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Evaluation of the morpho-functional characteristics of the foot and the habit of walking barefoot in individuals with foot alterations

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Abstract

This study aimed to evaluate the functional profile, foot characteristics, and barefoot walking habits of individuals with musculoskeletal foot alterations and compare them with control individuals. Participants were assessed through an electronic questionnaire. Anthropometric data, foot functionality, barefoot walking habits, footwear type, foot type, foot arch, stride type, and foot impairments were collected. The total sample consisted of 160 individuals divided into a control group (CG) (n=82) and a foot problems group (FPG) (n=78). Hallux valgus was the main foot problem in the FPG (24.4%), with a higher percentage of participants having chronic conditions (35.9%), cavus foot types (left foot (LF) 16.7% and right foot (RF) 19.2%), or flat foot types (LF 21.8% and RF 21.8%), and with a compromised Foot Function Index in 7% (P=0.001). Both groups considered barefoot walking healthy (72% CG and 66.7% FPG), but they are not practitioners of this habit (93.9% CG and 91% FPG). Shoes were the least utilized type of footwear in the FPG (10.3%). In conclusion, individuals in the FPG showed a stronger association between morpho-functional alterations and foot disorders. Although barefoot walking is considered beneficial for foot health in both groups, neither group practices this habit.

Keywords: Gait. Foot Types. Functionality.

INTRODUCTION

The human foot is a flexible structure composed of 28 bones, 33 joints, and 112 ligaments controlled by 13 extrinsic muscles and 21 intrinsic muscles[1], capable of adapting to variations in surface and load to maintain effective force transmission between the lower limb and the ground during locomotion[2]. The entire musculoskeletal locomotor system has evolved to an upright posture and bipedal gait, and the mechanisms of the foot have evolved and developed for the dual purpose of support and propulsion[3]. This allows humans, in a bipedal gait, to walk, run, and jump efficiently on various types of surfaces without pain or injuries[4].

The medial longitudinal arch (MLA), a unique human foot structure among primates, is crucial for human bipedalism[5]. This structure can elongate and recoil in response to external load during locomotion[2], providing the foot with the necessary rigidity to act as a lever that transmits propulsive forces generated by the muscles of the lower limbs when they make contact with the ground[5,6]. It offers enough

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flexibility to function as a spring, storing and releasing mechanical energy[6].

The height of the MLA has long been recognized as a key parameter for classifying foot type and is considered an essential tool for the prognosis and diagnosis of lower limb injuries[7]. Foot type is a clinical concept that aims to simplify the anatomical complexities of this segment[1]. The interest in using a classification is associated with the fact that the morphology of a non-neutral foot, such as cavus or flat feet, may lead to impaired foot function and the development of injuries in the lower extremities and the lumbar spine[8].

In addition to these considerations about foot type, the use of footwear can also be a compromising factor for functionality and the determination of foot type. This can explain the growing interest in investigating barefoot locomotion, attracting scientific focus to this subject[9]. It's important to highlight that the human foot was anatomically modern long before footwear was invented and adapted to walking barefoot on natural substrates[10]. Several cross-sectional studies have evaluated the effect of habitual barefoot living on posture and foot mechanics, and there is a consensus that individuals who habitually go barefoot have stronger feet and fewer deformities[11,12]. The most evident difference is the wider forefoot region for individuals who habitually walk barefoot[13], along with a higher medial longitudinal arch (MLA) for barefoot habituated children[11], in addition to greater flexibility[14].

Furthermore, the use of shoes can affect force transmission during dynamic conditions such as locomotion and static conditions[14]. Most shoes have embedded medial arch support and a narrower toe box than the actual forefoot width[14]. This can lead to poor dynamic foot adaptation and have a negative impact on its functional capacity[14]. Another study also suggests that shoe use is associated with weaker intrinsic foot muscles, potentially predisposing individuals to develop flat feet[12].

Therefore, this study aimed to evaluate the morpho-functional profile, foot characteristics, type of footwear, and the habit of walking barefoot in individuals with musculoskeletal foot disorders and compare them with control individuals. The hypothesis of this study was that individuals with musculoskeletal foot disorders would present different morpho-functional characteristics, would not habitually walk barefoot, and would exhibit decreased functional performance compared to control individuals.

METHOD

This cross-sectional study with descriptive components and quantitative analysis was conducted remotely, following the guidelines outlined in Strengthening the Reporting of Observational Studies in Epidemiology (STROBE)[15] for observational studies. The target population consisted of individuals with musculoskeletal foot disorders. Volunteers were recruited through social media platforms (WhatsApp groups and social networks) in the years 2020 and 2021 and responded to questionnaires virtually due to the COVID-19 pandemic.

The sample size calculation was conducted using G*Power 3.1.9.2 software, utilizing an independent t-test (based on the presence of two different groups), with an estimated effect size of 0.8, an *alpha* error probability of 0.05, and a power of 1 - β of 0.8[16]. A total of 42 individuals were required for the formation of the groups. Participants included in the study's musculoskeletal foot disorders group (FPG) were: individuals above 18 years of age, of both sexes, with a musculoske-

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letal disorder in one foot. Exclusion criteria included a history of surgery in the last six months and neurological disorders. The control group (CG) consisted of individuals above 18 years of age, of both sexes, without musculoskeletal symptoms or injuries in the lower limbs and spine in the last six months.

For participation, a link to an electronic questionnaire was provided. Participants were informed about the research procedures and their right to withdraw from participation at any time through an Informed Consent Form, which was available for download along with the link to access the questionnaire. The Research Ethics Committee of Unicentro-PR approved the study following Resolution 466/12 of the National Research Council (4.619.354/2021).

The questionnaire included anamnesis data (presence of musculoskeletal foot disorders), personal and physical data (body weight and height), and the type of footwear habitually used. Based on self-reported anthropometric measurements, the Body Mass Index (BMI) was calculated and classified as follows: underweight (<18.5 kg/m²), normal weight (18.5 to 24.9 kg/m²), overweight (25.0 to 29.9 kg/m²), obesity grade I (30.0 to 34.9 kg/m²), obesity grade II (35.0 to 39.9 kg/m²), and obesity grade III (>40.0 kg/m²)[17].

Furthermore, other tools were used to characterize the variables, which are as follows:

Evaluation of foot functionality: Foot Function Index (FFI) adapted for the Portuguese language in Brazil[18], developed to assess foot function in patients with musculoskeletal injuries. This is a self-administered index consisting of 23 items divided into three domains. Since the assessment is focused on the foot, the questionnaire has greater accuracy and sensitivity to identify changes in this area compared to other available instruments[19], with excellent reliability and validity for use in research and clinical practice[20]. The final percentage of all domains should be summed and divided by three (total number of domains) to obtain the questionnaire's result. The results can vary from 0 to 100% and are directly proportional to the functional impairment of the limb. The higher the percentage, the greater the functional alteration presented by the patient.

Questionnaire about the habit of walking barefoot scored using a three-point Likert scale. Participants were asked how often they walked barefoot: a) during school/work, b) during sports, and c) inside and around the house. The options were: 2 points for most of the time, 1 point for half of the time, and 0 points for none of the time. Participants were classified as habitually barefoot if they scored three or more (out of a maximum of 6 points), equivalent to being barefoot at least half the time[21]. Participants were also asked whether they considered walking barefoot a healthy habit.

Participants were also asked to identify their foot type (flat, high-arched, or neutral), footwear pattern, and kind of footstep (supinated, pronated, or neutral) through self-assessment of reference images inserted in the questionnaire for comparison.

The level of physical activity was classified using the adapted version for the Portuguese language (Brazil) of the International Physical Activity Questionnaire (IPAQ), which assesses physical activity in a typical week or the last seven days by investigating minutes of moderate, vigorous, and walking activity. The leisure and commuting modules of the extended version of IPAQ were used, which have acceptable validity compared to accelerometry and are suitable for evaluating moderate and vigorous physical activity in Brazilian adults[22].

The data were presented descriptively in tables of absolute and relative frequency

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(categorical variables). Due to the non-normal distribution of the data according to the Shapiro-Wilk test, the data were presented as median and interquartile ranges (25-75%). The comparison between groups (FPG X CG) was performed using the Mann-Whitney U test. To assess the association between variables, univariate analysis was conducted using the Chi-squared test (with or without Yates correction) or Fisher's exact test when necessary. Significance was set at 5%. The analyses were conducted in SPSS[25].

RESULTS

The total sample consisted of 160 individuals divided into CG (n=82) and FPG (n=78) to account for possible sample losses. Table 1 presents the characteristics of the CG and FPG groups. There was no statistically significant difference between the groups for the variables age, body mass, height, and BMI. The Foot Function Index (FFI) showed a statistically significant difference for the FPG compared to the control (P=0.001), with a low percentage of functional impairment. Regarding the foot problems found in the FPG, foot pain was the most common cause (30.8%), followed by hallux valgus (24.4%), foot type (high-arched or flat) (12.8%), ankle fractures/injuries (12.8%), plantar fasciitis (9%), calcaneal spur (9%), and other issues (5.1%).

Table 1 – Characteristics of the control group (CG) and foot musculoskeletal disorders group (FPG) samples, median and interquartile ranges (25-75%), Guarapuava-PR (2020).

	CG (n=82)	FPG (n=78)
Age (years)	33 (24.7-41.5)	27 (21-40.25)
Body Mass (kg)	68.5 (60-78)	74 (61.7-82)
Height (m)	1.65 (1,60-1,71)	1.68 (1.62-1.75)
BMI (kg/cm^2)	24.78 (21.82-27.57)	25.31 (22.25-29.11)
FFI (%)	0 (0-1)	7 (1-17)

Table 2 presents the distribution of sex, BMI, and level of physical activity between the groups. In both groups, half of the sample was classified with a BMI not recommended for health (overweight and obese)[17], even with a percentage of around 70% of active individuals for both groups. There was no statistically significant difference between the groups in terms of BMI or level of physical activity. Regarding the presence of chronic disease, there was a higher presence of individuals with chronic disease in the FPG group (P=0.004).

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Table 2 – Distribution of sex, BMI, and level of physical activity between the groups (absolute and relative frequency), Guarapuava-PR (2020).

		CG (n=82)	FPG (n=78)	P	Total (n=160)
Gender n (%)	Male	21 (25.6)	19 (24.4)	0.85	40 (25)
	Female	61 (74.4)	59 (75.6)		120 (75)
BMI Classification n (%)	Normal	42 (51.2)	37 (47.4)	0.89	79 (49.4)
	Overweight	32 (39)	33 (42.3)		65 (40.6)
	Obesity	8 (9.8)	8 (10.3)		16 (10)
Active or Sedentary n (%)	Active	59 (72.0)	57 (73.1)	0.87	116 (72.5)
	Sedentary	23 (28.0)	21 (26.9)		44 (27.5)
Chronic Disease n (%)	Yes	13 (15.9)	28 (35.9)	0.004	41 (25.6)
	No	69 (84.1)	50 (64.1)		119 (74.4)

Table 3 presents the distribution of types of footwear used, the habit, and the opinion on the importance of walking barefoot being healthy among the groups. Sneakers and sandals were the most commonly used footwear models in both groups. The FPG showed a statistically significant higher distribution of individuals who do not use shoes as their preferred footwear. Around 70% of the sample considers walking barefoot healthy; however, only 7.5% of the sample have the habit of walking barefoot, with no statistically significant difference between the groups.

Table 3 – Distribution of types of footwear, the habit, and the importance of walking barefoot among the groups (absolute and relative frequency), Guarapuava-PR (2020).

		CG (n=82)	FPG (n=78)	P	Total (n=160)
Shoe	Yes	21 (25.6)	8 (10.3)	0,01	29 (18.1)
	No	61 (74.4)	70 (89.7)		131 (81.9)
Sneaker	Yes	46 (56.1)	53 (67.9)	0.12	99 (61.9)
	No	36 (43.9)	25 (32.1)		61 (38.1)
Sandals	Yes	46 (56.1)	45 (57.7)	0.83	91 (56.9)
	No	36 (43.9)	33 (42.3)		69 (43.1)
Habit of walking barefoot	Yes	5 (6.1)	7 (9)	0.49	12 (7.5)
	No	77 (93.9)	71 (91)		148 (92.5)
Walking barefoot is healthy	Yes	59 (72)	52 (66.7)	0.46	111 (69.4)
	No	23 (28)	26 (33.3)		49 (30.6)

The characteristics of the participants' feet are described in Table 4. There was a statistically significant difference in the type of foot between the groups, with a higher percentage of high-arched and flat feet in the FPG group.

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Table 4 – Characteristics of the feet among the groups (absolute and relative frequency), Guarapuava-PR (2020).

n (%)		CG (n=82)	FPG (n=78)	P	Total (n=160)
Wear LF	Lateral	35 (42.7)	36 (46.2)	0.4	71 (44.4)
	Medial	11 (13.4)	15 (19.2)		26 (16.3)
	Equal	36 (43.9)	27 (34.6)		63 (39.4)
Wear RF	Lateral	37 (45.1)	35 (44.9)	0.18	72 (45.0)
	Medial	8 (9.8)	15 (19.2)		23 (14.4)
	Equal	37 (45.1)	28 (35.9)		65 (40.6)
Type of gait	Neutral	54 (65.9)	38 (48.7)	0.09	92 (57.5)
	Pronated	13 (15.9)	18 (23.1)		31 (19.4)
	Supinated	15 (18.3)	22 (28.2)		37 (23.1)
Foot type (LF)	Normal	65 (79.3)	48 (61.5)	0.04	113 (70.6)
	High arch	8 (9.8)	13 (16.7)		21 (13.1)
	Flat	9 (11.0)	17 (21.8)		26 (16.3)
Foot type (RF)	Normal	66 (80.5)	46 (59.0)	0.01	112 (70.0)
	High arch	7 (8.5)	15 (19.2)		22 (13.8)
	Flat	9 (11.0)	17 (21.8)		26 (16.3)

LF: left foot and RF: right foot.

DISCUSSION

This study aimed to assess the morpho-functional profile, foot characteristics, footwear habits, and the habit of walking barefoot in individuals with musculoskeletal foot disorders and compare them with control individuals. The hypothesis of this study was partially confirmed as individuals with musculoskeletal foot disorders (FPG) presented around 7% compromised foot function, hallux valgus was one of the main reported problems in the FPG group and a higher percentage of participants with chronic diseases and high arch or flat foot types. Additionally, individuals in the FPG group showed a lower percentage of those who prefer shoes as their most commonly used footwear, which was unexpected. Both groups considered walking barefoot a healthy habit, but neither group practiced it regularly, including the control group. Other investigated characteristics, such as BMI, level of physical activity, and foot characteristics, did not show an association between the presence or absence of foot problems.

It is essential to highlight that obesity is reported as a significant factor affecting foot structure and function[23]. Increased body mass can lead to foot overload and promote the development of flat feet due to increased stress on the soft tissues of the lower limbs, increasing the risk of injuries[24] and influencing foot postural alignment and body stability[25]. This relationship between excess weight and foot problems arises from structural changes and muscular weakness in the feet and ankles[23]. Kumar *et al.* (2021)[26] investigated the association between flat feet in individuals with obesity and found a strong correlation between flat feet and increased body mass in middle-aged individuals. They emphasize that individuals should engage in physical activity to maintain body weight

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and prevent any biomechanical changes in foot structures. Although no associations were found between BMI and foot characteristics or related problems, both groups had around 50% of participants classified as overweight. This could pose a risk to foot health; however, more than 70% of the sample engaged in physical activity, which suggested by Zhao *et al.* (2018)[23], might be a protective factor for foot health. Furthermore, evidence suggests that in terms of intervention, engaging in physical activity could be more effective for foot structure and function than just weight loss[23]. Thus, it should be prioritized in treatment programs.

We can observe that both groups have a favorable opinion about the benefits of walking barefoot for foot health, but they do not practice this habit, which could be detrimental to foot health. This aligns with a systematic review proposed by Franklin *et al.* (2015)[27], which reports that prolonged footwear use, regardless of the model, leads to anatomical and functional changes as they do not respect the natural shape and function of the foot and end up altering its morphology and biomechanical behavior. This can result in alterations such as increased stride length and greater dorsiflexion at foot-ground contact due to the constraints imposed by the shoe structure[27]. Holowka *et al.* (2018)[12] also suggest that conventional modern footwear is associated with weaker intrinsic foot muscles, predisposing individuals to reduced foot rigidity and potentially flatter feet.

In addition to these changes, the type of footwear can interfere with gait patterns, such as during the double support phase, where sandals allow greater plantar flexion than sneakers, leading to a longer stride length[28]. Our results showed a lower percentage of participants who prefer using shoes, which could be because this model is less comfortable and more prone to causing symptoms. On the other hand, individuals who habitually walk barefoot experience benefits like a reduction in initial vertical impact force and a more evenly distributed pressure along the foot, likely resulting from a larger contact surface area achieved through a flatter foot placement on the ground[27].

However, the use of footwear remains necessary, especially on non-natural surfaces. In such cases, when the terrain does not allow barefoot movement, one should opt for models that protect the feet from injuries while being unrestricted, allowing the foot to function as closely as possible to a barefoot condition[13]. This may explain the lower percentage of individuals who prefer using shoes as their preferred footwear in the FPG, possibly to minimize pain. This highlights the importance of considering the appropriate type/model of footwear to ensure foot health.

Regarding the foot impairments found, hallux valgus was one of the main issues reported by the FPG. This is one of the most common foot deformities in adults[29], with a prevalence of 58% in adult women and 25% in adult men in the American population[30]. Consequences of this condition include interference with the normal weight-bearing function of the foot, leading to impaired balance[31], gait instability[32], and an increased risk of falls[33], all of which can have a detrimental impact on quality of life[34].

Another relevant factor from the results was the higher percentage of individuals in the FPG with chronic diseases. Chronic diseases, including musculoskeletal conditions, are associated with reduced quality of life[35]. Therefore, the need for interventions involving diagnosis and treatment for these individuals is crucial to prevent progression and a higher risk of complications, as reported in the mentioned studies, and to ensure a good quality of life.

Furthermore, it's important to note that a

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non-neutral foot morphology, such as the high-arched foot, presents abnormally elevated ALM associated with a more rigid structure and reduced mobility, especially in the rearfoot and forefoot joints. During movement, this foot type doesn't perform the necessary pronation to absorb impact, resulting in forces transmitted upwards through the lower limb[36]. The reduced mobility diminishes the capacity to absorb loads, making it more susceptible to injuries related to shock attenuation reduction[37] or increased peak plantar pressures[38], and more prone to stress fractures and deformities like hammer or claw toes[36].

On the other hand, the flat foot presents with a visibly lowered ALM and is often associated with rearfoot inversion[36]. It's the most common type of foot deformity[39], with factors like joint hypermobility and increased body mass or obesity being associated with higher prevalence, regardless of age[40]. During weight-bearing, the flat foot cannot form a rigid lever for efficient propulsion and remains in inversion when it should be everted. This type of foot is hypermobile, allowing excessive movement of the rearfoot and forefoot during walking due to the lack of stability to create a robust platform for propulsion, imposing extreme loads on soft tissue structures and adjacent joints, especially during activities involving power and agility. This instability or hypermobility forces the intrinsic muscles to work far beyond their normal expectations[36]. Due to these factors, flat feet pose a risk for the development of lower limb overuse injuries and foot dysfunctions[39], such as medial tibial stress syndrome[41], plantar fasciitis, and calcaneal tendinopathy, due to increased loads on the foot and ankle structures[36].

In the present study, there was a higher number of non-neutral feet in the FPG group. Therefore, the assessment of foot type should be mainly considered for this group to guide treatment approaches to make them more effective individually.

This study had some limitations, such as the remote data collection and the subjective classification provided by the participants themselves regarding foot type and gait due to the pandemic situation experienced in recent times. However, future studies should focus on evaluating the quality of life related to foot health, biomechanical characteristics, and the follow-up and treatment of these patients to assess the most effective treatment approaches.

CONCLUSION

In conclusion, we can assert that the hypothesis of this study was partially confirmed. Individuals with musculoskeletal disorders in the feet exhibited a low level of foot function impairment, and hallux valgus was one of the main reported issues. There was a higher percentage of participants with chronic diseases and non-neutral foot types (cavus or planus) in the FPG group. Surprisingly, individuals in the FPG group showed a lower percentage of individuals who preferred shoes as their primary footwear choice. Both groups recognized the health benefits of walking barefoot, yet neither group, including the control group (CG), practiced this habit consistently. Other investigated characteristics, such as body mass index (BMI), level of physical activity, and foot characteristics, did not demonstrate an association with the presence or absence of foot problems.

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Author Statement CREdiT

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All authors read and agreed with the published version of the manuscript.

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