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Association of First Metatarsal Pronation Correction With Patient-Reported Outcomes and Recurrence Rates in Hallux Valgus

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Abstract

Background: The purpose of this study was to determine if a postoperative decrease in first metatarsal pronation on 3-dimensional imaging was associated with changes in patient-reported outcomes as measured by the Patient-Reported Outcomes Measurement Information System (PROMIS) physical function, pain interference, and pain intensity domains or recurrence rates in patients with hallux valgus (HV) who undergo a first tarsometatarsal fusion (modified Lapidus procedure).

Methods: Thirty-nine consecutive HV patients who met the inclusion criteria and underwent a modified Lapidus procedure had preoperative and ≥2-year postoperative PROMIS scores and had first metatarsal pronation measured on preoperative and at least 5-month postoperative weightbearing CT scans were included. Multivariable regression analyses were used to investigate differences in the change in PROMIS domains preoperatively and 2 years postoperatively between patients with "no change/increased first metatarsal pronation" and "decreased first metatarsal pronation." A log-binomial regression analysis was performed to identify if a decrease in first metatarsal pronation was associated with recurrence of the HV deformity.

Results: The decreased first metatarsal pronation group had a significantly greater improvement in the PROMIS physical function scale by 7.2 points ($P = .007$) compared with the no change/increased first metatarsal pronation group. Recurrence rates were significantly lower in the decreased first metatarsal pronation group when compared to the no change/increased first metatarsal pronation group (risk ratio 0.25, $P = .025$).

Conclusion: Detailed review of this limited cohort of patients who underwent a modified Lapidus procedure suggests that the rotational component of the HV deformity may play an important role in outcomes and recurrence rates following the modified Lapidus procedure.

Level of Evidence: Level III, retrospective cohort study.

Keywords: hallux valgus, pronation, weightbearing CT scans, patient-reported outcomes, PROMIS

Introduction

Hallux valgus (HV) is a common and frequently painful forefoot deformity that impairs gait and has considerable effects on patients' quality of life and physical function.[17,21,33,34] Operative management of the disease has evolved as surgeons' perceptions have changed, with more than 100 operative procedures described for the treatment of HV.[19] However, the pathogenesis of HV is still poorly understood, which may contribute to inadequate correction or failure of treatment in some cases.[43] Postoperative patient dissatisfaction following operative correction of HV has been reported to be 10.6%, and recurrence of the HV deformity occurs in 4.9% to 25% of patients depending on the study cited and operative technique.[2,38]

HV is a triplanar deformity of the first ray in which the first metatarsal adducts, dorsiflexes, and pronates.[14,15,25,29] As early as the 1950s, Mizuno et al proposed performing a detorsion osteotomy to address the rotational aspect of HV[35]; however, only recently has there been renewed attention to better understand pronation of the first metatarsal in HV. The advent of weightbearing CT (WBCT) scans has built off earlier work using weightbearing radiographs by Saltzman et al and others[20,49] and allowed examiners to

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quantify the 3-dimensional HV deformity, especially the first metatarsal pronation deformity.[3,6,8,12,18,28,29,41,46] Although there is no commonly accepted method to measure first metatarsal pronation, previous studies have demonstrated a mean increase in first metatarsal pronation between 2 and 13 degrees in patients with HV compared with normal control patients.[3,6,12,18,28,29,41,46] However, other recent studies have demonstrated a wide range of first metatarsal pronation in patients without HV, which has called into question the clinical importance of the first metatarsal pronation deformity in HV.[31,36,48]

As knowledge of first metatarsal pronation in HV continues to evolve, numerous operative techniques have been proposed to address first metatarsal pronation in HV patients.[13,51-53] The Proximal Rotational Metatarsal Osteotomy (PROMO) and Proximal Oblique Slide Closing Wedge Osteotomy (POSCOW) have been employed to operatively correct the 3-dimensional HV deformity with an emphasis on improving the first metatarsal pronation deformity.[51-53] The modified Lapidus procedure, or first tarsometatarsal (TMT) fusion, has also been shown to decrease first metatarsal pronation in HV patients between 5.8 and 8.8 degrees.[13,46] However, there are few studies investigating if correction of the first metatarsal pronation deformity in HV affects postoperative outcomes. Okuda et al found that greater postoperative pronation as identified by a more rounded shape of the lateral first metatarsal head was associated with an increased recurrence rate, but the investigators used plain weightbearing radiographs, which have inherent limitations in quantifying first metatarsal pronation changes.[39] The authors also did not address whether it is possible to overcorrect the first metatarsal pronation deformity. Previous studies investigating outcomes following reconstruction of the progressive collapsing foot deformity have demonstrated that overcorrection of the hindfoot and midfoot deformities results in less improvement in patient-reported outcomes compared to patients with less correction of these deformities.[7,9,10] Additionally, no studies have identified whether addressing the first metatarsal pronation deformity in the operative management of HV affects patient-reported outcomes or if there exists a specific amount of pronation correction that surgeons should perform. Consequently, a better understanding of the implications of correcting this deformity may result in improved patient satisfaction and decreased recurrence rates in HV.

The primary purpose of this study was to determine if a postoperative decrease in first metatarsal pronation in HV patients was associated with changes in patient-reported outcomes as measured by the Patient-Reported Outcomes Measurement Information System (PROMIS) physical function, pain interference, and pain intensity domains. We also sought to determine if a postoperative decrease in first metatarsal pronation was associated with a decrease in the rate of recurrence of the HV deformity. We hypothesized that a decrease in first metatarsal pronation would be associated with improvements in patient-reported outcomes and a lower recurrence rate of the HV deformity.

Methods

Inclusion and Exclusion Criteria

Data for this study were acquired from a prospective, institutional review board–approved orthopedic foot and ankle registry. Approval was obtained from the registry's steering committee prior to obtaining data. The foot and ankle registry includes office and operative notes, imaging studies, demographic information, and patient-reported outcome measures. Patients were prospectively enrolled and eligible for inclusion in this study if they were diagnosed with HV, underwent a primary modified Lapidus procedure by 2 fellowship-trained foot and ankle orthopedic surgeons (S.J.E., A.J.E.) between November 2016 and December 2018, were older than 18 years old at the time of surgery, completed the preoperative PROMIS physical function questionnaire, and had a preoperative weightbearing computed tomography scan (WBCT) scan. The modified Lapidus procedure operative technique was performed as previously described.[11,13] Patients were excluded if they did not have greater than or equal to 2-year postoperative PROMIS physical function scores and at least 5-month postoperative WBCT scans. Five months was chosen as the minimum follow-up for postoperative WBCT scans because patients are expected to be fully weightbearing at this time and has been used as the minimum follow-up in other WBCT scan studies that have demonstrated postoperative changes in first metatarsal pronation.[12] Postoperative WBCT scans were used in this population to assess healing of the arthrodesis site. Patients were also excluded from the study if their primary TMT fusion during the time period was a revision surgery for a HV deformity, if the modified Lapidus procedure was performed as part of another procedure such as a reconstruction of a progressive collapsing foot deformity, or in the setting of midfoot arthritis or concomitant hindfoot pathology.

The number of patients meeting the inclusion and exclusion criteria is shown in Figure 1. Thirty-nine consecutive patients (36 females, 3 males) who met the inclusion and exclusion criteria were included in the study. All patients underwent a concomitant modified McBride procedure (n = 39, 100.0%). Other concomitant procedures included an Akin osteotomy (n = 25, 64.1%), a second metatarsal–shortening osteotomy (n = 6, 15.4%), and a third metatarsal–shortening osteotomy (n = 2, 5.1%). The 2 patients who underwent third metatarsal–shortening osteotomies also had second metatarsal–shortening osteotomies.

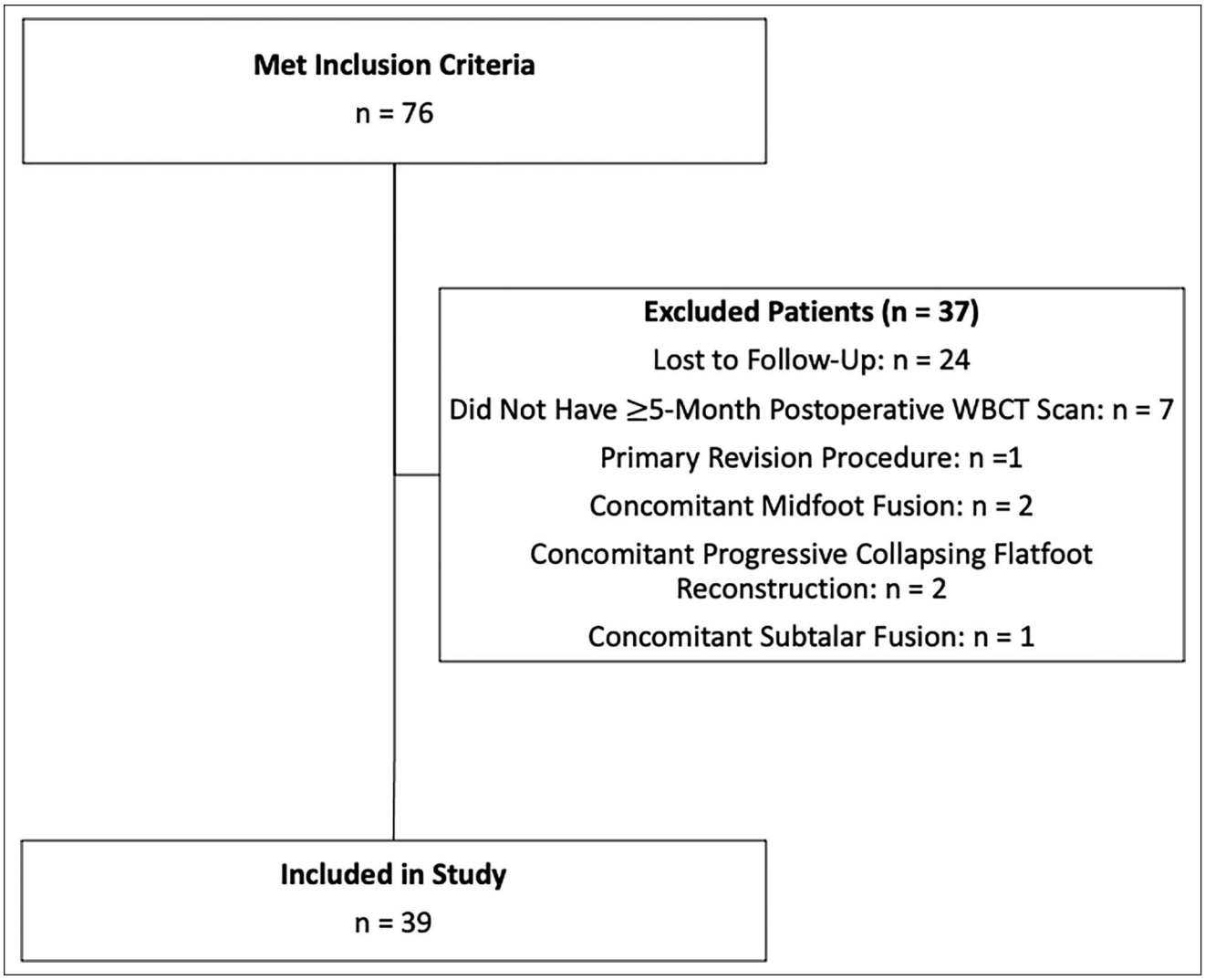

Figure 1. CONSORT flow diagram. Seventy-six consecutive patients with hallux valgus over the age of 18 years underwent a primary first tarsometatarsal (TMT) fusion for hallux valgus between November 2016 and December 2018, had preoperative PROMIS physical function scores, and had a preoperative WBCT scan.

Patient-Reported Outcomes Assessment

Patient-reported outcomes were measured using the Patient-Reported Outcomes Measurement Information System (PROMIS) physical function, pain interference, and pain intensity domains, which are collected as part of the foot and ankle registry. The PROMIS physical function domain measures patients' self-reported performance of different physical activities such as walking, going up and down stairs, and running errands. The PROMIS pain interference domain measures how patients' pain affects different aspects of their life including social, physical, and recreational activities. The PROMIS pain intensity domain measures the severity of their pain.

Each PROMIS domain is reported as a *t* score between 0 and 100, with a *t* score of 50 representing the mean of the US population. Ten points on a PROMIS domain represents 1 SD of the reference population. Higher *t* scores suggest more of the health measure that is being assessed. Therefore, higher scores on the PROMIS physical function domain indicate better physical function, and positive changes in the PROMIS physical function domain postoperatively indicate improvement in that scale. Lower PROMIS pain interference and pain intensity scores represent lower pain, and negative changes in the PROMIS pain interference and pain intensity domains postoperatively indicate improvement in those scales.

PROMIS scores were collected preoperatively and at least 2 years postoperatively. If PROMIS scores were obtained at multiple time points prior to surgery, the PROMIS score closest to the surgery date was chosen. Similarly, the most recent PROMIS score at a minimum of

2 years postoperatively was chosen (mean 2.1 years, range 2.0-2.4 years).

Assessment of Pronation and Radiographic Measurements

Radiographic and WBCT scan measurements were performed on the Sectra (Linköping, Sweden) IDS7 Picture Archiving and Communication System (PACS), version 22.1. Hallux valgus angle (HVA) and intermetatarsal angle (IMA) measurements were performed on preoperative and at least 5-month postoperative anteroposterior (AP) weightbearing radiographs or digitally reconstructed weightbearing radiographs from WBCT scans using the technique described by the American Orthopaedic Foot & Ankle Society (AOFAS).[16] Eight patients had postoperative HVA and IMA measured on digitally reconstructed radiographs from WBCTs. Radiographs or digitally reconstructed radiographs were obtained at a mean of 8.3 months postoperatively (range 5.0-22.5 months).

Pronation of the first metatarsal was determined using preoperative and at least 5-month postoperative WBCT scans. WBCT scans were performed at a mean of 6.5 months postoperatively (range 5.0-17.5 months), with patients standing upright in the cone-beam WBCT scanner with equal weight distributed between their feet. Pronation was measured using the previously described triplanar angle of pronation (TAP) with reference to the second metatarsal base.[12] The TAP measurements were performed by one orthopedic surgery resident with extensive training in foot and ankle imaging (M.S.C.).

In order to determine if a decrease in first metatarsal pronation was associated with improvement in patient-reported outcomes or recurrence, patients were divided into 2 groups based on the preoperative to postoperative change in first metatarsal pronation: (1) patients who had no change or an increase in first metatarsal pronation ("no change/increased 1MT pronation") and (2) patients who had a decrease in first metatarsal pronation ("decreased 1MT pronation"), which included patients with any amount of decrease in first metatarsal pronation. A previous study demonstrated a large range of TAP measurements in a normal cohort of patients, which suggested that normal first metatarsal pronation may be patient-specific.[12] Therefore, rather than attempt to identify an ideal postoperative TAP value for the entire population, the change in first metatarsal pronation was used in this analysis to determine if addressing the first metatarsal pronation deformity affected patient-reported outcomes. Recurrence of the hallux valgus deformity was defined as a postoperative hallux valgus angle $\geq$20 degrees on at least 5-month weightbearing radiographs or digitally reconstructed radiographs from WBCT scans.

To elucidate if a specific amount of pronation change resulted in better patient-reported outcomes, a secondary analysis was performed in which patients were divided into 3 pronation change groups. This was reserved as a secondary analysis because of the small sample size of the cohort and limited literature to guide how to divide these patients based on changes in first metatarsal pronation. The secondary analysis was used to determine if patients who had a postoperative decrease in pronation between 2 and 8 degrees, which was deemed to be "moderate pronation change" (n = 14), had greater improvements in PROMIS scores than patients with <2-degree decrease in their first metatarsal pronation ("minimal pronation change," n = 15) and those who had a >8-degree decrease in their first metatarsal pronation ("substantial pronation change," n = 10). A 2- to 8-degree decrease in first metatarsal pronation was selected as the range for the "moderate pronation change" group for 2 reasons. First, previous research has demonstrated that patients have between 2 and 13 degrees on increased first metatarsal pronation compared with normal control patients,[3,6,18,28,29,41,46] and the average decrease in first metatarsal pronation following a modified Lapidus procedure has been reported to be between 5.8 and 8.8 degrees.[13,46] Additionally, this range was approximately one-half standard from the mean decrease in first metatarsal pronation for our patient cohort. Therefore, this range appeared to be a reasonable estimate of moderate pronation change in HV patients following a modified Lapidus procedure.

Preoperative and postoperative sesamoid position or station were measured on coronal WBCT scan images. Patients were categorized into 4 groups based on a grading scheme initially described by Smith et al[47] on radiographs and modified by Kim et al[28] for WBCT scans. In order to ensure that assessment of the sesamoid position was consistent between patients, an axis was drawn down the shaft of the third metatarsal on the axial and sagittal WBCT scan views, and the coronal plane was made perpendicular to this axis.[28] The anteroposterior plane was set when coronal plane bisected the tibial sesamoid on the axial view.[28] Using this view, sesamoid positions were grouped into 4 stations by the location of the tibial sesamoid relative to a vertical line in the center of the intersesamoid ridge, or crista, that is perpendicular to a line that connected the apices of the medial and lateral sesamoid grooves. Patients were then categorized into the following 4 stations: (1) station 0 indicates that the tibial sesamoid was entirely medial to the vertical line of the crista, which demonstrates that the tibial sesamoid is reduced within its sesamoid groove; (2) station 1 indicates that less than half of the width of the tibial sesamoid is lateral to the center of the crista; (3) station 2 indicates that more than half of the width of the tibial sesamoid is lateral to the center of the intersesamoid ridge; and (4) station 3 indicates that no part of the tibial sesamoid touches the vertical line from the center of the crista.[28]

Statistical Analysis

Descriptive statistics were summarized for the entire cohort. Additionally, descriptive statistics were summarized for the no change/increased 1MT pronation group and decreased 1MT pronation group, which included patients who had a decrease in first metatarsal pronation from preoperatively to postoperatively as measured by the TAP measurement on WBCT scans, in the primary analysis and for the minimal, moderate, and substantial pronation change groups in the secondary analysis. Fisher exact tests were employed to determine if Akin osteotomies were associated with recurrence of the HV deformity.

For the primary analysis comparing the 2 pronation groups, Student *t* tests or their nonparametric equivalent, the Mann-Whitney *U* test, was used for continuous variables. The assumption of normality for these continuous variables was evaluated using Shapiro-Wilk tests, and all variables except age ($P = .001$) were found to be normally distributed (all other P values $> .05$). Mann-Whitney *U* tests were also used to examine differences in ordinal variables, and Fisher exact tests were used to examine differences in categorical variables. For the secondary analysis comparing the 3 pronation change groups, 1-way analysis of variance (ANOVA) or Kruskal-Wallis test were used for continuous variables, according to the distribution. Fisher exact tests explored differences in categorical variables.

Multivariable linear regression models were used to investigate differences in the change in PROMIS physical function, pain interference, and pain intensity domains preoperatively and 2 years postoperatively between the no change/increased 1MT pronation and decreased 1MT pronation groups. To account for baseline differences in preoperative PROMIS *t* scores between the 2 groups, for each multivariable regression model, preoperative PROMIS *t* scores were included. Confounding variables were included in the multivariable regression models only if they were significantly different between the 2 pronation groups to avoid overfitting the regression models (Table 1). A log-binomial regression model was performed to identify if a decrease in first metatarsal pronation was associated with recurrence of the hallux valgus deformity.

For the secondary analysis, multivariable regression models were employed to determine if preoperative to postoperative changes in the PROMIS physical function, pain interference, and pain intensity were different between the minimal pronation change, moderate pronation change, and substantial pronation change groups. The moderate pronation change group was used as the reference group in the regression models so that binary variables comparing the minimal pronation change to moderate pronation change groups and substantial pronation change to moderate pronation change groups were included. Preoperative PROMIS *t* scores were included in the regression models to control for baseline differences between the 3 groups in preoperative physical function, pain interference, and pain intensity. Similar to the primary analysis, confounding variables were included in the model if there were significant preoperative differences between the 3 pronation groups (Table 2).

Statistical tests were performed using SPSS, version 22.0 (IBM Corp, Armonk, NY). Statistical significance was set to $P < .05$.

Results

For the entire cohort, the average age of patients at the time of surgery was 51.5 years (range, 24.1-64.3 years). Radiographic results for the entire cohort are shown in Table 3.

Improvement in PROMIS Domains by Change in First Metatarsal Pronation

The decreased 1MT pronation group had greater improvement in the PROMIS physical function scale by 7.2 points (95% confidence interval [CI] 2.1, 12.3 points, $P = .007$) compared to the no change/increased 1MT pronation group (Figure 2). In the PROMIS pain interference domain, there were no differences in the amount of improvement in the domain between the 2 groups (coefficient −2.0 points, 95% CI −6.5, 2.4 points, $P = .380$). Similarly, there were no differences in the change in PROMIS pain intensity scores between the 2 groups (coefficient −1.7 points, 95% CI −6.3, 2.8 points, $P = .443$).

For the secondary analysis, the median preoperative sesamoid station in all 3 groups was 2 (IQR 2) ($P = .793$). The median postoperative sesamoid station was 0 in the minimal (IQR 1) and moderate pronation (IQR 0) change groups and 1 (IQR 1) in the substantial pronation change group ($P = .130$).

Compared to the moderate pronation change group, the minimal pronation change group had −8.2 points (95% CI −13.9, −2.5 points, $P = .006$) of postoperative improvement in the PROMIS physical function domain (Table 4). There were no differences between the moderate pronation change group and substantial pronation change group in the PROMIS physical function domain (coefficient −1.3, 95% CI −8.2, 5.6, $P = .699$). In the PROMIS pain interference domain, the substantial pronation change group had 6.6 points (95% CI 1.0, 12.3 points, $P = .023$) less improvement than the moderate pronation group, and there were no differences between the minimal and moderate pronation change groups (coefficient 4.2, 95% CI −0.5, 9.0, $P = .08$). In the PROMIS pain intensity domain, the minimal pronation change group had 5.4 points (95% CI 0.7, 10.2 points, $P = .025$) less improvement than the moderate pronation change group, and the substantial pronation change group had 7.9 points (95% CI 1.9, 13.8 points, $P = .011$) less improvement than the moderate pronation change group.

Table 1. Differences in Preoperative Variables Between the Decrease in First Metatarsal Pronation and No Change/Increase in First Metatarsal Pronation.[a]

Covariates	Decrease in First MT Pronation (n = 26)	No Change/Increase in First MT Pronation (n = 13)	*P* Value
Age, y, median (IQR)	54.4 (19.1)	59.3 (9.2)	.281[b]
Body mass index	24.7 (4.8)	25.9 (3.7)	.466
Preoperative PROMIS physical function, *t* score	49.7 (7.2)	49.7 (6.1)	.988
Preoperative PROMIS pain interference, *t* score	55.8 (7.4)	54.7 (4.4)	.625
Preoperative PROMIS pain intensity, *t* score	46.8 (8.3)	46.3 (5.5)	.840
Preoperative intermetatarsal angle, degrees	15.6 (3.2)	15.6 (3.3)	.994
Preoperative hallux valgus angle, degrees	32.1 (10.9)	35.5 (10.1)	.360
Metatarsal shortening, n (%)	4 (15.4)	2 (15.4)	>.999[c]
Akin osteotomy, n (%)	18 (69.2)	7 (53.8)	.482[c]
Race, white, n (%)	21 (80.8)	12 (92.3)	.643[c]
Gender, female, n (%)	24 (92.3)	12 (92.3)	>.999[c]
Preoperative first MT pronation, degrees	37.4 (10.1)	35.2 (8.2)	.510
Preoperative sesamoid station, median (IQR)	2 (2)	2 (2)	.848[b]

Abbreviations: IQR, interquartile range; MT, metatarsal; PROMIS, Patient-Reported Outcomes Measurement Information System.
[a]No differences in patient characteristics, preoperative PROMIS domains, or preoperative deformity were found. Differences between groups were calculated using Student *t* tests unless otherwise noted. Results are reported as mean (SD) unless indicated.
[b]Mann-Whitney *U* test.
[c]Fisher exact test.

Table 2. Differences in Preoperative Variables Between the Minimal, Moderate, and Substantial Pronation Change Groups.[a]

Covariates	Minimal Pronation Change (<2 Degrees) (n = 15)	Moderate Pronation Change (2-8 Degrees) (n = 14)	Substantial Pronation Change (>8 Degrees) (n = 10)	*P* Value
Age, y, median (IQR)	57.2 (8.7)	53.3 (18.0)	54.4 (23.9)	.458[b]
Body mass index	25.6 (3.4)	26.0 (5.6)	23.1 (2.8)	.252
Preoperative PROMIS physical function, *t* score	49.5 (5.8)	47.8 (7.4)	52.7 (6.9)	.230
Preoperative PROMIS pain interference, *t* score	54.8 (4.3)	58.4 (6.3)	52.1 (8.2)	.055
Preoperative PROMIS pain intensity, *t* score	46.1 (5.3)	50.3 (6.0)	42.0 (9.5)	.023
Preoperative intermetatarsal angle, degrees	15.7 (3.6)	14.9 (3.3)	16.4 (2.2)	.523
Preoperative hallux valgus angle, degrees	35.9 (10.0)	31.1 (12.0)	32.2 (9.8)	.458
Metatarsal shortening, n (%)	2 (13.3)	2 (14.3)	2 (20.0)	>.999[c]
Akin osteotomy, n (%)	8 (53.3)	10 (71.4)	7 (70.0)	.638[c]
Race, white, n (%)	14 (93.3)	10 (71.4)	9 (90.0)	.247[c]
Gender, female, n (%)	14 (93.3)	13 (92.9)	9 (90.0)	>.999[c]
Preoperative first-MT pronation, degrees	33.5 (9.1)	35.2 (8.6)	43.4 (8.4)	.025
Preoperative sesamoid station, median (IQR)	2 (2)	2 (2)	2 (2)	.793[b]

Abbreviations: IQR, interquartile range; MT, metatarsal; Preop, preoperative; PROMIS, Patient-Reported Outcomes Measurement Information System.
[a]Preoperative first metatarsal pronation was found to be different between the 3 groups ($P = .025$), so it was included in the multivariable regression analysis. Preoperative PROMIS pain intensity scores were also found to be statistically different between the 3 groups ($P = .023$), and preoperative PROMIS physical function, pain interference, and pain intensity scores were included in the regression models to account for baseline differences between the 3 groups. No other differences in patient characteristics, preoperative PROMIS domains, or preoperative deformity were found. Differences between groups were calculated using 1-way analysis of variance unless otherwise noted. Results are reported as mean (SD) unless indicated.
[b]Kruskal-Wallis test.
[c]Fisher exact test.

Table 3. Demographic and Radiographic Characteristics of the Study Cohort.[a]

	Preoperative	Postoperative	*P* Value
Preoperative IMA, degrees	15.6 (9.3-21.3, 3.2)	6.2 (0.8-14.7, 3.0)	<.001
Preoperative HVA, degrees	33.2 (16.6-61.4, 10.7)	12.5 (1.0-30.1, 7.5)	<.001
Preoperative TAP, degrees	36.7 (16.0-59.0, 9.5)	32.6 (12.0-50.0, 9.5)	.001
Preoperative sesamoid station[b]	2 (0-3, 2)	0 (0-3, 1)	<.001

Abbreviations: HVA, hallux valgus angle; IMA, intermetatarsal angle; TAP, triplanar angle of pronation.
[a]Results are reported as mean (range, SD) unless otherwise noted.
[b]Results reported as median (range, interquartile range).

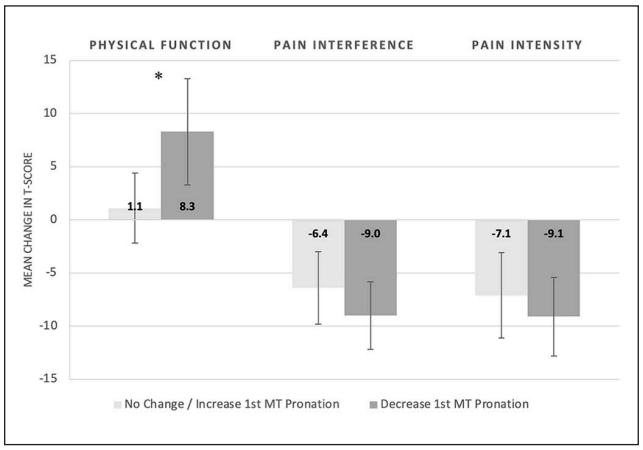

Figure 2. Change in PROMIS domains by first metatarsal pronation change group. The mean changes in the PROMIS physical function, pain interference, and pain intensity domains by first metatarsal pronation change group is shown above. Patients in the decreased first MT pronation group had statistically significantly greater improvement in the PROMIS physical function domain than the no change/increased first MT pronation group. Error bars demonstrate 95% confidence intervals for the mean change in PROMIS scores. *Statistical significance.

Recurrence Rate by Change in First Metatarsal Pronation

Using the definition of a postoperative hallux valgus angle ≥20 degrees, the rate of recurrence of the hallux valgus deformity was 11.5% (n = 3) and 46.2% (n = 6) in the decreased 1MT pronation group, which was the group of patients who had a decrease in first metatarsal pronation from pre- to postoperatively as measured by the TAP measurement on WBCT scans, and no change/increased 1MT pronation group, respectively ($P = .039$). There was no difference in recurrence of the deformity in patients who had a simultaneous Akin osteotomy (recurrence rate 20.0%) and those who did not have an Akin osteotomy (recurrence rate 28.6%, $P = .696$). Patients with decreased 1MT pronation had a risk ratio of 0.25 (95% CI 0.07, 0.84, $P = .025$) of recurrence compared to patients who had no change/increased 1MT pronation.

Complications

No patients in this cohort had a nonunion that required revision surgery. One patient who had a delayed union was treated with vitamin D and a bone stimulator and went on to union at 10.4 months postoperatively. Two patients underwent removal of the 2 screws crossing the tarsometatarsal fusion site at 11.7 and 24.0 months after surgery.

Discussion

Although pronation of the first metatarsal has been recognized as an important component of the triplanar HV deformity, little attention has been paid to the effect of operatively correcting pronation on patient-reported outcomes and recurrence rates. Our study found that patients who had a decrease in first metatarsal pronation had greater improvements in the PROMIS physical function domain at 2 years postoperatively than patients who had no change or increased pronation of the first metatarsal. Additionally, patients with decreased first metatarsal pronation had lower rates of recurrence of their deformity (postoperative HVA ≥20 degrees) at a minimum of 5 months' follow-up.

Improvements in the IMA and HVA have not been found to be associated with improvements in clinical outcome scores.[2,5,32,45,50] However, Chong et al, at a mean follow-up of 5.2 years, found that patients with recurrence of their HV deformity had worse postoperative patient-reported outcomes.[5] Although changes in the HVA and IMA have not demonstrated significant effects on patient-reported outcomes, other aspects of the HV deformity, such as reduction of the sesamoids underneath the first metatarsal head have been shown to affect postoperative

Table 4. Results of Multivariable Regression Models for the First Metatarsal Pronation Secondary Analysis.

	Multivariable Regression Effect Estimate	95% Confidence Interval (lower, upper)	*P*-Value
Change in PROMIS physical function domain			
Minimal pronation change group[a]	−8.2	−13.9, −2.5	0.006*
Substantial pronation change group[a]	−1.3	−8.2, 5.6	0.699
Preoperative first metatarsal pronation	−0.02	−0.31, 0.275	0.915
Preoperative PROMIS physical function score	−0.5	−0.9, −0.2	0.007*
Change in PROMIS pain interference domain			
Minimal pronation change group[a]	4.2	−0.5, 9.0	0.080
Substantial pronation change group[a]	6.6	1.0, 12.3	0.023*
Preoperative first metatarsal pronation	−0.17	−0.41, 0.07	0.154
Preoperative PROMIS pain interference score	−0.6	−0.9, −0.2	0.002*
Change in PROMIS pain intensity domain			
Minimal pronation change group[a]	5.4	0.7, 10.2	0.025*
Substantial pronation change group[a]	7.9	1.9, 13.8	0.011*
Preoperative first metatarsal pronation	−0.02	−0.26, 0.22	0.852
Preoperative PROMIS pain intensity score	−0.6	−0.9, −0.3	<0.001*

Abbreviation: PROMIS, Patient-Reported Outcomes Measurement Information System.
[a]Reference group was the moderate pronation change group; therefore, effect sizes are compared to the moderate pronation change group. In the PROMIS physical function domain, negative effect estimates suggest smaller improvement than the moderate pronation group. In the PROMIS pain interference and pain intensity domains, positive effect estimates suggest smaller improvement than the moderate pronation group.
*Statistical significance.

clinical outcomes.[4] Chen et al examined the role of postoperative sesamoid position on postoperative satisfaction and found that patients with greater postoperative sesamoid subluxation on postoperative weightbearing AP radiographs were more likely to be dissatisfied with surgery at 2 years postoperatively.[4]

In our study, HV patients who had a postoperative decrease in first metatarsal pronation had greater improvement in 2-year postoperative PROMIS physical function scores by 7.2 points compared to patients with no change or increased first metatarsal pronation. Previous studies using distribution-based methods to calculate the minimal clinically important difference (MCID) in foot and ankle orthopedics and HV, in particular, have proposed a MCID between 3.0 and 4.5 for the PROMIS physical function domain.[23,30] The MCID for the PROMIS pain interference domain has previously been estimated to be between 2.9 and 4.3, and although an MCID for the PROMIS pain intensity scale has not been estimated for foot and ankle patients, a study in spine patients calculated an MCID of 4.5 for this domain.[23,26,30] As a result, patients in our study with a decrease in first metatarsal pronation had statistically and clinically significant improvements in the PROMIS physical function domain compared with patients with no change or increased first metatarsal pronation. Additionally, greater improvements seen in the moderate pronation change group as part of the secondary analysis also represent clinically significant improvements in the PROMIS physical function, pain interference, and pain intensity domains (Figure 3).

A prior study that used the same technique as the present study to measure first metatarsal pronation found that first metatarsal pronation was increased by a mean of 9.5 degrees in patients with HV compared with a normal cohort.[12] Therefore, our moderate pronation change group in which pronation was decreased by 2 to 8 degrees represents a correction of first metatarsal pronation that is, on average, less than what would be expected to correct hallux valgus patients to a normal amount of first metatarsal pronation and suggests that intentionally leaving patients undercorrected may be better than attempting to normalize the rotational deformity. Our results are in line with the senior author's (S.J.E.'s) experience, in which he felt that he had overcorrected and supinated the first metatarsal in some patients. This is similar to previous work that demonstrated that overcorrecting the hindfoot valgus, midfoot abduction, and forefoot supination deformities in progressive collapsing foot deformity resulted in less improvement in patient-reported outcomes.[7,9,10] Therefore, for our secondary analysis, we hypothesized that the moderate pronation group would have the greatest change in patient-reported outcomes, which was supported by the available data. A larger number of patients in our study may have led to more robust differences between the 3 groups or perhaps a linear trend between first metatarsal pronation change and patient-reported outcomes. Future work with a larger number of patients may help to corroborate our findings.

A decrease in first metatarsal pronation as a result of the surgery was also associated with a lower rate of recurrence

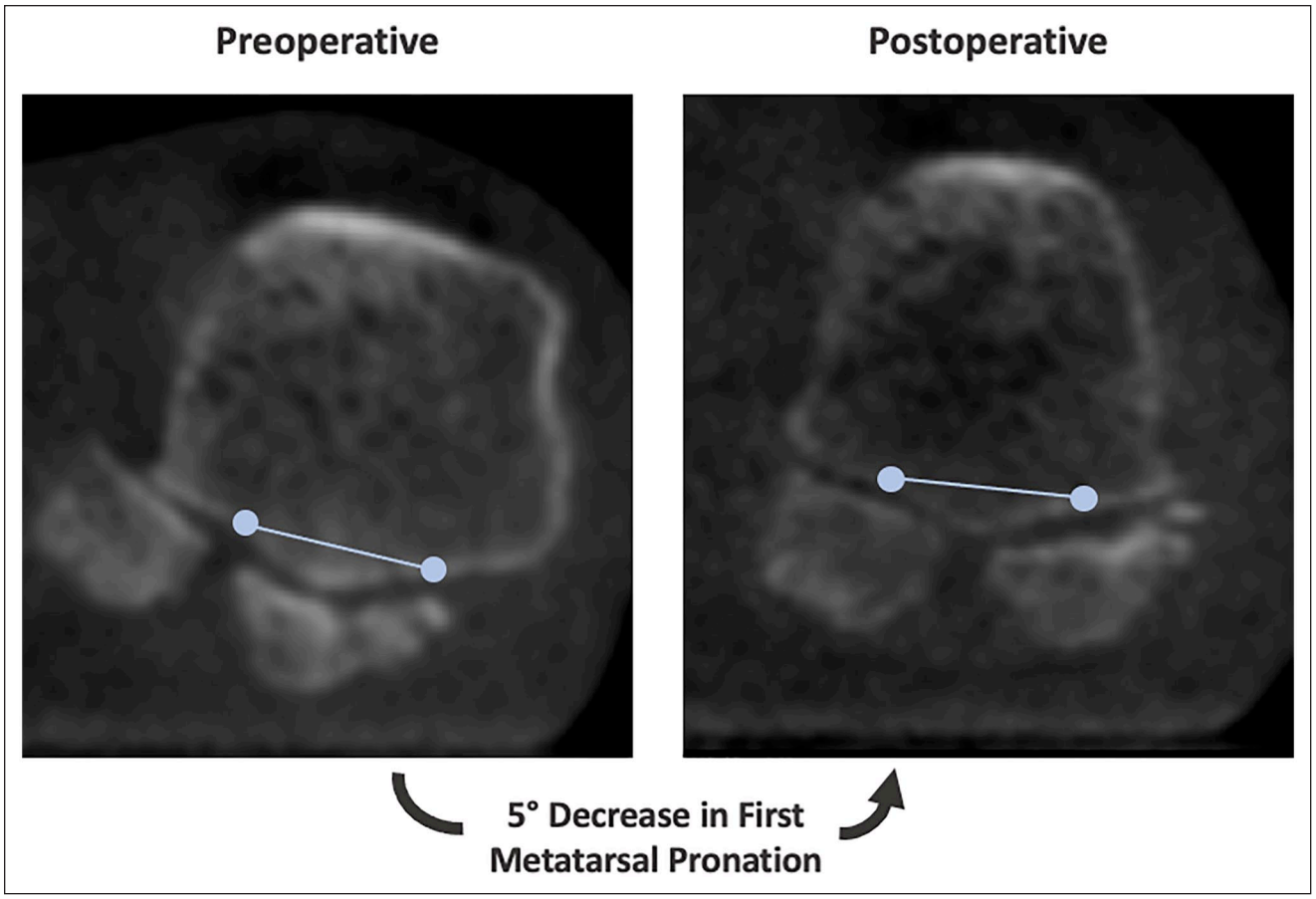

Figure 3. Illustration of change in first metatarsal pronation between 2 and 8 degrees. Although our technique for measuring first metatarsal pronation used the dorsal cortex of the second metatarsal base as a reference, this coronal weightbearing CT (WBCT) scan view demonstrates a patient with a 5-degree decrease in first metatarsal change from pre- to postoperatively. This change is subtle but may significantly affect changes in patient-reported outcomes in patients who undergo a modified Lapidus procedure for hallux valgus.

of the HV deformity with a risk ratio of 0.25 ($P = .025$) compared to those patients with no change or increased first metatarsal pronation. Okuda et al reported their findings of 40 patients with HV who were treated with a distal soft tissue procedure and proximal crescentic osteotomy of the first metatarsal and had a minimum follow-up of 12 months.[39] They divided patients into 3 groups based on the shape of the lateral edge of the first metatarsal, with a more rounded lateral head shape corresponding to increased first metatarsal pronation.[39] In their study, patients with a positive rounded lateral head shape at early follow-up had a greater risk of having recurrence of their HV deformity (HVA $\geq$ 20 degrees), with an odds ratio of 12.71 compared to those patients with a negative round sign, and the authors concluded that increased first metatarsal pronation is a risk factor for recurrence of the HV deformity.[39] Similar work has been performed looking at postoperative subluxation of the sesamoids on postoperative AP weightbearing radiographs as a possible risk factor for recurrence of the HV deformity.[38] The authors found that patients with sesamoid subluxation grade V or more on the Hardy and Clapham scale had an increased risk of recurrence (odds ratio 10.0) compared to patients with more normal position of the sesamoids.[38] Similar to other studies, postoperative first metatarsal pronation may be a potential confounding variable when evaluating sesamoid position on AP weightbearing radiographs.[28]

Improving the first metatarsal pronation deformity may change the biomechanical forces acting on the first metatarsal resulting in a decreased rate of recurrence.[44] Correction of first metatarsal pronation may lead to improvement in the pull vector of the flexor hallucis longus (FHL) as the FHL rotates medially and underneath the first metatarsal head. Persistent pronation of the first metatarsal may result in the force vector of the FHL remaining lateral to the first metatarsal head, which exerts a deforming force on the hallux, possibly leading to recurrence of the HV deformity.[44]

This may also explain the differences in clinical outcomes seen in the secondary analysis. In patients with minimal pronation change, the FHL pull vector may result in recurrence of the HV deformity, which may lead to less improvement in the PROMIS physical function domain for this cohort. Previous studies have demonstrated that the HV deformity affects functional outcomes in older patients.[33] This effect is not present in patients with substantial pronation change in which the pull vector of the FHL tendon has been restored in line with the first metatarsal shaft generating less lateral deviation force on the hallux, and therefore, may not have an important impact on PROMIS physical function scores in this group of patients.

In addition, over- or undercorrecting the first metatarsal pronation deformity may affect tracking of the sesamoids and postoperative pain as measured by the PROMIS pain interference and pain intensity domains. Although there were no differences in sesamoid station between the 3 groups, we were unable to examine dynamic sesamoid tracking within the sesamoid grooves. Because the sesamoid metatarsal joint is degenerative in patients with HV,[27] changes in first metatarsal pronation may affect tracking, and even subtle differences in first metatarsal pronation changes such as those seen in the minimal pronation and substantial pronation change groups may result in the sesamoids maltracking and less improvement in the PROMIS pain interference and pain intensity domains.

Implementation of these recommendations into clinical practice depends on being able to intraoperatively estimate changes in first metatarsal pronation. One of the senior authors (S.J.E.) has begun to use electrocautery to mark a line from the base of the first metatarsal to the medial cuneiform. Using this technique, the first metatarsal can then be supinated between 2 and 8 degrees while correcting the metatarsus primus varus deformity and maintaining plantarflexion of the first metatarsal.

The strengths of our study including using PROMIS scores, which are validated outcome measures for the assessment of HV, and previously recognized radiographic measurements.[6,12,22,23,30,37,42] For the measurement of first metatarsal pronation on WBCT scans, we employed the triplanar angle of pronation using the second metatarsal base as a reference, which has been shown to have excellent interobserver (intraclass correlation coefficients of 0.906 and 0.923, respectively, for preoperative and postoperative measurements) and intraobserver (intraclass correlation coefficient of 0.971 for both preoperative and postoperative measurements) reliability.[12] In addition, we defined recurrence as a postoperative HVA ≥20 degrees, which is consistent with the definition used in other work.[42] Although some of the patients in our study had digitally reconstructed radiographs from WBCT scans for postoperative HVA and IMA measurements, a previous study comparing measurements on weightbearing plain radiographs and digitally reconstructed radiographs from WBCT scans in patients with HV found a Pearson correlation between the 2 modalities of 0.94 for HVA measurements and 0.81 for IMA measurements, and the mean difference between HVA measurements on plain radiographs and digitally reconstructed radiographs was 2 degrees.[6] Digitally reconstructed radiographs from CTs have been used in other studies to perform radiographic measurements in place of conventional plain radiographs.[1,24,54]

This study had a few important limitations. Because of the need for pre- and postoperative WBCTs and 2-year postoperative PROMIS scores, there were only 39 patients who met the inclusion and exclusion for this study. Because of the observational nature of our study, no a priori power analysis was performed, but the minimum sample size for a univariable regression to be performed for a continuous outcome has been suggested to be 15.[40] The sample size for our study exceeds this minimum. We still may have been underpowered to detect differences between the decreased 1MT pronation group and no change/increased 1MT pronation group in the PROMIS pain interference and pain intensity domains. Similarly, we may have been underpowered to detect differences between the 3 groups in the secondary analysis, but despite this, we were able to identify significant differences between the 3 groups. There may also be a selection bias that was unaccounted for in our results; however, the 39 patients in our study were enrolled consecutively. Additionally, the observational nature of our study may limit our ability to draw causal interference as we cannot eliminate residual confounding. Future studies could confirm our results in a larger patient population with varied operative techniques to increase the generalizability of our findings. This study was also limited by the loss of 24 (31.6%) of the 76 patients eligible for inclusion in this study to 2-year follow-up, which may bias our results if these patients systematically chose to not follow-up because of poor outcomes or if they had their complications managed at an outside institution. Additionally, follow-up radiographic examinations were performed at a minimum of 5 months postoperatively but were not routinely taken after their 6-month follow-up appointment. Previous studies have demonstrated significant changes in HVA between early and late radiographic follow-up between 2 and 5 degrees; however, Okuda et al reported that patients with a negative round sign, or less first metatarsal pronation, did not have a statistically significant difference in their HVA between early and late radiographic follow-up.[38,39] Therefore, it is less likely that we missed a recurrence of the hallux valgus deformity in the decreased first metatarsal pronation group than in the no change/increased first metatarsal pronation group with early radiographic follow-up.

Conclusion

Despite increased attention to the first metatarsal pronation deformity in HV over the last few years, few studies have investigated the role of correcting this deformity on outcomes. Our results suggest that the rotational component of the HV deformity may play an important role in outcomes following surgery, and consequently, surgeons should consider addressing first metatarsal pronation deformity when performing an operative procedure for the treatment of HV such as a modified Lapidus procedure.

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