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Foot Anatomical Structural Variations Increase the Risk of Falls in Older Adults

Almudena Sánchez-Sanjuan [1,2], Carlos Romero-Morales [1], Javier Alfaro-Santafé [2,3], Alejandro-Jesús Almenar-Arasanz [3,4], Antonio Gómez-Bernal [2,3,*] and Helios Pareja-Galeano [5]

1 Faculty of Sports Sciences, Universidad Europea de Madrid, 29670 Madrid, Spain
2 Biomechanical Unit, R & D Department, Podoactiva Headquarters, Walqa Technological Park, 22197 Huesca, Spain
3 Department of Podiatry, Faculty of Health Sciences, Universidad a Manresa, 08242 Manresa, Spain
4 Department of Physiotherapy, Faculty of Health and Sports Sciences, Universidad San Jorge, 50830 Villanueva de Gállego, Spain
5 Department of Physical Education, Sport and Human Movement, Universidad Autónoma de Madrid, 28049 Madrid, Spain
* Correspondence: antoniogomez@podoactiva.com

Abstract: Falls are common among older adults. The purpose of this study was to demonstrate the relationship between foot anatomical structural variations and balance in older adults and quantify foot posture and stabilometry as predictors of fall risk. This case-control study of older adults classified cases or controls according to falls in the last five years. All subjects were healthy women and men > 65 years old (n = 164), who were divided into two groups: 83 individuals who had suffered from a fall in the previous five years (case group) and 81 individuals who had not suffered from a fall (control group). Hallux abductus valgus (HAV) and tailor's bunion are stability-determining factors. Women have a higher probability of falling. HAV ($p = 0.042$) and tailor's bunion ($p = 0.069$) also increased the fall probability. Morphological foot variations (HAV and tailor's bunion) linked to gender and age increase fall risk among older adults. In women fallers with HAV, there was a higher possibility of falling (63.9%). According to age, in older adults with HAV, the percentage of falls is high (62%). Fallers with tailor's bunion (60.7%) are more numerous than fallers without this pathology. Older adults with HAV and tailor´s bunion had twice the probability of suffering a fall than older people without foot anatomical structural. Foot morphology is decisive in falling risk.

Keywords: falls; elderly; foot morphology; hallux abductus valgus; tailor's bunion; gender

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1. Introduction

The number of people older than 80 years increased during the 20th century. In the next 30 years, this age group will represent 30% of the population in developed countries and 12% in undeveloped countries [1–3]. Current literature is focused on improving their quality of life instead of increasing their life expectancy. Quality aging depends on good physiological function and physical fitness [1,3]. According to the American Geriatrics Society (AGS) and British Geriatrics Society (BGS), falls are related to impaired mobility, bone fractures, depression, functional impairment, loss of independence and autonomy, decreasing quality of life, socioeconomic aspects and medical system overload [4]. The American and British Geriatrics Societies recommend that adults older than 65 years be screened annually for fall history or balance impairment [4].

Foot pathologies decrease postural control and predispose the elderly to falls [5], and postural instability is correlated with falls [6]. Worldwide, falls are the second most common cause of accidental death and the leading cause of injuries in subjects older than 65 years. It would be advisable for elderly people to be medically assessed to prevent falls or balance loss [7]. Falls are common in the elderly population and their probability increases with age. Every year, 30–40% of people older than 65 years suffer from falls that may cause serious injuries, loss of independence or even death. Falls are a strong indicator of fragility in geriatrics [8,9]. In the last few years, fall-related research has been developed with the aim of improving quality of life among older people. According to current data, 70% of older people suffer from falls, and these are more common among women [7,10]. Falls in older people result in high medical costs and the value of medical costs attributable to falls provides vital information about the magnitude of the problem [11].

Deficient postural stability is one of the main causes of falls in older adults; therefore, strength and balance improvement through exercise can prevent the risk of falls [5,6]. Current research provides enough evidence to state that foot problems are related to fall risk in this population [12].

The main functions of the foot are to stabilize and support body weight and human gait. However, as time goes, foot structure is modified by age, morphology, functions and body weight, which can lead to musculoskeletal pathologies [13,14]. Older people present significantly lower hallux mobility and higher values for width of forefoot and transverse arch index compared to younger adults [13]. Flat feet are prevalent in obese people [12]. The Foot Posture Index (FPI-6) can be a useful diagnostic tool for assessing adult foot posture [14]. Older people show flatter feet, a pronated arch index, greater width of forefoot, HAV, a reduced range of motion, articular rigidity, less tactile sensation and a higher prevalence of foot deformity [15,16]. Greater foot pronation may contribute to increasing pain in older people [16]. Approximately 60% of older adults have forefoot pathologies [17]. Hallux valgus, lesser toes and claw toe deformities are highly prevalent foot problems in older people [17,18]. These pathologies could be causes of pain and influence body posture. The characteristics of older adults' gait, such as changes in the center of gravity position, stride length reduction and unbalance are the principal factors of fall risk [15,16,18–20]. Reduced toe flexor strength and the presence of toe deformities also increase the risk of falls in older people [17].

In the current literature, there are actual studies that are methodologically variable, and the results are inconsistent. Additionally, evidence about any screening instruments is currently inadequate and insufficient for predicting falls [21]. However, plantar pressure platforms to measure baropodometry and stabilometry in older adults can be effective instruments.

The aim of this study was to demonstrate the relationship between foot posture and balance in the elderly and quantify foot posture, morphology and stabilometry as predictors of fall risk in older people.

2. Materials and Methods

2.1. Study Design

An observational, analytical nested case-control study was conducted between September 2020 and April 2021 at a podiatric clinic in Zaragoza (Spain). Subjects older than 65 years were recruited to relate foot posture and fall risk factors. This study followed the STROBE guidelines for reporting observational studies. All subjects were informed of the relevant data privacy and signed an informed consent form before the beginning of the study. This study protocol was approved by the Intervention Clinical Committee of the European University of Madrid (CIPI/20/178).

The principal investigator obtained the informed consent of 164 voluntary participants (N = 164), who were classified into cases (N = 81) and controls (N = 83). The case group was composed of fallers in the last five years, whereas the control group was composed of non-fallers.

Participant inclusion criteria included subjects older than 65 years, without cognitive impairment and able to walk independently. Exclusion criteria included previous musculoskeletal surgery on a lower limb, people who were not able to remain standing for more than 10 min, those with neuromuscular disorders, opioid therapy, severe visual disturbance, mental impairments and those who did not sign the informed consent form [20,22–26].

2.2. Study Variables

Falls were determined during the interview by the principal investigator. The following study variables were extracted from the initial database: age (years), gender (male or female), height (cm), weight (kg) and body mass index (BMI; kg/m^2). The parameters of height, weight and BMI were calculated with a GIMA Pegaso scale. The variables were: HAV pathology (grade I–IV) [27,28], lesser toes (flexible, semi-flexible or rigid) [29] and tailor's bunion (grade I–III) [30,31]. Anatomical structural variations (HAV and tailor's bunion) were measured in a supine position with a conventional goniometer [27]. The pathology of lesser toes was classified by its reducibility [31]. Balance was measured using the Berg Balance scale (from 41 to 56 points) [32]. The PASE, "Physical Activity Scale for the Elderly," quantifies the level of activity (hours/week) [33]. The foot posture index (FPI) quantifies the foot posture (total, left or right). Score−12 (maximum supinated) and +12 (maximum pronated) [34]. Static baropodometry and stabilometry were analyzed using a Footwork Pro pressure platform, software version 3.7 (Amcube, France, 2018). Baropodometry measured the maximum pressure and its localization (Kpa). Stabilometry measures the transversal axis, anteroposterior axis, ellipse surface, LFS, and distance for both feet and CoP. Baropodometrical and stabilometrical variables were measured three times for 30 s. Each variable was assessed with open and closed eyes [35,36].

2.3. Statistical Analysis

Statistical analysis was performed with R 4.0.5 (R Core Team 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/ accessed on 3 September 2020), and the *p* value was set at 0.05 (95% confidence interval CI). A normality test (Shapiro–Wilk) was conducted. Faller and non-faller group means were compared with the Mann–Whitney U test or Student's *t* test. The relationship between dependent and independent variables was measured with the odds ratio (OR).

First, a descriptive analysis of the control and case groups was performed, calculating the absolute (n) and relative frequencies (%). To estimate the relationship between fallers or non-fallers and clinical variables (anatomical structural variations, Berg Balance scale, PASE, FPI, baropodometry and stabilometry), we performed a multivariate analysis using the Chi-square test or Fisher's test.

3. Results

The sample size was 164 voluntary subjects; 39% were men and the other 61% were women. The average age of the sample was 70 years old (67.0; 73.3).The cases were subjects having had falls in the previous five years (Fallers N = 83), and the controls were without falls in the previous five years (Non-fallers N = 81). Independent variables are shown related to the dependent variable (falls in the last five years) in Table 1. Falls were more common among women (56.6%) than among men (40.6%) (χ^2 = 3.33, p = 0.068, odds ratio = 1.89, p = 0.049). The purpose of this research was to demonstrate the relationship between foot disorders (HAV, hammer or claw toes and tailor's bunion) and falls in the elderly. The results were stratified by gender and age. The average age was 70 years old, which is the median of the variable.

3.1. HAV (Hallux Abductus Valgus)

The results show that falls are more common in subjects with HAV (57.7%) than without this pathology (40.3%) (χ^2 = 4.14, p = 0.042, odds ratio 2.01, p = 0.030). Of the total sample, 59.2% had HAV, of which 40.3% were non-fallers and 57.7% were fallers. HAV grade II was the most frequent deformity (40.2%), followed by HAV grade III (36.1%). However, in the case group, the prevalent deformity was HAV grade III (65.7%). With respect to gender, women fallers with HAV had a higher possibility of falling (63.9% with HAV; 37.0% without HAV) (χ^2 = 4.72, p = 0.03, odds ratio 2.96, p = 0.019). Generally, there were more women (72.7%) with HAV than men (39.1%) (χ^2 = 16.912, $p < 0.05$, odds ratio

4.11, $p < 0.05$). However, men fallers were not different ($\chi^2 = 0$, $p = 1$, odds ratio 0.96, $p = 0.940$).

According to age, there were more fallers older than 70 with HAV (62%) than without HAV (28%) ($\chi^2 = 6.407$, $p = 0.011$, odds ratio = 5.07, $p = 0.006$). However, among the younger subjects, there were no differences ($\chi^2 = 0.097$, $p = 0.755$, odds ratio 1.25, $p = 0.608$). This pathology was more frequent in subjects older than 70 years (66.7%). On the other hand, subjects younger than 70 years with HAV represented 52.8% ($\chi^2 = 2.686$, $p = 0.10$, odds ratio 1.78, $p = 0.075$).

Table 1. Anthropometric description and characteristics of the case and control groups.

Variables	N = 164	Non-Fallers N = 81	Fallers N = 83	OR	*p*. Ratio	*p*. Overall
Gender						0.068
Men	64 (39.3%)	38 (59.4%)	26 (40.6%)	Ref.	Ref.	
Men with HAV	25 (39.1%)	15 (60.0%)	10 (40.0%)	0.96 [0.34; 2.70]	0.940	
Men with lesser toes	46 (71.9%)	26 (56.5%)	20 (43.5%)	1.51 [0.49; 5.11]	0.478	
Men with tailor´s bunion	19 (29.7%)	9 (47.4%)	10 (52.6%)	1.99 [0.66; 6.11]	0.222	
Women	99 (60.7%)	43 (43.4%)	56 (56.6%)	1.89 [1.00; 3.62]	0.049	
Women with HAV	72 (72.7%)	26 (36.1%)	46 (63.9%)	2.96 [1.19; 7.70]	0.019	
Women with lesser toes	74 (74.8%)	30 (40.5%)	44 (59.5%)	1.58 [0.63; 4.02]	0.330	
Women with tailor´s bunion	42 (42.4%)	15 (35.7%)	27 (64.2%)	1.72 [0.76; 3.99]	0.192	
Weight (kg)	71.0 [63.0; 82.0]	71.0 [62.0; 82.0]	71.0 [64.0; 83.0]	1.00 [0.98; 1.02]	0.791	0.914
Height (cm)	165.0 [158.0; 170.0]	168.0 [160.0; 173.0]	162.0 [157.0; 168.0]	0.97 [0.94; 1.00]	0.033	0.021
BMI (kg/cm^2)	26.4 [24.0; 29.0]	25.8 [24.0; 28.1]	26.7 [24.0; 29.4]	1.06 [0.98; 1.15]	0.139	0.096 0.545
Under Weight	16 (9.8%)	9 (56.3%)	7 (43.8%)	Ref.	Ref.	
Normal Weight	41 (25.0%)	23 (56.1%)	18 (43.9%)	1.00 [0.31; 3.37]	0.996	
Obese	82 (50.0%)	41 (50.0%)	41 (50.0%)	1.28 [0.43; 3.96]	0.661	
Obese I	19 (11.6%)	6 (31.6%)	13 (68.4%)	2.68 [0.67; 11.6]	0.164	
Obese II	3 (1.8%)	1 (33.3%)	2 (66.7%)	2.33 [0.16; 83.6]	0.545	
Obese III	3 (1.8%)	1 (33.3%)	2 (66.7%)	2.33 [0.16; 83.6]	0.545	
Age (years old)	70.0 [67.0; 73.3]	70.0 [66.0; 73.0]	70.0 [67.0; 73.5]	1.00 [0.98; 1.01]	0.500	0.661 1.000
Older than 70	75 (45.7%)	37 (49.3%)	38 (50.7%)	Ref.	Ref.	
Younger than 70	89 (54.3%)	44 (49.4%)	45 (50.6%)	1.00 [0.54; 1.85]	0.990	

BMI = Body Mass Index; OR = Odds ratio; Ref. = Reference; *p*. overall: *p*-value associated with the Mann–Whitney U test for qualitative variables or *p*-value associated with the Chi-square test for quantitative variables. *p*-ratio: *p*-value associated with the odds ratio. Qualitative variables are expressed as n (%), quantitative variables as Mean ± SD. Significant at $p < 0.05$.

3.2. Lesser Toes

According to the pathology of lesser toes, there were no differences. Fallers with lesser toes represented 53.3%, and fallers without this pathology represented 43.2% ($\chi^2 = 0.952$, $p = 0.329$, odds ratio 1.50, $p = 0.256$). No relationship was found regarding age or gender.

3.3. Tailor's Bunion

Fallers with tailor's bunion (60.7%) were more numerous than fallers without this pathology (44.7%). ($\chi^2 = 3.307$, $p = 0.069$, odds ratio 1.90, $p = 0.05$). Regarding gender, there were no differences between subjects with tailor's bunion. Men fallers with tailor's bunion represented 52.7%, while fallers without this pathology represented 35.6% ($\chi^2 = 0.984$, $p = 0.321$, odds ratio 1.99, $p = 0.222$). In the case of women, fallers with tailor's bunion accounted for 64.3% compared to fallers without tailor's bunion (56.9%) ($\chi^2 = 1.266$, $p = 0.261$, odds ratio 1.72, $p = 0.192$). There was no statistical correlation between this pathology and gender, but there were more women with tailor's bunion (42.4%) than men (29.7%) ($\chi^2 = 2.176$, $p = 0.140$, odds ratio 1.73, $p = 0.104$). In relation to age, fallers older than 70 years with tailor's bunion (65.7%) were more numerous than fallers without this pathology (37.5%) ($\chi^2 = 4.869$, $p = 0.027$, odds ratio 3.13, $p = 0.017$). According to the sample, more subjects older than 70 years had tailor's bunion (46.7%) than subjects younger than 70 years (29.2%) (χ^2 = 4.586, *p* = 0.032, odds ratio 2.11, *p* = 0.023).

3.4. FPI (Foot Posture Index)

FPI is related to foot anatomical structural pathologies. The most frequent pathology was HAV. Normal and pronated feet had a higher prevalence of forefoot pathologies. Falls in subjects with pronated feet were higher (63.0%) than the percentage of falls with very pronated feet (31.3%) (odds ratio 3.66 *p* = 0.007).

Falls with normal feet were 52.9%. Older adults with a pronated foot had a higher probability than those with very pronated foot (odds ratio 2.44, *p* = 0.046).

Falls in older adults with a supinated foot were 44.4% and did not show significant differences compared to subjects with a very pronated foot (odds ratio 1.74, *p* = 0.372) (Table 2).

Table 2. Relationship of the general FPI and the foot anatomical structural pathologies.

	N = 164	Non-Fallers N = 81	Fallers N = 83	OR	*p*. Ratio	*p*. Overall
FPI	5.0 [3.0; 9.0]	5.0 [3.0; 10.0]	5.0 [2.5; 8.0]	0.95 [0.88; 1.03]	0.188	0.181
FPI						0.045
More pronated	32 (19.5%)	22 (68.8%)	10 (31.3%)	Ref.	Ref.	
Pronated	46 (28.1%)	17 (36.7%)	29 (63.0%)	3.66 [1.42; 9.97]	0.007	
Normal	68 (41.5%)	32 (47.1%)	36 (52.9%)	2.44 [1.02; 6.17]	0.046	
Supinated	18 (11.0%)	10 (55.6%)	8 (44.4%)	1.74 [0.51; 5.93]	0.372	

FPI = Foot Posture Index.

3.5. Logistic Regression Model

A logistic regression model has been proposed to study the influence of the variables sex, age, BMI, presence of HAV and tailor´s bunion in falls and labeled "falls" as a dependent variable. In addition, it was observed that for each unit in which BMI increased, independently, the risk of falls increased by 10% (OR = 1.10, CI = 1.01–1.21, *p* = 0.038). Moreover, it was stratified by gender. In women with HAV, the risk of falls increased 3.07 times compared to those who did not have HAV (OR = 3.07, CI = 1.15–8.68, *p* = 0.029) (Table 3).

Table 3. General multivariate.

Dependent: Falls		No	Yes	OR (Multivariate)
Gender	Men	38 (59.4%)	26 (40.6%)	-
	Men with HAV	15 (60.0%)	10 (40.0%)	1.07 [0.33–3.54, *p* = 0.907]
	Men with tailor´s bunion	9 (47.4%)	40 (52.6%)	2.38 [0.71–8.52, *p* = 0.167]
	Women	43 (43.4%)	56 (56.6%)	1.52 [0.75; 3.08, *p* = 0.246]
	Women with HAV	26 (36.1%)	46 (63.9%)	3.07(1.15–8.68, *p* = 0.029)
	Women with tailor´s bunion	15 (35.7%)	27 (64.3%)	1.34 [0.52–3.45, *p* = 0.541]
Years	Younger than 70	44 (49.4%)	45 (50.6%)	-
	Older than	37 (49.3%)	38 (50.7%)	0.70 [0.35; 1.37, *p* = 0.299]
BMI	Mean of BMI	26.2 (3.5%)	27.2 (4.3%)	1.10 [1.01; 1.21, *p* = 0.038]
HAV	No	40 (59.7%)	27 (40.3%)	-
	Yes	41 (42.3%)	56 (57.7%)	1.88 [0.91; 3.94, *p* = 0.090]
Tailor's bunion	No	57 (55.3%)	46 (44.7%)	-
	Yes	24 (39.3%)	37 (60.7%)	1.69 [0.83; 3.47, *p* = 0.151]
Sport	Never	65 (46.1%)	76 (53.9%)	-
	Frequent	16 (69.6%)	7 (30.4%)	0.45 [0.15; 1.19, *p* = 0.117]

HAV = Hallux Abductus Valgus; Never = 0 days/week; Frequent = 2 or 3 days/week.

4. Discussion

The results related anatomical structural variables (HAV, lesser toes and tailor's bunion) with falls through the odds ratio (OR). We also found a strong relationship of anatomical structural variations with gender and age. The comparison of HAV and tailor's bunion with fallers revealed significant results. On the other hand, fewer toes with fallers did not show significant results. HAV and tailor's bunion recorded a higher frequency in women and these pathologies increased with age.

According to the current literature, HAV is the prevailing forefoot pathology in women. Between 35% and 79% of the elderly have HAV. Approximately 30% to 48% have HAV grade IV [17,20,37,38]. Older subjects with anatomical structural variations presented with foot posture alterations. The prevalence of HAV and pronated feet increased to 60% with age. Elderly people´s feet were wider, flatter and pronated with lower mobility and balance [15,18,37–39]. A pronated foot increases the risk of injury, especially in older adults [38,40]. Strength training of the intrinsic muscles of the foot improves pronation and prevents the risk of injury [41]. Feet with higher FPI values (more pronated) have more falls than supinated feet.

According to gender, morphological variations are due to muscle strength and balance. Working strength exercises on the intrinsic muscles of the foot improve balance [15]. HAV, lesser toes and tailor's bunion modify the plantar pressure and gait parameters. Anatomical variations modify balance and functionality, increasing the risk of falls [38,41–43].

According to Scott et al., among a 100-subject sample, 60% had HAV; 30% had HAV grade II; 24% had HAV grade III; and 6% had HAV grade IV. Compared with our study, 59.2% of elderly subjects had HAV; 40.2% had HAV grade II; 36.08% had HAV grade III; and 10.31% had HAV grade IV. In both studies, the prevalent level was HAV grade II, followed by HAV grade III. HAV grade IV recorded the lowest level in the sample. The results of both studies were similar; while the percentage of elderly people with HAV obtained by Scott et al. was 60%; our value was 59.2% [15].

Menz and Lord developed a study in 2001 with 135 subjects looking at the HAV pathology. According to gender, women presented with more morphological foot disorders, and they increased with age [44]. The same results were found in our study; morphological foot disorders were more frequent in women. HAV pathology among women was 72.7%, whereas it was 39.1% among men. Additionally, foot disorders increased with age; the percentage of subjects older than 70 years with HAV was higher (66.7%) than the percentage of subjects with HAV younger than this age (52.8%) ($\chi^2 = 2.686$, $p = 0.10$, odds ratio 1.78, $p = 0.075$). This was also the case with tailor's bunion. The percentage of subjects older than 70 with tailor's bunion was higher than the percentage of subjects younger than this age (29.2%). However, lesser toes pathology did not show significant differences in relation to gender or age [44].

According to these authors, fallers frequently have more foot disorders (8.1 $\pm$ 4.5) than non-fallers (5.6 $\pm$ 4.3, $p < 0.05$) [43]. Similarly, in our study, fallers with HAV (57.7%) were more numerous than fallers without HAV (40.3%). Additionally, the percentage of fallers with tailor's bunion (60.7%) was higher than the percentage of fallers without this pathology (44.7%). In other words, subjects with tailor's bunion are twice as likely to suffer a fall.

Clinical prevention was the main purpose of this investigation. The clinical application of this study was founded on fall investigations and foot biomechanics pathologies among the adult and older populations [21,45].

According to the results obtained, researchers might expand the functional assessment of balance in older adults. Clinical applications of the research include baropodometry and stabilometry as an equilibrium measurement system, together with other functional balance tests. The treatment of foot structural variations in conjunction with other treatments applied contributes to improving balance in clinical practice.

Notwithstanding our findings, this study has some limitations. In elderly subjects, it was difficult to isolate foot pathologies and balance from other pathologies related to age.

Another limitation was that the number of supinated feet was too low, and we needed an extensive sample to obtain a significant sample. On the other hand, the strength of this study is the relationship between foot disorders and balance. Stabilometry is shown to be a quantitative measuring system for balance, which can be used in future investigations about fall risk and other factors related to balance.

5. Conclusions

Foot morphological variations (HAV and tailor´s bunion) determine balance, increasing the fall risk in the elderly. Accordingly, there is a higher probability of falls and pathology in the increased age and in the female gender. Footcare is an important factor in preventing the risk of falls.

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