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Hallux Pronation in Hallux Valgus: Experimental and Radiographic Study

Mercedes Gómez Galván, PhD, MD[1], JA Constantino, PhD, MD[1,2], María José Bernáldez, MD[1], Manuel Quiles, PhD, MD[1,2,3]

[1] Surgeon, Infanta Cristina University Hospital, Badajoz, Spain
[2] Professor, Infanta Cristina University Hospital, Badajoz, Spain
[3] Head of Orthopedic Surgery, Infanta Cristina University Hospital, Badajoz, Spain

A R T I C L E I N F O

Level of Clinical Evidence: A

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A B S T R A C T

Toe pronation is a frequent sign in hallux valgus (HV), but it is difficult to assess and quantify. The aim of this study was to evaluate the relation between big toe pronation with both radiological and clinical findings and to determine if toe pronation is an influential factor in severity of HV. Six big toe donor proximal phalanges were used to create a radiographic calibrating system controlling their pronation at 0° to 60°. A linear regression model was used to predict proximal phalanx pronation in radiographs. Big toe pronation in HV was clinically evaluated with a prospective study using 132 patients from our surgical waiting list and a control group of 30 patients without HV. Patients standing barefoot on a rigid platform were used to obtain the nail–floor angle. We obtained the following angles: HV, intermetatarsal, interphalangeal, distal articular set angle, proximal articular set angle, first metatarsal pronation, proximal phalanx pronation, and sesamoid bones displacement. We obtained an equation to predict proximal phalanx pronation according to the proportion of the rotated phalanx ($p < .001$, $r = 0.98$), and used an intraclass reliability test to assess the intra-/interobserver reliability ($p < .001$, intraclass correlation [ICC] = 0.89/$p < .001$, ICC = 0.82). We found that the relation between HV severity and proximal phalanx pronation, nail–floor angle, and first metatarsal pronation was statistically significant ($p < .0001$, $r = 0.64$). Proximal phalanx pronation and nail–floor angle should be considered to classify the severity of HV. Using a mathematical formula, we can predict proximal phalanx pronation on radiographs.
Clinical Level of Evidence:

Hallux valgus (HV) is one of the most common foot and musculoskeletal deformities. This deformity is usually defined by a progressive first metatarsophalangeal joint (MTP) subluxation. There is, occasionally, a static deformity as a result of the valgus angulation in the distal articular surface in the first metatarsal and the proximal phalanx. For many years, there have been concerns about treating this as a tridimensional deformity, as skeletal patterns and radiological studies on pronation and rotation of the first ray in HV have been developed (1).

Foot eversion implies longitudinal rotation in the first ray (metatarsal and phalanges) that locates the axis of the first MTP joint on an oblique plane with the floor. In this position, feet seem less able to resist the deforming forces applied on them by footwear or body weight (2).

Eustace et al (3) focused on the frontal plane of HV deformity. In their study, they designed a method to measure the pronation of the first metatarsal based on the observation of the location of the inferior proximal tuberosity of the first metatarsal base. They found that, as intermetatarsal angles (IMAs) increase, the first metatarsal pronation does so as well. It is believed that the degree of the big toe rotation could partially predict the severity of HV. However, big toe rotation has never been included in HV severity classification measurements.

The main aims of this study were (1) to design an experimental model to predict in a viable and reproducible way the radiological pronation of the first phalanx of the big toe and (2) to determine if toe pronation is an influential factor in severity of HV.

Patients and Methods

Our clinical study consisted of 132 adult patients on the surgical waiting list for HV from January to December 2015. The exclusion criteria were pregnancy, rheumatoid arthritis, previous surgery on the affected foot, and nail alteration that did not allow the measurement of the nail–floor angle. In cases of bilateral HV, only the more symptomatic foot was included. Previous spoken and written informed consents were obtained. We collected social and demographic data from these patients.

The nail–floor angle was obtained with patients standing barefoot on a rigid platform so that the nail of the big toe was on the same plane as the free edge of the platform. Five photographs were taken from the front of the foot. A line was drawn on the free edge of the platform and another one using the secant of the toenail edge, using their junction to

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Address correspondence to: Mercedes Gómez Galván, PhD, MD, Infanta Cristina University Hospital, Avenue Adolfo Suarez number 18, 1° C, 06007 Badajoz, Badajoz, Spain.
E-mail address: mercedes.gomez.galvan@gmail.com (M. Gómez Galván).

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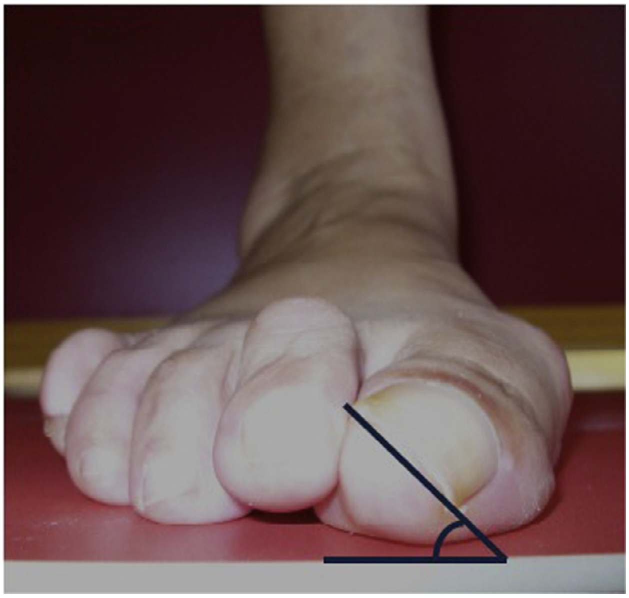

Fig. 1. HV deformity on right foot: frontal view to obtain nail–floor angle (first toe pronation).

form an angle. The mean value of the angles measured on the 5 photographs of each foot was used (Fig. 1).

All of the patients were evaluated with the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot-ankle score (4). We also obtained the following measurements on the foot standing radiographs: HV angle, IMA, interphalangeal angle, proximal articular set angle (PASA), distal articular set angle (DASA), proximal phalanx pronation, first metatarsal pronation (Eustace et al technique [3]), and sesamoid bones displacement (Hardy and Clapham technique [5]). Patients were classified according to the severity of HV as mild, moderate, or severe deformity according to the values obtained from HV angle, IMA, and subluxation of the lateral sesamoid bone, assessed in an anteroposterior radiograph.

An experimental method was designed to measure the proximal phalanx rotation on radiographs. In agreement with the Hospital Infanta Cristina Bioethics Committee, 6 donor proximal phalanges from the big toes were taken, 3 from right feet and 3 from left feet. The authors used a platform obtained from wooden blocks from a construction game for children, a rectangular piece of wood of 6 × 3 × 3 cm whose upper part had a concavity that allowed rotation in the medial-lateral direction of a second convex wooden piece of 4 × 2 × 3 cm, with a flat surface on its top. We designed a calibrated measuring system with a goniometer, scoring from 0° to 90°. The phalanx remained fixed on the flat surface of the convex piece, the mobile one, allowing rotation of 10° each time, secure and precisely. The author (M.G.G.) rotated it to the right or to the left depending on the right or the left foot phalanx being used (Fig. 2).

Phalanx radiographs were taken from 0° to 60° in increments of 10° in a Faxitron cabinet X-ray with these technique values: 83 kV, 3 mA/s, and 3 s (Fig. 3). To assess the proximal phalanx rotational degree of the big toe, the anatomical axis was drawn on a radiograph. Additionally, a parallel line to this anatomical axis was drawn, going through the deepest point of the intercondylar surface. Then, a perpendicular line to the axis was drawn, going through the widest part of the condyles. We named this line "line A." Line A was divided in 2 by the anatomical axis, naming "line B" the part of this line connecting the anatomical axis and the outer cortical. With these 2 measurements, we established the proportion B/A that would determine the radiological proportion of the rotated phalanx (Figs. 4 and 5).

This method was applied to the radiographs of our patients. To check the intraobserver reliability, 30 patients were chosen from our database by means of a simple random system using Excel (Microsoft Corporation, Redmond, WA). The author (M.G.G.) performed the same measurement 3 times (not in a continuous but rather in different ways) obtaining 3 values for each patient. In addition, to check the interobserver reliability, 3 orthopedic surgeons in our hospital were chosen randomly and were instructed to perform the same measurements. Thirty patients without forefoot pathology were also evaluated by this method as a control group. To perform the statistical analyses, we used a software package: SPSS for Windows (release 15.0; SPSS, Chicago, IL). The distribution of the scores for each variable was checked using Kolmogorov-Smirnov and Shapiro-Wilk tests. All p values <.05 indicated statistically significant differences between samples.

Results

Clinical Study

Of the 132 (N = 132) patients studied,15 (11.36%) were male and 117 (88.64%) were female. The mean age was 58 (range 18 to 81) years; 73 (55.30%) left and 59 (44.70%) right feet were studied. The median AOFAS hindfoot-ankle score was 37 (range 0 to 77) points. With measurements from the radiographs, we obtained the following data: mean (± SD) HV angle 36° ± 9.4°, IMA 13° ± 3.1°, interphalangeal angle 10° ± 6.5°, PASA 18° ± 8°, DASA 4° ± 3.5°, and nail–floor angle 28° ± 13.5°. The most frequent radiological amount of first metatarsal pronation was 10° (31%),

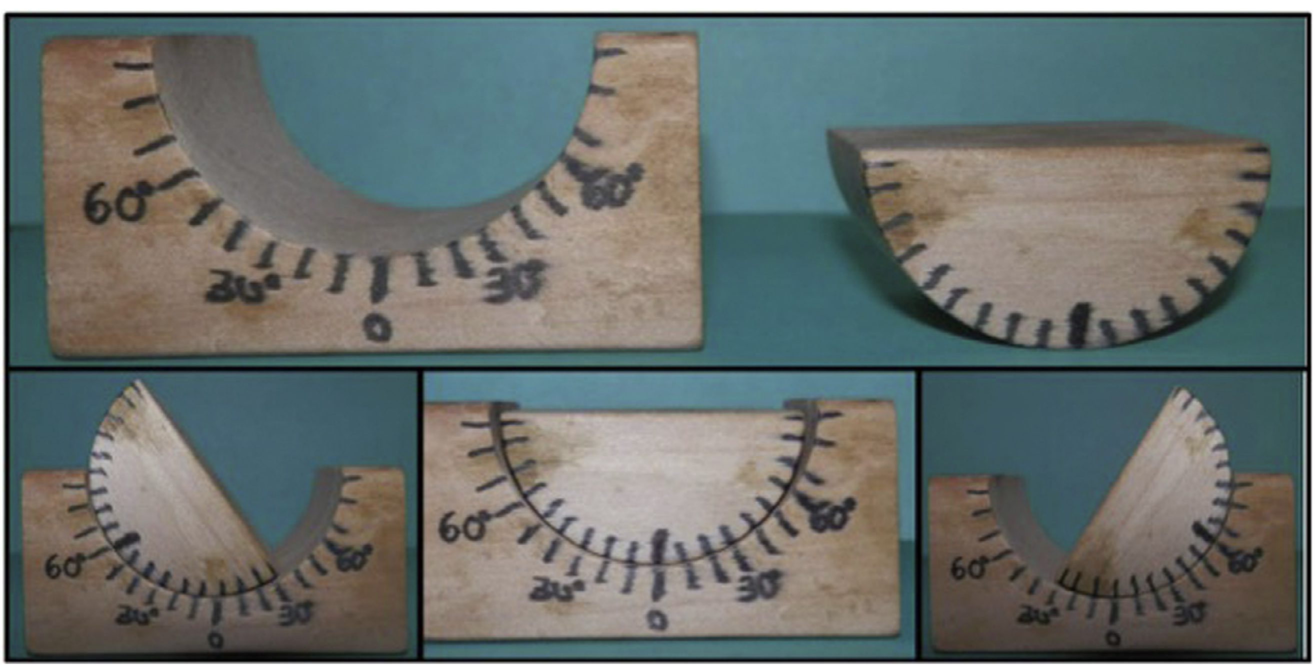

Fig. 2. Calibrated measuring system designed with wooden blocks.

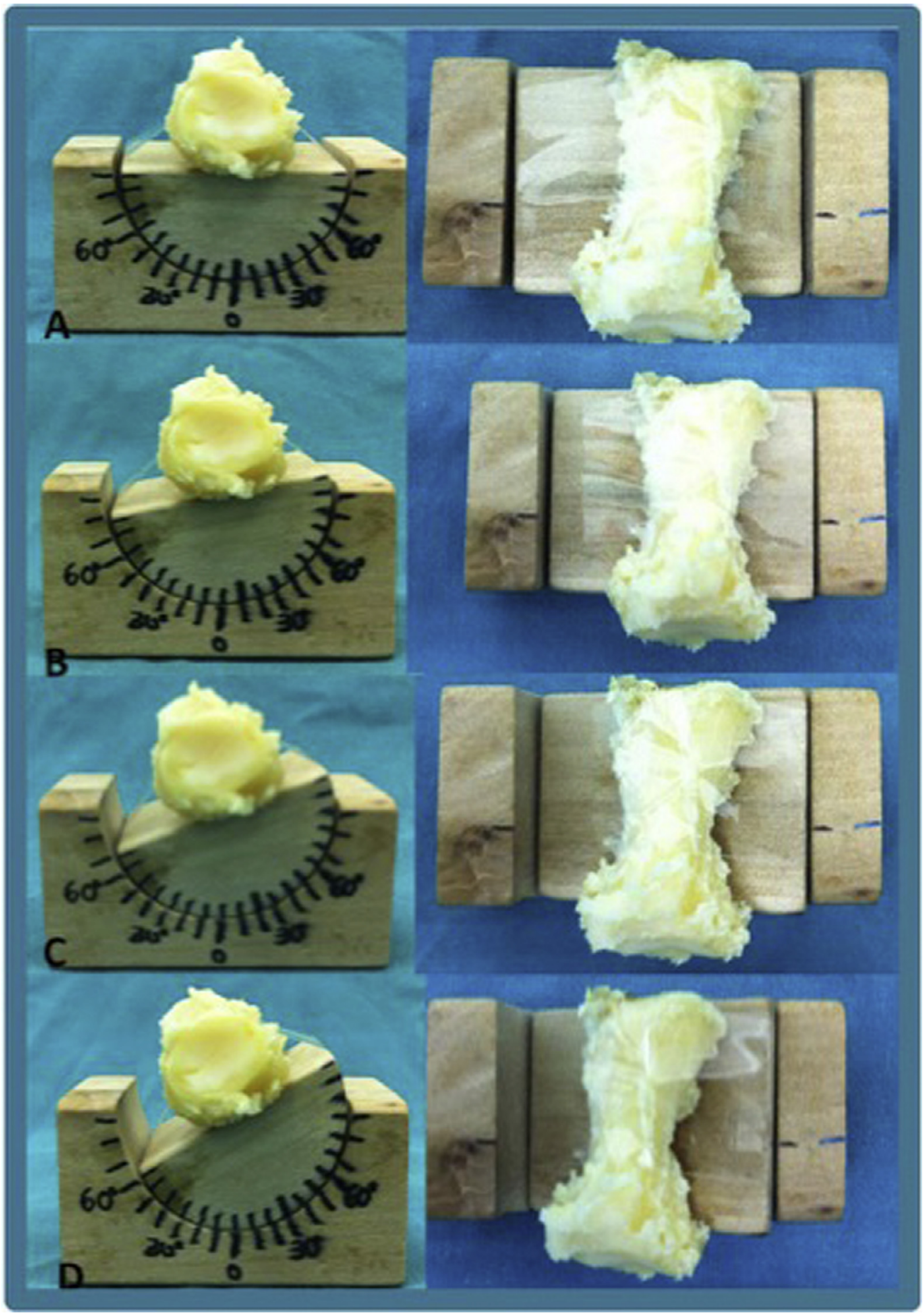

Fig. 3. Different rotational phalanx degrees in frontal (left) and superior (right) view. (*A*) 0° rotation. (*B*) 10° rotation. (*C*) 20° rotation. (*D*) 30° rotation.

followed by pronation of 20° (24.2%), 0° (18.2%), 15° (15.2%), 30° (9.1%), 25° (1.5%), and 5° (0.8%). The sesamoid bone displacement was characterized by a predominance of the types 5, 6, and 7 stages with percentages of 20.5%, 20.5%, and 46.2%, respectively.

Experimental Study

Six skeletal maps were created, showing the changes in the radiological aspect of the proximal phalanx of the big toe while increasing the rotation using a calibrating system (Fig. 6). According to the method established to find the radiological proportion of the rotated phalanx, values were obtained for each rotational degree detailed in Table 1. Linear regression was carried out to study the relation between the radiological proportion of the rotated phalanx and proximal phalanx pronation degree, obtaining a statistically significant relation in each one. The results are shown in Table 2. After performing an intraclass reliability test, we obtained intraclass correlation (ICC) = 0.91, alpha = 0.99, and $p = .0001$ for the right phalanges and ICC = 0.97,

Fig. 4. Radiological proportion of nonrotated phalanx. (*A*) Anatomic axis going through the widest part of the condyles. (*B*) Line A (white), perpendicular to the anatomic axis. (*C*) Line B (red), part of line A, connecting anatomic axis and the outer cortical.

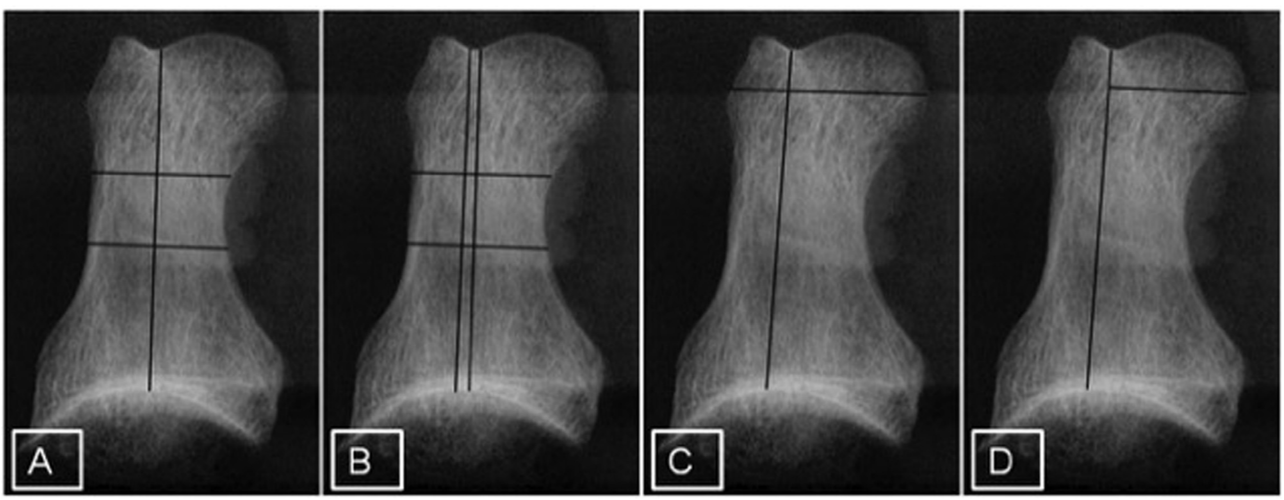

Fig. 5. Obtaining the radiological proportion of the proximal phalanx (right foot) with 50° rotation. (*A*) Drawing the anatomic axis. (*B*) Parallel line to the anatomic axis, going through the deepest point of the intercondylar surface. (*C*) Line A, going through the widest part of the condyles. (*D*) Line B, part of line A, connecting anatomic axis and the outer cortical.

alpha = 0.97, and $p = .0001$ for the left phalanges. A reliability test of the 6 phalanges obtained ICC = 0.97, alpha = 0.97, and $p = .0001$.

A formula was created to predict the proximal phalanx pronation using linear regression associating the right and left proximal phalangeal radiological rotation and the radiological proportion of the rotated phalanx in each of our 6 samples, obtaining a very statistically significant relation ($p = .001$) and the following equation:

$$\text{Proximal phalanx pronation} = 189.043 \times \text{rotated phalangeal radiological proportion} - 94.553.$$

This equation (predicting the proximal phalanx pronation according to the proportion of the rotated phalanx) was applied to the radiographs of our patients, obtaining a series of values for the proximal phalanx pronation. The mean result was 14° (range 0° to 44°).

An intraclass reliability test was carried out to assess the intraobserver reliability, which was statistically significant ($p = .001$, ICC = 0.89, alpha = 0.96). An intraclass reliability test was carried out to assess that the interobserver reliability was also statistically significant ($p = .001$, ICC = 0.82, alpha = 0.96).

Our control group had 30 patients (n = 30); 15 (50%) were male and 15 (50%) were female, with a mean age of 53 (range 22 to 85) years. We used 50% left and 50% right feet. We applied our formula to their radiographs, obtaining mean pronation of −1° (range −9° to 2°) with a mode of 0°. Student's *t* test was used to compare the mean values of proximal phalanx pronation in the control group and our HV study group, finding a statistically significant difference ($p = .0001$).

Pearson's correlation was used to study the relation between the following statistically significant variables: HV severity and proximal phalanx pronation, nail–floor angle, and first metatarsal pronation ($p = .0001$, $r = 0.64$); HV severity and proximal phalanx pronation ($p = .0001$, $r = 0.35$, 95% confidence interval [0.11 to 0.29]); sesamoid bones displacement and proximal phalanx pronation ($p = .001$, $r = 0.279$); IMA, proximal phalanx pronation, and first metatarsal pronation ($p = .001$, $r = 0.74$) (Fig. 7); HV severity and nail–floor angle ($p = .0001$, $r = 0.49$, 95% confidence interval [0.007 to 0.197]); and AOFAS scale score and HV severity ($p = .008$, $r = 0.23$). Between AOFAS scale score and proximal phalanx pronation, no statistically significant relation could be detected ($p = .4$, $r = 0.07$) nor between lesser toes deformities and HV severity ($p = .038$, $r = 0.18$).

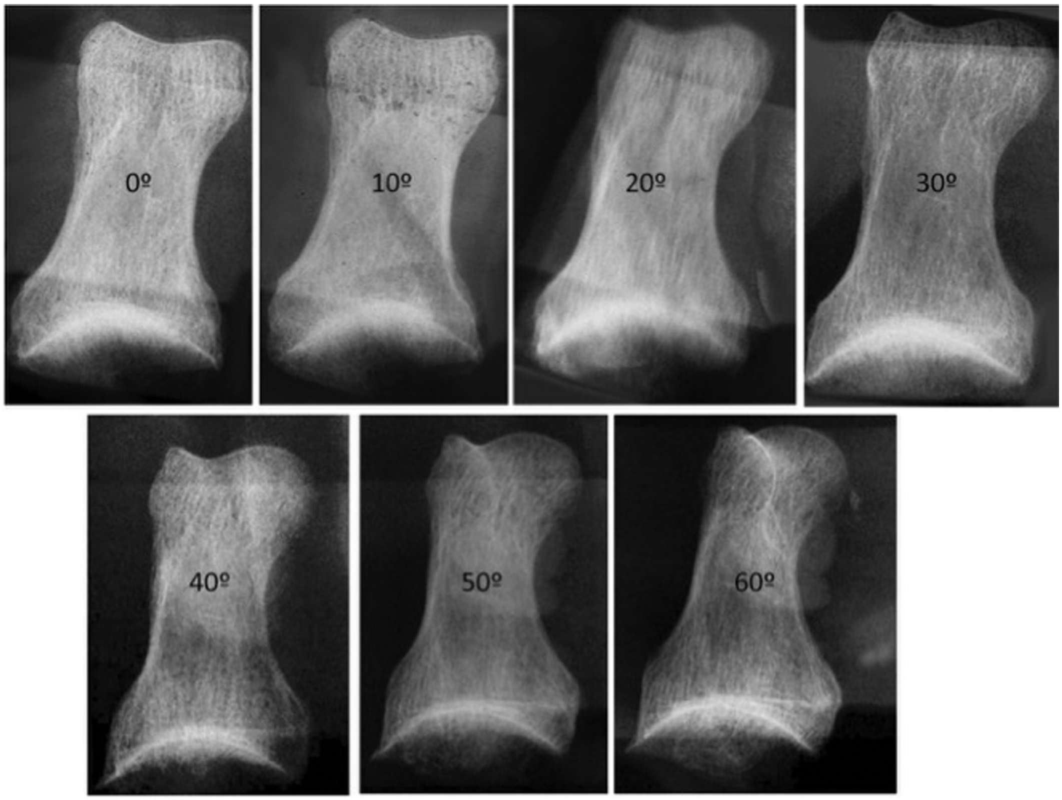

Fig. 6. Radiographs of 0° to 60° phalanx rotation.

Table 1
Results of rotation according to radiological proportion of the rotated phalanx and different rotational degrees

Proximal Phalanx Pronation	Radiological Proportion of the Rotated Phalanx					
	Right 1	Right 2	Right 3	Left 1	Left 2	Left 3
0°	0.5000	0.5833	0.5000	0.5000	0.5000	0.5000
10°	0.5476	0.6600	0.5400	0.5700	0.5400	0.5330
20°	0.6279	0.6800	0.6200	0.5950	0.5625	0.5810
30°	0.6744	0.7100	0.6400	0.7104	0.6380	0.6000
40°	0.6842	0.7500	0.7390	0.7500	0.7000	0.6900
50°	0.7142	0.7600	0.7500	0.7800	0.7500	0.7500
60°	0.7500	0.7700	0.7830	0.8300	0.8050	0.8000

Table 2
Correlation coefficients between proximal phalanges rotation and radiological proportion of the rotated phalanx

Proximal Phalanx	*p* Values	Coefficient (*r*) Values
Right 1	.002	0.96
Right 2	.001	0.96
Right 3	<.001	0.98
Left 1	<.001	0.98
Left 2	<.001	0.99
Left 3	<.001	0.98

Discussion

It is not convenient to ignore first ray pronation, because it can sometimes play a significant role in the development and progression of specific deformities in HV, as well as in its treatment. In some pronated feet, especially in patients with ligamentous laxity, the pressure applied on the medial capsule of the first MTP joint can lead to a deformity in HV, given that the weak parts that support the osseous structures are unable to contain these deforming forces. The pronation of the first toe is quite frequent in cases of severe deformities.

Big toe pronation occurs frequently in HV. It has not always been considered as a factor to be studied in this pathology, or it has been mentioned but not quantified because of technical difficulties in its measurement. In addition, to our knowledge, there are no studies on the normal pronation of the big toe, and no one has ever studied the proximal phalanx pronation with precision.

Eustace et al (3) described a method for detecting first metatarsal pronation on the basis of the movement of the inferior tuberosity of the base of 20 cadaveric first metatarsals at 0°, 10°, 20°, and 30° pronation. They concluded that pronation and varus deviation of the first metatarsal are linked ($r = 0.69$). We also found that the relation between the IMA and the proximal phalanx pronation, and that of the first metatarsal pronation and the proximal phalanx pronation, were statistically significant, with a correlation coefficient of $r = 0.74$.

Saltzman et al (6) designed a technique to determine the first metatarsal rotation by means of tangential radiographs of loadbearing axial feet, comparing them with the controlled rotation of the metatarsals in 15 cadaveric specimens. They concluded that the radiological measurement was viable and precise although with some limitations; but in their study they obtained a weak relation between the first metatarsal pronation and the HV angle.

Talbot and Saltzman (7) described a method for measuring hallucal rotation on weightbearing tangential radiographs, taking as reference the angle formed between the metallic platform and the line formed by the 2 points, the medial and lateral aspect of the lunula of each toenail marked with 2 metallic beadlets. Radiographs were taken at 0°, 10°, 20°, 30°, and 40° of hallucal pronation and 10° hallucal supination. They

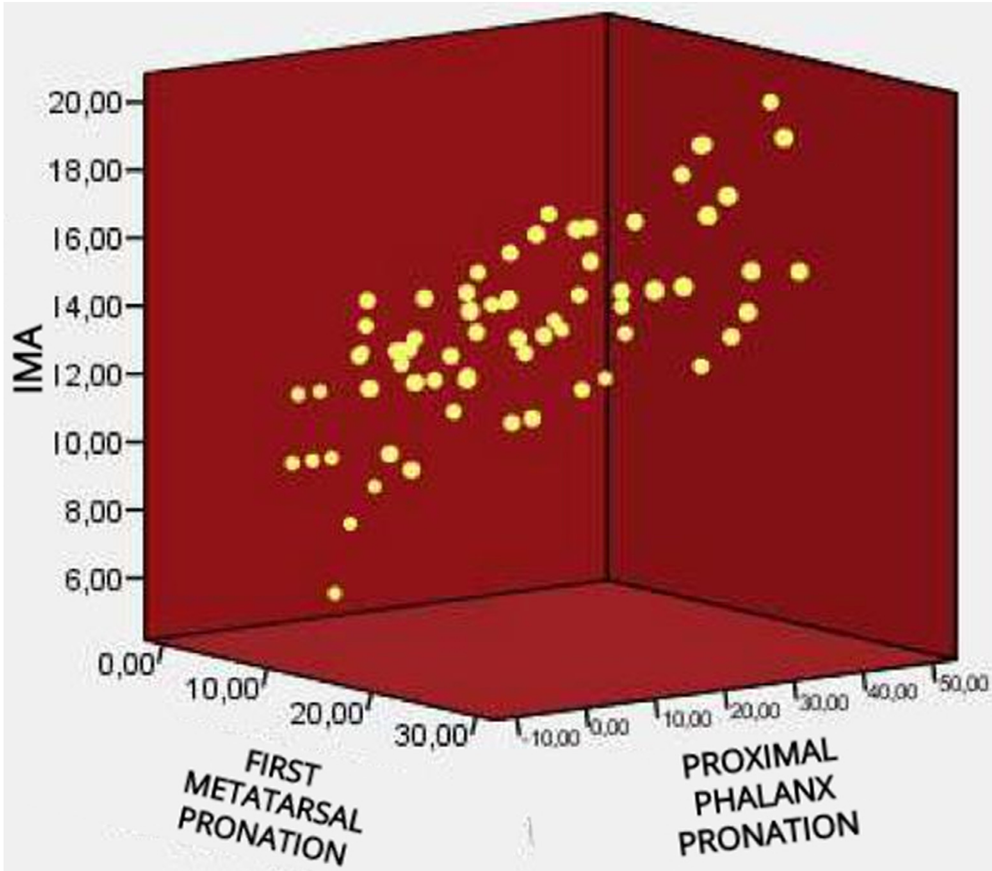

Fig. 7. Correlation between IMA, proximal phalanx pronation, and first metatarsal pronation.

concluded that patients with pain and deformity in the first metatarsal had higher values of hallucal rotation, although this rotation had a weak relation with the severity of HV angle.

We have studied the hallucal rotation with the radiological and the clinical method previously described. Our clinical method used photographs of the big toe taken on a frontal plane, obtaining an angle formed by the secant line of the toenail edge and the line formed by the platform edge. For the radiological method, we used cadaveric specimen phalanges to establish the proximal phalanx pronation. In addition, we studied the clinical-radiological relation in patients with HV. A statistically significant relation was obtained between HV severity and the nail−floor angle, with a correlation index $r = 0.49$, emphasizing a higher correlation between the HV angle and the nail−floor angle, with a correlation coefficient of $r = 0.56$.

Saltzman and Talbot (6,7) concluded that the standard method described by Hardy and Clapham (5) to classify the sesamoid bones displacement in the anteroposterior projection of the foot is not completely valid and agreed that they preferred the tangential or axial view. This conclusion was concordant with the results obtained in our study: although a statistically significant difference was found between the sesamoid bones displacement and the results obtained for the proximal phalanx and the first metatarsal pronation, the correlation coefficient was low, perhaps because sesamoid bones displacement classification includes discontinuous stages that are less precise.

Kuwano et al (8) explained that the position of the hallucal sesamoids was important in the evaluation of HV and a new weightbearing tangential radiograph was established by means of a specially designed tangential positioning device. A lead marker plate was placed on the depression to show the horizontal plane, and the sesamoid rotation angle (SRA) was measured. The SRA is the angle between the tangential line of the most inferior aspect of the medial and lateral sesamoids and the lead marker line. The SRA was compared with values of the 4-grade scale and 7-position scale, which were measured from the anteroposterior view, with respect to the HV angle, by conventional methods. They concluded that the scale of position of the sesamoid on the AP view was not valid in some cases, whereas the SRA was useful for assessing quantitatively the rotational position of the hallucal sesamoids in cases of HV (8).

Dayton et al (9), concerned about the first metatarsal rotation and its repercussions in HV pronation, performed a study with 5 cadaveric specimen feet to study the relation between first metatarsal rotation and the sesamoid bones displacement, IMA, HV angle, and PASA. In their study, they used a calibration system that marked the neutral position, 10°, 20°, and 30° of rotation in varus (inversion) and 10°, 20°, and 30° of rotation in valgus (eversion), concluding that there was a statistically significant relation between valgus rotation of the first metatarsal and IMA. They supported the hypothesis that frontal plane rotation of the first metatarsal is an integral component of HV pathologic features, specifically in relation to the sesamoid bones displacement and IMA. They also supported the hypothesis that the frontal plane rotation of the first metatarsal or “third plane of deformity” is an integral component of the HV deformity and a derotation must be carried out for a complete deformity correction (9).

Dayton et al (10) tried to propose a new paradigm that considered the frontal plane rotation of the first metatarsal as a priority to choose the most appropriate procedure for the correction of HV, revising previous publications to awaken the debate and encourage the performance of future investigations. They concluded that an effort must be carried out to conduct procedures that permit the complete control of the deformity on all the planes, including the frontal plane, and thereby, the capacity to anatomically align the joint (10). The rotational degree of the proximal phalanx and the nail–floor angle predict the HV severity, as they are both related.

One of the problems in our study was to find an exact anatomical structure in the proximal phalanx to be able to determine the rotation. Finally, we used the curvature in the distal part of the condyles as our reference, given that it is a constant and symmetric structure. The experimental study in cadaver phalanges allowed us to obtain a mathematical formula to predict the rotational degree of the proximal phalanx by means of an anteroposterior radiograph of the foot, finding statistically significant differences among the mean measurements obtained in the control and the HV group.

It must be pointed out that measurement of the nail–floor angle with the supporting plane is not always feasible given that some alterations of the nail can disallow its clear identification, a fact that could make the fulfillment of this technique impossible or could lead to mistakes in the measurements.

The HV severity does not take into account the first ray pronation, because, as previously discussed, it is very complex and has not been the subject of much interest until now. Therefore, it would be important to consider it, with the method that has been designed or with new methods that could be developed, as the importance of the rotation in surgical planning is reported in all the literature and is considered an important factor in HV recurrences. In this study, a statistically significant relation was found between HV severity and proximal phalanx pronation, nail–floor angle, and the first metatarsal pronation, with a correlation coefficient of $r = 0.644$.

A statistically significant relation was found between the AOFAS scale score and HV severity, but with a very low correlation coefficient. It has been impossible to prove that a statistically significant relation exists between the AOFAS hindfoot-ankle score and the proximal phalanx pronation, which may be because the aforementioned scale does not indirectly include any measurement of rotation (11). The examination of the published data and the findings of our study reveal the clear and consistent presence of the frontal plane rotation of the first ray as an integral part in HV deformity (12).

The main limitations of the present study included the lack of a control group of patients who had not undergone surgery (selection bias), lack of a sensitivity analysis (for the potential influence of an unmeasured variable on an outcome), use of discontinuous degrees in the calibrated measuring system, and the relatively small number of patients.

In conclusion, it is important to pay attention to this new paradigm of multiplanar deformity to improve the ability to analyze rotational deformity and plan correction.

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