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RESEARCH

FUNCTIONAL PROFILES OF THE FEET AND ITS RELATION TO THE BALANCE IN ELDERLY PEOPLE

Abstract

Introduction: The aim of this study was to investigate functional profiles of the feet and its relation to the balance in asymptomatic elderly people.

Materials and Method: We assessed 114 asymptomatic elderly subjects (34 men and 80 women) with a mean age of 67.2±3.4 years (range 65–80 years) using computerized baropodometric and analysis in standing and walking conditions. Load on the forefoot, rearfoot and total foot, support surface of the foot, foot angle, mean and maximum pressures exerted on the ground, cadence, gait velocity and step width parameters were assessed with baropodometric analysis. To evaluate balance, stabilometric analysis was performed and center of pressure excursions were measured.

Results: The baropodometric analysis revealed a significantly greater support surface and total load in the static condition and larger foot angle in the dynamic condition for the right foot than for the left one among women. However, there was no asymmetry between the right and left feet among men. Gait velocity was higher in men than in women; when standing, the foot angle and total load of the left foot was greater in men than in women. Center of pressure excursions were significantly greater in women compared to the men in anterior–posterior and in medio-lateral direction.

Conclusion: The results suggest that compared with elderly men, elderly women are more likely to develop functional left–right foot asymmetries in static and balance disturbances in dynamic conditions. These conditions should be considered as possible causes for increased risk of fall in elderly women.

Key Words: Aged; Foot; Gait; Posture

ARAŞTIRMA

YAŞLILARDA FONKSİYONEL AYAK PROFİLİ VE DENGE İLE İLİŞKİSİ

Öz

Giriş: Bu çalışmanın amacı asemptomatik yaşlı bireylerde ayağın fonksiyonel profili ve denge ile ilişkisini araştırmaktı.

Gereç ve Yöntem: Bu çalışmada, yaş ortalaması 67.2±3.4 yıl (65 ile 80 yaş arası) olan 114 asemptomatik yaşlı birey (34 erkek, 80 kadın), bilgisayarlı baropodometrik analiz yöntemi ile ayakta duruş ve yürüme değerlendirildi. Değerlendirilen parametreler ön ayak, arka ayak ve tüm ayak üzerindeki yük, destek yüzeyi, ayak açısı, yere aktarılan ortalama ve maksimum basınçlar, kadans, yürüyüş hızı ve adım genişliğiydi. Dengeyi ölçmek için ise stabilometrik analiz yapıldı ve basınç merkezi ekskürsiyonları ölçüldü.

Bulgular: Baropodometrik analizler kadınlarda, sol ayak ile karşılaştırıldığında sağ ayakta artmış destek yüzeyi ve yük varlığını gösterdi. Erkeklerde sağ ve sol ayak arasında herhangi bir parametrede asimetri saptanmadı. Yürüme hızı erkeklerde kadınlardan daha fazlaydı. Ayakta duruşta sol ayağın ayak açısı ve üzerine binen yük, erkeklerde kadınlardan daha fazlaydı. Antero-posterior ve medio-lateral yönde basınç merkezi ekskürsiyonları kadınlarda, erkeklere göre daha fazlaydı.

Sonuç: Çalışmanın sonuçları kadınların, statik durumda yapılan ölçümlerde sağ ve sol ayak arasında fonksiyonel asimetri, dinamik durumlarda ise denge bozukluğu geliştirmeye ve yatkın olduğunu gösterdi. Bu sonuçların, yaşlı ve kadın bireylerde düşme riskini artırabileceği açısından dikkate alınması önerilmektedir.

Anahtar Sözcükler: Yaşlılık; Ayak; Yürüyüş; Postür; Denge

INTRODUCTION

The foot constitutes a support surface that has sufficient flexibility for maintaining a stable upright stance and for effective weight transfer during gait (1). The feet play an important role in maintaining the postural balance during static and dynamic conditions by providing information to the central nervous system. External information provided by the feet relates to gravitational and reaction forces from the supporting surface; furthermore, information related to internal constraints such as proprioceptive signals and position sensing is provided by joint receptors and plantar mechanoreceptors (2).

Maintenance of body posture and symmetrical distribution of plantar loading primarily depends on proper biomechanics of the foot. Biomechanical variations in the lower extremities and in foot shape, biomechanics, and function are associated with functional overload and may predispose to risk factors that cause pain, dysfunction, accidents, and falls in elderly people (3).

With aging, alterations in joint mobility, biomechanics, and proprioception and muscle atrophy have been shown to occur in the foot. These changes affect foot functions and alter the plantar pressure distribution, which results in altered gait patterns in elderly people (4).

Computerized baropodometry analysis is a commonly used method for detecting functional alterations in feet that may be associated with possible risk factors, such as loading asymmetries, discrepancy in feet contact area, and excessive increase in plantar pressure. Therefore, this is an important method for understanding foot-related postural adaptation and asymmetries (5). The aim of this study was to investigate the functional profiles of the feet using baropodometric method in elderly asymptomatic people.

MATERIALS AND METHOD

Subjects

The study was approved by the Non-interventional Clinical Research Ethics Board of Hacettepe University GO 16/221 on May 24, 2016. The patients were sequentially enrolled from the Orthotic and Biomechanics Unit, Physiotherapy and Rehabilitation department of the Hacettepe University. The subjects were recruited in Ankara through public announcements, meetings and personal contacts. All the participants were informed about the study and signed the informed consent forms prior to participation.

We included 114 asymptomatic elderly volunteers (34 men and 80 women) with an average age of 67.2±3.4 years (range 65–80 years). The inclusion criteria were age 65 and above; being right-footed (i.e., having right lower extremity dominance), as defined by the Waterloo Footedness Questionnaire-Revised (WFQ-R) (6); and independent ambulation without an assistive device. Exclusion criteria were presence of any of the following conditions or characteristics: cognitive impairment; foot-related problems or pain 3 months prior to the visit; history of traumatic injury to or surgery of the lower extremity; previous neurological, musculoskeletal, rheumatic, or orthopedic disease; or diabetes or neuropathies diagnosed by a physician.

Examination procedure

The general characteristics evaluated for the subjects included their age, sex, body weight, height, and body mass index (BMI). Subjects were classified into four BMI categories according to World Health Organization categories as underweight, (BMI<18.5 kg/m^2), normal weight (18.5<BMI<25.0 kg/m^2), overweight (25≤BMI<30.0 kg/m^2) and obese (BMI ≥30 kg/m^2) (7). All examination procedures were performed by the first author.

For assessment of electronic baropodometric and stabilometric variables, a barosensitive force platform (Diasu Company, Rome, Italy; 120 cm long and 40 cm wide; 4024 sensors; frequency, 300 MHz) was used. The measuring system comprised the platform placed on the floor and connected to a computer running the manufacturer's software. The assessments were performed for static and dynamic conditions (standing upright and walking across the platform, respectively) of the subjects. No instructions were given to the subjects as to how to step onto the device; this allowed them to assume their habitual standing posture and walking characteristics.

Foot type was determined by obtaining arch index values using foot print analyses taken while the subject stood on the force plate platform. Foot type was classified based on the arch index as follows: arch indices≥0.260 were considered low-arched; arch indices between 0.210 and 0.260 were considered normal; and arch indices≤0.210 were considered high-arched as introduced by Cavanagh and Rodgers (8).

For the static condition, the subjects were requested to stand barefoot on the force plate platform with their arms resting down alongside the trunk and to maintain this position for 1 min while looking directly straightforward with their eyes open. The following data were collected for each foot: percentages of the load on the forefoot and rearfoot, support surface of the foot, total load on the foot, and foot angle.

For the dynamic condition, the subjects were requested to walk barefoot across the platform. During walking, the support surface of the foot, total load on the foot, foot angle, mean and maximum pressures exerted on the ground, cadence, gait velocity, and step width were assessed.

For stabilometric recordings, center of pressure (COP) excursions in antero-posterior and medio-lateral direction during walking were measured. The distance from center of gravity of the foot to the center of gravity of the body (CGF-CGB distance) was recorded.

Statistical analysis

The Kolmogorov–Smirnov and Levene's tests were used to confirm the normal distribution of data and homogeneity of variances, respectively. Statistical comparisons were made using Student's t-test, considering p values<0.05 as significant. Data are expressed as means and standard deviations (SDs) (and 95% confidence interval). Analyses were performed using SPSS for Windows version 11.0 (SPSS Inc., Chicago, IL).

RESULTS

Initially, 162 elderly people were assessed for eligibility. Of them, 12 refused to participate and 36 were excluded from the study for not meeting the inclusion criteria, with diabetes, degenerative joint disease, balance problems, and pain cited as the main reasons. Thus, we included 114 asymptomatic elderly volunteers who agreed to participate in the study and underwent the computerized baropodometric analysis.

Demographic and clinical characteristics of the subjects according to the gender are presented in Table 1. Age, height, and body weight were significantly higher in men than in women (p<0.05). The BMI difference between these two groups was not statistically significant (p>0.05).

Of the 228 feet included in this study, 41 (18.0%) were classified as low-arched, 90 (39.5%) were classified as normal, and 97 (42.5%) were classified as high-arched. No significant difference in foot type was found between men and women (p>0.05). (Table 2).

Table 1. Demographic and clinical characteristics of the subjects (n=114)

Characteristic	Men (n=34) Mean±sd	Women (n=80) Mean±sd	p
Age (years)	68.3±4.1	66.8±3.0	0.032*
Height (cm)	171.8±8.7	159.4±5.9	0.000**
Weight (25)	85.0±14.2	76.5±12.1	0.002*
Body mass index (kg/m^2)	28.7±3.9	30.1±5.0	0.160
BMI classification n (%)			
Obese	13 (38.2)	41 (51.7)	
Overweight	18 (52.9)	26 (32.5)	0.112
Normal weight	3 (8.8)	13 (16.3)	

* p<0.05, ** p<0.001
Group values are expressed as mean±Standard Deviation or n (%).

Table 2. Foot type of the subjects

Foot type	Men (n= 34)		Women (n=80)		p
	Right n (%)	Left n (%)	Right n (%)	Left n (%)	
Low-arched	5 (14.7)	7 (20.6)	12 (15.0)	17 (21.3)	
Normal	14 (41.2)	10 (29.4)	38 (47.5)	28 (35.0)	0.788
High-arched	15 (44.1)	17 (50.0)	30 (37.5)	35 (43.8)	

A comparison of the baropodometric analysis results between men and women showed significant differences in some parameters (Table 3). The total load on and foot angle of the left foot were greater in men than in women while standing; furthermore, gait velocity was higher in men (p<0.05).

For all baropodometric parameters, no differences between right and left lower extremities were found for men (p>0.05). In women, the support surface of and total load on the right foot were significantly greater than those for the left foot while standing; furthermore, the foot angle of the right foot was greater than that of the left one during walking (p<0.05) (Table 3).

The results obtained stabilometric recordings revealed statistically significant differences between men and women. Center of pressure excursions were significantly greater in women compared to the men in anterior–posterior and in medio-lateral direction (p<0.05). CGF-CGB distance was greater in men than women (p<0.05) (Table 3).

DISCUSSION

This study demonstrated that the functional profile of the feet of people aged 65 and above differed between men and women. Women showed asymmetry between the right and left feet in loading and support surface area while standing and in foot angle during walking. This is consistent with previous studies reporting that women tend to exhibit plantar pressure asymmetries between the dominant and non-dominant sides of lower extremities during walking (9). Furthermore women had a slower preferred walking speed and greater COP excursions in antero-posterior and medio-lateral direction than men. These alterations in functional profile of the feet and postural balance might reflect a movement strategy intended to enhance stability and adaptability in elderly women (10).

Several factors, including foot structure, gait velocity, and body weight, have been shown to influence plantar pressure in elderly people (11). Load distribution has been shown to be uniform and equally distributed between the right and left support surfaces, and under normal conditions, 40% and 60% of the load should burden the forefoot and rearfoot, respectively. However, it has been found that compared with younger people, elderly people are more likely to show a decline in the magnitude of load and pressure under the heel, lateral foot, and hallux (12). In the present study, foot type distribution, comprising of high, normal and low foot type, showed similarity among men and women. Women were mostly obese and men were mostly overweight, but the differences in BMI between groups were not statistically different. Analysis during the static condition revealed that the support surface and total load were greater for the right foot than for the left one in women, but there was no asymmetry between the feet in men. In both men and women, the load distribution between the forefoot and rearfoot was normal in this study, in contrast to the results of a study by Scott et al. (12).

Table 3. Comparison of Static and Dynamic Baropodometric Values Among the Two Gender and Between the Right and the Left Foot

	Men (n= 34)		Women (n=80)		p	
	Right foot	**Left side**	**Right foot**	**Left foot**	**Right foot**	**Left foot**
Static measurements						
Load % forefoot	40.44±13.95	41.41±11.76	39.59±14.00	39.27±13.52	0.770	0.424
	(p=0.462)		(p=0.722)			
Load % rearfoot	59.56±13.95	68.60±11.77	60.41±14.00	60.71±13.52	0.770	0.432
	(p=0.472)		(p=0.741)			
Support surface (cm^2)	108.08±32.50	107.23±29.21	105.43±29.03	101.18±27.66	0.669	0.296
	(p=0.739)		(p=0.016)[a]			
Total load (kgf)	40.30±10.41	42.55±12.48	39.01±9.12	36.61±9.01	0.511	0.005[b]
	(p=0.221)		(p=0.040)[a]			
Foot angle (º)	10.93±5.43	12.50±6.37	10.20±5.33	10.12±5.13	0.509	0.039[b]
	(p=0.193)		(p=0.906)			
Dynamic measurements						
Support surface (cm^2)	110.95±35.34	108.84±33.38	103.05±31.77	103.41±32.54	0.243	0.421
	(p=0.595)		(p=0.884)			
Total load (kgf)	49.32±8.76	50.67±8.75	49.51±8.49	50.62±8.50	0.917	0.976
	(p =0.655)		(p=0.561)			
Foot angle (º)	14.54±4.45	13.59±5.19	14.39±5.34	12.55±5.92	0.893	0.375
	(p=0.325)		(p=0.023)[a]			
P_{mean} (kgf/cm^2)	833.16±469.33	999.54±1003.95	814.05±361.11	859.90±602.91	0.815	0.363
	(p=0.367)		(p=0.347)			
P_{max} (kgf/cm^2)	1282.97±539.35	1372.30±519.95	1244.86±569.61	1351.92±783.08	0.741	0.895
	(p=0.369)		(p=0.119)			
Cadance (step/min)	44.32±11.93	43.71±13.51	42.02±12.26	41.71±13.57	0.427	0.536
	(p=0.813)		(p=0.896)			
Step width (cm)	10.20±4.24	10.12±3.82	10.18±4.13	10.05±4.47	0.987	0.943
	(p=0.716)		(p=0.545)			
	Men (n= 34)		Women (n=80)		p	
Gait velocity (m/s)	61.13±20.39	51.63± 19.01			0.046[b]	
CGF- CGB distance	15.29±7.63	19.74±10.51				0.015[b]
COP ant-post (mm)	403.97±133.14	477.66±44.81			p<0.001[b]	
COP med-lat (mm)	253.90±86.89	310.10±61.19			0.001[b]	

Load % forefoot, Percentage of load on the forefoot; Load % rearfoot, Percentage of load on the rearfoot; Pmean, mean pressure; Pmax, maximum pressure; CGF-CGB distance, distance from center of gravity of the foot to the center of gravity of the body; COP ant-post, center of pressure excursion in the antero-posterior plane; COP med-lat; center of pressure excursion in the medio-lateral plane.

a significance value among the two sides of the lower extremity, p<0.05.

b significance value among the two gender, p<0.05

All values are expressed as mean±Standard Deviation.

The present study also showed that the total load on the left foot was greater in men than in women in the static condition. Preliminary baropodometric surveys have suggested that a significant increase in the contact area and plantar pressure predisposes to lower limb complications, such as pain and discomfort, and negatively affects walking and activities of daily living (13). According to the present study results, it appears that elderly women tend to overload the dominant lower extremity; this might lead to pressure-related foot problems on the dominant side in women. Kernozek and Lamott found a greater support surface and lesser contact time in the elderly than in young adults in both sides (4).

The specific positioning of the feet is known to influence postural responses and balance control in the subject's preferred standing position and during walking. The foot angle is defined as the angle between the direction of progression of the subject and a reference line on the sole of each foot (14). In the present study, during the assessment in the static condition, the foot angle of the left foot was found to be greater in men than in the women. During gait, the foot plays an important role in shock absorption in the heel-contact phase, adapting to irregular surfaces in the mid-stance phase and contributing to momentum generation for forward propulsion in the pushing-off phase (15). During walking, the foot angle of the right foot was greater than that of the left one in women, whereas this asymmetry was not observed in while standing. Changing the position of the foot at contact may affect all other joints and create a modifying effect on the moment around the lower extremity during gait. These asymmetries in foot angle between the feet may have been influenced by alterations in balance control.

Gait velocity provides valuable information about physical performance and is a predictor of functional dependence as well as future disability and mortality in elderly people. A decrease in gait velocity has been associated with decreased gait performance and increased risk of falls in elderly people (16). In the present study, preferred gait velocity was slower in women than in men and may be related to the foot angle asymmetry between the two sides in women. We propose that a decrease in walking velocity places elderly women at a greater risk of falls. During normal walking, the foot is the only part of the body that is in direct contact with the ground. Thus, any factor that alters normal foot function during ambulation may impair postural stability and balance, thereby increasing the risk of falls (17). A study found that concerns related to falls are greater in women than in men and this fear of falling results in a decreased mobility in elderly women (18). Kirkwood et al. suggested increasing the step length in elderly women with the aim of slowing the decline in gait velocity, thereby reducing the risk of falls (19).

Voluntary movements result in internal perturbations of balance and equilibrium. Proper control of the center of gravity motion and its coordination with COP are considered important to maintain the dynamic stability of the body and resultant kinetic demands at the joint of the supporting limb when walking (20). Postural stability decreases with age and causes the increase in risk of falls in elderly population (21). Although the groups kept similar ratio of foot type distribution and had no significant difference in BMI, women subjects displayed greater COP excursions in antero-posterior and medio-lateral direction and had greater distance between CGF and CGB than men, as stabilometric parameters, in this study. It has been demonstrated that an increase in the amplitude of the COP displacement represents an increase in the foot tilt strategy mechanism (generating a stabilizing moment force of the body in order to counteract body tilt) for balance control (22). Greater COP excursions in women could be interpreted as increase in foot tilt strategy to overcome the balance challenge of walking. Previous research has found excessive medio-lateral linear momentum during gait in elderly with gait instability from bilateral vestibular hypofunction (23). A compensatory adjustment for great CGB-CGF distance for women may show difficulty to maintain the line of progression within the base of support to avoid imbalance. Therefore we propose that elderly women adopt strategies to maintain dynamic stability and balance. The modulating mechanism for balance control is complex, possibly affecting the COP displacement (24). Interpretations of these findings may not generalize the effect of foot structure on balance control, but also consider the relation between functional profile of the feet and balance control during walking for elderly adults. Further studies are needed to clarify the relationship between postural control and foot structure.

In the present study, although men's body weight was significantly greater than that of women's and both genders had a similar support surface, there was no difference between the two genders in the mean and maximum pressures applied to the ground during walking. This may indicate that, despite their lower body weight, women tend to apply foot pressures to the ground similar to those applied by men. This can result in pressure-related foot complaints in women in the long term. Mickle et al. found that high plantar pressures during gait contribute to a risk of falls in community-dwelling elderly people (17). Kim et al. found unequal balance between the dominant and non-dominant feet, as well as increases in the support surface, particularly on the medial and posterior aspects of the plantar surface of the dominant side of older women during walking. They reported these findings as an indication of a high risk of falls in elderly women (9). In the present study, we observed similar findings in elderly women for the static condition, but they accommodated these alterations while walking. There are several reasons that might explain the change in pressure patterns in elderly people: temporospatial gait parameters, such as gait velocity, cadence, and step length; demographic characteristics, such as height and body weight; and altered foot biomechanics, such as foot posture, a limited range of motion, and foot deformities (11).

Limitations

There are several limitations and challenges to developing this research. One limitation of this study is the difference in mean age between the elderly men and women population. Another limitation is that the elderly population of this study mostly consisted of obese and overweight people. It appears that there is need for a continuing study investigating whether the influence of body weight on functional profile of the feet. Separate analyses by age groups and BMI in both genders would provide an opportunity to compare outcome measures between elderly people with similar ages. Moreover, there was the lack of data collection about the foot deformities of the subjects. Larger studies that include adults of different ages are needed to assess the exact relationship between the plantar pressure distribution, foot type, and postural balance and the underlying mechanism responsible for asymmetry between functional profiles of the feet in elderly women.

In conclusion, multiple alterations in foot biomechanics can affect the functional profile of the foot and may require clinical attention even in asymptomatic elderly people. This study revealed an unequal weight distribution between the lower extremities in elderly women. Furthermore, decrease in preferred gait velocity and increase in COP excursion during walking may indicate altered balance control elderly women. These should be considered as possible causes of fall during walking in elderly women. There is need for further investigation to clarify the relationship between postural control and foot structure in elderly people.

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