The Lapidus Arthrodesis: Examining the Effect of the Metatarsal Base Transfixation Screw

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Statement of Purpose

Through our biomechanical cadaveric study, we aim to compare load to failure values in the first metatarsocuneiform arthrodesis. This poster is to presents the differences in strength between commercially available five-hole locking plates with interfragmentary compression versus a crossed screw with a third "transfixation" screw construct in a controlled setting. Although this procedure has been extensively studied, no clear consensus has been achieved regarding optimal fixation for this thought-provoking procedure. We hypothesize that interfragmentary cross-screw fixation with an additional third screw from the first to second metatarsal base for first metatarsocuneiform joint arthrodesis will display non-inferiority to the hybrid locking plate construct with regards to load to failure.

Introduction

The first metatarsocuneiform joint arthrodesis is a versatile and powerful procedure utilized to correct first ray hypermobility and hallux abducto valgus. Since originally described by Albrecht in 1911 and popularized by Lapidus in 1934, advances in joint preparation and fixation techniques have aided in decreased nonunion rates from 12% reported in older literature (1-5). Following the improvement in union rates in the last decade, much of the focus has shifted to early mobilization and weight-bearing to improve patient satisfaction, expedite return to work times, and decrease scar tissue formation and postoperative stiffness (6-17). Locking plate constructs have been at the center of this revolution given the stability afforded by them. To assess the impact of locking plate constructs, there have been numerous publications comparing fixation methods (18-25). The strongest load to failure fixation construct was reported by Cottom et al. in his biomechanical cadaveric study utilizing a standard low-profile locking plate with an intraplate compression screw and a plantar interfragmentary screw (15). However, there remains conflicting evidence in other biomechanical studies comparing standard crossing interfragmentary screws and locking plate constructs (19, 20, 23, 25, 26).

The Principal Investigator (DJE) routinely utilizes crossing 4.0 mm cannulated interfragmentary screws along with a stabilization screw from first to second metatarsal base similar to the technique described by Blitz et al. and King et al. (10, 16). This method has shown to be effective in terms of cost and ability to begin weight-bearing as early as 12 days post-operatively without compromise in fixation or increased nonunion rates (16). The addition of a third screw from the first to second metatarsal or first metatarsal to medial cuneiform was investigated by Ray et al., however no significant difference in terms of load to failure was seen with the additional screw and there was no comparison to locking plate constructs. It should be noted that the load to failure values with a third screw were in fact higher, and may have approached statistical significance with a larger sample size or utilization of our operative technique (26). Our biomechanical cadaveric research, aimed to compare load to failure values in the first metatarsocuneiform arthrodesis for (1) interfragmentary crossed screw fixation with an additional third (transfixation) screw from the first to second metatarsal base and (2) the strongest hybrid locking plate fixation technique reported to date. This study was funded through a grant from the **OCPM Foundation**.

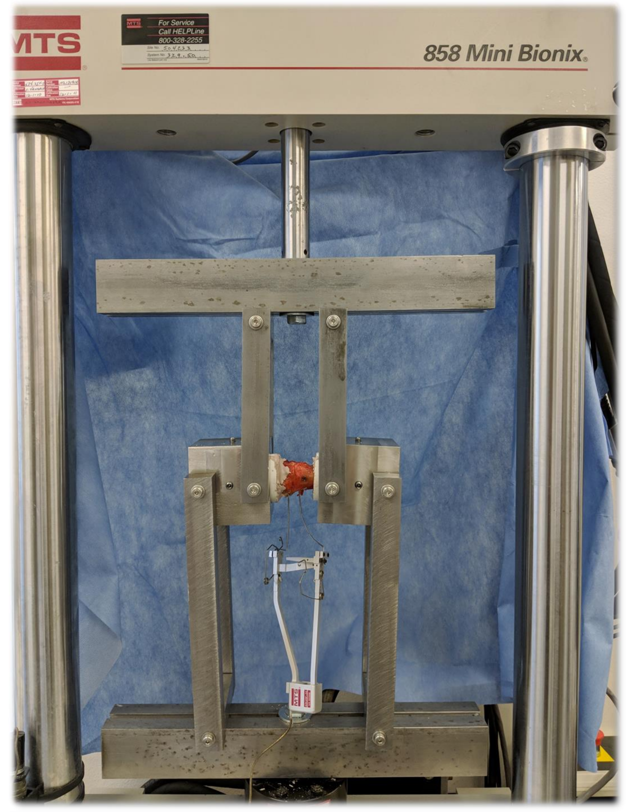
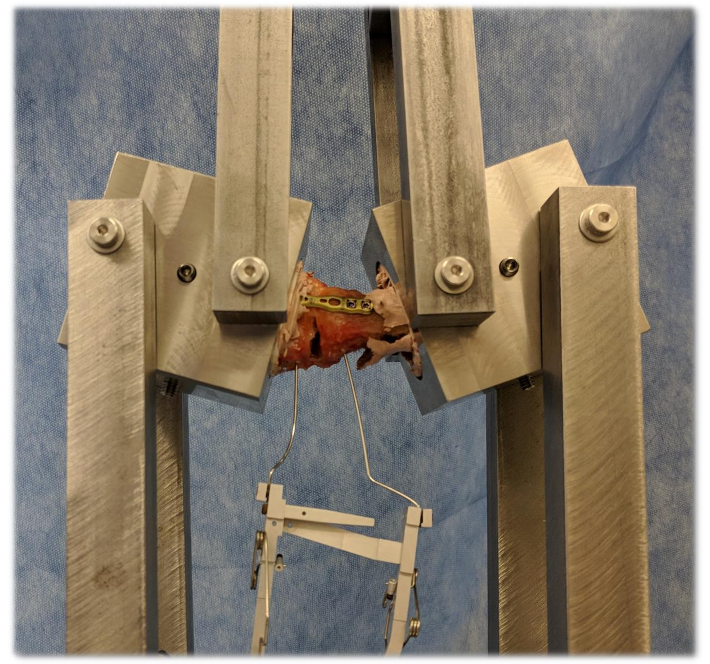


Figure 4. Testing consisted of potted specimens in a custom made four-point bending fixture. The fixture was bolted to the servohydraulic load frame and loaded at a rate of 5mm/min. Note the plantar placement of the extensometer, which measured plantar displacement at the arthrodesis site.

Figure 5. Extensometer measuring plantar displacement. Note the gapping as a result of the axially applied load. The four-point bending fixture is necessary to isolate forces across the first tarsometatarsal joint.



Materials and Methods

Specimen Preparation

Ten matched-pairs of fresh frozen human cadaveric below-knee limbs were obtained and thawed. All donors were matched to sex, general medical comorbidities, and age range. Donor criteria included a history free from previous foot and ankle surgery or systemic musculoskeletal disease. Sample size was determined based on previous studies using similar methodology to evaluate different fixation techniques for the same surgical procedure (21, 23). A standard dorso-medial incision was performed over the first tarso-metatarsal joint. The skin, subcutaneous tissue, deep fascia, and periosteum were elevated, and the joint capsule was exposed. All ligamentous structures about the first tarso-metatarsal joint were resected. This ensured that maintenance of joint apposition would be solely reliant on fixation applied. The joint structures were preserved to eliminate any potential differences in joint resection, theoretically affecting the coefficient of friction between the adjacent bones.

Implantation

All plate and screw implantation were performed by a board-certified foot and ankle surgeon (DJE). Three fixation constructs were evaluated. Within each matched-pair, one specimen was assigned to a screw-only fixation construct, while the contralateral limb was assigned to a medial locking plate with interfragmentary screw construct. The first construct (10 limbs) consisted of two crossing 4.0 mm partially-threaded, stainless-steel, cannulated screws, with an additional 4.0 mm partially-threaded, stainless steel, cannulated screw transfixating the first and second metatarsal bases (Figure 1). The second construct (5 limbs) consisted of one 4.0 mm partially-threaded, stainless-steel, cannulated interfragmentary screw combined with a medially placed stainless steel locking plate with five 2.7 mm locking screws. The third construct (5 limbs) consisted of one 4.0 mm partially-threaded, stainless-steel, cannulated interfragmentary screw combined with a medially placed titanium locking plate with five 3.0 mm locking screws (Figure 2). Interfragmentary screws were kept consistent between plating groups to eliminate variable between cannulated screw design; ensuring a direct examination between plating designs. Hardware was implanted utilizing the respective manufacturer's published technique. Each screw was placed to ensure bicortical purchase, and locking screws were placed in axial "fixed-angle" positions.

Figure 1. Standard dissection with three-screw construct

Figure 2. Standard dissection with a five-hole locking plate (titanium in this photo) with interfragmentary compression screw construct

Figure 3. Specimens potted in 1.5 inch PVC pipe with auto filler. Top construct is the five-hole stainless steel plating. Bottom construct is the five-hole titanium alloy. The three-screw constructs were potted in the same fashion.

Potting

After fixation, each specimen was meticulously dissected from the remaining foot. The first and second metatarsal, as well as the medial, intermediate cuneiform, and navicular were preserved for testing. All ligaments were preserved, except for the ligaments surrounding the first tarsometatarsal ligament. The second ray was then resected at the mid-diaphyseal region to allow potting of the first metatarsal head. Specimens were embedded into a 1.5 inch cylindrical PVC pipe utilizing as much automotive filler as possible without interference of the first tarsometatarsal joint (Figure 3).

Biomechanical Testing

Mechanical testing was conducted using a computer-controlled servohydraulic load frame under the guidance of a biomechanical engineer (JK). Each potted specimen was loaded into a custom made four-point bending fixture (Figure 4), like that previously described by Gruber et al. (19). The four-point bend method ensures a consistent load between contact points. Specimens were secured in the fixture such that the plantar aspect of the construct was facing downward. An extensometer was mounted plantarly across the fusion site to measure and record deformation (Figure 5). Specimens were loaded at a displacement rate of 5mm/min until failure. Failure was defined as the load that resulted in 3 mm of plantar gapping/deformation, as measured by the extensometer, or catastrophic failure of the fixation. 3 mm represented a value detrimental to osseous healing. For statistical analysis of plate vs screw fixation, a paired t-test was used; for plate vs plate fixation, a student's t-test was used; significance was defined as $p<0.05$.

Results

The results of maximal load testing and load to failure are listed in Tables 1 and 2. The mean load to failure of all locking plate constructs (n=10) was 264.1 ± 100.9 N and all screw constructs (n=10) was 310.9 ± 109.4 N. This was not statistically significant (p=0.328). This is illustrated in Chart 1. The mean load to failure of the titanium plates (n=5) was 304.6 ± 107.2 N and the matching screw constructs (n=5) was 308.8 ± 123.2 N. This was not statistically significant (p=0.918). The mean load to failure of the stainless steel plates (n=5) was 223.6 ± 85.5 N and the matching screw constructs (n=5) was 312.9 ± 108.4 N. This was not statistically significant (p=0.341). The mean load to failure of the stainless steel plates (n=5) was 223.6 ± 85.5 N and the titanium plate constructs (n=5) was 304.6 ± 107.2 N. This was not statistically significant (p=0.223).

Table 1: Biomechanical Data from Cadaveric Specimens (Matched Pairs (paired t-test))

Comparison Groups	Plates	Screws	P value
All Plates vs. All Screws	264.1 ± 100.9 N	310.9 ± 109.4 N	0.328
Titanium Plate vs. Matching Screw	304.6 ± 107.2 N	308.8 ± 123.2 N	0.918
Stainless Steel Plates vs. Matching Screws	223.6 ± 85.5 N	312.9 ± 108.4 N	0.341

Table 2: Biomechanical Data from Cadaveric Specimens (Unmatched Plate Fixation)

Titanium Plates	Stainless Steel Plates	P value
304.6 ± 107.2 N	223.6 ± 85.5 N	0.223

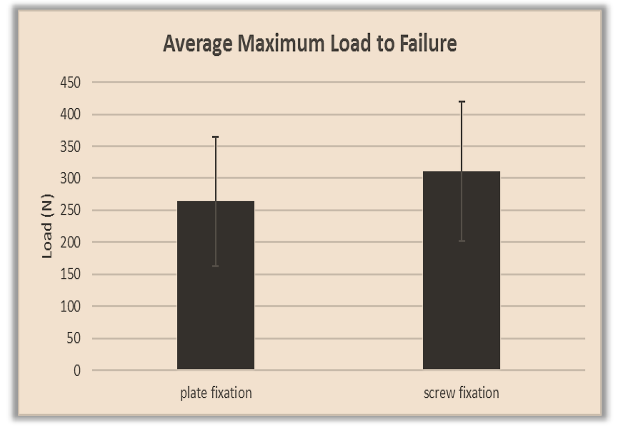


Chart 1. Bar graph illustration comparing locking plate constructs vs. all screw constructs. Note that the three screw construct did demonstrate a higher load to failure, however this was not statistically significant.

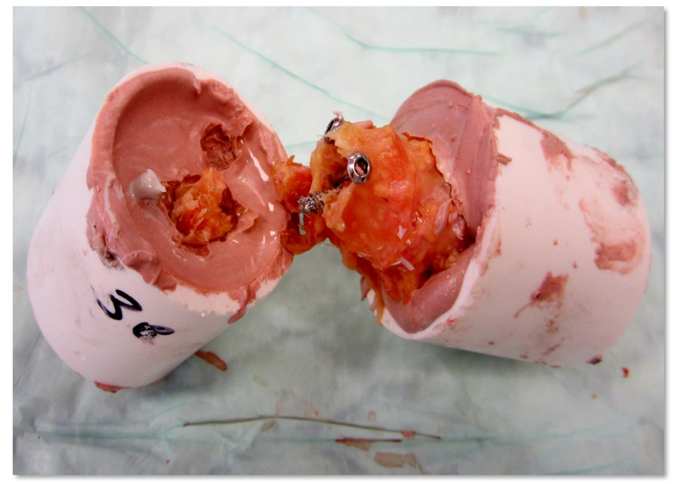


Figure 6. This photo demonstrates the only "catastrophic" failure of our sample.

Mode of Failure

All 10 plate fixations and 9 out of 10 screw fixation samples failed because of plantar gapping $\geq$ 3 mm. One screw fixation specimen failed as a result of the bone fracturing near the junction of the three-screw construct (Figure 6).

Limitations

We do recognize some weaknesses to our study report. There is a relatively large standard deviation among each fixation construct's maximum load. This could be due to differences in bone density. Some previously published works suggested the use of DEXA scanning of each cadaveric specimen to ensure similar bone stock. Instead of DEXA scanning we instituted a strict selection criterion for cadaveric limbs. Subtle bone mineral density differences could be possible due to pre-expiration ambulatory demands, and explain for the wide standard deviation. A larger sample size would also help alleviate this issue. We also chose to limit our study to maximum load to failure. Some authors have previously suggested that cyclical loading would be a more clinically relevant form of evaluation, and that maximum load to failure methods only evaluate possible "catastrophic moments" in the post-operative setting. Finally, our study only evaluated the effect of force vectors within the sagittal plane. Some authors suggest that torsional forces play a key role in the development of the bunion deformity (29). Future studies should evaluate torsional forces about the first metatarsocuneiform joint.

Analysis and Discussion

There are approximately 130 different bunionectomy procedures described to date (28). The Lapidus arthrodesis has a long track record of reliable and powerful corrective abilities (5). A wide variety of fixation options for using the first metatarsocuneiform joint have been previously investigated, with crossing screw constructs being the most evaluated (5,6,8,16,18,19). Over the last two decades locking plate technology has saturated the foot and ankle surgical theatre as a theoretically more reliable form of fixation for a variety of reconstructive techniques. Ironically, this technology persists amongst those surgeons who perform the Lapidus bunionectomy despite mixed reported outcomes from the various fixation options. In fact, most in vitro studies have demonstrated crossed screw constructs to be superior or non-inferior, in regard to stiffness, as compared to locking plate constructs (18, 19, 25). To our knowledge, the only two published reports that suggest superior stiffness of locking plate constructs compared to crossed screws were authored by Scranton et al. (21) and Klos et al. (20). Neither of these reports, however, evaluated the effect of the transfixation screw. Additionally, plantarly placed locking plates have been shown to be significantly stiffer than dorsomedially placed locking plates, suggesting that plate placement may have an effect on construct stiffness (22). This corresponds with traditional AO methodology, however plantar plating options are typically very difficult, and hence less likely to be used in clinical practice. In 1998 Ray et al. reported objective findings regarding the effect of the position of the transfixation screw on the stiffness and stability of the first metatarsocuneiform joint (26). Their results showed clear superiority of three-screw constructs versus two screw constructs.

Clinical outcomes have also demonstrated non-inferior results for crossed-screw constructs. Saxena et al. initially reported a level II study comparing outcomes of patients treated with crossed-screw versus locking plate constructs (8). There were no differences in outcomes or complications between the groups, however the locked plating group did begin weightbearing two weeks earlier than the crossed-screw group. In 2009, Sorensen et al., reported on their results with locked plating and early weight-bearing (14). This level III study suggested that locking-plate constructs provided a suitable form of fixation to allow early weight-bearing. Since then, other investigators have reported similar outcomes in early weight-bearing with crossed screw constructs (9, 10, 16). Despite a plethora of available reports, there remains no clear consensus regarding fixation construct for the Lapidus bunionectomy.

Our investigation is the first to report direct comparative results for objective stiffness of medial locking plate with interfragmentary compression compared to a crossed-screws with an additional transfixation screw construct. Our results suggested a three-screw construct is not inferior in regard to stiffness as compared to commercially available locking plate constructs. Additionally, plate composition (stainless steel vs. titanium) had no statistically significant effect on locking-plate construct stiffness. The peak load to failure for our all-screw construct was 310.9 ± 109.4 N.

In conclusion, our findings suggest no difference in maximum strength between commercially available five-hole locking plates with interfragmentary compression and crossed interfragmentary screws with additional transfixation screw constructs for the Lapidus arthrodesis. Though not statistically significant, the three-screw construct showed a greater ability to resist plantar gapping at the fusion site. Although locking plates may provide a role in cases with bony defects, or other situations were screw purchase is unsuitable, their routine use is unjustified.

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