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Comparison of Tibial Sesamoid Position on Anteroposterior and Axial Radiographs Before and After Triplane Tarsal Metatarsal Joint Arthrodesis

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ABSTRACT

We reviewed the radiographic results of a group of patients who had undergone triplane correctional tarsometatarsal arthrodesis for symptomatic hallux abducto valgus with metatarsus primus abducto valgus. Of the 21 feet included in the present review, 17 (81%) displayed radiographic findings of metatarsal pronation preoperatively based on axial sesamoid views and positive lateral round sign on anteroposterior radiographs. At a mean follow-up period of 5.2 ± 1.6 months, a significant improvement in the tibial sesamoid position (TSP) on both anteroposterior (AP) and axial radiographs was measured. A negative metatarsal round sign, indicating correction of coronal plane metatarsal rotation, was observed in 20 of the 21 feet (95.2%) on AP radiographic evaluation. All 21 patients (100%) had obtained resolution of sesamoid subluxation on the sesamoid axial view at the final follow-up examination. The sesamoid axial position was consistently normal when the round sign was absent, and the TSP was in the normal range of 1 to 3 on the AP radiograph. Sesamoid subluxation from the normal position with the tibial sesamoid on or lateral to the crista was noted in 4 feet (19%) preoperatively and 0 feet postoperatively. This confirmed that lateral round sign of the first metatarsal head and a high TSP noted on the AP radiograph are both related to metatarsal pronation and can be corrected concurrently with coronal plane varus rotation of the first metatarsal as a part of the procedure.

Most often, the severity of a bunion deformity is defined along a continuum defined using measurements from anteroposterior (AP) radiographs. These measurements include the 1-2 intermetatarsal angle (IMA), proximal articular set angle (PASA), hallux abduction angle, and tibial sesamoid position (TSP). Greater values for each of these measurements are associated with greater severity of bunion deformity and decisions regarding the procedure are made according to these observations. Using the most common radiographic measurements and algorithmic process, the deformity is largely defined as a singular plane (transverse) positional deformity. Although it is common to select from the >100 procedures to correct a bunion according to this radiographic severity scale, most osteotomy procedures move the metatarsal in the transverse plane only and do not provide complete reduction owing to the presence of uncorrected deformity in the coronal and sagittal planes.

Research has suggested that the popular preoperative AP radiographic findings are inconsistent. Martin (1) found that the preoperative PASA is rarely visualized intraoperatively and was often decreased postoperatively without any procedure used to address the PASA or the head of the metatarsal. Chi et al (2), and others (3), have shown a decreased PASA with proximal bunion repair procedures using the pre- and postoperative radiographic measurements. A significant improvement has been reported in the PASA without the use of distal procedures owing to the positional artifact that is present when the first metatarsal is rotated in the coronal plane (4). A second AP radiographic finding that changes with coronal plane rotation is the TSP (4,5). The idea that the sesamoids sublux away from the head of the first metatarsal in feet with hallux valgus has been challenged by research showing that the distance from the lateral sesamoid to the second metatarsal remains constant. That finding has led to the thought that the first metatarsal drifts medially off its anchorage to the medial and lateral sesamoids (6). Others have found that the apparent sesamoid position on radiographs is attributable to coronal plane rotation of the metatarsal, with little to no translational displacement of the sesamoids from

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beneath the metatarsal in some but not all patients. In other words, the sesamoids appear displaced from the first metatarsal on the AP radiograph when, indeed, they are positioned normally in their plantar metatarsal grooves (4,7) (Fig. 1). Recently, a review and comparison between AP and axial sesamoid radiographic views showed poor agreement between the 2 regarding subluxation of the sesamoids (8). Eversion or valgus rotation might be the initial deformity that sets into motion the malposition of the hallux and subsequent retrograde medial deviation of the first ray. Therefore, it might be the coronal plane malposition of the first metatarsal that is the inciting event that sets into motion the progression to a bunion. It has also been suggested that failure to correct the TSP might be the reason for the hallux abducto valgus (HAV) recurrence and poor functional outcomes (9,10). True soft tissue balancing requires realignment and redirection of the longitudinal pull of all soft tissue structures inserting on the distal aspect of the first ray. When the first metatarsal is moved in the transverse plane exclusively, as is the case with most osteotomies, the lateral position of the sesamoids will be maintained and the vector of force with tendon action of the extensors and flexors will pull the hallux into adduction and valgus rotation and the retrograde force will push the metatarsal medially, increasing the IMA. Triplane correction of the first metatarsal position will reassure the surgeon that the sesamoids are maintained in their anatomic grooves and orientated neutrally in the sagittal plane, avoiding the pseudocorrection resulting from aligning a pronated metatarsal over the sesamoids without the latter necessarily in their anatomic grooves. This also theoretically removes the deforming forces on the hallux and, secondarily, the first metatarsal (Fig. 2).

The lateral round sign described by Okuda et al (11) has been shown to be an indicator of first metatarsal pronation. This finding can be visualized on the AP radiograph along the lateral margin of the first metatarsal head. Because the metatarsal is everted relative to the plane of the foot and the AP radiograph, the rounded plantar surface of the first metatarsal comes into view, resulting in a rounded appearance to the lateral first metatarsal (lateral round sign). Without eversion, the lateral profile of the head will be quite straight. This finding is easily visualized and can be used as a guide to restoring neutral frontal plane rotation during intraoperative fluoroscopic examination (Fig. 3).

We hypothesized that triplane tarsometatarsal joint (TMTJ) arthrodesis would result in normalization of the TSP on the AP radiograph, not because of soft tissue balancing, but because of correction of the coronal plane of the deformity. We also sought to evaluate the association of an increased TSP with a positive lateral round sign to determine whether the 2 findings will be normalized concurrently when the first metatarsal has been inverted as a part of the corrective procedure (triplane correction TMTJ arthrodesis). Finally, we aimed to identify the percentage of patients in the present cohort with pure rotational deformity causing sesamoid changes on the AP radiograph (no sesamoid subluxation) and the percentage with associated sesamoid subluxation causing the AP TSP abnormality and to compare this to previous published research data reporting the incidence of sesamoid subluxation as a part of HAV deformity (Fig. 2).

Patients and Methods

The Des Moines institutional review board exempted the present retrospective analysis. We reviewed a consecutive series of symptomatic HAV patients who had undergone triplane TMTJ arthrodesis by a single surgeon from September 2015 to June 2016. The subjects were identified through a medical record search using the Common Procedural Terminology codes 28297 and 28740. The criteria for inclusion in the study were $\geq$2 months of postoperative follow-up data available, the availability of pre- and postoperative weightbearing AP and sesamoid axial radiographs, and patient participation in an early weightbearing protocol.

The surgical procedure was performed through a dorsal longitudinal incision over the first TMTJ. The metatarsal position was manually corrected in the transverse, coronal, and sagittal planes after TMTJ release and held with a specialized clamp before the bone cuts. The IMA was corrected to $<8^{\circ}$, and the coronal and sagittal planes of the deformity were corrected to neutral. Intraoperative fluoroscopic guidance was used to adjust and confirm the metatarsal correction. The criteria for complete correction was a TSP <2, an IMA $<8^{\circ}$, and anatomic alignment of the MTPJ and hallux. The prepared first TMTJ was reduced and provisionally fixated with an olive Kirschner wire. Two small-profile, 4-hole titanium locking plates were used in biplanar fashion to maintain correction in the transverse, frontal, and sagittal planes. No compression screw was used with this fixation approach. An intermetatarsal neutralization screw was used in 17 of 21 feet (81%) for added stability of the fixation after complete correction was achieved. No additional distal metatarsal osteotomy was performed. Capsular balancing was not performed in any of the patients. Postoperatively, the patients underwent an early weightbearing protocol with protected weightbearing in a removable walking boot at an average of 13.3 $\pm$ 3.1 (range 0 to 14) days. One of us (P.D.) measured the IMA, HVA, lateral shape of the metatarsal head (lateral round sign) (11), and TSP on the pre- and early postoperative AP radiographs. The TSP was measured using the Hardy and Clapham 1 to 7 scale (12). The semi-weightbearing sesamoid axial views were used to evaluate frontal plane rotation of the first metatarsal relative to the plane of the lesser metatarsals and subluxation of the metatarsal off the sesamoids. A standardized patient position with a rigid foam block was used to ensure consistency in obtaining the axial views. The results of the measurements were reviewed by both of us (P.D., M.F.) and discussed to ensure accuracy. Paired *t* tests (corrected for multiple comparisons) were conducted to determine the change in the radiographic morphologic measures.

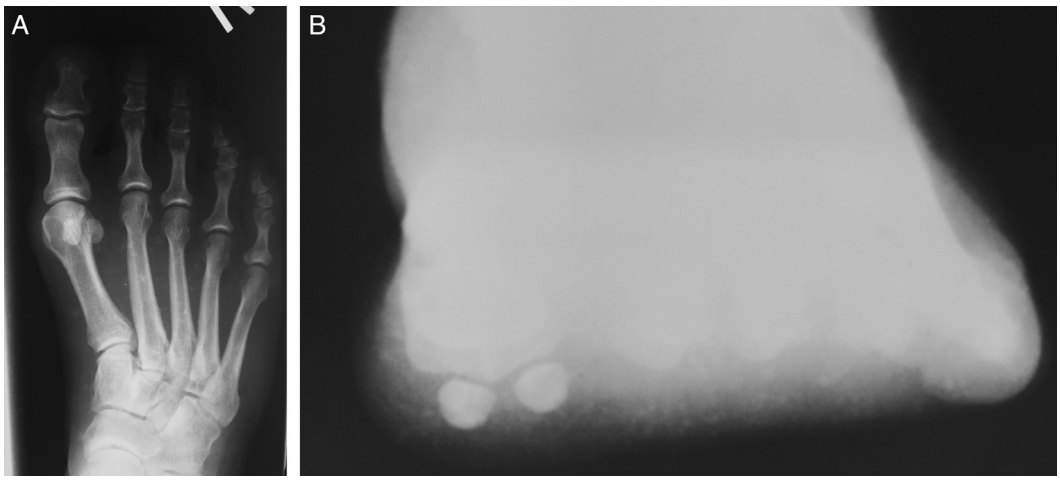

Fig. 1. (*A*) Anteroposterior radiograph showing positive lateral round sign and tibial sesamoid position suggesting metatarsal eversion. Traditional evaluation of the tibial sesamoid position would suggest metatarsal subluxation off the sesamoids. (*B*) Semi-weightbearing sesamoid axial view showing sesamoids located normally, medially and laterally to the median crista. Eversion of the first metatarsal has altered the findings visualized and assessed on the anteroposterior projection.

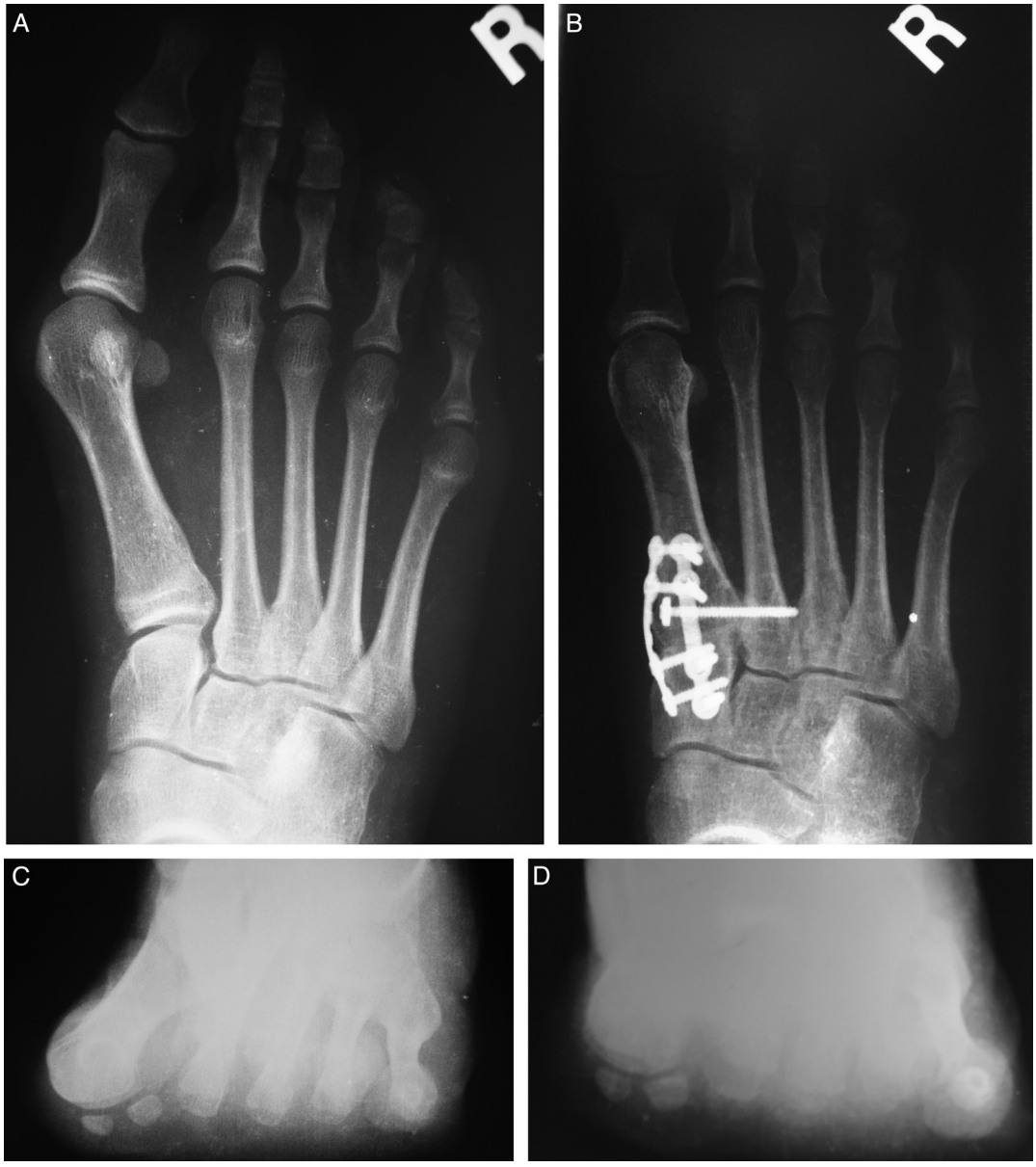

Fig. 2. (*A*) Preoperative and (*B*) postoperative anteroposterior radiographs of a 16-year-old female demonstrating the triplane deformity correction. (*C*) The axial preoperative radiograph clearly shows coronal plane rotation of the metatarsal without sesamoid subluxation. (*D*) The postoperative axial view shows normalization of the frontal plane rotation.

Results

Consecutive cases were identified, with 21 of 22 surgical records meeting the inclusion criteria. The average patient age at the follow-up examination was 32.42 (range 15 to 55) years. Nineteen patients, all female, and 21 feet, were included in the present analysis. At a mean follow-up point of 5.2 ± 1.6 months, a significant improvement in the IMA, HVA, and TSP was measured (Table). A negative metatarsal round sign, indicating correction of the frontal plane metatarsal rotation, was observed in 20 of the 21 feet (95.2%) using the AP radiographic measurement. All patients had had semi-weightbearing sesamoid axial views taken preoperatively and postoperatively. Of the 21 feet, 17 had metatarsal pronation preoperatively (81%). All the patients had maintained neutral coronal plane rotation at the final follow-up visit (100%). When the lateral round sign was absent on the AP radiograph, the sesamoid position was consistently normal on the axial view. This corresponded to an AP TSP of 1 to 3. Sesamoid subluxation from the normal position with the tibial sesamoid on or lateral to the median crista was noted in 4 feet (19%) preoperatively and no feet postoperatively (Fig. 4). We identified 1 case (4.8%) of continued lateral roundness of the first metatarsal postoperatively, which might indicate undercorrection of rotation or an anatomic variation.

Discussion

A constant relationship of the fibular sesamoid to the second metatarsal has been described in published studies (6). This observation lends itself to a widely accepted pathologic process wherein the first metatarsal deviates medially off a stable and stationary sesamoid apparatus in the transverse plane only. However, the appearance of the sesamoids on AP radiographs in a high percentage of cases does not indicate actual subluxation in relation to the median crista and bisection of the metatarsal shaft (13). Pronation of the first

Fig. 3. Preoperative anteroposterior and axial radiographs with the lateral round sign indicated preoperatively and absent postoperatively after triplane correction. Note the reduction in the lateral round sign and normalization of the apparent tibial sesamoid position on the anteroposterior radiograph resulting from inversion or supination of the first metatarsal. The axial views showed that the sesamoids were in their normal location before the procedure on a first metatarsal that was everted relative to the plane of the lesser metatarsals, confirming that it was the inversion that was responsible for the anteroposterior tibial sesamoid position changes, not capsular balancing.

metatarsal alters how the metatarsal is viewed on the AP radiographic projection much the same as an oblique radiograph of the foot does (4,5,7). With pronation of the metatarsal, it appears that lateral displacement of the sesamoids has occurred on the AP radiograph despite the normal position of the sesamoids medially and laterally to the crista; with supination, this apparent position will be corrected. In this situation, the metatarsal does not move off the sesamoid apparatus, rather, the rotation alters what is observed on AP radiographs. Actual subluxation of the metatarsal medially off the sesamoids without rotation does occur in a small percentage of cases. This subluxed sesamoid state, without any significant or pure metatarsal pronation, was shown to occur in approximately 10% of a population of patients reported by Kim et al (13) and 19% of the feet in our study. In most cases, the appearance of sesamoid displacement observed on AP radiographs results from metatarsal pronation. Therefore, the 2-dimensional radiographic findings are based on a 3-dimensional deformity that includes frontal plane rotation. This must be considered to achieve complete deformity correction.

The metatarsal in a bunion will not be deformed, rather it will have deviated from the normal anatomic position in 3 planes at the level of

Table
Mean morphologic measurements (preoperatively and after triplane correction, N = 21 feet)

Measurement	Preoperatively	Final Follow-Up Visit
IMA (°)	13.2° ± 2.3°	5.5° ± 1.9°*
HVA (°)	19.3° ± 8.5°	7.3° ± 3.9°*
TSP	4.8 ± 1.1	1.8 ± 0.7*
Axial metatarsal pronation (n)	17 of 21 (81)	1 of 21 (4.8)
Sesamoid subluxation (n)	4 of 21 (19.0)	0 of 21 (0.0)
Lateral round sign (n)	17 of 21 (81)	1 of 21* (4.8)

Abbreviations: HVA, hallux valgus angle; IMA, 1-2 intermetatarsal angle; TSP, tibial sesamoid position.
Data in parentheses are percentages.
* $p < .001$.

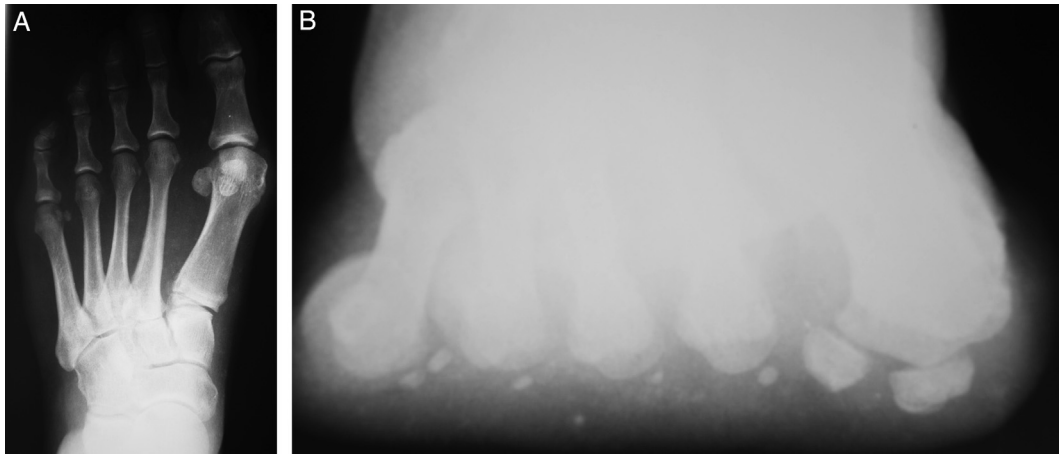

Fig. 4. Patient with hallux valgus and high tibial sesamoid position indicated on (*A*) anteroposterior radiograph and (*B*) sesamoid axial view showing medial sesamoid subluxation onto the crista, in addition to a small amount of eversion rotation.

the first TMTJ. Surgeons easily recognize the transverse plane component of the deformity (IMA), and this parameter has received the greatest priority in preoperative decision-making. However, the sagittal plane has been considered to a lesser degree. Historically, very little attention has been given to the metatarsal coronal plane position when operatively addressing hallux valgus. We have found that coronal plane rotation of the first metatarsal has a profound effect on the basic anatomy of the deformity and that inclusion of coronal plane derotation as a part of the corrective procedure provides a powerful tool for the surgeon to more accurately correct this complex deformity. This has been highlighted in the present series in which we were able to achieve a normal anatomic position of the sesamoid position without distal osteotomy or first metatarsophalangeal joint capsular balancing procedures.

Examination of the published data revealed the clear and consistent presence of metatarsal coronal plane rotation associated with a bunion deformity, which was first recognized in 1956 by Mizuno et al (14). The published data have used various terminologies to describe the same coronal plane position of the first metatarsal. This has created significant confusion in the discussion of the problem. Unless one is aware that the terms eversion, valgus, and pronation can be used synonymously when applied to the coronal plane position of the first metatarsal, one might overlook some of the published work regarding the topic of metatarsal pronation in a bunion (15).

In 1980, Scranton and Rutkowski (16) used sesamoid axial radiographs to observe the position of the metatarsal in both a control group and a group with bunion deformities. Their study found that the feet with bunions had a mean of 14.5° of metatarsal pronation and that the normal feet had a mean of 3.1° of metatarsal pronation. They concluded that the 3 components present in a bunion must be corrected, including the abducted hallux, adducted metatarsal, and pronated metatarsal. Mortier et al (17) in 2012, also used sesamoid axial radiographs to observe a mean pronated position of 12.7° of the metatarsal in feet with a bunion deformity. They concluded this rotation resulted from metatarsal cuneiform instability rather than from torsion of the metatarsal shaft and that valgus metatarsal rotation in bunion deformities is common. Grode and McCarthy (18) studied a similar view of the foot using cryomicrotomy rather than radiographs. Their observations included that, in a bunion, the position of the medial eminence or bump actually represents the dorsomedial surface of the head of the first metatarsal that is "brought into prominence by rotation through eversion." The frontal plane sections confirmed the pronated position of the metatarsal head.

Metatarsal rotation cannot directly be seen clinically; however, radiographic assessment of the rotational position can be determined on both AP and axial views of the sesamoids. The results of the present review strengthen the idea that certain findings on the AP radiograph can be used to qualify the rotational position. These include the lateral round sign of the first metatarsal head and the sesamoid position. These findings are closely linked with correction of the triplane deformity, as noted by others (19). In our series, we noted improvement in both these AP radiographic findings through deliberate supination or inversion of the first metatarsal during the procedure.

The limitations of the present study include that it was retrospective. The number of subjects was relatively small and the follow-up time should ideally be $\geq$1 year. However, this is a preliminary observation, and the primary outcome measure was the sesamoid positional change, not the clinical outcomes. We hope to expand the number of subjects and the follow-up period in the future. Another potential source of measurement error was that determination of the lateral round sign is a subjective visual finding for which surgeons might not agree. We found the round sign to be quite intuitive and easy to visualize; however, this likely resulted from our consistent observation of this finding for many years. All procedures and measurements were performed by 1 of us, which could lead to a potential observational bias. Therefore, additional measurements by independent raters would increase the validity of these findings.

We found that the TSP is a very consistent, but not universal, sign of coronal plane pronation, as evidenced by 81% of our patients having high TSP but no subluxation of the metatarsal from the sesamoid complex. In 19% of our patients, metatarsal head subluxation off the sesamoids, with or without frontal plane pronation noted. Although not universal, apparent lateral displacement of the sesamoids on the AP view is a strong marker of metatarsal pronation. Additionally, correction of rotation through triplane TMTJ arthrodesis consistently provided normalization of the sesamoid position both in rotation and in subluxation in the present series. The clinical significance of the present study was the potential reduction of recurrence by more accurate deformity correction, consistent with previously reported series linking failure to correct and maintain the sesamoid position with high rates of HAV recurrence. We recommend that the coronal plane deformity be evaluated in all bunion patients and given consideration in correction.

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