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RESEARCH ARTICLE

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Computational analysis of Lisfranc surgical repairs

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Abstract

Ligamentous Lisfranc injuries cause debilitating pain and loss of function. Even small diastasis of this normally rigid joint after injury requires surgical treatment, but outcomes remain poor. Existing literature has compared the different surgical procedures using cadaveric models, but no approach has been recommended over others. This study uses a computational biomechanical approach consistent with a cadaveric study to evaluate the different procedures' ability to stabilize the Lisfranc joint without inducing secondary consequences. A validated rigid body model for the cadaver foot with a Lisfranc injury was extended to compare the stability of four different surgical repairs—three open reduction and internal fixation procedures with different hardware (cannulated screws, endobuttons, and screws with a dorsal plate) and primary arthrodesis with screws. Forces calculated from the rigid body model for 50% partial weight bearing provided boundary conditions for a finite element model of the surgical repairs. Comparing the different surgical procedures, the open reduction and internal fixation with screws and primary arthrodesis with screws showed the most stable postoperative Lisfranc joint. However, the use of cannulated screws for fixation showed regions of high stress that may be susceptible to breakage and also resulted in higher contact forces in joints adjacent to the surgery site. Endobuttons and dorsal plates did not restore sufficient stability. Since all procedures showed different points of concern that could impact outcomes, additional surgical approaches could be needed in the future. This study offers a standard protocol for benchmarking the new procedures against those currently used.

KEYWORDS

biomechanics, foot and ankle, fusion and arthrodesis, modeling, surgical repair

1 | INTRODUCTION

The Lisfranc joint in the midfoot exhibits limited motion in an anatomically healthy individual and supplies stability to the transverse and medial arches of the foot.[1,2] While not the most common of injuries (prevalence of 1 in 55,000 per year),[3,4] conservative treatments are only recommended for stable, nondisplaced injuries. Even subtle Lisfranc joint injuries, characterized as 1–5 mm of diastasis between the medial cuneiform and second metatarsal, are recommended for surgical intervention to temporarily or permanently secure the injured joint in its anatomical orientation.[5–7] However, patient satisfaction ratings for these surgeries are low; in some cases as few as 45% of patients are satisfied with the outcome.[6] An additional challenge is that for the more severe injuries (such as dislocations) anywhere between 40% and 94% of patients develop osteoarthritis in the tarsometatarsal joint.[8,9]

This clinical situation has resulted in competing procedures and hardware being proposed for the internal fixation of the Lisfranc injury. Recent literature has compared a range of surgical repairs with conflicting recommendations on which procedure provides the optimal environment to promote healing and avoid implant failures.[6,10–12] The combination of multiple procedures and suboptimal outcomes in surgical corrections (Table 1) demonstrates the need for a controlled examination of all procedures in a single study to quantify specific biomechanical characteristics of the postoperative joint. Computational modeling of joints has been shown to provide the controlled environment for comparing the healthy, injured, and postoperative mechanics of the foot and ankle.[18–20]

The primary surgical procedures used clinically fall into two groups. The first group is open reduction and internal fixation (ORIF) procedures. At a high level, all ORIF surgeries have open incisions made to the foot so the excessive displacement of the bones away from their normal anatomical position can be reduced.[10,11,21] The difference then comes from the hardware used to fix the bones in the correct position: transarticular screws, endobuttons, or dorsal plates with screws. Past studies have commonly compared transarticular screw ORIF procedures with either the use of endobuttons or a dorsal plate. Depending on the clinical postoperative observations, the hardware may be removed.[6] The second group of treatments is arthrodesis of the injured joint where the articular surfaces of the bones are debrided before the bones are placed in the correct orientation. Then screws are used to permanently fix the bones in place to allow for bone fusion.[10,22]

This study focused on providing clinically relevant biomechanical insights on these different corrective surgeries to treat Lisfranc injuries. These recommendations are based on how well the surgery returns the injured joint to normal position because this is a key indicator for successful outcomes.[14] Secondary consequences of joint forces, plantar contact forces, and implant stresses were also examined. A combination of rigid body modeling and finite element analysis were used to compare the biomechanics of the postoperative foot for the different repair procedures. From the kinematic analysis, diastasis (separation) measurements of the joint along with joint contact forces were obtained, while finite element analysis provided implant stresses. Both were used to characterize the different behaviors of the postoperative foot. These results provide useful information to consider the advantages and disadvantages of the corrective surgery for this type of injury.

2 | METHODS

In previous work, a rigid body model was developed in SolidWorks (Dassault Systemes) that represented the bony anatomy, ligaments, and extrinsic flexor muscles of the lower leg and foot. The model was used to compare the steady-state loading of the healthy foot to one with ligamentous Lisfranc injuries when under compressive loading in 30° plantarflexion (Figure 1). Motion in the

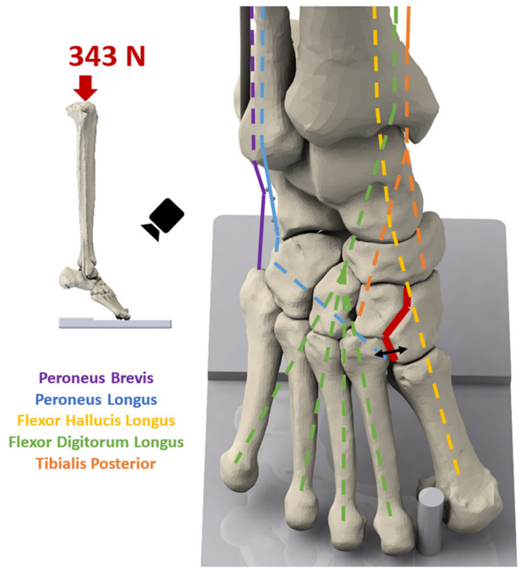

FIGURE 1 Sagittal view of computational model and inclined anteroposterior view of mid and forefoot with highlights of joint space where ligaments were transected (red line), example of diastasis distances measured (black arrows), and illustrative muscle paths with dashed lines represented along plantar/posterior aspects of the foot and ankle [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Previous studies of patient outcomes after Lisfranc repair surgeries

Study	Year	Number of patients	Treatment	Outcome
Myerson et al.[8]	1986	72 patients, 76 feet	Open reduction and internal fixation (ORIF)	49% good to excellent, 51% fair to poor
Arntz et al.[13]	1988	41	ORIF	34/41 good to excellent, 6/41 fair to poor
Kuo et al.[14]	2000	48	ORIF	AOFAS score: 77
Richter et al.[15]	2001	49	ORIF, closed, arthrodesis	AOFAS score: 71
Rajapaske et al.[16]	2006	16	Various	AOFAS score: 78.3
Zhang et al.[17]	2012	29 patients, 30 feet	Various	AOFAS score: 80.6

Note: Expanded from data aggregated by Desmond et al.

joints was determined solely by the 3D articular surfaces of the bones and the ligament/muscle forces. The model predictions of joint diastasis was confirmed to be within the standard deviation of the previous cadaveric study.[23] Results from the previous validation work for healthy and injured models were used as a point of comparison for the four different surgical procedures. The previously developed rigid body model and new finite element models in this study were used to investigate the kinematics and other clinical indicators that could be observed in postoperative radiographs for the surgical procedures.

2.1 | Modeling surgical repair

The four surgical procedures evaluated were ORIF with screws, endobuttons, or dorsal plates, as well as arthrodesis. Each of the procedures were first simulated in the existing rigid body model based on procedure descriptions from previous studies.[10–12,24] For ORIF with screws, two transarticular cannulated screws were modeled based on 3.75 mm fully-threaded AR-7000 screws from Arthrex Inc. One screw was placed laterally from the medial cuneiform to the second metatarsal base while the other one was from the medial cuneiform to the intermediary cuneiform (Figure 2A). ORIF with endobuttons was modeled as two tension only elements with a similar orientation as the screws (Figure 2B). The endobuttons were based on the Mini TightRope FTAR8917DS from Arthrex Inc. which uses a Number 2 FiberWire. Work by Najibi et al. provided the material properties and stiffness of the fiberwire.[25] The dorsal plate procedure used a plate modeled after the Arthrex Lisfranc plate (AR-8951) where four screws were secured through the dorsal surface of the medial and intermediary cuneiforms and the first and second metatarsal bases (Figure 2C). The dorsal plate commonly is contoured or curved to fit the patient's anatomy and to prevent the introduction of gaps in the plantar portion of the joint. The last procedure was an arthrodesis where the articular surfaces between the medial, intermediary, and lateral cuneiforms, as well as the bases of the first and second metatarsals were removed to simulate debridement. After the articular surfaces of these bones were removed, the bones were translated laterally and posteriorly to bring them in contact again with each other before fixing in place with five cannulated screws (Figure 2D).

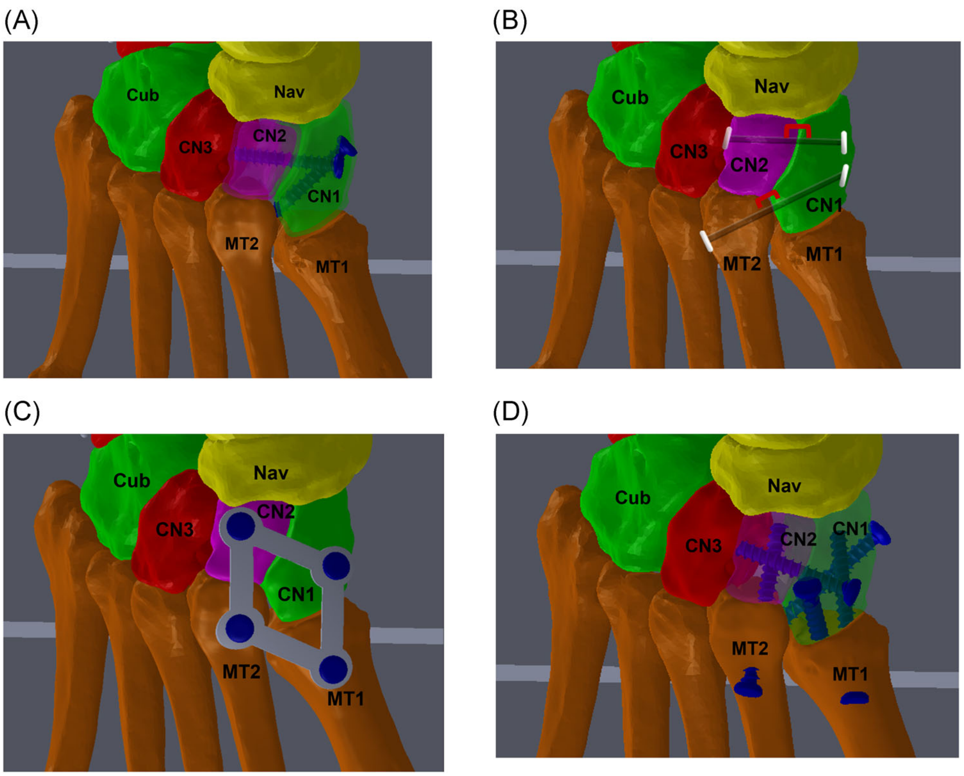

FIGURE 2 (A) Dorsal view of the hardware used for the four different Lisfranc repair surgeries in the kinematic model: (A) open reduction and internal fixation (ORIF) with screws performed with two cannulated 3.5 mm screws running from the medial cuneiform (CN1) to the intermediate cuneiform (CN2) or the second metatarsal (MT2). Other bones of the midfoot labeled for clarity—navicular (Nav), cuboid (Cub), lateral cuneiform (CN3), first metatarsal (MT1), and second metatarsal (MT2). (B) ORIF with endobuttons modeled as tension only elements passing from CN1 to CN2 and to MT2 across joints. Red brackets identify the portion of the fiberwire modeled in the rigid body model. (C) ORIF with dorsal fixation via a titanium plate modeled after Athrex's AR-8951 with four screws. (D) Arthrodesis performed by debriding a portion of the articular surface and moving bones into contact. Five screws used to fuse the three cuneiforms and first two metatarsals as per clinical practice [Color figure can be viewed at wileyonlinelibrary.com]

2.2 | Rigid body kinematic simulations

Once the hardware was incorporated into the rigid body model, the first round of simulations was performed. These simulations applied a 50% weight bearing steady-state compressive load and tensile muscle loads, the same loading as the model validation work for a post-injury joint.[23] The rigid body model allowed for ligament and joint contact forces to be captured for the postoperative foot. The contact forces in the joints adjacent to the surgical site, specifically for the other portions of the tarsometarsal, cuneonavicular and cuneocuboid joints, were of particular interest because of the pattern of adjacent joints developing arthritis after surgery.[26,27]

Since ORIF with endobuttons could be modeled with tension only force elements to represent the stiffness of the FiberWire of the endobutton, the bones of the Lisfranc joint were able to move relative to each other in the rigid body model. This allowed for the diastasis (separation) of the Lisfranc joint to be captured in three depths of the joint for ORIF with endobuttons using the rigid body model. However, the rigid body assumption of the material used for fixation in the ORIF with screws, ORIF with dorsal plates, and arthrodesis procedures restricted all motion in the Lisfranc joint contrary to what would be expected in vivo. For these three cases, a finite element analysis was also created as described below which permitted a limited set of bodies to be modeled as deformable. This enabled motion at the Lisfranc joint per prescribed boundary conditions and determination of stresses in the hardware. The ORIF with endobuttons did not require the additional finite element analysis because the flexibility in the FiberWire of the endobutton could be modeled as a tension only element in the rigid body kinematic model. This allowed for motion in the Lisfranc joint and measurements of the key model output (joint diastasis). Stresses could also be calculated in the FiberWire spanning the joint from this tension and wire cross-sectional area. Thus, all desired parameters were determined for the endobutton procedure from the kinematic model. However, this meant stresses were not calculated in the bone-button interface, but this has not been reported clinically to be an area of failure. Further, stresses in the hardware was the specific measure of interest from the finite element analyses of the other three procedures.

2.3 | Finite element analysis (FEA)

For each of the three procedures that required FEA to determine joint motion, the FEA was built using ANSYS Workbench. The models for the bones and implants involved in the surgery were directly imported into ANSYS. Because of the different material properties of cortical and cancellous bones, the bone volume was modeled as a cancellous interior and with a cortical shell. The thickness of the cortical shell was determined based on pixel intensity identified in a CT scan of the bones used in the model. The result was thicker cortical bone in the metatarsal shaft compared to the metatarsal head or base.

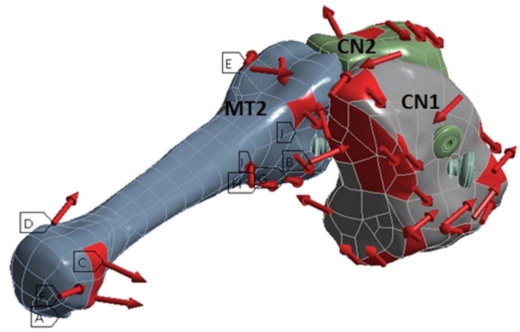

FIGURE 3 Example of the finite element model with forces applied (red arrows) for open reduction and internal fixation with screws in steady-state plantarflexed weight-bearing simulation [Color figure can be viewed at wileyonlinelibrary.com]

Once the geometries were prepared, a mesh was created with tetrahedral elements. The number of elements ranged from 30,000 to 185,000 depending on the procedure being modeled. Then the forces that were captured from the rigid body model were incorporated into the FEA (Figure 3). Additionally, the boundary condition and contact settings defined in ANSYS specified the plantar surface of the metatarsal heads to be fixed while contact settings varied based on the materials involved. Bone on bone contact was modeled as frictionless to model the environment of a diarthrodial joint except for the arthrodesis case where the contact was modeled as rough (i.e., coefficient of friction modeled as infinite). Last, any contact between implant material for screws and bone was modeled as rough so that the implants could separate from the bone but not slide relative to each other. This was important since screws were modeled both with and without threads. In the simulations where the screws did not have threads, the rough contact prevented them from being pulled out from the bone.

The three materials included in the FEA were cortical bone, cancellous bone, and titanium. All materials were treated as isotropic and elastic. While bone is considered orthotropic, particularly in long bones, for the purposes of this study, the assumption of isotropic for the small bones of the foot was sufficient and is used in many other studies.[28–30] To define the material properties, density, Young's modulus, Poisson's ratio, and yield strength were designated (Table 2). The finite element model could then analyze the steady-state displacements and stresses in the bones and implants.

2.4 | Relation to clinical concerns

The data captured from the computational models were chosen to inform on the stability of the postoperative joint and implant stresses. Previous research has equated poor stability of the joint after fixation with higher frequency of complications and poor patient rates on the outcomes.[14,31] This was evaluated by recording the diastasis of the Lisfranc joint from nonweight bearing to partial weight bearing at three different depths of the joint: dorsal, interosseous, and plantar. The healthy, injured, and endobutton procedure could be evaluated with the rigid body model since there were no rigid implants spanning

TABLE 2 Material properties used in the finite element analysis

Material	Density (kg/m^3)	Young's modulus (GPa)	Poison's ratio	Yield strength (MPa)
Cortical bone	1850	15	0.3	100
Cancellous bone	1100	1.5	0.2	2
Titanium	4429	104.8	0.31	827.37

the Lisfranc joint. However, the other three procedures required FEA to determine joint diastasis values.

The next patient concern was from secondary arthritis developing after surgery.[26,27] To evaluate this concern, the magnitude of contact forces for joints adjacent to the surgical site were captured from the rigid body models. Additionally, the distribution of contact force along the five metatarsal heads with the plantar surface was also captured.

The last major concern evaluated was the risk of implanted materials to fracture, which has been reported in the literature.[14,32] Since the material and geometric properties of the endobutton FiberWire are known, the FiberWire stress could be determined from the amount of diastasis the joint experienced. Therefore, only a rigid body model was needed. However, the other three surgical procedures required finite element analysis to determine the stresses experienced throughout the implanted material.

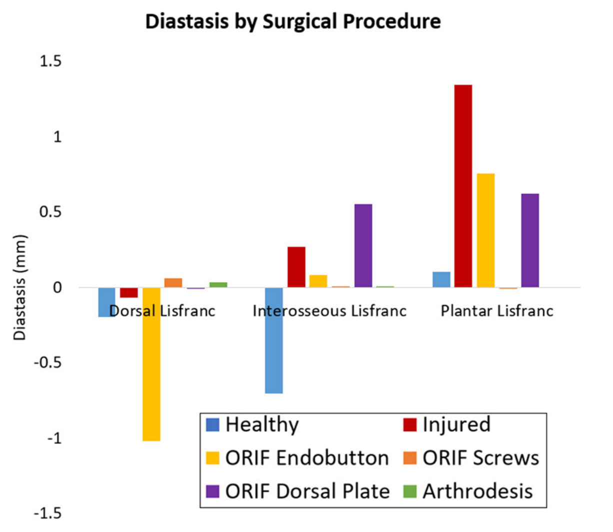

FIGURE 4 Diastasis (separation) between CN1 and MT2 when loaded vs unloaded for the four surgical repair procedures through three depths of the Lisfranc joint along with the values for a healthy and injured foot without intervention [Color figure can be viewed at wileyonlinelibrary.com]

3 | RESULTS

Diastasis measurements at three depths (dorsal, interosseus, and plantar) in the Lisfranc joint were captured in the rigid body model for the ORIF with endobutton while the other three surgical procedures had diastasis captured from the FEA simulations. The diastasis of the Lisfranc joint could be compared across all four surgeries and with a healthy and injured foot from previous work (Figure 4).[23] ORIF with screws and arthrodesis did not replicate the small amount of motion in the healthy joint; however, the little to no diastasis these procedures showed throughout the depth of the joint was the closest in returning the injured joint to diastasis values comparable to a healthy state. ORIF with endobutton had larger diastasis on both the dorsal and plantar sides while the dorsal plate minimized diastasis on the dorsal side but had increased levels interior to the joint as well as on the plantar side.

The contact forces of the metatarsals with the plantar surface and in several of the adjacent joints were captured for the four different procedures as well as the healthy and injured models using the rigid body models. The distribution of the plantar contact across the metatarsals changed to be concentrated in the second metatarsal after rigid fixation with screws or dorsal plates (Figure 5A). The contact forces in the joints proximal to the injury/fixation (cuneonavicular joint) and on the lateral portion of the transverse arch (cuneocuboid joint) were captured and compared. Rigid fixation with screws or plates resulted in greater forces in the cuneonavicular joint between the medial cuneiform and navicular (CN1-Nav) (Figure 5B).

When considering the peak von Mises stresses in the different implants (Figure 6), both the models with and without screw threads for the three procedures using screws or plates had high values that were close to their yield stress (Table 3). When reviewing the stress contours, ORIF with screws and arthrodesis procedures both had stress concentrations in the bolt of the screw passing through the joint space. The dorsal plate stresses had high values at the locking screw and plate interface on the first metatarsal.

4 | DISCUSSION

This study sought to characterize the stability of the Lisfranc joint after a repair surgery as well as evaluate the forces and stresses in the mid-foot and implanted materials. The results showed that all four procedures reduced some portion of the post-injury instability (Figure 4), but the kinematics still had differences from the healthy foot. The study was also able to highlight additional concerns that have been raised about the different procedures which may be contributing to poor patient outcomes. For the procedures with screws and plates, the concerns are hardware failure and higher joint contact forces that may precipitate secondary OA. For the

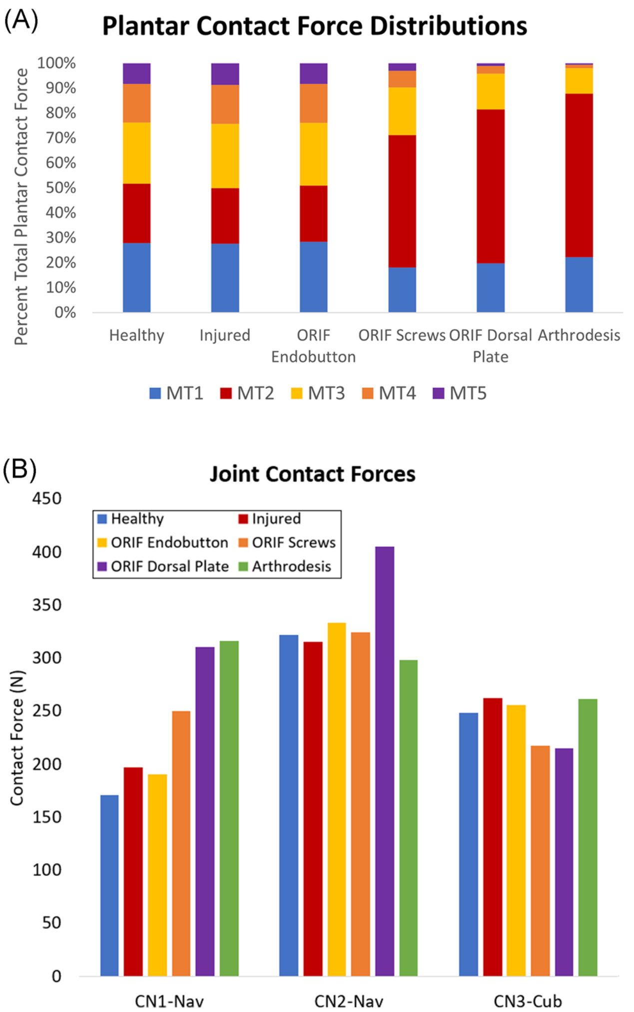

FIGURE 5 (A) Distribution of the plantar contact force across the different metatarsals for the healthy, injured, and surgical procedures. Contact forces were captured from the rigid body model. (B) Contact force in the naviculocuneiform joint (CN1-Nav and CN2-Nav) and the cuneocuboid joint (CN3-Cub) [Color figure can be viewed at wileyonlinelibrary.com]

endobuttons, the concerns were that irregular or excessive joint motion beyond the healthy range could hinder soft tissue healing.

ORIF with screws was the technique that provided the most similar diastasis values to a healthy cadaver foot throughout the depth of the joint as this procedure brought the injured foot's diastasis value closer to the healthy model than other ORIF procedures (Figure 4). In the dorsal measurement, all three fixations with screws showed a slight widening of the joint compared to the healthy model. However, both the injured and healthy models showed reduction of the joint space for the dorsal portion of the joint when loaded.

The less rigid fixation of the Lisfranc joint with the endobuttons is hard to state as an outright negative outcome. From a structural sense, the endobutton having a single tension element holding the medial cuneiform and second metatarsal will not be as stable as with the three native ligaments that support this joint in a healthy foot. The result is that there are some abnormal movements of the bones, like a reduced separation in the dorsal portion of the joint while increased separation in the plantar portion. This is not to say that the endobutton fails to reduce the injury (i.e., return bones to their anatomical orientation), but once in the original position with the endobutton centrally located, the bones of the Lisfranc joint have more freedom to pivot relative to each other under the effects of muscle and bodyweight loading. Some movement in the joint space

TABLE 3 Peak stresses experienced by the implanted hardware and the resulting safety factor of the hardware

Surgery	Peak stress (MPa)	Safety factor (yield stress/peak stress)
Open reduction and internal fixation (ORIF) with screws	358	2.3
ORIF with endobuttons	54	14.1
ORIF with dorsal plate	741	1.1
Arthrodesis	808	1

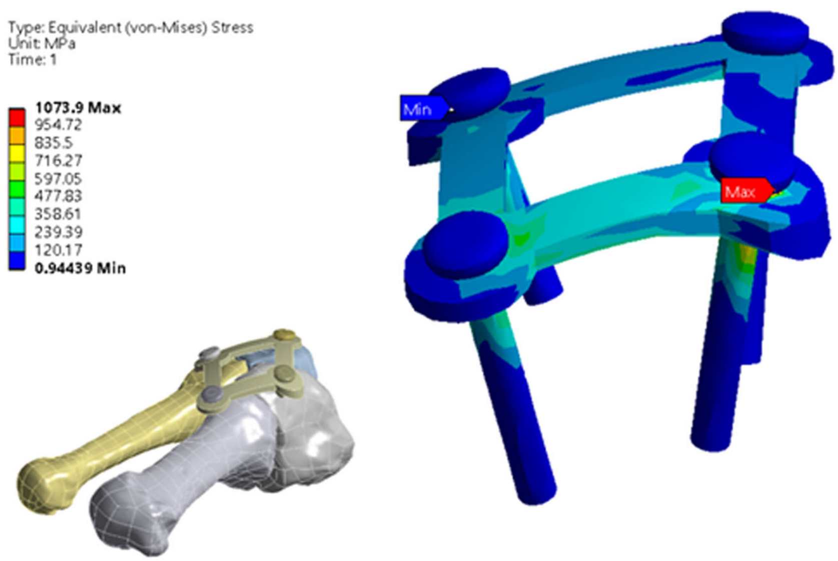

FIGURE 6 Von Mises stress contours of the titanium dorsal plate and the screws from an orthogonal angle for the finite element analysis with simplified screws [Color figure can be viewed at wileyonlinelibrary.com]

has been seen as a positive for soft tissue healing response in animal models.[11,33,34] The idea is that the additional movement helps promote remodeling of the injured and scarred tissue. The amount of motion or types of motion that would promote versus impede remodeling have not been quantified.

ORIF with dorsal plates showed signs of the plantar portion of the Lisfranc joint splaying apart. Similar behaviors of greater diastasis in the plantar portion of the joint when repaired with a dorsal plate was observed by Bansal et al.[24] Ultimately, the fact that the plate fixation only spans the joint space in the dorsal aspect of the joint means that even small bending of the dorsal plate contour can result in larger separations in the plantar part of the joint. This somewhat mimics the behavior of the endobutton where the wire running through the midsection allows motion in the dorsal and plantar portions of the joint.

For the arthrodesis procedure, there are several factors that contribute to the negligible diastasis. The first is the sheer volume of metal that is implanted as part of the procedure. The larger modulus of the screws compared to the bone as well as the physical connection between the different bones resist movement. Additionally, the debriding process before bone fixation removes the low friction cartilage so the bones cannot glide easily across each other. The debriding process also brings larger surface areas in contact with each other which in turn limits the possible motion of the bones.

Depending on the surgical procedure, there were changes in the distribution of the plantar contact force across the five metatarsals. When the injury was introduced and then repaired using ORIF with endobuttons, contact force distributions changed very little from a healthy model. However, the rigid fixation procedures with screws and plates greatly increased the percent of the plantar contact carried by the second metatarsal. This aligns with common complaints from patients that experience discomfort after ORIF procedure.[6,35] The larger contact forces on the second metatarsal after fixation results in the hardware implanted in the second metatarsal having to carry larger forces than other implant constructs. This could play an important factor in the ability of the hardware to survive without breakage or failures.

When joints are fixed in place in the foot, there are higher rates of OA in the adjacent articulations within the tarsometatarsal joint.[26] A possible reason for this is because of changes in the joint contact forces or stresses after a fixation procedure. When looking at the joints proximal to the surgery location (cuneonavicular joints), there are indications that the medial portion of the joint (CN1-Nav) has increased contact force after a rigid fixation procedure (ORIF with screws/plates or arthrodesis). However, the lateral portion of the transverse arch (cuboid and lateral cuneiform) did not experience large changes in contact force after an ORIF procedure (Figure 5B). The changes in joint contact forces may help explain the higher rates of osteoarthritis in these joints after a Lisfranc repair and may suggest greater focus is needed on the medial portion of the cuneonavicular joint.[36]

The high stress observed in hardware for the ORIF with screw procedure agreed with hardware failure patterns reported in the literature.[11] Most ORIF screw fixation failures occur in the area spanning the Lisfranc joint where the screw fracture occurs in the joint space. In the model, the portion of the screw as it entered the second metatarsal demonstrated increased stress. While this increase was not beyond the yield strength, the high peak stress regions experienced 50% of yield strength where fatigue failure could be a concern with repetitive loading. This supports the clinical practice of nonweight bearing for 4–6 weeks post-surgery. This allows time until ligament or capsular tissue begins to regain organizational alignment and increased thickness. While these are qualitative assessments for the soft tissue, the reorganized soft tissue should help resist motion across the joint and thus reduce the stress experienced by screw implants. In terms of return to normal activities of daily living for those undergoing endobutton procedures, clinicians have allowed patients to begin weight bearing at earlier time points because there is less concern of the implant failing when compared to screws.[11] These results are supported by the simulations of this study with the FiberWire having a higher safety factor compared to screws or plates when loaded in a plantarflexed foot (Table 3).

The stress contours for arthrodesis showed similar concerns as the ORIF with screws. With five screws spanning five different joints, the implanted screws were loaded in many different orientations. The stress contours showed the intercuneiform screw experiencing the highest stress values which were close to the yield strength for titanium. The high-stress regions suggest that there might need to be a second intercuneiform screw, which is seen in procedures by some researchers and clinicians.[37]

The key limitation of this study was the fact that only a single anatomy was used in the computational model. While this did allow for a comparable anatomy across the different procedures, it did not consider how results may differ depending on the subject. Potential future automation of subject-specific models could reduce the time to generate the model or even extend the ability to compare surgical outcomes for specific patients in the future. Additional assumptions were implemented for the FEA simulations of the model. Instead of modeling the entire foot in FEA, only the implant hardware and the bones directly contacting the implant hardware were included. To account for the rest of the foot, contact forces of the assembly from the omitted bones served as boundary conditions in the FEA. This approach allowed the rigid body modeling to capture the mechanics driven by soft tissues while also capturing the stresses experienced by the implants and bones around the Lisfranc joint in the finite element model. Also, this study does not consider the changes that a patient may make to their gait kinematics as a result of fixation or pain from the injury. In reality, the patient may adopt a gait pattern that could obscure the metrics used to determine normal anatomical function. Last, this study only considers the immediate postoperative mechanical state of the foot. The work did not explore how the implanted materials or the results of early loading of the injury could impact the biological processes of tissue repair after surgery. Over time, soft tissue will heal and in some ORIF procedures, the hardware will be removed which would change the mechanics of the Lisfranc and adjacent joints. The exclusion of these factors was deemed acceptable given the importance of joint stability immediately after the surgical procedure to allow normal biological repairs to occur in the soft tissue.

In conclusion, these studies have created a benchmark for the mechanical stability of the different Lisfranc repair surgeries. Arthrodesis provided the most mechanically stable midfoot and Lisfranc joint. However, this procedure is permanent and will result in fused bones and is not geared at producing an environment for soft tissue healing. Additionally, the rigid fusion of other joints in the foot have been noted to lead to arthritis developing in adjacent joints after fusion.[26] Of the three ORIF procedures, ORIF with screws provided the most mechanically stable postoperative joint but has other concerns regarding implant survival and changes to contact forces in the mid foot.

This model and procedures can hopefully also function as a benchmark for any new or proposed Lisfranc repairs. Since none of the surgeries in this study have received universal approval in the literature[6] or support in this study, new procedures are likely to be developed. If this model is used in the future to compare new surgical techniques, there are already a standard set of measurements and values for the existing procedures to which the new surgery can be compared. Ultimately, the results of these studies suggest favorable stability using cannulated screws for ORIF procedures to treat Lisfranc injuries assuming the patient avoids early weight-bearing because of the risk of implant failure. However, in cases where treatment plans favor early weight-bearing activities, ORIF with endobuttons may have a lower chance of implant failure. These considerations can help surgeons select procedures based on the success criteria they prioritize, assuming initial reduction of the injury is properly performed.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Michael T. Perez: Research design, analysis/interpretation of data; all aspects of manuscript preparation. John R. Owen: Contribution to research design; approval of manuscript draft. Robert S. Adelaar: Contribution to research design; approval of manuscript draft. Jennifer S. Wayne: Research design, data interpretation; manuscript critical revision and approval of submitted/final versions.

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