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Intra- and Interobserver Agreement in Hallux Valgus Angle Measurements on Weightbearing and Non-Weightbearing Radiographs

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ABSTRACT

The choice of treatment of hallux valgus deformity is influenced by angles measured on radiographs. Angles of interest are the hallux valgus angle (HVA), 1,2-intermetatarsal angle (IMA), and distal metatarsal articular angle (DMAA), as well as the presence of first metatarsophalangeal joint (MTPJ) subluxation. Guidelines for measuring those angles have been distributed by American Orthopaedic Foot and Ankle Society (AOFAS), although the influence of weightbearing on these angles and its clinical relevance is not clear. We conducted a study to determine the influence of weightbearing and the inter- and intraobserver agreement in the measurement. A total of 104 patients were enrolled in this study. Both weightbearing and non-weightbearing radiographs were obtained. In 2 rounds, 2 orthopedic surgeons and 2 musculoskeletal radiologists measured the angles in blinded digital radiographs according to AOFAS guidelines. Agreement on measurement of HVA, IMA, and DMAA in both weightbearing and non-weightbearing radiographs, as well as the presence of MTPJ subluxation, was calculated using the linear-weighted kappa coefficient and the intraclass correlation coefficient (ICC). Examiner agreement strength was defined according to the guidelines of Landis and Koch. HVA decreases significantly with weightbearing, whereas IMA significantly increases. The change in magnitude was 1° to 2° on average. No significant influence on DMAA could be noted. Interobserver agreement was excellent in both weightbearing and non-weightbearing radiographs for HVA (ICC 0.99 and ICC 0.99, respectively), IMA (ICC 0.98 and ICC 0.86, respectively), and DMAA (ICC 0.95 and ICC 0.97, respectively). The agreement on presence of subluxation was moderate to good (Fleiss kappa 0.50 to 0.63). Weightbearing alters forefoot geometry significantly. Adhering to AOFAS guidelines yields excellent interobserver agreement on HVA, IMA, and DMAA. First MTPJ subluxation presence is not an alternative for DMAA. The magnitude of change in IMA and HVA is small and therefore not clinically important. Both weightbearing and non-weightbearing radiographs can be used for determination of the correct treatment of hallux valgus deformity.

Hallux valgus is the most prevalent pathology affecting the human great toe, with 28% of the general population and up to 74% in the elderly population affected (1,2). Hallux valgus severity is defined by the angular deformity, and the severity of this deformity is key to the choice of treatment. Measurement of angles on forefoot radiographs is an important tool for determining the choice of treatment of hallux valgus deformity (1). The angles of importance reported in literature are the hallux valgus angle (HVA), the 1,2-intermetatarsal angle (IMA), and distal metatarsal articular angle (DMAA) (3–6).

These angles were traditionally measured by hand on hard-copy radiographs. Digital radiography has been popularized since the beginning of the 21st century. Intra- and interobserver agreement for radiographic measurement of HVA and IMA is reported to be good in both traditional radiographs and in digital techniques. Unfortunately, DMAA measurement has proved to be unreliable in both techniques, demonstrating a poor interobserver agreement. In cadaveric studies, a more severe HVA is correlated with a higher DMAA (7–15).

The agreement on presence of first metatarsophalangeal joint (MTPJ) subluxation has not been studied widely in the literature. Because of the variable interobserver agreement on DMAA reported in

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the literature, subluxation may be an alternative qualifier to define hallux valgus deformity severity (10,14,16,17).

Only a few publications address the effect of weightbearing on determining the angles needed for hallux valgus surgery. The influence of weightbearing on HVA is unclear because studies report both an increase and decrease after weightbearing (18,19). Regarding the IMA, studies agree on the increase of this angle with weightbearing (18,19); yet, it is crucial to measure correct angles because it is accepted that treatment depends on it (1,3,6,20,21). In 2002, on behalf of the American Orthopaedic Foot and Ankle Society (AOFAS), Coughlin et al (5) published standards for measuring HVA, IMA, and DMAA. After this publication, no study reported on the influence of weightbearing on different angles. The standards of Coughlin et al (5) advise measuring the angles in weightbearing radiographs, but it is unclear whether choice of treatment, based on angles measured in non-weightbearing radiographs, will change when compared with weightbearing radiographs.

This prospective study was performed to evaluate the intra- and interobserver agreement on the radiological measurement of the HVA, IMA, and DMAA in weightbearing and non-weightbearing conditions, as well as the presence of subluxation as a possible alternative for the DMAA. Consequently, the influence of weightbearing on these parameters was determined.

Patients and Methods

Study Design

Between May 2012 and April 2013, consecutive patients visiting the outpatient department for forefoot disorders were included in this study, which was approved by the medical ethical committee and institutional review board (registration no. NL37753.098.011). All patients gave written informed consent after receiving oral and written information about the study.

Inclusion criteria were age ≥18 years, clinical hallux valgus deformity, and signed informed consent. Exclusion criteria were earlier foot surgery, earlier fracture of the foot, cerebral palsy, rheumatoid arthritis, and pregnancy.

Radiographic Protocol

After inclusion, patients were referred to the radiology department for evaluation. Anteroposterior (AP) and lateral foot radiographs were taken in weightbearing and non-weightbearing settings. Orthopedic treatment for hallux valgus deformity was undertaken according to the local standards of care.

Digital foot radiographs were taken according to our standard institution protocol, using an UT 2000 X-ray machine (Philips Medical, Best, The Netherlands). AP weightbearing radiographs were performed with the patient standing on both feet on the detector and knees extended. The medial foot border was aligned on the detector to point straight forward to correct for incidental internal or external rotation of the leg. The beam was inclined 15° in an AP direction centered on the base of the third metatarsal at a distance of 1.2 m.

Positioning the patient supine with the hip and knee flexed and the foot flat on a radiolucent table obtained non-weightbearing radiographs. The beam was inclined 15° in an AP direction centered on the base of the third metatarsal at a distance of 1.2 m. Lateral radiographs were not used in this study for angle measurement.

Measurement of Angles

The HVA is the angle between the long axis of the first metatarsal and the proximal phalanx. The IMA is the angle between the shaft of the first and second metatarsal. Both angles define the magnitude of the hallux valgus deformity (1). The DMAA is the angle between the articular surface and the diaphysis of the first metatarsal.

Digital radiographs were stored and assessed with a picture archiving and communication system and the system's software (GE Healthcare, Hoevelaken, The Netherlands). Radiographs were digitally anonymized for patient characteristics and received a study number from a radiology assistant. After the first assessment, the anonymized radiographs received a new study number and were shuffled to blind the observers and to prevent memory bias. The identification key was concealed to the observers. Four independent observers assessed all radiographs in 2 observation rounds. The time interval between the 2 rounds was at least 6 weeks.

Two orthopedic surgeons (OS 1 and 2) with 29 and 12 years of experience, respectively, and 2 musculoskeletal radiologists with 20 and 1 year of experience performed the measurements. The observers were aware of the presence of forefoot complaints but had no additional information regarding patients' demographics, clinical findings, and orthopedic treatment. In this manner, HVA, IMA, and DMAA and the presence or absence of subluxation of the first MTPJ were determined.

Assessment of the HVA, IMA and DMAA was performed according to the guidelines of the AOFAS ad hoc Committee on Angular Measurements and the digital technique described by Coughlin et al (5) and Chi et al (14) (Figs. 1 and 2). The presence of subluxation in the first MTPJ was also recorded by the observers. Subluxation was defined as the lateral articular border of the proximal phalanx passing the lateral articular border of the first metatarsal head and thus deviation of the joint and overhanging surfaces (14,22).

Statistical Analysis

Descriptive statistics were used to summarize patients' demographics and radiographic measurements. Normality was tested using the Shapiro-Wilk test. Statistical differences in angles between weightbearing and non-weightbearing radiographs were calculated using a paired *t* test. The intraclass correlation coefficient (ICC) was measured as absolute agreement using a 2-way random effects model to investigate the intraobserver variability (single measurement). For the interobserver variability (average measurement), the ICC consistency was calculated (23). The Wilcoxon signed-rank test was used to compare paired data between groups. A weighted kappa coefficient (κ) was used to determine consistency among observers for categorical data, including subluxation. For both rounds, the Fleiss κ was calculated to show the overall agreement for the 4 observers in weightbearing and non-weightbearing radiographs. The strength of examiner agreement was defined according to the guidelines of Landis and Koch (24) as follows: poor, $\kappa \leq 0.20$; fair, $\kappa = 0.21$ to 0.40; moderate, $\kappa = 0.41$ to 0.60; good, $\kappa = 0.61$ to 0.80; and excellent, $\kappa = 0.81$ to 1.00. Statistical differences between groups were calculated with Student's *t* test. Statistical significance was set at 5% level ($p < .05$). Data were analyzed using SPSS 22.0 (IBM, Chicago, IL).

Results

Demographics

A total of 73 patients (65 female [89%] and 8 male [11%]) were included. There were 32 patients (30%) included with both feet because of bilateral problems. A total of 104 feet could be evaluated. Mean age was 53 years (standard deviation 14, range 20 to 92 years). Fifty-five left feet and 49 right feet were available for radiological appraisal. Time interval between the 2 observation rounds was at least 6 weeks.

Angle Measurements

The mean results of the angle measurements for the weightbearing and non-weightbearing radiographs are depicted in Table 1. ICCs were determined for each observer in weightbearing and non-weightbearing radiographs. All observers measured a smaller HVA and a higher IMA in weightbearing radiographs. The ICC was excellent for HVA and IMA, except for the IMA measurement in non-weightbearing radiographs for observer OS 2 (S.B.K.), which showed poor agreement. Intraobserver agreement for DMAA was moderate to good for OS 2 (S.B.K.) and good to excellent for the other observers.

Results of the interobserver agreement on HVA, IMA, and DMAA are shown in Table 2. Interobserver agreement was excellent for all 3 angles (ICC at least 0.857) in the weightbearing and non-weightbearing radiographs.

Presence of Subluxation

Intraobserver agreement for both orthopedic surgeons and radiologists was good on the presence of subluxation in the first MTPJ (Table 3). Interobserver agreement on the presence of subluxation in weightbearing radiographs in both measurement rounds was good with a Fleiss κ of 0.625 and 0.614 in round 1 and round 2, respectively. For the non-weightbearing radiographs, the agreement was moderate, with a Fleiss κ of 0.506 and 0.509 in round 1 and round 2, respectively. The interobserver agreement on the presence of subluxation is presented in Table 4.

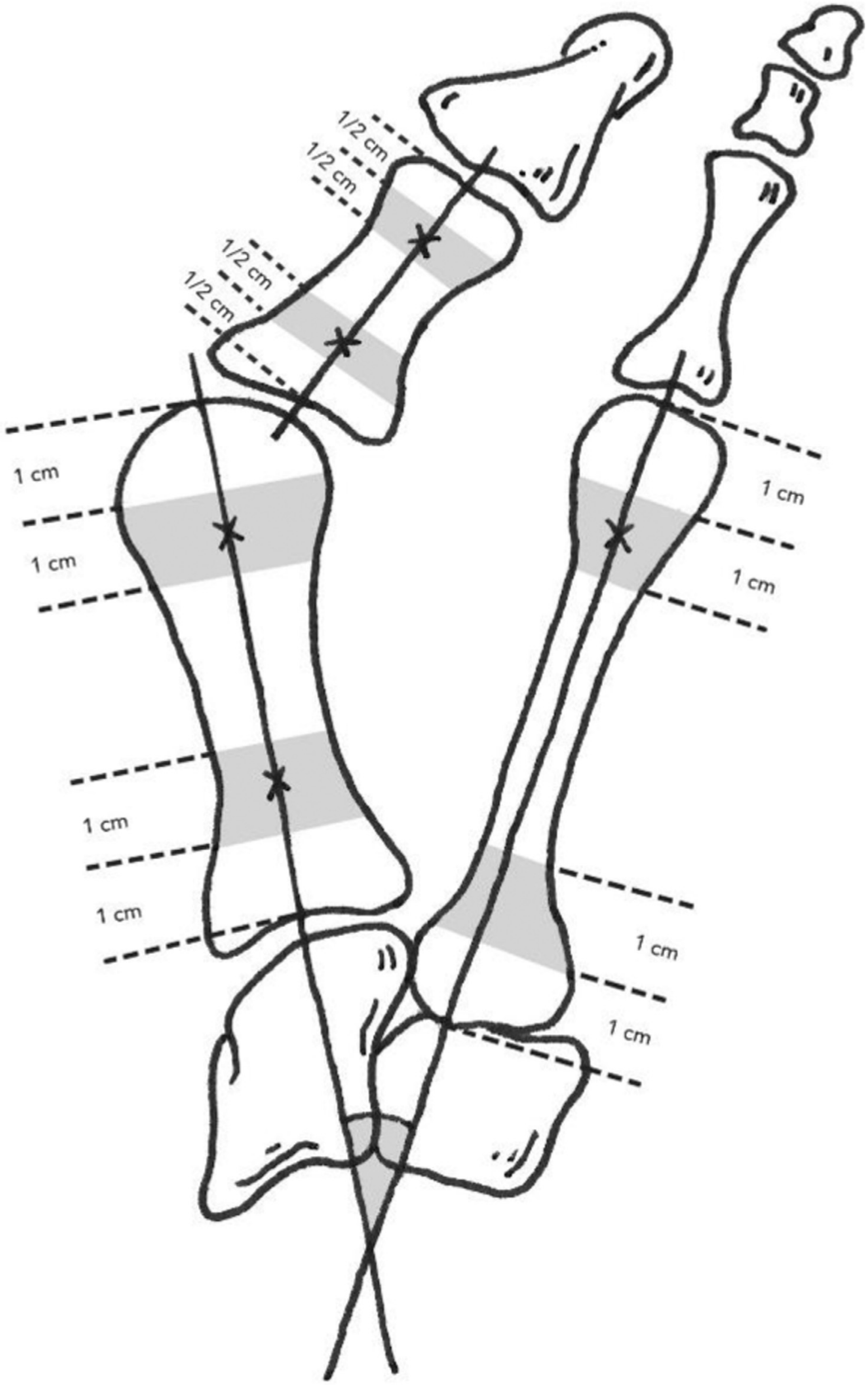

Fig. 1. Location of reference points on first and second metatarsal are between 1 and 2 cm from the proximal and distal articular surface of each metatarsal. In the proximal phalanx, the reference points are placed between 0.5 and 1 cm. Drawing by Roos Stelloo, adapted from (5).

Influence of Weightbearing

All observers showed a decrease in HVA measurements on weightbearing radiographs, whereas the mean IMA increased on weightbearing radiographs with at least 1.5°. The change in IMA was statistically significant in all observers. DMAA did not alter significantly in any observer. The changes with weightbearing on these angles per observer are shown in Table 5.

Discussion

The main results of this observational study showed an excellent interobserver agreement for measuring HVA, IMA, and DMAA on weightbearing and non-weightbearing radiographs. An excellent intraobserver agreement for HVA, IMA, and DMAA was found for all except 1 observer, who had a poor intraobserver agreement for IMA

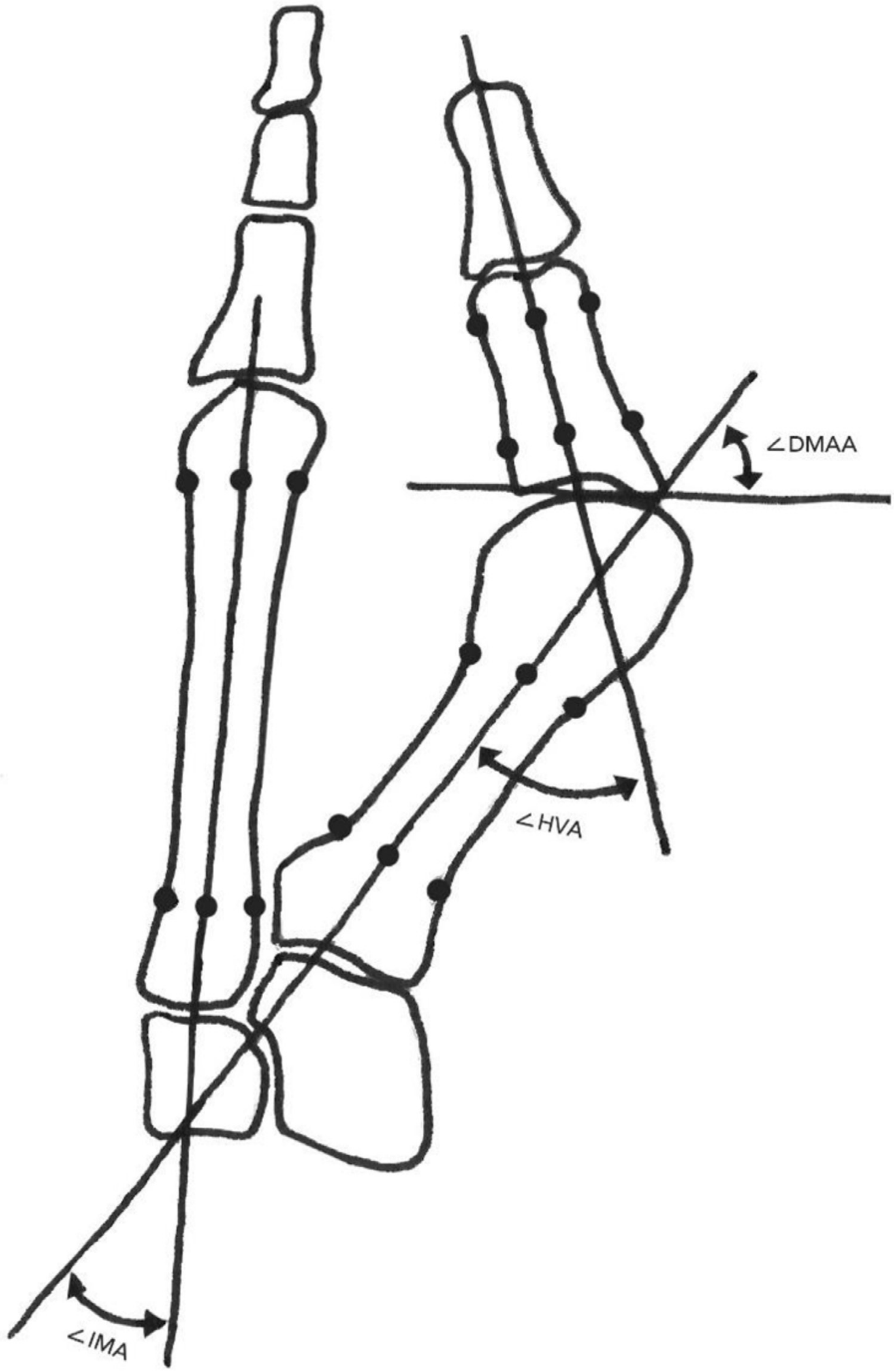

Fig. 2. Details for determining the hallux valgus angle, 1,2-intermetatarsal angle, and 1,2-intermetatarsal angle, including landmarks. Drawing by Roos Stelloo, adapted from (14).

on non-weightbearing radiographs and a moderate to good intraobserver agreement on DMAA. For HVA and IMA, we found a slightly lower intraobserver variation in the non-weightbearing radiographs. The opposite was true when measuring DMAA. In determining the presence of first MTPJ subluxation, all observers demonstrated a good intraobserver agreement for both weightbearing and non-weightbearing radiographs. Interobserver agreement for the presence of first MTPJ subluxation on non-weightbearing and weightbearing radiographs was moderate and good, respectively. For the presence of first MTPJ subluxation, we report a higher Fleiss κ in weightbearing radiographs. This may be explained by the significant increase in pronation of the proximal phalanx as shown on computed tomographic (CT) scans (25). Weightbearing had a statistically significant influence on the magnitude of HVA and IMA: HVA showed a decrease with weightbearing, whereas IMA increased. No statistically significant influence on DMAA was found.

Table 1
Mean hallux valgus angle, 1,2-intermetatarsal angle, and 1,2-intermetatarsal angle values for each observer

		HVA			IMA			DMAA		
		Avg (T1-T2)	ICC	95% CI	Avg (T1-T2)	ICC	95% CI	Avg (T1-T2)	ICC	95% CI
OS 1	WB	31.86	.979	.970 to .986	14.93	.937	.909 to .957	63.82	.772	.681 to .839
	NWB	32.90	.921	.886 to .946	13.05	.848	.784 to .895	63.74	.872	.817 to .911
OS 2	WB	28.51	.931	.894 to .954	13.02	.850	.779 to .898	66.85	.561	.412 to .680
	NWB	30.07	.924	.889 to .948	11.46	.194	−.001 to .374	66.26	.690	.573 to .779
RAD 1	WB	27.20	.961	.943 to .974	12.77	.855	.793 to .899	66.05	.921	.885 to .946
	NWB	28.99	.956	.936 to .970	11.25	.847	.782 to .894	65.51	.931	.900 to .953
RAD 2	WB	27.59	.983	.976 to .989	12.54	.946	.907 to .966	64.50	.874	.820 to .913
	NWB	29.39	.970	.956 to .979	10.83	.910	.841 to .946	64.76	.973	.958 to .982

Mean HVA, IMA. and DMAA measurement presented in degrees for each observer.
Abbreviations: Avg, average; DMAA, distal metatarsal articular angle; HVA, hallux valgus angle; ICC, intraclass correlation coefficient (absolute agreement, intraobserver agreement); IMA, 1,2-intermetatarsal angle; NWB, non-weightbearing; OS, orthopedic surgeon; RAD, radiologist; T, measurement round; WB, weightbearing. OS 2, S.B.K.; RAD 2, M.W.K.

Table 2
Interobserver agreement for the different angles in weightbearing and non-weightbearing radiographs combined for both measurement rounds

		ICC	95% CI	*P*
WB	HVA	.993	.990 to .995	.0001
	IMA	.976	.968 to .983	.0001
	DMAA	.954	.937 to .967	.0001
NWB	HVA	.990	.987 to .993	.0001
	IMA	.857	.806 to .898	.0001
	DMAA	.970	.959 to .979	.0001

Abbreviations: DMAA, distal metatarsal articular angle; HVA, hallux valgus angle; ICC, intraclass correlation coefficient (absolute agreement); IMA, 1,2 intermetatarsal angle; NWB, non-weightbearing; WB, weightbearing.

Table 3
Intraobserver agreement on presence of first metatarsophalangeal joint subluxation on weightbearing and non-weightbearing radiographs

		κ	95% CI
OS 1	WB	.761	.634 to .888
	NWB	.748	.615 to .881
OS 2	WB	.715	.574 to .856
	NWB	.643	.469 to .817
RAD 1	WB	.689	.550 to .828
	NWB	.644	.495 to .793
RAD 2	WB	.789	.671 to .907
	NWB	.715	.582 to .848

Abbreviations: CI, confidence interval; κ, weighted kappa coefficient; NWB, non-weightbearing; OS, orthopedic surgeon; RAD, radiologist; WB, weightbearing. OS 2, S.B.K.; RAD 2, M.W.K.

Table 4
Interobserver agreement on the presence of first metatarsophalangeal joint subluxation on weightbearing and non-weightbearing radiographs

	T1 WB		T2 WB	
	κ	95% CI	κ	95% CI
OS 1 vs RAD 1	.589	.432 to .746	.627	.478 to .776
OS 1 vs OS 2	.573	.412 to .734	.521	.360 to .682
OS 1 vs RAD 2	.547	.384 to .710	.613	.462 to .764
RAD 1 vs OS 2	.582	.425 to .739	.542	.395 to .689
RAD 1 vs RAD 2	.806	.692 to .920	.864	.766 to .962
OS 2 vs RAD 2	.659	.512 to .806	.534	.387 to .679
Fleiss κ	.625		.614	
OS1 vs RAD 1	.579	.422 to .736	.616	.463 to .769
OS 1 vs OS 2	.361	.177 to .545	.500	.335 to .665
OS 1 vs RAD 2	.593	.432 to .754	.578	.417 to .739
RAD 1 vs OS 1	.493	.338 to .648	.405	.250 to .560
RAD 1 vs RAD 2	.600	.453 to .747	.763	.638 to .888
OS 2 vs RAD 2	.615	.444 to .786	.444	.285 to .603
Fleiss κ	.506		.509	

Abbreviations: κ, weighted kappa coefficient; NWB, non-weightbearing; OS, orthopedic surgeon; RAD, radiologist; T, measurement round; WB, weightbearing. OS 2, S.B.K.; RAD 2, M.W.K.

Table 5
Mean angles presented in degrees measured per observer in weightbearing and non-weightbearing radiographs

Angle	Obs	WB	NWB	Mean Difference	95% CI
HVA	OS 1	31.86	32.90	−1.048	−1.973 to −1.048
HVA	OS 2	28.51	30.07	−1.565	−2.428 to −0.701
HVA	RAD 1	27.20	28.99	−1.791	−2.607 to −0.976
HVA	RAD 2	27.59	29.39	−1.803	−2.693 to −0.913
IMA	OS 1	14.93	13.05	1.875	1.466 to 2.284
IMA	OS 2	13.02	11.46	1.560	1.560 to 2.404
IMA	RAD 1	12.77	11.25	1.524	1.100 to 1.948
IMA	RAD 2	12.54	10.83	1.712	1.354 to 2.069
DMAA	OS 1	63.82	63.74	.0817	−0.994 to 1.157
DMAA	OS 2	66.85	66.26	.585	−0.853 to 2.022
DMAA	RAD 1	66.05	65.50	.544	−0.391 to 1.478
DMAA	RAD 2	64.50	64.76	−.264	−1.250 to 0.721

Abbreviations: DMAA, distal metatarsal articular angle; HVA, hallux valgus angle; IMA, 1,2 intermetatarsal angle; NWB, non-weightbearing; Obs, observer; OS, orthopedic surgeon; RAD, radiologist; WB, weightbearing. OS 2, S.B.K.; RAD 2, M.W.K.

Reliability of forefoot geometry measurement in general and HVA, IMA, and DMAA in particular has been addressed in the literature several times (10–14,16,18). Studies highly agree on a good to excellent intra- and interobserver agreement for measurement of HVA and IMA. Intraobserver agreement for DMAA is also reported to be good or excellent in recent studies (10,17,26). However, interobserver agreement on DMAA is more variable, ranging from poor to excellent (10,14,16,17). We found an excellent intraobserver agreement for HVA and IMA in 3 of 4 observers. One observer (OS 2; S.B.K.) had a very low ICC for IMA in non-weightbearing radiographs (.194). No direct explanation for this deviation was found. Intraobserver agreement for DMAA ranged from moderate to excellent. Poorer agreement for DMAA is a well-known phenomenon in the literature, as reported previously (10,14,16,17). We found excellent interobserver agreement in measuring HVA, IMA, and DMAA on both weightbearing and non-weightbearing radiographs, which might be explained by the measurement technique instructions given to the observers at the beginning of the study. Yet, it can be concluded that adhering to a measuring protocol reveals a reproducible angle measurement.

The agreement on presence of first MTPJ subluxation has not been studied widely in the literature. Because of the variable interobserver agreement on DMAA reported in the literature, we were interested in an alternative qualifier to define the severity of hallux valgus deformity (10,14,16,17). We found a moderate to good interobserver agreement on the presence of subluxation. Chi et al (14) reported poor results on interobserver agreement. ICCs for MTPJ subluxation are inferior when compared with the interobserver agreement for DMAA in this study; therefore, we believe that subluxation in its present definition is not useful in clinical practice because overhanging surfaces are difficult to expose on a standard radiograph.

Furthermore, weightbearing had a statistically significant influence on the magnitude of HVA and IMA. The HVA showed a decrease with weightbearing. However, the IMA increased with weightbearing on the foot. Several dated publications report on the change of magnitude of HVA and IMA. These findings were inconsistent for HVA, both reporting a decrease (18,27) and an increase (19,27) with weightbearing. For IMA, 2 studies report an increase (18,19), and a third one is inconsistent (27). These studies were published without using the standards as published by Coughlin et al (5). The first publication considering the effect of weightbearing on forefoot geometry since the publications of the AOFAS standards reported on the biomechanics of the first metatarsal bone analyzed with load-bearing CT scans (5,25). Although CT measurement has not been validated in the literature previously, it can be assumed that it is a modality that may lead to higher accuracy because of the multiplane imaging and possibility to correct for rotation. Our results, using the standards for measurement that HVA and IMA are in line with the CT findings, suggest a decrease of HVA and an increase of IMA under the influence of weightbearing. The AOFAS ad hoc Committee on Angular Management advises measuring the HVA, IMA, and DMAA on weightbearing radiographs (5). We reviewed both weightbearing and non-weightbearing radiographs, and some differences related to weightbearing were observed. For HVA and IMA, we found a slightly lower intraobserver variation in the non-weightbearing radiographs. The opposite was true when measuring DMAA. For the presence of first MTPJ subluxation, we report a higher Fleiss κ in weightbearing radiographs. The difference between these radiographs may be explained by rotation of the first metatarsal and proximal phalanx with weightbearing, as was reported by Coughlin et al (5) and in the detailed CT studies by Collan et al (25).

A study by Burg et al (16) was published in which 21 experienced physicians were given blinded radiographs from 10 random clinical cases. All cases had both a weightbearing and non-weightbearing AP radiograph. Observers were asked about their choice of treatment considering the radiograph; there was no difference in the choice of treatment when comparing the weightbearing and non-weightbearing radiographs. The authors concluded that both types of AP radiographs can be used to determine the choice of treatment. Our results are in line with this report. The mean HVA and IMA measured in the radiographs demonstrated a mild to moderate hallux valgus deformity (1,3–6). The change in magnitude with weightbearing was a few degrees. More factors are important in the choice of treatment of hallux valgus deformity, including age, comorbidity, laxity of the tarsometatarsal joint, and passive correction possibilities of the first MTPJ; therefore, we conclude that in clinical situations, both weightbearing and non-weightbearing radiographs can be used to determine reproducible HVA, IMA, and DMAA measurements as an element for clinical decision making regarding hallux valgus deformity treatment.

This study had several strengths. First, all radiographs were taken according to a strict protocol, which does eliminate the possibility of technical failure. Second, all radiographs were blinded and randomized before evaluation. Third, the second measurement round took place at least 6 weeks after the first round, eliminating a possible memory bias. Fourth, all observers were well instructed in the technique of measuring the angles in the digital radiographs, which can be seen from the high interobserver agreement.

Our study population consisted of consecutive patients presenting at an outpatient clinic, which led to including far more female patients. This is in line with previous reports (1,2,6). We are not aware of anatomical differences in the foot between males and females nor of a gender-based difference in the reaction of the foot skeleton to weightbearing; therefore, we believe that this does not introduce selection bias.

The observers included 2 orthopedic surgeons, with 12 and 29 years of experience, and 2 musculoskeletal radiologists, with 1 and 15 years of experience. Although this study was not designed to do so, we could not find any conspicuous difference related to profession and experience. One observer, an experienced orthopedic surgeon, was least consistent in his measurement, as reflected in a low intraobserver agreement for both IMA and DMAA in weightbearing radiographs; therefore, a weakness of this study may be that we used only 4 different observers.

In conclusion, measuring HVA, IMA, and DMAA according to the gold standard as advised by the AOFAS yields excellent interobserver agreement in both weightbearing and non-weightbearing radiographs. The presence of first MTPJ subluxation showed moderate to good interobserver agreement, which makes this a less valid and reliable measurement suitable for the clinical practice. Weightbearing affects HVA and IMA, in which HVA decreases and IMA increases significantly with weightbearing on the foot. DMAA does not change significantly. Differences of HVA and IMA with weightbearing were statistically significant, yet the difference was not clinically significant because of the magnitude of the results, which concluded that both weightbearing and non-weightbearing radiographs can be used in clinical practice

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