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The influence of subtalar axis orientation on the foot posture of older adults in a closed kinetic chain

A influência da orientação do eixo subtalar na postura do pé de idosos em cadeia cinética fechada

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Abstract

Objectives: This study compared the influence of subtalar axis position on foot behavior in a closed kinetic chain in older and younger adults.
Methods: The sample included 50 older adults and a control group of 50 younger adults. The variables were initially analyzed for both feet together, and were later analyzed separately, comparing each foot (right and left) between groups. Range of motion was assessed by validated goniometric procedures: the position of subtalar axis was evaluated by the palpation technique, while the Foot Posture Index was used to assess behavior in a closed kinetic chain. Student's t-test / Mann-Whitney test compared the main variables according to sample distribution, while Student's t-test / Wilcoxon test was used for paired samples. A standardized Haberman residuals test was also used to determine the connection between the position of subtalar joint axis and the Foot Posture Index.
Results: Data from the right and left feet were similar for all variables. The older group had reduced mobility in the ankle and first metatarsophalangeal joint (5.42º [SD (Standard Deviation), 4.49] and 76.12º [SD, 19.24], respectively) with statistically significant values, ($p<0.001$), as measured by the Mann-Whitney test for the ankle joint and the t-Sutdent test for the first metatarsophalangeal joint, while the younger group had normal values (11.46º [SD, 6.49] and 97.17º [SD, 13.65], respectively)($p < 0.001$). The difference in subtalar axis position was not significant ($p = 0.788$), with more internal deviations in both groups. There was a significant difference in Foot Posture Index ($p = 0.006$, by applying the chi-square test), with the normal position more prevalent in the older group and the prone position more prevalent in the younger group.
Conclusions: Regarding internal deviations in the subtalar joint axis, the older group had a higher frequency of feet in the normal position, while the younger group had a higher frequency of feet in the prone position which, in this case, agrees with the rotational balance theory. For the normal axis position, a higher frequency of normal position was found in both groups. Regarding external deviations of the subtalar joint axis, neither group followed the pattern expected in rotational balance theory. The most consistent connection in the older group was between external axis position and supine foot position, whereas in the younger group it was between normal axis position and normal foot position.
Keywords: subtalar joint axis; foot posture index; older group; foot; ankle joint; metatarsophalangeal joint.

Resumo

Objetivos: Este estudo comparou a influência da posição do eixo subtalar no comportamento do pé em cadeia cinética fechada em idosos e adultos jovens.
Metodologia: O grupo amostral incluiu 50 idosos e o grupo controle, 50 adultos jovens. As variáveis foram estudadas inicialmente para ambos os pés e comparadas entre os grupos, sendo posteriormente analisadas separadamente, comparando-se cada pé (direito e esquerdo) entre os grupos. A amplitude de movimento articular foi avaliada por procedimentos goniométricos validados; a posição do eixo subtalar foi avaliada pela técnica de palpação; o *Foot Posture Index* foi utilizado para avaliar o comportamento do pé em uma cadeia cinética fechada. O teste t de Student/teste de Mann-Whitney comparou as principais variáveis de acordo com a distribuição amostral, enquanto o teste t de Student/teste de Wilcoxon foi utilizado para amostras emparelhadas. O teste de resíduais ajustados de Haberman padronizado foi usado para a relação entre a posição do eixo da subtalar e o *Foot Posture Index*.
Resultados: Os dados dos pés direito e esquerdo foram semelhantes para todas as variáveis. O grupo mais velho apresentou mobilidade reduzida no tornozelo e na primeira articulação metatarsofalângica (5,42 [desvio padrão — DP, 4,49] e 76,12 [DP, 19,24] graus, respectivamente), enquanto o grupo mais jovem apresentou valores normais (11,46 [DP, 6,49] e 97,17 [DP, 13,65], respetivamente) com valores estatisticamente significativos, ($p<0{,}001$), aferidos pelo teste de Mann-Whitney para a articulação do tornozelo e pelo teste t-Sutdent para a primeira articulação metatarsofalângica. A diferença na posição do eixo subtalar não foi significativa ($p = 0{,}788$, pela aplicação do teste de Qui-quadrado), com mais desvios internos em ambos os grupos. O *Foot Posture Index* diferiu significativamente entre os grupos ($p = 0{,}006$ pela aplicação do teste de Qui-quadrado), sendo a postura normal mais prevalente no grupo mais velho e a postura pronada mais prevalente no grupo mais jovem.
Conclusões: Em relação aos desvios internos do eixo da articulação subtalar, o grupo mais velho apresentou maior frequência de pés na postura normal, enquanto o mais jovem apresentou maior frequência de pés pronados, o que, neste caso, corrobora a teoria do equilíbrio rotacional. Na posição normal do eixo, foi encontrada maior frequência de pés com postura normal em ambos os grupos. Em relação aos desvios externos do eixo da articulação subtalar, nenhum dos grupos seguiu o padrão esperado na teoria do equilíbrio rotacional. A relação mais consistente no grupo mais velho foi entre a posição do eixo externo e a posutra supinada do pé, enquanto no grupo mais jovem se deu entre a posição normal do eixo e a postura normal do pé.
Palavras-chave: eixo da articulação subtalar; Foot Posture Index; pessoas idosas; pé; articulação do tornozelo; articulação metatarsofalângica.

INTRODUCTION

In its full range, foot function should have a fair ability to adapt to any terrain, although sometimes the foot must become a rigid lever to propel the body forward. It should also absorb the rotational forces of the leg, which occur mainly in the pelvis.[1] This ability to transduce leg movement is only truly effective when the foot's normal biomechanics are functionally preserved. When this is lost, however, the inability to absorb rotational forces causes them to direct upwards, overloading the upper joints.[1]

With aging there is a gradual loss in range of motion, muscle strength, and contraction speed, leading to a reduction in gait speed and a reduced capability to correct balance loss. However, some changes in the foot can exacerbate these conditions. Several studies have reported an association between decreased mobility, namely in ankle joint, and the ability to sustain balance.[2]

One study even suggested that exercises which increase ankle dorsiflexion might increase the effectiveness of clinical interventions to decrease falls in older people.[3] Other studies have reported that individuals who underwent subtalar[2] or ankle[4] joint fusion surgery experience difficulties in walking on irregular terrain. These studies support the relationship between motion amplitude, subtalar joint function, and postural stability.

Although loss of joint mobility has been widely documented as an inherent factor of aging, other non-physiological factors may also be responsible for decreased joint mobility. In this regard, we highlight diabetes mellitus and diabetic neuropathy. The relationship between diabetic neuropathy and reduced joint mobility has been widely documented. In fact, the reduced joint mobility syndrome is considered a non-painful, non-inflammatory limitation in joint mobility that affects the feet and large joints.[5] Multiple biochemical abnormalities appear to be related to its appearance, such as increased non-enzymatic glycolysis of collagen fibers, increased cross linking of collagen and its consequent resistance to enzymatic digestion, increased hydration mediated by the aldose reductase pathway, and increased formation of advanced glycolysis end products.[6]

The present study was based on Kirby's rotational balance theory,[7] which postulates that the spatial location of the subtalar joint axis implies changes in the lever arms of the ground reaction forces that act on the foot when it is in a closed kinetic chain, and thus condition foot posture under loading. This theory is related to the functioning of any fixed lever. It is based on the idea that to find the conditions of rotational equilibrium, any object must have zero moments of resultant force. Thus, to create equilibrium around an axis of rotation, the sum of the moments acting in a given direction must be equal to the sum of the moments acting in the opposite direction.[8]

Relating these theories to the foot, in order to find conditions of rotational equilibrium around the axis of the subtalar joint, the sum of the magnitudes of the pronating forces (external to the axis) must be equal to the magnitude of the sum of the supinating forces (internal to the axis). However, for this to occur the foot will have to yield to different ground reaction forces,[7] which requires the joint structures to have an effective range of motion. If this does not happen, it is possible that, regardless of the position of the subtalar axis and the ground reaction forces, the foot will not yield and will not be able to find its rotational equilibrium point.

The concept of rotational balance around the subtalar joint axis could also explain why the spatial location of the subtalar joint is so important in foot functionality. This concept may be as equally well founded for normal axis position as for changes in its position, since these changes will create different lever arm lengths for pronating and supinating forces, and only the contribution of the ground reaction forces will be able to counterbalance these forces to create equilibrium.[7]

In a static biped standing position, the resulting rotational position of the subtalar joint is commonly measured using the position of the calcaneus in relation to the ground, which is commonly called the relaxed calcaneal position. This is valid for feet with both normal and altered function.[7] However, since the relaxed position of the calcaneus alone can only indicate changes in the frontal plane of the foot, we opted in this study to analyze the complete Foot Posture Index, which offers a more detailed analysis in three planes, gauging the foot's behavior with greater accuracy.[9]

In this context, the theory of rotational equilibrium regarding the subtalar articular axis was a real revolution in the way we interpret the behavior of the foot and was the starting point for this study. We tried to determine whether it has the same implications for the foot independently of its ability to yield to ground reaction forces or, on the contrary, whether the foot involves factors that prevent it from finding a rotational equilibrium point. If the latter is the case, equilibrium theory would not apply to feet with compromised articular mobility. Our hypothesis was that whenever joint mobility is decreased, either due to aging or pathological causes such as diabetic neuropathy, the theory of rotational balance of the subtalar joint may not have the same applicability, given that in feet with less joint mobility the orientation of the subtalar axis could be less influential on foot posture in the support phase. We reasoned that by not excluding individuals with neuropathy we could better clarify whether reduced mobility would have less effect on the subtalar axis position in the support phase. Therefore, the main objective of this study was to analyze the influence of subtalar joint axis position on Foot Posture Index in a sample of 50 older adults compared to 50 younger controls.

OBJECTIVES

Main objective

The main objective of this study was to compare the influence of subtalar joint axis position on foot behavior in a closed kinetic chain between sample and control groups.

Secondary objectives

The secondary objectives of this study were to compare the position of subtalar axis between the sample and control groups, compare the foot posture index between the groups, compare dorsiflexion mobility of the ankle and the first metatarsophalangeal joints between groups, and compare the general characteristics of the groups, such as body mass index (BMI), diabetes, and osteoarticular pathology.

METHODS

This study was approved by the research ethics committee of the Vale do Ave College of Health (Portugal). Data collection only occurred in institutions that formally consented. All procedures in this study were non-invasive, and all ethical conduct was based on the Declaration of Helsinki.[10]

Participants

Two groups of 50 individuals each were recruited. The older group's mean age was 73.40 (SD, 6.97) years and 33% were men. The younger group's mean age was 23.16, (SD, 2.19) years and 26% were men. Individuals who were bedridden, had osteoarticular inflammation, a central or peripheral neurological pathology (except diabetic neuropathy, for the reasons outlined above), foot sequelae, or a BMI > 35 were excluded from this study. The younger group consisted of Vale do Ave College of Health podiatry students, and the older group consisted of patients from two health charities and two private medical clinics. Only those with a BMI > 35 were excluded, since changes in foot support are often attributed to overweight, especially greater pronation. In reality, however, studies that have tried to demonstrate this concept have found that it can occur only in more extreme cases of overweight. On the contrary, studies have shown that weight has little influence on supination resistance, that is, regardless of an individual's weight, feet with certain changes will always have very little supination resistance. In this regard, Griffiths and McEwan[11] showed that the force required for the supination of a foot was independent of posture, and only about 12% was explained by body weight. It was then documented that even in those with normal weight, feet with low supination resistance pronate abundantly. It could be the case that in heavy individuals feet have low supination resistance and tend to supinate. Other studies have also found that even in children, the correlation between BMI and foot posture index is very weak.[12]

Procedures

Passive mobility in dorsiflexion of the ankle[13] and the first metatarsophalangeal joint was evaluated by goniometry in dorsal decubitus. This technique has shown an acceptable interobserver reliability in previous studies if measured by the same therapist over a short period of time.[14] In spite of lower reliability compared to closed kinetic chain testing,[15] goniometry was selected due to its feasibility with older participants, because of the frequent presence of knee arthropathy, which impeded performance of the Lunge test.

The position of the subtalar joint axis was determined by a validated palpation technique.[16] The Foot Posture Index[17] was determined through observation according to author recommendations.

After the evaluation in decubitus, the participants positioned themselves on a podoscope in a relaxed standing position. Closed kinetic chain testing was conducted using a podoscope, which functioned only as a flat elevated support base. With the patient in a standing position, the 6 following items in the Foot Posture Index were evaluated:

a. Talar head palpation;
b. Supra- and infra-lateral malleoli curvature (viewed from behind);
c. Calcaneal frontal plane position (viewed from behind);
d. Prominence in the region of the talonavicular joint (viewed at an angle from inside);
e. Congruence of the medial longitudinal arch (viewed from inside);
f. Abduction/adduction of the forefoot towards the rearfoot (view from behind).

To reduce sample dispersion, groups were formed based on the subtalar joint axis and Foot Posture Index, such that feet with the "most supine" posture index were combined with feet with a "supine" posture, while feet with the "most prone" posture were combined with feet with the "prone" posture, resulting in 3 posture categories: prone, normal, and supine.

Statistical procedures

Student's *t*-test or the Mann-Whitney test was used to compare the main variables according to sample distribution. Student's *t*-test or the Wilcoxon test was used for paired samples. Pearson's correlation coefficient was used to determine the correlation of quantitative variables, while the chi-square test and the Cramer coefficient were used for qualitative variables. A standardized Haberman residuals test was also used to determine the connection between subtalar joint axis and Foot Posture Index group.

RESULTS

Based on BMI values, 50% of the older group was overweight, 26% had normal weight, 18% were obese and 4% were underweight. In the younger group, 62% had normal weight, 22% were underweight and 14% were overweight.

Some data used in the selection criteria, such as BMI, osteoarticular pathology, and diabetes, differed between the groups: overweight was significantly higher in the older group, which suggests that age is a relevant factor in BMI. Regarding osteoarticular pathologies, 50 and 0% of the older and younger groups, respectively, reported suffering from osteoarthrosis. Among those with osteoarthrosis, the most affected joint was the knee (60%), followed by the hip (40%) spine (36%), shoulder (approximately 16%), and hand (12%). Diabetes was reported by 34 and 0% of the older and younger groups, respectively, being significantly more prevalent with age.

In decubitus observation, the data for right and left feet were similar for all variables. The older group had a lower degree of ankle and metatarsophalangeal joint mobility (5.42, SD of 4.95 and 76.12, SD of 19.24, respectively), although it was normal in the younger group (11.46 SD of 6.49 and 97.21 SD of 13.65, respectively) ($p < 0.001$). Due to internal deviations, no significant difference ($p = 0.788$) was found for subtalar joint axis position.

The Foot Posture Index results differed significantly ($p = 0.006$) between the groups. The normal position was more prevalent in the older group, while the prone position was more prevalent in the younger group. Regarding internal axis position, according to the relationship between the subtalar joint axis position and the Foot Posture Index, there was a higher incidence of feet with normal posture (33.70%) in the older group and a higher incidence of prone feet (34%) in the younger group. Regarding normal axis positions, there was a higher incidence of normal posture index (14.30 and 10.30%, respectively) in both the older and younger groups. Regarding external axis deviations, the same incidence was found in feet with normal, prone, and supine posture (6.12%) in the older group, whereas in the younger group there was a higher incidence in feet with prone posture (10.30%).

Subsequent investigation involved Haberman residual analysis, which showed that the most consistent connection was between an external axis of rotation and supine foot position in the older group, and between a normal axis of rotation and normal foot position in the younger group. This indicates that the presuppositions of the rotational balance theory were more effectively fulfilled in an external axis of rotation in the older group and a normal axis position in the younger group (Tables 1 and 2).

DISCUSSION

Regarding the general features of the sample, the older group had a higher BMI, a higher incidence of osteoarticular pathology, and a higher prevalence of diabetes. The results were consistent with many studies for these parameters.

TABLE 1. Relationship between the position of the subtalar joint axis using the Standardized Haberman residuals and the Foot Posture Index in the younger group on both feet.

			FPI			Total
			Supine Position	**Normal**	**Prone Position**	
SBT Joint Axis Position	Internal	N	8	20	33	61
		Standardized Haberman residuals	-,5	-,6	,9	
	Normal	N	1	10	6	17
		Standardized Haberman residuals	-1,1	2,3	-1,4	
	External	N	5	4	10	19
		Standardized Haberman residuals	1,6	-1,4	,2	
Total		N	14	34	49	97

SBT: Subtalar, FPI: Foot Posture Index, N: Number of cases.

TABLE 2. Relationship between the position of the subtalar joint axis using the Standardized Haberman residuals and the Foot Posture Index in the older group on both feet.

			FPI			Total
			Supine Position	**Normal**	**Prone Position**	
SBT Joint Axis Position	Internal	N	5	33	21	59
		Standardized Haberman residuals	-2,3	,5	-1,3	
	Normal	N	4	14	3	21
		Standardized Haberman residuals	,5	1,3	-1,8	
	External	N	6	6	6	18
		Standardized Haberman residuals	2,4	-2,0	,3	
Total		N	15	53	30	98

SBT: Subtalar, FPI: Foot Posture Index, N: Number of cases.

Anjos,[18] for example reported a higher incidence of obesity in a group of older adults, especially women. In 2014, Ksibi et al.[19] reported that aging influences the incidence of osteoarthrosis and that the knee is the most affected joint, as we also found in the present study.

The higher incidence of diabetes in the older group was also expected, being well documented in the literature.[20,21] Some studies have found that its higher incidence is associated with obesity and physical inactivity,[21] both of which were common in our group of older adults.

The range of motion in the ankle and metatarsophalangeal joint were significantly lower in the older group. This is consistent with other studies, which report that the range of motion tends to decline over time due to changes in mechanics and joint structure associated with aging.[21–23] In 1992, Nigg, Fisher, Allinger, Ronsky, and Engsberg[24] found a significant difference in the range of motion of the foot and ankle between a younger control group and individuals aged between 70 and 79 years. One curious fact reported in the literature is that although significant changes occur in the range of ankle dorsiflexion in healthy older men and women, greater declines occur in women.[25] This was confirmed by Vandervoort et al.,[26] who found a greater decrease in ankle mobility among women than men. However, Walker et al.[27] assessed the range of 28 active motions in the articular structures of the upper and lower limbs of 30 men and 30 women over 60 years of age, including dorsiflexion and plantar flexion of the ankle and first metatarsophalangeal joint. They found that 12 of the 28 motions differed significantly between men and women and that in 8 of these 12 motions, women had greater mobility than men, although the values were practically the same in men and women for dorsiflexion of the ankle joint (9º and 10º, respectively). Nevertheless, unlike Vandervoort et al., Walker et al. assessed active rather than passive mobility, which could be the source of the discrepancy. Moreover, their values were much higher than ours. One possible explanation for this could be that the mean participant age in Walker et al. was lower than ours. In addition, the dorsiflexion results did not significantly differ between the left and right foot, which agrees with Mecagni et al.,[3] who in a group of 34 older women with a mean age of 74.70 years, assessed active dorsiflexion in the ankle with the knee in a stretched position, finding very similar values for left and right foot.

The bilateral range-of-motion values for dorsiflexion of the first metatarsophalangeal joint in the younger group were approximately 97º. These values agree with long-standing literature, which reports an estimated range of motion for the first metatarsophalangeal joint of approximately 80–90º of dorsiflexion.[28]

Nevertheless, in our older group the mean range of motion was approximately 76º. This represents a clear reduction in mobility in comparison with reference values,[29] suggesting that a reduction in the mobility of the metatarsophalangeal joint occurs with aging. Similar results were found in a study that divided men into three age groups, one < 30 years old, one 30–44 years old, and one > 45 years old.,[30] i.e., there was a clear decrease in range of dorsiflexion of the first metatarsophalangeal joint with increasing age. Another study of 60 older adults that measured the active articular range in the upper and lower limb found 62º and 59º of dorsiflexion of the first metatarsophalangeal joint in men and women, respectively.[31] However, in the present study we did perform comparisons according to sex due to the unequal distribution, which could lead to bias. Moreover, the values we found for this variable were higher than the reference values. One explanation for this could be that active mobility was used in the reference study, but we used passive mobility, which results in a slightly better range of motion. A more recent study by Scott, Menz and Newcombe,[31] which included 50 younger and 50 older adults, assessed focal changes in the structure and function of the foot associated with aging, finding values of 81.40º and 56.40º for passive dorsiflexion of the first metatarsophalangeal joint in the younger and older groups, respectively. These values are also slightly lower than ours, and this difference was more significant in the older group. Provided that this study also used passive mobilization, these discrepancies, though not very significant, could simply be due to real differences in our older population. However, one explanation for this finding could be the mean age of the studied populations, since the older adults in our study were approximately seven years younger than those in Scott, Menz and Newcombe. Nevertheless, age is not the only conditioning factor for reduced mobility: as explained previously, pathologies such as diabetes mellitus contribute heavily to decreased joint mobility. This was verified by Abate et al. in 2011,[32] who, despite finding significantly lower mobility in all joints in the older group (except knee and elbow flexion), determined that this decrease was more marked in individuals with diabetes.

Although a reduced rate of motion in the ankle joint of older adults has been widely reported in the literature,[3,24,33] the finding about metatarsophalangeal joint mobility in dorsiflexion,[34] which seemed to be new in Scott et al.,[31] has now been consolidated in the present study.

On the other hand, it should be pointed out that there is consensus about the decreased mobility of these joints in older adults.[3,24,30,33,35] The fact that some studies report an association between decreased mobility, especially in the ankle joint, and the ability to maintain balance, makes this all the more important.[4] One study even suggested that exercises that lead to better ankle dorsiflexion could increase the effectiveness of clinical interventions to reduce falls among older adults.[3] Other studies have reported that individuals who underwent surgery to fuse the subtalar[4] or ankle joint[36] experience difficulties walking in irregular terrain, which strengthens the connection between range of motion and postural stability.

Another relevant factor about decreased mobility was described by Vianna and Greve,[37] who found a negative correlation between foot and ankle mobility and the vertical ground reaction force generated during gait, which could lead to foot pain over time.[37] This could have even greater importance when associated with increased risk of foot ulceration, as is the case in diabetic patients.

This connection between reduced foot mobility, namely in metatarsophalangeal and ankle joints, and the risk of falls among older adults, aroused such curiosity that a prospective study tried to establish a connection between changes in the foot and ankle and the risk of falls in older adults. This study analyzed two groups of older adults: those with and without a history of falls. The group with a history of falls had more foot problems, including decreased ankle mobility, greater deformity of the first metatarsophalangeal joint (hallux valgus) and decreased toe plantar flexion force, leading to the conclusion that foot and ankle problems increase the risk of falling in older adults.[3]

We also found that decreased mobility in dorsiflexion of the first metatarsophalangeal joint was more significant than decreased ankle mobility in the older group. Scott et al.[31] found a similar result, which could mean that smaller joints are more affected by the non-pathological mobility restriction inherent to aging. Nevertheless, because the metatarsophalangeal and ankle joints involve distinct features and their ranges of motion are also very distinct, this finding requires further investigation. Although this pertinent question arose from a secondary aim of this study, it could become the primary aim of a follow-up study.

Large variability was observed in the position of the subtalar joint axis in our sample, with internal and external deviations, as well as normal position, occurring in both groups. This agrees with Kirby,[38] who reported that the subtalar joint axis is inconstant and varies considerably between individuals. Although, on average, the axis rotates 16º in the sagittal plane and 42º in the transverse plane, these numbers are contested, since the values for most individuals are quite dissimilar.[39] Therefore, the considerable variability in axis position in our sample is not a new finding. There were no significant differences between the groups regarding subtalar joint axis position, but rather similarities: internal deviation predominated, with very similar rates for both populations. Since we could find no study reporting on similar data for comparison, our results for this parameter could not be confirmed by previous studies.

The Foot Posture Index in the older group was mainly normal, while that of the younger group was mainly prone. On the other hand, there was a lower incidence of extreme (most prone and most supine) postures in the older group, while supine postures were more prevalent in the younger group, with a significant incidence of prone postures (7.5%). The higher mean Foot Posture Index in the older group indicates that their foot support is closer to that which is considered normal, while that in the younger group tends to be more prone. These differences were statistically significant for both the qualitative and the numeric Foot Posture Index values.

These findings do not align with previous studies that used Foot Posture Index. Scott et al.,[31] for example, also compared younger and older groups, finding that the older group had more prone feet and a higher Foot Posture Index than the younger group. Staheli et al.[40] found a more prone foot position among older adults using plantar print data, including a reduction in longitudinal foot arch after 30 years of age. However, it should be pointed out that these authors used the term "prone" to indicate a reduced internal longitudinal arch, whereas in the Foot Posture Index, the position of the internal angle is only one criterion and is not the only determinant of the final value. Since this Foot Posture Index criterion was not used independently in our study, it may not be wise to compare our results with these studies, since we would be judging individual Foot Posture Index parameters through final values alone.

In this regard, it should be pointed out that there was a smaller difference between the maximum and minimum Foot Posture Index values in the older than the younger group (-9 and +12, respectively vs. -9 and +13, respectively). This clearly shows more homogeneous foot support behavior in the older group than the younger group. Again, there were few studies to corroborate these results. Nevertheless, one study[41] that used the Foot Posture Index to assess a population of 399 individuals between 60 and 90 years old found values of 1.18 for the female group and 0.91 for the male group, with no significant differences between the left and right feet. These values were very low, lower than those of the present study, and closer to normal support values. However, this could have been because the mean age in this study was even higher than ours. Nevertheless, a trend towards normal support in among older adults appears to be a common finding.

In addition, regarding the Foot Posture Index results, when the right and left feet were compared separately between the groups, the differences were no longer statistically significant. One explanation for this could be that separating the left and right feet leads to larger sample dispersion and, thus, destroys the significance of the results. Nevertheless, the same trend was found in the right and left feet when they were assessed globally. The greater incidence of feet with normal support in the older group seems to agree with the results of Castro et al.[41]

For more objective Foot Posture Index data, the extreme positions "most prone" and "most supine" were consolidated with the prone and supine positions, respectively, reducing the results into three final categories: normal, prone, or supine support. The left and right feet were also compared separately according to these parameters, but showed similar results to the previous analyses, given that there were no significant differences between the older and younger groups when the right and left feet were separated. We point out, however, that in the separate assessment of right and left feet, the p-values were closer to significance than those of the original 5-category Foot Posture Index, which supports the idea that the loss of significance in separate analysis is due to the larger sample dispersion, suggesting that a larger sample may better distinguish older from younger individuals when comparing right and left feet separately.

Once again, in the grouped version of the Foot Posture Index, there was a higher incidence of normal and prone position in the older and younger groups, respectively, which was the greatest difference found for this parameter. As previously mentioned, these data do not seem to agree with other studies that compared foot support in older and younger adults. Nevertheless, there may still be an explanation for this. One persistent finding over the years,[3,4,29,30] which was also observed in the present study, is that older adults have less articular mobility. In addition to the ankle and metatarsophalangeal joints, lower mobility has been found in other joints, such as the subtalar joint, which is generally associated with degenerative processes.[31] Therefore, the higher incidence of normal support found in our older group might be due to the fact that the prone position is either a consequence of greater foot mobility, the foot adapting to the ground, or the result of prone subtalar motion.[41,42]

It seems that decreased joint mobility, especially in the subtalar joint, implies better adaptation of the foot to the ground and, thus, smaller deformity in the frontal plane. Hence, it is possible that the predominance of the normal position in the older group was simply the result of reduced mobility, which prevents the foot from yielding to force produced by body weight or to ground reaction force.

A study assessing gait in older and younger adults reported a curious finding that might explain this phenomenon: significant differences in the distribution of foot pressure. In this study, the older group had a more exterior distribution during in the stage of heel contact and propulsion, with lower values in the medial foot surface during the total support stage.[36] Moreover, Kernozek et al.[43] reported lower pressure on the hallux among older adults. These data indicate that there is less overload of internal foot structures in older adults than younger adults, mainly during gait, which could indicate a lower tendency toward prone support among older adults.

In view of the differences we found between the groups, it must be pointed out that they cannot be attributed in a linear manner to aging. Moragas,[44] for example, reports that the boundary between healthy and pathological aging is often imprecise. The fact that pathological phenomena accumulate with age might explain the differences found between the groups, and these may have little to do with biological aspects of aging.[45]

CONCLUSIONS

Concerning our study's main objective, to compare the influence of the subtalar joint axis position (in the transverse plane) on foot behavior in a closed kinetic chain in older and younger adults, we found very similar patterns in both feet. Regarding internal deviations in the subtalar joint axis, the older group had a higher frequency of normal position, while the younger group had a higher frequency of prone position, which, in this case, agrees with rotational balance theory.

In the normal position of the axis, both groups had a higher frequency of feet in the normal position, although in external deviations of subtalar joint axis, neither group followed the patterns established by rotational balance theory. However, it is possible that the results were biased since there was a very low incidence rate of this position.

The most consistent connection in the older group was between external axis position and supine foot position, whereas in the younger group it was between normal axis position and the normal foot position.

Regarding the study's objective to compare the position of subtalar joint axis between the older and younger groups, both groups had the same pattern for both feet. The internal position was the most prevalent, followed by the normal position, especially in the older group; finally, the external position was more prevalent in the younger group.

In the Foot Posture Index results, the older group had a higher incidence of normal posture, with the most prone posture occurring only rarely. However, in the younger group there was a higher incidence prone posture, with the supine posture occurring less frequently. A more significant difference in this parameter was observed in the left foot.

Regarding the objective of comparing dorsiflexion in the ankle and first metatarsophalangeal joints, the older group had significantly lower mobility in these joints than the younger group, whose values were normal.

Finally, regarding the general features of the two groups, as expected, the older group had a higher BMI, a higher incidence of osteoarticular pathology, and a higher prevalence of diabetes.

Conflicts of interest

The authors declare no conflicts of interest.

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Author contributions'

LA: Conceptualization, data curation, methodology, project administration, writing – review & editing. FMR: Conceptualization, data curation, writing – review & editing. JCDG: Conceptualization, methodology, investigation, supervision. EPI: Conceptualization, methodology, supervision. JMN: Data curation, investigation, supervision.

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