Characteristics of static and dynamic loading of the plantar surface of the foot in women with hallux valgus deformity

Charakterystyka warunków statycznego i dynamicznego obciążania powierzchni podeszwowej stóp u kobiet z koślawym zniekształceniem palucha

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Key words
transverse arch of the foot, forefoot, rear-foot, center of pressure line

Abstract
Introduction: Hallux valgus is one of the most common foot deformations, which occurs twice as frequently in women than in men. The aim of the study was to evaluate the feet soles pressure distribution pattern of young women with hallux valgus deformity.
Material and methods: The study sample consisted of 23 young women (21-27 years). Among the participants, 14 demonstrated the presence of single- or double-sided hallux valgus (study group – a total of 22 feet with hallux valgus) and 15 women had the correct angle of the big toe for one or both feet (control group – a total of 23 feet without deformation). The research tool was the Podoscan 2D platform and the FreeMED force platform (Sensor Medica, Italy). Using the FreeStep Professional software on the plantocontourograms of the feet, the angle of hallux valgus was determined (ALFA angle). In statics the following parameters were assessed: maximal fore- and rear-foot loading, percentage loading of forefoot and the Weissflog indicator, and in dynamics (gait): the percentage loading of forefoot and medial part of the foot, the value of maximum foot pressure and the passage point of the center of pressure line.
Results: There were no differences between the study and control group regarding loading of the fore- and rear-foot or pressure distribution pattern on the lateral and medial side of the foot, however, statistically significant differences were observed in the value of the Weissflog indicator and the exit place of the center of pressure line.
Conclusions: 1. Hallux valgus deformity changes the foot rollover pattern, in which instead of the big toe as the main place to transfer forces during the final support phase, the increased load is transferred through the second foot ray. 2. hallux valgus promotes flattening of the transverse arch of the foot. 3. changes in foot pressure pattern observed in the group of women with hallux valgus are not dependent on the valgus angle.

The individual division of this paper is as follows: A – research work project; B – data collection; C – statistical analysis; D – data interpretation; E – manuscript compilation; F – publication search

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Słowa kluczowe
łuk poprzeczny stopy, przodostopie, tyłostopie, linia centrów nacisków

Streszczenie
Wstęp: Koślawość palucha jest jedną z najczęstszych deformacji stopy, która z dwa razy większą częstotliwością występuje u kobiet. Celem pracy była ocena wzorca obciążenia powierzchni podeszwowej stóp młodych kobiet z deformacją koślawą palucha.
Materiał i metody: Materiał badany stanowiły 23 młode kobiety (21-27 lat). U 14 badanych wykazano występowanie koślawości palucha jedno- lub obustronne (grupa badana – łącznie 22 stopy z koślawością palucha), a u 15 kobiet wykazano prawidłowy kąt ustawienia palucha dla jednej lub obu stóp (grupa kontrolna – łącznie 23 stopy bez deformacji). Narzędzie badawcze stanowił Podoscan 2D oraz platforma sił reakcji podłoża FreeMED (Sensor Medica, Włochy). Wykorzystując oprogramowanie FreeStep Professional na plantokonturogramach stóp wyznaczono kąt koślawości palucha (kąt ALFA), w statyce oceniono parametry: maksymalne obciążenie przodo- i tyłostopia, procentowe obciążenie przodostopia oraz wskaźnik Wejsfloga, a w dynamice (chód): procentowe obciążenie przodostopia i przyśrodkowej części stopy, wartość maksymalną sił nacisku stopy na podłoże oraz miejsce wyjścia linii centrów nacisków.
Wyniki: Nie wykazano różnic pomiędzy grupą badaną i kontrolną w obciążeniu przodostopia i tyłostopia oraz w rozkładzie obciążeń na boczną i przyśrodkową stronę stopy, zaobserwowano natomiast statystycznie istotne różnice w wartości wskaźnika Wejfsloga i w miejscu wyjścia linii centrów nacisków.
Wnioski: 1. Koślawość palucha zmienia wzorzec odbicia stopy od podłoża, w którym zamiast palucha, jako głównego miejsca przeniesienia sił w trakcie końcowej fazy podporu, zwiększone obciążenie przenoszone jest przez drugi promień stopy. 2. Koślawość palucha sprzyja spłaszczeniu łuku poprzecznego stopy. 3. Obserwowane w grupie kobiet z koślawością palucha zmiany w obciążeniu stopy nie są zależne od kąta koślawości.

INTRODUCTION

The hallux valgus (known colloquially as the bunion) is a structural deformity of the foot characterised by lateral deviation of the hallux with simultaneous medial deviation of the first metatarsal bone[1]. The probability of the occurrence of hallux valgus increases with age and is dependent on gender: the deformity is twice as likely to occur in women than in men[2,3]. It is often accompanied by other dysfunctions as well: flattening of the longitudinal and transverse arches of the foot, widening of the forefoot, change in the pressure distribution pattern under the metatarsal heads, pain in the metatarsal area and in the knee joint[4-6]. The most common diagnostic procedure used to assess the extent of the hallux deformity is radiological examination, on the basis of which the angle of the hallux valgus, the angle between the first and second metatarsal bones and the metatarsal angle are determined[7].

However, radiological imaging only serves as a reference point; assessment of the severity of deformity and the type of treatment are determined based on other factors such as age, pain (its location and duration) or gait disorders[5]. Analysis of foot sole pressure distribution pattern is a useful way to assess the function of both the foot and ankle joints during gait[8]. Scientific reports have indicated changes in the pressure on the plantar surface of the forefoot related to hallux valgus, however, their results are inconsistent with respect to the changes in the pressure both to the hallux[2,9,10-15] and other toes[2,12,14,15]. Also, the loading rate of individual heads of the metatarsal bones and the load distribution between the lateral and medial forefoot in patients with hallux deformity is different according to different authors[1,2,9,10,13-19]. Similarly, there is a lack of agreement among scientists on the issue of the relationship between the severity of deformity and distribution of compressive forces on the plantar surface of the foot[14,15,17]. Conflicting research results make it difficult to assess foot loading pattern in relation to whether or not it is characteristic of feet with hallux valgus deformity. Hence, there is a need to determine the plantar pressure characteristics of hallux valgus deformity, which could be helpful for creating a reliable assessment of feet with hallux valgus in a clinical setting.

AIM OF THE STUDY

The aim of the study was to evaluate the feet pressure distribution pattern in young women with hallux valgus and to determine whether the changes observed in the loading rate are dependent on the extent of deformity, i.e. the angle of hallux valgus. The following research questions were posed:

1. Does the bunion influence the distribution and magnitude of the forces acting on the plantar surface of the foot in the group of women examined?
2. Does the bunion affect the transverse arch shape in the examined group?
3. Does the bunion affect the foot rollover pattern in the push-off phase, i.e. does it affect the passage point of the gait line in the examined group?
4. Are the changes in the foot loading pattern in the examined group associated with hallux valgus dependent on the extent of deformity?

MATERIAL AND METHODS

Study material

The study material consisted of 23 young women (aged 21 to 27 years). On the basis of the angle of the big toe, determined with the help of Podoscan 2D, the examined women were assigned either to the study or the control group. Cases of unilateral hallux valgus were included both in the study group (foot with hallux valgus) and in the control group (foot with correct position of the big toe). The study group (GHV) consisted of 14 young women, including 8 with bilateral and 6 with unilateral hallux valgus deformation (HV), a to-

Table 1

Characteristics of the study (GHV) and control (GK) groups

Data	**GHV Mean (*SD*)**	**GK Mean (*SD*)**
Age (years)	23.45 (1.6)	22.78 (1.24)
BMI (kg/m^2)	20.98 (1.6)	20.2 (1.51)
Hallux angle (°)	13.91 (3.34)	5.09 (-8.54)

tal of 22 feet. Inclusion criteria for the groups were: (A) the angle of deformity of the first metatarsophalangeal joint (HVA), as measured by Podoscan 2D, ranging from 10° or more (study group) to less than 10° (control group); (B) no other type of foot deformity or other dysfunction of the lower extremities; (C) normal body mass (BMI<25 kg/m2). The control group consisted of 15 women: 9 of them demonstrated bilaterally normal hallux angle, and the remaining 6 demonstrated normal angle of the big toe on one side only (a total of 24 feet). The results for one of the feet of a member of the control group were excluded from the analysis due to a measurement error, therefore 23 feet were included in the final analysis. The age of the women in the study group ranged from 21 to 27 years, and the age of the women in the control group (GK) ranged from 22 to 26 years. BMI of all subjects were normal, amounting to 18.3 to 23.4 kg/m2 for GHV and 18.7 to 23.9 kg/m2 for GK. The angle of deformity of the hallux in the HV group ranged from 10 to 22° (Table 1).

Measuring tools and examination procedure

Using Podoscan 2D (Sensor Medica, Italy), precise footprints of the subjects were obtained. With the use of the FreeStep Professional software, the angle of hallux valgus (the ALPHA angle) for both feet was then determined on the resulting image (Figure 1). The ALPHA angle is the angle between the tangent to the medial edge of the foot and the tangent drawn from the point in which the forefoot is the widest to the outer edge of the big toe. The standard angle for the hallux is 0-9°[20].

The next phases of the study included evaluation of the foot loading rate in statics and dynamics using the FreeMED force platform (Sensor Medica, Italy). The static examination was performed three times in standing position with both feet on the platform. The result that repeated itself (at least 2 times) was used in the analysis. Evaluated were: maximum loading of the fore- and rearfoot (a value normalised to body weight), the percentage loading of the forefoot and the Weissflog's indicator (the ratio of the length of the foot to its width). Weissflog's indicator, considered to be the most accurate method in the assessment of the transverse arch of the foot[21], was determined taking into account the width and length of the foot calculated by the software during the static test. It should amount to 3: 1, but it usually is a value between 2 and 3.

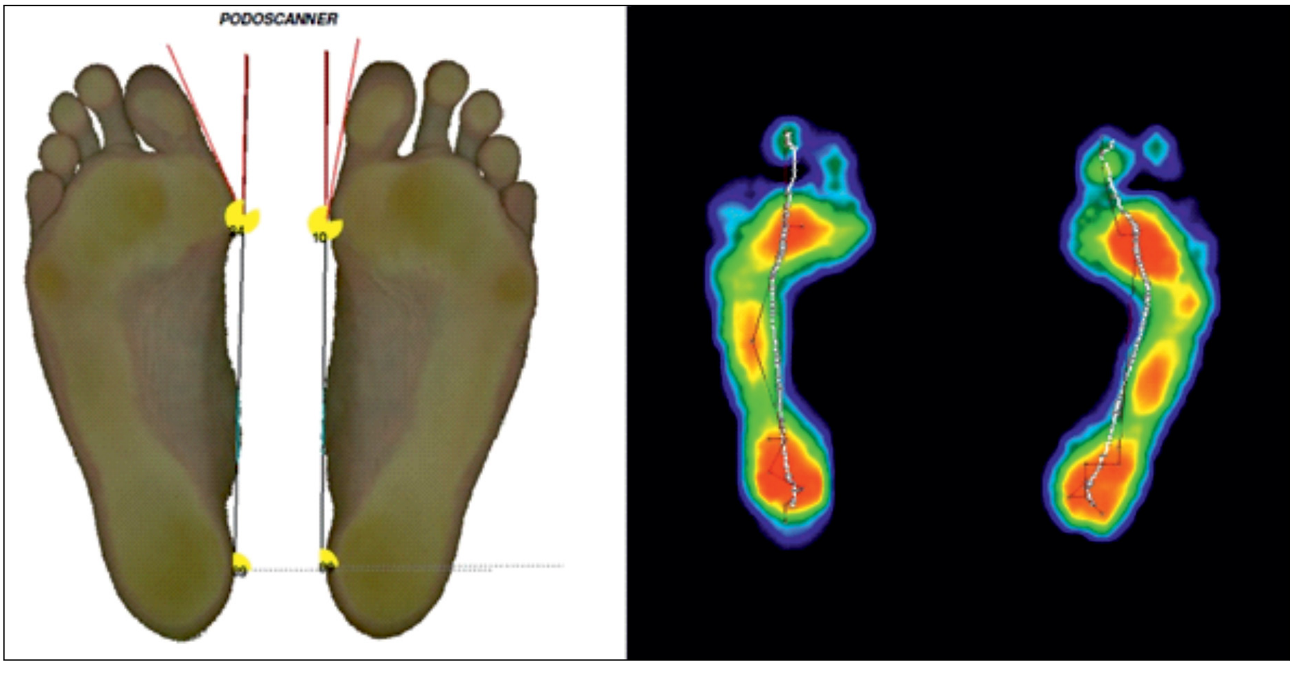

Figure 1.

Example results: on the left – determining the angle of the valgus deformity of the hallux (the ALPHA angle) on the prints obtained with the use of Podoscan 2D, on the right – the image of the feet of the same patient obtained during a dynamic examination, visible for the right foot (the one with the smaller ALPHA valgus angle equal to 10°) the COP line exit through the hallux (category A), and the left foot with a greater ALPHA angle (24°), the exit of the COP line through the second toe (category C).

The values closer to 2 point to transverse flatfoot, whereas those closer to 3 demonstrate the proper foot arch shape. The dynamic examination consisted of passing along the 2.4 metres long measuring path (divided into 40x40 centimetres contact platform and 2-metre-long path excluded from measurement, of the same structure and height as the platform) with gait speed and rhythm natural for a given individual[22]. The starting point was determined in such a way so that, regardless of the step length, the foot could achieve full contact with the platform at least at the third step ('midgait technique')[23]. The examination continued until 3 correct footprints for each side were achieved. In the dynamic study, rated were: percentage loading of the forefoot and medial part of the foot (rated for the most repeated footprint), the value of maximum foot pressure (the average of the 3 footprints obtained, normalised to the body weight of the subjects) and the passage point of the center of pressure line (COP) (the most repeatable one for 3 obtained footprints). Motooka et al.[24] classified the pattern of the COP line at the forefoot. They identified four categories: (A) exit of the COP line through the hallux, (B) exit of the COP line between the big toe and the second toe, (C) exit of the COP line at the second toe, (D) exit of the COP line before its passage through toes[25]. Since no person that could be classified in the category D was found in the present study, the analysis used the classification consisting of the aforementioned A, B and C category. Motooka et al.[24] noted the relationship between the knee joint alignment and the place of final exit of the COP line. In patients with valgus knee deformity the COP line often ended at HV, in patients with varus knee deformity – at T2; the place of the exit of the COP line in people with normal linear setting of the knee was most often the space between T2 and HX[24]. The authors of the present study believe that the obtained pattern of the COP line can be used to evaluate the position of the foot in the push-off phase and to determine whether propulsion of the foot occurs through the hallux as the fulcrum (category A), or not (categories B and C) (Figure 1).

The Shapiro-Wilk test was used to examine the compatibility of variable distribution with normal distribution, and Levene's test was used to assess the homogeneity of variances in groups. For cases that met the assumption of normality and homogeneity of variable distribution and variance, the t-test for independent samples was used to assess the significance of differences between groups; otherwise, the Mann-Whitney U-test was used. Fisher's exact test was used for the evaluation of inter-group differences in the place of the exit of the COP line. Correlations between hallux valgus angle and the evaluated variables were assessed, for the case of normal distribution, by calculating the Pearson correlation coefficient or by using the ANOVA variance analysis; otherwise, the Spearman coefficient was used. The differences and connections obtained during the analyses were evaluated as statistically significant at the significance level of $p < 0.05$.

RESULTS

Higher values of maximum pressure in statics in both forefoot and rear-foot were observed in GHV, at 9.63 and 10.06 g/cm²/kg respectively, compared with GK (9.16 and 9.39 g/cm²/kg respectively). Also, in the dynamic examination, slightly higher pressure values was observed in GHV (GHV - 25.11 g/cm²/kg, GK - 24.47 g/cm²/kg). The percentage loading rate of the forefoot, both in the static and dynamic examination was greater for the GHV than for GK (GHV - 53 and 60.41%, GK - 51.61 and 58.3%). In GHV, there was observed a slightly decreased, compared to the GK, percentage loading of the medial foot surface in a dynamic test (GHV - 48%, GK - 49.48%). However, statistical significance of any of the above-described differences has not been proven. Weissflog index reached a lower value in GHV than in GK (2.26 and 2.47, respectively). The resulting difference turned out to be statistically significant ($p = 0.0127$), which shows that in the group of patients with hallux valgus the transverse arch was significantly lower than for the CG (Table 2).

Table 2

Comparison of static and dynamic foot loading of subjects with correct hallux angle and hallux valgus

	GHV Mean (*SD*)	GK Mean (*SD*)	Student-*t* test value	Mann-Whitney U test value	Level of significance (*p*)
Max. Fore. Stat. (g/cm²/kg)	9.63 (1.11)	9.16 (1.47)	1.21	-	0.23
Max. Rear. Stat. (g/cm²/kg)	10.06 (1.22)	9.39 (2.07)	-	1.33	0.18
% Fore. Stat.	53.00 (8.08)	51.61 (6.95)	0.62	-	0.54
% Fore. Dyn.	60.41 (5.06)	58.30 (3.71)	1.60	-	0.12
% Med. Dyn.	48.00 (3.09)	49.48 (4.70)	-1.24	-	0.22
Max. Dyn. (g/cm²/kg)	25.11 (2.31)	24.47 (3.39)	-	0.91	0.36
Weissflog ind.	2.26 (0.21)	2.47 (0.32)	-2.60	-	0.01*

Abbreviations: *SD* – standard deviation; HV – study group; GK – control group; Max. Fore. Stat. – maximal load of forefoot in static test; Max. Rear. Stat. – maximal load of rear-foot in static test; % Fore. Stat. – percentage load of forefoot in static test; % Fore. Dyn. – percentage load of forefoot in dynamic test; % Med. Dyn. – percentage load of medial part of the foot in dynamic test; Max. Dyn. – maximal load of foot in dynamic test; Weissflog ind. – Weissflog indicator measured as the ratio of the length to the width of the foot.
* $p<0.05$

Table 3

COP line exit in control and study group			
COP exit	**GHV Number (%)**	**GK Number (%)**	**Total**
A	5 (22.7)	13 (56.5)	18 (40.0)
B	13 (59.1)	5 (21.7)	18 (40.0)
C	4 (18.2)	5 (21.7)	9 (20.0)

Abbreviations: COP exit – end of center of pressure (COP) line; A – at big toe height; B – between big toe and the second toe; C – at height of the 2nd toe; GHV –study group; GK – control group

Table 4

The relationship between the hallux valgus angle and the assessed parameters				
Parameters - relationship, hallux valgus angle	**Pearson's linear correlation coefficient**	**Spearman's rank correlation coefficient**	**One-way ANOVA (*F*)**	**Level of significance (*p*)**
Max. Fore. Stat. (g/cm²/kg)	0.053	-	-	0.73
Max. Rear. Stat. (g/cm²/kg)	-	0.107	-	0.49
% Fore. Stat.	-0.020	-	-	0.89
% Fore. Dyn.	-0.237	-	-	0.12
% Med. Dyn.	-0.178	-	-	0.24
Max. Dyn. (g/cm²/kg)	-0.005			0.97
Wiessflog ind.	-0.162	-	-	0.29
COP exit	-	-	0.301	0.74

Abbreviations: Max. Fore. Stat. – maximal load of forefoot in static test; Max. Rear. Stat. – maximal load of rear-foot in static test; % Fore. Stat. – percentage load of forefoot in static test; % Fore. Dyn. – percentage load of forefoot in dynamic test; % Med. Dyn. – percentage load of the medial part of the foot in dynamic test; Max. Dyn. (g/cm²/kg) – maximal load of foot in dynamic test; Weissflog ind. – Weissflog indicator measured as the ratio of the length to the width of the foot.
* $p<0.05$

In the HV group, the COP line most often ended between the first and second toe (59.1%), rarely at the big toe or second toe. In the control group the most frequently observed COP line exit point was at the height of the hallux (56.5%), less often at the second toe or between the first and second toe (Table 3). With the use of the analysis of variance (ANOVA) it was shown that group affects significantly the result of the COP exit parameter (p = 0.0297) (Table 3).

Assessed was the correlation between the angle of hallux valgus in the GHV (which indicates the severity of deformity evaluated) and the parameters analysed. There were no statistically significant effects of the hallux valgus angle on any of the evaluated parameters (Table 4).

DISCUSSION

Conflicting scientific reports on the characteristics of the foot pressure distribution pattern for the hallux valgus deformity make it difficult to establish, in the framework of clinical assessment, whether the observed abnormalities in the foot loading may be typical of the deformity. The literature confirms the changes in the pressures on the plantar surface of the foot associated with HV, however, the results are inconclusive[9]. The scientific reports concerning the forefoot loading pattern in patients with HV analysed pressure on the toes and metatarsal bone heads separately, according to different methodological divisions. Some authors indicate decreased pressure on the big toe in patients with valgus deformity in relation to the control group[2,9-12]; however, there are also studies in which increased[14] or the same pressure[15] is reported. There is also no agreement on the issues related to the changes in the other toes loading co-occurring with hallux valgus. Some researchers note an increased pressure on the toes[2,12], while others report no effect of hallux valgus on the loading of the remaining toes[15]. Scientific reports indicate no differences in metatarsal bones heads loading in people with HV[2], or the reduced pressure on the fourth and/or fifth and increased pressure on the first, second and third metatarsal bone heads[13,17,18]. Observations concerning the loading of the first metatarsal bone head showed its increased[18,19] or unchanged[9] loading in patients with HV.

The aim of the study was to present a simplified analysis of the plantar loading and to determine the characteristics of the plantar loading distribution in feet with hallux valgus deformity, including: analysis of the forefoot loading as a whole without separation of its individual parts, loading of the medial part of the foot, COP line exit– informing whether propulsion of the foot occurs through the hallux as the fulcrum, and the evaluation of the transverse foot arch with the use of a simple indicator relating foot width to its length. Obtaining simple indicators indicating changes in the foot loading pattern characteristic for hallux valgus deformity could help in forming a reliable assessment of the foot with HV in the clinical setting.

The present study has shown a slightly higher maximum pressure values in statics within the forefoot in GHV (9.63 g/cm^2/kg) compared with GK (9.16 g/cm^2/kg), but the difference was not statistically significant. Moreover, the forefoot loading was not statistically significantly higher in both the static and dynamic examinations, in GHV compared with GK (GHV - 53 and 60.41%, GK - 51.61 and 58.3%). The scientific reports concerning changes in foot loading pattern in people with HV rarely evaluated the hindfoot loading[9]. A longer contact time of the rear-foot with the ground in patients with HV was noted, among others, by Wen et al.[9], Nyska et al.[10] and Chopra et al.[12]. As to the hindfoot loading rate in people with HV compared to the control group, Wen et al.[9] found higher differences, Galicy et al.[2] found smaller differences, whereas in Nysa et al.[10] and Bryant et al.[13] research no difference whatsoever was found. The differences found in research by Wen et al.[9] were more pronounced in the group in which pain was felt; this was linked to the fact that in order to avoid loading of the painful forefoot, patients overload the rear-foot. This interpretation is confirmed by the shortened duration of contact of the forefoot with the ground in patients with HV. The present study also assessed the maximum pressures within the rear-foot and demonstrated that they were bigger (10.06 g/cm^2/kg) in GHV than in GK (9.39 g/cm^2/kg), but the difference was not statistically significant.

It seems that due to the pronation of the foot often accompanying hallux valgus greater load of the medial part of the foot, including the forefoot, should be expected in GHV[2]. This is confirmed by the report by Bryant et al.[13], in which it was noted that the increased load on the medial forefoot in patients with HV may be associated with increased pronation in this group. Among other things, the position of the hindfoot affects which part of the foot – lateral or medial – is more loaded. The varus heel position is associated with a higher loading of the lateral side of the foot, and the valgus, often observed in patients with HV, is associated with the loading of the medial side[25]. Wen et al.[9] found greater loading of the medial portion of the foot in patients with HV as compared with the control group, starting from the initial contact phase of the feet with the ground and subsequent transfer of the load from the medial to the lateral side of the foot. However, hallux valgus is often accompanied by pain, which may cause avoidance of loading of the first ray of the foot and increased loading of the lateral part of the foot. In the present study, during gait, a slightly lower percentage loading of the medial part of the foot in the dynamic examination of the study group was observed (GHV - 48%, GK - 49.48%), which could suggest that people in the study group load the lateral side of the foot to a greater extent. The result was not statistically significant.

Interestingly, it was shown that for the patients in the study group the COP line exit through the big toe is statistically significantly less frequent ($p = 0.0297$) than for the people in GK (COP exit type A in GHV - 22.7%, in GK - 56.5%), which means that at the end of the push-off phase, the women examined avoid foot propulsion through the hallux by loading the central portion of the forefoot (i.e. the second foot ray) more. Tokita et al.[26] assessed the COP line exit in patients with HV, and found that it ends on the third metatarsal bone more frequent than in the GK, rather than go further and go through the first metatarsal and the hallux, as observed in the control group. Waldecker[16], comparing people with symptomatic and asymptomatic HV noted that the former put greater load on the lateral side of the forefoot, with the largest load being transferred from the big toe to the lateral side of the forefoot; the load transferred from the head of the first metatarsal to the side of the metatarsal was less important .

Also, Shih et al.[1] showed lateral transfer of the load (lateral shift of the COP line in relation to the head of the first metatarsal bone) in patients with HV, which they linked with the attempt to reduce the load of the first foot ray in response to pain during the final part of the support phase[1]. They also noted the relationship between the lateral shift of the load and increased inward setting of the foot[1]. Such positioning of the foot may be due to increased internal rotation of the hip and may contribute to problems to the patellofemoral joint (PFJ), which in turn can cause pain to the front of the knee and infrapatellar pains. This is confirmed by the results of studies in which different angles of the big toe on both sides were observed in patients with unilateral PFJ pain[27]. The first metatarsophalangeal joint is extremely important, since it is this joint that, in normal conditions, serves as the place of transferring forces during the final stage of the support phase[28]. Its progressive subluxation impairs propulsion through the big toe in the preswing (toe off) phase. Jacob[29] says that if the first foot ray together with the hallux are devoid of the load transfer function, e.g. due to their excessive motion, much higher loads start to be put on the second ray of the foot, not designed for such loads, as it has only minimal support of muscles; and the mobility of the second tarsometatarsal joint comparing to the second tarsometatarsal joint is law.

The research by Wen et al.[9] showed an increased loading of the second and third metatarsal heads in people with HV, which may suggest a flattening of the transverse arch of the foot in this group[4,9]. The increased load on the second metatarsal head was also showed by other authors[13,15]. Wen et al.[9] also showed a reduced load on the fourth metatarsal head, which in their opinion, is related to its relative elevation, resulting from the flattening of the transverse arch of the foot. The said investigators did not observe differences in the pressure put on the fifth metatarsal head, and they saw the reasons for this in its relatively long distance from the area of deformity[9]. In the present study, the transverse foot arch was assessed on the basis of the Weissflog indicator and its value was shown to be statistically significantly lower ($p = 0.0127$) in the GHV than GK (2.26 and 2.47, respectively). This demonstrates that the transverse foot arch is low in the group of patients with hallux valgus (Table 2).

The aim of the study was to assess the impact of the hallux valgus angle on the parameters analysed. The differences in feet loading rates at various stages of hallux valgus may be associated with the adaptation of the soft tissue to the deformation of the forefoot and progressive degeneration of the metatarsophalangeal joint[30]. Scientific reports concerning the relationship between the severity of hallux valgus deformity and distribution of pressure on the plantar surface of the foot are contradictory[14,17]. Martínez-Nova et al.[14] observed a relationship between the increasing valgus angle and the increase in mean pressure on the hallux. On the other hand, Plank[17] noted no association between the valgus angle and the maximum pressure on the first, second and third head of the metatarsal bones, and significantly lower pressure on the heads of the fourth and fifth metatarsal bones with increasing hallux valgus angle. Reverse research results were obtained by Ferrari and Watkinson[31], who did not observe the relationship between HVA and the pressure acting on the big toe. Yamamoto et al.[19] noticed that in the group with the biggest pressure placed on the first metatarsal head there occurred simultaneously a larger angle of the hallux valgus and a larger metatarsal angle than among people who experienced the greatest pressure placed on the second and third metatarsal heads. This increasing load on the medial part and the decreasing load on the lateral part of the forefoot, along with the worsening of the hallux valgus deformity may be due to increasing hyperpronation, often accompanying the HV[17].

The loads which are usually carried by the hallux during the toe-off phase are then deposited to a greater extent on the heads of the first three bones of the metatarsal[17]. This results in impaired propulsion and prolonged time of the contact of metatarsal heads with the ground and the location of the ends of COP line on the head of the second metatarsal bone[17]. In the present study, no relationship between the hallux valgus angle and any of the parameters analysed was demonstrated (Table 4).

To summarise what has been said, the results obtained in the present study indicate no statistically significant differences in the loading rate of the forefoot and rear-foot, both in statics and in dynamics, in patients with HV compared with the control group. There were also no differences between the groups in the load distribution on the medial and lateral side of the foot during walking. Interestingly, it has been shown that in women with HV, the final stage of propulsion is statistically significantly less often executed through the hallux as the fulcrum, which proves the malfunction of the first ray of the foot and can be associated with a greater load on the central and lateral parts of the metatarsal. Flattening of the transverse arch foot in patients with HV was also shown: this, according to the literature, can facilitate metatarsalgia. The limitation of the research presented is the lack of assessment of pain in the study group and its impact on the evaluated parameters.

CONCLUSIONS

Based on the results obtained, the following conclusions has been drawn:

1. There were no statistically significant differences observed in the plantar pressure distribution pattern, nor in the maximum pressure values in the group of women with hallux valgus compared with the control group.
2. Hallux valgus deformity facilitates flattening of the transverse arch of the foot in the group of women examined.
3. In the studied group of women with hallux valgus deformity, the exit of the gait line was placed at the big toe more seldom than in the control group.
4. The changes in the foot loading pattern observed in the group of women with hallux valgus are independent from the valgus angle measured in the present study, i.e. from 10° to 22°.

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