



Evaluation of the relationship between hallux valgus and foot measurements in radiographic images of adult female

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Abstract

Purpose In the present study, we aimed to determine the relationship of HV angle with angles and measurements obtained from lateral and anteroposterior (AP) radiological images of the foot in individuals with HV.

Methods The present study had a retrospective design, and the participants consisted of 66 female patients between the ages of 19 and 64 who applied to Orthopedics and Traumatology and were diagnosed with Hallux valgus. Metatarsus adductus angle, metatarsus primus adductus angle, hallux valgus angle, hallux interphalangeal angle, metatarsal break angle, first metatarsal protrusion distance, metatarsal width, talocalcaneal angle, AP Meary's angle were measured on AP view and calcaneal inclination angle, talar declination angle, lateral talocalcaneal angle, first metatarsal declination angle, fifth metatarsal declination angle, navicular height, lateral Meary's angle, tibiotalar angle were measured on a lateral radiograph. The IBM SPSS 21.0. program was used for statistical analysis, and the level of significance was taken as $p < 0.05$.

Results There were statistically significant differences between the right and left feet in MPA and AMA measurements. The results showed that HV angle (HVA) had a weak relationship with MAA and MW, as well as a moderately positive relationship with MPA. However, it had a moderately negative relationship with AMA and a weak negative relationship with HIPA.

Conclusion We believe that in addition to the HVA angle, MPA and AMA angles should be considered in the diagnosis of HV, especially as the HVA angle is moderately positively correlated with the MPA angle and moderately negatively correlated with the AMA angle.

Keywords Hallux valgus deformity · Radiographic evaluation · Hallux valgus angle · Radiographic angles · Foot

Introduction

Hallux valgus (HV) is a very common foot deformity that affects the anterior side of the foot and it presents with a gradual subluxation of the first metatarsophalangeal joint caused by lateral deviation of the hallux and medial deviation of the first metatarsal bone. This deformity typically results in the development of soft tissue and bony protrusion in the medial of the first metatarsal head [9].

HV is a complex condition characterized by a series of deformities of variable severity, suggesting that several factors may be involved in its formation. The role of heredity and sex in the occurrence of this deformity is significant. However, other anatomical and biomechanical factors, such as variations in the metatarsal bones, particularly the first metatarsal bone, round articular face, bunion, medial prominence, degenerative osteoarthritis and metatarsus primus varus deformation, are also critical. These variations may render them more prone to hypermobility of the first row, flat feet, and loosening of the ligaments [5, 23, 25]. This pathology is also associated with bone deviation from axes and the deterioration of muscle stabilization around this joint. The first metatarsal, in particular, deviates medially, and the hallux rotates and deviates to some extent laterally in the two main segments of the joint. As a result, the medial capsular ligament is torn and weakened, and the sesamoid bones and metatarsal head are moved away from the normal plantar joints [5, 10, 11].

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The incidence of HV is higher in women. Although the rate is 2:1 in infants, it increases drastically to 15:1 in adults. These findings indicate that the prevalence of this deformity in women, especially at older ages, is attributable to the use of narrow and high-heeled shoes that may induce it [5, 20, 23, 30].

As a deformity, HV is clearly visible and can be easily diagnosed in the clinic with a simple examination. Although there are still studies in the literature conducted on the reliability and validity of X-ray measurements, these measurements are still considered the gold standard in the preoperative evaluation of deformities. In the radiological evaluation of the patient, 15° is generally accepted as the upper limit of the normal range for the hallux valgus angle (HVA) [3, 9, 10, 14]. Sex, genetic factors, shoe selection, body mass index, first metatarsal shape and length, pes planus, race, and ligamentous laxity have all been associated with HV in previous studies. This deformity is considered that it is diagnosed at a higher rate in women than in men as they prefer narrow and high-heeled shoes, especially at older ages [4, 7, 11, 22, 23].

Despite this high prevalence and its impact on quality of life, only a small number of studies have been performed on women. In the present study, we aimed to determine the relationship of HV angle with angles and measurements obtained from lateral and anteroposterior (AP) radiological images of the foot in individuals with HV.

Materials and methods

The present study had a retrospective design. The study included 66 women (age, 19–64 years) diagnosed with HV who had sought treatment from the Orthopedics and Traumatology Department of Cukurova University Balcali Hospital Health Practice and Research Center between 2008 and 2020. The patient images were retrieved from the archive

system. In this study, we evaluated the radiographic images of a total of 114 feet of 66 people who were admitted to the Orthopedics and Traumatology Department, with HV on physical and radiological examinations and were indicated for surgery. In our study, 48 of 66 participants were diagnosed with HV in both feet, whereas 18 patients were diagnosed with HV in only one foot. Radiographic images of these feet were available. The inclusion criteria were a minimum age of 18 years, closed epiphysis, and a positive HV diagnosis. The patients with a history of surgical operation on the foot and ankle region, fractures, trauma, congenital anomalies, and inadequate radiographs were excluded from the study. The study obtained the approval of the Ethics Committee with the number 11.06.2021/112 from the Cukurova University Faculty of Medicine Non-Invasive Clinical Research Ethics Committee. The radiographic measurements were performed on 114 feet of 66 participants (48 bilateral, 18 unilateral) on standard weight-bearing AP and lateral images. A total of 17 angle and distance measurements were recorded, 9 on the AP and 8 on the lateral radiographic images. The images were viewed using the Enlil PACS system software (Eskisehir, Turkey). The required measurements were performed using PACS measurement tools. Tables 1 and 2 show detailed descriptions of the angle and distance measurements, and Figs. 1 and 2 show some of the measured angle and distance values. The angle values in the opposite direction of the normal angle values were evaluated as negative and used as an example in the measurements, as presented in Fig. 3 on the hallux interphalangeal angle (HIPA) angle measurement.

All angles and distances were measured twice, independently by two authors (A.K.A., F.B.). Intraclass correlation coefficients (ICC with 95% confidence intervals) were used for reliability testing. When the intra-observer reliability was examined in all measurements, the ICC value was 0.94–0.98 in both observers, while it was 0.92–0.96 in the interobserver

Table 1 Definitions of measurements in the AP view

Measurements	Definitions of measurements
Metatarsus adductus angle (MAA)	Angle between the bisection of the second metatarsal and the line constituted by drawing a 90° angle constituted by the line connecting the midpoint of the borders of the midfoot [17]
Metatarsus primus adductus angle (MPA)	The angle between the lines bisecting the first and second metatarsals [17]
Hallux valgus (abductus) angle (HVA)	The angle between the lines bisecting the proximal phalanx of the hallux and shaft of the first metatarsal [17]
Hallux interphalangeal angle (HIPA)	The angle between the lines bisecting the proximal and distal phalanx of the hallux [17]
Metatarsal break (parabola) angle (MBA)	The angle between the line connecting the distal ends of the shaft of the first and second metatarsals and the line connecting the distal ends of the shaft of the second and fifth metatarsals [17]
First metatarsal protrusion distance (MPD)	The distance between the arcs of the bisecting lines of the first and second metatarsals from the intersection of the two lines [18]
Metatarsal width (MW)	Measured on the widest point of the metatarsal heads [26]
Talocalcaneal angle (Kite angle)	The angle between the lateral edge of the calcaneus and the line bisecting the neck of the talus [17]
AP Meary's angle (AMA)	The angle between the line bisecting the neck of the talus and the shaft of the first metatarsal [17]

Table 2 Definitions of measurements in the lateral view

Measurements	Definitions of measurements
Calcaneal inclination angle (CIA)	Angle constituted between the line formed in the direction of the weight-bearing surface and the line that outlines the plantar aspect of the calcaneus [17]
Talar declination angle (TDA)	The angle between the line formed in the direction of the weight-bearing surface and the line bisecting the neck of the talus [29]
Lateral talocalcaneal angle (TCA)	Angle constituted between the line bisecting the neck of the talus and the line that outlines the plantar aspect of the calcaneus [29]
First metatarsal declination angle (IMDA)	Angle constituted between the line bisecting the first metatarsal and the line formed in the direction of the weight-bearing surface [29]
Fifth metatarsal declination angle (5MDA)	Angle constituted between the line bisecting the fifth metatarsal and the line formed in the direction of the weight-bearing surface [29]
Navicular height (NHT)	The distance between the plantar medial aspect of the navicular and the line formed in the direction of the weight-bearing surface [17]
Lateral Meary's angle (LMA)	Angle constituted between the line bisecting the neck of the talus and the shaft of the first metatarsal [17]
Tibiotalar angle (TTA)	The angle between the neck of the talus axis and the tibial anatomic axis [17]

Fig. 1 **a** Measurements in anteroposterior view of the weight-bearing foot; *MAA* Metatarsus adductus angle, *HIPA* Hallux interphalangeal angle, *MBA* Metatarsal break (parabola) angle, *MW* Metatarsal width. **b** Measurements in anteroposterior view of the weight-bearing foot; *MPA* Metatarsus primus adductus angle, *HVA* Hallux valgus angle, *HIPA* Kite angle: Talocalcaneal angle, *AMA* AP Meary's angle



Fig. 2 **a** Measurements in lateral view of the weight-bearing foot; *CIA* Calcaneal inclination angle, *TDA* Talar declination angle, *IMDA* First metatarsal declination angle, *LMA* Lateral Meary's angle. **b** Measurements in lateral view of the weight-bearing foot; *TCA* Lateral talocalcaneal angle, *5MDA* Fifth metatarsal declination angle, *NHT* Navicular height, *TTA* Tibiotalar angle

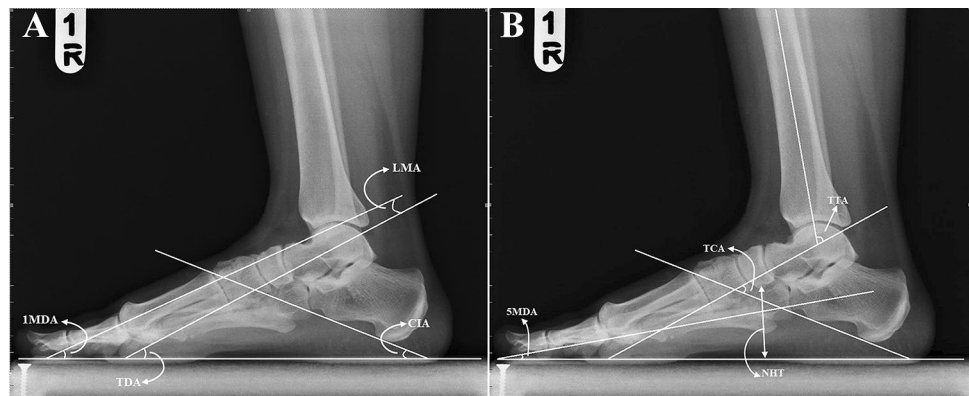
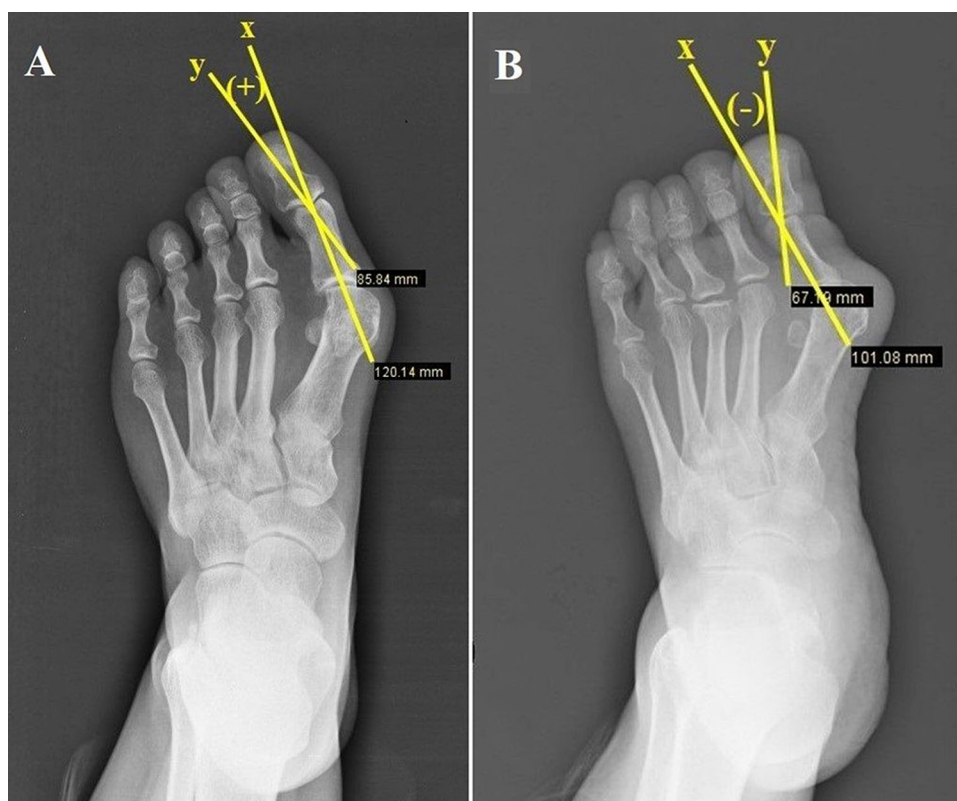


Fig. 3 The image of positive (A) and negative (B) measurement values of HIPA angle measurement in AP foot radiographs



reliability. All measurements had excellent intra- and inter-observer reliability [16].

Statistical analysis

The conformity of the variables to the normal distribution was assessed using a Shapiro–Wilk test and graphics. The mean, standard deviation, median, and range (minimum–maximum) of the measurements were calculated using descriptive analysis. The Paired Samples *t* test was performed for the right and left foot comparison of the normally distributed data. The relationship between quantitative variables was assessed using the correlation analysis, and the level of the relationship was determined using the Pearson Correlation Coefficient. The statistical analysis was performed using the IBM SPSS (version 21; SPSS, Armonk, NY, USA) software, with a significance level of $p < 0.05$.

Results

In our study, we evaluated AP and lateral radiographs of the feet from 66 patients with HV (mean age 44.35 ± 13.12 years; range 19–64 years). Table 3 shows the descriptive statistics of the radiological angle and

distance measurements obtained from 114 AP and lateral foot images of 66 patients included in the study.

The differences between the radiographic measurements of the right and left feet of 48 patients (96 feet) with HV, who had radiographic images of both feet, were examined (Table 4). Although the MPA ($p = 0.022$) and AMA ($p = 0.021$) measurements showed significant differences between the right and left feet, there were no significant differences in other measurements.

The correlation between age and all measurements obtained from the AP and lateral foot images, as well as the metatarsus primus adductus angle (MPA), hallux valgus angle (HVA), hallux interphalangeal angle (HIPA), metatarsal break (parabola) angle (MBA), first metatarsal protrusion distance (MPD), metatarsal width (MW), and AP Meary's angle (AMA) measurements associated with the hallux, were also investigated (Table 5). The significant correlation coefficients between our measurement outcomes were -0.188 – 0.658 . The results showed that HV angle (HVA) had a weak relationship with MAA ($r = 0.213$, $p = 0.023$) and MW ($r = 0.199$, $p = 0.034$), as well as a moderately positive relationship with MPA ($r = 0.480$, $p < 0.001$). However, it had a moderately negative relationship with AMA ($r = -0.333$, $p < 0.001$) and a weak negative relationship with HIPA ($r = -0.281$, $p = 0.002$) [6].

Table 3 The descriptive statistics of the age, radiological angle, and measurements of the patients

Radiographic angle and measurements	N	Mean±S.D.	Median	Minimum	Maximum	Std. Error
Age (year)	66	44.35±13.12	46.50	19	64	1.62
MAA (°)	114	12.81±4.63	12.75	3.50	24.00	0.43
MPA (°)	114	13.56±3.07	13.40	4.90	21.50	0.29
HVA (°)	114	30.63±8.81	29.40	15.20	51.90	0.83
HĪPA (°)	114	9.03±6.01	8.90	− 6.00	21.90	0.56
MBA (°)	114	145.18±7.04	145	127.70	162.10	0.66
MPD (mm)	114	0.49±2.73	0.82	− 6.55	6.92	0.26
MW (mm)	114	85.74±4.46	85.69	74.34	100.00	0.42
Kite angle (°)	114	25.23±4.43	25.80	15.06	35.70	0.42
AMA (°)	114	− 1.01±6.27	− 1.850	− 13.60	12.70	0.59
CIA (°)	114	22.22±6.36	21.95	9.20	37.71	0.60
TDA (°)	114	26.76±5.54	25.85	13.70	39.10	0.52
TCA (°)	114	48.40±7.54	48.90	30.10	66.70	0.71
1MDA (°)	114	25.80±3.27	26	18.20	32.80	0.31
5MDA (°)	114	12.42±3.54	11.80	4.10	20.40	0.33
NHT (mm)	114	39.83±5.193	39.55	27.61	52.27	0.49
LMA (°)	114	0.91±6.36	1.75	− 11.40	14.40	0.60
TTA (°)	114	65.85±3.61	66.20	56.80	72.90	0.34

Table 4 Radiographic measurements according to sides of foot

Measurements	Right		Left		Mean difference	SEM	t value	p value
	Mean	S.D	Mean	S.D				
MAA (°)	12.708	5.086	12.818	4.161	− 0.110	0.551	− 0.199	0.843
MPA (°)	13.048	2.885	13.910	2.946	− 0.863	0.363	− 2.377	0.022
HVA (°)	30.148	8.679	30.985	8.980	− 0.838	0.881	− 0.951	0.346
HĪPA (°)	9.358	5.671	9.458	6.180	− 0.100	0.689	− 0.145	0.885
MBA (°)	145.335	6.788	145.017	6.758	0.319	0.393	0.812	0.421
MPD (mm)	0.797	2.740	0.657	2.362	0.140	0.264	0.530	0.599
MW (mm)	85.794	4.296	85.279	4.106	0.515	0.399	1.290	0.203
Kite angle (°)	25.264	4.878	25.393	4.283	− 0.129	0.402	− 0.321	0.750
AMA (°)	− 1.278	6.477	0.012	6.403	− 1.290	0.539	− 2.392	0.021
CIA (°)	22.598	6.452	22.204	6.748	0.394	0.577	0.683	0.498
TDA (°)	27.172	5.686	26.851	5.199	0.321	0.478	0.672	0.505
TCA (°)	48.894	7.946	48.800	7.587	0.094	0.595	0.158	0.875
1MDA (°)	26.030	3.317	25.723	3.171	0.307	0.391	0.785	0.436
5MDA (°)	12.487	3.738	12.757	3.505	− 0.270	0.295	− 0.915	0.365
NHT (mm)	39.995	5.466	39.906	4.892	0.089	0.358	0.249	0.804
LMA (°)	1.084	6.728	0.572	6.307	0.512	0.523	0.980	0.332
TTA (°)	66.036	3.533	65.914	3.441	0.122	0.370	0.331	0.742

p values in bold signify a statistically significant difference

S.D. standard deviation, *SEM* standard error of the mean, * *p* < 0.05

Discussion

In surgical planning, the reference lines, angles, and measurements in radiological images play a significant role. These provide the foundation for the precise evaluation

of foot and ankle deformities in orthopedics, physical therapy, rehabilitation, and surgical sciences in general. HV deformity is among the most common musculoskeletal disorders in the foot and ankle impacting foot comfort. It is most commonly associated with a medial deviation of

Table 5 The correlation between hallux-related measurements and all measurements

		Age	AMA	MW	MPD	MBA	HIPA	HVA	MPA
MAA	r	0.130	-0.362**	-0.085	0.448**	0.127	-0.105	0.213*	-0.288**
	P	0.299	<0.001	0.371	<0.001	0.179	0.266	0.023	0.002
Kite angle	r	0.088	0.250**	-0.164	-0.166	-0.039	-0.045	-0.088	0.143
	P	0.482	0.007	0.080	0.078	0.677	0.631	0.353	0.129
CIA	r	0.046	-0.068	0.010	0.175	0.195*	-0.034	0.108	0.055
	P	0.715	0.472	0.914	0.062	0.038	0.723	0.254	0.563
TDA	r	0.176	0.319**	0.102	-0.188*	-0.195*	-0.058	-0.140	0.066
	P	0.157	0.001	0.278	0.045	0.038	0.537	0.136	0.487
TCA	r	0.105	0.223*	0.091	0.092	0.107	-0.033	-0.024	0.098
	P	0.400	0.017	0.335	0.328	0.258	0.727	0.797	0.301
1MDA	r	0.032	-0.032	-0.045	0.226*	0.263**	0.013	0.019	-0.002
	P	0.796	0.734	0.631	0.016	0.005	0.894	0.837	0.983
5MDA	r	0.034	0.225*	0.038	0.093	0.194*	0.074	0.038	0.143
	P	0.784	0.016	0.686	0.325	0.039	0.432	0.687	0.129
NHT	r	-0.112	-0.142	0.007	0.171	0.067	0.154	-0.017	-0.060
	P	0.370	0.131	0.939	0.069	0.480	0.102	0.859	0.528
LMA	r	-0.207	-0.073	0.073	0.309**	0.348**	0.176	0.048	-0.002
	P	0.095	0.440	0.443	0.001	<0.001	0.061	0.613	0.983
TTA	r	-0.119	-0.106	-0.115	-0.001	0.030	0.044	-0.133	-0.122
	P	0.341	0.263	0.222	0.993	0.748	0.642	0.158	0.197
MPA	r	0.125	-0.148	0.353**	-0.247**	-0.146	-0.246**	0.480**	1
	P	0.319	0.117	<0.001	0.008	0.120	0.008	<0.001	
HVA	r	-0.001	-0.333**	0.199*	0.137	0.042	-0.281**	1	
	P	0.993	<0.001	0.034	0.146	0.659	0.002		
HIPA	r	-0.298*	0.113	-0.022	0.233*	-0.004	1		
	P	0.015	0.230	0.819	0.013	0.968			
MBA	r	-0.106	0.134	-0.111	0.653**	1			
	P	0.397	0.156	0.240	<0.001				
MPD	r	-0.151	-0.067	-0.110	1				
	P	0.226	0.480	0.244					
MW	r	0.010	-0.209*	1					
	P	0.939	0.026						
AMA	r	-0.256*	1						
	P	0.038							
Age	r	1							
	P								

$r < 0.3$ poor, $r = 0.3-0.5$ fair, $r = 0.6-0.8$ moderately strong, $r > 0.8$ very strong [6]

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

the first metatarsal bone, deformity of the phalangeal bone and interphalangeal joint, and pronation with sesamoid subluxation [13]. Sex, heredity, and osteoarthritis all influence the prevalence of HV [24]. According to the literature, its prevalence is higher in women than in men [21]. The reason for this may be attributable to the shoe preferences in women, which are influenced by sociocultural structure and lifestyles [24]. Although previous studies have often evaluated various radiographic measurement data of patients with HV, very few studies have assessed

comprehensive radiographic measurement covering the patient's entire foot and explored the relationship of these measurement data with HV, as we performed in the present study. Hence, we believe that the present study is significant as it evaluated the measurement data that may be useful in HV diagnosis.

Steinberg et al. investigated the relationship between lower extremity alignment and HV in women, claiming that it developed because of a chain reaction that started in the hip joint [27]. Cavalheiro et al. studied the relationship

between HV and anatomical changes and radiographic findings on 22-foot radiographs of cadavers with HV. They determined that the hallux valgus angle (HVA) was 18.6° and the intermetatarsal angle (MPA) was 27.3° and hypothesized that anatomical changes in HV might depend on the degree of radiographic deformity [5].

Adult acquired flat foot (pes planus) is a condition that occurs or persists after the attainment of skeletal maturity and is characterized by the loss of height in the medial longitudinal arch and Some studies suggested the presence of a significant relationship between HV deformity and pes planus [1, 8, 15, 19, 25, 28]. Komeda et al. showed a significant relationship between HV deformity and pes planus [15]. These values were higher in the present study. Investigating the relation between HV and pes planus, Atbaşı et al. indicated that the mean values of HVA, MPA, Lateral Meary's angle (LMA), calcaneal inclination angle (CIA), and lateral talocalcaneal angle (TCA) angles in the AP and lateral radiographic images of the case group consisting of 56 participants with HV were 23.1° , 9.7° , 3.3° , 11.9° , and 32.8° , respectively. Their results also showed the presence of a high correlation between pes planus and HV [1]. However, the relationship between pes planus and HV remains controversial in the literature. In a study performed on men by Coughlin and Shurnas, no correlations were reported between HV and pes planus [8]. Saragas and Becker indicated that there were no differences in the incidence of pes planus between the HV and the control group in 110 African women with HV and healthy women [25]. However, Suh et al., investigated the relationship between HV and pes planus in 142 adult patients and concluded that there was no significant relationship between the two [28]. In our study, there was a significant and positive correlation between HVA and MAA, MPA, and MW measurements, as well as a negative correlation between AMA and HIPA measurements ($p < 0.05$). Furthermore, there was no significant correlation between age, HVA, HIPA, MPA, and MW measurements and foot lateral radiographic measurements. There were no significant relationships between HV deformity and pes planus angles in our study.

There are numerous studies in the literature that provide average values for different angle and length measurements of the feet of individuals with HV deformity. These studies compare the foot angle and length measurements of HV and healthy individuals on foot radiographic images and examine the relationship between HV and different foot pathologies. Preoperative radiography results in 516 patients with HV deformity were analyzed by Götze et al., who indicated that the mean HVA value was 34.5° and MPA 15.5° [12]. However, Lee et al. used radiographic images of 732 patients with HV to compute the mean of HVA, MPA, HIPA, MAA, and MPD measurements, which were 23° , 12° , 11° , 25° , and 2 mm respectively [18]. In a patient group of 30 participants,

Bryant et al. compared the foot radiographic images of control, HV, and hallux limitus. Although no significant differences in lateral radiographic measurements were found across study groups, they did find significant differences between the groups in MPA, HVA, HIPA, MPD, and MW measurements obtained from AP radiographic images [2]. In our study, the mean values of MAA, MPA, HVA, HIPA, MBA, MPD, Kite angle, AMA, and MW measurements in AP radiographic foot images were 12.81° , 13.56° , 30.63° , 9.03° , 145.18° , 0.49 mm, 25.23° , -1.01° , and 85.74 mm. On lateral radiographic images, the mean of CIA, TDA, TCA, 1MDA, 5MDA, NHT, LMA, and TTA measurements were 22.22° , 26.76° , 48.40° , 25.80° , 12.42° , 39.83 mm, 0.91° , and 65.85° , respectively. A comparison could not be established since the study used the mean values of the total population and the Study Group consisted of only women. The low number of male patients diagnosed with HV in our hospital archive, the lower number of female patients than predicted, and the small number of unilateral feet with an HV deformity in one foot but no deformity in the other ($n = 18$) were all limitations of our study. Moreover, multi-center studies with a larger sample size and a larger geographical area can be planned in future research.

Conclusion

Based on the results, we determined that the HV angle (HVA) is related to MAA, MPA, AMA, HIPA angles, and MW measurement. We believe that in addition to the HVA angle, MPA and AMA angles should be considered in the diagnosis of HV, especially as the HVA angle is moderately positively correlated with MPA angle and moderately negatively correlated with the AMA angle.

Author contributions AKA: project development, study design, data collection, data analysis, statistics, manuscript writing. ŞDM: study design, data collection, FB: data collection, data analysis, supply of radiological data. MGB: study design, manuscript editing, supervision of the study, revision of the manuscript.

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Availability of data and material All data can be shared transparently if there will be request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval Ethical approval was waived by the Non-Invasive Clinical Research Ethics Committee of Çukurova University (11.06.2021/112) in view of the retrospective nature of the study and all the procedures being performed were part of the routine care.

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