Ultrasound Assessment of Dorsal Lisfranc Ligament Strain Under Clinically Relevant Loads

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Background: Pure Lisfranc ligament injuries have a varied clinical presentation, making them difficult to diagnose. This study seeks to understand in vivo strain characteristics of the dorsal Lisfranc ligament under clinically relevant stress loads and foot orientations measured by ultrasound.

Methods: Randomized ultrasound imaging trials were performed on 50 asymptomatic feet of 20-to-32-year-old individuals who were free of lower-extremity abnormalities. The dorsal Lisfranc ligament was ultrasound imaged under low, medium, and high stress while at 0° and 15° abducted foot orientations. Load was applied using a seated calf-raise apparatus, and a single examiner performed all of the tests. Two-way repeated-measures analysis of variance was used to determine any significant load or position main effects or load × position interaction.

Results: Position main effect for dorsal Lisfranc ligament length demonstrated a significant overall increase in ligament length of 0.21 mm (P < .001), which reflects a 4.03% change in ligament length between the rectus and 15° abducted orientations. Furthermore, low and medium loads demonstrated significant length increase with position effect (P = .03 and P < .001, respectively). No significant load main effect or interaction was determined.

Conclusions: Dorsal Lisfranc ligament length undergoes more strain in an abducted foot position at the same load compared with in a rectus foot. We advocate measuring under a medium load if possible and comparing foot positions for the maximum length changes. The participant stress loads and foot positions used are clinically feasible, which makes it possible to perform this ultrasound procedure in the clinical setting. (J Am Podiatr Med Assoc 104(1): 11-18, 2014)

Named after Napoleonic French field surgeon and physician Jacques Lisfranc, the tarsometatarsal joint complex encompasses the transverse arch of the foot. Overall, Lisfranc joint mobility is rigid. Range of motion limitation is primarily due to ligament constraints, joint contact, and muscle activity. Interaction among these factors allows for smooth load transition during the typical physiological forces of daily living.

Unlike the Lisfranc joint, the Lisfranc ligament spans only the medial cuneiform and the base of the second metatarsal. This ligament complex is divided into three distinct segments: dorsal, interosseous, and plantar respective to their anatomical positions (Fig. 1A). There is a substantial difference in cross-sectional area of these three ligaments. The interosseous ligament has the largest cross-sectional area and, thus, is the strongest, whereas the dorsal ligament is the smallest and weakest of the three. Owing to the unique absence of a transverse ligament between the first and second metatarsal bases, compared with the lesser metatarsals, this is an area of relative weakness. The
interosseous Lisfranc ligament primarily provides first-ray stabilization, thereby preventing diastasis under loaded conditions. Ligamentous strain characteristics allow for elongation in a nonlinear manner until ultimate strain is achieved at ligament rupture. In addition to strain, foot position has been shown to be a factor in reaching Lisfranc ligament injury sooner. An abducted position may facilitate injury and make ligamentous instability more apparent with diagnostic evaluation. Investigation into load versus position stress/strain characteristics of the Lisfranc ligament would allow for more definitive understanding of the complex function of these structures.

The traditional osseous Lisfranc injury classification by Hardcastle et al in 1982, and later modified by Myerson et al, has a high degree of interrater reliability to communicate injury patterns but fails to address rupture without diastases. Twenty years later, Nunley and Vertullo proposed a new classification system that addresses this type of subtle injury. The variable presentation patterns with subtle Lisfranc injuries make them notoriously difficult to diagnose, and this is where the true controversy lies. This variability is due to several reasons, including confusion from overlapping articulations, dislocations followed by spontaneous reduction, and the inability to tolerate weightbearing to create displacement during imaging. Injury frequency is approximately 1 case per 55,000 individuals in a year, making them rare. Nonetheless, approximately 20% of initial Lisfranc joint injuries that present to emergency departments are missed on standard weightbearing radiographs. The uncommon and variable nature of Lisfranc injuries makes them unique, but more recent literature suggests that they are more common than previously thought owing to the subtle nature of a pure ligamentous rupture.

Missed or misdiagnosed injury not only has medicolegal implications but also carries long-term sequelae for pure ligamentous Lisfranc injury. Although soft-tissue involvement is the primary concern, individuals can experience degenerative arthritis, chronic pain, and disability if left untreated. Because of these insidious ramifications, this type of injury has been considered by some to be a fracture equivalent. Weightbearing radiographs are fairly standard first-line imaging for a patient presenting with midfoot pain from a known incident; however, ligamentous injuries frequently fail to receive a detailed diagnosis because of normal radiologic findings despite severe ligamentous damage. A second series of stress radiographs or additional imaging of static or dynamic nature (computed tomography, magnetic resonance imaging, sonography, or bone scintigraphy) may be more useful for a correct diagnosis when radiographs are unremarkable.

Ultrasound imaging of the Lisfranc joint complex is a relatively novel concept in podiatric medicine. Literature is nearly absent in this field. Signal attenuation at the joint space, due to the proximity of the bony surfaces, does not allow for imaging of the interosseous Lisfranc ligament. In 2009, Woodward and colleagues advocated using the dorsal Lisfranc ligament as an indicator of Lisfranc complex intactness for ligamentous stability. Because the dorsal Lisfranc ligament can easily be viewed owing to its superficial location, it is the prime subject for this evaluation. An intact dorsal Lisfranc ligament indirectly indicates an intact Lisfranc ligament complex, whereas rupture or absence may indicate joint instability. This information could, thereby, provide a timely diagnosis and prompt treatment. This study assessed strain characteristics of the dorsal Lisfranc ligament under clinically and physiologically relevant stress and foot positions. Understanding the in vivo nature of the dorsal Lisfranc ligament by ultrasound imaging

Figure 1. Transverse section through the Lisfranc joint. A, Representative drawing of the dorsal, interosseous, and plantar Lisfranc ligaments. B, Ultrasound image for medium load in the abducted position. C, Ultrasound image for medium load in the rectus position. C1, medial cuneiform; M2, second metatarsal; M3, third metatarsal.
may potentially add another diagnostic modality for Lisfranc ligament instability.

**Methods**

**Design**

The length of the dorsal Lisfranc ligament of 50 asymptomatic individuals (25 men and 25 women) was measured using ultrasound imaging. The left or right foot of each participant was selected randomly for imaging purposes under three different stress conditions and in two separate foot positions. The stress conditions were low, medium, and high (representing non-weightbearing, bipedal stance, and single-leg stance, respectively). The foot positions were 0° (rectus) and 15° abduction. Institutional review board approval was received from Des Moines University (Des Moines, Iowa) before commencement of this project. Verbal and written informed consents were obtained from all of the individuals before participation. Data were collected in the order of the following protocol: 1) explanation of the project and consent, 2) completion of a medical history questionnaire, 3) collection of relative clinical anthropometric measures, and 4) stress and foot position measurements of the dorsal Lisfranc ligament strain by a single examiner (D.D.R.) using ultrasound imaging technology. The participant inclusion criterion was an age of 20 to 45 years. The exclusion criteria were a history of congenital foot abnormalities, previous foot surgery, trauma to the lower extremity in the past 10 years, allergy to ultrasound transmission gel, and females currently or expecting to become pregnant. Clinical measurements were obtained from all of the participants before the load position testing protocol. The measures included body weight, height, foot length, foot width, ankle dorsiflexion, subtalar joint range of motion, and navicular height in bipedal stance (Table 1). These measures were used to characterize the participant population relative to the normative biomechanical range. The testing date relative to where women were in their menstrual cycles was also recorded because hormone levels have been shown to relate positively with ligamentous stress/strain characteristics.

**Instrumentation**

A commercially available seated calf-raise apparatus was modified in-house to allow for lower-leg placement directly under the knee loading pad with the foot flat and the tibia vertical (Fig. 2). A portable force plate (Advanced Mechanical Technology Inc, Watertown, Massachusetts) was used as the support structure under the foot, and it was used to measure the exact compression load applied (Table 2). Two footprints with 0° and 15° abduction angles were drawn on the surface of the force plate to ensure proper foot placement orientation for each foot position. The plate was calibrated before each participant and was zeroed before each trial. Low, medium, and high stress loads were applied using the seated calf-raise apparatus loaded with the corresponding amount of weight plates, accounting for a 16:45 moment arm ratio for knee load to the weight plates applied. Dorsal Lisfranc ligament ultrasound images were obtained using an ultrasound imaging system (SONOLINE Antares; Siemens Medical Solutions USA Inc, Issaquah, Washington) with a 10.0-MHz linear array transducer. The acquired images were saved in digital format for

<table>
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<th>Measure</th>
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<td>Body weight (kg)</td>
<td>75.17 ± 17.04</td>
<td>44.00–119.29</td>
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<td>Height (cm)</td>
<td>173.93 ± 9.43</td>
<td>153.4–192.29</td>
</tr>
<tr>
<td>Foot length (cm)</td>
<td>25.40 ± 2.08</td>
<td>19–30</td>
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<tr>
<td>Foot width (cm)</td>
<td>9.48 ± 0.83</td>
<td>8.0–11.5</td>
</tr>
<tr>
<td>Ankle dorsiflexion (°)</td>
<td>10.14 ± 3.77</td>
<td>1–20</td>
</tr>
<tr>
<td>Subtalar joint ROM (°)</td>
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<td></td>
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<tr>
<td>Neutral</td>
<td>9.57 ± 1.55</td>
<td>7–13.67 inversion</td>
</tr>
<tr>
<td>Inversion</td>
<td>20.78 ± 5.44</td>
<td>10–37</td>
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<tr>
<td>Eversion</td>
<td>7.92 ± 2.75</td>
<td>3–13</td>
</tr>
<tr>
<td>Navicular height at medium weight (mm)</td>
<td>69.80 ± 7.63</td>
<td>54.95–83.50</td>
</tr>
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</table>

Abbreviation: ROM, range of motion.

**Table 1. Anthropometric Measures**

**Figure 2.** The modified calf raise apparatus used for isometric loading of the foot, allowing for lower-leg placement directly under the knee loading pad with the foot flat and the tibia vertical.
measurement of dorsal Lisfranc ligament length using in-house written software in MATLAB 8.0 (The MathWorks Inc, Natick, Massachusetts).

**Ultrasound Imaging Procedure**

Participants were seated with their knee and ankle joints positioned at 90° for all of the tests. An initial ultrasound scan of the dorsal Lisfranc ligament for each foot was used to determine the actual orientation of the ligament: generally from slightly proximal-medial to distal-lateral. Parallel lines were marked on the skin along the dorsal Lisfranc ligament to be used as a guide to ensure proper probe alignment between trials. Proper probe placement reduces anisotropy, which is a hypoechoic artifact created by not being parallel with the long axis of the ligament. Ultrasound imaging data were collected for each trial simultaneously with force plate load data for each foot orientation and stress load condition. Starting from the dorsomedial distal foot, the ultrasound probe was maintained perpendicular to the skin surface, midshaft over the first metatarsal, with ample transducer gel to aid sound transmission and return of echoes. The probe was moved proximally up the long axis of the first metatarsal to look for the first metatarsal–medial cuneiform joint congruence. Distal to the congruence, it was noted that the first metatarsal base slopes toward the dermis and then dives off into the joint space, which is marked by the hypoechoic synovial fluid. Proximal to the congruence, 0.5 to 1.0 cm onto the medial cuneiform, the probe while maintained parallel to the skin lines was shifted laterally until the dorsomedial edge of the second metatarsal base came into view. The dorsal Lisfranc ligament lies in this area, which is characterized by the bone contour and plateau at its medial cuneiform attachment (Fig. 1A). The dorsal Lisfranc ligament imaging procedure was consistent with that recommended by Woodward et al. The ultrasound rater (D.D.R.) had no formal ultrasound training; however, he was carefully instructed by a trained musculoskeletal radiologist who approved his technical skills and procedures after multiple practice sessions.

**Data Interpretation**

All of the statistical analyses of data were performed in SPSS version 17.0 (SPSS Inc, Chicago Illinois). A two-way repeated-measures analysis of variance design was used to determine any significant main effects on the strain measures of the dorsal Lisfranc ligament. Load effect was analyzed for each of the three stress levels at the same foot position. Positional effect was analyzed for the two positions in the same load group. Load × position interaction was analyzed among the different load levels and both positions. The reproducibility of dorsal Lisfranc ligament length was determined using the intraclass correlation coefficient (intrarater: ICC[2,1]) to assess the consistency of measurement for a single examiner in a single session (50 participants and 100 feet) and between sessions on a subset of the sample (20 participants and 40 feet).

**Results**

The participant population was primarily based on otherwise healthy graduate school–aged individuals (mean ± SD age, 24.74 ± 2.70 years; age range, 21–32 years) who were asymptomatic and free of foot abnormalities and previous foot surgeries. The average participant body weight was 75.17 kg; height, 173.93 cm; foot length, 25.40 cm; foot width, 9.48 cm; passive ankle dorsiflexion, 10.18; total subtalar joint range of motion, 29.98; and navicular height in bipedal stance, 69.80 mm (Table 1). All of these clinical parameters were well within the normative range. In addition, the time from the start of a female participant’s menstrual cycle was a mean ± SD of 12.77 ± 8.11 days (range, 1–31 days).

The Pearson correlation coefficient was used to determine any relationship between anthropometric measures and dorsal Lisfranc ligament length. This allowed for potential normative documentation of dorsal Lisfranc ligament length across individuals expressed as a percentage. The correlations between dorsal Lisfranc ligament length and anthropometric measures were low to medium at best. The dispersion of coefficients across all of the variables range from r = 0.367 to 0.435 for height,
\( r = 0.327 \) to 0.382 for foot length, and \( r = 0.347 \) to 0.397 for foot width.

The mean ± SD dorsal Lisfranc ligament length over all of the conditions was 7.02 ± 0.21 mm (95% confidence interval [CI], 6.60–7.45 mm). The mean ± SD dorsal Lisfranc ligament length in the rectus position was 6.91 ± 0.21 mm (95% CI, 6.50–7.33 mm) and in the abducted position was 7.12 ± 0.21 mm (95% CI, 6.70–7.54 mm). The position main effect found for dorsal Lisfranc ligament length demonstrated a significant overall increase in ligament length of 0.21 mm \((P < .001)\) from a rectus to a 15° abducted foot orientation. Although there was a significant position main effect for the dorsal Lisfranc ligament to become elongated when moving between the rectus and abducted positions, only low and medium stress loads elicited significant length increases \((P = .03\) and \(P < .001\), respectively\) (Fig. 3). These ligament length changes, expressed as a percentage of ligament length change, represented 2.13% and 4.03%, respectively. Table 3 displays dorsal Lisfranc ligament length data for all of the stress loads at each position.

The mean ± SD overall dorsal Lisfranc ligament length changes with load were as follows: low load, 6.98 ± 0.20 mm (95% CI, 6.57–7.39 mm); medium load, 7.02 ± 0.21 mm (95% CI, 6.59–7.45 mm); and high load, 7.04 ± 0.21 mm (95% CI, 6.62–7.46 mm). There was no load main effect for dorsal Lisfranc ligament length overall, indicating no increase in ligament length with stress as may be expected. There was a nonsignificant decrease in dorsal Lisfranc ligament length in the rectus position from low to medium loads and from medium to high loads in the abducted position (Table 3). We also found a nonsignificant load × position interaction.

The normalized values for dorsal Lisfranc ligament length to foot length across all of the load and position conditions ranged from 2.07% to 2.84%. The longest length, mean ± SD 2.84% ± 0.60% of foot length (95% CI, 2.66%–3.01%) was achieved at the 15° abducted position under moderate load, which can be achieved easily in bilateral stance close to 50% of the body weight (mean ± SD 56.77% ± 8.24% of body weight). These findings did not change when normalized foot length values were used instead of raw ligament lengths in the analysis.

The average (across position and load conditions) intraclass correlation coefficients were 0.889 (range, 0.873–0.913) and 0.747 (range, 0.607–0.811) for the within and between sessions, respectively. These values reflect substantial strength of measurement agreement (range, 0.61–0.80) to almost perfect (range, 0.81–1.00) according to Landis and Koch.28

### Discussion

The mechanical behavior of the tarsometatarsal joints is quite complex. It has been described by Huson29 as a constraint mechanism in which joints are interdependent on adjacent joints and motion happens simultaneously. Similarly, Lakin et al1 agree that forces are redirected to adjacent tarsometatarsal joints to aid in regulating pressures. Movement of the medial cuneiform–second metatarsal joint occurs in this constrained anatomical system that is bound by ligament length, insertion patterns, and joint mechanics, all of which are mutually supporting29 and offer rigidity.1 These mechanics are evident in the present data.

The Lisfranc ligament complex is responsible for structural support and for maintaining this portion of the medial column without the aid of the proximal transverse first metatarsal–second metatarsal ligament. When contrasting foot positions, the ligamentous strain observed between the low and medium stress loads demonstrates decreased liga-ment strain in the rectus and increased strain in the abducted position. This implies decreased motion in the Lisfranc joint in the rectus position and, thus, greater stability. Conversely, the joint structure becomes less stable in the abducted position. This mechanism of unlocking the Lisfranc joint in the abducted position has the potential for greater arch deformation under load.18

Although the loads applied in this study did not exceed full body weight, some participants experi-
enced mild knee discomfort at the higher loads. We suspect that these individuals were not fully relaxed at the high load condition and used compensatory mechanisms by either leaning back to decrease the load on the knee or by activating arch support muscle groups, potentially imposing motion limitations to resist the load discomfort.

The foot position main effect demonstrates that orientation of the foot can affect the magnitude of the length changes of the dorsal Lisfranc ligament in the asymptomatic typical foot. This finding is critical because knowing the normal dynamics of the dorsal Lisfranc ligament will not only let the examiner know what is to be expected on the asymptomatic foot but will also provide the normative range for clinical evaluation purposes. This may facilitate clinical decision making. When the ligament seems to be intact, conservative treatment could be applied versus when ruptured, which will most likely need to be surgically treated to stabilize the foot and prevent future arthrosis.

A medium-weightbearing ultrasound examination comparing the abducted and rectus positions is definitely feasible considering the clinical practice constraints. These data show that such a contrast is ideal and should detect a significant change in dorsal Lisfranc ligament length (Fig. 1 A and B). This could potentially make detection of Lisfranc ligament injuries easier and more timely. Clinically, this translates into taking diagnostic images in the bilateral stance position with the patient distributing weight evenly on both feet (for medium load imaging) or sitting nonweightbearing (for low load), measuring the difference in dorsal Lisfranc ligament length between the rectus and abducted positions for each. These data show a 4.03% average Lisfranc ligament length change. This can be used as a value against which clinical measures are compared. However, depending on patient pain tolerance, this may not be feasible. In this case, significant length change could be seen at low load by comparing the abducted and rectus position measures without causing significant patient discomfort. Radiographically, pure Lisfranc ligament injury depends on evaluation of the diastasis due to change in load: nonweightbearing versus weightbearing. Local anesthetic ankle blocks have been described to make stress evaluation of an injured foot more tolerable, which may be beneficial for achieving medium loading conditions.30

Pure Lisfranc ligamentous injury is difficult to pick up on radiographs, primarily because the patient cannot tolerate full weightbearing to create a diastasis. These findings suggest that significant dorsal Lisfranc ligament length change can be achieved based on change in positioning under the effect of moderate load. This could be attributed to the contact mechanics of the tarsometatarsal joint transferring load to adjacent joints to preserve ligament length and stabilize the medial column. We advocate that clinical ultrasound images acquired under variable load conditions at a fixed foot position may not be the best protocol for dorsal Lisfranc ligament length change. Ultrasound is not recommended to replace standard weightbearing radiographs on initial presentation of midfoot injury but could be used as an additional imaging procedure when there is a high clinical suspicion of Lisfranc complex injury despite negative radiographs.

Although there is some apprehension about the use of ultrasound technology among some clinicians, this technology offers many distinct advantages that make it a superb modality for imaging the dorsal Lisfranc ligament. Not only is ultrasound readily available in most clinical settings, but measures can be taken quickly and recorded reliably; it is cost effective27; and, being nonionizing, it limits risk to patients and practitioners.

Current ultrasound technology allows for dynamic and real-time foot images. In the present study, we relied on single digital images to measure dorsal Lisfranc ligament length, not allowing for continuous

<table>
<thead>
<tr>
<th>Load</th>
<th>Position</th>
<th>Mean ± SD (mm)</th>
<th>Range (mm)</th>
<th>Length Change from Low Load Rectus Position (%)</th>
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<tbody>
<tr>
<td>Low</td>
<td>Rectus</td>
<td>6.90 ± 1.43</td>
<td>4.16–10.05</td>
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</tr>
<tr>
<td></td>
<td>Abducted 15°</td>
<td>7.05 ± 1.50</td>
<td>4.68–11.05</td>
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<tr>
<td>Medium</td>
<td>Rectus</td>
<td>6.85 ± 1.52</td>
<td>4.34–11.26</td>
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<td></td>
<td>Abducted 15°</td>
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<tr>
<td>High</td>
<td>Rectus</td>
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<td>4.42–10.98</td>
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<tr>
<td></td>
<td>Abducted 15°</td>
<td>7.10 ± 1.46</td>
<td>4.48–11.07</td>
<td>2.82</td>
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</table>

Table 3. Dorsal Lisfranc Ligament Length by Load and Position

Abbreviation: NA, not applicable.
dynamic change assessment due to load change. Further investigations of dorsal Lisfranc ligament length as it changes from low to high stress using ultrasound and stress-strain plots could possibly further the understanding of dorsal Lisfranc ligament functional characteristics. The clinical need for and relevance of this should be established first. This participant population age range was narrow, with most individuals’ age in the mid-20s, and the measures were taken under static conditions. However, most current injuries happen as the result of high-velocity axial longitudinal force, such as in motor vehicle accidents, consistent with the age group around the third decade of life. Regarding female participants, ligament laxity is increased during ovulation, when estrogen levels are high, and the female participants had displayed a wide distribution across the menstrual cycle. Still, with the wide array of anthropometric measures and demographic features in this population, we believe that further studies of sex differences should be performed.

Conclusions

Measuring the dorsal Lisfranc ligament using ultrasound under medium and low load conditions showed significant length changes when compared between the rectus and 15° abducted foot positions in asymptomatic participants. We advocate a measurement protocol under a medium load comparing the rectus and 15° abducted foot positions for the most effective strain changes in dorsal Lisfranc ligament length. The significance seen with low weight may be used for those who cannot tolerate full weightbearing. In addition, we did not observe any significant load main effect or load × position interaction. Furthermore, the results of this investigation could be used in the development of future prospective cohort studies comparing the characteristics of confirmed Lisfranc ligament injuries with the normative data presented herein.

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Conflict of Interest: None reported.

References


