Biomechanical Comparison of Fully Threaded Solid Cortical Versus Partially Threaded Cannulated Cancellous Screw Fixation for Lisfranc Injuries

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abstract

There currently exists an array of operative strategies to manage Lisfranc injuries. Modular fixation systems present surgeons with a choice between fully threaded solid cortical (FSC) and partially threaded cannulated cancellous (PCC) bone screws when using a transarticular screw approach. It is currently unknown how screw design influences fixation strength in Lisfranc reconstructions. The purpose of this study was to evaluate the biomechanical differences of FSC and PCC screws using a cadaveric model of a simulated Lisfranc injury and controlled benchtop experiments. Ten matched pairs of cadaveric feet received an acute Lisfranc injury and were repaired with FSC or PCC screws. Diastasis was measured between the medial and intermediate cuneiforms and the first and second metatarsals during simulations of partial weight bearing. Three-point bending and axial pull-out tests were performed to characterize screw mechanics that could not be measured within the cadaveric model. Screw design did not affect cuneiform or metatarsal diastasis. Neither screw loosening nor deformation was observed following cadaveric testing. Bending tests indicated FSC screws had higher ultimate strength, but there was no significant difference in yield load. Partially threaded cannulated cancellous bone screws exhibited superior axial pull-out strength. Fully threaded solid cortical and PCC screws provide equal amounts of fixation strength during partial weight bearing and similar resistance to deformation under bending loads. Partially threaded cannulated cancellous screws may simplify the operative procedure and minimize nonoptimal screw placement. If a clinician so desires, PCC screws may be used in lieu of FSC screws without sacrificing fixation strength. [Orthopedics. 2018; 41(2):e222-e227.]

Lisfranc injuries often lead to patient morbidity and, if not treated, may result in substantial pain, chronic instability, and arthritis.1–5 A wide spectrum of injury severity exists for the Lisfranc joint, as activities such as sports or motor vehicle accidents can be responsible for the disruption of the midfoot.3–8 The risk of posttraumatic arthritis is increased when the injury is unrecognized or partially treated, or when anatomical reduction is not adequate.5,9–12 Open reduction and internal fixation methods are often used to restore the keystone of the midfoot.8,9,13,14 Transarticular screw fixation is commonly used to address this injury, but it is unknown if the type of screw used has the potential to directly impact outcomes.

In a clinical setting, small fragment fixation systems provide surgeons with a choice between fully threaded solid corti-
cal (FSC) or partially threaded cannulated cancellous (PCC) bone screws. It has been shown that cannulated screws have reduced ultimate loads, yield strengths, and cycles to failure when compared with solid screws of the same dimensions.\(^\text{15}\) Additionally, it is known that cancellous screws provide superior axial pull-out strength when compared with similar cortical screws.\(^\text{16,17}\) However, the screws in a small fragment set are not limited to a single variation in design, but instead have a variety of differences (Table; Figure 1). To date, for Lisfranc repair, FSC screws are preferred over PCC screws\(^\text{4,8}\); however, it remains unclear if PCC screws are robust enough to stabilize the midfoot under physiological loading.

This study had 2 aims. The first was to compare the biomechanical performance of PCC and FSC screws in an in vitro model of a Lisfranc reconstruction. The authors hypothesized that there would be no difference in fixation between PCC and FSC screws. The second was to eliminate the variability inherent to in vitro models and perform benchtop experiments to thoroughly investigate the relevant parameters of resistance to bending and resistance to axial pull-out. The authors hypothesized that the PCC screws would have lower ultimate and yield strengths but higher pull-out strength than the FSC screws.

**Materials and Methods**

**Specimen Preparation**

The methods used in this study were based on established protocols.\(^\text{10,18}\) Ten matched pairs of fresh-frozen mid-tibia to toe tip segments (7 men, 3 women; mean age, 72.4 years [range, 54-89 years]) were used. Sample size was based on an a priori power analysis with the following parameters: expected differences in mean diastasis=10%, standard deviations=7.5%, desired power=0.8, and α=0.05. The skin of the dorsal midfoot of each specimen was carefully removed to expose the first and second metatarsals and the medial and intermediate cuneiforms. Next, the ankle and tibiotalar joints were fixed in approximately 30° of plantarflexion (Figure 2) by inserting 2 steel screws through the plantar surface of the calcaneus, across the talus, and into the distal tibia. Although this position is not physiologically comparable with that of living patients with intact joints, it is advantageous because it applies a substantial amount of stress across the midfoot, thus aiding in creating measurable diastasis between bones, and it has been used in other Lisfranc biomechanical studies.\(^\text{10,18}\)

All specimens were securely mounted into a universal testing frame (Electroforce 3550; TA Instruments, Eden Prairie, Minnesota) equipped with a 15 kN/49 Nm load/torque cell. Potted tibial shafts were securely attached to the frame. Retroreflective marker clusters were fixed to the first metatarsal, second metatarsal, medial cuneiform, and intermediate cuneiform with a 1.6-mm Kirschner wire (Figure 2). Motions of the marker clusters were tracked with a 3-dimensional motion capture system (Optitrack; Natural Point Inc, Corvallis, Oregon). Specimens remained in the universal frame throughout the en-

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**Table**

<table>
<thead>
<tr>
<th>Element</th>
<th>FSC</th>
<th>PCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thread coverage</td>
<td>Full</td>
<td>Partial (one third)</td>
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<tr>
<td>Body type</td>
<td>Solid</td>
<td>Hollow</td>
</tr>
<tr>
<td>Thread pitch, mm/revolution</td>
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<td>Thread depth, mm</td>
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<td>Inner diameter, mm</td>
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<td>Outer diameter, mm</td>
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<td>4.0</td>
</tr>
<tr>
<td>Length, mm</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

Abbreviations: FSC, fully threaded solid cortical; PCC, partially threaded cannulated cancellous.
tire testing process to minimize unwanted marker cluster perturbation.

**Operative Technique**

Disruption of the Lisfranc ligament was achieved over the dorsal aspect of the foot with a scalpel, similar to previously published studies. Briefly, the joints between the medial cuneiform and the first metatarsal, second metatarsal, and intermediate cuneiform were acutely disrupted to simulate a complex Lisfranc ligament injury (Figure 3A). Sectioning was repeated several times to ensure that no unwanted ligamentous attachments remained.

For both groups, reconstructions were performed under standardized conditions. Assignment of screw type was randomized for the left and right limbs of the matched pairs. For the FSC group, the gaps between the first and second metatarsals and the medial and intermediate cuneiforms were manually reduced and held. A 2.5-mm drill was used to drill holes from (1) the medial cuneiform to the intermediate cuneiform, (2) the medial cuneiform to the base of the second metatarsal, and (3) the base of the first metatarsal to the intermediate cuneiform (Figure 3B). Partially threaded cannulated cancellous screws were placed over the guidewires and subsequently drilled in place. To reduce the effects of overcompression, care was taken to stop insertion just as the head of the screw sat flush with the bone.

**In Vitro Testing**

Each test consisted of 4 phases during which the relative distances between midfoot bones were determined. First, healthy specimens were loaded at a rate of 20 N/s to a static load of 343 N and locations of bone marker clusters were recorded. Second, the Lisfranc ligaments were sectioned as previously described, the static load of 343 N was reapplied, and locations of bone marker clusters were recorded. Third, either FSC or PCC reconstruction was performed, the static load of 343 N was reapplied, and bone marker cluster locations were recorded. Finally, repaired specimens were cycled 100 times between 10 N and 343 N at a rate of 1 Hz. Specimens were returned to a static load of 343 N and bone marker cluster locations were recorded. Screws were retrieved after testing and inspected for permanent deformation.

Diastases were measured as the normalized distance between landmarks on the medial and intermediate cuneiforms and the first and second metatarsals (Figure 3B). Landmarks were identified using an instrumented pointing device that was tracked with a 6-camera motion capture system. These displacements were measured with an accuracy threshold of 0.2 mm, as determined during calibration of the motion capture volume.

**Benchtop Testing**

A 3-point bending test was performed on 15 retrieved screws from each group to simulate a failure mechanism that may be seen clinically. Screws were selected such that at least 1 screw from each specimen was used to create the group of 15 and screw positions within the cadaveric model were randomized. The test was performed on a universal test frame (Electroforce 3330; TA Instruments) equipped with a 3-kN load cell. The 30-mm screws were placed on hardened steel rods spaced 24 mm apart, and a hardened steel actuator applied a compressive force at the midpoint of the supports (Figure 4A). The actuator moved at a constant rate of 1 mm/min for 4 minutes. Force-displacement plots were created, and ultimate failure load was recorded. Yield strength was derived by performing a 0.2% offset analysis.
on the flexural stress–strain curve that represented the underside of the screw, which underwent the highest amounts of bending stress and strain.

A screw pull-out test was performed in accordance with industry standards\(^1\) on the remaining 15 retrieved screws from each group to simulate another clinically relevant failure mode. Blocks of cellular foam with a density of 15 lb/ft\(^3\) (Sawbones, Vashon, Washington) were used to represent bone for this portion of the study. The rotational actuator of the Electroforce 3550 test frame inserted the screws at a rate of 3 rpm to a depth of 20 mm. Screws were subsequently distracted using a custom screw head grip in line with a universal joint to isolate axial distraction forces (Figure 4B). Screws were distracted at a rate of 5 mm/min. Maximum pull-out load was recorded for each sample.

**Statistics**

Initial distances between metatarsals and cuneiforms of healthy specimens were normalized, and changes in diastasis were converted to percent increases. One-tailed, paired Student’s \(t\) tests were used to evaluate the changes in diastasis following acute injury. This technique was chosen because only increases in diastasis were expected, and measures took place within the same specimen. For all other tests in this study, 2-tailed, 2-sample, equal variance \(t\) tests were used to assess unknown responses across groups. Significance was set at \(\alpha=0.05\) for all tests.

**RESULTS**

**In Vitro Testing**

Sectioning the Lisfranc ligament created significant diastasis between the intermediate and medial cuneiforms and the first and second metatarsals. When compared with healthy specimens, the mean cuneiform and metatarsal diastasis for injured specimens was 12.3\(\pm\)18.1\% \((P=0.03)\) and 8.4\(\pm\)18.0\% \((P=0.032)\), respectively. Diastasis following reconstruction did not differ significantly between the FSC and PCC groups (Figure 5). In the case of cuneiform diastasis, the mean normalized value after reconstruction was 10.2\(\pm\)11.5\% for FSC and 6.2\(\pm\)18.2\% for PCC screws \((P=0.58)\). The mean normalized metatarsal diastasis after fixation was 2.0\(\pm\)20.3\% for FSC and 4.5\(\pm\)10.5\% for PCC screws \((P=0.73)\). There were also no significant differences after 100 cyclic loads, as mean values for cuneiform diastasis were 10.1\(\pm\)18\% for FSC and 11.8\(\pm\)12.9\% for PCC screws \((P=.82)\). Metatarsal diastasis mean values were -0.7\(\pm\)17.3\% for FSC and 14.6\(\pm\)24.6\% for PCC screws \((P=.15)\). Screws were removed following in vitro

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**Figure 4:** Photograph of the experimental setup used for the 3-point bending of screws. The actuator moved in the direction of the arrow at a constant rate to create a bending moment (A). Photograph of the experimental setup used for the pull-out test. Grips clamp a custom-made fixture around the neck of the screw head and pull in the direction of the arrow at a constant velocity (B). Fully threaded solid cortical screws are being tested in both photographs.

**Figure 5:** Box and whisker plots for the diastasis between cuneiforms (A) and metatarsals (B). The median is represented by the thick black line, and the quartiles are shown with colored boxes or vertical lines. Individual data points for fully threaded solid cortical (FSC) screw and partially threaded cannulated cancellous (PCC) screw groups are represented with small boxes and triangles, respectively. Points outside of the whiskers are considered outliers. Blue plots represent measures of diastasis after reconstruction, whereas green plots represent diastasis after 100 cycles of loading.
observed no statistically significant differences between groups, and the amounts of variability within the in vitro experiment were considerably high.

There were instances when the injury increased diastases between the cuneiforms but reduced the distance between the metatarsals, and vice versa. This result is not entirely surprising, given the highly complicated and variable loading mechanics of the midfoot. A similar study supports this finding, as diastases between cuneiforms before and after ligament injury were not statistically different.\textsuperscript{10} Unlike the previous study, statistical analysis of the current dataset confirmed significant diastasis between both the cuneiforms and the metatarsals after injury.

None of the screws retrieved from the tested specimens had indications of permanent bending, deformation, or loosening. Because the screws retrieved after biomechanical loading had no permanent deformation and because variability within benchtop measures was small, it was assumed that the mechanical properties were not altered prior to benchtop testing. Loads applied by the actuator to the tibia during the biomechanical test were relatively close to measured yield loads. However, a large degree of load sharing occurs within the foot, so it is reasonable to deduce that the bending loads experienced by the screws during testing were not close to yield points. Additionally, no screws were loose during retrieval, so it is also apparent that pull-out loads were not reached during the course of in vitro testing.

This benchtop experiment successfully eliminated the variability associated with in vitro testing, allowing the authors to measure differences in resistance to bending and pull-out strength. As hypothesized, the authors observed significantly higher ultimate strength in FSC screws. In contrast to a previous study comparing solid and hollow screws of the same diameter,\textsuperscript{15} there were no significant differences between yield points, which can be attributed to the 0.5-mm increase in outer diameter of the PCC screw. Because the clinical failure of a screw is better defined by the yield point (permanent deformation) rather than ultimate force, the current findings suggest that the screws tested in this study performed similarly when subjected to bending.

As hypothesized, PCC screws provided superior resistance to axial pull-out loads when tested in cellular foam. The results agree with a previous study examining the effect of screw thread design on the pull-out strength of bone screws in cancellous bone.\textsuperscript{17} The results of the current study are interesting because the PCC screw has only 10 mm of threads engaged in a 20-mm hole, yet the pull-out strength is superior to that of a fully threaded screw. It is unclear how these 2 screw designs would perform if they were tested in a composite where a cortex surrounded the cancellous bone.

This study examined the differences in fixation strength between 2 unique screw designs. Most notably, the FSC screw is designed to restrict relative motion between 2 bones, whereas the PCC screw is intended to compress the 2 bones together. A previous study used an over-drilling technique to make the FSC screw behave more like the PCC compression screw.\textsuperscript{20} The current authors took the opposite approach, minimizing the amount of compression that was applied as the screw head approached the near cortex. They think that this approach created a scenario that was equal across groups, while mitigating unwanted high amounts of compression of the articular cartilage.

This study had inherent limitations. The static pose used in the experiment was successful in applying stress to the midfoot, but this scenario does not realistically represent the complex motions of human gait. Degradation of ankle fusion constructs limited the number of cyclic loads that could be applied. Similar studies that assessed 1000 and 10,000 cyclic loads reported no changes in diastasis.\textsuperscript{10,20} Additionally, high numbers of
cyclic loads are not clinically relevant, as most postoperative rehabilitation protocols advise against weight bearing for several weeks. Finally, a post hoc power analysis of the results indicated that differences between groups were not as large as expected. Future in vitro studies should involve a larger cohort of samples.

CONCLUSION

This study is the first to directly compare the biomechanical differences between 2 screw types often used to fix a Lisfranc injury. Some clinicians may opt for FSC screws because of their greater ultimate strength and smaller diameters that minimize the impact on articular cartilage. Others may prefer PCC screws so that a Kirschner wire can first be used to ensure appropriate screw trajectory and reduce drill passes, which also has the potential to limit articular damage. In this era of cost containment, despite surgeon preference and multiple fixation options, both types of screws provide reasonable biomechanical fixation without compromising clinical outcomes. A clinical follow-up study should be performed to confirm the findings of this investigation.

REFERENCES