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Triplanar Quantitative Radiographic Analysis of the First Metatarsal-Phalangeal Joint in the Hallux Abductovalgus Deformity

Todd Hasenstein, DPM[1], Andrew J. Meyr, DPM, FACFAS[2]

[1] *Resident, Temple University Hospital Podiatric Surgical Residency Program, Philadelphia, PA*
[2] *Clinical Associate Professor, Department of Podiatric Surgery, Temple University School of Podiatric Medicine, Philadelphia, PA*

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ABSTRACT

Although hallux abductovalgus (HAV) is widely considered to be a triplanar deformity involving the transverse, sagittal, and frontal planes, most of the published literature has focused on evaluating the deformity in only the transverse plane, and we are unaware of any investigation objectively evaluating the relationship among the 3 planes in the setting of HAV deformity. The objective of this investigation was to quantitatively evaluate radiographic measurement of the relationship between the transverse, sagittal, and frontal planes in the HAV deformity. Anteroposterior, lateral, and sesamoid axial radiographs from 42 consecutive feet were evaluated with measurement of the first intermetatarsal angle, hallux abductus angle, metatarsal sesamoid position, first metatarsal inclination angle, sesamoid rotation angle, and tibial sesamoid grade. Variables were graphically depicted against each other on frequency scatter plots with calculation of a regression line and Pearson's correlation coefficient. As transverse plane deformity increased, the frontal plane deformity also tended to increase and the first metatarsal inclination angle tended to decrease. And as frontal plane deformity increased, the first metatarsal inclination angle tended to decrease. To our knowledge, these are the first quantitative and objective data in support of a triplanar component to the HAV deformity, and we believe this reinforces the evaluation of this deformity with emphasis on all 3 planes.

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Hallux abductovalgus (HAV, or the "bunion" deformity) is a commonly encountered patient complaint, and its correction is a relatively frequently performed elective foot surgical procedure (1–4). It is widely considered to be a triplanar deformity, with involvement of the transverse, sagittal, and frontal planes (5–7). Despite this, clinical evaluation and most of the published literature has tended to focus on clinical and radiographic evaluation primarily in the transverse plane, with relatively little information available regarding the frontal and sagittal planes (4,5,8–22). Additionally, we are unaware of any investigation specifically evaluating the relationship of the three planes across a spectrum of the deformity.

The objective of this investigation was therefore to quantitatively evaluate radiographic measurement of the relationship among the transverse, frontal, and sagittal planes in the HAV deformity.

Patients and Methods

The radiographs of patients from the Temple University Foot and Ankle Institute were retrospectively reviewed for this investigation. Included in the present study were consecutive patients who had undergone radiographic evaluation with at least a weight-bearing anteroposterior (AP) foot radiograph, a weight-bearing lateral foot radiograph, and a weight-bearing sesamoid axial radiograph before undergoing elective reconstruction of the first metatarsal-phalangeal joint for the HAV deformity. Radiographs were excluded with a history of previous foot or ankle surgery and/or evidence of osseous trauma. Institutional review board approval was obtained.

All AP and lateral radiographs were taken with standard technique in the angle and base of gait, and performed by 1 of 2 radiologic technicians with a combined 50 years of clinical experience (23). The purpose of the angle and base of gait is to radiographically represent the structure of the foot during weight-bearing midstance. The angle of gait is defined as the degree of abduction or adduction of the foot from midline during gait, whereas the base of gait is defined as the distance between both heels during the gait cycle. At our facility, the patient is positioned into the angle and base of gait by the radiology technician following an observation of gait and stance.

Three measurements were recorded from each standard weight-bearing AP radiograph, including the first intermetatarsal angle (IMA), hallux abductus angle (HAA), and metatarsal sesamoid position (MSP) (12,24,25). The AP radiograph was defined as the film placed in a horizontal position flat on the orthoposer with the tubehead angulated 15° from vertical, directed posteriorly, and aimed at the second metatarsocuneiform joint (23). The first IMA was defined as the angular relationship between the bisectors of the first and second metatarsal shafts. Bisectors were determined by individually identifying the proximal and distal midpoints of the diaphyseal-metaphyseal junctions and then forming a line connecting the 2 points. This was considered a continuous variable. The HAA was defined as the angular relationship between the bisectors of the first metatarsal

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Address correspondence to: Andrew J. Meyr, DPM, FACFAS, TUSPM Department of Surgery, 2nd Floor, 8th at Race Street, Philadelphia, PA 19107
E-mail address: ajmeyr@gmail.com (A.J. Meyr).

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Table
Relationship of the transverse, sagittal, and frontal planes in the hallux abductovalgus deformity (N = 42 feet in 32 patients)

Pearson Correlation Coefficient (*p* Value)	First Metatarsal Inclination Angle	Sesamoid Rotation Angle	Tibial Sesamoid Grade
First intermetatarsal angle	−0.101 (*p* = .522)	0.338 (*p* = .028*)	0.287 (*p* = .065)
Hallux abductus angle	−0.523 (*p* = .000*)	0.585 (*p* = .000*)	0.589 (*p* = .000*)
Metatarsal sesamoid position	−0.487 (*p* = .001*)	0.611 (*p* = .000*)	0.490 (*p* = .001*)
First metatarsal inclination angle	N/A	−0.442 (*p* = .003*)	−0.513 (*p* = .001*)

* Indicates statistical significance to $p \leq .05$.

and hallux proximal phalanx shafts. This was considered a continuous variable. The MSP was measured on a 7-point scale as described by Hardy and Clapham (25). This was considered a categorical variable.

One measurement was recorded from each standard weight-bearing lateral radiograph and included the first metatarsal inclination angle (Inclin_1). The lateral radiograph was defined as the image receptor placed in an upright, vertical position in the orthoposer with the tube head angulated at 90° from vertical, directed medially, and aimed at the lateral cuneiform/cuboid (23). The first metatarsal inclination angle was defined as the resultant angulation between the supporting surface and the longitudinal bisection of the first metatarsal (24). This was considered a continuous variable.

Two measurements were recorded from each standard weight-bearing sesamoid axial radiograph, including the tibial sesamoid grade (SG) and sesamoid rotation angle (SRA). The sesamoid axial radiograph was defined as the image receptor placed in an upright, vertical position in the orthoposer with the tubehead angulated at 90° from vertical, directed anteriorly, and aimed at the plantar midline of the foot (23). The foot is positioned in a sesamoid axial positioning device (Fig. 1) that dorsiflexes the metatarsophalangeal joints and allows for visualization of the metatarsal-sesamoid articulation. The tibial sesamoid grade was defined as the position of the tibial sesamoid relative to the intersesamoid ridge and categorized on the 4-point scale described by Yildirim et al. (26). This was considered a categorical variable. The sesamoid rotation angle was measured as the angular relationship between the weight-bearing surface (positioning device) and a line connecting the most inferior aspect of the medial and lateral sesamoids as described by Kuwano et al. (27). This was considered a continuous variable.

The radiographic measurements were made by a single author (T.H.) using computerized digital software (Opal-RAD PACS, Viztek, Garner, NC), which measured to a precision of 0.1°. After taking the radiographic measurements, the data were stored in a personal computer for subsequent statistical analysis. All statistical analyses were performed using Statistical Analysis Systems software, version 9.2 (SAS Institute, Cary, NC), by the senior author (A.J.M.). Each parameter was graphically depicted against each other on a frequency scatter plot and analyzed with both a regression line and Pearson's correlation coefficient to evaluate for relationships among the variables. A level of statistical significance was set at $p = .05$.

Results

A total of 42 feet in 32 patients met study inclusion criteria. Seven (21.88%) of the 32 patients were male, and 22 (52.38%) of the studied feet were right feet. The mean ± standard deviation (range) patient age was 40.4 ± 15.3 years (range 18 to 63) (Table).

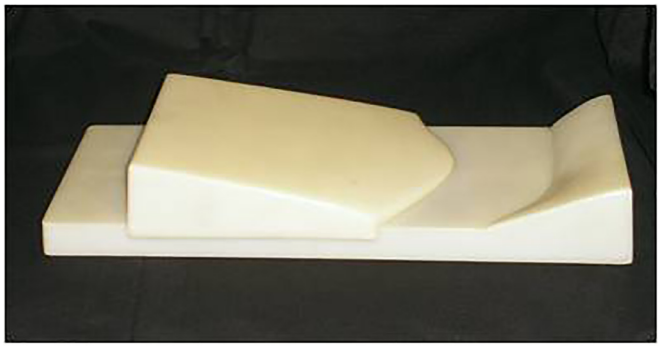

Fig. 1. Sesamoid axial positioning device. This device was used for positioning of the sesamoid axial radiographic projection.

Relationship of the Transverse and Frontal Planes

Figure 2 demonstrates the relationship of the transverse plane IMA to the frontal plane SRA. A positive relationship was observed with a corresponding Pearson's correlation coefficient of 0.338 ($p = .028$). Figure 3 demonstrates the relationship of the transverse plane HAA to the frontal plane SRA. A positive relationship was observed with a corresponding Pearson's correlation coefficient of 0.585 ($p = .000$). Figure 4 demonstrates the relationship of the transverse plane MSP and the frontal plane SRA. A positive relationship was observed with a corresponding Pearson's correlation coefficient of 0.611 ($p = .000$).

Figure 5 demonstrates the relationship of the transverse plane IMA to the frontal plane SG. A positive relationship was observed with a corresponding Pearson's correlation coefficient of 0.287 ($p = .065$). Figure 6 demonstrates the relationship of the transverse plane HAA to the frontal plane SG. A positive relationship was observed with a corresponding Pearson's correlation coefficient of 0.589 ($p = .000$). Figure 7 demonstrates the relationship between the transverse plane TSP and the frontal plane SG. A positive relationship was observed with a corresponding Pearson's correlation coefficient of 0.490 ($p = .001$).

Relationship of the Transverse and Sagittal Planes

Figure 8 demonstrates the relationship between the transverse plane IMA and the sagittal plane Inclin_1. A negative relationship was observed with a corresponding Pearson's correlation coefficient of −0.101 ($p = .522$). Figure 9 demonstrates the relationship between the transverse plane HAA and the sagittal plane Inclin_1. A negative relationship was observed with a corresponding Pearson's correlation coefficient of −0.523 ($p = .000$). Figure 10 demonstrates the relationship between the transverse plane TSP and the sagittal plane Inclin_1. A negative relationship was observed with a corresponding Pearson's correlation coefficient of −0.487 ($p = .001$).

Relationship of the Frontal and Sagittal Planes

Figure 11 demonstrates the relationship between the frontal plane SRA and the sagittal plane Inclin_1. A negative relationship was observed with a corresponding Pearson's correlation coefficient of −0.442 ($p = .003$). Figure 12 demonstrates the relationship between the frontal plane SG and the sagittal plane Inclin_1. A negative relationship was observed with a corresponding Pearson's correlation coefficient of −0.513 ($p = .001$).

Discussion

The results of the present investigation have provided a quantitative comparison of descriptive statistics of radiographic parameters of the hallux abductovalgus deformity in the transverse,

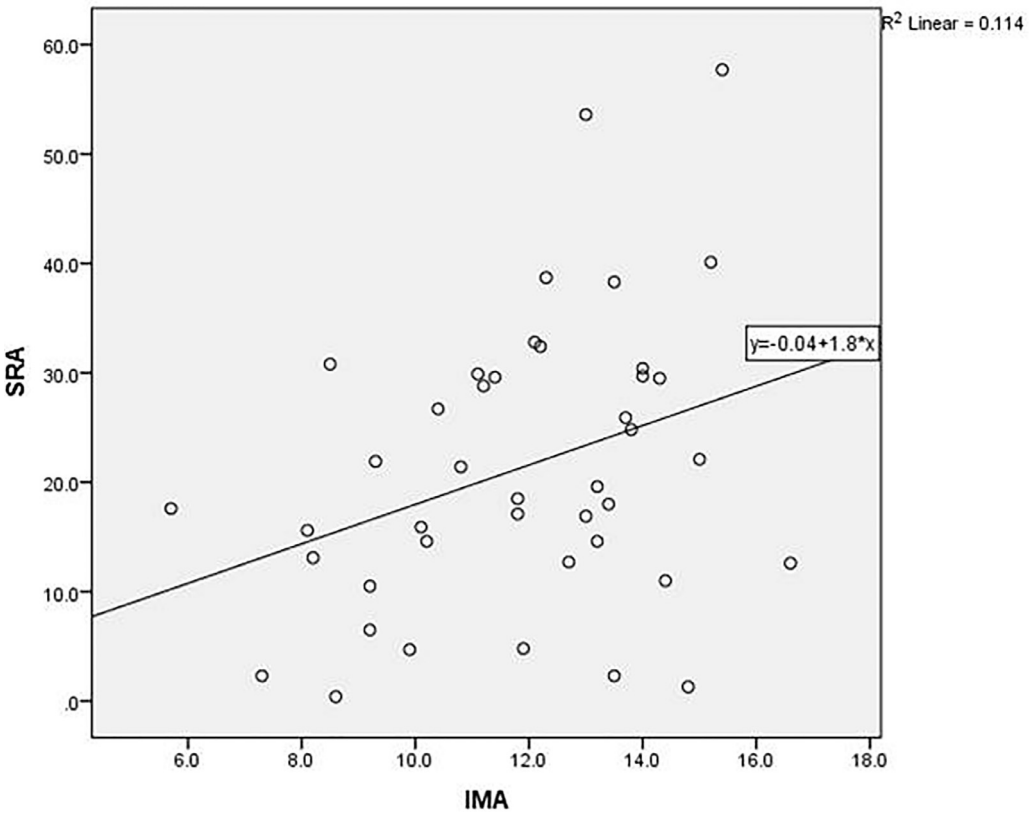

Fig. 2. Relationship between the transverse and frontal planes. These frequency scatter plots demonstrate the radiographic relationship between transverse and frontal plane deformity in the hallux abductovalgus deformity. As transverse plane deformity increased, the frontal plane deformity also tended to increase. HAA, hallux abductus angle; SG, sesamoid grade; SRA, sesamoid rotation angle (N = 42 feet in 32 patients).

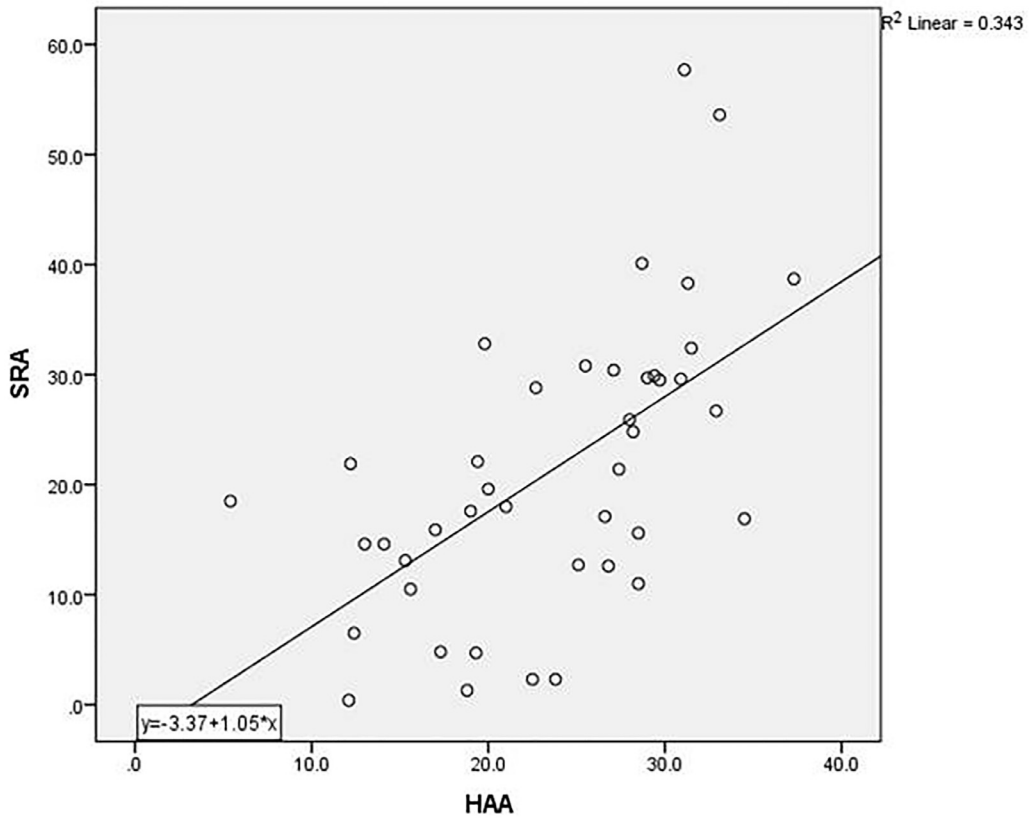

Fig. 3. The relationship between the hallux abductus angle (HAA) and the sesamoid rotation angle (SRA) (N = 42 feet in 32 patients).

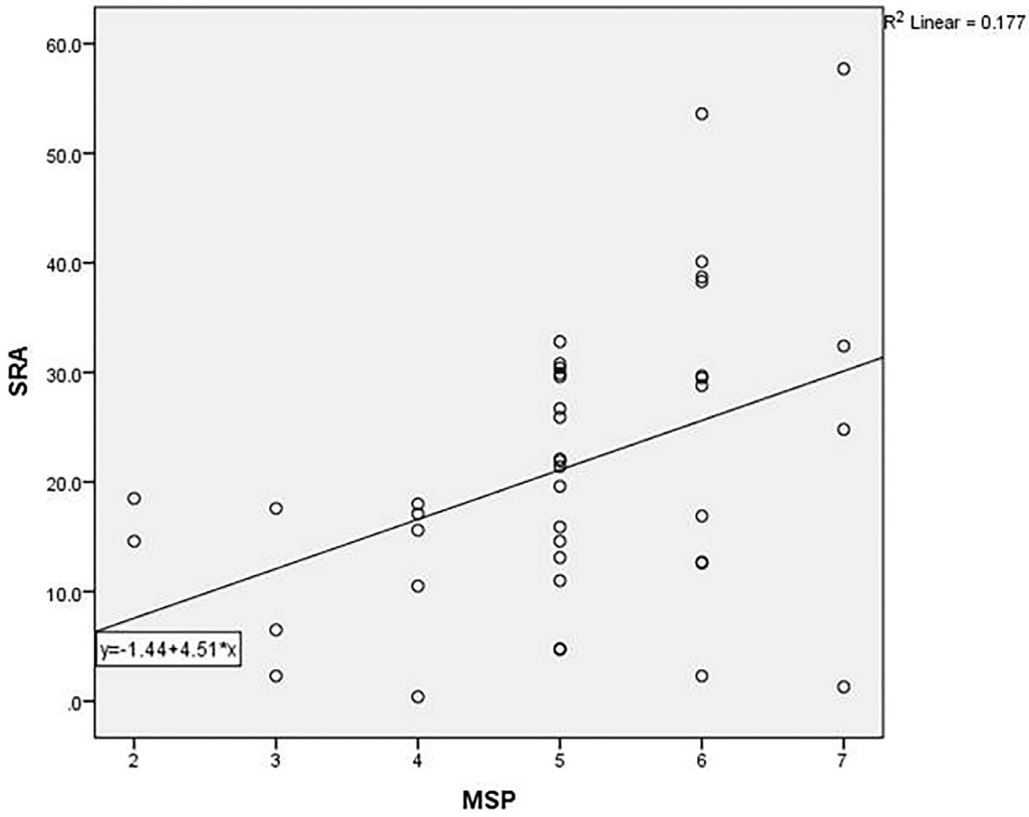

Fig. 4. The relationship between the metatarsal sesamoid position (MSP) and the sesamoid rotation angle (SRA) (N = 42 feet in 32 patients).

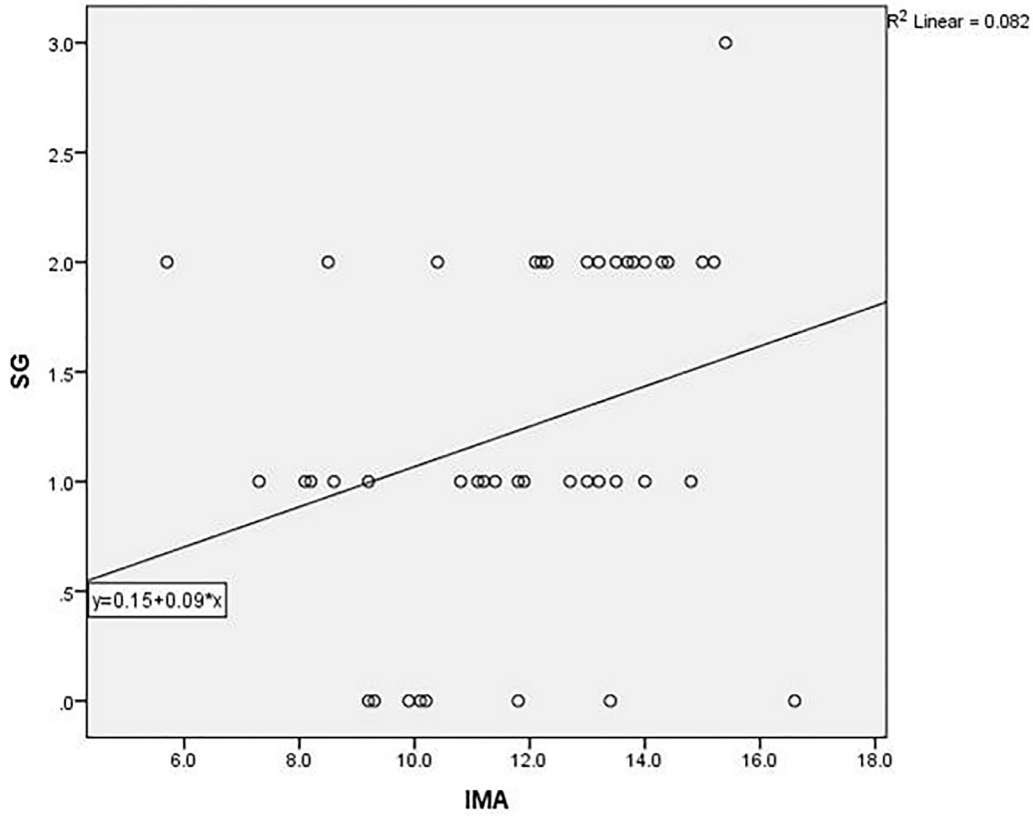

Fig. 5. The relationship of the intermetatarsal angle (IMA) and the sesamoid grade (SG) (N = 42 feet in 32 patients).

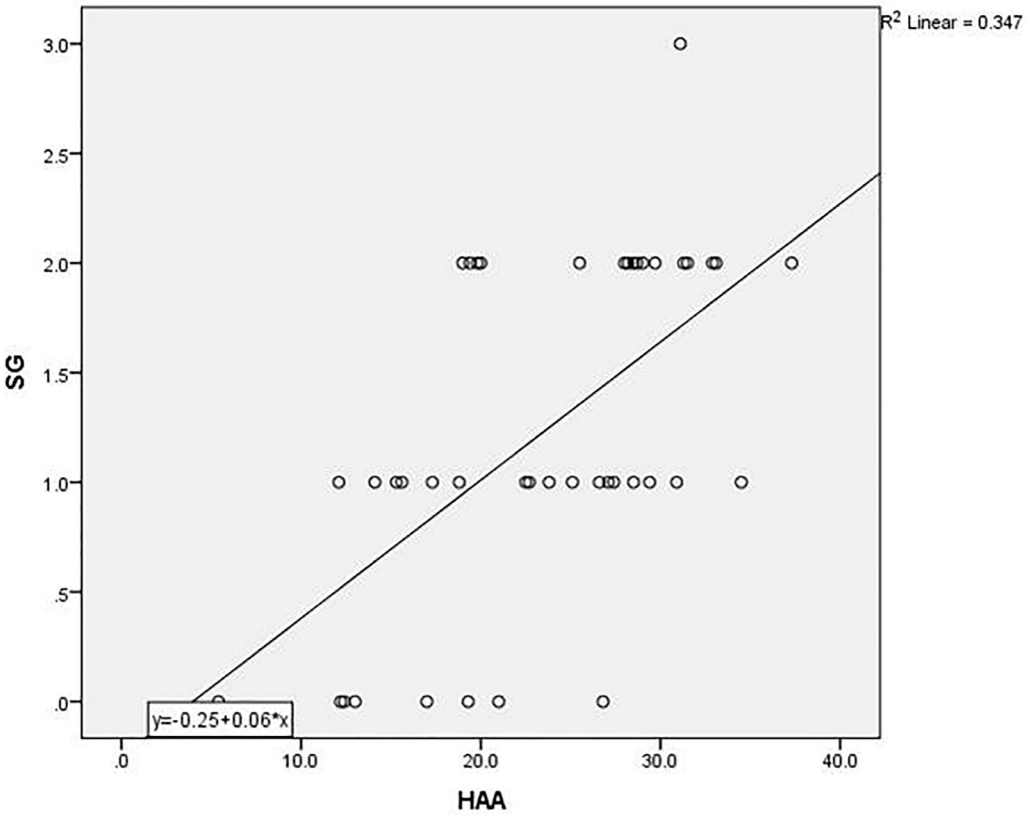

Fig. 6. The relationship between the hallux abductus angle (HAA) and the sesamoid grade (SG) (N = 42 feet in 32 patients).

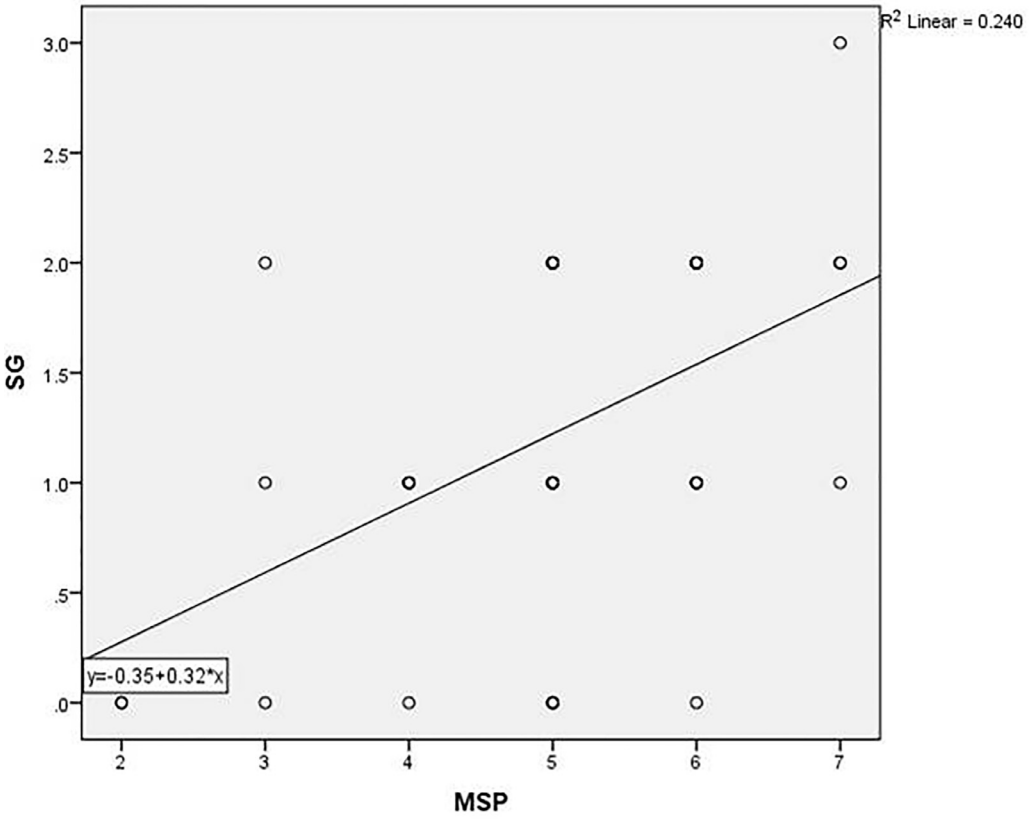

Fig. 7. The relationship between the metatarsal sesamoid position (MSP) and the sesamoid grade (SG) (N = 42 feet in 32 patients).

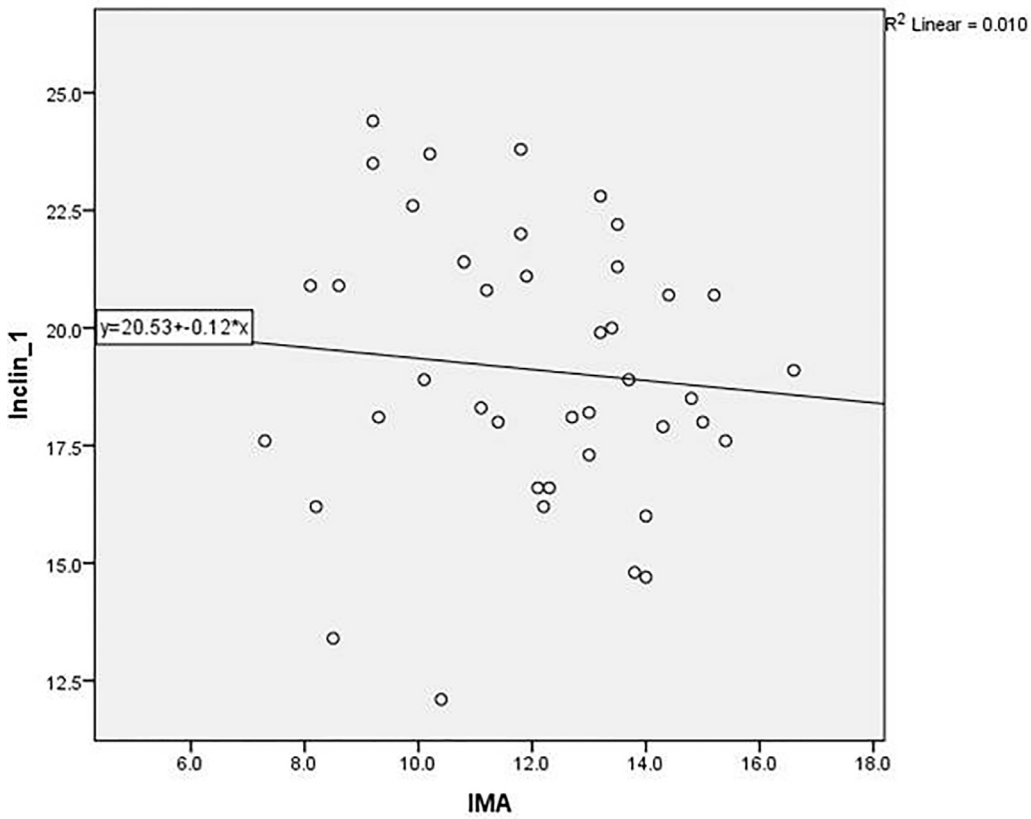

Fig. 8. Relationship between the transverse and sagittal planes. These frequency scatter plots demonstrate the radiographic relationship between transverse and sagittal plane deformity in the hallux abductovalgus deformity. As transverse plane deformity increased, the first metatarsal inclination angle tended to decrease (N = 42 feet in 32 patients). HAA, hallux abductus angle; IMA, intermetarsal angle; Inclin_1, first metatarsal inclination angle; MSP, metatarsal sesamoid position.

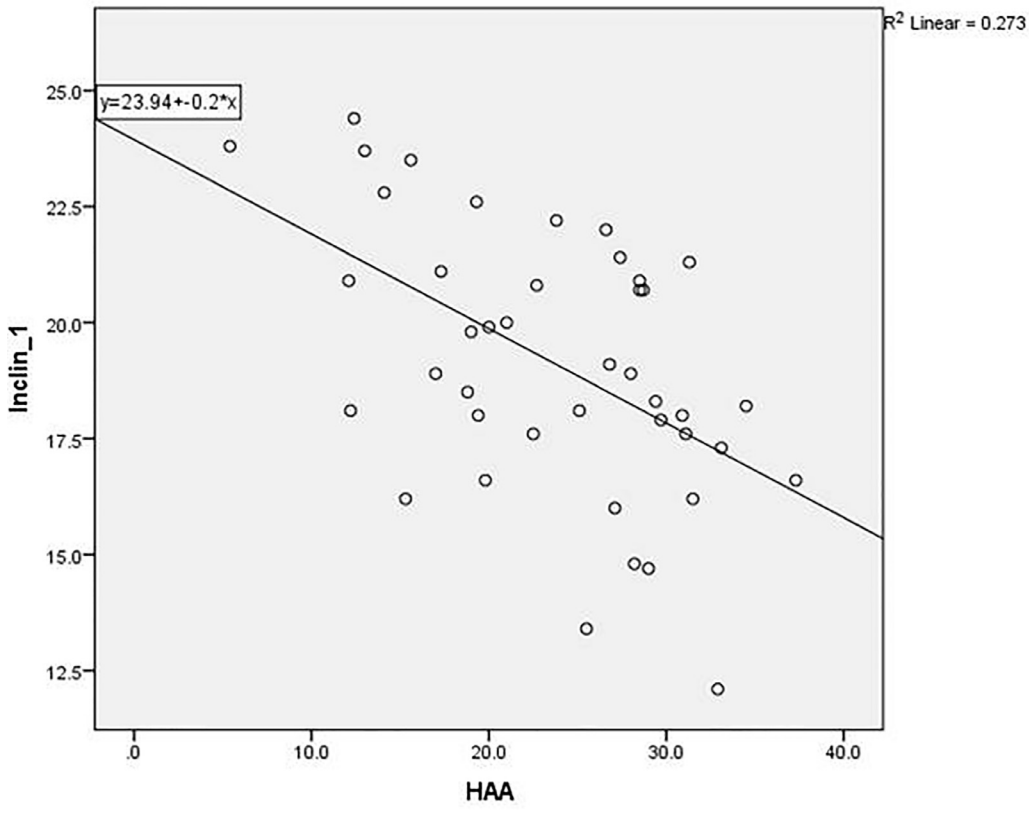

Fig. 9. The relationship between the hallux abductus angle (HAA) and the first metatarsal inclination angle (Inclin_1) (N = 42 feet in 32 patients).

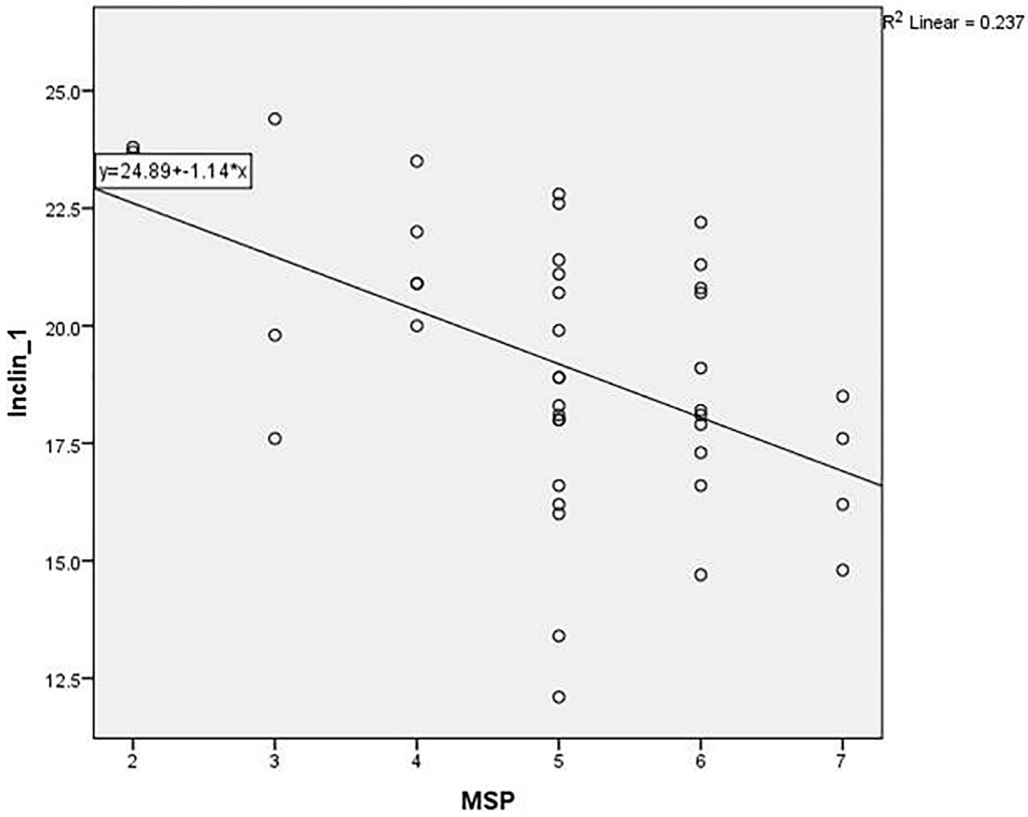

Fig. 10 The relationship between the metatarsal sesamoid position (MSP) and the first metatarsal inclination angle (Inclin_1) (N = 42 feet in 32 patients).

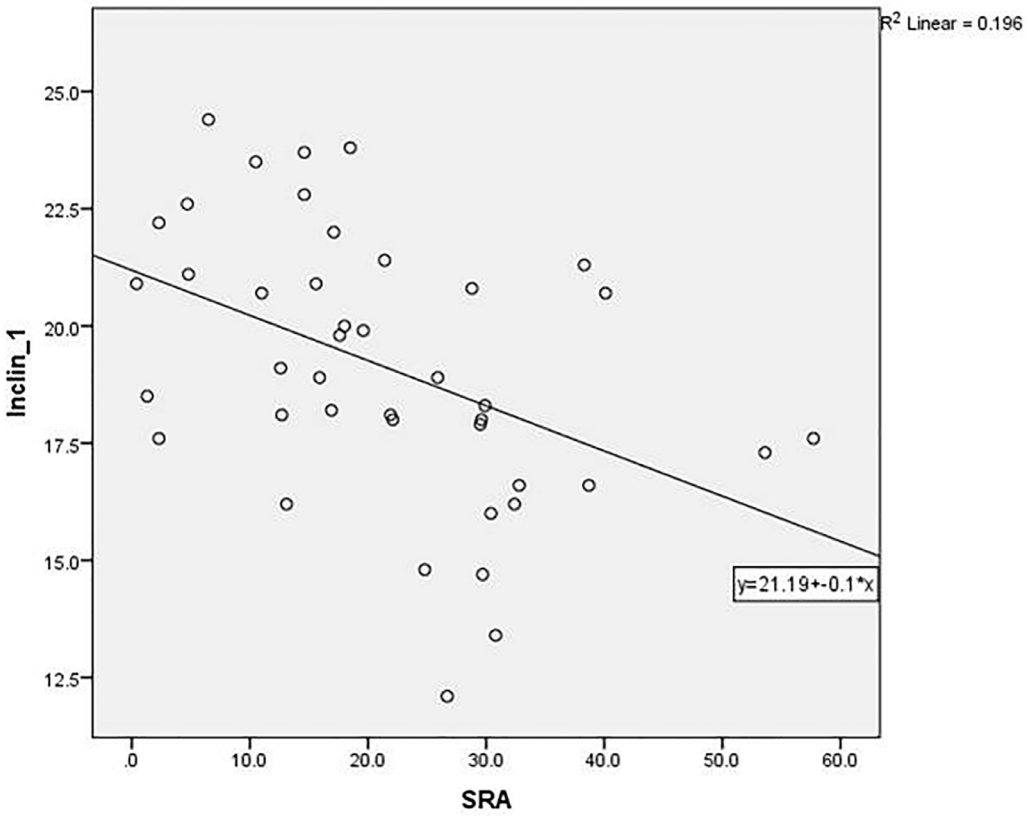

Fig. 11. The relationship between the metatarsal sesamoid position (MSP) and the first metatarsal inclination angle (Inclin_1) (N = 42 feet in 32 patients).

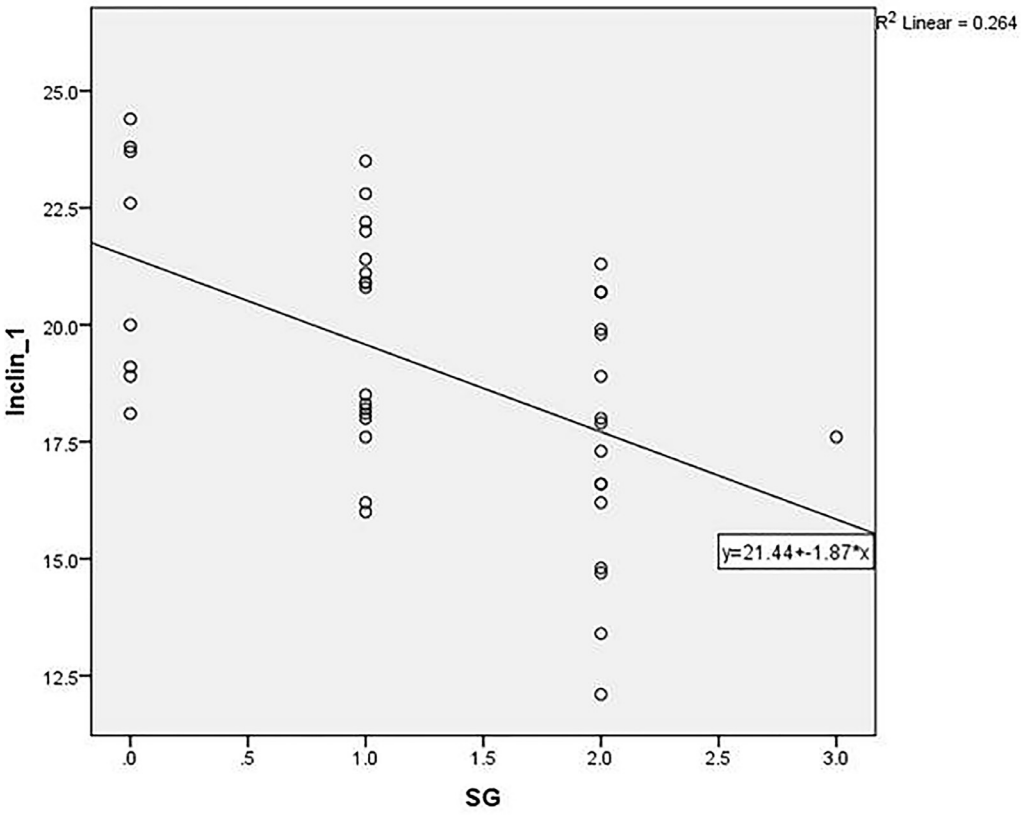

Fig. 12. The relationship between the sesamoid grade (SG) and the first metatarsal inclination angle (Inclin_1) (N = 42 feet in 32 patients).

sagittal,andfrontalplanes. As with any scientific investigation, critical readers are encouraged to review the study design and results to reach their own conclusions, whereas the following represents our conclusions based on the preceding results. As scientists, we also never consider data to be definitive but do think that these results are worthy of attention and future investigation.

We primarily conclude that these results provide objective evidence in support of a triplanar component to the HAV deformity. We observed consistent and statistically significant correlations when observing scatter plots and calculating Pearson's correlation coefficients using commonly performed radiographic parameters. As transverse plane deformity of the first metatarsal and hallux phalanges increased, the frontal plane deformity of the sesamoids also tended to increase and the first metatarsal inclination angle tended to decrease. And as frontal plane deformity of the sesamoids increased, the first metatarsal inclination angle tended to decrease. To our knowledge this is the first quantitative and objective data in support of a triplanar component to the HAV deformity, and we believe reinforces the evaluation of this deformity with emphasis on all three planes.

The present study has several important limitations. Data was collected from a single institution, using a limited number of patients, and therefore these results might not be representative of our entire institution or other institutions. There may also be some disagreement among foot and ankle surgeons with respect to the specific radiographic measurements that we included in this investigation. We did not evaluate all possible radiographic measures that can be used in the evaluation of the HAV deformity, and there might be some disagreement with respect to the exact definition and measurement of these angles.

Another limitation of any radiographic study is the variability of the positioning and projection of the radiographs, particularly when multiple radiographic technicians are involved. This is particularly true when considering the sesamoid axial projection where different orthoposers might be used placing the first metatarsal-phalangeal joint in varying degrees of extension. We also used a single evaluator, which could be considered both a limitation and a strength. Using a single evaluator for the radiographic measurements likely improves the reliability of our measurements, although any error by our evaluator could misrepresent the findings reported here.

Another limitation is with respect to our measurement of the frontal plane. The AP and lateral projections are taken in the angle and base of gait, which is not the case for the sesamoid axial projection. Additionally, both the sesamoid rotation angle and tibial sesamoid grade are primarily measures of the sesamoid position, as opposed to the first metatarsal and/or hallux phalanges. The measurements performed in this investigation were primarily of the first metatarsal. We believe these represent general limitations in our measurement of the frontal plane, but to our knowledge are the only measurements readily available in clinical practice. We are unaware of any more specific measure of the frontal plane position of the first metatarsal or hallux. In the future, it is possible that weight-bearing computed tomography scans might provide additional insight into this clinical question. This technology, however, was unavailable and beyond the scope of the present investigation.

In conclusion, the results of this study provide objective quantitative data in support of the HAV deformity not only involving the transverse, frontal, and sagittal planes, but also provides objective data on the relationship of these planes over the course of the deformity.

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