Clinical Research

# Comparison of Transverse and Coronal Plane Stability at the First Tarsal-Metatarsal Joint With Multiple Screw Orientations

Mindi Feilmeier, DPM,
Paul Dayton, DPM, MS,
Merrell Kauwe, DPM,
Andrea Cifaldi, BS,
Britney Roberts, BS,
Hannah Johnk, DPM,
and Rachel Reimer, PhD

Abstract: *Intercuneiform instability has been recognized as a potential cause of hallux valgus recurrence following tarsal-metatarsal joint (TMTJ) fusion. Recommendations have been made for additional screw placement between the metatarsals and/or the cuneiforms to improve stability. The screw orientation that provides the best stability has not been documented. Twelve cadavers with the first TMTJ fixated were used for testing. Using a consistent force application of 15 pounds in both the transverse and coronal planes, we measured the change in intermetatarsal angle on radiographs. Force testing was repeated with screws deployed individually in the following orientations: first to second cuneiform (CC), first to second metatarsal (MM), and first metatarsal to middle cuneiform (MC). Our results indicate that stability of the first ray in the transverse and coronal planes is not improved with TMTJ fixation alone or with an additional CC screw. The MM screw consistently reduced first metatarsal instability in both planes. The MC screw had intermediate results. These findings strengthen the notion that first ray instability is complex and involves the tarsal and metatarsal articulations at multiple levels outside of the TMTJ alone.*

Levels of Evidence: *Diagnostic and Therapeutic, Level IV: Cadaveric Study*

Keywords: bunion surgery (Lapidus procedure); diagnostic and therapeutic techniques; hallux abducto valgus; bunions; forefoot; toe; midfoot

> "Intercuneiform instability has been recognized as a potential cause of hallux valgus recurrence following tarsal-metatarsal joint (TMTJ) arthrodesis . . ."

Intercuneiform instability has been recognized as a potential cause of hallux valgus recurrence following tarsal-metatarsal joint (TMTJ) arthrodesis, however, little research has been done to document how to best prevent this instability.[1-3] Fleming et al[1] studied transverse plane instability using an intraoperative manual stress test, demonstrating that marked instability can remain following stable fixation of the first TMTJ. They recommended additional screw fixation between the first and second metatarsals to reduce this instability and prevent recurrence. Further recommendation has been made for the placement of a screw in the midfoot to

DOI: 10.1177/1938640016666920. From the College of Podiatric Medicine and Surgery, Des Moines University, Des Moines, Iowa (MF, PD, AC, BR, RR); UnityPoint Clinic Foot and Ankle, Fort Dodge, Iowa (PD); and UnityPoint Health, Trinity Regional Medical Center, Fort Dodge, Iowa (MK, HJ). Address correspondence to: Mindi Feilmeier, DPM, College of Podiatric Medicine and Surgery, Des Moines University, 3200 Grand Avenue, Des Moines, IA 50312; e-mail: mindi.feilmeier@dmu.edu.

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provide additional stability following a TMTJ arthrodesis. The anatomic placement of this screw, however, varies widely among surgeons. Hansen[2(pp330-331)] presented a surgical methodology for restoring stability in the midfoot by fusing one or more of the intercuneiform joints. In this procedure, 1 or 2 screws are inserted into the first cuneiform and extend to the second or third cuneiform. An additional screw may be placed from the first to second metatarsal to prevent rotation around the intercuneiform screws. This recommendation is supported by Roling et al[3] who demonstrated the ability of intercuneiform fixation to increase sagittal plane stability following a first TMTJ fusion. Galli et al[4] studied sagittal plane instability following fixation of the first TMTJ for arthrodesis. They tested both a 2-point fixation, which was isolated to the TMTJ, as well as 3-point fixation, which included fixation from the base of the first metatarsal to the middle cuneiform. They noted a significant decrease in sagittal plane motion in the first ray with 3 points of fixation versus 2.

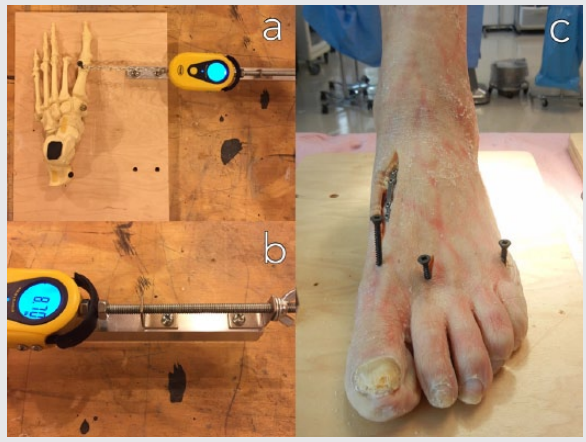
The purpose of this cadaveric study is to determine the radiographically observed instability of the first ray following stable fixation of the first TMTJ with the application of transverse and coronal plane forces, as well as the change in stability observed with the addition of a supplementary screw in three different anatomic orientations. We hypothesize that the addition of supplementary fixation will reduce the radiographically observed instability of the first ray following both transverse and coronal plane force application.

## Materials and Methods

Twelve below-the-knee fresh frozen cadaveric specimens were used for this study. All specimens were thawed to room temperature approximately 24 hours prior to use. Each specimen was securely fixated to a wooden platform by placing screws through the calcaneus, second metatarsal head, and the fifth metatarsal head. A bicortical screw was inserted in the sagittal plane into the first metatarsal neck approximately 1 cm from the first metatarsal phalangeal joint (MTPJ) to act as a fixed point to apply traction force. For each specimen, 3 anterior posterior (AP) radiographs were taken prior to fixation of the TMTJ: baseline (no force), transverse force, and coronal force application. All radiographs used positioning of the foot affixed to the platform in neutral subtalar joint (STJ) position and the x-ray tube angle of 90° to the specimen platform. Force was applied utilizing a custom jig with a digital scale that measured force application in pounds (Figure 1). A solid hook connected the tension apparatus to the metatarsal screw. Fifteen pounds of force was applied to the screw in the metatarsal neck, directly adjacent to the dorsal cortex and directly in line with the transverse plane, thereby inducing a transverse plane dominant force. When 15 pounds of force was achieved, an AP radiograph was taken. The scale hook was then repositioned on the metatarsal neck screw to a predetermined point approximately 28 mm from the dorsal cortical surface, producing a combination of transverse plane force and coronal plane rotational forces on the metatarsal. Radiographs were taken following each force application. To simulate first TMTJ arthrodesis, 2 locking plates were secured across the joint utilizing a biplane construct, effectively eliminating motion at the first TMTJ. A baseline radiograph was taken, followed by transverse plane and rotational force applications, with radiographs to document each trial. Next, first ray stability was tested using the same setup and series of radiographs for each of the following screw placements: first cuneiform to second cuneiform (CC), first metatarsal to second metatarsal (MM), and first metatarsal to middle cuneiform (MC). The coarsely threaded screws were placed bicortically, avoiding engaging the head of the screw into the medial cortex as the goal of screw placement was neutralization of forces, not compression across the site. Following each respective screw placement and force application, an AP radiograph was obtained. All radiographs were labeled by specimen number, fixation location, and force application. Using DICOM (Digital Imaging and Communications in Medicine) file images on PACS (picture archiving and communication system) software, the intermetatarsal angle (IMA) 1-2 was

**Figure 1.**

(a) Attachment of digital scale to first metatarsal head screw. (b) Scale used to apply 15 pounds of force to first metatarsal. (c) Incision and placement of locking plate, screw placement used to secure specimen to wooden block, and first metatarsal screw placed for force application.

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measured using the mid-diaphyseal line of the first and second metatarsals each trial. Measurements were recorded in a spreadsheet.

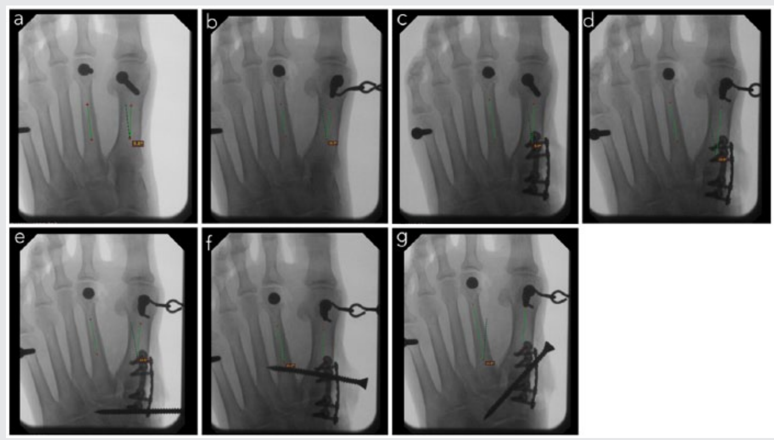
Statistical analysis was conducted with the SPSS version 22 (IBM Corp). A series of repeated-measures analyses of variance (ANOVAs) were conducted with the single time factor (4; baseline, CC, MM, and MC). A series of follow up pairwise *t* tests were conducted to examine paired group comparisons.

## Results

Two of the specimens were female and 10 were male, with a mean age at the time of death of 72.5 years (range 55-90 years). Prior to testing, each cadaveric specimen was examined for gross deformities. A single female cadaveric specimen was found to have a clinically significant bunion deformity. Furthermore, each specimen was examined throughout the testing procedure for bone integrity, including the ability to withstand the screw placement and testing forces. A single female cadaveric specimen was unable to withstand screw placement and has therefore been excluded from the analysis.

**Figure 2.**

(a) Baseline radiograph, no force or fixation. (b) Baseline radiograph with transverse force, no fixation. (c) Tarsal-metatarsal joint (TMTJ) fixation radiograph, no force. (d) TMTJ fixation radiograph with transverse force applied. (e) TMTJ fixation radiograph with supplementary first cuneiform to second cuneiform (CC) screw and transverse force applied. (f) TMTJ fixation radiograph with supplementary first metatarsal to second metatarsal (MM) screw and transverse force applied. (g) TMTJ fixation radiograph with supplementary first metatarsal to middle cuneiform (MC) screw and transverse force applied.




### Transverse Plane Dominant Force Application

Comparing mean change in angle from baseline to CC, MM, and MC for the transverse plane force application trial revealed an overall significant effect of intervention, $F(1, 10) = 6.57$, $P < .03$. Specifically, follow-up pairwise *t* tests reveal that the transverse plane dominant force application showed an increase in stability for the first to second metatarsal screw (MM), $t(10) = 2.39$, $P < .05$ and the metatarsal cuneiform (MC) screw, $t(10) = 2.09$, $P < .05$. The CC screw trial and the TMTJ plates alone trial did not provide stability that differed significantly from the control with no fixation. The mean IMA increase was noted to be significant $P <. 001$ when we compared baseline AP radiographs with transverse force application with no TMTJ fixation and with stable plate fixation at the TMTJ (Figure 2). All other pairwise comparisons were not statistically significant.

### Coronal Plane Dominant Force Application

Similarly, the repeated-measures ANOVA revealed an overall effect of time, $F(1, 10) = 5.68$, $P < .04$. Overall difference in stability between the screw placement trials from the repeated-measures ANOVA for the coronal plane dominant force application showed an increase in stability for the first to second metatarsal screw (MM), $t(10) = 2.37$, $P < .05$ and not the metatarsal cuneiform screw (MC), $t(10) = .59$, $P > .60$ as was seen in the transverse force application. The CC screw and MC screw trials and the TMTJ plates alone trial did not provide stability that differed significantly from the control with no fixation. When comparing the MC and MM screws for the rotational force application the MM orientation was significantly different $t(10) = 2.25$, $P < .05$ indicating that the MM screw stability improvement was more likely due to the intervention than to chance. All other pairwise comparisons were not statistically significant.

## Discussion

Our results indicate that first ray stability in the transverse and coronal planes is not improved with TMTJ fixation alone or with the application of a screw between the first and second cuneiforms. The IMA increase after transverse and coronal force application with stable TMTJ plating and without TMTJ fixation (baseline) was not significantly different ($P > .5$), showing that the TMTJ fixation alone did not improve the overall stability when transverse and coronal forces were applied. The inability of TMTJ plating alone to reduce first ray instability warrants consideration of placing additional fixation beyond that used for a TMTJ arthrodesis alone. Of the screw positions tested, the first metatarsal to second metatarsal screw was the only

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orientation that reduced instability with both transverse and coronal force application. The placement of a supplementary CC screw did not provide any additional stability as compared with baseline. This finding contradicts the recommendation of Hansen[2(pp330-331)] for fusion of the intercuneiform joints to improve midfoot stability following TMTJ fusion. Roling et al[3] performed a cadaveric study that showed improved sagittal plane stability with a CC screw following TMTJ fusion as compared to the TMTJ fusion alone. They did not test a MM or MC screw and did not test transverse or coronal plane instability. Our results show no improvement of transverse or coronal stability with the CC screw. This finding would argue against the CC screw as the most stable option to limit recurrence of IMA and rotation. We did not test the effect on sagittal plane stability so no conclusion can be drawn.

Our results indicate that the first to second metatarsal screw did consistently reduce first ray instability during transverse and coronal plane force application. These results are similar to studies that have advocated the use of a first to second metatarsal screw clinically. The ability of a supplementary MM screw to reduce instability in the first ray has been demonstrated clinically by Fleming et al.[1] Using an intraoperative stress test, they determined that 73.68% of their patients had intercuneiform instability, which they stabilized with the placement of an MM screw. They theorized that this screw would reduce recurrence of a bunion deformity. They reported reduction in the average pre-operative IMA from 17.89° to 7.68° postoperative in these patients. At a mean follow-up period of 1.5 years, 97.37% of feet demonstrated first TMTJ union and 5.26% of feet required a revision surgery for symptomatic hallux valgus recurrence.

In this experiment, the MC screw had intermediate results. These findings strengthen the notion that first ray instability is complex and involves the tarsal and metatarsal articulations at multiple levels outside of the TMTJ alone. Galli et al[4] found that first ray and medial column sagittal plane stability is improved after 2-point fixation of the first TMTJ and addition of a tarsal-metatarsal pin, compared with isolated cross pin fixation. The motion of the first ray in the sagittal plane was reduced by 40.8% with 2-point TMTJ fixation and 58.1% with 3 points of fixation as compared to the nonfixated state. The number of fixation points correlated negatively with the amount of sagittal plane stability. However, a mean of 3.1 mm of metatarsal displacement remained. From this study, it is unclear whether or not improving sagittal plane stability also improves transverse plane stability, thus aiding in maintenance of the achieved IMA and decreasing risk of recurrence. Our study clarifies that both transverse plane and coronal plane stability are improved with the first to second metatarsal screw, but not with the other screw orientations. We did not test the sagittal plane stability of our specimens either before or after fixation. In our opinion, recurrence may occur due to both transverse plane and coronal plane instability that may be present following TMTJ arthrodesis. The forces that result in medial displacement of the first ray following TMTJ fusion may be directly associated with a residual pronated position of the first metatarsal as noted by Yasuda et al[5] and Mortier et al[6] or coronal instability and lateral soft tissue buckling. Residual pronated position or significant instability may lead to continued lateral soft tissue pull, resulting in the hallux deviating laterally, and subsequent retrograde buckling forcing the first ray medially, thus increasing the IMA and leading to recurrence of the bunion. This phenomenon was shown to be possible in a cadaveric study by Dayton et al.[7]

Coetzee et al[8,9] performed a study on satisfaction of patients and functional outcome after modified Lapidus procedures. They found that patients with first ray hypermobility were more likely to have recurrence of hallux valgus unless the hypermobility of the metatarsocuneiform joint was addressed in the initial procedure. They found that TMTJ and first to second metatarsal arthrodesis reduces the IMA and eliminates more rotation of the first ray, therefore decreasing the chance of recurrence. Our results corroborate the notion that stability is improved with first to second metatarsal fixation. Since our study was not clinical in nature, we cannot speculate as to whether fusion of the first and second metatarsals is necessary or whether the screw application alone without arthrodesis would be sufficient in the clinical situation. A potential concern is that if the joint is not fused, the screw could eventually break due to residual motion. DiDomenico et al (DiDomenico LA, Thomas Z, Lowe L, Schaeffer S, Luckino FA. Retrospective analysis of intermetatarsal screw failure in a modified Lapidus arthrodesis technique. Unpublished data, 2015) studied the long term prevalence of screw breakage following TMTJ fusion with a supplementary screw placed between the first and second metatarsals. They reported a relatively low screw failure rate of 7.6% and attributed this finding to the stable construct achieved by a supplementary first to second metatarsal screw as well their procedures for adequate joint preparation and standard AO fixation. Ray et al[10] demonstrated the ability of a supplementary screw placed from the first metatarsal into either the second metatarsal or middle cuneiform to allow the first TMTJ arthrodesis to withstand a greater load to failure and bending moment. They hypothesized that this construct allows forces to be dispersed throughout the midfoot and forefoot, effectively unloading the first TMTJ and promoting healing.

The clinical relevance of this research lies in the potential for increased stability of the first ray to prevent the recurrence of hallux valgus following TMTJ fusion. A recent report by Chong et al[11] has determined the patient dissatisfaction rate following surgical correction of hallux valgus to be as high as 25.9% at a mean follow-up period of 5.2 years. When Faber et al[12] evaluated patient-reported surgical outcomes of first TMTJ fusion procedures, they found a patient dissatisfaction rate of 13%. These findings

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warrant further investigation for alternative methods of fixation.

The limitations of this study include the small sample size and the use of cadaveric specimens, which may inherently restrict motion. It is not known how each screw orientation will function in patients undergoing surgical correction of hallux valgus; however, the results of this study will allow surgeons to make the most informed decision possible, based on the current evidence available. There are additional possible screw orientations including a medial cuneiform to second metatarsal screw. This study was to compare previously published orientations and does not include assessment of all possible orientations. Further studies must evaluate the clinical outcomes of different screw orientations, including: application considerations, effectiveness in preventing recurrence and subjective patient outcomes, including satisfaction.

In conclusion, we have demonstrated that supplementary fixation between the first and second metatarsals following a first TMTJ fusion significantly reduces instability of the first ray in both the transverse and coronal planes. Supplementary fixation between the first metatarsal and middle cuneiform had intermediate results, showing reduced instability in the transverse plane, but not in the coronal plane. There was no reduction in instability observed with the TMTJ plate alone or with supplementary fixation between the first and second cuneiforms. Identification of methods to reduce postoperative transverse and coronal plane instability may help to reduce recurrence of IMA following TMTJ fusion for HAV and metatarsus primus adducto valgus. FAS

## References

1. Fleming JJ, Kwaadu KY, Brinkley JC, Ozuzu Y. Intraoperative evaluation of medial intercuneiform instability after lapidus arthrodesis: intercuneiform hook test. *J Foot Ankle Surg*. 2015;54:464-472.
2. Hansen ST Jr. *Functional Reconstruction of the Foot and Ankle*. Philadelphia, PA: Lippincott Williams & Wilkins; 2000.
3. Roling BA, Christensen JC, Johnson CH. Biomechanics of the first ray: part IV. The effect of selected medial column arthrodeses. A three-dimensional kinematic analysis in a cadaver model. *J Foot Ankle Surg*. 2002;41:278-285.
4. Galli MM, McAlister JE, Berlet GC, Hyer CF. Enhanced lapidus arthrodesis: crossed screw technique with middle cuneiform fixation further reduces sagittal mobility. *J Foot Ankle Surg*. 2015;54:437-440.
5. Yasuda T, Okuda R, Jotoku T, Shima H, Hida T, Neo M. Proximal supination osteotomy of the first metatarsal for hallux valgus. *Foot Ankle Int*. 2015;36:696-704.
6. Mortier JP, Bernard JL, Maestro M. Axial rotation of the first metatarsal head in a normal population and hallux valgus patients. *Orthop Traumatol Surg Res*. 2012;98:677-683.
7. Dayton P, Feilmeier M, Hirschi J, Kauwe M, Kauwe JS. Observed changes in radiographic measurements of the first ray after frontal plane rotation of the first metatarsal in a cadaveric foot model. *J Foot Ankle Surg*. 2014;53:274-278.
8. Coetzee JC, Resig SG, Kuskowski M, Saleh KJ. The Lapidus procedure as salvage after failed surgical treatment of hallux valgus: a prospective cohort study. *J Bone Joint Surg Am*. 2003;85-A:60-65.
9. Coetzee JC, Resig SG, Kuskowski M, Saleh KJ. The Lapidus procedure as salvage after failed surgical treatment of hallux valgus. surgical technique. *J Bone Joint Surg Am*. 2004;86-A(suppl 1):30-36.
10. Ray RG, Ching RP, Christensen JC, Hansen ST Jr. Biomechanical analysis of the first metatarsocuneiform arthrodesis. *J Foot Ankle Surg*. 1998;37:376-385.
11. Chong A, Nazarian N, Chandrananth J, Tacey M, Shepherd D, Tran P. Surgery for the correction of hallux valgus: minimum five-year results with a validated patient-reported outcome tool and regression analysis. *Bone Joint J*. 2015;97-B:208-214.
12. Faber FW, van Kampen PM, Bloembergen MW. Long-term results of the Hohmann and Lapidus procedure for the correction of hallux valgus: a prospective, randomized trial with eight- to 11-year follow-up involving 101 feet. *Bone Joint J*. 2013;95-B:1222-1226.

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