; echo time, 110-120 ms, turbo spin echo factor 30-40, resolution $0.6 \times 0.6 \times 0.6$ mm) sequence and were reformatted in arbitrary planes by each reviewer using a 3D workstation (Ziosoft Inc, Tokyo, Japan).

MRI Evaluation

The MRIs were analyzed by 2 musculoskeletal radiologists with 8 and 17 years of experience in musculoskeletal imaging without knowing the patients' clinical backgrounds or operative results. The consensus interpretation was used for analysis. The following features of the Lisfranc ligament and dorsal ligament were evaluated: (a) continuity of the ligament to both sides of the attachment, (b) changes in shape (thinning, thickening, deformity, or irregularity), and (c) changes in signal intensity on proton density-weighted images. A complete tear was defined as a loss of ligament continuity. An incomplete tear was defined as an abnormality of shape or signal intensity of the ligament without disruption. Only the ligament continuity was evaluated about the interosseous C1-C2 ligament because it is too small to evaluate signal intensity or shape. The presence or absence of soft tissue swelling and fracture with bone marrow edema or a bone bruise in the tarsal bones or base of the metatarsal bones at the Lisfranc joint were evaluated.

The shortest distance between the lateral surface of C1 and the medial surface of the base of M2 was measured to assess the presence or absence of malalignment. The measurement was performed by 1 musculoskeletal radiologist 3 times and the results were averaged (the C1-M2 distance) (Figure 3).

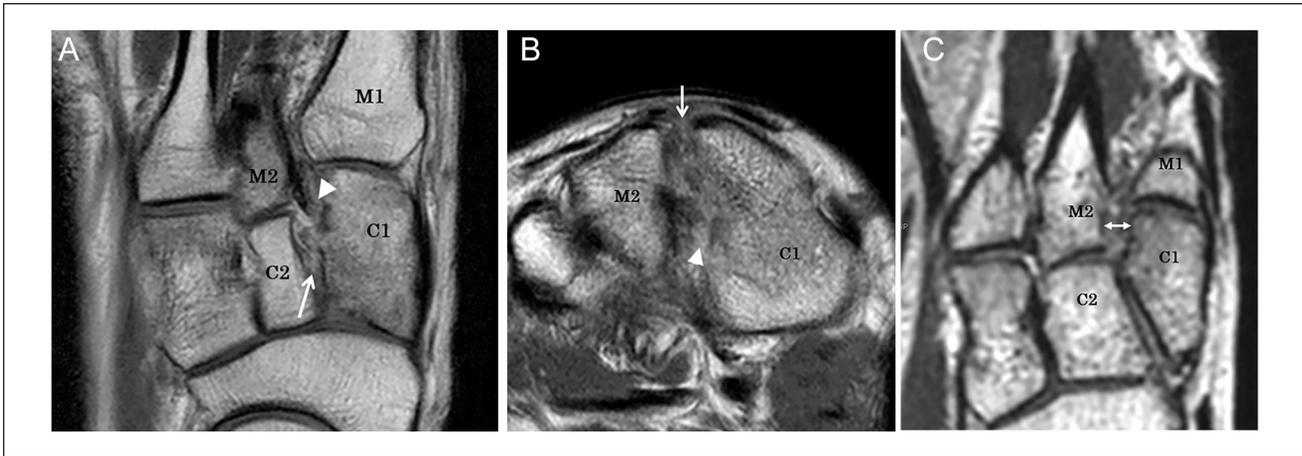


Figure 3. A 16-year-old woman with right foot pain after sprain. (A and C) Long axis and (B) oblique sagittal proton density-weighted images 10 days after tremble injury. There were discontinuity of the Lisfranc ligament near the attachment of the medial cuneiform (arrowhead in A and B) and absence of the interosseous C1-C2 ligament (long arrow in A), and the dorsal ligament (short arrow in B), indicating complete tear. Findings were confirmed at surgery. The measurement of C1-M2 distance is shown in C. C1, medial cuneiform; C2, middle cuneiform; M1, first metatarsal; M2, second metatarsal.

Statistical Analysis

Sensitivity, specificity, and diagnostic accuracy of MRI for Lisfranc, dorsal, and interosseous C1-C2 ligament injuries were calculated using operative findings as a standard of reference. The 95% CI of these estimations was calculated. Mann-Whitney tests were used to evaluate the differences in the C1-M2 distance between groups with and without injuries to each of the ligaments. A P value $<.05$ was considered significant. Statistical analysis was performed using EZR (Saitama Medical Center, Jichi Medical University, 1.54), which is a graphical user interface for R.¹¹

Results

Operative Findings

All of the 27 patients (100%) had a complete tear of the Lisfranc ligament at surgery. Twenty (74%) patients had a complete tear of the dorsal ligament. Continuity of the dorsal ligament was present in 7 patients (26%), and there was a hemorrhage at the dorsal ligament in 3 of these 7 patients. In these 7 patients, there was stability of the dorsal ligament, so that it was judged at surgery as not torn. All dorsal ligament injuries were accompanied by a Lisfranc ligament injury. The interosseous C1-C2 ligament was torn in 6 patients (22%), and both the Lisfranc and dorsal ligaments were torn in these patients.

MRI Evaluation and Correlation to the Operative Findings

In the consensus interpretation, MRI showed a Lisfranc ligament injury in 27 patients (complete tear in 26 and incomplete tear in 1). MRI suggested a complete tear of the

dorsal ligament in 27 patients. No patient was diagnosed with normal Lisfranc and dorsal ligaments. MRI depicted a tear of the interosseous C1-C2 ligament in 12 patients, and a normal ligament in 15 patients.

MRI resulted in 27 true-positive diagnoses of a Lisfranc ligament injury, for a sensitivity and accuracy of 100% (95% CI 0.82-1.0). Specificity was not calculated because there were no true-negative diagnoses. MRI resulted in 20 true-positive and 7 false-positive diagnoses of dorsal ligament injury (with no negative diagnoses) for a sensitivity of 100% (95% CI 0.76-1.0), specificity of 0% (95% CI 0-0.53), and accuracy of 74% (95% CI 0.54-0.89). MRI resulted in 5 true-positive, 1 false-negative, 7 false-positive, and 14 true-negative diagnoses of the interosseous C1-C2 ligament injury for a sensitivity of 83% (95% CI 0.36-1.0), specificity of 67% (95% CI 0.43-0.85), and accuracy of 70% (95% CI 0.50-0.86) (Figures 3-6).

Soft tissue swelling was present in all patients (27/27, 100%). Fractures with bone marrow edema or a bone bruise (edema but without a fracture) in the tarsal bones or base of the metatarsal bones were present in 26 patients (26/27, 97%). MRI findings and operative findings are summarized in Table 1.

The mean value of the C1-M2 distance in the 3 ligaments is presented in Table 2. With the sample size available, the C1-M2 distance was significantly greater in the group with a dorsal C1-M2 injury than in those without ($P <.05$). There was no significant difference between groups with or without interosseous C1-C2 injury.

Discussion

This study demonstrates that acute Lisfranc ligament injury can be diagnosed accurately on MRI using 2D planes along

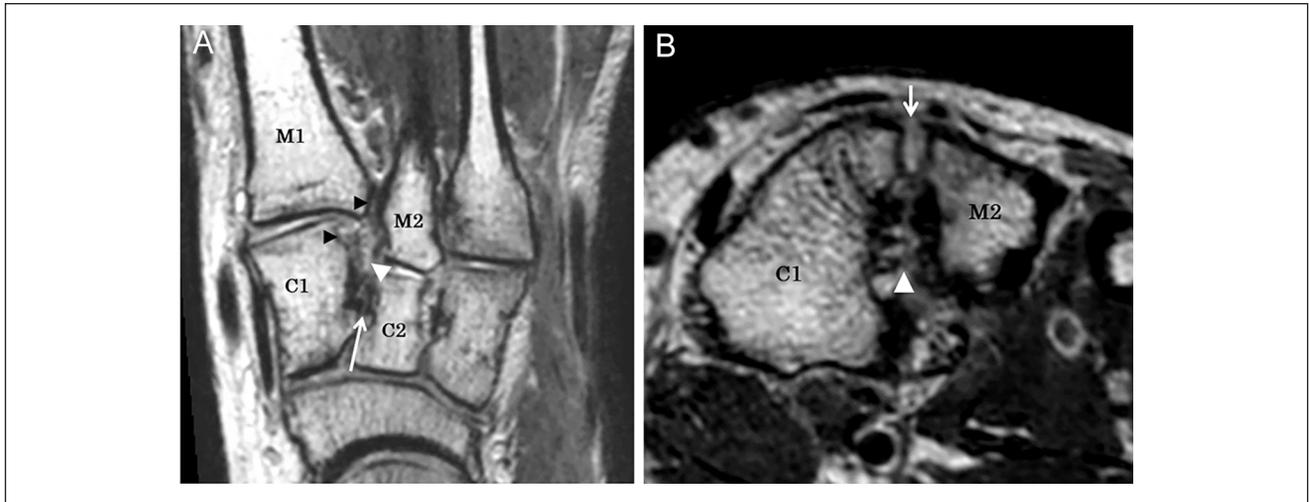


Figure 4. A 17-year-old man with left foot pain 10 days after a sports injury. (A) Long axis and (B) oblique sagittal proton density-weighted images show disruption of the Lisfranc ligament (white arrowhead in A and B) and the interosseous C1-C2 ligament (long arrow in A), indicating a complete tear. No dorsal ligament is present (short arrow in B). Note the lateral dislocation of M1 against C1 (black arrowhead in A). There was a complete tear of the Lisfranc ligament. However, the dorsal and interosseous C1-C2 ligaments were intact according to the operative record. C1, medial cuneiform; C2, middle cuneiform; M1, first metatarsal; M2, second metatarsal.

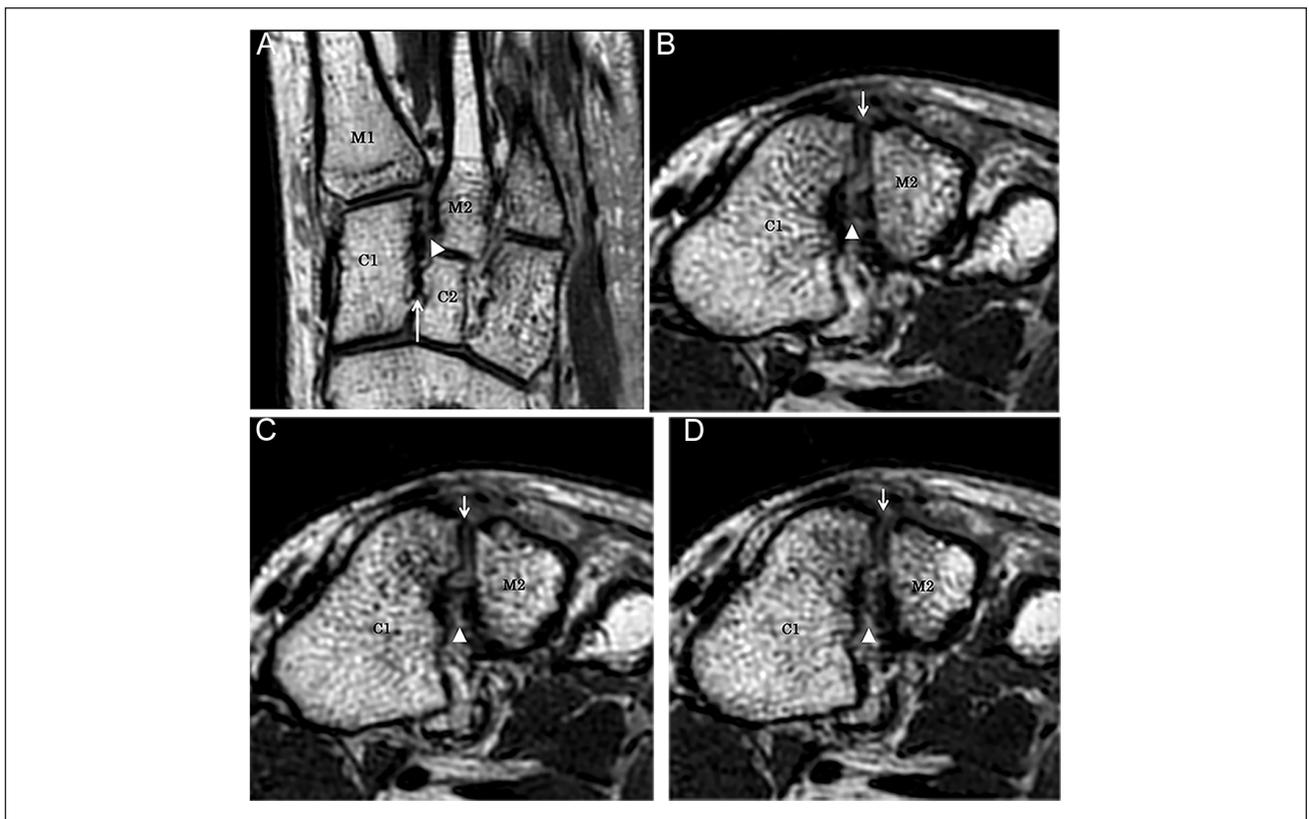


Figure 5. A 14-year-old man with left foot pain 9 days after injury. (A) Long axis and (B-D) continuous 3 oblique sagittal proton density-weighted images show disruption of the Lisfranc ligament (white arrowhead in A and B-D) and the interosseous C1-C2 ligament (long arrow in A), indicating a complete tear. No dorsal ligament is present (short arrow in B-D). There was a complete tear of the Lisfranc ligament. However, the dorsal ligament and interosseous C1-C2 ligament were intact according to the operative record. C1, medial cuneiform; C2, middle cuneiform; M1, first metatarsal; M2, second metatarsal; M3, third metatarsal. Images were reconstructed from isotropic 3D proton density-weighted images.

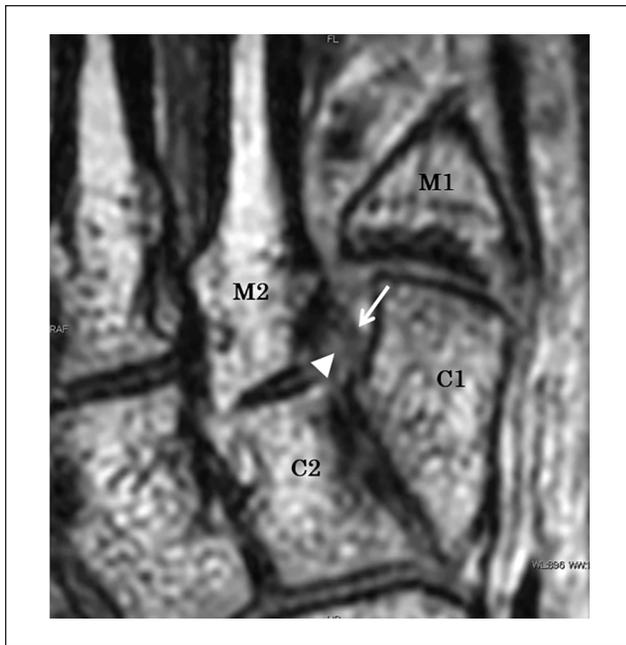


Figure 6. A 42-year-old woman with right foot pain 4 days after sprain. Long axis proton density-weighted images show discontinuity and a wavy appearance of Lisfranc ligament fibers (arrowhead). Continuous fibers remain at the medial aspect of the Lisfranc ligament (long arrow). This case was judged an incomplete tear. There was a complete tear of the Lisfranc ligament at surgery. C1, medial cuneiform; M1, first metatarsal; M2, second metatarsal; M3, third metatarsal.

the ligament with isotropic 3D MRI. The diagnostic accuracy of MRI for the dorsal ligament injury was not as high compared with that of the Lisfranc ligament injury. MRI showed a complete tear of the dorsal ligament in all patients, although it was considered intact at surgery in 7. The diagnostic accuracy of the interosseous C1-C2 ligament was slightly lower compared with the Lisfranc and dorsal ligaments. Soft tissue swelling and fractures with bone marrow edema or a bone bruise were present in almost all patients, consistent with acute injury.

Anatomical studies of the ligaments at the Lisfranc joint^{3,19,25,26} show it to be a large interosseous C1-M2 ligament with single³ or multiple fasciculi.^{7,26} The dorsal ligament is a short and flat ligament that runs superficial to the joint between C1 and M2.^{3,7} The differences in anatomical characteristics between the Lisfranc ligament and the dorsal ligament are reflected in their appearance on MRI. The Lisfranc ligament appears striated with low to intermediate signal intensity bands, whereas the dorsal ligament appears as a single homogeneously low-intensity signal band on proton density-weighted images.^{1,12}

For MRI evaluation of soft tissues at the Lisfranc joint, imaging with a small field of view is recommended to improve spatial resolution due to the relatively small size of

the ligamentous structures.²⁸ Furthermore, many ligaments at the Lisfranc joint are not parallel to orthogonal planes of the foot, so that isotropic 3D MR images are thought to be optimal for assessment of the ligaments of this joint.^{12,32} In the present study, acute Lisfranc ligament injury was diagnosed accurately on MRI.

Seven patients were diagnosed with a complete tear of the dorsal ligament on MRI, but the ligament was confirmed to be intact at surgery. Three of these 7 patients had hemorrhage at the dorsal ligament with continuity; it is possible that these changes were reflected by increased signal intensity on the MRI. We speculate that the MRI is sensitive in demonstrating hemorrhage and edematous change of acutely injured ligaments, which resulted in overdiagnosis of the ligament injury. This may limit accurate diagnosis of an acute injury of the dorsal ligament on MRI.

Diagnostic accuracy for the interosseous C1-C2 ligament was low compared to that of the Lisfranc ligament. The interosseous C1-C2 ligament injury is related closely to the longitudinal type of Lisfranc joint injury,¹⁰ so it is meaningful to depict integrity of this ligament. Because it is small, it can be overlooked on low-resolution images. We utilized isotropic MRI with a voxel size of 0.6 mm, which we believed would depict small ligaments. The results indicated that the special resolution was not high enough to demonstrate the integrity of the intercuneiform ligament.

The dorsal ligament is considered much weaker than the Lisfranc ligament,^{14,29} but there were 7 cases with complete tear of the Lisfranc ligament with a preserved dorsal ligament at the time of surgery. The reason for this remains unclear. The Lisfranc ligament is an interosseous ligament whereas the dorsal ligament is a superficial ligament, and this anatomical difference may affect how they perform differently when they receive excessive external force. For example, plantar structures crushed first, and depending on the degree of power, the dorsal ligament was intact while the Lisfranc ligament was torn. Further histologic and biomechanical investigations are needed to resolve this question.

A systematic review reports that a Lisfranc injury should be suspected if the C1-M2 distance is greater than 3 mm in nonweightbearing conditions.³¹ In this study, MRI was performed in the nonweightbearing condition and the average of the C1-M2 distance was 2.9 mm, almost equal to the threshold presented by previous studies.³¹ As all patients in this study had a torn Lisfranc ligament, the C1-M2 distance on MRI may underestimate the incidence of Lisfranc injuries. The C1-M2 distance was significantly greater in patients with a dorsal ligament tear than in those without. This suggests that the dorsal ligament may contribute as an important stabilizer of the Lisfranc joint.¹⁴

Anatomic reconstruction of the Lisfranc ligament is a possible treatment option for acute Lisfranc ligament

Table 1. MRI and the Operative Findings.

Patient	Age (y) / Sex	Interval Between Trauma to MRI, (days)	MR Imaging						Operation		
			LL	DL	CI-C2	Soft Tissue Edema	Fracture/ Bone Bruise	Interval Between MRI and Surgery, (days)	LL	DL	CI-C2
1	19/F	4	C	C	NT	Y	Y	5	T	T	NT
2	13/F	9	C	C	T	Y	Y	1	T	T	T
3	42/F	4	I	C	T	Y	Y	11	T	NT	NT
4	49/M	6	C	C	T	Y	Y	1	T	T	NT
5	28/F	11	C	C	T	Y	Y	6	T	NT	NT
6	46/F	10	C	C	NT	Y	Y	6	T	T	NT
7	48/F	10	C	C	NT	Y	Y	7	T	T	NT
8	30/M	2	C	C	NT	Y	Y	13	T	T	NT
9	14/F	17	C	C	NT	Y	Y	6	T	NT	NT
10	26/M	35	C	C	T	Y	Y	181	T	T	NT
11	31/M	3	C	C	NT	Y	Y	6	T	T	NT
12	16/F	9	C	C	T	Y	Y	7	T	T	T
13	57/M	15	C	C	NT	Y	Y	3	T	T	NT
14	32/F	6	C	C	T	Y	Y	5	T	NT	NT
15	24/M	3	C	C	NT	Y	Y	12	T	T	NT
16	17/M	10	C	C	T	Y	Y	15	T	NT	NT
17	21/F	7	C	C	T	Y	Y	9	T	T	T
18	47/M	9	C	C	NT	Y	N	9	T	NT	NT
19	43/F	6	C	C	NT	Y	Y	8	T	T	NT
20	44/M	11	C	C	T	Y	Y	5	T	T	NT
21	39/M	14	C	C	NT	Y	Y	3	T	T	NT
22	46/M	4	C	C	NT	Y	Y	4	T	T	T
23	57/F	17	C	C	T	Y	Y	5	T	T	T
24	16/F	10	C	C	T	Y	Y	5	T	T	T
25	14/M	9	C	C	NT	Y	Y	16	T	NT	NT
26	22/M	27	C	C	NT	Y	Y	40	T	T	NT
27	72/F	10	C	C	NT	Y	Y	4	T	T	NT

Abbreviations: C, complete tear; CI-C2, interosseous CI-C2 ligament; DL, dorsal ligament; IC, incomplete tear; LL, Lisfranc ligament; MRI, magnetic resonance imaging; N, absent; NT, no tear; T, tear; Y, present.

Table 2. The CI-M2 Distance on MRI Between Groups With and Without Ligament Injuries at Surgery.

Distance, mm, mean ± SD (n)	Ligament Injuries at Surgery		P Value
	Presence	Absence	
Lisfranc ligament	2.9±1.3 (27)	NA*	NA*
Dorsal ligament	3.2±1.4 (20)	2.1±0.8 (7)	.046
Interosseous CI-C2 ligament	2.5±0.8 (6)	3.0±1.4 (21)	NS (.54)

Abbreviations: CI-M2 distance, the shortest distance between the lateral surface of the medial cuneiform and the medial surface of the base of the second metatarsal; MRI, magnetic resonance imaging; NA, not available because there was no patient without Lisfranc ligament injury at the time of surgery; NS, not significant.

injury.^{8,17,34} For this purpose, MRI is useful to know the condition of the Lisfranc, dorsal, and plantar ligaments in the acute phase of injury. If open reduction and screw fixation or primary arthrodesis were selected for operative management, MRI was not indicated for diagnosis of acute Lisfranc injury.

There are some limitations to this study. First, the number of the patients included was small. Second, only patients who had an MRI with available operative findings of the Lisfranc ligament and dorsal ligament injury were included. Because the surgeons were aware of the MRI findings at the time a decision was made about the operative indication for

the Lisfranc injury, the sensitivity of the MRI identification of the Lisfranc ligament injury could be affected by selection bias. Third, assessment of injury to the plantar ligament, which is also strong and supports the transverse plantar arch,^{3,29} was not included in this study. There was no operative record of the condition of the plantar ligament because it was not included in the operative plan and was too deep to observe its integrity.

In conclusion, assessment of an acutely traumatized Lisfranc ligament using MRI in an oblique plane parallel to the ligament together with an isotropic 3D MRI was reliable for demonstrating ligament injury. Precise evaluation of the condition of the injured Lisfranc ligament may be useful to decide the optimal treatment, including ligament reconstruction. Applying isotropic 3D MRI is convenient to observe midfoot ligaments even when there is malalignment from dislocation. However, MRI findings for the dorsal C1-M2 ligament and the interosseous C1-C2 ligament were less consistent with operative identification.

Authors' Note

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Ethical Approval

Ethical approval for this study was obtained from the Institutional Review Board at St Marianna University School of Medicine (approval number 3720).

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. ICMJE forms for all authors are available online.

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