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Original Research

# 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

Paul Dayton, DPM, MS, FACFAS [1,2], Merrell Kauwe, DPM [3], Lawrence DiDomenico, DPM, FACFAS [4], Mindi Feilmeier, DPM, FACFAS [5], Rachel Reimer, PhD [6]

[1] Residency Director, UnityPoint Health, Trinity Regional Medical Center, Fort Dodge, IA
[2] Assistant Professor, Des Moines University College of Podiatric Medicine and Surgery, Fort Dodge, IA
[3] Resident, UnityPoint Health, Trinity Regional Medical Center, Fort Dodge, IA
[4] Director, Fellowship Training, Youngstown, OH; and Adjunct Professor, Kent State University College of Podiatric Medicine, Independence, OH
[5] Assistant Professor, Des Moines University College of Podiatric Medicine and Surgery, Des Moines, IA
[6] Associate Professor, Chairperson, and Program Director, Des Moines University, Des Moines, IA

A R T I C L E I N F O

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A B S T R A C T

The data from 35 consecutive patients with hallux valgus undergoing triplane arthrodesis at the first tarsal metatarsal joint were studied to determine the amount of first metatarsal frontal plane rotation (supination) needed to anatomically align the first metatarsal phalangeal joint on an anterior posterior radiograph without soft tissue balancing at the first metatarsal phalangeal joint. Radiographs were measured both pre- and postoperatively to assess the 1-2 intermetatarsal angle, hallux abductus angle, and tibial sesamoid position (TSP). The mean amount of varus (supination) rotation performed during correction was 22.1° ± 5.2° and the mean amount of intermetatarsal angle reduction achieved after completion of the procedure was 6.9° ± 3.0°. The TSP changed by a mean of 3.3° ± 1.2°. A series of univariate linear regression analyses was performed to analyze the relationship between the frontal plane rotation of the first metatarsal performed during the operation and the preoperative intermetatarsal angle, hallux abductus angle, and TSP. Greater preoperative TSP scores were associated with greater intraoperative varus (supination) rotation required for joint alignment. Direct observation of the alignment changes at the first metatarsal phalangeal joint after metatarsal rotation without distal procedures strengthened the notion that the frontal plane rotational position plays an important role in the bunion deformity.



The inconsistency in clinical outcomes when using popular metatarsal osteotomies with supplementary soft tissue balancing for hallux abducto valgus (HAV) correction prompted us to explore the role of frontal plane rotation of the first metatarsal as a component of operative treatment. Available investigations regarding bunion-affected feet have reported both the first metatarsal and the phalangeal components of the first metatarsal phalangeal joint (MTPJ) in a valgus (pronated) position (1–4). Studies reporting the observed frontal plane position of the first metatarsal include both qualitative and quantitative descriptions. Grode and McCarthy (1) and Eustace et al (2) commented on the directional description, with the terms “eversion” and “pronation” used to, respectively, describe the valgus frontal plane position of the first metatarsal. Scranton and Rutkowski (3) reported both with a preoperative mean metatarsal pronation value of 14.5°, and Mortier et al (4) reported a mean metatarsal pronation of 12.7°.

Recent reports describing the surgical manipulation of first metatarsal frontal plane position have reported data using a qualitative or directional description alone (5–9). The purpose of the present investigation was to report our results quantifying the amount of frontal plane rotation (supination) used to align the first MTPJ during a modified tarsal metatarsal arthrodesis without distal joint capsular work. We also report the associations between common preoperative radiographic HAV measurements and the degree of rotation imparted surgically in our patients.

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Address correspondence to: Paul Dayton, DPM, MS, FACFAS, UnityPoint Clinic, 804 Kenyon Road, Suite 310, Fort Dodge, IA 50501.
*E-mail address:* daytonp@me.com (P. Dayton).

## Patients and Methods

The Des Moines University institutional review board granted exempt status to our retrospective review. A medical record review was conducted of 35 consecutive

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patients (34 females, 1 male) with symptomatic HAV for whom conservative treatment had failed. These patients had undergone a tarsal metatarsal arthrodesis modified to correct the frontal plane rotational component of the deformity from September 2012 to July 2014. Patients were excluded if previous first ray surgery had been performed. The criteria for inclusion in the study were as follows: (1) intraoperative measurement of the degree of frontal plane rotational correction and (2) pre- and postoperative anteroposterior radiographs available.

The surgical technique consisted of a dorsal incision made medial to the extensor hallucis longus tendon and lateral to the tibialis anterior tendon from the mid-first metatarsal shaft to the proximal aspect of the medial cuneiform. Direct dissection was carried to the level of the bone, with the periosteal tissue reflected as part of a full-thickness flap. A custom-designed protractor, used during tarsal metatarsal corrective fusion for the past several years by the senior author (P.D.) to guide correction, was used to perform the rotational measurements. The measurement device was placed to overlie the first tarsal metatarsal joint, and 3 pins were inserted through the device to capture an arbitrary zero point of rotation. The initial pin placement was reproduced in all patients, because the pins were placed in line through the device. Two pins were inserted into the cuneiform and one pin into the metatarsal shaft. After the pins were inserted, the device was removed, and the joint was appropriately resected to preserve the metatarsal length and correct the transverse aspect of the deformity. After transverse correction was complete, the first MTPJ joint was observed under a fluoroscopic anteroposterior view and manipulated by pushing the metatarsal pin to rotate the first metatarsal in a varus direction (supination) until the MTPJ was aligned both radiographically and clinically. Our observation criteria for joint alignment consisted of an assessment of aspects of the MTPJ that the published data have suggested are related to rotational position, including the distal metatarsal articular angle (10,11), the hallux abductus angle (HAA) (7), the prominence of the medial eminence (1), lateral rounding of the metatarsal head (12), and the tibial sesamoid position (TSP) (13–15) (Fig. 1).

After temporary fixation, the device was turned perpendicular to its initial position and placed on the pins in the medial cuneiform. These 2 pins served as a stable reference point of the original rotational position. The degree of supination used to reduce the first MTPJ was measured by comparing the position of the metatarsal pin after rotational correction to the scale built into the measurement device, and the data were recorded (Fig. 2). Final fixation was performed in this same position.

The pre- and postoperative radiographs were measured by 1 of us (M.K.) to assess the 1-2 intermetatarsal angle (IMA), HAA, and TSP. The measurements were consistent with those described by Hardy and Clapham (15), with the TSP measured on a scale of 1 to 7. All analyses were conducted by 1 of us (R.R.) using SPSS, version 22 (IBM Corp., Armonk, NY). First, a series of paired *t* tests were conducted to examine the differences in pre- and postoperative angle measurements. Next, a series of univariate linear regression analyses was conducted to examine the effects of the preoperative IMA, HAA, and TSP on the postoperative varus rotation. All beta (β) values reported are unstandardized. Statistical significance was set at the 5% level ($p \leq .05$).

## Results

Of the 35 patients identified, 34 (36 feet), with a mean follow-up period of 5 (range 3 to 12, median 5) months, met our inclusion criteria. One (2.9%) patient did not have the amount of rotation imparted recorded in the medical record due to the measurement device being unavailable at the time of their surgery. Additionally, the HAA value of 1 (2.9%) patient was not included in the statistical analysis because a phalangeal osteotomy had also been performed. This did not affect the rotational measurement; therefore, that patient was not excluded from our study.

Complete descriptive statistics are listed in the Table. The mean change in the IMA following the procedure was 6.97° (SD = 3.04°), $p < .001$; mean change in HAA was 13.61 (SD = 6.46), $p < .001$; mean change in TSP was 3.33 (SD = 1.22), $p < .001$ positions respectively. In sum, all angles were significantly reduced from pre to post measurements. The average degree of rotation imparted to the first metatarsal to obtain MTPJ and sesamoid alignment was 22.1° ± 5.15°. We conducted a series of hierarchical linear regression analyses. The effects of the preoperative IMA and HAA on operative varus rotation were not significant ($p > .2$). The effect of the preoperative TSP on varus rotation was statistically significant (β = 1.28, standard error = 0.61, $p = .043$). Specifically, greater preoperative TSP scores were associated with greater intraoperative varus rotation required for joint alignment.

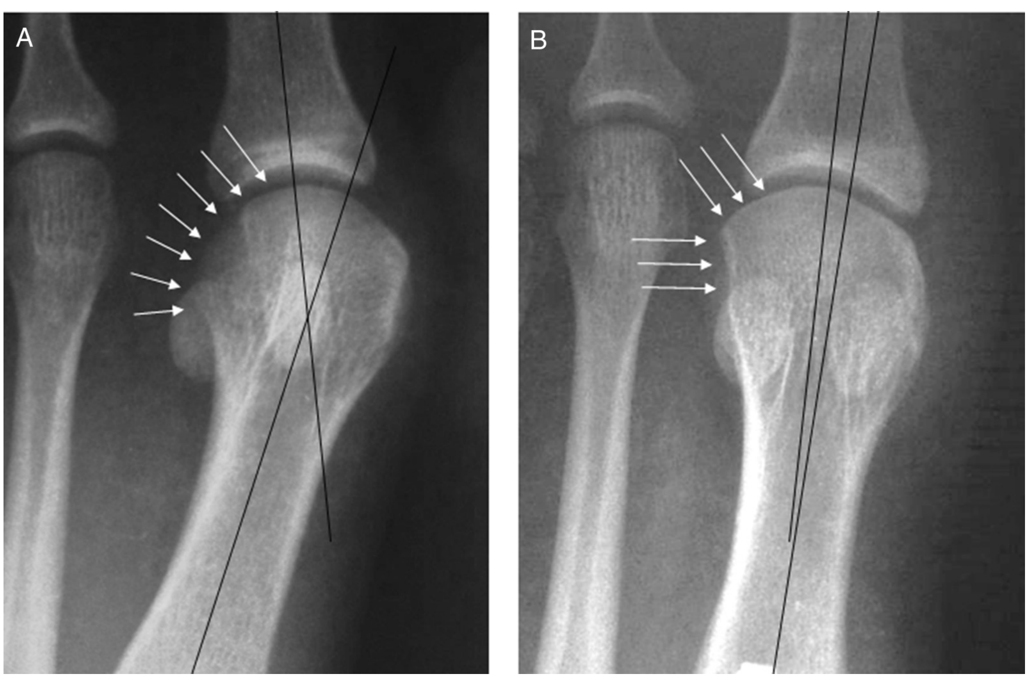


**Fig. 1.** (*A* and *B*) Aspects of the first metatarsal phalangeal joint that the published data show to be indicative of the frontal plane rotational position, including the prominence of a medial eminence, lateral deviation of the tibial sesamoid, lateral shape of the metatarsal head, and proximal articular set angle. These changes can be observed on these pre- and postoperative anteroposterior radiographs (*A* and *B* respectively) after Lapidus arthrodesis with varus rotation (supination) of the metatarsal without capsular balancing. *Arrows* indicate the change in the lateral roundness of the first metatarsal head. With metatarsal pronation, the lateral plantar aspect of the metatarsal becomes more prominent; the rounding is reduced with supination. This sign is both an indicator of rotational position and a predictor of recurrence (12). Note the change in the prominence of the medial eminence without medial resection and the sesamoid position after rotational correction without capsular balancing. These collective changes to the metatarsal phalangeal joint can be used to assess the joint position intraoperatively.

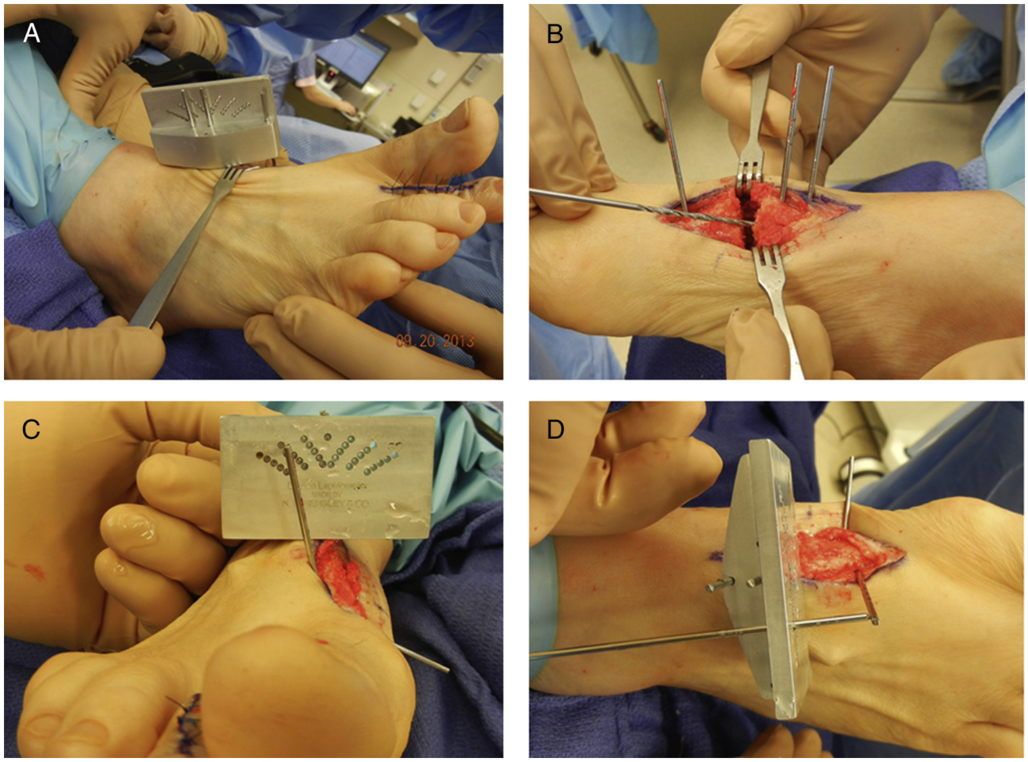


**Fig. 2.** (*A*) View of the device used for operative assessment of rotational correction with its initial placement with 2 pins in the cuneiform and 1 pin in the metatarsal, capturing an arbitrary zero point for rotational assessment. (*B*) The device is removed, and the triplanar correction, using osteotomies and rotation, is imparted. After correction and temporary fixation, the device is rotated 90° and placed back over the 2 cuneiform pins to maintain the arbitrary zero point of rotation initially established. The position is maintained until final fixation has been implemented. (*C*) The front of the device captures the value in degrees of the rotational correction. (*D*) A view that helps one to visualize the magnitude and direction of rotation. Note that no soft tissue or capsular balancing was performed to correct the deformity.

## Discussion

The most common corrective surgery for HAV involves ≥1 metatarsal osteotomies, along with capsular balancing. Using this paradigm, priority has been focused on the transverse plane component of what is becoming better understood to be a multiplanar deformity. In our study, the average correction of the IMA was 7°, with a mean postoperative IMA of 6.4°. In contrast, the amount of rotational correction averaged 22.1° (Fig. 3). The mean value of supination correction of the first metatarsal needed to achieve clinical and radiographic alignment of the first MTPJ without soft tissue balancing in our series was very close to the mean metatarsal pronation found in feet with bunions reported in a recent partial weightbearing computed tomography study (16). That computed tomography study reported a mean pronated position of the first metatarsal in a bunion deformity of 21.9°, significantly different from that of their normal control subjects (16). Our results have indicated that a frontal plane correction of an average of 22.1° of supination of the first metatarsal, concurrently with transverse plane IMA correction, reduces the deformity nearly completely at the first MTPJ according to the observation of sesamoid position and joint congruency. Correction of the first metatarsal in the frontal plane, in addition to the transverse and sagittal planes, is a distinct departure from the nearly ubiquitous approach of addressing the transverse and sagittal plane components of the deviated first metatarsal with osteotomy and relying on capsular balancing to align the hallux and sesamoids by soft tissue pull (Fig. 4). Using the proposed triplanar paradigm of metatarsal supination will eliminate, in most cases, the need for additional surgical procedures or any form of manipulation at the distal joint. Dramatic improvements in the HAA, sesamoid position, and distal metatarsal articular angle can be realized with proximal correction alone, if all 3 planar components are addressed.

**Table**
Descriptive statistics

| Angle | Feet (n) | Minimum (°) | Maximum (°) | Mean (°) | SD (°) |
|---|---|---|---|---|---|
| Preoperative IMA | 36 | 6.60 | 22.20 | 13.36 | 3.34 |
| Preoperative HAA | 36 | 7.70 | 39.00 | 22.46 | 7.95 |
| Preoperative TSP | 36 | 3.00 | 7.00 | 5.11 | 1.36 |
| Postoperative IMA | 36 | 2.50 | 13.00 | 6.39 | 2.43 |
| Postoperative HAA | 35 | 1.10 | 22.60 | 9.08 | 4.68 |
| Postoperative TSP | 36 | 1.00 | 4.00 | 1.77 | 0.83 |
| IMA change* | 36 | 0.10 | 13.70 | 6.97 | 3.04 |
| HAA change* | 35 | 2.30 | 25.30 | 13.61 | 6.46 |
| TSP change* | 36 | 1.00 | 5.00 | 3.33 | 1.22 |
| Varus rotation | 36 | 12.00 | 30.00 | 22.10 | 5.15 |

Abbreviations: HAA, hallux abductus angle; IMA, intermetatarsal angle; SD, standard deviation; TSP, tibial sesamoid position.
* $p < .001$.

Radiographic assessment of the metatarsal rotation of feet with HAV can be difficult. The studies reporting on metatarsal rotation using axial radiographs have been inconsistent in the positioning of the foot and the method of measurement used. Scranton and Rutkowski (3) and Saltzman et al (17) obtained their axial image in line with the long axis of the foot, and Mortier et al (4) obtained the radiograph in line with the first metatarsal to avoid any tangential views skewing the perspective of the crista and the actual rotation visualized at the metatarsal head. Also, although they both used the long axis of the foot as their guide, Scranton and Rutkowski (3) and Saltzman et al (17) used different parameters to measure rotation. Scranton and Rutkowski (3) used the lesser metatarsal heads as

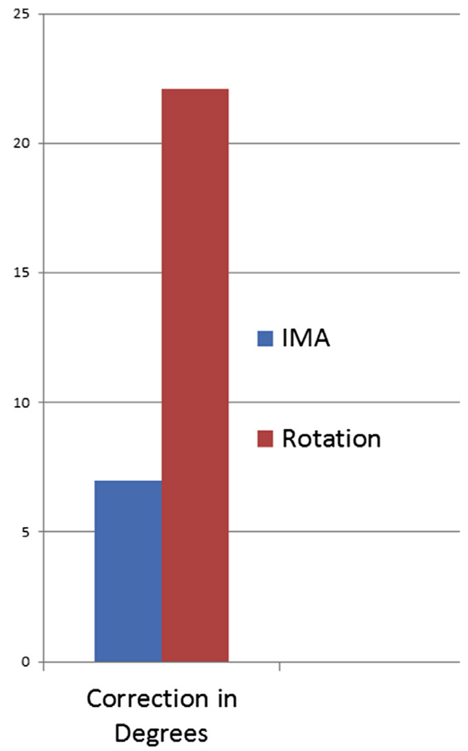


**Fig. 3.** Graphic representation of the mean amount of correction in degrees obtained in our case series. A mean of 22.1° of varus rotation (supination) was required for deformity correction and was measured with the custom protractor shown in Fig. 2. A mean of 6.9° in the transverse plane was required for deformity correction measured by the 1-2 intermetatarsal angle (IMA).

their reference, and Saltzman et al (17) used the weightbearing surface of the foot. It is unclear which position and measurement would be the most accurate when assessing the deformity. Eustace et al (2) used anteroposterior radiographs to assess the amount of rotation and determined that a linear relationship is present between the IMA and metatarsal pronation. The study by Eustace et al (2) did not use an open continuous scale and thus would be of little benefit when surgically planning the magnitude of rotational correction. Because of the difficulty in quantifying the exact amount of rotation that exists preoperatively, it was not considered in our treatment paradigm. We simply acknowledged that pronation of the metatarsal would influence the first MTPJ alignment. Therefore, we reduced the joint with the degree of supination required to appropriately align the sesamoids and decrease the lateral round sign of the first metatarsal head, the distal metatarsal articular angle, and the HAA.

The position of the metatarsal in the frontal plane in feet with HAV is not easily appreciated in a clinical setting. The assessment will be more difficult if the reported normal mechanics of the first ray are applied and one assumes that the first ray is dorsiflexed and inverted in a bunion deformity. This would lead to the inaccurate conclusion that in feet with HAV, the hallux is in a frontal plane valgus position and the metatarsal is in a frontal plane varus position. It is improper to apply the asserted normal mechanics to the position of the first ray in a bunion deformity, because the valgus (pronated) rotational position has been clearly delineated in the published data (1–8). Misunderstanding the position can lead to inaccuracies. Klemola et al (9), reporting on their derotational tarsometatarsal arthrodesis, repeatedly applied the commonly accepted mechanical axis of the first ray to describe the rational for the procedure they were performing. They purported that inversion or supination of the hallux will create an opposing eversion or pronation positional change to the metatarsal. Careful analysis of the radiographs in their study showed changes to the first metatarsal phalangeal joint that are not consistent with their conclusion, which was that inversion or supination rotation of the hallux will lead to eversion or pronation of the metatarsal (Fig. 1). Their application of the reported normal range of motion to define the osseous position in a foot with HAV, rather than relying on published data regarding the metatarsal position in a foot with HAV, shows that confusion regarding the anatomy of a bunion deformity still exists. In 2014, Dayton et al (19) dedicated a report to the description of the position and associated terminology of the bunion deformity to clarify both the position and the descriptors of the position.

Okuda et al (6) reported on a study of metatarsal rotational correction, showing that lateral roundness of the metatarsal head is a sign of pronation or eversion that will be corrected with varus or supination rotation. This lateral roundness becomes evident as the lateral and plantar aspects of the metatarsal head become prominent with first metatarsal pronation. They also hypothesized that the sesamoid position might be related to the amount of rotation (18). Dayton et al (13,14), in a series of cadaveric studies, showed that lateral roundness of the metatarsal head and sesamoid position are a product of metatarsal eversion or pronation. In addition, Dayton et al (13,14) showed that the hallux could be a driver of this positional change in the metatarsal. DiDomenico et al (8) described using this ligamentotaxis to directionally drive the metatarsal in the same direction as the rotating hallux to correct the rotational component of a bunion when performing Lapidus arthrodesis.

We have shown a consistent pronated position of the metatarsal in patients with bunion deformities in the present series. However, our study did not show a significant linear relationship between the preoperative value of the IMA and HAA and the amount of varus rotation required for alignment of the MTPJ. Although rotational correction was required to align the MTPJ, the degree of rotational correction required did not linearly increase as the IMA or HAA increased. Thus, we do not recommend use of the IMA and HAA as indicators of the preoperative, intraoperative, or postoperative assessment of rotation. This result is consistent with the work by Mortier et al (4) and Saltzman et al (17), which used an open continuous scale to observe the rotation on axial radiographs and found metatarsal pronation does not have a linear relationship to the IMA. We have seen cases in which very little metatarsal pronation is present in patients with a high IMA. However, we have yet to identify any patient with an HAV deformity with a supinated metatarsal.

Our study has shown a significant relationship between the preoperative sesamoid position and the degree of varus rotation required to align the MTPJ. This result is consistent with the studies by Inman (20), Talbot and Saltzman (21), and Dayton et al (13,14), which showed a pronated metatarsal will increase the sesamoid position on anteroposterior radiographs. In conjunction with the work by Okuda et al (6,12,18) and Grode and McCarthy (1), we advance the idea that the sesamoid position, lateral rounding of the metatarsal head, and the appearance of a medial eminence are effective indicators of the rotational position in the assessment, correction, and follow-up of patients with bunion deformities. Reduction of the lateral round sign of the metatarsal head and sesamoid position improvement, which are indicators of rotational position, have been shown to decrease the incidence of deformity recurrence (6,12,18). Thus, rotational correction reduces the likelihood of recurrence.

The number of patients and feet involved limited the direct conclusions of the present retrospective observation. Additional limitations included that our investigation did not report on outcomes. Rather, we reported solely on the quantification of the intraoperative


**Fig. 4.** (*A*) Two views of a patient's foot before operative correction of hallux abducto valgus and metatarsus primus adducto valgus. Note the sesamoid subluxation viewed on the anteroposterior radiographs does not match the position observed in the axial image owing to the pronated or valgus position of the metatarsal. (*B*) View of the same patient 5 months after operative intervention with no first metatarsal phalangeal joint soft tissue balancing performed. Note the alteration of sesamoid position, lateral rounding of the metatarsal head, appearance of the medial eminence, and proximal articular set angle observed on the anteroposterior radiographs. Also, the pronated position of the metatarsal has been reduced as observed on the axial radiograph.

rotation to align the MTPJ. Also, no preoperative assessment of rotation was performed to guide our operative planning. Future studies should assess which axial position and measurement techniques correlate most closely with the measured operative values to give the surgeon better preoperative guides. In addition, long-term outcome studies should be performed to assess the incidence of recurrence and complications and patient satisfaction after rotational tarsal metatarsal arthrodesis.

In conclusion, we found a consistent pronated position of the first metatarsal in feet with HAV in our series. This finding is consistent with those from other reports. When frontal plane rotation is corrected with metatarsal supination, our results showed an improvement in alignment of the first MTPJ, including the sesamoid position, without capsular balancing. Higher sesamoid position scoring was associated with greater degrees of rotation needed to align the MTPJ in the frontal plane. With the knowledge that frontal plane metatarsal rotational exists in patients with HAV, the surgeon can fully consider this previously underreported anatomic component in the operative planning and surgical technique.

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