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Original article

Evaluation of dorsal Lisfranc ligament deformation with load using ultrasound imaging

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HIGHLIGHTS

Contributions of the present study:

- Load from bilateral stance is enough to deform the dorsal Lisfranc ligament (dLL).
- In the clinical setting ultrasound imaging can reliably detect dLL deformation.
- Deformation trends of the dLL can generate normative data for assessment purposes.
- Foot orientation in bilateral stance does not affect dLL deformation measurements.

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ABSTRACT

Background: Research findings have linked dorsal Lisfranc ligament (dLL) rupture to complete Lisfranc ligament complex rupture; identifying deformation characteristics of the dorsal Lisfranc ligament alone may be helpful in diagnosing complete ligament rupture. The goal of the present study was to assess the deformation characteristics of the asymptomatic dLL using physiologically relevant stress/loads in a clinical setting and to discern normative dLL parameters.
Methods: Unilateral dLL measurements were taken from 50 healthy volunteers, using sonographic imaging under three different stress/load conditions. Stress/load was applied using the individuals' bodyweight (low—seated; medium—bilaterally equal weight bearing in standing; and high—single leg standing). Digital images of the dLL captured using ultrasound were visualized to determine the dLL length. One-way repeated measures ANOVA was used to assess changes in the dLL length with load.
Results: The average dLL elongation, as percent resting length change, was 8.76% between seated and single leg standing positions. Most of the dLL elongation (6.26%) occurred between seated and bilateral standing.
Conclusions: The deformation and role of the dorsal Lisfranc ligament can be observed using sonographic imaging resulting from physiological loading in the clinical setting.
Clinical Relevance: These deformation parameters can be used to generate normative data for diagnostic purposes.

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1. Introduction

The Lisfranc joint complex, anatomically recognized as the series of tarsometatarsal articulations of the foot, creates a transverse arch that contributes to propulsion and shock absorption during surface contact of a striding bipedal gait [14,28,29]. Particular dorsal, plantar and interosseous tarsometatarsal ligaments, as well as transverse intermetatarsal ligaments, are responsible for maintaining structural integrity of the joint complex and prevent splaying of the involved structures during weight bearing dynamic tasks [2,28]. These ligaments, in conjunction with muscle activity, bone on bone contacts and other periarticular soft tissue structures contribute to the midfoot stability and allow for a smooth transition of load from hind foot to forefoot [8].

Within the Lisfranc joint, specifically at the articulation between the first and second metatarsal bases, exists a unique anomaly,

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with respect to the lesser metatarsals. Lack of a transverse intermetatarsal ligament between the first and second metatarsal bases creates an area of weakness, relative to the other metatarsal base articulations [5]. The Lisfranc ligament complex, comprised of the dorsal, plantar, and interosseous ligaments, exists only between the medial cuneiform and the base of the second metatarsal [1]. These Lisfranc ligaments compensate for the lack of the transverse ligament, and contribute to first ray stabilization [1]. While functionally similar, each Lisfranc ligament differs in cross-sectional area and strength: the interosseous portion being the biggest and strongest, and the dorsal being the smallest and weakest [10].

Incidence of Lisfranc ligament injury is rare, frequenting approximately one case in 55,000 annually [6]. However, nearly 20 percent of all Lisfranc ligament injuries that present in the emergency department are missed by standard radiographic assessment [6,26]. Recent literature published claims that, because of the presentation variability and uniqueness of Lisfranc injuries, they might be more common than we suspect [24,26]. Regardless, missed diagnoses of Lisfranc ligament injuries can result in long term complications, including degenerative arthritis, chronic pain, and diminished function [1,5,12].

Currently, there are multiple methods that can be used to clinically diagnose Lisfranc ligament complex injuries. Physical examination can be used to identify diagnostic indicators in a symptomatic foot, when compared to the contralateral foot. These indications include plantar ecchymosis, subtle midfoot convexity, pain and the gap sign, represented by increased space between the great and second toe upon a weightbearing foot [4,9,23]. The most common imaging modality utilized for diagnostic purposes is the standard weightbearing radiograph. The current protocol for evaluating Lisfranc ligament injuries with radiography involves inspection for 1st and 2nd ray diastasis in a weightbearing stance and in stress view under local anesthetic; non-weightbearing views may not reveal diastasis [18,20]. Additionally, a positive Fleck sign, represented by a bony avulsion between the 1st and 2nd metatarsal bases, is a radiological indication of Lisfranc ligament injury [18]. Advanced imaging modalities, such as magnetic resonance imaging (MRI) and computed tomography (CT) can also be used in the assessment Lisfranc ligament injuries.

Today's diagnostic methodologies do, however, have their drawbacks. As previously mentioned, standard radiographs have an alarmingly high false negative rate, with respect to Lisfranc ligament injury diagnosis. Additionally, radiographs do not directly reveal connective tissue injury. While MRI technology is superior in soft tissue assessment, it can be expensive, time consuming, not readily available in the emergency room, and potentially uncomfortable for the patient. Physical examination in itself leaves room for misinterpretations from the physician, or inaccuracies due to noncompliance from patients [25]. Thus, with ligamentous injury diagnosis, shortcomings of standard medical imaging and clinical evaluation merit a closer look into a more viable diagnostic option.

Ultrasound imaging is utilized to make dependable clinical diagnoses, and is often cheaper and safer than most other types of medical imagining techniques. Additionally, ultrasound imaging is dynamic allowing the potential for real-time diagnosis and treatment guidance [16]. Though visualization using ultrasound imaging for Lisfranc ligament injury assessment is a relatively new concept, it has shown promise. In works past, studies have shown that ultrasound can be used to evaluate the integrity of the asymptomatic dorsal Lisfranc ligament, and moreover, can reliably determine change in length of the ligament with respect to change in controlled load [8]. The results of a recent investigation showing bilateral symmetry in the Lisfranc ligament using ultrasound imaging suggest its potential for diagnosis based on deformation characteristics seen at the contralateral side [17]. Because an increase in dorsal Lisfranc ligament length with respect to an increase in load is a function of weight dispersion by the ligament's presence within the Lisfranc joint, it is reasonable to expect that capturing ligament deformation using ultrasound can be used diagnostically when comparing asymptomatic and symptomatic patients or asymptomatic and symptomatic sides.

In this study, ultrasound imaging was utilized to study the relationship between force applied to the foot, and the amount of dorsal Lisfranc ligament length change. It is hypothesized that the ligament deformation data acquired through ultrasound imaging, and the image itself, will eventually contribute to a protocol that allows diagnosis of a Lisfranc ligament injury based on ligament characteristics. In contrast to past works [8], where the force was applied by a weight loading apparatus, this study investigated dorsal Lisfranc ligament strain under physiological load conditions, allowing for a more clinically applicable protocol. Physiological weight bearing conditions were used to evoke ligament deformation, similar to standard weightbearing radiographs. Although biomechanically all three segments of the Lisfranc ligament complex deform with load, the dorsal segment alone is enough to infer Lisfranc complex injury [31]. Establishing the *in vivo* function of the dorsal Lisfranc ligament and its strain characteristics in response to physiological stress will enhance our understanding of the role of the Lisfranc ligament and highlight potential injury diagnosis protocols.

2. Methods

Fifty volunteer participants (25 males and 25 females) were enrolled in the study and were included in the final analysis. This study was approved by the Institutional Review Board of Des Moines University and each subject provided a written informed consent prior to participation in the study.

Participants were recruited to satisfy the following criteria: Adults younger than 45 years old without lower extremity deformity, injury, or surgery. Any volunteers with a history of congenital foot abnormalities, prior foot surgery, trauma to the lower extremity, or allergy to ultrasound transmission gel were excluded from the study. Prior to conducting the dorsal Lisfranc ligament (dLL) imaging protocol, subject body weight and height were recorded, along with the following clinical/biomechanical measurements of the foot: longitudinal arch angle (LAA), truncated foot length (TFL), and navicular height (NH). The arch height index (AHI) was calculated as the ratio of the navicular height over the truncated foot length. In order to measure the LAA, the center of the medial malleolus, the navicular tuberosity and the center of the medial aspect of the first metatarsal head were palpated and marked. A goniometer was used to measure the obtuse angle between these three landmarks. The TFL, the NH measurements, and the calculated AHI were performed as described by Williams and McClay using a Brannock device and a modified digital caliper [30]. These measures were used to characterize our subject population relative to normative values.

Unilateral images of the dLL from each subject were obtained under three separate stress/load conditions. The stress conditions were low load, medium load, and high load, represented by seated, bilateral standing, and standing on one foot, respectively. The dLL was imaged in two separate foot positions under the medium load stress condition (bilateral standing), specifically, in parallel and in self-selected foot alignment. Three images were obtained under each stress/load condition for total of 12 images per subject. Stress/load conditions were randomized, with each of the 12 images being collected in no particular order, and each image series was unique to each subject and visit.

A subset of 20 participants (10 males and 10 females) was randomly selected for a second visit in order to assess intrarater reliability. An additional random subset of 20 participants (10 males

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