The Journal of Foot & Ankle Surgery 58 (2019) 1095–1099

Contents lists available at ScienceDirect

The Journal of Foot & Ankle Surgery

journal homepage: www.jfas.org

Relationships Between First Metatarsal and Sesamoid Positions and Other Clinically Relevant Parameters for Hallux Valgus Surgery

Naohiro Shibuya, DPM, MS, FACFAS[1,2,3], Jacob Jasper, DPM[4], Blake Peterson, DPM[4], John Sessions, DPM, PhD[4], Daniel C. Jupiter, PhD[5,6]

[1] *Professor, College of Medicine, Texas A&M University, Temple, TX*
[2] *Chief, Section of Podiatry, Central Texas Veterans Health Care System, Temple, TX*
[3] *Staff, Baylor Scott and White Health Care System, Temple, TX*
[4] *Podiatric Medicine and Surgery Resident, Texas A&M Health Science Center, Scott and White Health Care System, Temple, TX*
[5] *Associate Professor, Department of Preventive Medicine and Community Health, The University of Texas Medical Branch, Galveston, TX*
[6] *Associate Professor, Department of Orthopaedic Surgery and Rehabilitation, The University of Texas Medical Branch, Galveston, TX*

ARTICLE INFO

Level of Clinical Evidence: 3

Keywords:
bunion
first ray
flatfoot
Lapidus procedure
pes planus

ABSTRACT

Relationships between hallux valgus (HV) and other measurements within the first ray have been extensively studied. It is becoming more popular to correct HV deformity with tarsometatarsal joint arthrodesis while internally (varus) rotating the first metatarsal. This, in turn, reduces the sesamoid position when viewed in the dorsoplantar projection on radiographs. However, it has been shown that not all HV deformities have pathological external (valgus) rotation of the first metatarsal. In this study, we explored the relationships between frontal-plane rotations of the first metatarsal as well as the sesamoids, and other factors not limited to the first ray, to better understand the pathological process of HV deformity and to assist in surgical planning. We found that when adjusting for these covariates, the only factor associated with first metatarsal external rotation was having less metatarsus adductus. Sesamoid rotation, on the other hand, was independently associated with the HV angle, tibial sesamoid position, and medial column collapse. When surgically treating HV, correction of sesamoid rotation may need to be prioritized.

Published by Elsevier Inc. on behalf of the American College of Foot and Ankle Surgeons.

A successful, durable, surgical correction of hallux valgus (HV) deformity is associated with good reduction of a sesamoid position back underneath the first metatarsal head (1). Traditionally, the first metatarsal bone is relocated laterally to be placed over the sesamoids during HV corrective surgery, in the belief that HV deformity leads to subluxation of the first metatarsal from the sesamoids. However, in recent years, many have been advocating the addition of internal (or varus) rotation of the first metatarsal to reduce the sesamoid position relative to the first metatarsal, along with correction of subluxation in the transverse plane (2–7). The belief is that the pathological first metatarsal bone is externally (or valgus) rotated, often concurrently with the sesamoid bones, rather than being subluxed purely in the transverse plane from the sesamoid apparatus. Specifically, the simultaneous rotation of these structures as a unit causes the sesamoid, which sits under the first metatarsal head, to move more laterally relative to the first metatarsal head, and this produces the appearance of sesamoids subluxing farther out from under the first metatarsal in the dorsoplantar (DP) view on radiography (Fig. 1).

We observe such external rotation of the first metatarsal in many patients, but we have also observed patients with bunion deformity without significant first metatarsal rotation. Therefore, these 2 distinctive techniques in HV deformity correction are based on 2 fundamentally different theories regarding pathological first metatarsal and sesamoid positions. As a result, we questioned the applicability of this new technique in all patients with HV. Kim et al (8) showed that although 87% of the first metatarsals in HV deformity were in the valgus rotation, 26% had simultaneous rotation of the first metatarsal and sesamoids with these structures remaining congruous. They called this phenomenon a "pseudo-subluxation," implying that the complex is in the normal relationship although radiographically abnormal. They also showed that 12% did not have any rotation of the first metatarsal. Similarly, although Collan et al (9) showed more first metatarsal external rotation in patients with HV compared to patients without HV deformity, the difference did not reach statistical difference. Therefore, these findings imply that not all patients with HV benefit from derotation of the first metatarsal.

Shibuya et al (10) showed significant external rotation of the entire foot in patients with flatfoot deformity. Shibuya et al (10,11) also found

Financial Disclosures: None reported.
Conflicts of Interest: None reported.
Address correspondence to: Naohiro Shibuya, DPM, MS, FACFAS, College of Medicine, Texas A&M University, 1901 Veterans Memorial Drive, Temple, TX 76502.
E-mail address: shibuya@medicine.tamhsc.edu (N. Shibuya).

1067-2516/$ - see front matter Published by Elsevier Inc. on behalf of the American College of Foot and Ankle Surgeons.
https://doi.org/10.1053/j.jfas.2019.01.014

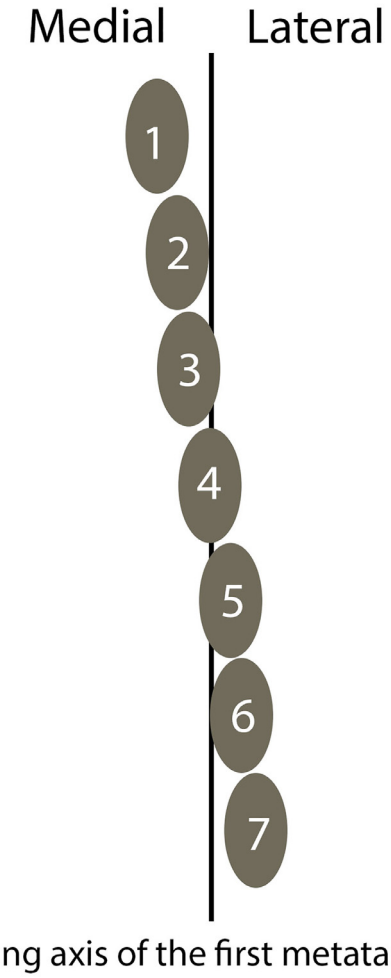

Fig. 1. Tibial sesamoid position described by Hardy and Clapham (12).

a significant association of HV deformity with flatfoot deformity, so perhaps some or all of the external rotation in the first metatarsal is coming from underlying flatfoot deformity rather than from HV.

The relationship of the first metatarsal to sesamoid rotations with HV deformity has been studied by various investigators, but other factors, including those outside of the first ray, affecting such a relationship, have not been studied as extensively. Therefore, exploring other potential factors affecting this overall outcome is important, and understanding such relationships may result in better surgical management of patients with HV. The current study is designed to explore characteristics of the first metatarsal and sesamoid frontal plane rotations in relation to both underlying HV and other factors such as patient demographics and underlying flatfoot deformity.

Patients and Methods

Weightbearing plain radiographs of feet taken at the podiatry clinic of the Baylor Scott and White Health Care System, Central Texas Campus, Temple, Texas, between January 1, 2015, and December 31, 2017, were identified from the radiology log maintained in the clinic. The radiograph log was then screened to identify sets of radiographs that included DP, lateral, and sesamoid axial views. These radiographs were then screened for inclusion and exclusion criteria.

To be included in the study, the patient had to be between the ages of 18 and 80 years. If a patient had previous osseous trauma or surgery, the patient was excluded. If a patient had multiple sets of radiographs that qualified for all of the criteria, only the most recent set of radiographs was included for analysis. If bilateral radiographs were taken on the same day, then only the radiographs for the right foot were included. Therefore, each patient could contribute only 1 set of data to this study.

After collection of the electronic radiographic records according to our inclusion and exclusion criteria, age, body mass index (BMI), and radiographic data for corresponding patients were collected from the medical records via the Epic electronic medical record system. BMI was calculated with the formula: BMI = weight (in kg)/height (in m^2).

The radiographic data included tibial sesamoid position [TSP, the 7-level grading system described by Hardy and Clapham (12) on the DP view of a plain radiograph] (Fig. 1), HV angle (HVA) (Fig. 2), first and second intermetatarsals (IMAs) (Fig. 2), metatarsus adductus angle (MAA, the angle created by the longitudinal axis of the second metatarsal and lesser tarsus), calcaneocuboid angle (CCA) (Fig. 2), calcaneal inclination angle (CIA) (Fig. 3), and talar-first metatarsal angle (Meary angle [MA]) (Fig. 3).

Our outcome variables were the first metatarsal rotation angle (MRA) and the sesamoid rotation angle (SRA), as described by Kuwano et al (13). The MRA was created from the weightbearing surface and a line connecting the deepest part of the sesamoid grooves (Fig. 4). These variables were evaluated for association with the independent variables listed here earlier.

Analysis of Data

All statistical analyses were carried out by using the R statistical package (R, Developmental Core Team, 2015; http://www.R-project.org) by the primary author (NS).

To identify average positions of the first metatarsal and the sesamoids in the frontal plane, the central tendency and dispersion of the SRA and MRA were determined in terms of mean and standard deviation (SD) values. These values are also determined separately in the HV group (HVA ≥15°) and the non-HV group (HVA <15°). These values were then compared between the groups with use of the Student's *t* test.

To identify factors associated with first metatarsal and sesamoid rotations, bivariate correlation tests (Pearson correlation coefficients) were conducted to identify factors to be included in the final multiple linear models. If the bivariate correlation test gave a

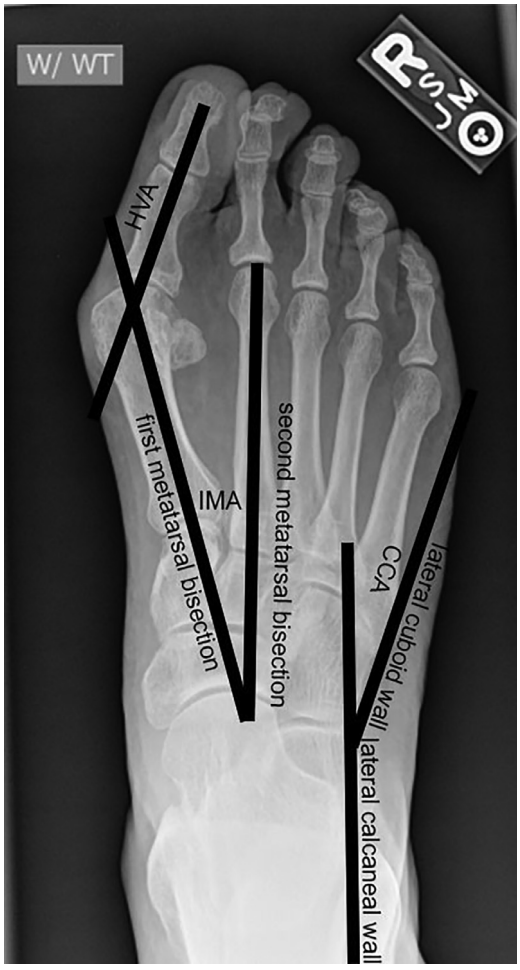

Fig. 2. Radiographic angles measured in the dorsoplantar projection radiograph.

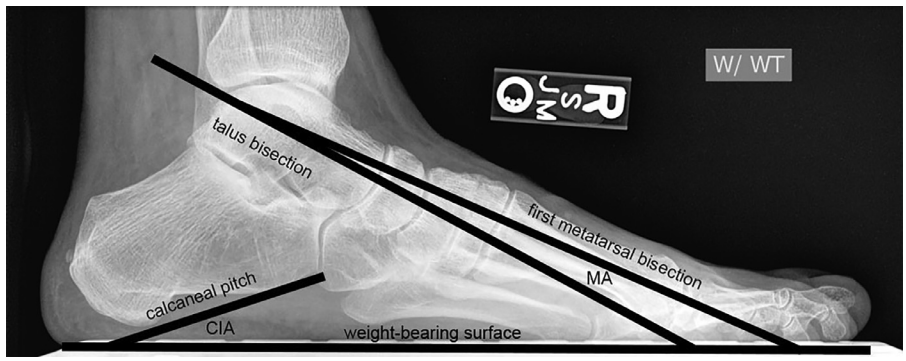

Fig. 3. Radiographic angles measured in the lateral projection radiograph.

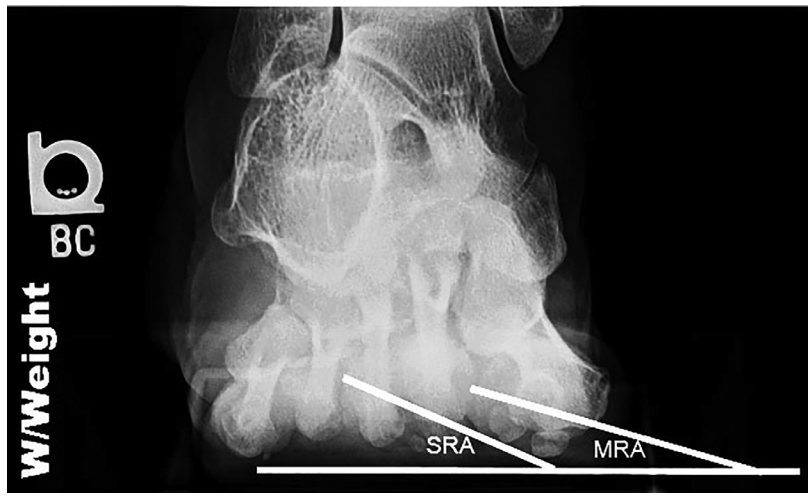

Fig. 4. Radiographic angles measured in the sesamoid axial view.

value of $p < .2$, the variable was included in the final linear model. The final model was then used to identify factors independently associated with each outcome variable (MRA or SRA), while adjusting for other covariates.

Overall significance of each model was determined in terms of p value (<.05 was considered significant) and r^2. Estimated coefficients (slope) of each variable with p value for significance and 95% confidence interval were also presented.

Results

A total of 114 sets of radiographs and patients were enrolled in the study. Of these, 76 patients were female and 38 patients were male. The average age of our cohort was 56 (SD 14) years. The mean (SD) HVA and IMA were 20.9° (11.54°) and 11.4° (3.21°), respectively, and the mean (SD) MRA and SRA were 4.86° (9.36°) and 12.9° (13.81°), respectively.

Based on the definition given here, we had 71 patients with HV and 43 without HV. In the HV group, there were 49 females and 22 males. The mean MRA in the HV group was 7.25° (9.44°), and that in the non-HV group was 0.9° (7.84°) (Student's t test $p = .001$). The mean SRA in the HV group was 19.2° (12.68°), and that in the non-HV group was 2.5° (8.18°) (Student's t test $p = .001$). The MRA and SRA were normally distributed within both the HV and non-HV groups (Shapiro-Wilk $p > .05$).

After bivariate analyses for correlation with MRA, we identified TSP, HVA, IMA, MAA, CCA, and MA to be included in the final model (Pearson's $p <. 2$) (Table 1). After adjustment for all of these covariates, only MAA remained significant in the final linear model ($p < .001$) (Table 2).

After bivariate analyses for correlation with SRA, we identified BMI, TSP, HVA, IMA, CCA, CIA, and MA to be included in the final model (Pearson $p < .2$) (Table 1). After adjustment for the covariates, we identified TSP, HVA, and MA to be independently correlated with SRA ($p < .01$) (Table 2).

To assess multicollinearity in our final model, we used the variance inflation factor. As a result, none of our included variables had a

Table 1
Bivariate analyses versus first metatarsal rotation angle and sesamoid rotation angle

Variable	Coefficient	p Value
Versus first metatarsal rotation angle		
Age	0.031	.7424
Body mass index	−0.079	.406
Tibial sesamoid position	0.470	.001*
Hallux valgus angle	0.362	.001*
Intermetatarsal angle	0.440	.001*
Metatarsus adductus angle	−0.295	.001*
Calcaneocuboid angle	0.197	.035*
Calcaneal inclination angle	−0.117	.214
Meary angle	−0.267	.004*
Versus sesamoid rotation angle		
Age	0.0249	.793
Body mass index	−0.146	.122
Tibial sesamoid postion	0.832	.001*
Hallux valgus angle	0.728	.001*
Intermetatarsal angle	0.689	.001*
Metatarsus adductus angle	−0.093	.327
Calcaneocuboid angle	0.246	.008*
Calcaneal inclination angle	−0.237	.012*
Meary angle	−0.439	.001*

* Variables included in the final analysis, with $p < .1$.

Table 2
Multiple linear regression analysis on first metatarsal rotation angle and sesamoid rotation angle

	Estimate	*p* Value	95% Confidence Interval (lower)	95% Confidence Interval (upper)
Positive (larger number) effect on first metatarsal rotation angle				
Intercept	0.58	.887	−7.51	8.67
Tibial sesamoid position	1.02	.225	−0.64	2.68
Hallux valgus angle	0.11	.379	−0.13	0.34
Intermetatarsal angle	0.52	.177	−0.24	1.28
Metatarsus adductus angle	−0.54	.001*	−0.87	−0.22
Calcaneocuboid angle	−0.01	.916	−0.22	0.20
Meary angle	−0.13	.219	−0.34	0.77
$r^2 = 0.32$.				
Positive (larger number) effect on sesamoid rotation angle				
Intercept	−13.85	.001	−22.06	−5.64
Body mass index	−0.03	.544	−0.11	−0.06
Tibial sesamoid position	4.77	.001*	3.32*	6.23*
Hallux valgus angle	0.27	.010*	0.07*	0.47*
Intermetatarsal angle	0.27	.438	−0.42	0.95
Calcaneocuboid angle	−0.05	.624	−0.23	0.14
Calcaneal inclination angle	0.04	.751	−0.22	0.30
Meary angle	−0.34	.001*	−0.54*	−0.14*
$r^2 = 0.75$.				
*Indicates (8)				

variance inflation factor >5, indicating that although we knew that these variables may be related, this did not cause any issues with the stability of our model estimates.

Discussion

The current data showed that sesamoid rotation had a stronger association with other variables than the first metatarsal rotation ($r^2 = 0.75$ for the SRA vs 0.32 for the MRA model). In this study, we chose radiographic variables that are commonly used to represent the degree of HV (IMA, EA, HVA) and flatfoot deformity (MA, CIA). Although MRA was higher in patients with HV, the difference disappeared when considering other variables, such as underlying flatfoot.

Shibuya et al showed significant association of flatfoot deformity with HV deformity by using various data sets (10,11). Generally, people who possess flatfoot deformity also have valgus rotation of the entire foot. Therefore, the first metatarsal's valgus rotation, which manifests in the sesamoid axial view, may be part of the underlying flatfoot deformity. This was confirmed by the association of the first metatarsal's external rotation with underlying flatfoot deformity, represented by CCAs and MAs in our bivariate analyses. Furthermore, after adjustment for these variables, the first metatarsal rotation was no longer associated with HV. Therefore, the need for derotation of the first metatarsal may have to be carefully examined, especially in persons with underlying flatfoot deformity.

The only factor that was independently associated with the first metatarsal rotation was metatarsus adductus (Table 1). This association has been identified previously (14). An increase in adductus was associated with internal (or varus) rotation of the first metatarsal. Therefore, caution should be taken when planning for internal rotation of the first metatarsal during HV correction in those patients with metatarsus adductus. The degree of flatfoot and/or metatarsus adductus at which surgeons should increase their suspicion for a need for internal rotation of the first metatarsal during HV correction should be further investigated in the future.

On the other hand, the sesamoids' valgus rotation was more predictable from other variables representing underlying flatfoot and HV deformities. While SRA also was associated with underlying flatfoot deformity to some degree in the bivariate analysis, it remained associated with HV after adjustment for the covariates. Therefore, the valgus rotation of the sesamoids is seen to be associated with HV deformity regardless of the presence of underlying flatfoot deformity.

The strongest association of the sesamoid rotation was found to be with the TSP viewed in the DP view on weightbearing radiographs ($r^2 = 0.83$ in bivariate analysis, estimate slope = 4.77 in the final model). Thus, the model shows that the sesamoids rotate approximately 5° for every 1 position of the 7-point scale TSP. This type of association did not exist between the first metatarsal rotation and the TSP, after adjustment for factors such as underlying flatfoot deformity.

Because underlying HV deformity was more strongly associated with sesamoid rotation ($p = .010$) than with first metatarsal rotation ($p = .379$), we believe that our focus in surgery should be to improve the sesamoid rotation. This may indeed require derotation of the first metatarsal when it is also in the valgus rotation (as this was a confounder in our study), but caution may need to be taken in these situations. The sesamoid rotation was strongly associated with sesamoid deviation relative to the first metatarsal on the DP view, but reduction of the DP sesamoid deviation, as done traditionally, is still very important in correcting HV deformity. To this end, it has been shown that sesamoid rotation reduces with lateral translation of the first metatarsal alone without any rotation of the first metatarsal (15,16). Lamo-Espinoza et al (15) showed an average reduction of 11 degrees of the SRA with SCARF osteotomy with or without Akin proximal phalanx osteotomy. Similarly, Ramdass and Meyr (16) showed a reduction of SRA by 7° when distal chevron osteotomy was used.

Our previous study showed that reduction of TSP viewed in the DP projection was the single most important factor to prevent HV recurrence (17), and this is supported by the results of many other studies (15,16,18–23). The surgeon, therefore, should spend a considerable amount of time and effort attempting to reduce the TSP.

There are several limitations to this study. First, to obtain the sesamoid axial view, the hallux needs to be significantly dorsiflexed at the metatarsophalangeal joint. This manipulation may change the rotation of the first metatarsal and the sesamoids. It has been shown that dorsiflexion of the hallux reduces the sesamoid position (24). Therefore, the relationship between the sesamoids and the first metatarsal is not as accurately depicted in this position, compared with some recent studies using computed tomographic scanning without dorsiflexion of the hallux (8,9). However, the SRA viewed in the sesamoid axial view has been shown to have a higher correlation to HV than does the sesamoid position measured in the DP view (13). Biomechanically, while the neutral metatarsophalangeal joint mimics the stance phase of gait, the dorsiflexed position is more representative of the toe-off phase of gait where the first ray is "loaded" as the windlass mechanism is activated. It is unknown, for our discussion of HV, which position is more important for assessment. In our study, the mean TSP measured in the DP view was 3.7 and that of the sesamoid axial view was 3.1. The difference was statistically significant ($p = .010$) and consistent with the previous study. However, the sesamoid positions measured in the sesamoid axial and DP views were correlated (Pearson $p = .001$, $r^2 = 0.84$).

Second, we excluded those patients whose radiographs were difficult to assess. If we were unable to trace out the metatarsal head in the sesamoid axial view, the case was excluded. This would most likely underrepresent those with more degenerative changes and those with hallux limitus. Even though the excluded number was small (<10% of the total number), it could have resulted in a selection bias.

Third, we looked at all the measurements as continuous variables. Even though all the measurements were normally distributed in our data, different types of HV with different etiologies occur. Kim et al (8) showed, in their study using computed tomographic scanning, that patients with HV can be categorized into 4 types in terms of their first metatarsal rotation and sesamoid subluxation. Most patients had some true subluxation of the sesamoids, but 26% had a congruent sesamoid–first metatarsal complex. For those patients, rotational

reduction of the sesamoids may be a great choice. Therefore, our findings may not apply to some subsets of patients with HV.

The strengths of our study come from the relatively larger sample size compared with other studies of similar topics and the inclusion of a diverse patient population. We did not limit patients to those with HV deformity. Additionally, we included only 1 foot per person; therefore, we did not duplicate patient characteristics by counting 2 feet per person. Finally, our study considered variables not just in the first ray but also clinically relevant measurements outside of the first ray, and this exercise resulted in showing lack of relationship between the first metatarsal rotation and other variables. Although we did not measure clinical and surgical outcomes, this finding may trigger an interest in the effect of HV surgery on underlying flatfoot, or vice versa, for future research.

In conclusion, the sesamoid rotation, rather than the first metatarsal rotation, was independently associated with HV deformity after adjustment for other variables, such as underlying flatfoot deformity.

References

1. Shibuya N, Kyprios EM, Panchani PN, Martin LR, Thorud JC, Jupiter DC. Factors associated with early loss of hallux valgus correction. J Foot Ankle Surg 2018;57:236–240.
2. Dayton P, Feilmeier M, Kauwe M, Hirschi J. Relationship of frontal plane rotation of first metatarsal to proximal articular set angle and hallux alignment in patients undergoing tarsometatarsal arthrodesis for hallux abducto valgus: a case series and critical review of the literature. J Foot Ankle Surg 2013;52:348–354.
3. Dayton P, Feilmeier M, Kauwe M, Holmes C, McArdle A, Coleman N. Observed changes in radiographic measurements of the first ray after frontal and transverse plane rotation of the hallux: does the hallux drive the metatarsal in a bunion deformity? J Foot Ankle Surg 2014;53:584–587.
4. Dayton P, Kauwe M, DiDomenico L, Feilmeier M, Reimer R. Quantitative analysis of the degree of frontal rotation required to anatomically align the first metatarsal phalangeal joint during modified tarsal-metatarsal arthrodesis without capsular balancing. J Foot Ankle Surg 2016;55:220–225.
5. DiDomenico LA, Fahim R, Rollandini J, Thomas ZM. Correction of frontal plane rotation of sesamoid apparatus during the Lapidus procedure: a novel approach. J Foot Ankle Surg 2014;53:248–251.
6. Campbell B, Miller MC, Williams L, Conti SF. Pilot study of a 3-dimensional method for analysis of pronation of the first metatarsal of hallux valgus patients. Foot Ankle Int 2018. 1071100718793391.
7. Ota T, Nagura T, Kokubo T, Kitashiro M, Ogihara N, Takeshima K, Seki H, Suda Y, Matsumoto M, Nakamura M. Etiological factors in hallux valgus, a three-dimensional analysis of the first metatarsal. J Foot Ankle Res 2017;10:43.
8. Kim Y, Kim JS, Young KW, Naraghi R, Cho HK, Lee SY. A new measure of tibial sesamoid position in hallux valgus in relation to the coronal rotation of the first metatarsal in CT scans. Foot Ankle Int 2015;36:944–952.
9. Collan L, Kankare JA, Mattila K. The biomechanics of the first metatarsal bone in hallux valgus: a preliminary study utilizing a weight bearing extremity CT. Foot Ankle Surg 2013;19:155–161.
10. Shibuya N, Kitterman RT, LaFontaine J, Jupiter DC. Demographic, physical, and radiographic factors associated with functional flatfoot deformity. J Foot Ankle Surg 2014;53:168–172.
11. Shibuya N, Jupiter DC, Ciliberti LJ, VanBuren V, La Fontaine J. Characteristics of adult flatfoot in the United States. J Foot Ankle Surg 2010;49:363–368.
12. Hardy RH, Clapham JC. Observations on hallux valgus; based on a controlled series. J Bone Joint Surg Br 1951;33:376–391.
13. Kuwano T, Nagamine R, Sakaki K, Urabe K, Iwamoto Y. New radiographic analysis of sesamoid rotation in hallux valgus: comparison with conventional evaluation methods. Foot Ankle Int 2002;23:811–817.
14. Dayton PD, ed. *Evidence-Based Bunion Surgery: A Critical Examination of Current and Emerging Concepts and Techniques*, New York: Springer Publishing, 2017.
15. Lamo-Espinosa JM, Florez B, Villas C, Pons-Villanueva J, Bondia JM, Aquerreta JD, Alfonso M. The relationship between the sesamoid complex and the first metatarsal after hallux valgus surgery without lateral soft-tissue release: a prospective study. J Foot Ankle Surg 2015;54:1111–1115.
16. Ramdass R, Meyr AJ. The multiplanar effect of first metatarsal osteotomy on sesamoid position. J Foot Ankle Surg 2010;49:63–67.
17. Shibuya N, Kyprios EM, Panchani PN, Martin LR, Thorud JC, Jupiter DC. Factors associated with early loss of hallux valgus correction. J Foot Ankle Surg 2017.
18. Lee WC, Kim YM. Correction of hallux valgus using lateral soft-tissue release and proximal Chevron osteotomy through a medial incision. J Bone Joint Surg Am 2007 (3):82–89.
19. Okuda R, Kinoshita M, Morikawa J, Jotoku T, Abe M. Distal soft tissue procedure and proximal metatarsal osteotomy in hallux valgus. Clin Orthop Relat Res 2000: 209–217.
20. Okuda R, Kinoshita M, Yasuda T, Jotoku T, Kitano N, Shima H. Postoperative incomplete reduction of the sesamoids as a risk factor for recurrence of hallux valgus. J Bone Joint Surg Am 2009;91:1637–1645.
21. Veri JP, Pirani SP, Claridge R. Crescentic proximal metatarsal osteotomy for moderate to severe hallux valgus: a mean 12.2 year follow-up study. Foot Ankle Int 2001;22:817–822.
22. Huang EH, Charlton TP, Ajayi S, Thordarson DB. Effect of various hallux valgus reconstruction on sesamoid location: a radiographic study. Foot Ankle Int 2013;34:99–103.
23. Park CH, Lee WC. Recurrence of hallux valgus can be predicted from immediate postoperative non-weight-bearing radiographs. J Bone Joint Surg Am 2017;99:1190–1197.
24. Yildirim Y, Cabukoglu C, Erol B, Esemenli T. Effect of metatarsophalangeal joint position on the reliability of the tangential sesamoid view in determining sesamoid position. Foot Ankle Int 2005;26:247–250.