

## Length of the first metatarsal and hallux in hallux valgus in the initial stage

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Received: 13 January 2007 / Accepted: 12 February 2007 / Published online: 21 March 2007  
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**Abstract** The aim of this study was to confirm whether the length of the first metatarsal and the length of the hallux are greater than normal in the initial phase of the hallux valgus deformity. In a sample of 152 radiographs (98 of normal feet and 54 of incipient hallux valgus feet), the length of the first metatarsal and the hallux was measured according to methods previously described. Comparisons were made between normal and hallux valgus feet, and between male and female feet. The results show significant differences between the two groups in the first metatarsal ( $P < 0.0001$ ) and hallux ( $P < 0.001$ ). In the male feet, these differences are more marked (when comparing the length of the hallux between the female hallux valgus feet and the female normal feet,  $P > 0.05$ ). This indicates that in men with hallux valgus, the excess in length of the first metatarso-digital segment is greater than in women that develop this deformity, at least in its initial phase. According to these results, the size of the first metatarso-digital segment could be involved in the development of the hallux valgus deformity.

**Résumé** Le but de cette étude est de confirmer l'excès de longueur du premier métatarsiens et du gros orteil lors de la survenue d'une déformation en hallux valgus. Cent cinquante-deux radiographies ont été analysées, 98 pieds normaux, 54 pieds présentant un début d'hallux valgus. La longueur du premier métatarsien et de l'hallux ont été mesurées et la comparaison a été réalisée entre les deux variétés de pieds, et entre les hommes et les femmes. Les résultats de cette étude montrent qu'il existe une différence significative entre les deux groupes  $P < 0.0001$  pour le premier métatarsien et  $p < 0.001$  pour la longueur du gros orteil. Cette différence est beaucoup plus marquée chez l'homme que chez la femme. Cette étude montre donc que chez l'homme présentant un hallux valgus, l'excès de longueur du premier métatarsien et du gros orteil sont plus importants que chez la femme, au moins au début de la déformation. Ceci doit être pris en compte lors de la survenue d'un Hallux Valgus.

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### Introduction

Many authors have referred in the podiatric and medical literature to an excessively long or excessively short first metatarsal as an aetiology of hallux valgus. Excessive length of the first metatarsal with respect to the second has been associated to hallux valgus [9, 10, 13, 14] more often than has a short first metatarsal relative to the second [23]. We also find authors who do not associate an alteration in the protrusion of the first metatarsal with hallux valgus [2, 3].

When a first metatarsal bone is said to be excessively long in absolute length, it does not mean that it is longer than the second, rather that the first metatarsal is longer than normal, while still shorter than the second. The association of an excessive absolute length of the first

metatarsal and the deformity of hallux valgus has been reported previously [22]. However, there are also authors who state that in feet with this deformity, the first metatarsal is not longer than the second, rather it has a greater relative protrusion [14]. Paradoxically, an excessively short first metatarsal has also been attributed to the aetiology of hallux valgus [23]. Also, the alteration in the length of the hallux has been related with the aetiology of hallux valgus, specifically an excessive length [8, 10, 18, 22].

In view of the different opinions in the literature regarding this matter, this study was designed with the following aims: (1) to establish normal values for the lengths of the first metatarsal and hallux; (2) to confirm whether the lengths, absolute or relative, of the first metatarsal and hallux are greater than normal in the initial phase of the hallux valgus deformity; (3) to assess the relationship between the lateral deviation of the great toe and the length of the first metatarsal and hallux.

## Materials and methods

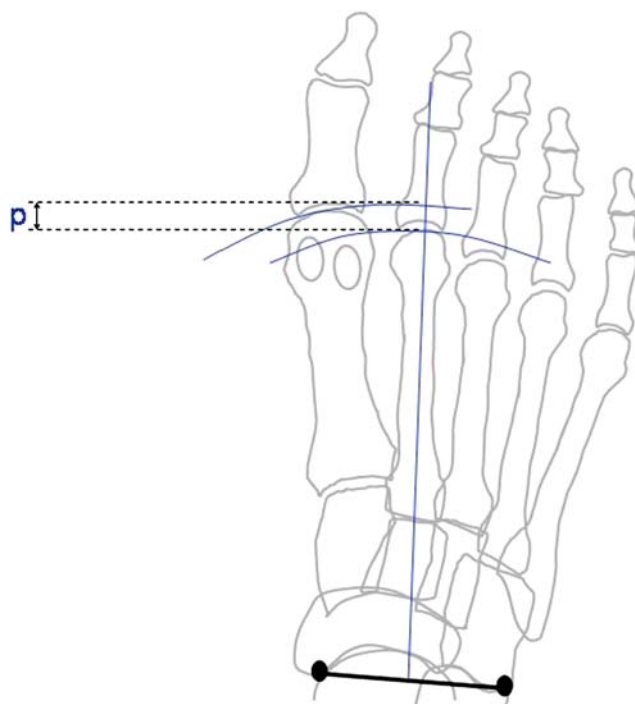
The subjects of this study were patients attending the Clinical Podiatric Service at the University of Seville from January 2004 to January 2006, and podiatry students who volunteered to take part in the research during the same period. After agreeing to participate in the study, each subject was asked to give written consent. This work has been approved by the Experimental Ethics Committee of the University of Seville.

The subjects participating in the study had to fulfill the following inclusion criteria: (1) to be in the 3rd decade of life (20–29 years), so that the growth physes had closed [20]; (2) never to have undergone osteoarticular surgery of the foot; (3) never to have suffered serious injury to the foot that might have altered its bone morphology; (4) not to suffer from degenerative osteoarticular diseases or neuromuscular imbalance; (5) not to present evident deformities of the forefoot that could affect the results of the study. First, subjects were recruited and radiographed. Then, the hallux abductus angle (HAA) and hallux dorsiflexion were measured so that they would be allocated to one of the two study groups: a control group and a group of feet with hallux valgus (HV group). The subjects comprising the control group had to have a hallux dorsiflexion of 65° or more, and a normal HAA—that is, equal to or less than 15° [4]. The subjects of the HV group had to present an HAA greater than 15° and less than 30°. This range was established according to the mild condition of hallux valgus previously reported [11]. A total of 92 subjects (184 feet) were initially included. HAA values of 14°, 15°, and 16° were eliminated in an attempt to reduce error probability in the measuring procedure, due to the proximity of those

values to the limit between normal and abnormal abduction of the hallux. Of the 152 resting feet (76 subjects), 98 formed the control group (49 subjects) and 54 the HV group (27 subjects). All the cases were bilateral.

A dorsoplantar weight-bearing radiograph was taken for each individual, with both feet together, with the tube inclined 15° to the vertical and at a tube-to-object distance of 1 m. A digital image of each radiograph was made using a scanner, allowing the exploration of images on positive film. The radiographic measurements were made using AutoCAD software (AutoCAD 2006; Autodesk Inc, San Rafael, CA), of proven efficacy for this task [17]. The following variables were studied: relative protrusion of the first metatarsal, length of the first metatarsal, length of the proximal phalanx of the hallux, length of the distal phalanx of the hallux, and length of the hallux (obtained from the sum of the lengths of the proximal and distal phalanges of the hallux). Other measurements made were the HAA and the length of the second metatarsal. All measurements were made by the same observer.

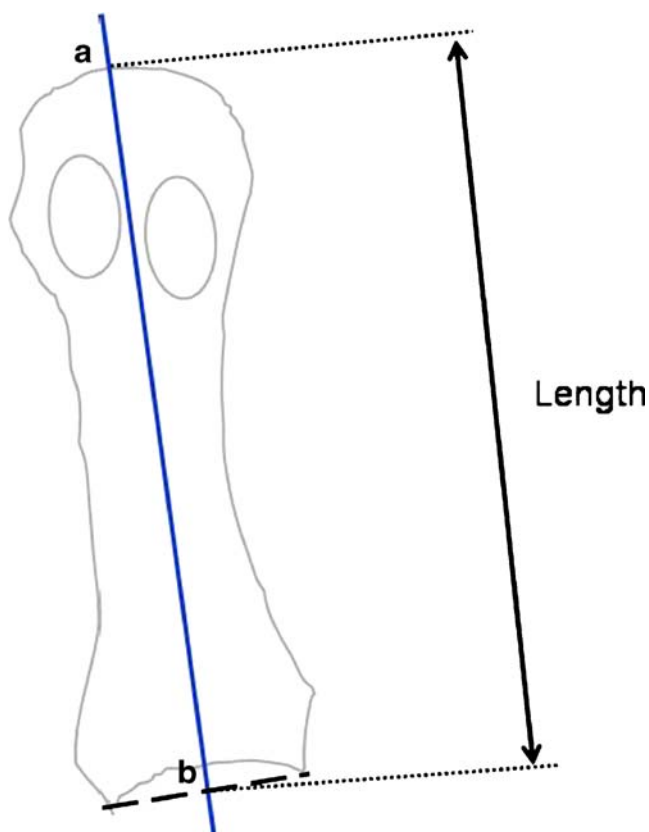
All the radiographic parameters were measured in accordance with previously described procedures: HAA [4], the relative first metatarsal protrusion [9] (Fig. 1), the lengths of the first and second metatarsals [10] (Fig. 2), the length of the proximal phalanx of the hallux [21] (Fig. 3), as well as the length of the distal phalanx [5].



**Fig. 1** Method of measuring the relative metatarsal protrusion between the first and second metatarsals, according to Hardy and Clapham (1951); p: protrusion

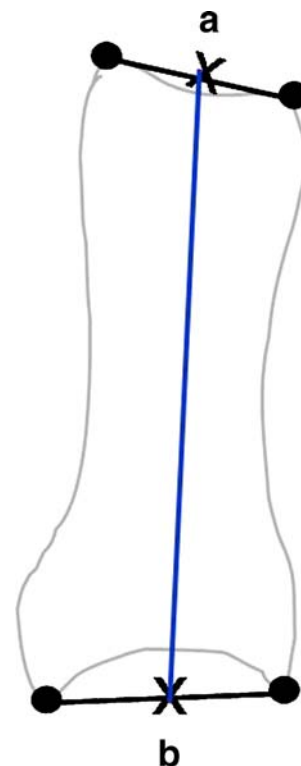
To standardise the set of measurements of the length of the first metatarsal, of the proximal and distal phalanges of the hallux, and of the hallux, these measurements have also been expressed as a percentage of the total length of the second metatarsal. These variables have been denominated “relative” to distinguish them from the absolute values.

To check the reproducibility of the measurement procedure, five radiographs were chosen at random from each group, and the measurements were made on three occasions, with intervals of a week between measurements. The data obtained from this group of measurements were used to calculate the intraclass correlation coefficient. The descriptive analysis gave the mean, standard deviation, and interval of confidence to 95% for each variable. To decide whether to use parametric or non-parametric tests, the Kolmogorov-Smirnov test was performed as a check of normality. Its result suggested that the Student’s *t* test for independent samples was the best to use for comparing the means between the control group and the HV group, because the data followed a normal distribution. The test of Levene was used for the equality of variance. Pearson correlation coefficients were calculated to assess the degree of relationship between the HAA and length of the first



**Fig. 2** Method of measuring the length of the first and second metatarsals. *a* Distal end of the first metatarsal head. *b* Point of intersection of the first metatarsal longitudinal axis of the metatarsal with a line connecting the proximal-medial and proximal-lateral ends of the metatarsal base

**Fig. 3** Method of measuring the length of the proximal phalanx of the hallux. *a* Midpoint between the distal-medial and distal-lateral ends of the phalanx head. *b* Midpoint between the proximal-medial and proximal-lateral ends of the phalanx head



metatarsal, protrusion of the first metatarsal, lengths of the proximal and distal phalanges of the hallux, and length of the hallux. *P* values below 0.05 were considered statistically significant. The data were analyzed using the software package SPSS 12.0 for Windows (SPSS Science, Chicago, IL).

## Results

The value of the intraclass correlation coefficient was greater than 0.95 for all the variables measured on the radiographs. All these coefficients can be considered very high, so that the reproducibility of the measurements is acceptable with the methods used.

The control group comprised 98 feet of 49 subjects, 19 men and 30 women, with a mean age of  $23.44 \pm 2.85$  years. The HV group comprised 54 feet of 27 subjects, 11 men and 16 women, with a mean age of  $23.15 \pm 2.22$  years.

The values from the descriptive analysis of the variables (absolute and relative values) are shown in Table 1. Comparisons were made using the relative values of the variables, except for first metatarsal protrusion.

When comparisons are made between control and HV groups with separated male and female feet, the results change (Table 2). In female hallux valgus feet, the excess of length affects only the first metatarsal, not the hallux. In male hallux valgus feet, variables related to the lengths of the first metatarsal and hallux appear to be increased.

**Table 1** Mean, standard deviation, and 95% confidence interval of the absolute and relative variables

	Absolute values		Relative values		Significance
	Mean $\pm$ SD	95% CI	Mean $\pm$ SD	95% CI	
Hallux dorsiflexion					
Control	75.00 $\pm$ 8.67	73.26–76.74	–	–	–
HV	61.71 $\pm$ 14.08	57.79–65.63			
HAA					
Control	8.73 $\pm$ 3.37	8.06–9.41	–	–	–
HV	20.50 $\pm$ 2.73	19.74–21.26			
1MTT protrusion					
Control	0.84 $\pm$ 3.01	0.24–1.45	–	–	<0.0001*
HV	3.49 $\pm$ 3.36	2.55–4.43			
1MTT length					
Control	65.48 $\pm$ 4.67	64.54–66.41	84.27 $\pm$ 2.83	83.70–84.84	<0.0001*
HV	67.91 $\pm$ 4.41	66.68–69.13	86.26 $\pm$ 3.00	85.42–87.09	
2MTT length					
Control	77.81 $\pm$ 6.47	76.51–79.11	–	–	–
HV	78.54 $\pm$ 5.51	77.04–80.04			
PFH length					
Control	32.70 $\pm$ 3.22	32.06–33.35	42.05 $\pm$ 2.57	41.53–42.57	<0.0001*
HV	34.57 $\pm$ 2.61	33.84–35.30	43.92 $\pm$ 2.52	43.22–44.63	
DFH length					
Control	24.09 $\pm$ 2.84	23.51–24.66	30.94 $\pm$ 2.45	30.45–31.43	0.292
HV	24.75 $\pm$ 2.84	23.96–25.54	31.37 $\pm$ 2.31	30.73–32.02	
Hallux length					
Control	56.79 $\pm$ 5.53	55.69–57.90	72.99 $\pm$ 3.82	72.22–73.76	<0.001*
HV	59.32 $\pm$ 5.10	57.90–60.75	75.30 $\pm$ 3.98	74.20–76.41	

HAA: hallux abductus angle; 1MTT: first metatarsal; 2MTT: second metatarsal; PFH: proximal phalanx of the hallux; DFH: distal phalanx of the hallux. Hallux dorsiflexion and HAA are expressed in degrees. First metatarsal protrusion and absolute variables are expressed in millimeters. Relative variables are expressed in percentage of the second metatarsal length. \*The difference was statistically significant

**Table 2** Comparison of first metatarsal protrusion and relative variables between control and HV groups with separated male and female feet

	Male feet		Female feet	
	Mean $\pm$ SD	P	Mean $\pm$ SD	P
1MTT protrusion				
Control	0.32 $\pm$ 4.09	<0.01*	1.17 $\pm$ 2.07	<0.0001*
HV	3.61 $\pm$ 4.04		3.57 $\pm$ 2.81	
1MTT length				
Control	83.23 $\pm$ 3.00	<0.01*	84.89 $\pm$ 2.55	<0.01*
HV	85.94 $\pm$ 3.11		86.56 $\pm$ 2.89	
PFH length				
Control	41.94 $\pm$ 2.53	<0.0001*	42.12 $\pm$ 2.62	<0.05*
HV	44.63 $\pm$ 1.76		43.63 $\pm$ 2.93	
DFH length				
Control	31.77 $\pm$ 2.25	<0.05*	30.41 $\pm$ 2.45	>0.5
HV	32.87 $\pm$ 1.67		30.28 $\pm$ 2.11	
Hallux length				
Control	73.71 $\pm$ 4.00	<0.0001*	72.54 $\pm$ 3.67	>0.5
HV	77.51 $\pm$ 2.64		73.69 $\pm$ 4.06	

First metatarsal protrusion is expressed in millimeters. Relative variables are expressed in percentage of the second metatarsal length. \*The difference was statistically significant

The values of the variables shown in Table 2 for the male feet are different from those for the female feet. When these variables are compared between men and women, lengths of the first metatarsal and distal phalanx of the normal male feet are different from those of the normal female feet ( $P < 0.01$ ). In the HV group, lengths of the distal phalanx and hallux of the male feet are different from those of the female feet ( $P < 0.0001$ ). These results are shown in Table 3.

Poor-to-moderate association was found between HAA and the first metatarsal protrusion ( $r = 0.498$ ,  $P < 0.0001$ ), the first metatarsal length ( $r = 0.443$ ,  $P < 0.0001$ ), proximal phalanx length ( $r = 0.383$ ,  $P < 0.0001$ ) and hallux length ( $r = 0.258$ ,  $P < 0.01$ ). Other correlations show some interesting data: strong and significant correlation was found between the first metatarsal protrusion and first metatarsal length ( $r = 0.832$ ,  $P < 0.0001$ ), between the proximal phalanx and hallux lengths ( $r = 0.814$ ,  $P < 0.0001$ ), and between the distal phalanx and hallux lengths ( $r = 0.759$ ,  $P < 0.0001$ ).

## Discussion

The authors consider that the main limitation of this work is the use of two-dimensional images to evaluate tridimensional elements. An attempt has been made to reduce as far as possible the risk of errors related with this aspect, following a standardised and rigorous radiological protocol. Other studies have already demonstrated that whenever radiography is performed with the same protocol, the differences with the actual situation can become non-significant, at least with regard to the first metatarso-digital segment [6].

Different authors have associated the increased protrusion of the first metatarsal to the hallux valgus deformity [9, 10, 13, 14]. The results of this study concur. The range of normality for the protrusion of the first metatarsal is considered to be  $-2$  mm to  $+2$  mm [13, 19, 21]. Thus, according to the results of our study, in the initial phase of the

pathology of hallux valgus there is an increased protrusion of the first metatarsal ( $0.84 \pm 3.02$  mm in the control group;  $3.49 \pm 3.36$  mm in the HV group). Moreover, we have found that the first metatarsal is not only further forward than the second in the HV group (relative protrusion), but is also longer than normal ( $65.48 \pm 4.67$  mm in the control group;  $67.91 \pm 4.41$  mm in the HV group).

Some authors maintain that in patients with hallux valgus, the length of the proximal phalanx is greater than in patients without hallux valgus [22]. Conversely, other studies found no direct relationship between the length of this segment and the HAA [12]. However, an excessive total length of the hallux has been related with the hallux valgus deformity on several occasions [8, 10, 18, 22]. Authors who reject the possibility that a very long hallux is related to pathologies such as hallux valgus can also be found [14]. The results of our study show that both the proximal phalanx of the hallux and the great toe are longer in the hallux valgus than in the normal feet ( $P < 0.0001$  and  $P < 0.001$ , respectively) of this sample.

When comparisons between men and women are made, it is observed that, in the case of the male feet, both the proximal and the distal phalanges are longer than normal. In the female feet, only the proximal phalanx is longer than normal. The result of this is that the hallux is significantly longer than normal in the men, possibly thanks to the additional contribution of the distal phalanx. However, in women there is no excessive length of the hallux, because the distal phalanx is not different between normal and hallux valgus feet and because the difference in the proximal phalanx is lower than in men's feet.

When the protrusion of the first metatarsal, the length of the first metatarsal, the length of the proximal phalanx of the hallux, or the total length of the hallux are separately analysed, the differences found between the control and HV groups might be considered clinically insignificant (although they were statistically significant), as they are relatively small differences. Nevertheless, the authors think that these differences should be considered. In fact, a strong and very significant association has been observed between the protrusion and length of the first metatarsal, indicating that it is very possible that when the protrusion of the first metatarsal is increased, its length is as well. The relationship between these two variables and the length of the hallux or its proximal phalanx is less, but still very significant. Thus, when the increases in length of these elements are combined, the result will be a very long first metatarso-digital segment.

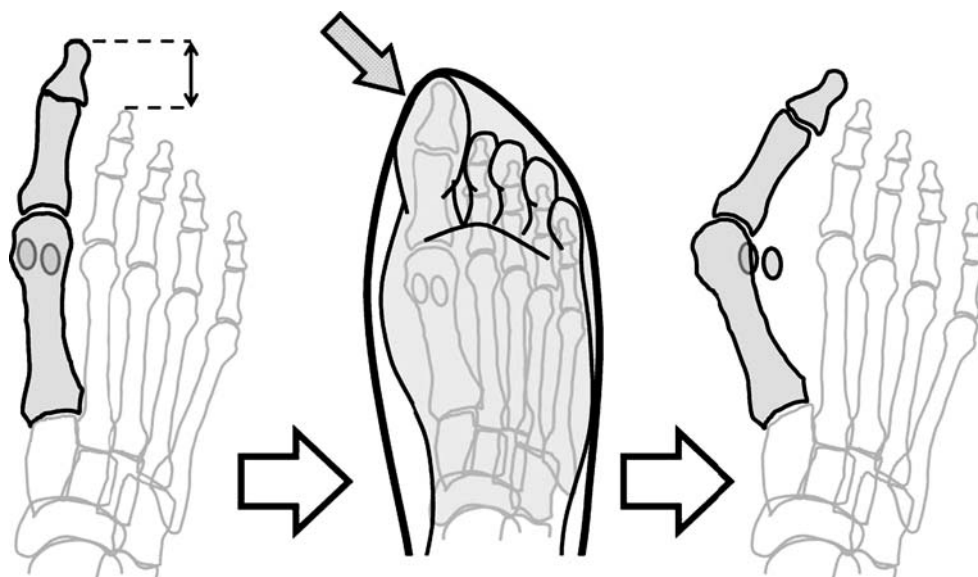
If the lever comprised by the first metatarsal and the hallux is over-long, the pressure received by the hallux in the push-off phase of gait [1], and the pressure from footwear, generate the need to shorten that lever. One way to functionally achieve this is by producing segmentary

**Table 3** P values from the comparison of the first metatarsal protrusion and relative variables of the male and female feet of both the control and the HV group

	Control male feet vs. female feet (P values)	Hallux valgus male feet vs. female feet (P values)
IMTT protrusion	0.178	0.971
IMTT length	0.008*	0.446
PFH length	0.731	0.159
DFH length	0.007*	<0.0001*
Hallux length	0.140	<0.0001*

\*The difference was statistically significant

**Fig. 4** With a long first metatarso-digital segment, pressure from the fore part of the shoe tends to deviate the hallux laterally. Grey arrow: pressure from the footwear

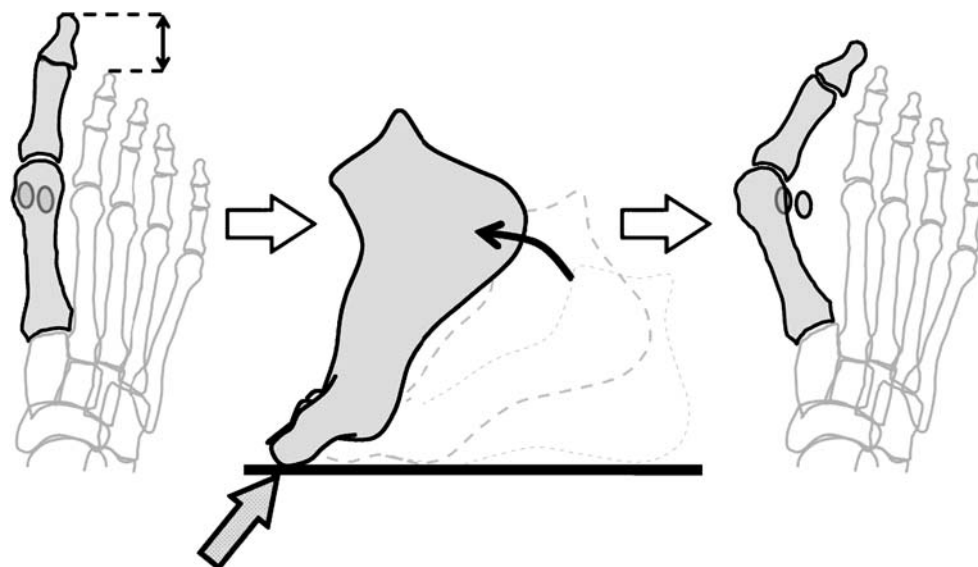


deviations in the transverse plane. The deviations that must be produced in the first metatarsal and the hallux to compensate this excessive length require a joint that allows movement in the transverse plane, so that it acts as a hinge. When excessive length is combined with a rounded shape of the head of the first metatarsal—as is very frequent in the hallux valgus deformity [7, 9, 15]—the deviation takes place at the level of the metatarsophalangeal joint (Figs. 4 and 5). The hallux moves in abduction because under normal conditions it is already found slightly in this position [16]. If this hypothesis is accepted, the shortening of the bone following osteotomies for the surgical correction of hallux valgus could be a beneficial secondary effect of hallux valgus surgery in some cases. It needs to be made clear that this is, indeed, a hypothesis, and that there is no directly supporting evidence on the

development of foot deformities on the basis of morphological or functional measurements.

It has been observed that in both male and female feet of the HV group, the protrusion of the first metatarsal, and the lengths of the first metatarsal and the proximal phalanx of the hallux, are increased with respect to the control group. However, the values of the differences of these three variables between males and females are higher for male feet than for female feet. In the case of men, the excessive length of the distal phalanx, and of the great toe, must also be added. It is possible that to arrive at the same degree of lateral deviation of the hallux, male feet need to have a greater increase in length of the first metatarso-digital segment than do female feet, to produce the compensation mentioned above, as women usually have a more-rounded head of the first metatarsal [7], so that the movement in the

**Fig. 5** Pressure on the hallux in the push-off phase in gait tends to deviate the hallux laterally. Grey arrow: pressure received by the hallux in the push-off phase of gait



transverse plane would be produced with less difficulty—that is, with lower intensity of the forces that deviate the hallux laterally. This could be the subject of further research.

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