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The Effect of Incorrect Foot Placement on the Accuracy of Radiographic Measurements of the Hallux Valgus and Inter-Metatarsal Angles for Treating Hallux Valgus

Vliv nesprávné polohy nohy na přesnost radiologického měření deformity a intermetatarzálních úhlů při léčení hallux valgus

M. ERDIL[1], E. KUYUCU[1], H. H. CEYLAN[2], S. SÜRÜCÜ[1], I. ERDIL[3], A. KARA[1], B. G GÜLENÇ[1], M. BÜLBÜL[1]

[1] Medipol University, Department of Orthopaedics and Traumatology, Istanbul, Turkey
[2] LNB State Hospital, Department of Orthopaedics and Traumatology, Istanbul, Turkey
[3] Bakirkoy Sadi Konuk Training and Research Hospital, Department of Radiology, Istanbul, Turkey

ABSTRACT

PURPOSE OF THE STUDY

Accurate radiographic measurements are crucial in treating hallux valgus (HV). This three-dimensional deformity should not be evaluated from one joint on one plane. However, in practice, surgeons measure the deformity only on transverse dorsoplantar radiographs. We determined the amount of error associated with positioning the foot incorrectly on radiographs.

MATERIAL AND METHODS

To simulate incorrect positions of the foot in radiographic evaluation, we designed an angled device that can move in transverse and frontal plane. In four patients with symptomatic HV, we took weight-bearing radiographs of the involved foot in seven different positions. These 28 radiographs were given identifying but meaningless labels. On each radiograph, six surgeons blinded to the position of the radiograph measured the HV angle (HVA) and the inter-metatarsal angle (IMA) and state the treatment plan according to five treatment options were given to participants.

RESULTS

Inter-observer agreement was high for measurements of HVA and IMA in all positions (interclass correlation coefficients, 0.96 and 0.88, respectively). However, intra-observer agreement was poor for HVA (intra-observer agreement, 0.17) but good for IMA (intra-observer agreement, 0.64). According to the measurements in different positions, intra-observer treatment choices revealed moderate results (ICC: 0.524).

Clinical Relevance

Radiographic measurements are very important on the treatment decisions of hallux valgus. The foot position can influence the measurement accuracy and can cause incorrect decisions. In this study, we evaluated the impact of foot positions on measurements of hallux valgus angle and inter-metatarsal angle. Additionally, we evaluated the incorrect foot positioning on treatment decisions. Moreover, we analyzed intra-observer and inter-observer agreements of these angles in various positions.

CONCLUSIONS

We recommend that measurements of IMA are more reliable than those of HVA for managing hallux valgus in terms of false weight bearing radiographs taken in different positions.

Positional changes during foot radiographs could lead clinicians to perform incorrect HVA and IMA measurements. This could change the treatment option. HVA measurements were more affected with foot positioning. It is important to take full weight bearing foot radiographs in correct technique.

Key words: hallux valgus, radiology, data accuracy.

INTRODUCTION

Hallux valgus (HV) is a common forefoot problem for which more than 130 surgical procedures have been proposed (2, 3, 5–7, 9, 11–19).

The severity of deformity is typically classified as mild, moderate, or severe on the basis of certain angles of the bones of the foot as measured on transverse dorsoplantar radiographs (1–7, 9, 11–19). However, hallux valgus is a complex deformity that should not be evaluated solely at one joint in one visual plane. Medial deviation of the first metatarsal, pronation of the big toe, and deformities on the phalangeal bone and interphalangeal joint are the components of this three-dimensional pathology (2). The most accurate measurements are made from weight bearing dorsoplantar foot radiographs (8, 15, 16).

Treatment decision of HV deformity is based on clinical examination and radiological evaluation. Weight bearing transverse dorsoplantar foot radiograph allows measuring the technique of weight bearing foot radiograph for the accurate measurement (8, 15, 16).

In this study, we determined the effect of incorrectly positioning the foot during radiography on measurements of the HV metatarsophalangeal angle (HVA) and first inter-metatarsal angle (IMA) that are crucial for determining treatment (2, 3, 6, 8, 15–17). We determined the reliability of these measurements in seven different positions and evaluated the correlations between these. We also aimed to impact the margin of error due to the wrong radiographic techniques on the treatment decision. Another purpose of this study was to evaluate the effect of false radiographs on measured angles and indications.

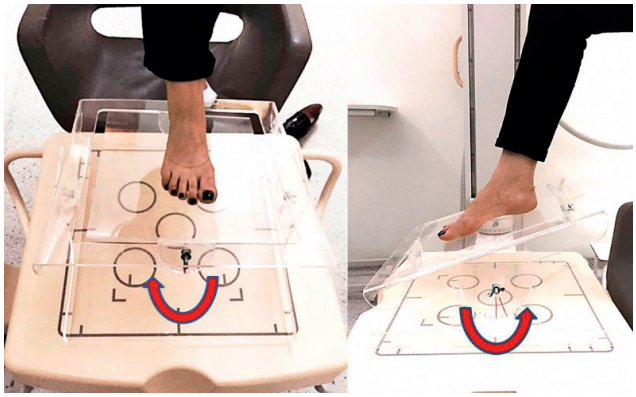

Fig. 1. Adjustable device that can move in the transverse and frontal planes to simulate the incorrect positioning of the foot on radiographic evaluation.

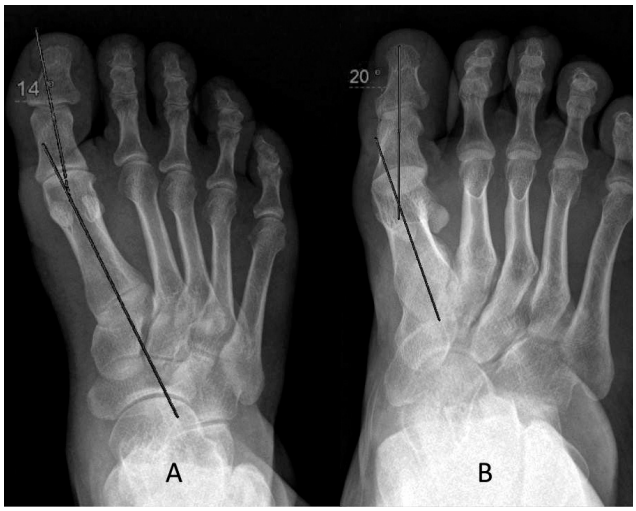

Fig. 2. The X-ray images of the figure 1 patients positions. a – incorrect position, b – neutral position.

MATERIAL AND METHODS

Ethics approval and consent to participate

The study was unanimously approved by the Medipol University Local Ethics Committee with the decision number 10840098-225 /09.09.2014. All patients provided written informed consent to participate in the study.

We conducted a prospective randomized study for intra-observer and inter-observer assessment of the HVA and IMA measurement and treatment decisions of six orthopedic surgeons with transverse dorsoplantar foot radiographs of various angles in various planes. To simulate the incorrect positioning of the foot on radiographic evaluation, we designed an adjustable device that can move in the transverse and frontal planes (Fig. 1–2).

The study group consists of 4 patients (1 male, 3 female) with a mean age of 36 (range, 28–45) years with a unilateral symptomatic HV deformity. All foot radiographs were taken using an X-ray machine (Discovery XR656 Plus; GE Healthcare, Hertfordshire, UK) at a source-to-image distance of 100 cm and were set to 50 kVp and 5 mAs with the patients standing. Radiographs were retrieved using a picture archiving and communication system (PACS) (IMPAX; Agfa Healthcare, Mortsel, Belgium). All radiographic measurements were performed digitally by this software.

We used the two most common radiographic measurements for evaluating HV severity, the hallux valgus and inter-metatarsal angles (2, 3, 5–7, 9, 11–19). The HVA is the angle between the longitudinal axis of the first metatarsal and that of the proximal phalanx on a dorsoplantar foot weight bearing radiograph (6). The IMA is the angle between the longitudinal axes of both the first and second metatarsals (6).

Preparing the radiographs

The foot was placed on the device with full weight bearing on the radiographic table. We then took radiographs with the involved foot in 7 positions. Position 1 was the correct, true neutral dorsoplantar position. We were not able to measure the loads of patients while they were standing on the device. Therefore we could not get any conclusion about the impact of different loads on the measured values. The foot was internally

rotated 10 degrees in position 2 and 20 degrees in position 3. The foot was externally rotated 10 degrees in position 4 and 20 degrees in position 5. Finally, the foot was rotated in the transverse plane at 10 degrees of dorsiflexion in position 6 and in the frontal plane at 10 degrees of plantar flexion in position 7. Each of the 28 radiographs was then labeled with a random number generated by Microsoft Excel's random number generator (Microsoft Corporation, Redmond, WA, USA).

Six surgeons (2 associated professors, 3 attending surgeons, 1 orthopedic resident) Each observer evaluated measured the HVA and IMA on each radiograph and selected one of five treatment plans by following a comprehensive treatment algorithm (3, 14).

The measurements were performed with drawing the axises of metatarsals and phalanxes in order to draw the axis of these bones, every clinician marked the cortices in 3 other points the were approximately proximal distal and midshaft. After that we marked the midpoint of cortices at the same levels. Axis line was formed with drawing a line through these 3 midpoints. Treatment options were:

1) conservative treatment,
2) soft tissue procedures,
3) proximal metatarsal osteotomy surgeries,
4) distal metatarsal osteotomies, and
5) metatarso-tarsal fusion.

Observers were blinded to each other's measurements, choice of treatment plan, and the patients' demographic characteristics. Surgeons evaluated the radiographs alone and in random order. All radiographs were rated 3 times for intra-observer correlations by each surgeon. We used averaging measurements of the surgeons.

Statistical methods

Intra-observer reliability and inter-observer agreement were determined for all HVA measurements, IMA measurements, and treatment plan for each radiograph with the use of the intra class correlation coefficient (ICC, r) and Fleiss's kappa correlation, a measure of agreement among multiple observers. Reports are analyzed as correlation coefficients, r, or the kappa statistic, κ, with 95% confidence intervals and *P* values for each of the seven positions. Paired analyses were performed using ICC and Cohen's kappa statistic, which measures inter-rater agreement between two observers on categorical judgments. According to Landis and Koch (10), a kappa value of

< 0 shows no agreement;
0.0 to 0.20 shows poor agreement;
0.21 to 0.40 shows fair agreement;
0.41 to 0.60 shows moderate agreement;
0.61 to 0.80 shows good agreement; and
0.81 to 1 shows very good agreement.

Data were analyzed with the NCSS (Number Cruncher Statistical System) 2007 and PASS (Power Analysis and Sample Size) 2008 Statistical Software (NCSSLLC, Kaysville, Utah, USA). Alpha was set at 0.05, and all tests were two-tailed.

RESULTS

Agreement among all six observers for measurements of HVA in all positions was very good (r, 0.96; 95% CI, 0.94 to 0.98 (Table 1). Measurements of HVA, on all radiographs had good or very good reliability. Position 3 had the highest inter-observer reliability among six physicians followed by position 1 and position 5. Position 7 had the lowest inter-observer reliability (ICC, 0.11; 95% CI, -0.118 to 0.804) (Table 1).

Intra-observer reliability for HVA among all physicians was only poor or fair. Physician 2 had the highest ICC value (ICC, 0.26; 95% CI, 0.04 to 0.85), whereas physician 1 had the lowest (ICC, 0.15; 95% CI, 0.02 to 0.75). The mean intra-observer reliability of all physicians' ICC was 0.172 (95% CI, 0.048 to 0.366) (Table 2).

Table 1. Agreement among six surgeons measuring the hallux valgus angle and the inter-metatarsal angle from radiographs with the foot in seven different positions and their choice of treatment plan

Foot position	Hallux valgus angle, nter-class coefficient (95% CI)	Inter-metatarsal angle, inter-class coefficient (95% CI)	Treatment plan Fleiss' Kappa (95% CI)
1	0.9 (0.9 to 0.9)	0.9 (0.6 to 0.9)	0.7 (0.5 to 0.8)
2	0.8 (0.5 to 0.9)	0.9 (0.7 to 0.9)	0.4 (0.2 to 0.6)
3	0.9 (0.9 to 0.9)	0.9 (0.8 to 0.9)	0.5 (0.3 to 0.7)
4	0.9 (0.7 to 0.9)	0.8 (0.6 to 0.9)	0.3 (0.2 to 0.5)
5	0.9 (0.7 to 0.9)	0.7 (0.3 to 0.9)	-0.0 (-0.2 to 0.2)
6	0.9 (0.7 to 0.9)	0.9 (0.7 to 0.9)	0.7 (0.5 to 0.8)
7	0.1 (-0.1 to 0.8)	0.9 (0.6 to 0.9)	0.6 (0.4 to 0.8)
All	0.9 (0.9 to 0.9)	0.9 (0.8 to 0.9)	0.5 (0.4 to 0.5)

Table 2. Intra-observer reliability for HVA, IMA and for treatment choice

Measure	Surgeon No.	Agreement for all 7 foot positions
	Inter-class correlation coefficient (95% CI)	
Hallux valgus angle	1	0.15 (0.02-0.75)
	2	0.26 (0.04-0.85)
	3	0.22 (0.03-0.82)
	4	0.23 (0.03-0.83)
	5	0.18 (0.02-0.79)
	6	0.21 (0.03-0.81)
	All	0.17 (0.05-0.37)
Inter-metatarsal angle	1	0.68 (0.32-0.97)
	2	0.77 (0.43-0.98)
	3	0.71 (0.35-0.97)
	4	0.64 (0.28-0.96)
	5	0.65 (0.29-0.97)
	6	0.73 (0.39-0.98)
	All	0.64 (0.48-0.79)
	Fleiss' kappa (95% CI)	
Treatment plan	1	0.48 (0.33-0.64)
	2	0.55 (0.38-0.72)
	3	0.79 (0.61-0.97)
	4	0.42 (0.27-0.58)
	5	0.47 (0.31-0.63)
	6	0.34 (0.19-0.49)
	All	0.52 (0.46-0.59)

Table 3. Intra-observer reliabilities of each radiographic measurements and indication (ICC ve Fleiss' kappa) for HVA

Surgeon No.	Surgeon No. 1	2	3	4	5	6
	Hallux valgus angle, intra–class correlation coefficient					
1	–	0.94	0.95	0.95	0.96	0.98
2		–	0.96	0.94	0.95	0.97
3			–	0.96	0.96	0.98
4				–	0.96	0.97
5					–	0.98
6						–
	Hallux valgus angle, intra–class correlation coefficient					
1	–	0.90	0.81	0.83	0.90	0.93
2		–	0.87	0.77	0.86	0.92
3			–	0.86	0.89	0.94
4				–	0.87	0.92
5					–	0.95
6						–
	Hallux valgus angle, intra–class correlation coefficient					
1	–	0.54	0.60	0.57	0.53	0.57
2		–	0.88	0.20	0.27	0.26
3			–	0.30	0.39	0.21
4				–	0.58	0.79
5					–	0.46
6						–

Table 4. Coupled agreement between each position on HVA measurements

Foot position	Foot position 1	2	3	4	5	6	7
1	–	0.108	0.056	0.067	0.040	0.142	0.160
2		–	0.255	0.114	0.009	0.166	0.389
3			–	0.105	0.037	0.196	0.202
4				–	0.703	0.532	0.584
5					–	0.258	0.348
6						–	0.669
7							–

ICC: Intra–class Correlation Coefficient

In terms of IMA measurements, agreement was good or very good for all positions. Position 3 had the highest inter-observer reliability similar as HVA measurements, with an ICC of 0.944 (95% CI, 0.804 to 0.996) and enrolled as very good according to Landis and Koch classification. The position 5 had the lowest inter-observer reliability with an ICC of 0.710 (95% CI, 0.330-0.974) (Table 1).

In intra-observer reliability for IMA, the physician 2 showed the highest ICC value (0.766; 95% CI, 0.431 to 0.980) and the physician 4 the lowest (0.641; 95% CI, 0.277 to 0.964), respectively. The intra-observer reliability of all physicians' was good with an ICC of 0.641 (95% CI, 0.479 to 0.793) (Table 2).

The treatment procedure decisions of surgeons according to measured HVA and IMA angles were analyzed with Fleiss' kappa. There was a good consistency for indications in Position 1 and 6 with highest Fleiss kappa value of 0.651 (95% CI, 0.468 to 0.835 and 0.467 to 0.835, respectively). The lowest consistency was achieved at position 5 with kappa value of -0.001 (95% CI, -0.197 to 0.179). The indication agreement among six physicians was moderate with a Fleiss kappa of 0.466 (95% CI, 0.397 to 0.534) (Table 1). Intra-observer treatment choices showed highest (good) results (ICC: 0.787) in physician 3 and lowest (fair) results (ICC: 0.388) in physician 6. The mean result for intra-observer treatment choice is moderate with ICC value of 0.524 (Table 2).

Table 5. Coupled agreement between each position on IMA measurements (ICC)

Foot position	Foot position 1	2	3	4	5	6	7
	IMA						
1	–	0.73	0.84	0.44	0.21	0.70	0.55
2		–	0.80	0.61	0.27	0.89	0.72
3			–	0.65	0.26	0.86	0.78
4				–	0.51	0.60	0.84
5					–	0.28	0.43
6						–	0.77
7							–

ICC: Intraclass Correlation Coefficient

Table 6. Coupled agreement between each position on indication (Cohen's kappa)

Foot position	Foot position 1	2	3	4	5	6	7
1	–	0.805	0.501	0.492	0.362	1.000	0.558
2	0.805	–	0.567	0.683	0.489	0.805	0.495
3	0.501	0.567	–	0.526	0.243	0.501	0.337
4	0.492	0.683	0.526	–	0.533	0.492	0.419
5	0.362	0.489	0.243	0.533	–	0.362	0.413
6	1.000	0.805	0.501	0.492	0.362	–	0.558
7	0.558	0.495	0.337	0.419	0.413	0.558	–

The HVA measurement agreement in all seven positions was highest between physicians 5 and 6, and lowest between 2 and 4, with an ICC of 0.983 and 0.936, respectively (Table 3). At IMA measurements analysis, just the same agreement and disagreement was noted between same surgeons, with an ICC of 0.951 and 0.765, respectively (Table 3). Interestingly the indication agreement between physician 2 and 3 was highest (Cohen's kappa, 0.876) (Table 3).

When we evaluated the coupled agreement between positions of X-ray and measured HVA angle for all physicians, the consistency of positions 4 and 5 was highest; while the positions 2 and 5 was lowest, with an ICC of 0.703 and 0.009, respectively (Table 4). The measured IMA agreement was highest between positions 2 and 6, lowest between positions 1 and 5, with an ICC of 0.894 and 0.210, respectively (Table 5). To determining the indication according to measured HVA and IMA, the positions 1 and 6 had the highest agreement among surgeons? (Cohen's kappa, 1.000) (Table 6).

DISCUSSION

The relationship between foot position at the time of radiography and its effect on choice of treatment plan has not been well established. We determined the intra-observer reliability and the inter-observer agreement in

measurements of HVA and IMA on transverse dorsoplantar foot radiographs for six observers, as well as the relationship between differences in angular measurements and treatment plan.

More than 130 surgical techniques and several conservative treatment options have been described for treating HV (2, 3, 14). The conservative treatment of HV is the first choice in case of mild to moderate deformities. Shoe modifications and night splints may alleviate the symptoms in many patients (2, 3, 14, 15). Distal soft tissue procedure (lateral release) may correct mild IMA deformities for angles less than 15º (2, 3, 14). Distal osteotomies are helpful in treating mild and moderate deformities (2, 3, 14, 15, 17) Proximal metatarsal osteotomies allow a greater correction than distal osteotomies for higher IMA values (2, 3, 12, 14, 17). Metatarsal arthrodesis is the treatment choice for recurrent and severe deformities, especially with arthrosis and hypermobility (2, 3, 14).

Several radiographic measurements are to define the severity of the angular deformity in patients with HV (1, 4–7, 9, 13) for example: HVA (6), IMA (6), distal metatarsal articular angle (13), interphalangeal angle (IPA) (1), proximal phalangeal articular angle (1), first metatarsal protrusion distance (2), first metatarsal cuneiform angle (4), tibia sesamoid-second metatarsal distance (7), sesamoid rotation angle (9) and axial tibial sesamoid-second metatarsal distance (7). The most commonly used are the HVA and IMA (2, 3, 5–7, 9, 11–19). The appropriate imaging technique is essential to obtain a true view and for choosing the appropriate treatment. The weight bearing dorsoplantar foot radiograph is the accepted standard for visualizing this deformity (2, 3, 6, 8, 15–17).

The HVA is the angle between longitudinal axes of the first metatarsal and the first proximal phalanx. The IMA is formed by the intersection of the longitudinal axes of the first and second metatarsals (5, 6). Before the invention of digital radiographic systems, the HVA was measured with a goniometer on conventional weight bearing radiographs. Recently, most physicians make their preoperative assessment with digital radiographic systems. Additionally, some smartphone applications can enhance the measurements in daily practice (19).

Basing treatment decisions on measurements of the HVA and the IMA is universally accepted in clinical practice (2, 3, 5–7, 9, 11–19). In our study, we used these two angles in seven various positions to determine intra- and inter-observer reliability. Additionally, to highlight the importance of accurate radiographic technique, we reveal the intra-observer and inter-observer changes in measurements and indications with different positioned radiographs simulating incorrect technique.

Radiographic studies have established that HVA is the most reliably measured angle for diagnosing HV deformity (11). The IMA has highest correlation with the HVA (11, 19). Additionally, these two angles had high reliability and prediction of deformity (11). Similarly, in our study, measurements of the HVA and IMA had very good inter-observer agreement. However, measurements of HVA had poor intra-observer reliability, whereas those of IMA had good intra-observer reliability. According to the measurements in different positions, intra-observer treatment choices revealed moderate results (ICC: 0.524).

Our study has several limitations. First, we studied only the preoperative radiographic measurements, not the symptomatic correlation of the radiographic measurements nor the indication related surgical outcomes. A longitudinal study can also be performed to investigate the clinical relevance of the radiographic measurements and related indications. In addition our sample size was small. We measured only the HVA and the IMA, which are two of many other measurements that could have been evaluated. We gave the observers only a single radiograph on which to based their choice of a treatment plan and limited their choice to only five treatments plan to make statistical analysis easier.

The inter-observer reliabilities for measuring HVA are very good. However, with the different positions intra-observer reliabilities showed poor results in HVA which can change the treatment decisions of the physicians. IMA is less influenced with the positional changes therefore IMA is more reliable angle for management of HV deformity. This study indicates that technique of taking weight-bearing radiographs for measuring the foot deformity is crucial in the treatment decision of HV deformity.

CONCLUSIONS

The inter-observer reliabilities for measuring HVA are very good. However, with the different positions intra-observer reliabilities showed poor results in HVA which can change the treatment decisions of the physicians. IMA is less influenced with the positional changes therefore IMA is more reliable angle for management of HV deformity. This study indicates that technique of taking weight-bearing radiographs for measuring the foot deformity is crucial in the treatment decision of HV deformity.

Abbreviations

HV: *hallux valgus*
HVA: *hallux valgus angle*
IMA: *inter-metatarsal angle*
IPA: *inter-phalengeal angle*
PACS: *Picture Archiving and Communication System*

Authors' contributions

EK organized the study and writing. HHC carried out the writing. IE, MB and SS evaluated the radiologic images. ME and MB organized the writing. BG and AK analyzed the data. All authors declared that they have no competing interests, no funding support and no financial support.

Consent

Written informed consents were obtained from the patients for publication of this cases and accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal.

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Corresponding author:
Ersin Kuyucu MD
Istanbul Medipol University
Department of Orthopaedics and Traumatology
TEM Avrupa Göztepe çıkışı, No: 4
Bağcılar/İstanbul/Turkey
E-mail: ersinkuyucu@yahoo.com.tr