Original Article

Evaluation of foot morphology in terms of laterality in elderly women

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Abstract:
Objective: The main study objective was to describe the differences of selected foot morphological parameters in terms of laterality in present elderly women. *Methodology:* Research group consisted of 310 elderly women attending the University of the Third Age of the Faculty of Physical Culture of the Palacký University in Olomouc. A podograph (Capron Podologie, France) was used to acquire footprints using the plantographic method. Length, width and angle parameters and the Chippaux-Smiřák index were evaluated using the NOHA program to assess the longitudinal foot arch condition. We used basic descriptive statistics to describe acquired measurements. T-test for independent samples was used to determine the differences between the right and left foot. *Results:* The elderly women had the highest incidence of the normally arched longitudinal foot arch second degree (Right: 51.3%, Left: 57.4%). When evaluating the average values of the Chippaux-Šmiřák index (Right: 35.7% ± 9.8%; Left: 34.1% ± 11.2%), significant differences (p = 0.00054) between the right and left foot were found. The average big toe rightward misalignment was 9.8° ± 8.1° and leftward misalignment was 10.7° ± 8.9°. The average little toe angle misalignment was 17.5º ± 6.8º (R) and 16.9º ± 6.8º (L). *Conclusions:* More than 80% of elderly women attending U3A had normally arched foot second degree (N2). Statistically significant differences in relation to the laterality were found in the forefoot length, heel angle, foot angle and the Chippaux-Smirak index. The big and little toe misalignment in terms of laterality may be assessed as similar, without any significant differences.
Key words: foot length, foot width, Foot Index, big toe misalignment, longitudinal foot arch, podography technique.

Introduction

Foot is an integral part of the support and movement apparatus. From the morphological structure of the foot, which is given by the longitudinal and transverse foot arch, its function is derived (Riegerová, Přidalová, & Ulbrichová, 2006). Abnormal reduction in the longitudinal foot arch or its complete disappearance is called flat foot (pes planus) (Dungl, 2014). Abnormal longitudinal foot arch, namely when the midfoot is not in contact with underlayment, is called high arch (pes cavus). The longitudinally flat foot and high arch adversely affect the hips and knee joints and affect the position of the pelvis (Faria, Gabriel, Abrantes, Brás, & Moreira, 2010). The longitudinally flat foot is linked to the heel valgosity and the forefoot abduction, occurring primarily in women rather than in men. This indicates strong correlation between laxity of the ligaments and obesity (Riegerová et al., 2006). Frey (2000) explained how the structural changes in female body affect the pronation of the foot: women compared to men have narrower shoulders, hips in a more varus position and knees in a more valgus position, which may induce the pronation of the hindfoot. The high arch is associated with muscle contraction, muscle imbalance and wearing of unsuitable footwear (Riegerová et al., 2006).

Senescence brings various changes, inter alia in the area of the foot. Foot deformities may cause its elongation, but also widening of its front part (Mann & Coughlin, 1981; Nguyen et al., 2010). We include among other foot deformities when the big toe is bend outwards or inwards, little toe misalignment, etc. Hallux valgus (big toe bend outwards) is the static subluxation of the first metatarsophalangeal joint with lateral deviation of the big toe, the medial displacement of the distal end of the first metatarsal and the bone enlargement of the first metatarsal head (Mann & Coughlin, 1981). Prevalence of this deformity increases with increasing age, it is more prevailing in women (Nguyen et al., 2010; Nix, Smith, & Vicenzino, 2010). Digitus quintus varus (little toe bend inwards) is a medial misalignment of the little toe from its axis, when the head of the fifth metatarsal is misaligned, similar changes occur as in hallux valgus (Liepold, Fuhrmann, & Venbrocks, 2005). In general, foot problems occur more commonly in elderly people (Dunn et al., 2004; Roddy, Zhang, & Doherty, 2008; Nix et al., 2010; Golightly, Hannan, Dufour, Renner, & Jordan, 2015), with the greater incidence of foot deformities in women than in men (Nguyen et al., 2010; Nix et al., 2010). In order to evaluate the condition of the foot, it is essential to use valid and reliable assessment method (Razeghi & Batt, 2002). We differentiate the foot classification methods into the following categories: a) visual non-quantitative aspects, b) anthropometric

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parameters, c) two-dimensional plantogram parameters and d) radiographic evaluation. Footprint evaluation is carried out by footprint scanning using different types of plantography examinations, where the evaluation is then visual or mathematical. In mathematical evaluations, index or segment methods are used (Riegerová et al., 2006). Advantage of evaluating foot plantograms is that it gives quick, simple and cheap method. It also may be objectively evaluated and may easily be used anywhere. However, it is crucial to consider which index or method is appropriate for the evaluation based on footprints (Kopecký, 2004).

Although the human body appears to be bilaterally symmetrical, scientists have long been aware of the presence of skeletal and morphological asymmetries in the human body. Bilateral asymmetry is defined as the difference between measurements of the left and right sides of the human body (Krishan, Kanchan, & DiMaggio, 2010). The aim of this study is to describe the differences in selected morphological parameters of the foot in terms of laterality in contemporary elderly women.

Methodology
Participants
Research group consisted of 310 elderly women from Olomouc (Table 1). Data collection took place in 2009, 2012-2015 at the University of the Third Age of the Faculty of Physical Culture of the Palacký University in Olomouc (U3A FPC UP). All participants were familiarised with the research and signed informed consent. The research was approved by the ethics committee of FPC UP in Olomouc.

Table 1. Research group basic description

Parameter	M	SD	Min.	Max.
Age (years)	66.1	6.5	51.0	85.0
Body height (cm)	160.8	6.5	143.0	178.0
Weight (kg)	72.2	13.6	44.0	152.0

Note: M – arithmetic average; SD – standard deviation; Min – minimum; Max – maximum
Procedure/Measurement
Measurements were carried out in the morning at the anthropometric laboratory of FPC UP in Olomouc. The participants underwent anthropometric examination, which included measurement of body height (anthropometer A-226, Trystom, Czech Republic) and body weight (InBody 720, Biospace, South Korea).
Footprints were acquired by using the plantography examination method, namely using the podograph (Capron Podologie, France). Subsequently, length of bare foot (mm) was measured anthropometrically by sliding gauge (Torakometer T-520, Trystom, Czech Republic). Outputs from the podograph were static paper impressions of the foot, which had to be scanned into the computer and processed using "Noha" (Foot) software (Elfmark & Přidalová, 2002). Accurately defined anthropometric points on the foot (Figure 1) were manually marked, based on which the software evaluated the length, width and angular parameters of the foot, including the selected indexes.
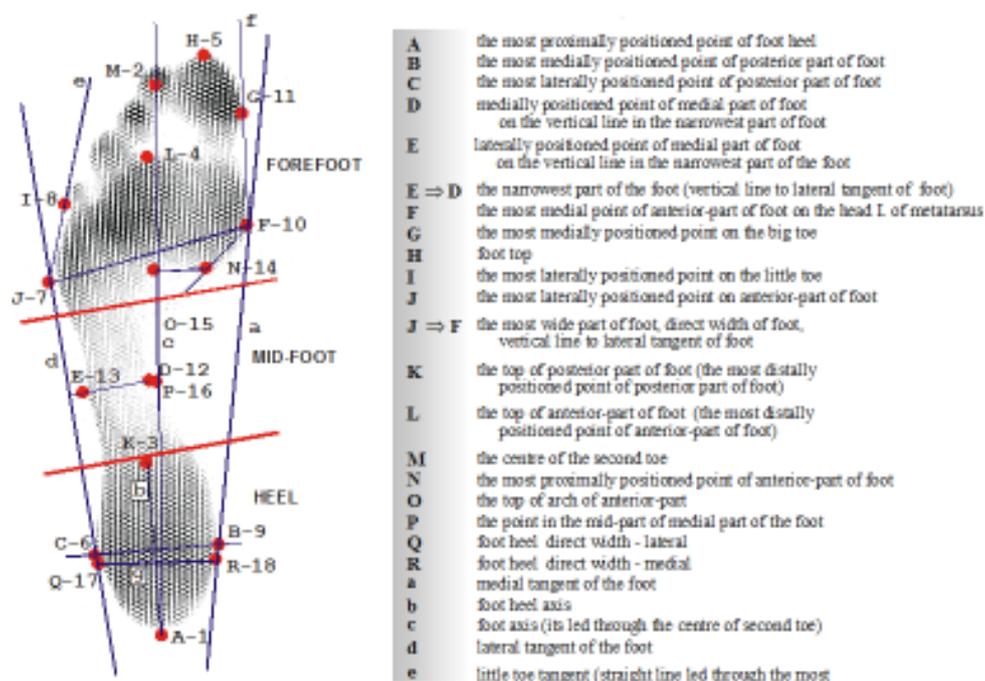

A	the most proximally positioned point of foot heel
B	the most medially positioned point of posterior part of foot
C	the most laterally positioned point of posterior part of foot
D	medially positioned point of medial part of foot on the vertical line in the narrowest part of foot
E	laterally positioned point of medial part of foot on the vertical line in the narrowest part of the foot
E ⇒ D	the narrowest part of the foot (vertical line to lateral tangent of foot)
F	the most medial point of anterior-part of foot on the head I. of metatarsus
G	the most medially positioned point on the big toe
H	foot top
I	the most laterally positioned point on the little toe
J	the most laterally positioned point on anterior-part of foot
J ⇒ F	the most wide part of foot, direct width of foot, vertical line to lateral tangent of foot
K	the top of posterior part of foot (the most distally positioned point of posterior part of foot)
L	the top of anterior-part of foot (the most distally positioned point of anterior-part of foot)
M	the centre of the second toe
N	the most proximally positioned point of anterior-part of foot
O	the top of arch of anterior-part
P	the point in the mid-part of medial part of the foot
Q	foot heel direct width - lateral
R	foot heel direct width - medial
a	medial tangent of the foot
b	foot heel axis
c	foot axis (its led through the centre of second toe)
d	lateral tangent of the foot
e	little toe tangent (straight line led through the most

Figure 1. Description of individual morphological points and parameters of the foot (Přidalová, 2005)

Length of the foot is defined as the distance between the most proximal point of the heel and the top of the foot. Length of the forefoot is the distance between the most proximal point of the heel and the most distal point of the forefoot. Width of the forefoot is the distance between the most medial point of the forefoot on the first metatarsal head and the most lateral point of the forefoot on the fifth metatarsal head. Length of the heel is given by the distance between the most proximal point of the heel and the top of the hindfoot (the most distal point of the hindfoot). Width of the heel is given by the distance between the most medial and the most lateral point of the hindfoot. Angle of the foot is defined as the magnitude of the angle that forms the medial and lateral foot connecting lines. The Chippaux-Šmiřák index (CSI) method was used to evaluate the longitudinal foot arch (Klementa, 1987). This index is calculated as follows:

$CSI = (|ED|/|JF|)*100$ [%]

Distance ED is the narrowest width of the foot; distance JF is the widest part of the foot (Riegerová et al., 2006). According to Klementa (1987) normally arched foot first degree is up to 25% (N1); second degree within the range of 25.1% and 40% (N2), and third degree from 40.1% up to 45% (N3). Values within the range of 45.1% and 50% are interpreted as the flat foot first degree (F1), from 50.1% up to 60% it is considered as the flat foot second degree (F2) and from 60.1% the foot is assessed as the flat foot third degree (F3).

The Foot Index (FI) was calculated for each sole of the foot. According to Moudgil, Kaur, Menezes, Kanchan and Garg (2008) the Foot Index is calculated as follows:

$FOOT\ INDEX = (FOOT\ WIDTH/FOOT\ LENGTH)*100$

We categorised the big toe misalignment as follows (Riegerová et al., 2006):
a) Big toe varosity describes the big toe misalignment in the medial direction. We depicted this angle as negative from mathematical point of view. Varosity, according to the magnitude of misalignment, may be described as physiological (from -2° up to -6°) or as prominent (more than -6°)
b) Big toe normal position – range within -2º and 2º
c) Big toe valgosity describes the big toe lateral misalignment. We depicted this angle as positive from mathematical point of view. Valgosity, according to the magnitude of misalignment, may be described as physiological (from -2° up to -6°) or as prominent (more than -6°)

We used the following categories for evaluating the little toe misalignment:
a) Little toe varosity describes the little toe lateral misalignment in relation to the forefoot with angle greater than 9º
b) Little toe valgosity describes the little toe medial misalignment in relation to the forefoot with angle smaller than 9º

Little toe normal position is deemed when the little toe angle is ± 9º.

Statistical analysis
Data was processed using Statistica program, Version 12. Statistical significance level was set to α = 0.05. We used basic descriptive statistics to describe acquired measurements. To determine differences between the right and left sole of the foot parameters T-test for independent samples was used.

Results
Significant differences between the left and right feet were found, namely in the length of the forefoot, the angle of the foot and the angle of the heel. The foot length, width of the forefoot, heel length, heel width, and Foot Index were not different in terms of laterality (Table 2).

Table 2. Descriptive morphology characteristics relating to the sole of the foot

(n = 310)	LEFT				RIGHT				p (P/L)
	M	SD	Min.	Max.	M	SD	Min.	Max.	
Foot length (mm)	232.8	11.4	207.0	261.0	233.1	11.5	204.0	262.0	0.2293
Forefoot length (mm)	201.7	9.7	176.2	224.7	202.6	10.0	177.1	231.9	0.0028
Forefoot width (mm)	90.4	6.0	71.4	108.2	90.4	5.9	76.3	109.8	0.6888
Heel length (mm)	61.8	5.7	48.1	78.8	61.7	5.9	43.5	79.4	0.6252
Heel width (mm)	51.9	5.1	35.1	64.6	51.6	4.9	40.4	75.2	0.0696
Foot angle (˚)	15.9	3.7	-15.3	24.4	16.3	3.3	-14.9	25.4	0.0103
Heel angle (˚)	11.3	3.8	-6.7	21.5	12.2	3.6	2.9	21.9	0.0041
Foot Index (%)	38.9	2.6	29.0	47.5	38.8	2.5	31.8	47.0	0.7170

Note: M – arithmetic average; SD – standard deviation; Min – minimum; Max – maximum; p (P/L) – statistical significance between the right and left foot

When evaluating the longitudinal foot arch according to the CSI, it was found that 80% of the elderly women had both feet normally arched. The incidence of high arch was within the range of 5.5% and 6.8%. The

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longitudinally flat left foot was found in 11.6% of participants; the incidence of the longitudinally flat right foot was slightly higher, namely 14.5% (Table 3).

Table 3. Incidence rate of types of the foot as per CSI

Foot arch		High	Normal			Flat		
Laterality			N1	N2	N3	F1	F2	F3
R	n	17	36	178	34	27	13	5
	%	5.5	11.6	57.4	11.0	8.7	4.2	1.6
L	n	21	59	159	35	17	13	6
	%	6.8	19.0	51.3	11.3	5.5	4.2	1.9

Note: R – right foot; L – left foot; n – number of participants; % – incidence rate in percentages; N1 – normally arched foot Ist degree; N2 – normally arched foot IInd degree; N3 – normally arched foot IIIrd degree; F1 – flat foot Ist degree; F2 – flat foot IInd degree; F3 – flat foot IIIrd degree

Significant average difference between the left and right foot relating to elderly women as per CSI was confirmed (Table 4).

Table 4. Descriptive characteristics and differences between left and right foot as per CSI

Laterality	n	M	SD	Min.	Max.	p (P/L)
R	293	35.7	9.8	9.5	71.7	0.00054
L	289	34.1	11.2	6.5	64.7	

Note: R – right foot; L – left foot; n – number of participants; M – arithmetic average; SD – standard deviation; Min – minimum; Max – maximum; p (P/L) – statistical significance between the right and left foot

Big toes valgosity appeared similar in terms of laterality. Big right toe valgosity was found as 11.3° ± 7.2° and the big left toe valgosity as 11.9° ± 7.8°. Big toe varosity values relating to both feet were lower than the valgosity values, namely R: -3.6° ± 2.7°; L: -5.2 °± 5.6°. Differences in average big toe misalignment in terms of laterality are not significant (Table 5).

Table 5. Descriptive characteristics and differences relating to big toe misalignment

	Lat.	n	M	SD	Min.	Max.
Big toe misalignment > 0°	R	280	11.3	7.2	0.2	40.0
	L	287	11.9	7.8	0.0	37.1
Big toe misalignment < 0°	R	30	-3.6	2.7	-9.1	0.0
	L	23	-5.2	6.5	-27.1	0.0
Total big toe misalignment (°)	R	310	9.8	8.1	0.0	40.0
	L	310	10.7	8.9	0.0	37.1
p (P/L)	0.116					

Note: Lat. – laterality; R – right foot; L – left foot; n – number of participants; M – arithmetic average; SD – standard deviation; Min – minimum; Max – maximum; p (P/L) – statistical significance between the right and left foot average values

Little toe medial misalignment (valgosity) significantly outweighed the varosity and was in terms of laterality almost within the same range, namely R: 18.7° to 22.6° and L: 18.4° to 22.2°. Little toe average misalignment was without significant differences (Table 6).

Table 6. Descriptive characteristics and differences relating to little toe misalignment

	Lat.	n	M	SD	Min.	Max.
Little toe misalignment > 9°	R	282	18.7	5.5	9.3	32.8
	L	278	18.4	5.2	9.1	35.3
Little toe misalignment < 9°	R	28	4.8	4.8	-23.7	8.3
	L	32	4.3	4.3	-15.2	8.9
Total little toe misalignment (°)	R	310	17.5	6.8	-23.7	32.8
	L	310	16.9	6.8	-15.2	35.3
p (P/L)	0.127					

Note: Lat. – laterality; R – right foot; L – left foot; n – number of participants; M – arithmetic average; SD – standard deviation; Min – minimum; Max – maximum; p (P/L) – statistical significance between the right and left foot average values

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Discussion

Elderly women in our research group had the average length of the foot 233.1 ± 11.5 mm (R) and 232.8±11.4 mm (L). Average width of the foot was 90.4 ± 6.0 mm (R) and 90.4 ± 5.9 mm (L). Compared to the study by Tomassoni, Traini and Amenta (2014), the average length and width of the foot in participants in our study is lower. Length of the foot in the abovementioned study in women aged between 65 and 70 years was 247.4 ± 16.2 (n = 140) and average width of the foot was 94.1 mm.

Foot Index in women relating to the left foot was higher, namely R: 38.8 and L: 38.9, and the FI of elderly women without any significant differences (p = 0.717). Our acquired Foot Index values are higher compared to the results of Singh and Yadav (2017), who found in their study the rightward FI of 36.9 ± 3.5 and the leftward FI of 36.1 ± 4.9; the left foot FI values were higher, however, the differences were not significant (p = 0.056). Results in Moudgil et al. (2008) study were reversed; women had higher right foot FI. It is apparent that the ethnic origin greatly influences the foot length and width and consequently the Foot Index or Heel-Ball Index.

It was found that 80% of the elderly women in our research group had normally arched longitudinal foot arch; more than 50% had second degree normally arched feet (R: 57.4%; L: 51.3%). Flat foot third degree occurred only rarely. Seventeen elderly women (5.5%) had the right high arch and 21 elderly women (6.8 %) the left high arch. Average values of the CSI were 35.7 ± 9.8 (R: 9.5 to 71.7) and 34.1 ± 11.2 (L: 6.5 to 64.7). Similar results were also found in the study by Fuchsová (2015), where in Slovak women aged 40 to 60 years, normally arched feet second degree (N2) were the most commonly found; 52.7% had normally arched right foot and 49.1% normally arched left foot. Flat foot third degree (F3) was not found within the group. Average values of the CSI were 35.7 ± 8.5 (R: 18.3 to 51.7) and 34.9 ± 9.7 (L: 15.0 to 58.1). The CSI average values were similar in our research group; however, the range of values was wider. Szotkowská, Riegerová, Přidalová and Rýznarová (2005) analysed feet of the U3A female students aged between 48 and 71 years and acquired similar results in terms of evaluating the longitudinal arch of the foot. More than 80% women had normally arched longitudinal foot arch given by the CSI. The average CSI values were lower (R: 31.3 ± 7.9; L: 29.8 ± 11.5) compared to our average values.

Incidence of foot deformities is more common in women and older persons (Dunn et al., 2004; Roddy, Zhang, & Doherty, 2008; Nix et al., 2010; Golightly, Hannan, Dufour, Renner, & Jordan, 2015), which may be linked to changes in muscle tissue with increasing age (Aiyer, Stewart, & Rome, 2015; Stewart, Ellis, Heath, & Rome, 2013; Verhulst et al., 2011). Elderly women in our study had the average misalignment of the right big toe of 9.8º (-9.1º to 40.0º) and of the left toe of 107º (-27.1º to 37.1º). Women in the Fuchsová (2015) study had lower average big toe misalignment (R: 6.4º; from -6.0º up to 21.0º; L: 7.5º, from -17.0º up to 22.0º), however we note wider range of age categories. Hallux valgus was evaluated in the Polish study by Puszczałowska-Lizis, Bujas, Omorczyk and Nosiadek (2016), where Polish elderly women aged between 60 and 69 let years had the right big toe valgosity of 11.1º (0.0º to 29.0º) and the left big toe valgosity of 11.3º (0.0º to 30.0º). Our elderly women had similar valgosity average values (P: 11.3º; 0.2º to 40.0º; L: 11.9º; 0.0º to 37.1º). In the abovementioned studies, the average values of big toe misalignment or big toe valgosity were higher in the left foot than in the right foot without any significant differences. Incidence of hallux valgus was greater than hallux varus. Hallux varus had lower misalignment than valgosity.

Right and left little toe medial misalignment in women was comparable (R: 18.7º ± 5.5˚; L: 18.4º ± 5.2˚). Fuchsová (2015) found in her study that women aged between 40 and 60 years had little toe rightward misalignment of 13.6º ± 5.6˚ and leftward misalignment of 13.4º ± 6.1˚. In the Puszczałowska-Lizis, Bujas, Omorczyk and Nosiadek (2016) study, the Polish women aged 60 to 69 years let had the average little right toe misalignment of 16.6º ± 5.8˚ and little left toe misalignment of 15.1º ± 6,5˚. Our average misalignment values appeared to be the highest.

When evaluating the differences between the right and left foot monitored parameters, we found statistically significant differences in elderly women in the length of the forefoot, the angle of the foot, the angle of the heel and the CSI. Ewunonu, Egwu, Eteudo and Ajoku (2014) study demonstrated occurrence of bilateral asymmetry in the foot dimensions in young adults; women in this study had their right foot longer and wider than the left one. Singh and Yadav (2017) found side differences only in the foot length parameters measured from the most proximal point of the heel (pternion) to the most distal point of the big toe. They also found significant differences in the width of the foot. In the study by Kanchan et al. (6), within the combined group, significant side differences were found only in the width of the forefoot. In all the above mentioned studies, bilateral significant differences were found in the length of the foot and forefoot width, however, statistically significant difference in the foot width was not demonstrated in our study.

Conclusion

Elderly women attending U3A had predominantly normal longitudinal foot arch, mostly normal arch second degree. Forefoot deformities were more serious, namely higher occurrence of big toe valgosity, which is a typical misalignment particularly in women with higher valgosity in relation to varosity. In most cases, statistically significant differences were not found in the monitored parameters in terms of laterality, which may be explained that the target group participants are relatively physically active.

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