HALLUX VALGUS AND FLAT FEET: ARE PLANTAR FORCES EQUAL?

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SUMMARY

Objective: to measure the plantar forces above the toes of women with hallux valgus and/or flat feet. Methods: This study involved women with hallux valgus and/or flat feet confirmed by X-ray images. The plantar forces were measured utilizing force plates. Force was measured three times, which were taken with the women on barefoot and at upright position, recording the average for the three measurements. Data were acquired from Spider 8 system (HBM) and analyzed by using a Catman® software. The measurements for both feet's toes force were reported and the averages were compared by the Student's t-test according to the presence of hallux valgus and flat feet; the association between these deformities was estimated by using the two-tailed Fischer's exact test, the statistical significance adopted was $\alpha = 5\%$. Results: For this study, 20 women with or without hallux valgus were included. The mean force values found showed to be higher on the fifth toe compared to first toe of both feet ($p < 0.05$) in both situations. Conclusion: in this study, we found strong forces on the fifth toe than on the first toe, contradicting some studies in literature.

Keywords: *Foot Joints; Foot; Hallux Valgus; Flat foot.*

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INTRODUCTION

Studies addressing pressure distribution measurements between foot surface and the ground have already been developed, since the late days of 19th Century[1].

Monitoring efforts generated on lower limbs as a result of specific human activities such as gait and run is important in studies addressing forces distribution at plantar region[2].

Old methods employed to estimate plantar forces were based only on footprints on appropriate materials, such as plaster and clay[3]. Currently, more sophisticated procedures to record plantar prints exist, such as: optical, piezoelectric, resistive and capacitive sensors, as well as a diversified technological development regarding systems, principles, components and devices used in biomechanics for measuring the distribution of plantar pressure, named as baropodometry[1].

Anatomical changes such as the hallux valgus are characterized by a side shift of the first phalange and medial shift of the first metatarsus. Due to that, a bone protuberance may develop on the medial surface of the first metatarsal head portion, causing an increase of surrounding soft tissues volume. The increased pressure and the friction with shoes may lead to the development of a pocket, which frequently becomes painful and inflamed[4].

Another anatomical change, the flat foot, is characterized by a reduced or absent medial longitudinal foot arch, being a common occurrence in childhood[5]. This can be described as a foot that, during load support, remains in a persistent pronation status[6].

The correlation between hallux valgus and flat foot is not fully understood; other more objective and quantitative studies are required. From the baropodometric view, there are no studies evidencing whether a potential inter-correlation exists or not.

The objective of this study was to estimate plantar forces on foot toes of women with hallux valgus and/ or flat foot.

METHODOLOGY

This was a cross-sectional study involving women from Guaratinguetá, in 2005. For performing experimental procedures, twenty women presenting with hallux valgus on both feet, confirmed by X-ray images by hallux valgus (HV) and intermetatarsal (IM) angles were selected. The maximum load determined for inclusion in the study was 80 kg, due to the maximum weight support capacity of the columns.

Data concerning weight (as Kg) and height (as meters) were collected from these women on an anthropometric scale in increments of 5 grams and 1 centimeter. Values of the body mass index (BMI) were estimated.

Plantar forces were estimated as Newtons by means of a pressure sensor developed at the FEG-UNESP Laboratory of Biomechanics. The pressure sensor was constituted of 2 25 cm-large and 35 cm-long steel metallic frames, one of which representing right feet and the other, left feet. To each frame, 16 prismatic columns were welded where the free end of each column corresponded to a specific foot point. On each column, two electric strain gages (Kyowa KFG-3-120-C1-11 model) with factor $k = 2.10$ (factor provided by the manufacturer, enabling an extensive deformation), were respectively fixed, one next to the upper fixed end of the column and another next to the lower fixed end, which, by means of a Wheatstone's half-bridge circuit, were used for measuring forces acting on column's end.

The columns were subsequently numbered, starting from the region corresponding to the first phalange through the whole external outline of the foot and ending at the region corresponding to the second metatarsus. On the force platforms, rubber surfaces were attached, measuring 25 cm large and

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35 cm long, where a 37-size inner shoe sole made of paper was stuck at the very center of the rubber surfaces, one for the right platform and the other for the left, aiming to guide the subject where to correctly step on (Figure 1).

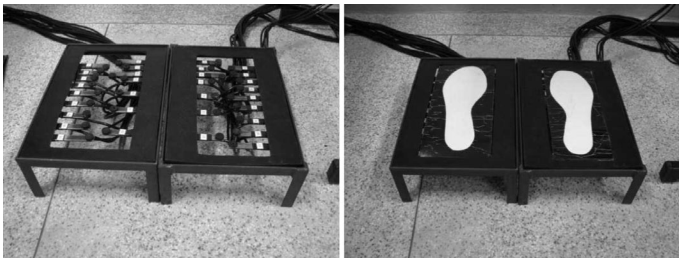

***Figure 1-** Detail of the right and left force platforms developed at DME – FEG/ UNESP, for estimating plantar forces.*

By means of a convenient Catman software[7] automatic calibration of sensors was provided. The signal originated from the bridge built with the gages in mV/V was automatically converted into force signal [N] by applying loads on each sensor built-in column's ends. This calibration was introduced into the software mentioned above and any other load applied on the sensor was automatically converted into force, instead of an electric signal (mV/V).
For performing the tests, the first step was constituted of collecting baropodometric activity by means of the contact of the plantar surface of women with hallux valgus and/ or flat feet on the platform. Data acquisition frequency used was 10 Hz. Once capturing was initiated, the subject stood up and remained so on the platforms for 20 seconds, then sitting down again. For each sensor, three measurements were made, enabling to obtain an average value. The total time for capturing was 20 seconds, but the first six and the last five seconds were excluded, respectively representing the moments in which the subjects were stepping up and down the platform.
The signals captured during measurements were amplified by means of an amplifier bridge, stored in a PC, and subsequently analyzed.
After baropodometric activity capture of the women, they were submitted to plantar printing in order to rate their plantar arches.
The rating method employed was the one described by Cavanagh and Rodgers[8] (Figure 2).
A longitudinal axis was designed from the center of the heel to the center of the second toe, respectively corresponding

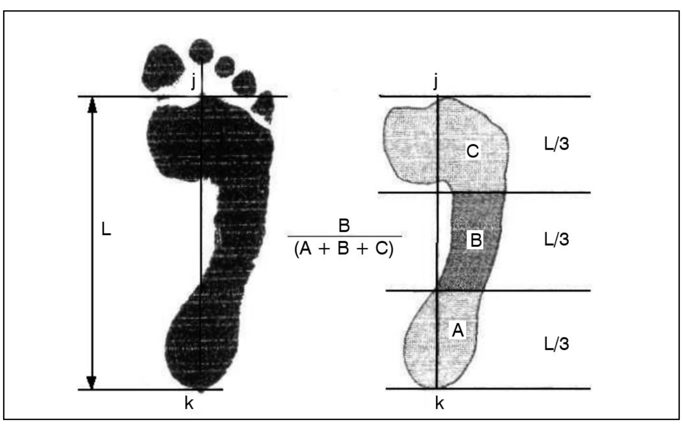

***Figure 2 -** Method employed for plantar arch classification, according to Cavanagh and Rodgers[8].*

to lines K and j, then, two perpendicular lines were drawn, one on heel base and another on foot's anterior region base, excluding the fingers, being the distance between those lines represented by L, which was divided into three equal portions, represented by A, B and C. Once the ratio coefficient of the foot areas was obtained, plantar arch rating was provided. The parameter employed to rate the kind of foot was:

$$\frac{B}{(A+B+C)}$$

Where A represents foot's anterior region (forefoot), B is foot's medial region (mesofoot) and C the area of foot's posterior region (hindfoot), with feet being rated as cavus (coefficient < 0.07), normal (between 0.08 and 0.24) and flat (between 0.25 and 0.36).
Subsequently to the baropodometric activity and plantar print collection, women were submitted to X-ray on both feet in order to classify the degree of hallux valgus.
Angle measurements made by means of X-ray images were also described by Hardy and Clapham[9] (Figure 3).

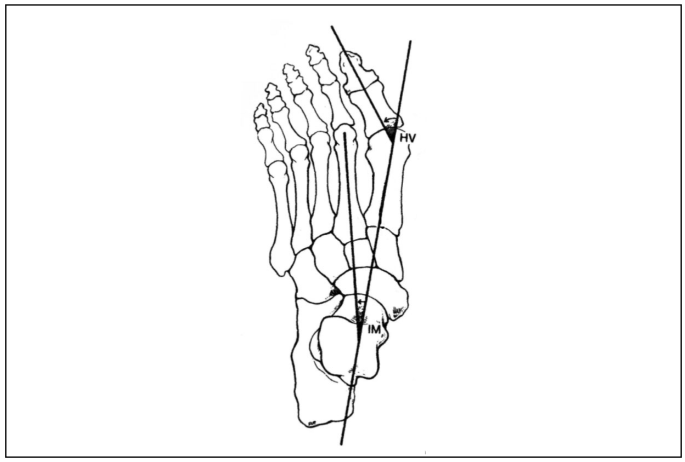

***Figure 3 -** Model used for hallux valgus classification, according to Hardy and Clapham (9).*

A longitudinal axis was sketched at the center of the first metatarsus, then, another longitudinal axis was delineated at the center of proximal hallux phalange, the intersection of these both axis formed the HV angle. Another angle was formed by the intersection between the longitudinal axis sketched at the center of the first metatarsus and the longitudinal axis made on the center of the second metatarsus, forming the IM angle, with hallux valgus being rated as normal (HV $\leq 15^o$ and IM $\leq 9^o$), medium (HV 16^o - 20^o and IM 10^o - 11^o), moderate (HV 21 - 40^o and IM 12 - 16^o) and severe (HV $> 40^o$ and IM $> 16^o$).
In order to analyze in which foot toe the subjects presented the strongest and weakest force, a comparison of the forces on sensors numbers 1 and 5 was performed (which represented, respectively, the first and fifth toes) of the women with hallux valgus and of those with flat feet, where averages and standard deviations for forces on sensors 1 and 5 were analyzed
The Student's *t*-test and the Fischer's exact test were employed in this study for statistical analysis of the sample. The Student's t-test was used to compare the average values of plantar forces in all women in the sample, particularly fractions of the 5th and 1st toes of both feet, both for those with hallux valgus and for those with flat feet. The two-tailed

Fischer's exact test was used to detect any correlation, if existent, between variables of women with and without hallux valgus.
The software programs employed for performing analyses and tests were the Microsoft Excel and the Epi-Info 6.04[10]. Statistical significance adopted in this study was $\alpha = 5\%$ ($p < 0.05$).
The present study was submitted to the appreciation of the Committee of Ethics in Research of the University of Taubaté, which, by complying with the use of competencies described on the Resolution CNS/MS 196/96 regarded the study as approved, according to the registration CEP/UNITAU nr. 041/04.

RESULTS

Twenty women were enrolled in the study, 12(60%) with flat feet and the remaining 8 (40%) with normal feet. Subjects ages ranged from 21 to 65 years (mean age 42.3 years; sd = 4.7 years), and the average BMI was 23.6 kg/m^2 (sd = 3.4 kg/m^2).
Eight women (40%) in the sample showed HV < 15^o, being regarded as normal.
It was found that women with hallux valgus had a mean age of 48.2 years (sd = 16.1 years), while those without the deformity were younger (mean age = 36.4 years; sd = 10.9 years) ($p > 0.05$).
No statistical significance was found on BMIs of women with and without hallux valgus ($p = 0.22$), and no statistically significant difference was found on BMIs of women with and without flat feet, as well ($p = 0.59$).
Also, no correlation was found between subjects' ages with and without flat feet ($p = 0.28$).
According to the averages found on right feet's 1st and 5th toes of all women with flat feet, it was possible to identify forces differences between 1st and 5th toes ($p < 0.001$) (Table 1).

Subjects with flat feet	F1D	F5D
1*	0.3	22.0
2*	3.5	29.6
3*	6.2	23.1
4*	6.5	16.4
5*	1.9	11.3
6*	11.7	23.6
7*	11.4	12.6
8*	7.2	22.5
9*	6.0	7.0
10	7.8	16.6
11	3.7	6.0
12	13.8	19.2
Average (sd)	6.7 (4.1)	17.5 (7.2)
	p < 0.001	
* Women with hallux valgus		

Table 1 - *Distribution of average forces on 1st and 5th toes of right feet with the respective averages of these forces and respective standard deviation values of 11 women with flat feet. Guaratinguetá, 2005.*

From the average values of force on 1st and 5th toes of the left feet of all women in the sample presenting with flat feet, we could find differences between the averages of those forces ($p < 0.01$) (Table 2).
The same was found by analyzing the forces on the 1st and 5th toes of right and left feet of all women in the sample presenting with hallux valgus, with differences being noticed between average values of forces ($p < 0{,}001$) for right feet and ($p < 0.01$) for left feet (Tables 3 and 4).
The two-tailed Fischer's exact test showed no correlation between hallux valgus and flat feet, possibly because of the sample size ($p = 0.17$).

Subjects with flat feet	F1E	F5E
1*	3.7	14.6
2*	6.1	23.5
3*	19.5	23.2
4*	6.2	13.0
5*	7.2	8.0
6*	4.0	19.8
7*	7.0	9.1
8*	3.6	26.3
9*	2.5	15.7
10	5.5	13.3
11	19.4	14.1
12	10.2	11.3
Average (sd)	7.9 (5.8)	16.0 (5.9)
	p < 0.01	
* Women with hallux valgus		

Table 2 - *Distribution of average forces on 1st and 5th toes of left feet with the respective averages of these forces and respective standard deviation values of 11 women with flat feet. Guaratinguetá, 2005.*

Subjects with hallux valgus	F1D	F5D
1*	0.3	22.0
2*	3.5	29.6
3	15.0	19.7
4*	6.2	23.1
5*	6.5	16.4
6*	1.9	11.3
7*	13.9	16.3
8*	11.4	12.6
9*	7.2	22.5
10	12.3	26.3
11*	6.0	7.0
12	8.6	19.0
Average (sd)	7.7 (4.7)	18.8 (6.5)
	p < 0.001	
* Women with flat feet		

Table 3 - *Distribution of average forces on 1st and 5th toes of right feet with the respective averages of these forces and respective standard deviation values of 12 women with hallux valgus. Guaratinguetá, 2005.*

Subjects with hallux valgus	F1E	F5E
1*	3.7	14.6
2*	6.1	23.5
3	4.1	22.8
4*	19.5	23.2
5*	6.2	13.0
6*	7.2	8.0
7*	0.3	0.4
8*	7.0	9.1
9*	3.6	26.3
10	17.7	22.9
11*	2.5	15.7
12	4.8	15.9
Average (sd)	6.9 (5.8)	16.3 (7.8)
	p < 0.01	
* Women with flat feet		

Table 4 - *Distribution of average forces on 1st and 5th toes of left feet with the respective averages of these forces and respective standard deviation values of 12 women with hallux valgus. Guaratinguetá, 2005.*

DISCUSSION

This was an innovative study, using plantar forces measured by means of two force platforms developed at FEG - UNESP, to estimate plantar forces on toes of women with hallux valgus and or flat feet.

The study was conducted only on women, in the light of the high prevalence of orthopaedic problems attributed to shoe models worn and to the structure of female's foot itself. We could identify differences between the forces on 1st and 5th toes, with the 5th toe showing stronger forces compared to the 1st toe, a finding that is contrary to other studies.

In the group of women with hallux valgus, only 3 (30%) were Afro-American, consistently to some authors' reports that the incidence of such deformity is higher among Caucasian women[11]. These subjects presented with flat feet, which, according to some reports, is consistently more frequently found in Afro-American populations[12].

It is suggested that flat feet have a causal relationship with hallux valgus, because this deformity was never found in a cavus foot, a fact also seen in our study, where in the group of women with that deformity, none of them presented with cavus feet, according to the method employed in the classification of plantar arch[13].

On the other hand, flat feet apparently should be ruled out as an important etiologic factor for hallux valgus[14]. Furthermore, the clinical appearance of the plantar arch should be regarded as totally irrelevant in assessing the deformity of the first metatarsophalangeal joint, which is consistent to studies by Saragas and Becker, where a high percentage of flat feet was reported in subject groups presenting the deformity, but no correlation was found between flat feet and hallux valgus, although the study has been performed from X-ray analysis, making it somehow unreliable[12]. The high percentage of flat feet was due to the fact that the sample is constituted of African-American women, as expected.

Concerning data obtained in this study's results, we can see that women with hallux valgus, despite of the more advanced age, were similar to those of the other group, as expected. According to Salomão, this deformity can be associated to a rheumatic etiology, which can explain its incidence in older individuals, although the frequency of such deformity in adults and children is above expectations[15,16].

On the other hand, the correlation between hallux valgus, flat feet and ground response force is not well understood yet[17]. These very researchers state that subjects with flat feet show overwhelming loads on first toe, which can become hypermobile and predispose to hallux valgus development, which is contrary to the values obtained in this study, where significantly heavier loads were seen on the 5th toe of both feet of women with flat feet compared to the first toe.

Subjects with normal feet can also show heavy loads on the first toe, because it is bigger and has stronger fixed muscles[18]. These results, once more, elucidate the fact of the inexistence of a correlation between hallux valgus and flat feet.

On the other hand, some authors report having found a correlation between hallux valgus and flat feet, but they suggest that further studies should be conducted to better assess the situation[13,19]. The prevalence of flat feet found was 8 to 24 times higher than expected in subjects with hallux valgus, showing some correlation between both deformities; however, it doesn't show what the cause and the effect of such correlation would be[19]. These conclusions were based only on X-ray analysis at HV and IM angles, which can render this study as less precise and reliable, because the way in which the angles are delineated to evaluate X-ray images is a little subjective[19].

Nevertheless, in addition to step on force platforms, the subjects were also submitted to X-ray studies and plantar print collection, where one can see that the values of plantar forces obtained by means of baropodometric activity were the most reliable ones.

The present study showed the reliability of data obtained by plantar force compared to X-ray and plantar prints data.

CONCLUSIONS

By the present study, it was possible to estimate plantar forces and identify differences in more intense ones on the 5th toe compared to the 1st toe of both feet of women with hallux valgus and/ or flat feet, as opposite to current reports.

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