RBCDH Revista Brasileira de CINEANTROPOMETRIA e Desempenho Humano

DOI: http://dx.doi.org/10.5007/1980-0037.2014v16n3p287

original article

# Lower limb joint alignment and postural control in elderly women

## *Alinhamento articular de membros inferiores e controle postural em idosas*

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**Abstract** – The aim of this study was to test whether quiet stance body sway is associated with ankle and knee joint angles in elderly women. Joint angles were measured using a manual goniometer and body sway was assessed using a force platform and four postural tasks with a combination of feet positions and eye condition. The sample (N = 58) showed the following angle values: 102 (100-104) for the tibiotarsal joint, 176 (174-180) for the subtalar joint, 184 (181-187) for knee flexion-extension, and 13 (10-15) for the Q-angle. Q-angle was significantly correlated ($p < 0.05$) with center of foot pressure (CP) displacement area (r = 0.36), anteroposterior (SDy, r = 0.34) and lateral (SDx, r = 0.31) CP standard deviation, and anteroposterior CP range (r = 0.38) during the closed base, eyes opened trial (CBEO). The *valgus* group showed statistically higher values than the normal and *varus* groups for SDy (0.56 vs. 0.52 and 0.46 mm; p = 0.02), SDx (0.55 vs. 0.49 and 0.36 mm; p = 0.02) and anteroposterior range (3.32 vs. 2.78 and 2.38 mm; p = 0.01), CBEO. The displacement velocity of the CP was significantly higher for the asymmetric than the symmetric Q-angle group (8.0 *vs.* 5.3 mm/s – closed base, eyes closed trial). Knee alignment was correlated with measures of body sway in elderly women, but ankle alignment showed no correlation. Knee morphology should be considered an associated factor for quiet stance postural control.

**Key words**: Aging; Ankle joint; Genu valgus; Genu varus; Knee joint; Postural balance.

**Resumo** – *O objetivo do estudo foi verificar se a oscilação corporal na postura quieta está associada aos ângulos articulares de tornozelo e joelho em idosas. Os ângulos foram medidos por um goniômetro manual e a oscilação corporal foi obtida por uma plataforma de força em quatro situações (combinando posição dos pés e condição visual). A amostra (N = 58) apresentou os seguintes valores angulares: 102 (100-104) para o tibiotársico, 176 (174-180) para o subtalar, 184 (181-187) para flexão-extensão de joelho e 13 (10-15) para ângulo Q. O ângulo Q se correlacionou significativamente (p < 0,05) com a área do deslocamento do centro de pressão dos pés (CP) (r = 0,36); com o desvio padrão anteroposterior (SDy, r = 0,34) e lateral (SDx, r = 0,31) do CP; e com a amplitude anteroposterior do CP (r = 0,38), durante a condição de base fechada, olhos abertos (BFOA). O grupo valgo, quando comparado aos grupos normal e varo, apresentou valores estatisticamente maiores de SDy (0,56 vs. 0,52 and 0,46 mm; p = 0,02), SDx (0,55 vs. 0,49 and 0,36 mm; p = 0,02) e amplitude anteroposterior (3,32 vs. 2,78 and 2,38 mm; p = 0,01), BFOA. A velocidade de deslocamento do CP foi significativamente maior para o grupo com ângulo Q assimétrico, comparando com o simétrico (8,0 vs. 5,3 mm/s – condição de base fechada, olhos fechados). O alinhamento do joelho se correlacionou com medidas de oscilação corporal em idosas, mas o tornozelo não mostrou nenhuma correlação. A morfologia do joelho deve ser considerada um fator influenciador no controle postural estático.*

**Palavras-chave**: *Articulação do tornozelo; Articulação do joelho; Equilíbrio postural; Envelhecimento; Geno valgo; Geno varo.*

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Received: 20 September 2012
Accepted: 18 September 2013

## INTRODUCTION

Posture control depends on the integration of sensory information from various senses so that appropriate motor adjustments are selected during a specific postural task[1,2]. The contribution of the visual, vestibular, and somatosensory systems in quiet standing is well described in the literature[3,4] and the objective method most often used to evaluate body stability is platform stabilometry, also known as posturography[1,2]. This technique measures the displacement of the center of pressure (CP), which is the spatial coordinate of the vertical ground reaction force. Thus, the CP is considered the neuromuscular response to imbalances in the body's center of mass[2].

The aged population is increasing worldwide. The percentage of people over 65 years of age is expected to reach 21.6% in Europe, 20% in North America, and 11.9% in Latin America by 2030[5]. In Rio de Janeiro, Brazil, 12.8% of the population is already considered elderly[6]. Accordingly, health care professionals dedicate more of their clinical practice to body stability issues. Postural instability can result from impairments in sensory, motor and other central processing systems[7]. The somatosensory system provides information from muscle spindles, Golgi tendon organs, and joint and skin receptors[7], all of which can be influenced by lower limb morphology. Because somatosensory perturbations during quiet stance increase body oscillation[8] and joint impairments lead to augmented values of CP displacement[9], it can be argued that lower limb morphology and joint alignment are linked to upright posture control, particularly in the elderly, who show an age-related deterioration of the sensory and neuromuscular control mechanisms[10], as well as structural deformities related to the degeneration of joint cartilage.

The relationship between lower limb and balance characteristics in young adults has been studied by Chiari et al.[11]. Those authors showed that some biomechanical factors (e.g., maximum foot width, base-of-support area and foot opening angle) significantly influenced stabilometric variables. Another group of researchers[12] evaluated 166 older people and found that ankle flexibility and toe plantarflexor strength were associated with participant performance on balance tests. In another study[13], young subjects (26.9 ± 5.2 years old) with *genu varus* (subjective assessment) presented a lower oscillation velocity than those with *genu valgus* in protocols where the feet were together. However, none of those studies assessed the relationship between objective measures of lower limb joint alignments and standing postural control.

There is no consensus in the literature about the relationship, if any, between ankle and knee morphological characteristics and stabilometric variables in the elderly. Research into what body characteristics are associated with postural instability in this population may provide health professionals (physiotherapists, physical educators, physicians and others) with important information about the early detection of postural imbalance and may aid treatment planning. For these reasons, the aim of the present study was to determine whether quantitative parameters of quiet standing body sway are associated with ankle and knee joint angles in elderly Brazilian women.

## METHODOLOGICAL PROCEDURES

### Subjects

This cross-sectional study enrolled 58 women from the Open University for the Elderly (UNATI) program at Bonsucesso, Rio de Janeiro, Brazil. The subjects volunteered after a lecture explaining the study protocol. Women over 60 years of age that agreed to participate in the study were included. Exclusion criteria were: (1) the presence of any musculoskeletal impairment or pain that could affect the ability to maintain the orthostatic posture; (2) diagnosed neurological diseases or any clinical manifestation of neurological impairment; (3) acute dizziness; and (4) alcohol intake in the previous 24h. Written informed consent was obtained from all volunteers before they participated in the study and the protocol was approved by the local ethics committee (number 003/10). No sample size calculation was performed because all women from the UNATI institutional program were invited and subsequently screened for eligibility criteria.

### Ankle and knee angle measurements

To characterize the ankle and knee alignment of the participants, four angles (tibiotarsal, subtalar, knee flexion-extension and Q-angle) were measured bilaterally while the participant was in a bipedal quiet standing position without shoes and with no joint replacement allowance, as described elsewhere[14,15,16] (Figure 1). To reduce measurement errors, all subjects were measured with the same goniometer with values rounded to the nearest two degrees (EMG Systems do Brasil, São Paulo, Brazil) and by the same expert examiner.

### Platform stabilometry

CP data were collected by a force platform (AccuSway Plus; AMTI - Massachusetts, USA) at a sample rate of 100Hz. The signals were stored and the variables were calculated with Balance Clinic Software (AMTI). All participants performed the following four trials (each lasting 60s) characterized by different postural tasks: opened base, eyes open (OBEO); opened base, eyes closed (OBEC); closed base, eyes open (CBEO); closed base, eyes closed (CBEC). A randomized blocked design was used to minimize fatigue and learning effects. Participants were requested to stand barefoot on the platform, arms by their sides, looking straight ahead at a specific point in the wall (distance to wall = 1.8 m) at their eye level. The analyzed stabilometric parameters were: lateral standard deviation (SDx); anteroposterior standard deviation (SDy); lateral range (RANGEx); anteroposterior range (RANGEy); effective area (encompassing approximately 66% of data); and mean velocity (path length/trial duration).

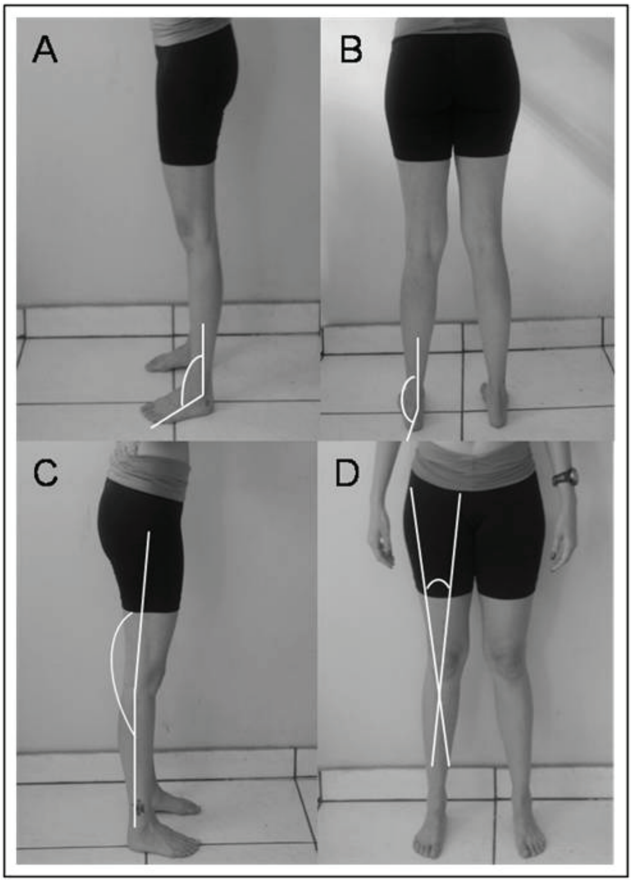


**Figure 1.** Goniometer positions for the measurement of the: (A) tibiotarsal angle (ankle); (B) subtalar angle (ankle); (C) flexion-extension angle (knee); and (D) Q-angle (knee).

## Anthropometric and body composition measurements

Subject weight and height were measured with an analog balance scale with a stadiometer applied (R110; Welmy - Santa Bárbara d'Oeste, São Paulo, Brazil). The body mass index (BMI) was calculated as the Quetelet index (BMI = Weight/Height$^2$) and the WHO classification was used for group characterization[17]. Waist circumference was measured at the narrowest point between the lower costal border and the iliac crest[18]. A flexible steel tape (Terrazul; Cambuci, São Paulo, Brazil) was used to measure this girth and the WHO classification was used for group characterization[17]. Body composition analysis was performed with a bioelectrical impedance analyzer (BIA 310e; Biodynamics, Seattle, Washington, USA). The test current used was 800 µA at 50 kHz. The equation chosen to predict fat free mass[19] was previously validated in an elderly Brazilian sample[20]. The Deurenbert et al.[21] classification for obesity (body fat percentage > 35%) was used.

## Statistical data analysis

Variables distributions were analyzed with a Kolmogorov-Smirnov test; nonparametric tests were chosen because a meaningful number of the variables did not have a normal distribution. Parameter values are presented as the median (first quartile - third quartile). Frequency distributions for categorical variables were analyzed with a *chi*-square test. Box plots illustrate median, first and third quartiles, and minimum and maximum values. The angle value was calculated as the mean of the right and left angles, except for symmetric analysis, as explained below.

A Spearman correlation coefficient was used to quantify the association between stabilometric parameters and lower limb joint angles at the $p < 0.05$ significance level. Subjects also were divided into three Q-angle groups: physiological *valgus* or 'normal' (Q-angle from 10º to 14º), *varus* (Q-angle < 10º), or *valgus* (Q-angle > 14º)[22,23]. A Kruskal-Wallis test was applied to detect differences between those groups (at the $p < 0.05$ significance level). A Mann-Whitney test was used for each pair of groups to identify where the differences were found when the Bonferroni correction was considered (0.05/3 = 0.017).

Additional data analysis was performed for the Q-angle bilateral symmetry: each angle value (right and left body sides) was considered and classified (*valgus*, *varus,* or normal) separately, and then all individuals were categorized as symmetric or asymmetric. The symmetric group comprised those elderly women with both knees categorized as the same classification (*valgus*, *varus* or normal). The asymmetric group had one knee classification different from the other. For this comparison, a Mann-Whitney test was used at the $p < 0.05$ significance level. The SPSS statistical software program (version 13.0 for Windows; SPSS, Chicago, IL, USA) was used for all statistical analyses.

## RESULTS

The characteristics of the studied sample are presented in Table 1 (data from all subjects and from each Q-angle group) and Table 2 (data from symmetric and asymmetric Q-angle groups). These data show high values of adiposity for the entire sample, as assessed by the BMI, fat percentage, and waist circumference.

The investigation into the relationship between knee and ankle angles and posture control variables was performed by using three approaches. First, a Spearman analysis showed statistically significant ($p < 0.05$) correlations between the Q-angle and the SDx (CBEO, $r = 0.31$), SDy (OBEO, $r = 0.28$; CBEO, $r = 0.34$; and CBEC, $r = 0.31$), RANGEy (OBEO, $r = 0.39$; and CBEO, $r = 0.38$) and Area (CBEO, $r = 0.36$). The flexion-extension knee angle showed a few weakly significant correlations with the SDy ($r = -0.36$), RANGEy ($r = -0.28$) and Area ($r = -0.29$), all of them during the OBEC trial. In contrast, the ankle angles did not show significant correlations with stabilometric variables.

After dividing the entire sample (second approach) with respect to the Q-angle groups (*varus*, n = 9; normal, n = 28; and *valgus,* n = 21), it was observed that *valgus* group showed higher values for most of the analyzed stabilometric variables. Statistical differences were verified for SDx (CBEO), SDy (CBEO), RANGEy (CBEO), and Area (CBEC), specifically between the extreme – *varus* and *valgus* – groups ($p < 0.017$; for each pair mentioned comparison the Bonferroni correction was applied: 0.05/3 = 0.017; Figure 2).

**Table 1.** Characteristics of the elderly women studied (N = 58)

| | All | Q-angle groups | | |
|---|---|---|---|---|
| Variable | | Varus | Normal | Valgus |
| Sample size (n, %) | 58 (100) | 9 (15.5) | 28 (48.3) | 21 (36.2) |
| Age (years) | 66 (61-72) | 65 (60-75) | 68 (62-72) | 66 (61-72) |
| Weight (kg) | 67.0 (58.7-79.0) | 70.0 (59.1-80.8) | 65.3 (58.3-86.8) | 67.5 (58.5-74.2) |
| BMI (kg/m²) | 27.9 (25.2-32.9) | 29.1 (25.3-36.1) | 27.3 (25.3-33.2) | 28.1 (24.9-32.1) |
| Overweight and obese | 48 (82.8) | 8 (88.9) | 24 (85.7) | 16 (76.2) |
| Fat percentage (%) | 44.1 (41.2-48.5) | 46.9 (40.4-51.0) | 44.0 (42.0-49.3) | 44.2 (40.6-47.7) |
| Obese – N (%) | 58 (100) | 9 (100) | 28 (100) | 21 (100) |
| Waist circumference (cm) | 89.0 (82.2-96.3) | 91.0 (85.0-102.5)292 | 89.0 (82.3-106.0) | 88.0 (81.9-90.8) |
| *High or very high risk – N (%)** | 48 (82.8) | 9 (100.0) | 22 (78.6) | 17 (81.0) |
| Months of UNATI program | 14 (6-24) | 10 (4-18) | 14 (5-24) | 14 (6-27) |
| Tt angle (º)** | 102 (100-104) | 102 (98-106) | 101 (100-103) | 102 (99-104) |
| St angle (º)** | 176 (174-180) | 177 (175-181) | 177 (174-180) | 175 (174-176) |
| F-E angle (º)** | 184 (181-187) | 185 (181-191) | 184 (180-185) | 183 (181-189) |
| Q-angle (º)** | 13 (10-15) | 7 (5-9)# | 13 (11-13)# | 16 (15-18)# |

Values are expressed as the median (1st-3rd quartile) for numerical variables and absolute number (percentage) for categorical variables. BMI = body mass index; F-E = flexion-extension angle; St = subtalar angle; Tt = tibiotarsal angle. *Risk for obesity-associated metabolic complications. **Mean value of the left and right sides # $p < 0.001$ when comparing Q-angle groups (Kruskal-Wallis test)

**Table 2.** Characteristics of Q-angle bilateral symmetry groups

| | Q-angle bilateral symmetry | |
|---|---|---|
| Variable | Symmetric | Asymmetric |
| Sample size (n, %) | 30 (51.7) | 28 (48.3) |
| Age (years) | 66 (61-72) | 66 (61-72) |
| Weight (kg) | 67.3 (58.8-80.3) | 66.3 (58.2-74.4) |
| BMI (kg/m²) | 28.8 (25.4-33.2) | 27.3 (25.1-32.7) |
| Overweight and Obese | 26 (86.7) | 22 (78.6) |
| Fat percentage (%) | 45.0 (41.6-48.6) | 43.9 (40.5-48.0) |
| Obese – N (%) | 30 (100) | 28 (100) |
| Waist circumference (cm) | 89.0 (82.9-96.8) | 84.0 (80.5-96.5) |
| High of very high risk – N (%)* | 27 (90.0) | 21 (75.0) |
| Months of UNATI program | 13 (3-23) | 15 (9-24) |
| Tt angle (º)** | 102 (100-104) | 102 (99-104) |
| St angle (º)** | 176 (175-181) | 175 (173-178) |
| F-E angle (º)** | 184 (181-188) | 183 (180-186) |
| Q-angle (º)** | 13 (11-17) | 13 (10-15) |

Values are expressed as the median (1st-3rd quartile) for numerical variables and absolute number (percentage) for categorical variables. BMI = body mass index; F-E = flexion-extension angle; St = subtalar angle; Tt = tibiotarsal angle. *Risk for obesity-associated metabolic complications (WHO, 1998). ** Mean value of the left and right sides. $p > 0.05$ for all analyses that compare Q-angle bilateral symmetry groups (no difference between groups).

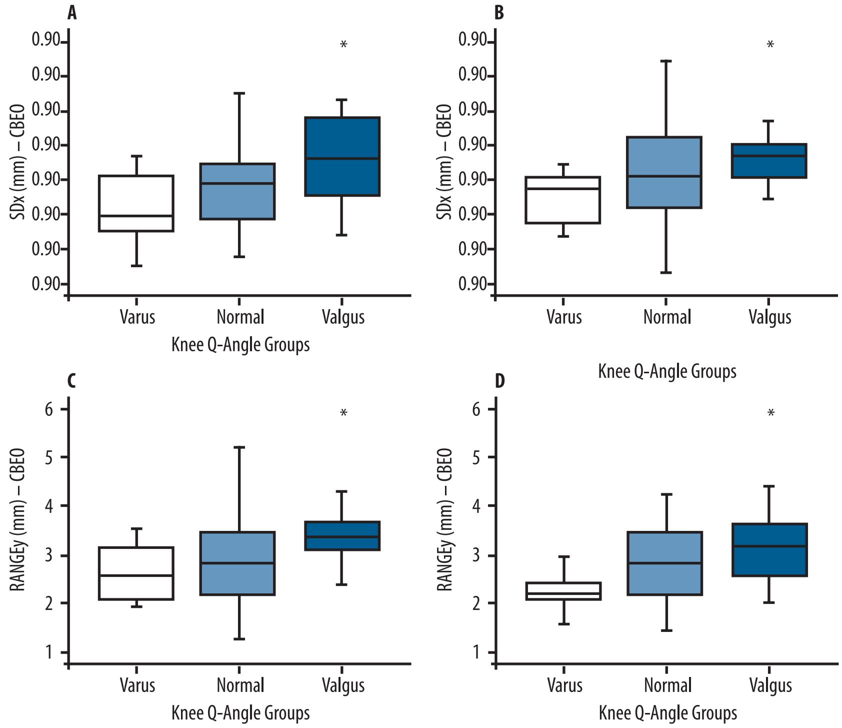


**Figure 2.** Box plots (median, 1st and 3rd quartiles, minimum and maximum) showing the body sway of elderly women classified as varus, normal, and valgus (knee Q-angle) during CBEO (2.A, 2.B, and 2.C) and CBEC trials (2.D). (A) Standard deviation of the CP values in the lateral direction (SDx); (B) Standard deviation of the CP values in the anteroposterior direction (SDy); (C) Range of the CP displacement in the anteroposterior direction (RANGEy); (D) Area of the CP displacement (Area). * $p < 0.017$ comparing varus versus valgus (Mann-Whitney test after Kruskal-Wallis).

The analysis of the Q-angle symmetry (third approach) revealed that the CP mean displacement velocity was higher for the asymmetric group (n = 28) than the symmetric group (n = 30) for both closed base trials (Figure 3). No significant difference was found for the open base trials.

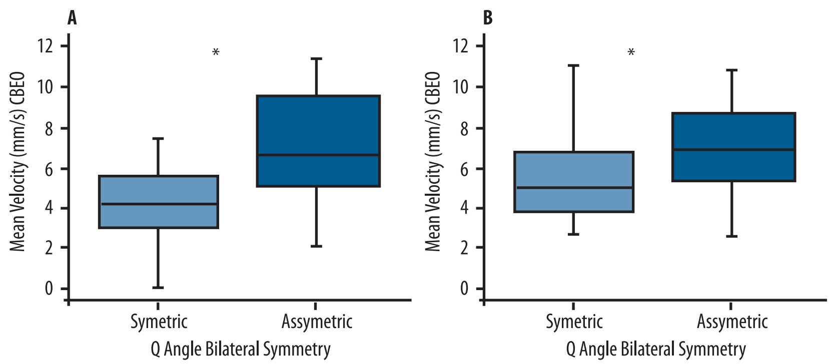


**Figure 3.** Box plots (median, 1st and 3rd quartiles, minimum and maximum) showing the mean velocity of the CP of elderly women with symmetric or asymmetric knee Q-angles. (A) During the closed base, eyes opened trial (CBEO); (B) During the closed base, eyes closed trial (CBEC). * $p < 0.05$ (Mann-Whitney test).

## DISCUSSION

The present results showed that high knee Q-angles are correlated with increased body sway. Subjects with *genu valgus* showed higher stabilometric variable values than those with *genu varus*. Furthermore, upon analyzing both knees of each participant, an asymmetric knee alignment was also associated with a greater oscillation. These findings highlight the importance of regular assessments of lower limb alignment (particularly of knee angles), especially for elderly people, who frequently suffer from instability complaints and falls. Health professionals should concentrate their preventive approaches on Q-angle and joint alignment to minimize balance disorder manifestations.

The flexion-extension angle and Q-angle of the elderly women showed a large number of correlations with the analyzed stabilometric parameters. The flexion-extension angle has not been studied as often as the Q-angle. Previous studies[14,24,25] revealed the mean flexion-extension angle values that classified the knees of the participants as *genu recurvatum*, as in the present study. The correlations observed between the flexion-extension angle and the stabilometric variables were weak, therefore it is not likely that the knee alignment in the sagittal plane influence body sway. The Q-angle has already been extensively explored in the literature[15,16,26]. Normal values for this angle range from 10º to 14º [22,23], but research has not focused on the relationship between this angle and body sway. The present study focused on the elderly because they usually show standing instability. The relationship between joint alignment and body balance is of greater importance to this population, so every effort should be made to screen those who are more unstable and prone to falling. It is important to notice that the presented coefficients do not characterize strong correlations for Q-Angle analysis. They were mainly weak and regular ones[27]. In fact, as posture control depends on a great number of factors, a simple bivariate correlation would rarely present a strong or very strong correlation. This motivated the other approaches performed in this research into Q-Angle.

When the entire sample was divided into *varus*, *valgus,* and normal groups, the *varus* group showed the lowest number of participants. The younger sample studied by Ferreira et al.[13] also had the lowest prevalence (22.6%) in the *varus* group. These researchers revealed that the *varus* knee group showed a lower CP mean velocity than the neutral and *valgus* knee groups. Differences in mean velocity were not found in our sample between the Q-angle groups. Nevertheless, the present results show that area, anteroposterior standard deviation, lateral standard deviation and anteroposterior range were significantly different between groups, which was not observed in the younger sample studied by Ferreira et al.[13] As expected, the stabilometric variables were more sensitive during the closed base conditions. Melzer et al.[28] stated that testing individuals in a wide-base stance is insensitive to balance function, allowing subjects to compensate. Under the narrow stance, the task becomes more challenging and a more rigid control must be exerted by the postural system. This helps explain why significant differences were observed only for closed base trials.

Livingston and Mandigo[26] reported that almost half of the individuals studied by them demonstrated a difference of at least 4º between the right and left Q-angles. The present results show that asymmetry resulted in greater mean velocity values during both closed base conditions. No other study has, to the authors' knowledge, investigated the relationship between Q-angle asymmetry and stabilometric variables during the quiet stance.

In the present sample, the tibiotarsal and subtalar angles showed no relevant correlation with the CP variables for most conditions. Ferreira *et al.*[13], analyzing young adults, also found no association between stabilometric variables and subtalar alignment. In another study exploring the relationship between foot features and stabilometric variables[11], it was found that maximum foot width, base-of-support area and foot opening angle were relevant biomechanical factors that influenced lateral direction stabilometric variables. Menz et al.[12] observed that ankle flexibility, plantar tactile sensitivity, and toe plantarflexor strength were associated with body sway. The same group of researchers, comparing fallers and nonfallers, found similar values for foot posture index, arch index, and navicular height, but not for ankle flexibility, presence of hallux valgus deformity, tactile sensitivity, toe plantar flexor strength and foot pain. Therefore, while ankle angle measures do not appear to be an important factor in risk for falls, the evaluation of anthropometric and morphological characteristics in elderly people should still be considered when assessing possible risk factors for falls.

The correlations and differences found in the present study corroborate the influence of somatosensory information on postural control and suggest the possible effects of structural morphological changes due to joint aging. Horlings et al.[29] state that it is generally assumed that lower limbs proprioception provides the main contribution to posture control. Ankle and knee morphological differences will provide different inputs to the central nervous systems, so it is reasonable that motor adjustments to a good posture control will also be different, reflecting CP variables. If we extrapolate the present results about the relationship between the Q-angle and posture control to a health professional's practice, it is expected that the higher the Q-angle, the higher the body sway when an assessment is performed with only one angle value. If one assessment is performed for the two limbs showing asymmetry, it also seems that this fact will influence body sway.

The present study has some limitations. First, it is a cross-sectional study, and no cause-consequence inference can be drawn from the observed associations. Another aspect that could be questioned is that the expert examiner who performed all the assessments was not tested for her inter-rater reliability. Because the examiner has worked for a long time with these measurements, we do not believe that this fact would significantly influence the observed results. Furthermore, the subjects were recruited from the UNATI program (convenience sample) and the results may not be generalized to all Brazilian elderly women.

## CONCLUSIONS

In the present study, knee alignment was associated with posture control in elderly Brazilian women. This was principally evident by the higher stabilometric variable values obtained for the *valgus* and asymmetric Q-angle groups. Conversely, ankle alignment showed no correlation with stabilometric variables.

### Acknowledgments

The authors are grateful to all the elderly women who participated in the present study. We would also like to thank UNATI manager Rose Cristina Soares, and physiotherapist Maria Madalena da Costa Glinardello, for their contribution inviting volunteers.

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