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AMERICAN ORTHOPAEDIC FOOT & ANKLE SOCIETY

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Comparison of Suture-Augmented Ligamentplasty to Transarticular Screws in a Lisfranc Cadaveric Model

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Abstract

Background: Lisfranc injuries represent a spectrum of trauma from high-energy lesions, with significant instability of the midfoot, to low-energy lesions, with subtle subluxations or instability without gross displacement. Recently, treatment options that allow for physiologic fixation of this multiplanar joint are being evaluated. The purpose of this study was to analyze the stability of a cadaveric Lisfranc injury model fixed with a novel suture-augmented neoligamentplasty in comparison with a traditional transarticular screw fixation construct.
Methods: Twenty-four fresh-frozen, matched cadaveric leg and foot specimens (12 individuals younger than 65 years of age) were used for this study. Two different types of Lisfranc ligament injuries were tested: partial and complete. Two different methods of fixation were compared: transarticular screws and augmented suture ligamentplasty with FiberTape. Specimens were fixed to a rotation platform in order to stress the joints while applying 400 N of axial load and internal and external rotation. Six distances were measured and compared between the intact, injured, and fixed states with a 3D Digitizer arm, in order to evaluate the stability between them. Analysis of variance was used with $P < .05$ considered significant.
Results: Using distribution graphs and analyzing the grouped data, it was observed that there was no difference between the 2 stabilization methods, but the augmented suture ligamentplasty presented lower variability and observed distance shortenings were more likely to be around the mean. The variability of the stabilization with screws was 2.9 times higher than that with tape ($P < .001$).
Conclusion: We suggest that augmented suture ligamentplasty can achieve similar stability to classic transarticular screws, with less variability.
Clinical Relevance: This cadaveric study adds new information on the debate about Lisfranc lesions treatment. Flexible fixations, such as the synthethic ligamentplasty used, can restore good stability such as conventional transarticular screws.

Keywords: Lisfranc, ligamentplasty, transarticular screws, FiberTape

Introduction

Lisfranc trauma represents a spectrum of injuries from high-energy lesions, with significant instability of the midfoot, to low-energy lesions, with subtle subluxations or instability without gross displacement. Due to the long-term disability that can occur after these injuries, restoration of joint stability and congruency should be achieved. Traditional fixation methods include percutaneous screws, open reduction and internal fixation (ORIF), and primary arthrodesis.[3]

Recently, there have been investigations of modern treatment options that explore physiologic fixation methods of this joint.[2] The interest in mobile fixation methods arose from the proven concept in the ankle that it is reasonable to

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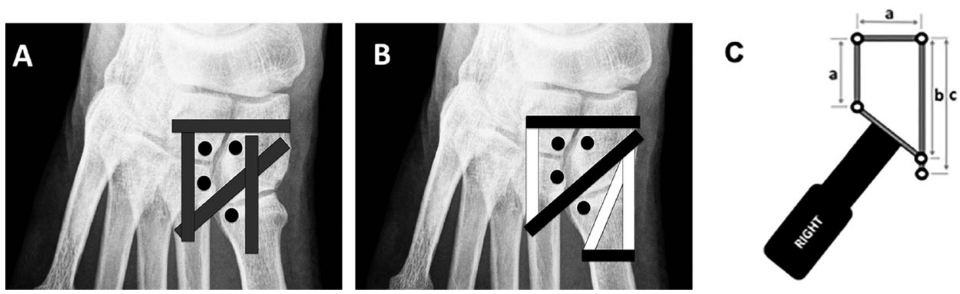

Figure 1. (A) Possible positioning of the screws (black bars) and free bone useful areas for the bone markers (black dots). (B) Possible positioning of the bone tunnels (black bars), superficial passages of the tape (white bars), and free bone useful areas for the bone markers (black dots). (C) Schematic drawing of the plastic guide used for the positioning of the bone markers: distance a = 10 mm (C1-C2 and C2-M2 measurements), distance b = 15 mm and distance c = 18 mm (C1-M1 measurements). Distance c being 3 mm bigger than distance b was necessary for the adequate positioning of the bone marker in larger specimens. C1, first cuneiform; C2, second cuneiform; M1, first metatarsal; M2, second metatarsal.

fix the syndesmosis with flexible fixation.[5,9] This is corroborated by a gait analysis study of patients who have had Lisfranc joint stabilization with transarticular screws or arthrodesis. The investigators found a significantly lower walking speed and a significantly decreased range of motion of the midfoot during the push-off phase.[16]

Patients with a rigid midfoot after arthrodesis or screw/plate fixation also have increased plantar pressure in the late portion of the stance phase, possibly due to arch stiffness.[8] In addition, range of motion has a significant correlation with functional scores, but not with radiographic reduction. Another study showed that patients have a persistent nonfunctional gait even if the hardware was removed before gait analysis.[15]

Currently, there is no universally accepted procedure for the treatment of pure ligamentous Lisfranc injuries.[13] Surgical approaches can be divided between rigid joint fixation and ligament reconstruction of the Lisfranc joint. Traditional transarticular screws (rigid joint fixation) are a reliable and reproducible method that is used worldwide, achieving good stability with good results. The drawbacks are the potential joint rigidity and the possible hardware breakage. Suture button fixation and the ligamentplasty technique are some of the flexible fixation options available, but still without definite results.[12] These methods can potentially bring a more physiological fixation, but with the drawbacks of possible suture failure, malunion, and lack of long-term results.

Panchbhavi et al[10] found that there was no statistically significant difference in fixation stability between cadaveric specimens with Lisfranc ligament injuries fixed with either a suture button device or an interfragmentary screw. Most cadaveric biomechanical studies use axial loading and have limited joint damage; therefore, relatively small intra-articular Lisfranc displacements are achieved, which makes it difficult to correlate the results to clinical scenarios.[4,6] It is important to note that fixation stability, after all, is most important only while healing is occurring.

The purpose of this study was to analyze the stability of a cadaveric Lisfranc injury model fixed with a novel augmented suture ligamentplasty in comparison with traditional transarticular screw fixation. We hypothesized that the augmented suture ligamentplasty proposed would achieve a similar stability to screw fixation in a model where supination and pronation motion are applied.

Methods

Lisfranc Model Preparation

Twelve pairs (12 individuals younger than 65 years of age) of fresh-frozen lower leg cadaveric specimens were used for this study. No history of injury, previous surgeries, or pathologies and deformities were evident in the specimens. All specimens were thawed at room temperature for 16 hours prior to testing. All ankles were fixed with 2 crossed 4.5-mm screws in 30 degrees of plantarflexion. The dorsal midfoot skin and soft tissue were removed to expose the extensor tendons and the tarsometatarsal region (Lisfranc joint).

To easily identify and locate the bone markers for measurement, a plastic guide was created with holes that corresponded to the first cuneiform (C1), second cuneiform (C2), first metatarsal (M1), and second metatarsal (M2). The same guide was used on both the right and left feet by reversing its position. The markers were located in areas that avoided tunnels, or where ligament reconstructions were going to be placed (Figure 1).

C1, C2, M1, and M2 were localized and marked with four 2.3-mm partially threaded 13-mm-long Phillips flathead wood screws under visual and radioscopic inspection. The screw heads were used as reference marks for 3D

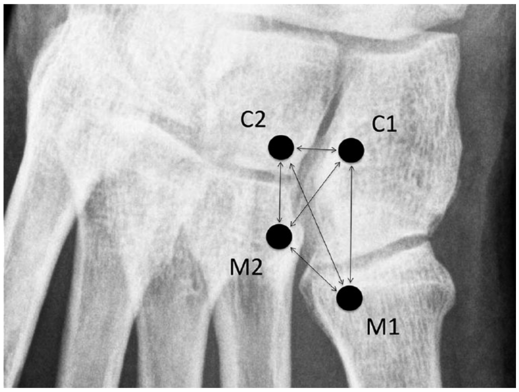

Figure 2. Close-up radiograph of the midfoot: the anatomical area of screws insertion (black dots) and the distances measured in this study (arrows). C1, first cuneiform; C2, second cuneiform; M1, first metatarsal; M2, second metatarsal.

Digitizer measurements (Immersion Microscribe, model No. G2X; Immersion Corp, San Jose, CA). This digitizer has a precision of hundredths of millimeters. The specimens were fixed to the E10000 Instron ElectroPuls Materials Testing Machine (Instron, Norwood, MA). The specimen mounting specifications and testing methods are well described in a sister study (Wagner et al's Lisfranc model study[17]). Relative positions of the screw heads were analyzed using SolidWorks 2017 (Dassault Systems, SolidWorks Corp, Waltham, MA).

Every intact specimen was preconditioned (preconditioning cycle [PCC]) and the 3D Digitizer arm was calibrated, applying 400 N of axial load and internal and external rotation motion axially, while keeping the foot fixed. In this way, a pronation motion (with internal rotation) and a supination motion (with external rotation) were obtained. Under these conditions, measurements were taken between the reference markers already mentioned, as follows: a PCC of 10 rotational movements of the tibia was performed on every intact specimen, under an axial load of 400 N.

After calibrating the 3D Digitizer arm, measurements were taken between the distances of the reference marks (center of the X-shaped slot at the Phillips screw head) as follows (Figure 2):

a. First measurement: C1-C2
b. Second measurement: M1-M2
c. Third measurement: C1-M1
d. Fourth measurement: C2-M2
e. Fifth measurement: C1-M2
f. Sixth measurement: C2-M1

The 24 specimens were divided into 2 matched groups, depending on the ligaments sectioned in each case. In group 1 (G1), 12 left foot specimens had the ligaments between C1-C2 and C1-M2 (Lisfranc ligament) sectioned with a 4-mm curved "banana blade" (Arthrex, Naples, FL). In group 2 (G2), the ligaments between C1-C2, C1-M2, C1-M1, and C2-M2 were sectioned with a 4-mm curved banana blade.

All specimen preparation was performed by the same surgeon (C. N.). After the ligaments were sectioned, the specimens were evaluated on an Instron testing machine under an axial load of 400 N; a second PCC of 10 movements composed of an internal rotation of 30 degrees and an external rotation of 30 degrees was performed. By the stabilization of the foot and leg on the machine, internal rotation of the leg produced pronation at the foot and external rotation of the leg produced supination at the foot. The same set of measurements between the tarsal bones already described was performed in both groups with the application of both pronation and supination.

Reconstruction Technique

G1 was further separated into 2 groups. Six specimens (G1-Screws) were stabilized with screws as follows: A 5-mm incision was made over the medial border of the C1 and then 2 guide wires were inserted between C1-C2 and C1-M2, checking their position under fluoroscopy. A cannulated drill of 2.5 mm was passed and the bones were fixed with two 3.5-mm cortical Low Profile Screws (LPS) (Arthrex) (Figure 3A). The PCC was repeated and the same set of measurements between the tarsal bones was taken.

The other 6 specimens (G1-Tape) were dynamically stabilized with FiberTape (Arthrex) as follows: A 5-mm incision was made over the medial border of the C1 and then 2 bone tunnels were produced with a 2.5-mm cannulated drill bit, the first between C1-C2 and the second between C1-M2 (the Lisfranc tunnel). Utilizing a flexible nitinol loop, a folded No. 2.0 FiberTape was passed through the bone tunnels starting from medial to lateral in the Lisfranc tunnel and, after that, from lateral to medial in the intercuneiform bone tunnel. After manually tightening the tape, two 3.0 × 8.0–mm Biotenodesis screws (Arthrex) were introduced at the medial end of each bone tunnel (Figure 3B). The PCC was repeated and a repeat set of measurements between the tarsal bones was taken.

G2 was divided into 2 groups as well. Six specimens (G2-Screws) were stabilized with screws as follows: A 5-mm incision was made over the medial border of the C1 and then 4 guide wires were inserted between C1-C2 (from medial to lateral), C1-M2 (from medial to lateral), M2-C2 (from distal to proximal), and M1-C1 (from distal to proximal), checking their position under fluoroscopy. A cannulated 2.5-mm drill bit was used to prepare the screw holes and the bones were fixed with four 3.5-mm LPS cortical screws (Figure 4A). The PCC was repeated and intertarsal bone measurements were taken.

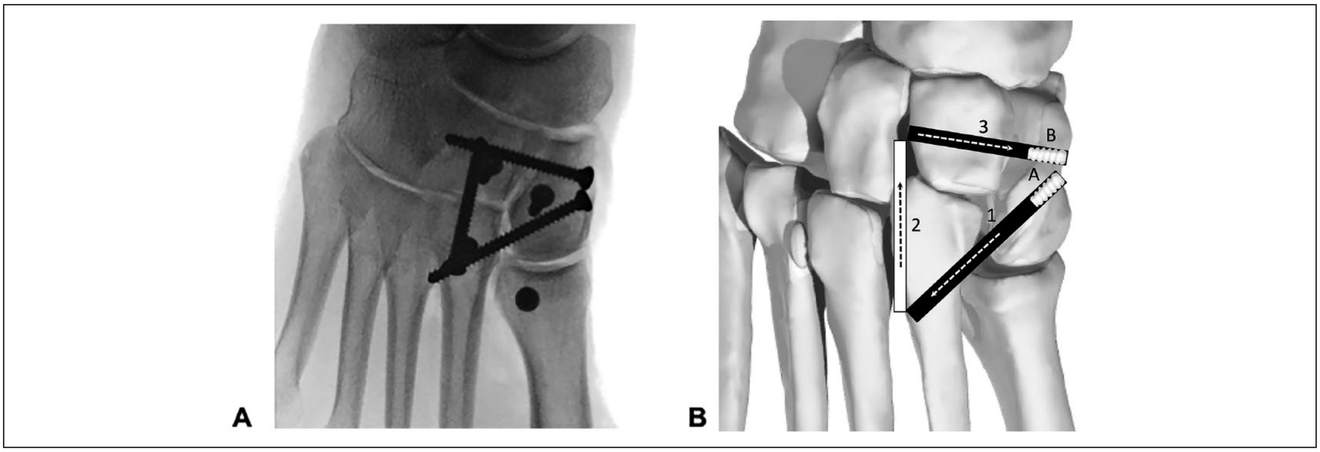

Figure 3. (A) Group G1-Screws construct; see text. (B) Group G1-Tape construct. The bone tunnels are represented in black and the external superficial passage of the tape is represented in white. Numbers indicate the sequence of passage of the tape, arrows indicate the direction of tape passage, and letters indicate the order of the Biotenodesis screw insertion.

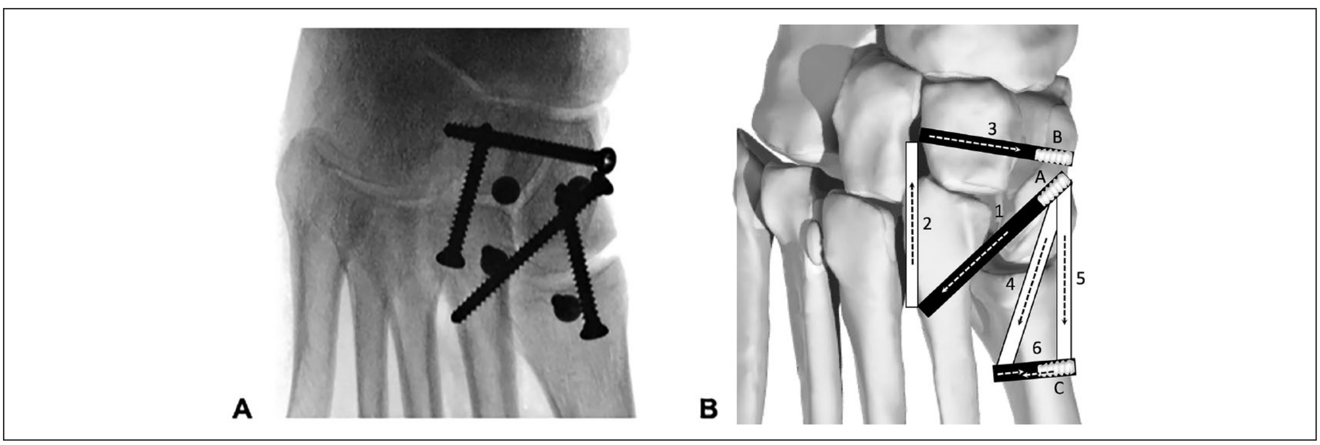

Figure 4. (A) Group G2-Screws construct; see text. (B) Group G2-Tape construct. The bone tunnels are represented in black and the external superficial passages of the tape are represented in white. Numbers indicate the sequence of passage of the tape, the arrows indicate the direction of tape passage, and letters indicate the order of the Biotenodesis screw insertion.

The other 6 specimens (G2-Tape) were dynamically stabilized with a FiberTape as follows: A 5-mm incision was made over the medial border of the C1, and then 3 bone tunnels were made with a 2.5-mm cannulated drill bit: the first tunnel between C1 and C2, the second between C1 and M2 (Lisfranc tunnel), and the third at the proximal metaphyseal region of M1. With the help of a nitinol loop, a folded No. 2 FiberTape was passed through the bone tunnels starting from medial to lateral in the Lisfranc tunnel and, after that, from lateral to medial in the intercuneiform bone tunnel. After manually tightening the tape, two 3.0 × 8.0–mm Biotenodesis screws were introduced at the medial end of each bone tunnel. The remaining 2 arms of the FiberTape were passed through the third bone tunnel, one of them from medial to lateral and the other from lateral to medial. After tensioning the 2 arms of the FiberTape in order to stabilize the C1-M1, another 3.0 × 8.0-mm Biotenodesis screw was introduced into the third tunnel (Figure 4B). The PCC was repeated and the same set of intertarsal bone measurements was taken. All sequential procedures are described below in the methodology chart (Figure 5).

The measured distances were compared between groups. Statistical analysis was performed using the percentage difference of the distances between the injured and the repaired conditions so as to compensate for size differences between the specimens.

The sample of the present study was composed of 864 measurements taken from 24 specimens, 12 with complete damage and 12 with partial damage, in internal and external rotation and in 6 different distances. All data presented in the Results section reflect the ability of the stabilization method to reduce the increase in distances between the bone markers produced by the injury. A panel data model was used in order to separate the unobserved effects of each

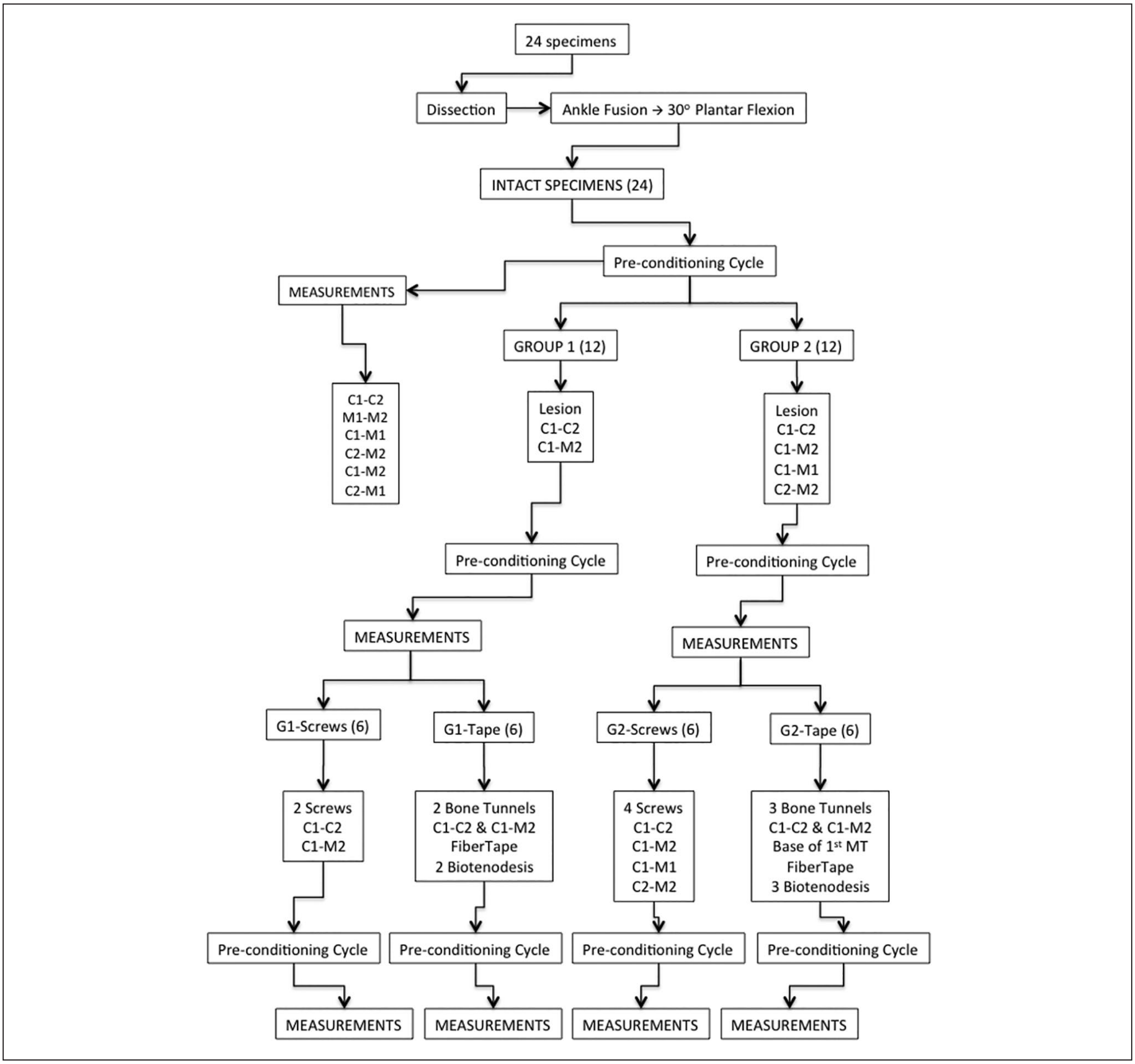

Figure 5. Flowchart summarizing the methodology used in this study. C1, first cuneiform; C2, second cuneiform; G1, group 1; G2, group 2; M1, first metatarsal; M2, second metatarsal; MT metatarsal.

individual over the measurements from the effect of the devices used to perform the stabilization. Differences in variance between the groups were calculated using a variance test ratio (*F* statistic).

A power analysis was made based on the assumption that a 1-mm statistical difference would be of clinical importance. Through adoption of a Student *t* distribution, the probability that such a difference would be undetected by our methods was less than 10^{-12}.

The torque needed to produce the rotation, 30 degrees of either external or internal rotation, was also measured and compared between the injured and stabilized conditions. All statistical calculations were made in R version 3.6.1 (2019-07-05) using the analysis of variance for nested data estimates by mixed models. A *P* value of $<.05$ was established as the limit for the rejection of the null hypothesis. Supplemental material (raw data) is available online with this article.

Results

In internal rotation, screws performed better than tape in C1-M2 (partial injury) and tape performed better than screws in C2-M1 (partial and complete injuries) and in M1-M2 (complete injuries). In external rotation, screws

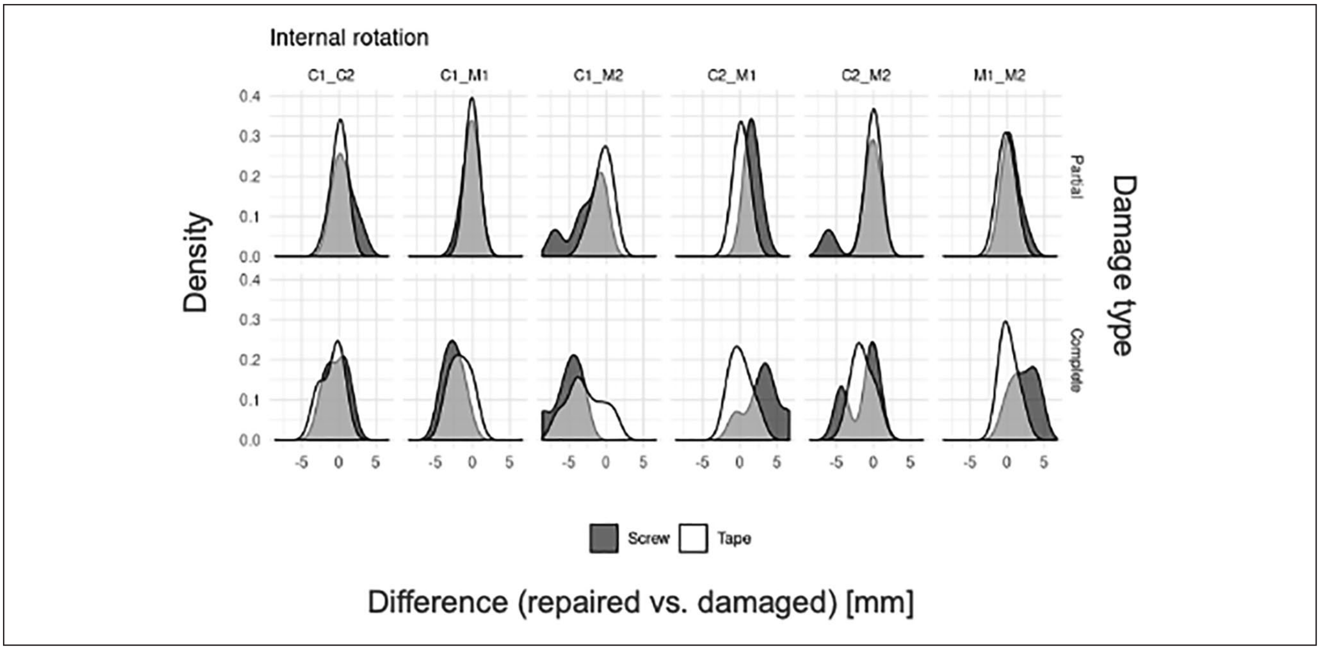

Figure 6. Smoothed distribution of observed distance shortening with internal rotation for each damage type and metric.

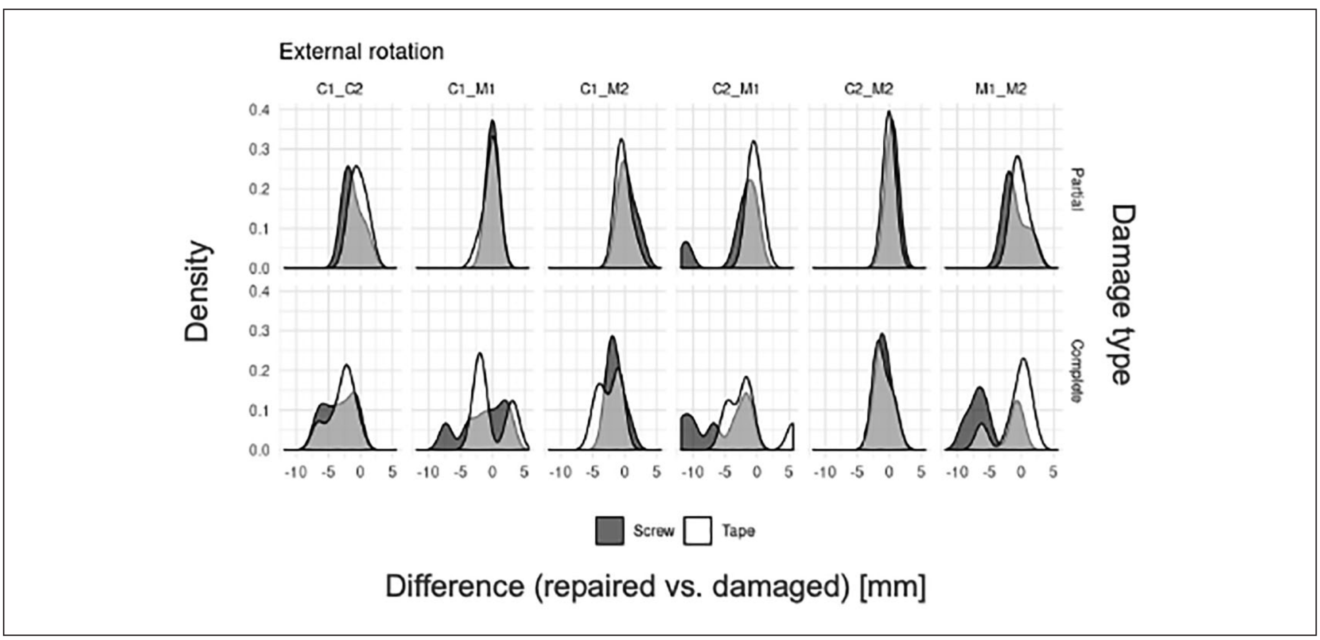

Figure 7. Smoothed distribution of observed distance shortening with external rotation for each damage type and metric.

performed better in C2-M1 (partial injury) and in M1-M2 (complete injury). Figure 6 presents the distribution pattern for the tests in internal rotation and Figure 7 in external rotation. Table 1 presents the *P* values for each comparison shown in the graphs. As can be seen, in most of the measurements, screws performed the same as the tape.

Figure 8 shows the distribution of the distance shortening for each group (internal rotation with partial and complete injury, and external rotation with partial and complete injury). Visually, there is no difference between the methods on average, but it appears that the tape method is more consistent than the screw method, as the variability is lower and the observed distance shortenings are more likely to be around the mean. None of the comparisons in this graph showed statistical significance. However, while testing of the 2 treatments differed in terms of variance, the variance of

Table 1. *P* Values for Each Comparison.

Rotation	Damage	C1-C2	C1-M1	C1-M2	C2-M1	C2-M2	M1-M2
Internal	Partial	.3125	.8438	.0313*	.0313*	.0938	.2188
	Complete	.6875	.2188	.2188	.0313*	$>$.0999	.0313*
External	Partial	.0625	.5625	.4375	.0313*	.0591	.4375
	Complete	.8438	.5625	.3125	.0625	.6875	.0313*

Abbreviations: C1, first cuneiform; C2, second cuneiform; M1, first metatarsal; M2, second metatarsal.
*Indicates a statistically significant difference.

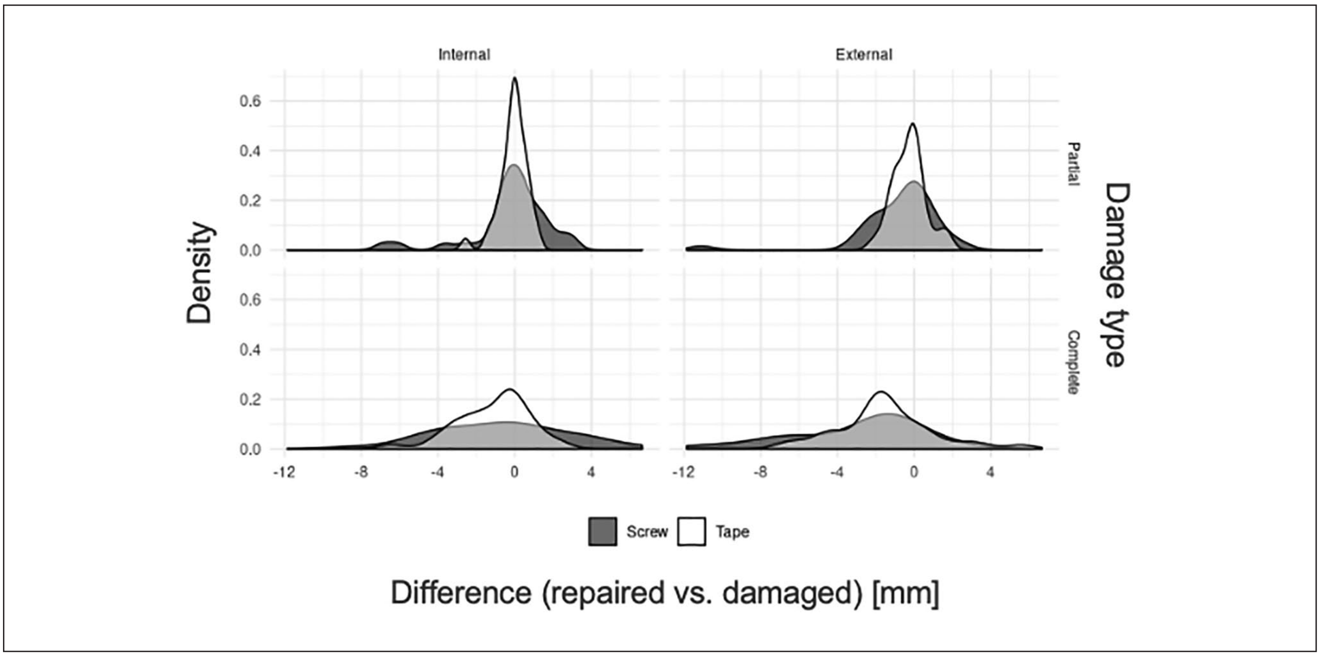

Figure 8. Smoothed distribution of observed distance shortening for each damage type and rotation for all metrics.

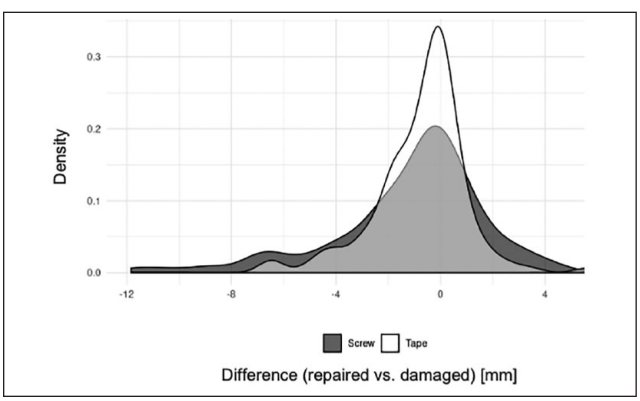

Figure 9. Smoothed distribution of observed distance shortening for all damage types, metrics, and rotations.

the screw treatment was found to be higher than that of the tape. The difference is higher in the internal rotation with partial damage, where the screw procedure is 7.9 times more variable than that of the tape ($P < .001$).

Table 2. Torque Values.

	Average (N)
Condition	
Intact	19.58
Injured	15.51
Repaired	17.29
Type of repair	
FiberTape	17.52
Screws	17.07

Figure 9 shows the distribution of the aggregated groups. No statistical differences were found, but the variance of the screw group was also higher than that of the tape groups. The variability of the treatment with screws was 2.9 times higher than that with tape ($P < .001$).

Table 2 shows the analysis of the torque needed to produce the rotation. The injured group showed significantly less torque when tested ($P < .001$). After repair, the torque increased, but it did not return to a normal value ($P = .035$). There was no difference regarding the type of repair ($P = .533$).

Discussion

Lisfranc injuries can result in persistent pain, arthritis, and disability without optimal initial treatment. The ideal treatment remains under debate, and therefore interest in testing different repair and reconstruction methods has emerged.[14] There is a paucity of studies that compare Lisfranc flexible types of fixation with transarticular screws in cadaveric models. These investigations are very heterogeneous as they use different methodologies of ligament sectioning, stress, and measurement.

Three papers were not able to show any difference between the fixation methods tested. Panchbhavi et al[10] were the first to compare a suture button device with screws in a cadaveric model and found no significant difference in displacement between them. Pelt et al,[11] using a model stressed with abduction and axial weightbearing, compared the fixation rigidity of screws and a suture-bottom device and showed that both fixation methods were effective in restraining motion to preinjury levels, with no statistical difference. Weglein et al,[18] using a model stressed with partial weightbearing, compared the fixation rigidity of screws and an allograft fixation and concluded that allografts provided adequate strength and stability and did not differ significantly compared with screw fixation.

Two other papers found differences between the rigid and flexible fixation methods, with both favoring screws. Marsland et al,[7] using a cyclic loading model to compare endo button and screws, found that diastasis after endo button fixation was significantly greater than that after screw fixation under initial loading but did not increase further after cyclic loading. Ahmed et al,[1] comparing screws and the Mini TightRope (Arthrex), found that the former had less displacement in isolated Lisfranc ligament injuries.

What is common in all those papers is that the models used often presented joint displacements of less than 2 mm, which is an observational, classical surgical indication that has not been statistically validated. It may be that 1 to 2 mm is too small to measure, which propagated the controversy of rigid versus flexible fixation. The model of this investigation uses pronation and supination in a Lisfranc injury cadaveric setting, which reproduces the scenario where the ligaments are tensioned and torn.

This is also the first paper to compare classical transarticular screws with an augmented suture ligamentplasty using FiberTape in a Lisfranc injury cadaveric model. Our data present some important conclusions, as the analysis groups 864 different measurements and reduces the lack of statistical power bias. When looking at the isolated difference in distances measured between screws and tape, it is evident that screws performed better in 3 measures (C1-M2, internal rotation, partial injury; C2-M1, external rotation, partial injury; and M1-M2, external rotation, complete injury) and tape performed better in 3 measures (C2-M1, internal rotation, partial injury; C2-M1, internal rotation, complete injury; and M1-M2, internal rotation, complete injury).

These apparent ambiguous outcomes could be a consequence of the sample size. When looking at the grouped data, the results suggest a pattern: for all metrics, rotations, and types of damage, there seems to be no statistical difference between the averages of the distance shortening between the stabilization methods; however, there is evidence in favor of the tape group with variability, as observed by distance shortening with FiberTape, which is more likely to be close to the mean. In actuality, the variability of the treatment with screws was 2.9 times higher than that with tape. These results suggest that the augmented suture ligamentplasty produces the same average stability as transarticular screws, but it is more likely to produce average results. The current study results therefore demonstrate that the use of screws as a stabilization method for Lisfranc injuries can result, in some cases, in 2 extreme conditions: a very stiff construct or a loose construct. This strengthens the argument for flexible fixation, such as this ligamentplasty with FiberTape, which can produce more results around the average.

Another important component of this study is the torque analysis. Neither the screws nor the tape was able to return the torque needed to produce rotation to the intact condition. This means that neither stabilization method could restore the native ligament isometry and stability.

The limitations of our study include the lack of bone mineral density testing between specimens. There was an attempt to minimize the variability by using matched left and right feet for groups 1 and 2. There could also have been variability of the ligament injury sectioning, but this possibility was limited by the use of a 4-mm curved banana blade, and the same investigator performed each sectioning for every specimen. Also, it is important to state that we had no ability to determine if ligament healing would be different between methods, as this is a cadaveric study. Finally, we have no knowledge of how much stability is optimal to achieve optimal healing, making it impossible to accurately conclude which treatment is clinically the best.

Conclusion

In conclusion, we have determined that augmented suture ligamentplasty can achieve similar stability to transarticular screws, with less variability. This finding may have clinical implications with more consistent reconstruction stability.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Daniel Baumfeld, MD, PhD, is a speaker for Arthrex and Geistilish. Caio Nery, MD, PhD, is a speaker for Arthrex, Geistilish, and Wright. Marcelo Prado, MD, is a speaker for Arthrex and Geistilish. Emilio Wagner, MD, and Pablo Wagner, MD, receive research support from Arthrex and Helico, and are consultants for CLP and Paragon 28. Eric Giza, MD, is a consultant for, receives royalties from, has a fellowship from, and receives research support from Arthrex. Caio Nery, MD, PhD, Daniel Baumfeld, MD, PhD, Marcelo Prado, MD, Eric Giza, MD, Pablo Wagner, MD, and Emilio Wagner, MD, report personal fees and nonfinancial support from Arthrex, Inc. ICMJE forms for all authors are available online.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Caio Nery, MD, PhD, Daniel Baumfeld, MD, PhD, Marcelo Prado, MD, Eric Giza, MD, Pablo Wagner, MD, and Emilio Wagner, MD, report personal fees and nonfinancial support from Arthrex, Inc, during the conduct of the study.

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Supplemental Material

Supplemental material is available online with this article.

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