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The Mechanical Axis of the First Ray: A Radiographic Assessment in Hallux Abducto Valgus Evaluation

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A B S T R A C T

The present report describes a new method of hallux abducto valgus deformity correction planning using the mechanical axis of the medial column (mechanical axis planning). This method of radiographic evaluation identifies an ideal position for the first metatarsal after correction and is useful regardless of the surgical procedure chosen. We retrospectively reviewed 200 radiographs to identify a “normal” value for the mechanical axis angle. We reviewed 100 radiographs of patients with hallux abducto valgus deformity (deformity group) and 100 radiographs of patients without hallux abducto valgus deformity (control group). The deformity group revealed an M1-M2 anatomic axis angle of 13.5° ± 2.83° and an M1-M2 mechanical axis angle of 11.58° ± 1°. The control group revealed an M1-M2 anatomic axis angle of 7.5° ± 1.76° and an M1-M2 mechanical axis angle of 11.19° ± 0.9°. The differences in the M1-M2 anatomic axis angle and M1-M2 mechanical axis angle were statistically significant between the control and deformity groups. We sought to provide a reliable method for planning hallux abducto valgus deformity correction by aligning the mechanical axis of the medial column and the mechanical axis of the first ray to the “normal” value of 11° to reduce the deformity.

Hallux abducto valgus (HAV) deformity is an acquired, progressive disorder involving the first metatarsal phalangeal joint and metatarsal-sesamoid complex. This often painful deformity is a common complaint of patients presenting to the foot and ankle specialist. A longstanding deformity can produce varying degrees of functional adaptation, leading to pain and difficulty with ambulation. Reduction of the intermetatarsal angle (M1-M2 anatomic axis angle) has long been identified as essential for successful correction of HAV (1–5). The extensive published data on HAV have concentrated on surgical procedures, fixation techniques, and longitudinal studies of various periods. Despite the extensive amount of data published, no consensus has been reached on the ideal position of the first metatarsal after deformity reduction.

A significant focus of the HAV deformity evaluation has been placed on radiographic interpretation. In addition to the multiple radiographic angles described to evaluate HAV, other areas commonly assessed on the HAV radiograph are the joint space, sesamoid position, axial rotation of the hallux, metatarsal head shape, bone stock, and degenerative joint disease (3,6). The M1-M2 anatomic axis angle, formed by bisecting the first and second metatarsal shafts (intermetatarsal angle) is commonly used to choose the correct surgical procedure. The final position of the first metatarsal varies among foot and ankle surgeons. The postoperative position has ranged from 12° to 0° and brings into question how consistent results can be achieved (1–6). The present report describes the concept of the mechanical axis of the medial column and first ray and provides instructions on how to determine this mechanical axis. The HAV deformity planning we describe is a reliable method of determining the amount of translation and angulation necessary for deformity correction.

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Anatomic and Mechanical Axis Description

All long bones have both a mechanical and an anatomic axis (7,8). The mechanical axis of a bone is a straight line connecting the joint centers of the proximal and distal joints. The anatomic axis of a bone is defined as the mid-diaphyseal line (Fig. 1) (7,8).

Hallux Valgus Mechanical Axis Planning Technique

Mechanical axis planning for HAV deformity is an accurate method to determine the amount of correction necessary to reduce the deformity. The following examples describe a method (mechanical axis planning) to determine the amount of angular and translational correction necessary with any osteotomy or fusion procedure. Adherence to this method will result in realignment of the axes of deformity (colinear). This technique requires weightbearing radiographs, preferably in angle and base of gait.

Mechanical axis deformity planning has been described in the lower extremity; however, it has not been applied to the HAV deformity (7,8). We applied the concepts described by Paley (7) for lower extremity deformity planning to the medial column and the first ray in an effort to standardize HAV deformity planning. Similar to the use of the center of the femoral head as the joint center in creating the mechanical axis of the femur, we used the center of the talar head as the joint center in creating the mechanical axis of the medial column. In the following paragraphs we outline our method to determine the mechanical axis of the first ray and medial column and apply this method to HAV deformity planning.

Fig. 1. Depiction of mechanical and anatomic axes. Right femur: mechanical axis is demonstrated by a line connecting the center of the femoral head and the center of the distal femur. Left femur: anatomic axis is demonstrated by a mid-diaphyseal line. Right tibia: mechanical axis is shown by a line connecting the midpoint between the tibial spines and the midpoint of the tibial plafond. Left tibia: anatomic axis is shown by a mid-diaphyseal line. Note the anatomic and mechanical axes of the tibia are parallel.

First, draw a point at the center of the proximal phalangeal base (point A), the center of the first metatarsal head (point B), the center of the second metatarsal phalangeal joint (point C), and the dorsal lateral proximal corner of the medial cuneiform (point D; Fig. 2*A*). Next, draw any 2 lines tangent to the curvature of the talar head (Fig. 2*B*). Then, draw a line perpendicular to each tangent line (Fig. 2*C*). The intersection of the 2 perpendicular lines represents the center of the talar head (point E).

Next, draw a line from the center of the talar head to the center of the base of the proximal phalanx (line EA). This represents the mechanical axis of the medial column (talus, navicular, medial cuneiform, and first metatarsal; Fig. 3*A*). This line should pass through the dorsal lateral proximal corner of the medial cuneiform (point D), the center of the metatarsal head (point B), and the center of the base of the proximal phalanx (point A). In the normal foot, this line will be colinear or parallel to a bisection of the first metatarsal shaft (anatomic axis). A segment of this line (DB) represents the mechanical axis of the first ray (cuneiform and first metatarsal).

Finally, draw a line from the center of the talar head (point E) to the center of the second metatarsal phalangeal joint (point C; Fig. 3*B*). Angle AEC (M1-M2 mechanical axis angle) represents the normal mechanical relationship of the first and second rays. The center of the base of the proximal phalanx will be directly opposite the center of the first metatarsal head (points A and B) in patients without an HAV deformity. The lines EA and DB will be colinear and pass through point D, the dorsal lateral proximal corner of the medial cuneiform. Additionally, the mechanical axis of the medial column and the mechanical axis of the first ray will be colinear or parallel to the bisection of the first metatarsal shaft (anatomic axis of the first metatarsal).

As HAV progresses, angle AEC (M1-M2 mechanical axis angle) will remain unchanged, suggesting that the proximal phalanx and sesamoid apparatus remain in their original position. The splaying of the first ray results in a new angle (ADB), which represents the amount of first ray deformity (Fig. 4). Point D (the dorsal lateral proximal corner of the medial cuneiform), therefore, represents the center of rotation of angulation (CORA) of the first ray. The example shown illustrates a 5° first ray deformity. On a calibrated radiograph, the distance between lines DB and EA at the level of the planned osteotomy or fusion represents the amount of translation necessary to achieve colinear axis lines (Fig. 5).

Metatarsus adductus is a complicating factor in HAV deformity planning. Investigators have described various methods for measuring the metatarsus adductus deformity for incorporation into HAV planning (9). We suggest that our method of mechanical axis planning simplifies deformity planning in the metatarsus adductus foot. We must point out that in the metatarsus adductus foot type, the mechanical axis of the medial column will not pass through the dorsal lateral proximal corner of the medial cuneiform (Fig. 6). Despite this, the goal of correction remains restoration of the M1-M2 mechanical axis angle, and the amount of correction needed can be found by measuring the angle and distance between the mechanical axis of the medial column (line EA) and the mechanical axis of the first ray (line DB).

What Is the "Normal" M1-M2 Mechanical Axis Angle?

Using the method described, we undertook a case-control study to ascertain the "normal" (average) M1-M2 mechanical axis angle in patients with a symptomatic bunion and compared it with the findings from a group of normal controls. In a retrospective review of 200 radiographs, we aimed to determine whether the differences in the M1-M2 mechanical axis angle were statistically significantly associated with any number of demographic variables. We hypothesized that the "normal" M1-M2 mechanical axis angle would be 11° and that

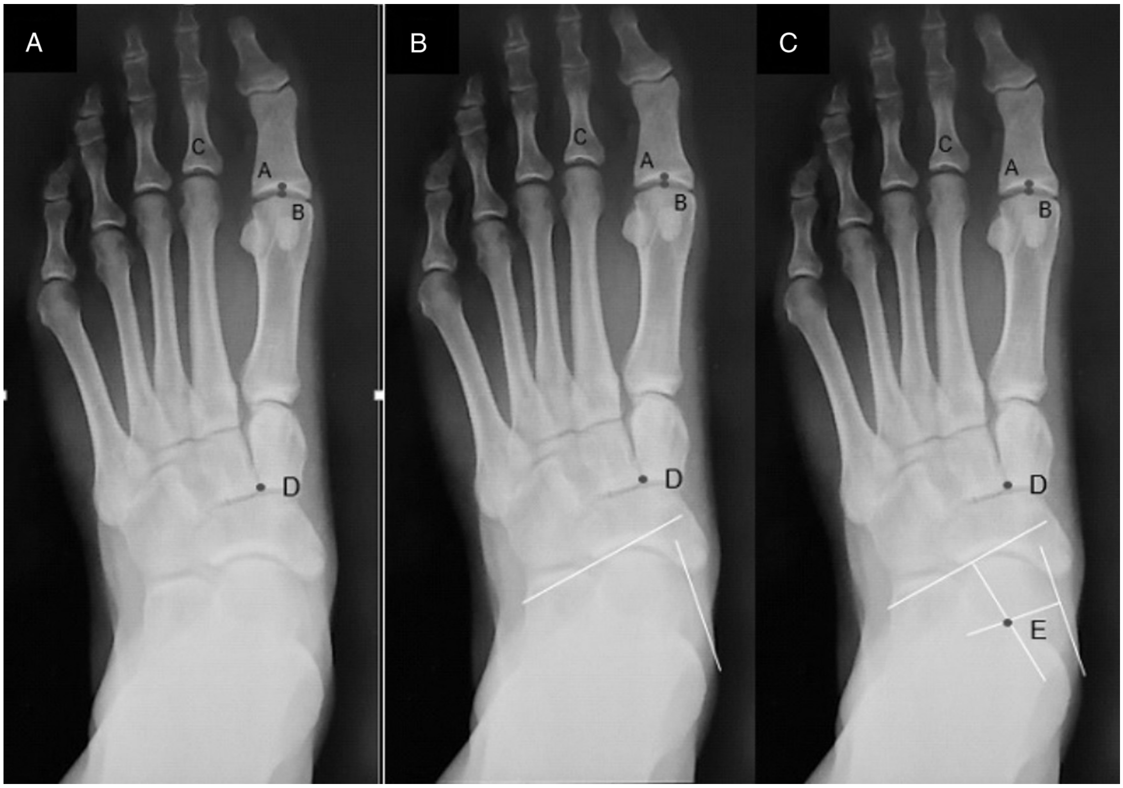

Fig. 2. (*A*) Points A through D depicted. (*B*) Two lines drawn tangent to curvature of the talar head. (*C*) Point E represents the point at which the 2 perpendicular lines cross.

correction of the HAV deformity to "normal" would result in restoration of the mechanical axis of the medial column and, therefore, correction of the deformity. Using mechanical axis planning, the surgeon can determine the amount of angular and translational correction necessary for the surgical procedure of their choice.

Materials and Methods

We performed a retrospective radiographic review of 100 feet with HAV deformity (deformity group) who had undergone surgical correction for this deformity and 100 feet without HAV deformity (control group). The selection of 100 control and 100 deformity participants was used to provide a large enough sample size to allow for an adequate comparison across the patient groups. We aimed to show that in both the deformity group and the control group, the mechanical axis angle was the same, irrespective of the measured M1-M2 anatomic axis angle (intermetatarsal angle). We did not seek institutional review board approval for the present study.

Control Group

From January 2007 through December 2013, patients with normal dorsal-plantar radiograph findings were consecutively enrolled in our study (beginning with the most recently seen, December 2013) until 100 patients had met the inclusion criteria, without meeting the exclusion criteria, were identified. The patients were selected if they had either an *International Classification of Diseases,* 9th revision (ICD9), code of 728.71 (plantar fasciitis) or an ICD9 code of 825.20 (closed fracture, unspecified bone, foot, except toes) and did not have an ICD9 code of 735.0 (hallux valgus deformity). The patients were selected from a single practice (LaPorta and Associates) and were seen by 1 of 3 associate physicians (G.L., M.M., D.K.). The inclusion criteria for the study were age older than 16 years at the time of the radiograph and an M1-M2 anatomic axis angle that was $\leq 10^{\circ}$. The patients were excluded from the study if they had undergone previous HAV surgery, had open epiphyseal plates, or if they had an M1-M2 anatomic axis angle $\geq 11^{\circ}$. A total of 83 patients (100 feet) were identified for enrollment.

Deformity Group

From January 2003 through December 2013, patients with an ICD9 code of 735.0 (hallux valgus deformity) and who had undergone HAV surgical correction with a preoperative dorsal-plantar radiograph were consecutively enrolled in our study (beginning with the most recently seen, December 2013) until 100 patients had met the inclusion criteria, without meeting the exclusion criteria, were identified. The patients were selected from a single practice (LaPorta and Associates) and underwent surgical correction performed by 2 of 3 associate physicians (G.L., M.M.). Intervention included first metatarsal osteotomy or Lapidus arthrodesis, with the procedure type determined by surgeon preference and the degree of deformity. The inclusion criteria were age older than 16 years at time surgical intervention for HAV correction. They were excluded from the study if they had undergone previous HAV surgery or had undergone surgical correction of either metatarsus adductus or midfoot/hindfoot reconstruction concurrently with HAV correction. A total of 95 patients (100 feet) were identified for enrollment.

Radiographic Evaluation

Measurements were performed by a single assessor for both groups (J.M.). The assessor had participated in the care of some of the patients, before their enrollment into the present study. The assessor was not blinded. All radiographic evaluations were digitally measured using TraumaCad® software (Voyant Health™, BrainLab Company, West Chester, IL). The measured values for each radiograph were recorded and included the M1-M2 anatomic axis angle and M1-M2 mechanical axis angle. During the subjective measurement of the radiographic angles, no ties or indecision in the measurements were encountered.

Statistical Analysis

The measurements of the M1-M2 anatomic axis angle and M1-M2 mechanical axis angle were analyzed in terms of the mean $\pm$ standard deviation, median and range (minimum to maximum), and 95% confidence intervals. The differences in these angles between the deformity and control groups were computed, using the Wilcoxon rank sum (Mann-Whitney *U*) test, and chi-square tests and logistic regression analysis were used to determine whether any statistically significant associations were present between the independent variables and the outcomes of interest (i.e., the normal M1-M2 anatomic axis angle and M1-M2 mechanical axis angle). Statistical significance was defined at the 5% ($p \leq .05$) level.

Analyzed Variables

1. *Patient*: Patient unique identification number, continuous numeric; 1,2,3,…n
2. *Surgeon*: Surgeon of record, categorical (binary); 1 = G.A.L., 2 = M.M., 3 = D.K.

Fig. 3. (*A*) Line EA represents the mechanical axis of the medial column. (*B*) The angle formed by the bisection of the mechanical axis of the medial column and second column (AEC) is 11°.

3. *Age*: Patient age, actual to nearest whole year, continuous numeric
4. *Sex*: Patient gender, categorical (binary); 0 = female, 1 = male
5. *Side*: Side involved (measured), categorical (binary); 0 = left, 1 = right
6. *Bilateral*: Whether the patient had both right and left feet measured, categorical (binary); 0 = no, 1 = yes
7. *Anatomic axis*: M1-M2 anatomic axis (mid-diaphyseal line) *of the first metatarsal*, measured in degrees (°), continuous numeric, actual to nearest degree
8. *Mechanical axis*: M1-M2 mechanical axis of the medial column and first ray, measured in degrees (°), continuous numeric, actual to nearest degree
9. *Difference*: Difference between the M1-M2 mechanical axis and M1-M2 anatomic axis angles, determined by subtracting the M1-M2 anatomic axis angle from the M1-M2 mechanical axis angle (°)
10. *Group*: Group in which the patient was included, categorical (binary) 0 = deformity, 1 = control (clarification: participants in the control group presented for)
11. *Normal*: 0 = mechanical axis >11°, 1 = mechanical axis ≤11°
12. *M1-M2 anatomic axis angle normal, 8°*: 0 = M1-M2 anatomic axis angle >8°, 1 = M1-M2 anatomic axis angle ≤8°
13. *M1-M2 anatomic axis angle normal, 10°*: 0 = M1-M2 anatomic axis angle >10°, 1 = M1-M2 anatomic axis angle ≤10°

Results

A statistical description of the results is given in the Table. The analysis showed the age in the deformity group was 49.07 ± 17.31 (median 53, range 16 to 83, 95% confidence interval [CI] 45.64 to 42.51) years. The age in the control group was 49.09 ± 16.16 (median 48, range 19 to 89, 95% CI 45.88 to 52.3) years in the control group. This difference was not statistically significant ($p = .5665$). Of the 100 feet in the deformity group, 87 (87%) belonged to females. In contrast, 61 (61%) of the feet in the control group belonged to females. This difference was statistically significant ($p = .0001$). Fifty-one of the feet (51%) in the deformity group were on the right and 56 (56%) of those in the control group were on the right. This difference was not statistically significant ($p = .478$). Five of the patients (5.26%) in the deformity group and 17 (20.48%) of those in the control group had bilateral foot involvement, and this difference was statistically significant ($p < .0001$). Eighty-eight (88%) of the feet in the deformity group were treated by surgeon 1, 12 (12%) by surgeon 2, and none by surgeon 3. In the control group, 67 (67%) of the feet were treated by surgeon 1, 17 (17%) by surgeon 2, and 16 (16%) by surgeon 3; these differences were statistically significant ($p = .0001$). The analysis also revealed that the M1-M2 anatomic axis angle was 13.5° ± 2.83° (median 13°, range 6° to 22°, 95% CI 12.94° to 14.06°) in the deformity group and 7.5° ± 1.76° (median 8°, range 2° to 10°, 95% CI 7.15° to 7.85°) in the control group, and this difference was statistically significant ($p < .0001$). Moreover, the analysis revealed the mean M1-M2 mechanical axis angle was 11.58° ± 1° (median 11°, range 9° to 17°, 95% CI 11.38° to 11.78°) in the deformity group and 11.19° ± 0.9°

Fig. 4. Dorsal-plantar foot radiograph in a hallux valgus deformity. The mechanical axis of the first ray is no longer colinear with the mechanical axis of the medial column. The angle formed by the mechanical axis of the first ray and the mechanical axis of the medial column represents the amount of deformity present (ADB).

Fig. 6. Dorsal-plantar radiograph of a hallux valgus foot with metatarsus adductus. Note that the mechanical axis of the medial column does not pass through the dorsal lateral proximal corner of the medial cuneiform. The intersection of the mechanical axis of the first ray (line DB) and the mechanical axis of the medial column (EA) forms an angle of 3°. This is the amount of correction necessary for axis restoration.

(median 11°, range 9° to 13°, 95% CI 11.01° to 11.37°) in the control group. This difference was statistically significant (p = .0047). Furthermore, the analysis revealed that the difference between the M1-M2 mechanical axis and the M1-M2 anatomic axis angle was −1.92° ± 2.58° (median −2°, range −8° to 4°, 95% CI −2.43° to −1.41°) in the deformity group and 3.69° ± 1.61° (median 3°, range 0° to 8°, 95% CI 3.37° to 4.01°) in the control group, and this difference was statistically significant ($p < .0001$). Still further, a statistical comparison (paired Student's t test) of the M1-M2 anatomic axis angle to the M1-M2 mechanical axis angle between the deformity and control groups showed the differences to be statistically significant ($p < .0001$). The M1-M2 anatomic axis angle (mean 13.5°, 95% CI 12.94° to 14.06°) was significantly greater statistically than the M1-M2 mechanical axis angle (mean 11.58°, 95% CI 11.38° to 11.78°; $p < .0001$) in the deformity group. In contrast, in the control group, the M1-M2 anatomic axis angle (mean 7.5°, 95% CI 7.15° to 7.85°) was significantly smaller statistically than the M1-M2 mechanical axis angle (mean 11.19°, 95% CI 11.0° to 11.37°; $p < .0001$).

Defining the normal M1-M2 mechanical axis angle as ≤11° and making this the dependent (outcome) variable, the logistic regression models failed to reveal any statistically significant association with the outcome, with the exception of a lower M1-M2 anatomic axis angle (odds ratio 0.8209, 95% CI 0.7539 to 0.8939, $p < .0001$).

Deformity Planning Formula

Angular Correction = angle ABD

Translation = distance between lines DB and EA at level of planned osteotomy or fusion

Fig. 5. Formula to determine the amount of angulation and translation necessary to achieve reduction of the hallux abducto valgus deformity at the level of the planned osteotomy or fusion procedure. See text for details.

Discussion

The analyses revealed the normal M1-M2 mechanical axis angle to be 11.19° ± 0.9° (95% CI 11.01° to 11.37°). In the deformity group, the

Table
Statistical comparison of patients with and without HAV deformity (N = 200 feet in 178 patients)

Variable	Deformity Group (n = 100 feet in 95 patients)	Control Group (n = 100 feet in 83 patients)	*p* Value*
Age (y)			.5665
Mean ± SD	49.07 ± 17.31	49.09 ± 16.16	
95% CI	45.64 to 42.51	45.88 to 52.3	
Median (range)	53 (16 to 83)	48 (19 to 89)	
Female sex	87 (87)	61 (61)	<.0001
Right side	51 (51)	56 (56)	.478
Bilateral (patient)	5 (5.26)	17 (20.48)	<.0001
Surgeon			.0001
1	88 (88)	67 (67)	
2	12 (12)	17 (17)	
3	0	16 (16)	
M1-M2 anatomic axis angle (°)			<.0001
Mean ± SD	13.5 ± 2.83	7.5 ± 1.76	
95% CI	12.94 to 14.06	7.15 to 7.85	
Median (range)	13 (6 to 22)	8 (2 to 10)	
M1-M2 mechanical axis angle (°)			.0047
Mean ± SD	11.58 ± 1	11.19 ± 0.9	
95% CI	11.38 to 11.78	11.01 to 11.37	
Median (range)	11 (9 to 17)	11 (9 to 13)	
Difference† between mechanical and anatomic axes (°)			<.0001
Mean ± SD	−1.92 ± 2.58	3.69 ± 1.61	
95% CI	−2.43 to −1.41	3.37 to 4.01	
Median (range)	−2 (−8 to 4)	3 (0 to 8)	

Abbreviations: CI, confidence interval; SD, standard deviation.
Continuous numeric data presented as mean ± SD, 95% CI, and median (minimum to maximum) and categorical data as n (%).
* Wilcoxon rank sum test for continuous numeric variables or chi-square or Kruskal-Wallis test for categorical data.
† Mechanical axis minus anatomic axis.

M1-M2 mechanical axis angle was 11.58° ± 1° (95% CI 11.38° to 11.78°; $p = .0047$). The statistically significant differences observed in regard to female sex, bilateral cases, and treating surgeon, we believe, were related to biases associated with our practice and the common finding that bunion deformities are more often symptomatic in females than in males (and this could be related to shoe gear). Also, we do not believe it is likely that these variables are strongly associated with whether the M1-M1 mechanical axis angle is ≤11°. The lack of a statistically significant association of age and side of involvement with the deformity or control groups was not surprising, because the patients in both groups were enrolled consecutively, thus reflecting the common age of the patients in our practice and a balance in the side of involvement.

It was interesting to observe that the M1-M2 anatomic axis angle was significantly greater statistically than the M1-M2 mechanical axis angle in the deformity group (mean 13.5°, 95% CI 12.94° to 14.06° versus 11.58°, 95% CI 11.38° to 11.78°, respectively; $p < .0001$). However, in the control group, the difference was smaller (mean 7.5°, 95% CI 7.15° to 7.85° versus 11.19°, 95% CI 11.0° to 11.37°, respectively; $p < .0001$). The angles outlined were influenced by the presence of hypermobility or instability of the first ray. Hypermobility of the first ray is a common etiology of HAV deformity, with the HAV M1-M2 mechanical axis angle measurements demonstrating higher values than the normal foot measurements.

We advocate the importance of the preoperative radiographic assessment combined with the clinical assessment, patient complaints, and postoperative goals. We routinely perform weightbearing dorsal-plantar and lateral foot radiographs and sesamoid axial views to assess the rotation of the metatarsal. Although debate exists in the published data regarding the need for weightbearing films for preoperative assessment (10,11), we believe that weightbearing radiographic assessment is paramount in deformity planning and therefore perform all preoperative radiographs with weightbearing in angle and base of gait.

We use digital radiographs in the clinic and hospital setting both and perform digital angular assessments on all our patients using the radiographic studies. We believe that digital radiographic deformity planning is a more convenient and reliable method than manual planning. Srivastava et al (12) substantiated the theory that the use of computer-assisted radiographic measurements results in a lower technical error than manual measurements.

Many investigators have described preoperative radiographic planning methods for HAV deformity correction. Piqué-Vidal (13) and Piqué-Vidal and Vila (14) attempted to summarize multiple angular radiographic measurements into a single radiographic point using the first metatarsophalangeal arc circumference. Although they found a direct correlation between the location of the arc's center and the magnitude of the radiographic measurements, this method does not assess the amount of correction desired with a given surgical procedure.

Mashima et al (15) attempted to create a method of HAV deformity planning using the CORA method. They measured the intermetatarsal angle and hallux valgus angle on 64 normal feet and described $CORA_1$ and $CORA_2$ as the intersection of the axes of the first metatarsal and the first proximal phalanx in the normal and HAV models, respectively. The investigators determined that in the normal foot, point A (intersection of the intermetatarsal angle) was 2.3 times the length of the second metatarsal proximally from the second metatarsal head. They determined that in a normal foot, point B (intersection of the hallux valgus angle) was 0.17 time the length of the first metatarsal proximally from the top of the first metatarsal head. Using these normal values, the investigators plotted lines during preoperative deformity planning to determine the CORA and assess the amount of correction necessary. They then performed a focal dome osteotomy at the $CORA_1$ or a medial wedge osteotomy at the $CORA_2$ for correction of the deformity. Using Paley's osteotomy rules, the investigators translated the distal fragment when the osteotomy was not performed at CORA.

We appreciate that the investigators attempted to use a CORA deformity planning method for HAV. We agree with and applaud their diligence to Paley's osteotomy rules, and their attention to the need for both angulation and translation when the osteotomy is not performed at the CORA. However, we disagree with their method of obtaining the CORA. We believe that the CORA, regardless of mechanical or anatomic axis planning, lies in the proximal tarsus, at the level of intersection of the first and second metatarsal anatomic or mechanical axes. We also argue that no bunion procedure exists to correct the deformity at the CORA; therefore, a combination of both angulation and translation is always necessary. We believe that our mechanical axis planning method provides a more accurate and simplistic description of determining both the CORA and the amount of angulation and translation necessary to correct the deformity.

Our method of mechanical axis deformity planning assesses only the transverse plane deformity. In a subsequent study, we will review frontal and sagittal plane mechanical axis HAV deformity correction. We advocate the use of sesamoid axial views for all patients with an HAV deformity to assess rotation of the metatarsal. If present, we correct this rotation at surgical intervention with the appropriate osteotomy or arthrodesis. We assess the lateral view first ray position and correct the sagittal plane deformity at surgical intervention.

Just as with all retrospective investigations, our study was limited by our ability to analyze a number of clinical variables that reasonable foot surgeons would likely consider to be clinically important, including pain, foot-related quality of life, symptom duration, and so forth. We are also aware of the potential biases related to the diagnosis and procedure coding that could have influenced our search for potentially eligible patients and controls. Nonetheless, our aim was to use the radiographic findings to point out the differences in the anatomic and mechanical axis angles, to relate these in terms of osteotomy rules to the surgical correction of HAV deformity, and to define these in terms of estimates of the central tendency (average) and dispersion (standard deviation and range) angles for patients with a symptomatic bunion deformity and those without a symptomatic bunion. The radiographs alone were measured; the clinical and biomechanical examination findings were not taken into account with our evaluation. We also did not correlate our results with patient satisfaction, procedure choice, or outcomes. The patients in the deformity group all underwent surgical correction for HAV deformity; however, the type of procedure was not evaluated. Our sample size was small for a retrospective radiographic review, and the physician evaluating the radiographs was involved in the patients' care.

Our goal in the present report was to provide foot and ankle surgeons with a simple and accurate method to determine the amount of HAV correction necessary with the osteotomy or fusion procedure of their choice. By aligning the mechanical axis of the first ray to the "normal" mechanical axis of the medial column (M1-M2 mechanical axis angle of 11º), the surgeon will reduce the HAV deformity. Using this method in preoperative planning, the surgeon can assess the amount of translation and angulation necessary for reduction of the deformity in the transverse plane.

In conclusion, the normal M1-M2 mechanical axis angle we observed was $11.19^\circ \pm 0.9^\circ$ (95% CI 11.01° to 11.37°). In contrast, in the deformity group, it was $11.58^\circ \pm 1^\circ$ (95% CI 11.38° to 11.78°); the observed difference between the 2 groups was statistically significant ($p = .0047$). Interestingly, the M1-M2 anatomic axis angle (mean 13.5°, 95% CI 12.94° to 14.06°) was significantly greater statistically than the M1-M2 mechanical axis angle (mean 11.58°, 95% CI 11.38° to 11.78°; $p < .0001$) in the deformity group. In contrast, in the control group, the M1-M2 anatomic axis angle (mean 7.5°, 95% CI 7.15° to 7.85°) was significantly smaller statistically than the M1-M2 mechanical axis angle (mean 11.19°, 95% CI 11.0° to 11.37°; $p < .0001$). We realize that additional clinical research is required to determine the usefulness of the M1-M2 mechanical axis angle as it relates to the subjective patient outcomes related to HAV surgery. We believe that the results of this investigation could be useful in regard to the development of future prospective cohort studies and randomized controlled trials that focus on the diagnosis and treatment of HAV.

References

1. Coughlin MJ, Mann RA. *Hallux Valgus*, ed. 8, vol. 1, pp. 207–208, Mosby Elsevier, Philadelphia, 2007.
2. Myerson MS. *Hallux Valgus*, vol. 1, pp. 222–224, WB Saunders, Philadelphia, 2000.
3. Vanore JV, Christensen JC, Kravitz SR, Schuberth JM, Thomas JL, Weil LS, Zlotoff HJ, Couture SD. Diagnosis and treatment of first metatarsophalangeal joint disorders. Section 1: hallux valgus. J Foot Ankle Surg 42:112–123, 2003.
4. Jahss MH. *Disorders of the Hallux and First Ray*, ed. 2, vol. 2, pp. 994–997, WB Saunders, Philadelphia, 1991.
5. Landers P. *Introduction and Evaluation of Hallux Abducto Valgus*, ed. 2, vol. 1, pp. 464–467, Williams & Wilkins, Baltimore, 1992.
6. Chhaya SA, Brawner M, Hobbs P, Chhaya N, Garcia G, Loredo R. Understanding hallux valgus deformity: what the surgeon wants to know from the conventional radiograph. Curr Probl Diagn Radiol 37:127–137, 2008.
7. Paley D. *Principles of Deformity Correction*, Springer, Berlin, Germany, 2005.
8. Lamm BM, Paley DP. Deformity correction planning for hindfoot, ankle, and lower limb. Clin Podiatr Med Surg 21:305–326, 2004.
9. Darwoodi A, Perera A. Reliability of metatarsus adductus angle and correlation with hallux valgus. Foot Ankle Surg 18:180–186, 2012.
10. Burg A, Hadash O, Tytiun Y, Moshe S, Dudkiewicz I. Do weight-bearing films affect decision making in hallux valgus surgery? J Foot Ankle Surg 51:293–295, 2012.
11. Tanaka Y, Takakura Y, Takaoka T, Akiyama K, Fugii T, Tamai S. Radiographic analysis of hallux valgus in women on weightbearing and nonweightbearing. Clin Orthop Relat Res 336:186–194, 1997.
12. Srivastava S, Chockalingam N, Fakhri TW. Radiographic angles in hallux valgus: comparison between manual and computer assisted measurements. J Foot Ankle Surg 49:523–528, 2010.
13. Piqué-Vidal C. The first metatarsophalangeal arc circumference: correlation with angular measurements. Foot Ankle Int 28:186–193, 2007.
14. Piqué-Vidal C, Vila J. A geometric analysis of hallux valgus: correlation with clinical assessment of severity. J Foot Ankle Res 2:15, 2009.
15. Mashima N, Yamamoto H, Tsuboi I, Tsuchiya H, Tanaka Y, Watanabe S. Correction of hallux valgus deformity using the center of rotation of angulation method. J Orthop Sci 14:377–384, 2009.