Title

Reliability of various diastasis measurement methods on weightbearing radiographs in patients with subtle Lisfranc injuries

Abstract

Objective. This study aimed to evaluate the reliability of the diastasis measurements between the medial cuneiform and the second metatarsal on weightbearing radiography.

Materials and Methods. We retrospectively examined 18 patients who underwent open surgery for subtle Lisfranc injuries. Preoperative weightbearing radiography of the affected and unaffected feet was evaluated in all patients. The diastasis between the medial cuneiform and the second metatarsal was measured in both feet using the following four methods: diastasis between parallel lines, distal-point diastasis, middle-point diastasis, and proximal-point diastasis. Intraclass correlation coefficients with consistency of agreement were calculated to evaluate inter- and intraobserver reliability.

Results. The intra- and interobserver reliabilities of all four methods were good. Intraclass correlation coefficients for intraobserver reliability ranged from 0.87 to 0.93. Those for interobserver reliability ranged from 0.81 to 0.91.

Conclusions. The reliabilities of the diastasis measurement methods between the medial cuneiform and the second metatarsal on weightbearing radiography were good. Measuring the diastasis between the medial cuneiform and the second metatarsal on weightbearing radiography is useful in evaluating subtle injuries when uniform measurement methods are used.

Keywords

subtle Lisfranc injuries; weightbearing radiograph; reliability; diastasis

Introduction

Lisfranc injuries were originally described as a partial or complete dislocation of the tarsometatarsal joints in 1909 [1]. Epidemiologic studies performed in the United States showed that the incidence of Lisfranc injuries is approximately 1 in 55,000 [2]. The Lisfranc ligament affected by injury is a thick oblique ligament extending from the base of the second metatarsal to the plantar aspect of the medial cuneiform (C1). The Lisfranc ligament is important for stability at the tarsometatarsal joint because there is no transverse metatarsal ligament between the first and second metatarsals (M2) as is the case between the second and fourth metatarsals. Lisfranc injuries are divided into severe and subtle injuries based on the trauma mechanism [3, 4]. Subtle injuries result from indirect low-energy traumas such as twists and sprains [3, 5] and can be difficult to diagnose because of their variable clinical presentations and radiographic findings [6-8].

Subtle injuries are commonly evaluated using one or more of the following imaging modalities: non-weightbearing radiography (non-WBR), weightbearing radiography

(WBR), computed tomography, weightbearing computed tomography, magnetic resonance imaging, and ultrasonography [8-11]. Several studies have reported that weightbearing imaging has a higher sensitivity for detecting subtle injuries compared with non-weightbearing imaging [2, 12]. Weightbearing computed tomography is particularly useful to evaluate subtle injuries [8, 10, 11]. A method to measure the diastasis between C1 and M2 using this modality has been proposed [8]. However, weightbearing computed tomography is not available in all institutions and the measurement methods have not been standardized [11, 13]. Therefore, WBR remains the most useful modality for primary evaluation and diagnosis [8, 13, 14].

Various measurement methods have been used in the radiographic assessment of Lisfranc injuries [2, 3, 7, 8, 10-12, 15]. In particular, the measurement of C1-M2 diastasis on WBR is important to determine the appropriate treatment of Lisfranc injuries [11, 16]. However, a specific method for C1-M2 diastasis measurement has not been established, and no studies have reported measurement reliability. We expect that the standardization of C1-M2 diastasis measurements might lead to the appropriate treatment of subtle injuries.

The aim of this study was to establish a method of C1-M2 diastasis measurement on WBR, and to evaluate the reliability of these C1-M2 diastasis measurements.

Materials and methods

We examined 26 consecutive patients who underwent open surgery for a subtle tarsometatarsal injury of the first and second columns from January 2013 to September 2019 and had a Lisfranc ligament tear confirmed by direct intraoperative visualization. Informed consent was obtained from all individual participants included in this study. Seven patients unable to bear weight because of severe pain or multiple fractures were excluded. Another patient was excluded because of a history of previous foot surgery. Finally, 18 patients (8 men and 10 women) were included for analysis. Mean patient age was 25.8 ± 10.7 years (range, 14–46). The injury was on the right in 8 patients and the left in 10. Two patients had a C1 fracture and four exhibited the fleck sign on radiography. All injuries were classified according to the Nunley and Vertullo system for Lisfranc injuries [3]. Subtle injury was defined according to the criteria of Faciszewski [17]: 1) diastasis between the bases of the first metatarsal (M1) and M2 that measures 2–5 mm by anterior-posterior radiography; 2) no other foot injury, including fracture or subluxation of the fourth or fifth metatarsal cuboid articulations by oblique radiography; and 3) no subluxation of the base of M1 relative to C1 [17, 18]. Patient characteristics are summarized in Table 1. Anterior-posterior WBR of the affected and unaffected feet was performed with the central beam oriented 15 degrees from the vertical and aimed at the center of the navicular while the patient was standing upright on both feet [19]. Radiographic parameters were measured using a picture archiving and communications system with a uniform image expansion rate (350%). We used the following four methods to measure C1-M2 diastasis on WBR in affected and unaffected feet: 1) diastasis between parallel lines (distance between parallel lines drawn along the C1-M2 articular surface); 2) distal-point diastasis (distance between the distal end of the C1-M2 articular surface); 3) middle-point diastasis (distance between the middle points of the C1-M2 articular surface); and 4) proximal-point diastasis (distance between the proximal end of the C1-M2 articular surface) (Figure 1). In some cases, the C1-M2 articular surface appeared to have a double floor related to the rotation of C1 associated with subtle Lisfranc injuries and differences in anatomical features. Such cases are defined as double floor in this study. When C1 and/or M2 had a double floor appearance, the longest distance between C1 and M2 was measured (Figure 2). WBR was independently assessed by four observers in accordance with previous studies [20, 21]; two were senior orthopedic surgeons with 10 or more years of experience and two were orthopedic surgery residents with 3 to 7 years of experience. The first observer measured the C1-M2 diastasis three times at intervals of one month.

Statistical analyses were performed using Statistical Package for the Social Sciences version 23.0 software (IBM Corp., Armonk, NY, USA). Clinical data are presented as means with standard deviation, numbers with percentage, or ranges. Continuous variables were compared using the Mann–Whitney *U*-test. Intraclass correlation coefficients (ICCs) with consistency of agreement were calculated to evaluate intraobserver reliability between the three measurements performed by the first observer and interobserver reliability between the four observers. Power analysis was performed using R software version 2.8.1 (www.r-project.org): 18 patients exceeded the minimum number of patients required to enable the accurate calculation of intra- and interobserver reliabilities. Post hoc power analysis to evaluate ICC showed that the statistical analysis performed was appropriate. $P < 0.05$ was considered statistically significant.

Results

The measurements obtained by the first observer using each of the four methods are shown in Table 2. All measurements of the C1-M2 diastasis on the affected side were significantly greater than those on the unaffected side by 2 mm or more (range, 2.14–2.35; $P < 0.01$).

The intra- and interobserver reliabilities of the measurements obtained by the four observers using each method are shown in Table 3. In the measurements of the unaffected side, the highest intraobserver reliability was seen for the middle-point diastasis and diastasis between parallel lines methods (ICC 0.93). In the measurements of the affected side, the highest intraobserver reliability was seen for the distal-point diastasis method (ICC 0.92), followed by the diastasis between parallel lines method (ICC 0.87). In the measurements of the unaffected side, the highest interobserver reliability was seen for the middle-point diastasis method (ICC 0.91), followed by the proximal-point diastasis and distal-point diastasis methods (ICC 0.89). In the measurements of the affected side, the highest interobserver reliabilities were seen for the diastasis between parallel lines and middle-point diastasis methods (ICC 0.88). The intra- and interobserver reliabilities of all methods were good. ICCs for intraobserver reliability ranged from 0.88 to 0.93 on the unaffected side and from 0.87 to 0.92 on the affected side. ICCs for interobserver reliability ranged from 0.81 to 0.91 on the unaffected side and from 0.84 to 0.88 on the affected side.

Discussion

All WBR C1-M2 diastasis measurement methods (diastasis between parallel lines, distal-point diastasis, middle-point diastasis, and proximal-point diastasis) used to evaluate subtle Lisfranc injuries in this study had high levels of inter- and intraobserver agreement. Therefore, C1-M2 diastasis measurement on WBR appears to be useful in evaluating subtle injuries when uniform measurement methods are used.

Subtle injuries are difficult to diagnose and treat properly because of their various clinical manifestations. Therefore, imaging tests have an important role in the accurate diagnosis of subtle injuries and various imaging modalities are used [8-11]. CT provides good accuracy in visualizing osseous morphology [8, 11]. Recent studies have shown that WBCT is useful for evaluating subtle injuries [8, 10, 11] and proposed a WBCT C1–M2 diastasis measurement method [8]. However, currently, it is difficult to investigate subtle injuries using WBCT because the method has not been standardized and it is not currently performed in all institutions [11, 13]. MRI is the superior modality to detect ligamentous abnormalities [11]. Despite its high sensitivity and specificity, MRI has several disadvantages. First, MRI is costly and not always readily available. Second, it is difficult to perform under weightbearing conditions and for the exact measurement of C1–M2 diastasis [11]. A recent systematic review recommended a diagnostic algorithm to guide their imaging [11]. Investigations should begin with radiography [10-12, 19, 22]. However, up to 50% of subtle Lisfranc injuries can be missed on non-WBR [3, 10]; therefore, WBR should be included [3, 23]. WBR is the preferred primary evaluation modality because of its ease and simplicity [13, 14]. In a cadaveric study, Panchbhavi et al. [23] found that bone displacement significantly differed between weightbearing and non-weightbearing conditions and reported that WBR of both feet was required to compare the affected and unaffected feet in patients with a high suspicion of injury. Nunley et al. [3] reported good treatment outcomes in athletes with Lisfranc injuries classified according to WBR, which was found to be sensitive, reproducible, and relatively inexpensive. WBR assessment of diastasis remains an effective primary evaluation tool in patients with Lisfranc injuries.

Diastasis resulting from Lisfranc injuries can be radiographically assessed using various methods. These include the measurement of tarsometatarsal joint alignment along the medial borders of the second metatarsal and the middle cuneiform [11], distance between the proximal parts of M1 and M2 [24], distance between C1 and M2 [17, 21], distance between C1 and the middle cuneiform bone [15], and others (Figure 3). The current consensus is that articular instability is indicated by the presence of C1-M2 diastasis on WBR [2, 8, 16, 22]. Seo et al. [15] examined the accuracy of the radiological diagnosis of Lisfranc injuries and found that the diagnostic sensitivity and specificity of radiographic C1-M2 diastasis (>2 mm distance between C1 and M2 in the anterior-posterior view) for unstable injury were 0.92 and 1, respectively. However, previous studies did not describe the specific anatomical C1 and M2 landmarks used as measurement reference points [15, 21, 24]. This lack of standardization can affect measurements and explain measurement differences between our and previous studies [11, 15, 19, 21]. Uniform diastasis measurement methods are important when evaluating subtle injuries.

Measurement reproducibility (intraobserver reliability) and reliability (interobserver reliability) are also important when evaluating methods of measurement [12]. Intraobserver reliability mathematically evaluates the test–retest reliability of a method [25] while interobserver reliability evaluates measurement correlations between observers [12, 26]. Ponkilainen et al. investigated inter- and intraobserver reliability and accuracy of non-WBR for Lisfranc injury diagnosis [12]. Although the diagnosis of Lisfranc injuries based on non-WBR had moderate interobserver agreement and substantial intraobserver agreement at different time points, they did not report the measurement accuracy reliability. To the best of our knowledge, our study is the first to examine the reliability of measurement accuracy on WBR. Sripanich et al. assessed the intra- and interobserver reliability of four measurements of C1-M2 diastasis on the unaffected side on weightbearing computed tomography: ICCs for intraobserver reliability ranged from 0.71 to 0.84 and those for interobserver reliability ranged from

0.65 to 0.81 [8]. Our study demonstrated nearly equivalent reliabilities with WBR using uniform measurement methods.

Our study had several limitations. First, WBR was evaluated by senior orthopedic surgeons and orthopedic surgery residents who are familiar with Lisfranc injuries rather than radiologists. However, orthopedic surgeons often evaluate radiographic findings without radiologist input or assistance in clinical practice. Second, this study did not evaluate WBR validity or weightbearing computed tomography because of its retrospective nature. Third, the sample size was small, which may have introduced bias. However, large-scale studies of Lisfranc injuries are difficult to perform because of their relative rarity; such studies would require an extended period to enroll a large number of patients.

In conclusion, the inter- and intraobserver reliabilities of the diastasis between parallel lines, distal-point diastasis, middle-point diastasis, and proximal-point diastasis methods for measuring C1-M2 diastasis were good for assessing the presence of Lisfranc injuries on WBR. Therefore, WBR is useful to evaluate subtle injuries when uniform measurement methods are used.

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Compliance with Ethical Standards

Conflict of Interest

The authors declare that they have no conflict of interest.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

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Tables

Table 1 Patient characteristics

Characteristic	n=18
Sex (male), n (%)	8 (44%)
Age (yr), mean (SD)	25.8 (10.7)
Affected side (right), n (%)	8 (44%)
Height (cm), mean (SD)	165.3 (9.4)
Weight (kg), mean (SD)	64.3 (14.5)
BMI (kg/m^2), mean (SD)	23.3 (3.8)
Nunley and Vertullo classification, n (%)	
Stage I	10 (56%)
Stage II	8 (44%)
Stage III	0 (0%)
Stage IV	0 (0%)

SD, standard deviation; BMI, body mass index

Table 2 Diastasis measurements by the first observer according to method

Method	Observer 1		
	Affected side (n=18)	Unaffected side (n=18)	*P* value
Diastasis between parallel lines (mm)	5.8 (1.5)	3.6 (1.0)	< .001
Distal-point diastasis (mm)	6.7 (1.7)	4.4 (0.8)	< .001
Middle-point diastasis (mm)	6.3 (1.4)	4.0 (0.9)	< .001
Proximal-point diastasis (mm)	5.8 (1.3)	3.8 (0.9)	< .001

All values are presented as means (standard deviation).

Table 3 Intra- and interobserver reliabilities for all diastasis measurement methods among all four observers

Method	Intraobserver reliability		Interobserver reliability	
	Unaffected side	Affected side	Unaffected side	Affected side
Diastasis between parallel lines	0.93	0.89	0.81	0.88
Distal-point diastasis	0.88	0.92	0.89	0.86
Middle-point diastasis	0.93	0.90	0.91	0.88
Proximal-point diastasis	0.92	0.87	0.89	0.84

Figure legends

Fig. 1 The four methods used to measure diastasis between the medial cuneiform and the base of the second metatarsal on weightbearing radiographs: I) diastasis between parallel lines, II) distal-point diastasis, III) middle-point diastasis, and IV) proximal-point diastasis.

Fig. 2 Radiograph showing the double floor appearance. When the medial cuneiform and/or second metatarsal had a double floor on weightbearing radiographs, we measured the longest distance between the two.

Fig. 3 Radiographs showing methods of diastasis measurement used in previous studies. (A) Alignment of the tarsometatarsal joint along the medial border of the second metatarsal and middle cuneiforms. (B) Distance between the proximal parts of the first and second metatarsals. (C) Distance between the medial and middle cuneiforms.

Fig. 1

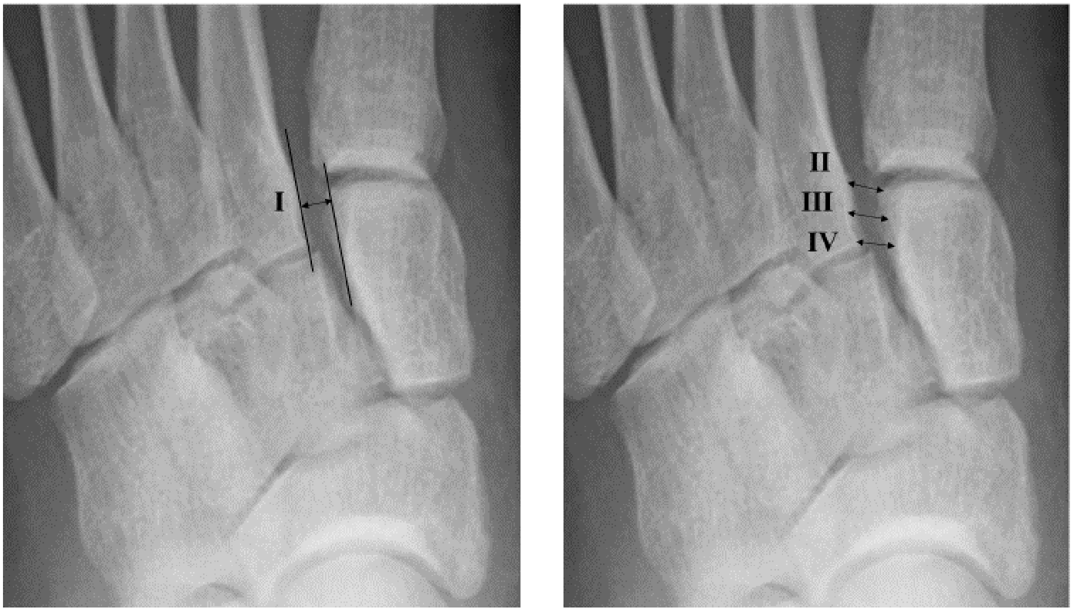

Fig. 2

Fig. 3

(A) (B) (C)