ORIGINAL

ASSOCIATIONS BETWEEN BODY COMPOSITION AND MOVEMENTS DURING GAIT IN WOMEN

RELACIÓN ENTRE COMPOSICIÓN CORPORAL Y MOVIMIENTOS REALIZADOS DURANTE LA MARCHA EN MUJERES

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ABSTRACT

The aim of this paper is to explore the relationships between gait parameters and body composition in healthy women. A cross-sectional study with a sample composed of 112 healthy adult women (64.1 ± 8.6 years). The subjects walked a distance of 20 meters with a triaxial accelerometer attached at the fourth lumbar vertebra. The test was repeated three times and the mean of the three trials was used for the analysis. Clinical indicators (Timed Up and Go Test, 6-Minute Walk Test and waist perimeter) and body composition (bioimpedance) were also evaluated. Total body and lower limb fat mass percentages were strongly correlated with the average acceleration in vertical axis and the minimum value of module vector of the accelerations. In women over the age of

71, the percentage of total body fat and lower limbs determines body movements during gait. Therefore, the amount of fat mass is related to the stability in the gait of the elderly.

KEYWORDS: Accelerometers; anthropometry; human biomechanics; human body composition; walking; older people; women.

RESUMEN

El objetivo de este trabajo es explorar las relaciones entre los parámetros acelerométricos de la marcha y la composición corporal en mujeres sanas. Para conseguirlo se realice un estudio transversal con una muestra de 112 mujeres adultas sanas (64,1 ± 8,6 años). Las participantes caminaron una distancia de 20 metros con un acelerómetro triaxial situado a la altura de la cuarta vértebra lumbar. La prueba se repitió tres veces y se utilizó la media de los tres ensayos para el análisis. También se evaluaron indicadores clínicos (Timed Up and Go Test, prueba de los seis minutos marcha y perímetro de cintura) y la composición corporal (bioimpedancia). Los porcentajes de grasa corporal total y en miembros inferiores se correlacionaron fuertemente con la aceleración media en eje vertical y el valor mínimo de módulo vector de las aceleraciones. En mujeres mayores de 71 años, la proporción de grasa corporal total y de miembros inferiores determina los movimientos del cuerpo durante la marcha. Por tanto, la cantidad de masa grasa está relacionada con la estabilidad en la marcha de las personas mayores.

PALABRAS CLAVE: Acelerómetros; antropometría; biomecánica; composición corporal humana; caminar; personas mayores; mujeres.

1. INTRODUCTION

Over the last fifty years, the populations of developed countries have been progressively aging. The prevalence of overweight individuals over this time has led to increased health risks, including an increased prevalence of cardiovascular, metabolic, respiratory and musculoskeletal diseases[1]. Moreover, the aging process is accompanied by decreased muscle mass (sarcopenia), bone loss and increased fat mass[2]. These changes in body composition often result in an increased body mass index (BMI), a parameter that can indicate morbidity, dependence and mortality in adults[3]. The consequent functional decline in health and quality of life also leads to increases in health care costs[4].

Walking is essential for the maintenance of activities of daily living and quality of life in older people[5,6]. Excess weight may contribute to an increased mechanical burden and altered dynamic movement in the lower limbs[7,8]. Since obesity is a growing public health problem, interventions that reduce BMI could represent effective primary and secondary prevention strategies for functional problems of mobility[9-11].

In fact, the gait speed is one of the most used signs for estimating the dependence on elderly[12]. But the usefulness of this indicator can be impaired when other syndromes or diseases are co-morbid in the patient. This is because muscle strength and range of motion slowly decline with age[13]. Consequently, the older people extend the support phase and reduce the time stride during gait. These adaptations are associated with decreased hip movements in the sagittal plane and an increase in pelvic tilt in the anteroposterior plane[14].

The use of accelerometers in research allows early identification of gait characteristics that provide additional information about the degree of functionality of the patient or their risk of suffering a fall[15,16]. Gait analysis based on the study of the acceleration of the body is considered to be valid and reliable for predicting the risk of falling or for discriminating between population groups with different age, illness or level of physical activity[17,18].

The identification of factors that impair gait stability is critical to designing interventions to maintain independence and mobility. This is especially important in women because of their longer life expectancy and greater incidence of falls in relation to men[19].

The aim of this study was to explore the relationship between gait parameters and body composition in healthy women with normal and overweight weight. Knowing these relationships will assist in prematurely identifying abnormal gait and body composition. Consequently, it allows us to design preventive treatments for impaired balance and diagnose, in the early stages, pathologies that could impair stability and increase the risk of falls.

2. MATERIAL AND METHODS

2.1. Participants

The sample was composed of 112 adult women with an average age of 64.1 (SD: 8.6) years (ranging between 51 and 80 years). The following inclusion criteria were used: a) profile of physical activity between 1 and 2 days per week; (b) walked between 30 and 90 minutes, four days a week; (c) have a good level on independence and gait stability (could complete the Timed Up & Go Test in 10 seconds or less)[20].

The exclusion criteria were: (a) the inability to walk independently; (b) a BMI below 18.5 (underweight) or over 29.9 (obesity)[21]; (c) the presence of any contraindication or illness that prevented evaluation using any of the tests/procedures employed in this study; (d) consume drugs affecting postural control (such as anxiolytics, antidepressants, anti-parkinsonian or inducing dreams), according to the dose and time of ingestion. Because it can hinder coordination and speed response.

2.2. Procedure

All subjects signed informed consent prior to their participation in the study, in accordance with the Declaration of Helsinki (rev. 2013). This research received ethical approval from the Commission of Ethics of the Faculty of Sciences of Education and Sport of the University of Vigo (Spain) (code: 3-0406-14).

Participants were asked to travel a distance of 10 meters, then turn around and return to the initial location (for a total distance travelled of 20 meters), at their habitual gait speed. The starting and finishing points were properly marked. The test was repeated three times, separated by intervals of 30 seconds, to prevent the effect of lower limb muscle fatigue[22]. The test was performed while subjects were wearing socks (no shoes) and comfortable clothing, allowing them to perform the tests comfortably.

A triaxial accelerometer (ActiGraph GT3X-plus) was used to measure acceleration. The accelerometer was placed directly to the skin over the L4 segment of the lumbar spine using an adjustable belt and hypoallergenic adhesive tape to ensure that the device did not move independently to the trunk of the subject during the performance of the tests. A point on the back posterior to the L4 segment was chosen as a surface indicator of the center of mass in upright stance and in walking for proper alignment and calibration the global axes of the accelerometer in order to compare the gait smoothness across subjects[23,24]. This accelerometer stored a time series of acceleration data in a non-volatile flash memory. The small dimensions of the module (4.6 x 3.3 x 1.5 cm), combined with its low weight (19 grames). The selected frequency was 30 Hz.

Before each evaluation sesión, each accelerometer was initialized with its specific software (the same where the data recorded were sent after each round of data collection). All accelerometers used in the study were calibrated in static before each use. The accelerometer measurements were configured for a time frame of one second.

Accelerometers provide data on body movements in three axes: axis 1 corresponds to the acceleration in the vertical axis (transverse/horizontal plane); axis 2 to the medio-lateral axis (sagittal plane); and axis 3 measured acceleration in the antero-posterior axis (frontal plane). The root mean square (RMS) of the accelerations in the three axis was also measured.

The mean of the duration and accelerations of three replicates was used for the analysis. From the mean data, we selected the maximun, minimun and mean values and the Root Mean Square (RMS) of their module vector.

2.3. Clinical indicators

The participants completed a battery of tests and clinical measurements associated with balance and physical condition:

(a) *Timed Up & Go* (TUG): This is a clinical test that evaluates the process and speed of transfers from sitting to standing position and gait along 3 meters. The results of TUG have been shown to correlate with factors such as the risk of fall or the degree of dependence[20].

(b) 6-Minute Walk Test (6MW): This test is used to measure the maximum distance that a person can walk in 6 minutes. This test is a useful integrated measure of mobility[25].

(c) Waist Perimeter (WP): This anthropometric variable was chosen because of its relationship with the state of physical health in older people[26]. . WP was measured at the level of the umbilical scar in upright position with subjects with legs separated 25-30 cm from each other, using a calibrated non-flexible tape Lufkin W606PM (Lufkin, Mexico), measure to the nearest .1 cm. The tape was placed over the skin without any compression and on the horizontal plane to the floor. The measurement was done after exhaling.

(d) Bioimpedance: Quantification of body composition was performed using bioimpedance electronics, according to a validated protocol for researchers[27]. All participants were measured while fasting, wearing only underwear and in the morning, after using the toilet. Participants were warned not to undertake any intense physical efforts the day before the test. First, height was measured with a scale-height board SECA 700 (SECA, Berlin, Germany). The height was measured twice. If the first two measures were not in agreement (with a margin of error of ± 1 mm), a third measure was completed and the average was calculated. The weight was then measured twice using the same calibrated beam scale. As with height, if the two measures were not in agreement (within a margin of error of ± 50 g), a third measurement was made and the average of the three values was calculated. Then the subjects were assessed using a multifrequency bioimpedance analyzer (InBody720, Biospace Japan Inc., Tokyo, Japan®) to measure parameters related to body composition: impedance, muscular mass, fat mass and their percentages (for total body, lower limb and trunk).

2.4. Statistical analysis

For the analysis of results, the sample was divided into three age groups: G1 between 45 and 60 years old (n = 29), G2 between 61 and 70 years old (n = 55), and G3 between 71 and 85 years old (n = 28).

Descriptive statistics were used as a measure of central tendency and the standard deviation as a measure of dispersion. The analysis of variance (ANOVA) with the Bonferroni correction was used to determine whether the differences between the groups were significant. We created linear regression models using the accelerometric mean outcomes (independent variables) and clinical indicators (dependent variable), along with adjustments for age with the data of all participants.

All calculations were performed using SPSS for Windows version 17.0 and the significance level was $p < .05$.

3. RESULTS

There were no significant differences between the groups with respect to weight, BMI or percentage of total fat mass. Among the groups G1 and G3, there were significant differences in height, WP, 6MW, impedance, and percentage of fat mass in the lower limbs (Table nº1). Among the groups G1 and G2, there were differences in WP, and percentage of fat mass in the lower limbs. There were not differences between G2 and G3 in any variable. Only the TUG identified significant differences between all three age groups (Table nº1).

Table 1. Descriptive statistic and comparison between age group of data collection

Variables		All (n=112)		G1 (n=29)		G2 (n=55)		G3 (n=28)	
		Mean (SD)	[95% CI]	Mean (SD)	[95% CI]	Mean (SD)	[95% CI]	Mean (SD)	[95% CI]
Age (years)		64.1 (8.6)	[62.5-65.7]	53.6 (5.6)$^{a***.b***}$	[51.4-55.7]	64.4 (2.7)$^{a***.c***}$	[63.6-65.1]	74.5 (4.8)$^{b***.c***}$	[72.7-76.4]
Weight (kg)		65.6 (10.1)	[63.7-67.5]	63 (7.6)	[60.1-65.9]	66.4 (11.1)	[63.4-69.5]	66.5 (10.1)	[62.5-70.4]
Height (cm)		154 (5.5)	[153-155]	155.6 (5.1)^{b*}	[153.6-157.5]	154.2 (5.5)	[152.7-155.7]	151.8 (5.3)^{b*}	[149.8-153.9]
BMI (kg·m2)		27.6 (4.1)	[26.8-28.3]	26 (3.3)	[24.8-27.3]	28 (4.7)	[26.7-29.2]	29 (3.2)	[27.1-29.5]
WP (cm)		91.9 (9)	[89.7-94.1]	85.4 (6.6)$^{a*.b**}$	[81.4-89.4]	92.4 (9.2)^{a*}	[89.2-95.7]	95.2 (8.1)^{b**}	[91.5-98.9]
TUG (s)		6.1 (1.1)	[5.9-6.3]	5.5 (0.8)$^{a*.b***}$	[5.2-5.8]	6 (0.8)$^{a*.c**}$	[5.8-6.3]	6.8 (1.3)$^{b***.c**}$	[6.3-7.3]
6MW (m)		592.5 (88.9)	[575.6-609.5]	613.6 (54.4)^{b*}	[592.9-634.2]	600.5 (101.4)	[572.5-628.4]	552.9 (82.5)^{b*}	[519.6-586.3]
Total body	IMP (S)	633.5 (60.6)	[622.2-644.8]	656.3 (54.9) ^{b*}	[635.4-677.2]	630.8 (65.2)	[613.2-648.5)]	615.2 (50.3)^{b*}	[595.7-634.7]
	MM (kg)	39.4 (3.4)	[38.7-40]	39.2 (2.6)	[38.2-40.2]	39.7 (3.7)	[38.7-40.7]	38.9 (3.3)	[37.6-40.2]
	%FM	24 (7.1)	[22.6-25.3]	21.8 (5.5)	[19.7-23.9]	24.8 (8)	[22.6-26.9]	24.7 (6.5)	[22.2-27.2]
Trunk	MM (kg)	22.6 (1.8)	[22.3-22.9]	22.5 (1.4)	[21.9-23]	22.8 (1.9)	[22.3-23.3]	22.4 (1.8)	[21.7-23.1]
	%FM	31.7 (6.6)	[30.4-32.9]	30.1 (5.8)	[27.8-32.3]	32 (7.1)	[30.1-34]	32.6 (6.3)	[30.2-35]
MMII	MM (kg)	6.4 (0.6)	[6.3-6.5]	6.4 (0.5)	[6.2-6.6]	6.4 (0.7)	[6.2-6.6]	6.2 (0.6)	[6-6.5]
	%FM	42.2 (4.8)	[41.3-43]	40 (4)$^{a*. b**}$	[38.5-41.5]	42.6 (4.9)^{a*}	[41.2-43.9]	43.6 (4.5)^{b**}	[41.8-45.3]

BMI: Body mass index; WP; Waist perimeter; TUG: Timed Up & Go; 6MW: 6-Minutes Walk Test; IMP: Impedance; MM: Muscular Mass; %FM: Percentage of Fat Mass.; SD: Estándar deviation; CI: Confidence interval.

a: comparison between G1 and G2; b: comparison between G1 and G3; c: comparison between G2 and G3

*p value < .05

**p value < .01

***p value < .001

There was a reduction in the values of acceleration recorded along all three axes and in RMS as age increased (Table nº2). This reduction was very significant for the minimum values registered along vertical and antero-posterior axes and for the maximum values along medio-lateral axis. Only the maximum values of the RMS demonstrated significant differences among the three age groups. The average duration of three attempts revealed a difference between G3 and the other two, but did not find a significant difference between G1 and G2.

Table 2. Ranges and mean accelerometric values (in g) for each axis and Root Mean Square

Variable		All (n=112)	G1 (n=29)	G2 (n=55)	G3 (n=28)
Vertical axis	Maximun	60 ± 15.2	68.2 ± 19.6^{b**}	61.9 ± 14.7	54.6 ± 11.5^{b**}
	Minimum	4.1 ± 5.1	7.4 ± 7.1$^{a***. b**}$	3.9 ± 2.1^{a***}	2.9 ± 3.1^{b**}
	Mean	39.7 ± 12.1	43.5 ± 14.1^{b*}	39.2 ± 11.2^{c*}	36.5 ± 9.3$^{b*. c*}$
Medio-lateral axis	Maximun	49 ± 13	53.9 ± 15.6$^{a*.b*}$	47.3 ± 11^{a*}	44.3 ± 10.8^{b*}
	Minimum	5.8 ± 3.8	6.7 ± 4.7^{b*}	6.64 ± 3.6	4.5 ± 3.8^{b*}
	Mean	21 ± 6.5	23.6 ± 5.1^{b*}	20.5 ± 5.2	18.6 ± 4.1^{b*}
Antero-posterior axis	Maximun	41.6 ± 11.7	48.5 ± 12.1^{b*}	41.8 ± 12.4	32.5 ± 10.8^{b*}
	Minimum	7 ± 5.6	9.6 ± 6.1$^{a***. b**}$	7.2 ± 4.3^{a***}	5 ± 6.5^{b**}
	Mean	22.4 ± 8.3	27.7 ± 9.7$^{a*. b}$	23.5 ± 7.1^{a*}	21.2 ± 6.9^{b*}
Root Mean Square	Maximun	76.6 ± 16.2	84.9 ± 20$^{a*. b***}$	76.5 ± 13.6$^{a*.c*}$	68.2 ± 11.9$^{b***.c*}$
	Minimum	23.2 ± 10.1	28.6 ± 13.8^{b*}	23.7 ± 6.8	20.7 ± 7.7^{b*}
	Mean	54.1 ± 12.6	60 ± 15.5^{b***}	59.9 ± 10.1^{c*}	44.6 ± 9.9$^{b***.c*}$
Duration (s)	Mean	16.4 ± 2.7	14.1 ± 2.3^{b*}	16.8 ±2.4^{c*}	17.7 ± 3.1$^{b*.c*}$

a: comparison between G1 and G2; b: comparison between G1 and G3; c: comparison between G2 and G3
*$p < .05$; **$p < .01$; ***$p < .001$

The accelerometric records indicated a reduction in the values of accelerations in all three axes and RMS as age and BMI increased (Figure nº1). This reduction was significant for minimum values of accelerations registered in vertical ($p = .001$) and antero-posterior axis ($p = .001$) and maximum values of accelerations in medio-lateral axis ($p = .03$). The maximum values of the RMS showed significant differences among the three age groups ($p < .001$). The average duration of three repetitions of accelerometer test difference the G3 of the other two groups ($p < .01$) but do not find significant difference between G1 and G2.
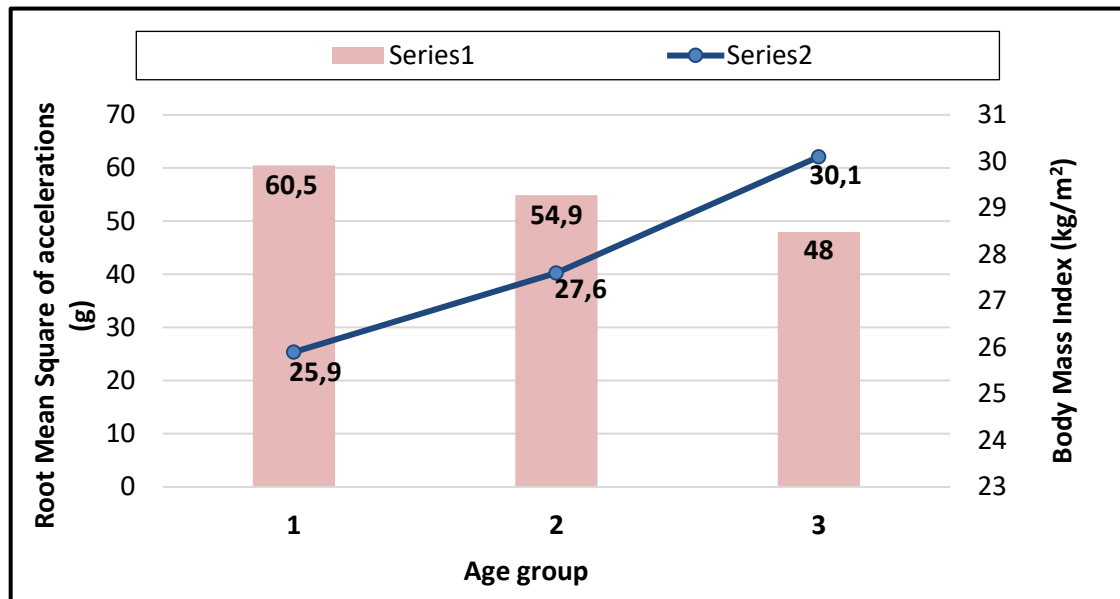
Figure 1. Progression of Body Mass Index and Root Mean Square of accelerations by age group

Only G3 showed significant correlations between variables of body composition and gait analysis. The percentage of total fat mass correlated significantly with the minimum values of vertical axis and RMS (r: -.52; p = .03). The percentage of fat mass (%FM) in the lower limbs was significantly correlated with the mean value of medio-lateral axis (r: .58; p = .01), the gait speed during the test accelerometer (r: -.65; p = .02) and TUG test (r: 6; p = .04). No significant difference in amounts of fat and muscle were observed (p > .05).

The linear regression analysis demonstrated the influence of the clinical variables and body composition on the accelerations of the body (Table nº3). The results showed a strong relationship between the clinical and accelerometric variables. The average results in vertical and medio-lateral axes and RMS were related with the results of TUG and 6MW. Only the maximum and mean values of vertical axis showed a correlation with the WP. %FM were strongly related to the average acceleration of vertical axis and the minimum value of RMS. Of them all, the %FM was the variable of body composition that showed stronger relationships with the values accelerometric. Amounts of muscle and fat mass did not obtain significant results with any variable.

Table 3. Linear regression models for clinical indicators (continuous variables)

Variable		β-WP	β-TUG	β-6MW	β-IMP	β-%FM		
						Total	Trunk	Lower limb
Vertical axis	Maximum	-.17*	-.01**	1.53**	.52	-.1**	-.08*	-.62*
	Minimum	-.4	-.03	.01	.81	-.26	-.21	-.25**
	Mean	-.22**	-.02**	1.72**	1*	-.14**	-.1*	-.95**
Medio-lateral axis	Maximum	.03	-.02***	2.09**	-.93*	.05	.03	.04
	Minimum	.00	-.04	4.87*	-2.78	.01	-.05	-.02
	Mean	.02	-.04***	3.17**	-2.55**	.18	.11	.16**
Antero-posterior axis	Maximum	-.02	-.03***	1.43	.36	-.1	-.1	-.04
	Minimum	-.36	-.02	.6	.48	-.26*	-.22	-.22**
	Mean	.02	-.02	.04	.3	-.16	-.14	-.1
Root Mean Square	Maximum	-.12	-.03***	1.93***	.21	-.1*	-.09*	-.06
	Minimum	-.08	-.02*	1.23	.19	-.14*	-.13*	-.11**
	Mean	-.17	-.03***	1.96**	.45	-.12*	-.1*	-.07*
Speed (m/s)	Mean	.67	.22***	-3.66	.72	-.2	-.09	-.2

WP; Waist perimeter; TUG: Timed Up & Go; 6MW: 6-Minutes Walk Test; IMP: Impedance; %FM: Percentage of Fat Mass.
*p value < .05
**p value < .01
***p value < .001

4. DISCUSSION

The results suggest that, in aging, the proportion of total body fat and lower limb movements affect balance during walking.

4.1. Relationships between functional tests and gait parameters

The correlations between the clinical variables are consistent with previous research demonstrating a increase in TUG results with age[28]. The results of the TUG test also correlated with the speed during the gait test with the accelerometer. Among the clinical tests employed in this study, the TUG produced significant differences between all three groups and 6MW only between the youngest and oldest. The accelerations and speed of accelerometric test were reduced with increasing age, as a result of the increase in the cadence and reduction in stride-length[15]. This fact is consistent with previous studies which observed that the aging reduces the speed of gait, as a neuromuscular adaptation[14]. The lower speed of gait, althought is a common preventative measure to maintain balance, increases the risk of falls. But, if the recorded accelerations do not increase, the gait is still coordinated and stable[29].

4.2. Relationships between body composition and gait parameters

Significant relationships between body composition and gait were only observed in participants over 71 years old. Especially for the proportion (percentage) of fat mass, compared with the amounts of fat and muscle mass. The lower relationship of the amount of muscle mass on the accelerometric results be due to the change in "locus" (shift in the locus of function in motor performance during gait) associated with a reduction in the natural motor and sensory functions during aging[14]. However, other authors have reported significant relationships between muscle mass and gait[19]. The lack of relationship between

these parameters in our study may be explained by the demographics of our study population – healthy women with normal and overweight weight.

The importance of the proportion (percentage) of fat mass above its amount may be due to an increase in intramuscular adipose tissue, which is a typical manifestation of aging[30]. A normal amount of body fat mass if it is accompanied by the maintenance of muscle mass, is not indicative of deterioration. While the gradual replacement of muscle by fat during aging is a factor that will influence the postural and biomechanical motion control[19].

One of the strongest significant associations observed in our study was between age and accelerations in the horizontal plane. A strong inverse correlation was also detected between the accelerations in the frontal plane with total and lower limb FM%. We also found that limitations in the mobility of the lower limbs in the sagittal plane increased with age; a finding that was offset by an increase in flexion and extension movements[31]. A excess of fat mass increases this alterations[32].

Higher values of lower limb FM% also correlated with a slow walking speed in the oldest group (G3). These results are consistent with the results of other studies that have linked higher BMI with extended support phases during gait[3,32].

The relationship between excess abdominal fat and the incidence of cardiovascular disease, cancer and increased mortality in postmenopausal women has been previously demonstrated[33,34]. Women who are predisposed to gluteofemoral fat accumulation have a lower risk of morbidity and mortality[35]. This may explain why the group of women over 71 years old (healthy and normal weight) had gait patterns characterized by a higher proportion of fat in the lower limbs.

In turn, the lower limb FM% and gait speed determine movements in the horizontal and mediolateral planes and RMS. As it was previously reported[32], excess of fat mass changes the patterns of load on knees and feet and reduces the mobility of the lower limbs in the sagittal plane.

4.3. Study advances and limitations

Previous studies have analyzed the influence of obesity on mobility in elderly people[1,3,32]. To our knowledge, this is the first study to investigate the interaction of body composition with gait in older women with a healthy weight. In this study, we demonstrate that lower limb FM% was associated with slower movements during gait. Even in older women with normal weight, and without structural pathologies, a excessive fat mass modifies the speed and movements of gait.

This study has several limitations. First, because of the small sample size and absence of males in it, the results have low generalizability. Second, the study population included only women; therefore it is unclear whether these findings are applicable to males. In future, we would suggest conducting a longitudinal study that relates changes in body composition with gait stability during aging.

With this study design, it would be possible to determine the evolution of fat and muscle percentages and kinematics gait parameters for each person.

5. CONCLUSIONS

This study shows how a simple analysis accelerometer can generate spatiotemporal parameters that allow early detection of abnormalities of gait in ambulatory environment. The results of this study demonstrate that, in women over 71 years old, the proportion of total and lower limb body fat is closely related to body movements during walking. Total body and, especially, lower limb fat mass are associated with gait stability in older women. Even in older women with normal weight, and without structural pathologies, an excessive fat mass is related to the speed and movements of gait.

Furthermore, the use of a simple accelerometer and the analysis of body composition by bioimpedance in normal and overweight older women can help to identify early gait disturbances. Both methods can be easily applied in the clinical environment in older women who show functional limitations and/or weight gain. Therefore, the accelerometer should be incorporated into public health because of the many possibilities offered by health services, such as improved methods of evaluating and optimizing the design of programs to improve the physical health.

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