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Multicenter Early Radiographic Outcomes of Triplanar Tarsometatarsal Arthrodesis With Early Weightbearing

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Abstract

Background: Hallux valgus is a multiplanar deformity of the first ray. Traditional correction methods prioritize the transverse plane, a potential factor resulting in high recurrence rates. Triplanar first tarsometatarsal (TMT) arthrodesis uses a multiplanar approach to correct hallux valgus in all 3 anatomical planes at the apex of the deformity. The purpose of this study was to investigate early radiographic outcomes and complications of triplanar first TMT arthrodesis with early weightbearing.

Methods: Radiographs and charts were retrospectively reviewed for 57 patients (62 feet) aged 39.7 ± 18.9 years undergoing triplanar first TMT arthrodesis at 4 institutions between 2015 and 2017. Patients were allowed early full weightbearing in a boot walker. Postoperative radiographs were compared with preoperative radiographs for hallux valgus angle (HVA), intermetatarsal angle (IMA), tibial sesamoid position (TSP), and lateral round sign. Any complications were recorded.

Results: Radiographic results demonstrated significant improvements in IMA (13.6 ± 2.7 degrees to 6.6 ± 1.9 degrees), HVA (24.2 ± 9.3 degrees to 9.7 ± 5.1 degrees), and TSP (5.0 ± 1.3 to 1.9 ± 0.9) from preoperative to final follow-up ($P < .001$). Lateral round sign was present in 2 of 62 feet (3.2%) at final follow-up compared with 52 of 62 feet (83.9%) preoperatively. At final follow-up, recurrence was 3.2% (2/62 feet), and the symptomatic nonunion rate was 1.6% (1/62 feet). Two patients required hardware removal, and 2 patients required additional Akin osteotomy.

Conclusion: Early radiographic outcomes of triplanar first TMT arthrodesis with early weightbearing were promising with low recurrence rates and maintenance of correction.

Level of Evidence: Level IV, retrospective case series.

Keywords: hallux valgus, modified Lapidus, tarsometatarsal arthrodesis, bunion, triplanar

Introduction

Hallux valgus is a complex deformity of the first ray. Traditional correction methods for hallux valgus prioritize correction in the transverse plane based on anteroposterior (AP) radiographs. In particular, traditional methods of correction primarily target improvement of the hallux valgus angle (HVA) and intermetatarsal angle (IMA). Both the severity of the deformity and the method of operative correction have been largely based on this 2-dimensional representation, resulting in variable outcomes and some studies reporting high long-term recurrence rates ranging from 15% to 78% with these traditional approaches.[1,3,7,8,19]

Recent evidence suggests that hallux valgus is a multiplanar deformity with significant contributions from the frontal and sagittal planes.[4,10,11] With the addition of weightbearing computed tomography (CT) scans, the 3-dimensional nature of hallux valgus is better characterized. Recent studies utilizing weightbearing CT scans have shown that patients with hallux valgus have abnormal first metatarsal pronation, greater 3-dimensional displacement at the first TMT joint,

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Figure 1. Preoperative and postoperative anteroposterior (AP) radiographs demonstrating triplanar tarsometatarsal (TMT) arthrodesis with the biplanar mini-plate construct.

and increased overall mobility of the first ray in comparison to patients with normal feet.[4,10,11] Furthermore, incomplete sesamoid reduction and the presence of a metatarsal round sign have been implicated as risk factors for recurrence of hallux valgus, emphasizing the importance of addressing the frontal plane component of the deformity.[16,17,23] In order to restore the true 3-dimensional anatomy of the first ray, it is critical to achieve correction in all 3 planes.

Another important thing to consider when achieving correction of hallux valgus is the center of rotation of angulation (CORA) or the apex of the deformity. Numerous studies have shown that the metatarsal is not inherently deformed in hallux valgus, and that the anatomic CORA of the first ray lies at the first tarsometatarsal (TMT) joint.[5,14,15,18,24,25] The anatomic CORA must be considered when choosing the optimal correction method for hallux valgus in order to reduce potential recurrence and prevent the formation of secondary deformities.

The authors believe that triplanar first TMT corrective arthrodesis (Figure 1) with early weightbearing is optimal for the correction of all 3 dimensions of hallux valgus at the anatomic CORA. Triplanar TMT arthrodesis uses a biplanar locked plating construct to allow physiological micromotion of early weightbearing to promote secondary bone healing at the fusion site.[20,21] Correction of the deformity is achieved via instrumented 3-plane correction (including derotation of the first metatarsal) and seeks to minimize bony resection while achieving correction.

The purpose of this study was to investigate multicenter early radiographic outcomes of triplanar first TMT arthrodesis with early weightbearing. It was hypothesized that triplanar TMT arthrodesis would result in significant improvements in the IMA, HVA, and tibial sesamoid position (TSP) at final follow-up with maintenance of correction. The secondary aims were to evaluate radiographic recurrence rates and symptomatic nonunion rates at final follow-up.

Methods

Patient Population

After receiving institutional review board approval, charts and radiographs were retrospectively reviewed for 57 patients (62 feet) aged 39.7 ± 18.9 years who underwent triplanar first TMT arthrodesis (Lapiplasty System, Treace Medical Concepts, Inc., Ponte Vedra, FL) for hallux valgus at 4 institutions between September 2015 and June 2017. The patient population included patients with symptomatic hallux valgus that had failed nonoperative management. Inclusion criteria were:

1. Symptomatic hallux valgus
2. TMT arthrodesis by 4 surgeons
3. Primary hallux valgus surgery
4. Minimum follow-up of 12 months

Exclusion criteria consisted of patients with previous surgery on the first ray, additional arthrodesis outside the first TMT joint, or severe osteoarthritis of the first metatarsophalangeal (MTP) joint.

Clinical Assessment

Patient demographic data included age, sex, body mass index (BMI), smoking status, relevant comorbidities (diabetes, peripheral neuropathy, rheumatoid arthritis, peripheral vascular disease), and any history of previous surgery on the operative extremity. Preoperative clinical exam noted any restricted motion at the MTP joint, along with any associated lesser toe deformities. Postoperatively, the date of return to weightbearing in a walking boot, return to wearing athletic shoes, and return to full activity was noted. Any complications of wound healing, infection, hardware removal, revision procedure of the first ray, or other complications requiring operative intervention were also recorded. At final follow-up, clinical assessment included an evaluation for any restricted MTP joint motion or pain at the first TMT joint with manipulation.

Radiographic Data

A single independent musculoskeletal radiologist blinded to the outcome reviewed all radiographs. Weightbearing AP,

oblique, lateral, and sesamoid axial radiographs were obtained preoperatively and at 6 weeks, 4 months, and 12 months postoperatively. Radiographic measures were conducted using a picture archiving and communication system (Centricity PACS, GE Healthcare Co., Barrington, IL) or ImageGrid (ImageGrid Platform, Candelis, Inc., Newport Beach, CA) by a single independent radiologist blinded to the outcome.

HVA was defined as the angle between the longitudinal axis of the first metatarsal and proximal phalanx. IMA was defined as the angle between the longitudinal axis of the first and second metatarsals. TSP was graded from 1 to 7 and defined as the position of the medial sesamoid in relation to the longitudinal axis of the first metatarsal.[6] The presence of a lateral round sign was measured by examining the shape of the lateral edge of the first metatarsal head according to a previously described method.[16] The HVA, IMA, TSP, and presence of a lateral round sign were measured preoperatively and at 6 weeks, 4 months, and 12 months postoperatively.

Hallux valgus recurrence was defined in 2 ways: (1) the traditional definition of recurrence defined as an HVA greater than 20 degrees and (2) a new measure of recurrence defined as greater than 50% loss of correction of the HVA, IMA, or TSP at any postoperative time point. Symptomatic nonunion was defined as pain at the first TMT joint with either weightbearing or attempted manipulation and the presence of any of the following radiographic criteria:

1. Lack of progressive bone formation at the TMT joint on subsequent x-rays
2. Hardware failure or loosening (any broken plate or multiple broken plate screws)
3. Change in alignment (hallux valgus recurrence)

Overall, 57 patients (62 feet) met inclusion criteria. The average patient age was 39.7 ± 18.9 years (95.2% female). The average BMI of patients was 26.7 kg/m^2. For the 62 feet that met inclusion criteria, 53 (85.5%) were never smokers, 6 (9.7%) were former smokers, and 3 (4.8%) were current smokers. In regard to relevant comorbidities, 2 (3.2%) were diabetic, 1 (1.6%) had rheumatoid arthritis, and 1 (1.6%) had peripheral vascular disease. Patient demographic characteristics are shown in Table 1.

Table 1. Demographics for Study Population Undergoing Triplanar TMT Arthrodesis.

Characteristic	Study Population
Age, mean ± SD	39.7 ± 18.9 years
Gender, *n* (%)	
Female	59/62 (95.2%)
Male	3/62 (4.8%)
BMI, kg/m^2	26.7
Smoking status, *n* (%)	
None	53/62 (85.5%)
Former	6/62 (9.7%)
Current	3/62 (4.8%)
Diabetic, *n* (%)	2/62 (3.2%)
Relevant comorbidities, *n* (%)	
Rheumatoid arthritis	1/62 (1.6%)
Peripheral vascular disease	1/62 (1.6%)

Abbreviations: BMI, body mass index; SD, standard deviation ; TMT, tarsometatarsal.

Operative Technique

The operative procedure was performed using a dorsal longitudinal incision over the first TMT joint, just medial to the extensor hallucis longus (EHL) tendon. The dorsal and medial aspects of the first TMT joint were exposed via subperiosteal dissection. The first TMT joint was planed with a sagittal saw and additional plantar release was achieved using an osteotome. A fulcrum device was placed into the interspace between the bases of the first and second metatarsals. Next, a positioner device was applied to achieve deformity correction in all 3 planes (axial, transverse, sagittal). The medial aspect of the positioner was placed over the plantar medial ridge of the first metatarsal, while the lateral portion was placed over the lateral cortex of the second metatarsal. Correction and satisfactory position were confirmed on fluoroscopy. A Kirschner wire placed through the positioner was sometimes used to temporarily hold the position. A joint seeker device was placed in the first TMT joint to reference the sagittal plane alignment of the joint, followed by placement of the cutting guide over it. After proper position was confirmed, the joint seeker was removed and cuts were made on the base of the first metatarsal and medial cuneiform. The joint surfaces were then fenestrated with a drill bit. Next, the joint was axially compressed with a threaded olive wire. Final fixation was applied using a biplanar mini-plate construct that consisted of 2 small-profile, 4-hole titanium locking plates applied in biplanar 90-90 fashion to achieve multiplanar stability. The first plate was applied dorsally across the first TMT joint, and a second plate was applied medially across the joint using either a straight 4-hole plate or a specially designed anatomic plantar medial–based plate. After the dual plate construct was applied, the surgeon had the option to add a screw from the first to second metatarsal if there was intercuneiform instability. Finally, the wounds were copiously irrigated and closed in standard fashion. A sterile dressing was placed and the patient was allowed early weightbearing in a walking boot.

Postoperative Protocol

Patients were allowed early full weightbearing as tolerated in a boot walker the day of surgery. One institution delayed weightbearing for the first 2 weeks after surgery, allowing

full weightbearing in a boot walker at 2 weeks postoperatively. Patients had follow-up appointments at 2 weeks, 6 weeks, 4 months, and 12 months postoperatively. Weightbearing x-rays of the operative foot were obtained at 6 weeks, 4 months, and 12 months postoperatively. Imaging included AP, oblique, lateral, and sesamoid axial views. In general, patients were allowed to return to normal athletic shoes at 6 weeks postoperatively and return to full activity at 4 months postoperatively.

Statistical Analysis

Assuming a change of 2.0 degrees in the IMA and a standard deviation of the change in outcomes of 4.0 degrees, a sample size of 52 would yield 95% power to reject the null hypothesis. The actual sample size of $n = 62$ patients was therefore deemed to have adequate power based on this sample size calculation. Continuous variables were reported using mean and standard deviation. For continuous variables, the means at various postoperative time points were compared using parametric tests (Student *t* test). Categorical variables were reported using ratios and percentages. Chi-square tests were used to compare differences in categorical variables. Statistical analysis was conducted using JMP 14.1 (SAS Institute, Inc., Cary, NC). A *P* value of $<.05$ was considered statistically significant.

Results

Radiographic measurements demonstrated significant improvements in IMA, HVA, and TSP that were maintained at 6 weeks, 4 months, and 12 months postoperatively (Table 2; $P < .001$). At final follow-up averaging 13.5 months, significant improvements in IMA, HVA, and TSP were noted compared with preoperatively ($P < .001$). IMA was 6.6 ± 1.9 degrees at final follow-up compared with 13.6 ± 2.7 degrees preoperatively ($P < .001$). HVA was 9.7 ± 5.1 degrees compared with 24.2 ± 9.3 degrees preoperatively ($P < .001$). TSP was also significantly improved (1.9 ± 0.9) at final follow-up compared with preoperatively (5.0 ± 1.3; $P < .001$). The lateral round sign was present in 2 of 62 feet (3.2%) at final follow-up compared with 52 of 62 feet (83.9%) prior to surgery.

In regard to additional procedures performed in conjunction with the first TMT arthrodesis, 60 of 62 feet (96.8%) had a lateral release (modified McBride). On average, patients returned to weightbearing at 10.9 ± 8.2 days postoperatively. Patients returned to normal athletic shoes by 58.7 ± 16.5 days and returned to full activity without restrictions by 102.6 ± 15.9 days after surgery.

At final follow-up, 2 of 62 feet (3.2%) had recurrence of hallux valgus defined as an HVA greater than 20 degrees. Furthermore, recurrence was 3.2% (2/62 feet) when defined as greater than 50% loss of correction of the HVA, IMA, or TSP (Table 3). The overall symptomatic nonunion rate was 1.6% (1/62 feet). There were no cases of overcorrection noted. There were 4 complications requiring operative intervention. Two patients required hardware removal with the addition of an Akin osteotomy. Two other patients required hardware removal due to plate irritation.

Table 2. Radiographic Measures After Triplanar Tarsometatarsal Arthrodesis Compared With Preoperatively.

	Preop, *n* (%)	6 Weeks Postop, *n* (%)	4 Months Postop, *n* (%)	12 Months Postop, *n* (%)	*P* Value
IMA	13.6 ± 2.7	6.1 ± 2.1	6.1 ± 2.3	6.6 ± 1.9	<.001*
HVA	24.2 ± 9.3	11.6 ± 5.1	10.2 ± 5.9	9.7 ± 5.1	<.001*
TSP	5.0 ± 1.3	1.6 ± 0.7	1.8 ± 0.9	1.9 ± 0.9	<.001*

Abbreviations: HVA, hallux valgus angle; IMA, intermetatarsal angle; TSP, tibial sesamoid position.
*Denotes significant difference at $P < .05$.

Table 3. Recurrence Rates After Triplanar Tarsometatarsal Arthrodesis.

Recurrence	6 Weeks Postop, *n* (%)	4 Months Postop, *n* (%)	12 Months Postop, *n* (%)
HVA > 20 degrees	3/62 (4.8%)	4/62 (6.4%)	2/62 (3.2%)
Loss of correction > 50% (IMA, HVA, or TSP)	2/62 (3.2%)	2/62 (3.2%)	2/62 (3.2%)

Abbreviations: HVA, hallux valgus angle; IMA, intermetatarsal angle; TSP, tibial sesamoid position.

Discussion

In order to achieve complete correction of hallux valgus and prevent recurrence, the complex 3-dimensional nature of the deformity should be considered. In this study, triplanar first TMT arthrodesis resulted in significant improvements in the IMA, HVA, TSP, and metatarsal lateral round sign at final follow-up with low recurrence rates ($P < .001$). Furthermore, correction of hallux valgus was consistent and maintained at all postoperative time points (6 weeks, 4 months, and 12 months) after triplanar correction of the deformity.

One traditional drawback noted in the literature of the TMT arthrodesis has been the necessity of prolonged nonweightbearing for several weeks to allow for primary bone healing and prevent elevation of the first ray. However, recent studies have shown low nonunion rates for the first TMT arthrodesis, even with early weightbearing.[13,22] A recent large ($n = 367$ patients) multicenter study that compared early (less than 21 days) with delayed (greater than 21 days) weightbearing after the modified Lapidus arthrodesis found no difference in nonunion rates ($P = .663$).[22] A separate multicenter retrospective study of 76 patients evaluated

early weightbearing at approximately 2 weeks after first TMT arthrodesis using a crossed-screw technique and found a 100% union rate with a mean time to union of 44.5 days.[2] In a similar fashion, another retrospective study of 136 patients investigated early partial weightbearing in a boot on average 12.2 days after first TMT arthrodesis, also using a crossed-screw technique. That study found a 2.2% nonunion rate, with 97.8% of patients achieving union with a mean time to radiographic union of 65.0 ± 37.2 days.[12] These findings all support early weightbearing after TMT arthrodesis without a resulting decrease in union rates or deformity correction. The findings of the current study provide further support in favor of early full weightbearing after triplanar TMT arthrodesis. The symptomatic nonunion rate in the current study was 1.6% (1/62 feet), and patients returned to weightbearing on average just over 10 days after surgery. Triplanar TMT arthrodesis used biplanar locked plates with early weightbearing to allow for physiological micromotion to promote fusion via secondary bone healing as previously described.[20,21]

Recurrence is one of the most common complications with hallux valgus surgery. In the literature, long-term recurrence rates vary considerably, ranging from as low as 8% to as high as 78%.[1,3,7-9,19] In the present study, recurrence rates at final follow-up averaging 13.5 months were only 3.2% (2/62 feet). A considerable limitation in the literature is the lack of a consensus definition to define recurrence after hallux valgus surgery. More commonly, an HVA over 20 degrees has been used to define recurrence. By choosing only the HVA to define recurrence, only the transverse plane is considered, giving a 2-dimensional representation of a 3-dimensional deformity. This is particularly important when considering that 2 major risk factors for the recurrence of hallux valgus are incomplete sesamoid reduction and the presence of a metatarsal round sign.[16,23] In our study, we propose a more sensitive measure of recurrence as greater than 50% loss of correction of the IMA, HVA, or TSP. This new measure to define recurrence is more sensitive to detect recurrence in multiple planes, giving added consideration to the recently emphasized frontal plane component of hallux valgus.[4,10,11] A particular strength of this study is that recurrence at final follow-up was consistent at 3.2% whether using the traditional measure of recurrence as HVA greater than 20 degrees or the greater than 50% loss of correction of the IMA, HVA, or TSP.

The limitations of this study include the inherent nature of any retrospective multicenter study. Similar to any multicenter study, there was slight variability among surgeons in regard to operative technique and postoperative protocol. The inability to correlate radiographic findings to patient-reported outcome measures is another limitation, and the union rates may be overestimated by using radiographs instead of CT scans to assess union. The presence and correction of lesser toe deformities was not considered in this study, which could have impacted patient satisfaction and the radiographic results. Another important thing to note is the high number of modified McBride procedures performed, which may result in selection bias. While the Lapidus is traditionally used for more severe bunion correction, it should be noted that our patient population consisted mostly of patients with a mild or moderate bunion. The increased cost of additional instrumentation from dual plating as opposed to traditional Lapidus procedures is a limitation, and a future cost comparison study between this newer technique and traditional Lapidus would be beneficial. The final follow-up interval at just over 12 months is another limitation, but nonetheless the authors thought it was important to report on the early outcomes of this new technique.

The strengths of this study include the use of a single independent radiologist blinded to the outcome. Another notable strength was the use of a single-fixation construct among multiple surgeons, making the results more generalizable. The similarity in postoperative protocols and operative technique among the surgeons also make the results more reproducible. Future studies to investigate long-term outcomes, complications, and recurrence rates of triplanar first TMT arthrodesis are currently underway.

Conclusion

Triplanar TMT arthrodesis resulted in significant improvements in IMA, HVA, and TSP at final follow-up with low recurrence rates. Patients tolerated early weightbearing and early return to normal athletic shoes with minimal complications. Triplanar TMT arthrodesis was a viable method to achieve hallux valgus correction in all 3 planes while minimizing bony resection. Future research should investigate long-term outcomes, complications, and recurrence rates of triplanar TMT arthrodesis for hallux valgus.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Paul D. Dayton, DPM, MS, Daniel J. Hatch, DPM, Bret Smith, DO, MS, and Robert D. Santrock, MD, report grants and personal fees from Treace Medical Concepts, Inc., during the conduct of the study. ICMJE forms for all authors are available online.

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