Listract Test: A Standardized Assessment Method for Isolated Lisfranc Instability in Cadaver Models

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Abstract

Aim and background: Ligamentous Lisfranc injuries are challenging to detect, with 20–40% of them remaining undiagnosed or misdiagnosed at initial presentation. While direct visualization in the operation room is the gold standard for detecting Lisfranc instability, it is also the most invasive. Other techniques currently available for assessment are unstandardized and nonreproducible. We aimed to introduce a novel reproducible intraoperative mechanical testing method (Listract test) for isolated Lisfranc instability assessment.

Technique: The Lisfranc ligament between the first cuneiform (C1) and second metatarsus (M2) in eight lower leg cadaveric specimens was dissected to replicate C1-M2 Lisfranc instability. Intraoperative radiographs were used for measuring C1-M2 diastasis and area in two states, "stable" and "unstable." A 50N distraction force was applied in the direction of the C1-M2 ligament through two K-wires for "unstable" conditions. Three methods of fixation—flexible fixation, metal screw, and bio-integrative screw were alternatively used to stabilize the joint, and the Listract test was applied again in a "stable" condition. Receiver operating characteristic (ROC) analysis for the Listract test was performed using Statistical Package for the Social Sciences (SPSS). The sensitivity and specificity of the Listract test for detection of ruptured ligament instability using C1-M2 diastasis (cutoff taken as 3 mm) were 100 and 77.8%. Similarly, the instability of ruptured ligament measured using C1-M2 area (cutoff taken as 26.1 mm) was 85 and 100%. The intraclass correlation coefficient (ICC) for C1-M2 diastasis and area measurements was 0.84 and 0.92, respectively.

Conclusion and clinical significance: The Listract test is a simple, standardizable, and replicable intraoperative method for evaluating the Lisfranc joint for instability. Developing a device with this mechanism can be clinically significant to accurately assess the severity of instability intraoperatively and provide appropriate treatment.

Keywords: Cadaver model, Diagnostic technique, Lisfranc instability.

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Introduction

Injuries to the Lisfranc joint represent 0.2% of all fractures and have an annual incidence of 1/55,000 individuals.[1,2] Ligamentous type of Lisfranc injuries is difficult to detect, with 20–40% of them remaining undetected or misdiagnosed at initial presentation.[3] In such cases, debilitating sequelae like midfoot instability, arch collapse, and traumatic arthritis are more likely to follow, thereby underlying the importance of timely diagnosis and treatment.[4] Surgical intervention is key to the preservation of the joint and to achieving anatomic reduction.[5,6] A high portion of instabilities caused by joint widening is observed between the first cuneiform (C1) and second metatarsus (M2) bones (C1-M2) and between the first and second cuneiform bones (C1-C2). Various types of metal and flexible fixations are used as fixation methods for Lisfranc instabilities.[7,8] Magnetic resonance imaging (MRI) and weight-bearing computed tomography (WBCT) have shown high sensitivity and specificity for the detection of Lisfranc instability; radiographs, especially in weight-bearing status, are the mainstay for primary assessment.

Despite various imaging methods, intraoperative examination remains the gold standard for confirmation of the diagnosis.[9,10] However, the intraoperative stress examination of the Lisfranc joint by applying a distraction force is not standardized and not a reproducible method.[11] Surgeons apply various amounts of force on the joint to confirm the diagnosis. This can lead to over or under-diagnosis of the instability. Aiming to introduce a more standardized and dynamic assessment method, a study suggested using a freer elevator to apply stress on the joint.[12] Another study found that the distracting forces applied to the joint should be in the direction of the forces that the actual ligaments bear in physiologic weight-bearing condition for accurate assessment.[13]

In this study, we aimed to introduce a standardized and reproducible intraoperative mechanical test for Lisfranc instability, particularly in isolated Lisfranc ligament injuries. Our hypothesis is that resembling a standard distracting force applied on the Lisfranc

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ligament in the physiologic weight-bearing position can result in a reproducible and more accurate evaluation method.

Technique

Materials and Methods

All experiments in this study were approved by the Institutional Research Board (IRB) protocol (IRB #2016P001295). Fresh-frozen lower-leg cadaveric specimens amputated from the proximal tibia were completely thawed passively before experimenting. Radiographic images, with and without the Listract test, were obtained in intact condition, after injury (unstable Lisfranc after C1-M2 ligament dissection), and after fixation (stable condition) using bioabsorbable radiolucent screws (OSSIO Inc, Massachusetts, United States of America), single cortical metal screws (DePuy Synthes, West Chester, Pennsylvania), and single flexible fixation method (MiniTightrope, Arthrex, Naples, Florida, United States). For induction of the instability, a complete dissection of the C1-M2 ligament was made from the dorsal to the plantar surface of the foot. The C1-M2 diastasis and area were measured on each of these images (Figure 1 shows the stepwise process of the experiment).

To apply the "Listract test" in the direction of the C1-M2 ligament, a K-wire was drilled through C1 from the dorsal to the plantar aspects of the foot at a 90° angle to the bone. Another K-wire was drilled through the base of M2 dorsal to plantar at a 90°angle to the bone. The positions of the K-wires were confirmed via radiographic images. These K-wires served as opposite pivot points to apply the distraction force between C1 and M2. Using a radiolucent wire that could tolerate a force of ~15 kg (33.1 lbs), the K-wires were pulled with a 50N (5 kg or 11.02 lbs). Figure 2 shows the construction of the test using K-wires, radiolucent wires (fish wire), and pulleys to direct the forces from both opposite directions. To select the amount of force needed to conduct the test, in a pilot study on four cadaver specimens prior to the main experiment, we used different distraction forces, including 25N (2.5 kg), 50N (5 kg), and 100N (10 kg). We considered 2 mm C1-M2 diastasis as the threshold for instability. The 25N forces from two directions were not sufficient to render 2 mm diastasis in unstable Lisfranc joints, while the 100N force, though it led to >2 mm widening in all four specimens, was too heavy, making the test hard to use in practice and to keep the feet steady while applying the forces. Thus, we selected 50N forces for the main experiment since it led to >2 mm widening in all the specimens and was also feasible to apply in practice.

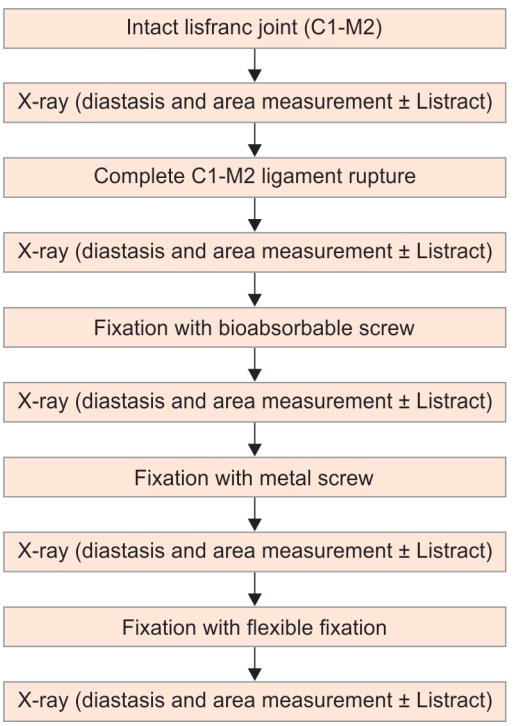


Fig. 1: The stepwise process of the experiment assessing the use of the Lisfranc distraction test (Listract test) for detection of isolated Lisfranc ligament rupture leading to instability

Eight orthopedic foot and ankle surgeons performed the experiment on separate cadavers. We could not perform direct measurement of the C1-M2 diastasis due to the presence of K-wires that barred the C1-M2 region. Three independent observers performed measurements on all radiographs. These three observers were unaware of the procedures and differences in the forces applied on the joint in each imaging stage. The measurements included C1-M2 diastasis and C1-M2 area on dorsoplantar radiographic images.

Statistical Analysis and Interobserver Reliability

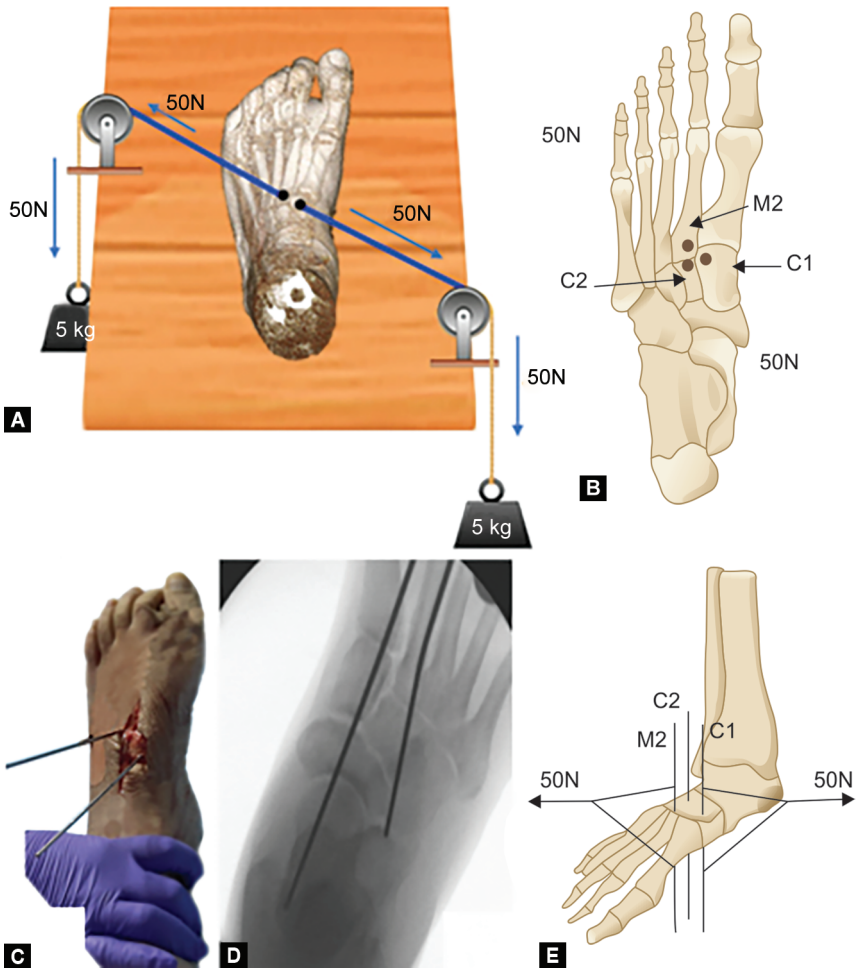
The sensitivity and specificity values for each intraoperative diagnosis and each measurement, diastasis, and area in detecting Lisfranc instability with and without the Listract test were calculated. The cutoff value for diastasis was considered 3 mm, and for the area, it was 26.1 mm.[2,14,15] For diastasis and area measurements among the observers with and without the Listract test, we used the intraclass correlation coefficient (ICC). For these analyzes, Statistical Package for the Social Sciences (SPSS) software (version 26.0, Armonk, New York, United States of America) was used. Bias was reduced by asking the three observers to assess the joint instability before and after dissecting the C1-M2 ligament while they were blinded to the condition of the ligament. Values <50%, between 50 and 75%, between 75 and 90%, and greater than 90% were considered poor, moderate, good, and excellent, respectively.[16]

Results

The measures of reliability of the Listract test in diagnosing instability of the Lisfranc ligament are summarized in Table 1. These measures are sensitivity, specificity, and positive and negative predictive values. The ICC for all C1-M2 diastasis measurements was 0.84 [95% confidence of interval (CI) = 0.754, 0.899], and that for C1-M2 area was 0.920 (95% CI = 0.878, 0.950).

Discussion

This study aimed to introduce a standardized, reproducible, and reliable examination method for Lisfranc instability assessment. Despite various radiological methods introduced to detect Lisfranc instability, particularly for C1-M2 and C1-C2 instabilities, intraoperative diagnosis remains the gold standard method for confirmation. However, the methods used by most of the surgeons in the operating room are not standardized or based on a specific amount of force and are, thus, not reproducible. Given that diastasis and area measurement are two radiographic methods for the detection of C1-M2 instability, we found that the Listract test can increase the specificity and sensitivity of these tests using predefined cutoff values while applying a fixed amount of force (50N) on the joint, consistently. Moreover, the Listract test has led to greater values both for diastasis and area; however, only the



Figs 2A to E: The Listract test (A) Schematic diagram of left foot showing mechanical forces of 50N applied across C1-M2 using a pulley-system; (B) Skeletal landmarks involved shown on left foot; (C) Cadaveric left foot with K-wire placement; (D) Radiographic image of right foot showing K-wires in C1 and M2; (E) Distraction force vectors acting across Lisfranc ligament in right foot test

Table 1: Receiver operating characteristic (ROC) analysis for Listract test for detection of instability

	Sensitivity (%, 95% CI)	*Specificity (%, 95% CI)*	*PPV (%, 95% CI)*	*NPV (%, 95% CI)*
C1-M2 diastasis				
Stable Lisfranc joint	–	100 (83.16, 100)	–	95.24
Unstable Lisfranc joint	100 (29.24, 100)	77.78 (52.36, 93.59)	42.86 (24.01, 64.03)	100
C1-M2 area				
Stable Lisfranc joint	80 (51.91, 95.67)	100 (54.07, 100)	100	66.67 (42.09, 84.62)
Unstable Lisfranc joint	85 (62.11, 96.79)	100 (2.5, 100)	100	25 (10.51, 48.62)

CI, confidence interval; NPV, negative predictive value; PPV, positive predictive value

area showed a significant difference. Future studies can also focus on introducing an intraoperative cutoff value for the diastasis measurements to increase validity.

While the Listract test produced good and excellent ICC for distance and area (84 and 92%, respectively), previous reports using three-dimensional (3D) WBCT scans have shown an ICC of >0.96 using 3D volume measurement for this noninvasive imaging method.[10,17–19] Bhimani et al. have shown that a WBCT scan can detect Lisfranc instability in C1-M2 joint with a sensitivity and specificity of 0.79 and 96.5 for diastasis and area, respectively.[10] They have also shown that 3D volume measurement can have a specificity and sensitivity of 0.98 and 0.92, respectively. However, performing a WBCT scan in patients who cannot tolerate the pain or in the operative room is not feasible. Kitsukawa et al. reported that diagnoses of Lisfranc injury on MRI in an oblique plane parallel to the ligament with isotropic 3D MRI reliably matched with direct intraoperative observations.[9] However, MRI is not a dynamic and weight-bearing imaging modality to show functional instability. Another study by Naguib and Meyr that tested the accuracy of surgeons' eye tracking assessment of intraoperative fluoroscopic imaging during stress examination of the tarsometatarsal joint complex in the diagnosis of Lisfranc injuries found that its reliability

was below the acceptable level for a gold standard test.[11] The Freer elevator test developed by Young and Lee has shown promise as a reliable method of intraoperative evaluation of the injured Lisfranc ligament but is limited by possible iatrogenic injury due to the twisting motion and lack of data on its accuracy.[12] None of these intraoperative methods were either standardized or made reproducible. Our study demonstrated a standardized method using a specific amount of force in a specific direction that can be fundamental in developing devices for intraoperative assessment of the Lisfranc joint, particularly C1-M2 and even C1-C2, as the next step.

A limitation of our study was that we only assessed the C1-M2 joint and did not include C1-C2 and other tarsometatarsal joints. Moreover, we did not conduct intraoperative measurement and the C1-M2 diastasis to compare with the radiographic measurement. Lastly, the number of our cadavers, though it was based on previous studies, was limited, which can lead to limited validity and reliability of our measurements.

We have demonstrated the effectiveness of the Listract test to detect and measure diastasis after Lisfranc ligament injury, which has applications for cadaveric and biomechanical testing. To use this method intraoperatively, we aim to design a device that can measure the amount of distraction force, apply 50N, and measure the amount of diastasis by the surgeon efficiently. This can help the surgeon assess the joint in a simulated real-life situation under a specific force for distraction and, by extension, instability. Future studies with larger cadaver populations to establish cutoff values for both radiographic measurement and intraoperative measurements under the Listract test are necessary.

Ethical Statement

All experiments in this study were approved by the IRB protocol (IRB #2016P001295).

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