

Analysis of Gait Pattern in Women with Knee Osteoarthritis by Angular Kinematics

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Abstract

Contextualization: Osteoarthritis (OA) is the most common cause of musculoskeletal pain and knee joint deficiency. It is characterized by the progressive destruction of articular cartilage. Changes resulting from OA in the extra-articular, intra-articular structures and common deformities cause several gait disorders in these patients. These changes include changes in step velocity, step frequency and step length.

Aim: To evaluate gait patterns by angular kinematics of lower limbs and trunk in the various gait phases of patients with knee OA.

Methods: A cross-sectional study was carried out with 48 female subjects aged 55.92 ± 8.08 years, being 19 healthy subjects and 19 subjects with knee OA (grade I-III, according to Kellgren-Lawrence classification). Evaluations included comparison of gait parameters between OA and non-OA patients, step and stride length, hip, knee and ankle joint amplitude measurements in the different phases of gait, functional gait outcomes of the 6-minute walk test and functional gait outcomes of the Timed "Up and Go" test, correlating gait parameters of subjects with OA to its degree of evolution.

Results: The OA group presented a significantly longer time in the Timed "Up and Go" test compared to the control group ($p = 0.004$). Analyzing the results of balance and coordination through the six-minute walk test, the subjects of the OA group walked a distance significantly less than that covered by the control group ($p = 0.016$). The step length evaluation showed a significant difference between the control group and the OA group ($p = 0.05$). Subjects with knee OA had a greater hip flexion than healthy subjects in the heel strike phase ($p < 0.05$) and in the double stance phase ($p < 0.05$). Subjects with knee OA had a knee extension deficit during the heel strike and midstance phases ($p < 0.05$). There was a greater ankle plantar flexion in the OA group in the heel strike and double stance phases ($p < 0.05$). No differences were found between the groups in any of the gait phases regarding the left ankle.

Conclusion: We conclude that knee OA leads to gait changes and muscular compensations in patients with knee OA.

Keywords: Knee Osteoarthritis; Gait; Photogrammetry; Postural Balance, Muscle Strength

Abbreviations

OA: Osteoarthritis; FICT: Free and Informed Consent Term; ASIS: Anterosuperior Iliac Spine; ATT: Anterior Tibial Tuberosity; TUG: Timed "Up & Go"; 6MWT: 6-Minute Walk Test; BMI: Body Mass Index; NMES: Neuromuscular Electrical Stimulation; ROM: Range of Motion

Introduction

Osteoarthritis (OA) is the most common cause of musculoskeletal pain and knee joint deficiency, being characterized by the progressive destruction of articular cartilage [1-2]. It has been suggested that the development and progression of the disease may be related to

atypical joint kinematics during gait [1]. Knee OA is a prevalent condition that affects more than 11.5% of adults worldwide³. Women have a two to three times greater risk of developing knee OA compared to men [1].

Few studies have investigated gait changes in patients with knee OA compared to control subjects [1]. Changes resulting from OA in the extra-articular, intra-articular structures and common deformities cause several gait disorders in these patients [4]. There is evidence that patients with knee OA have significant changes in knee joint amplitude during the various phases of gait [1]. Other changes include changes in step velocity, step frequency and step length [5]. Associated with this, kinetic changes occur in patients with knee OA, such as increased hip adduction and decreased knee extension and internal rotation [2-6].

Patients with knee OA also demonstrate a decrease in muscle strength of approximately 20% in hip abductors and an even greater deficit in the isometric and isokinetic strength of hip external rotators compared to healthy subjects [8]. Sang-Kyoon, *et al.* concluded that patients with knee OA showed decreased external hip rotation, knee extension and ankle inversion strength, as well as an increased dynamic knee valgus during gait [9].

Therefore, the aim of this study was to evaluate and quantify the angular changes produced in the joints of lower limbs and trunk in the various phases of gait of patients with knee OA.

Methods

A cross-sectional study was carried out with 48 female subjects aged 55.92 ± 8.08 years, being 19 healthy subjects and 19 subjects with knee OA (grades I-III, according to Kellgren-Lawrence classification). The study was approved by the Ethics and Research Committee of the Universidade Luterana do Brasil under opinion No. 1.378.387 and carried out at the Clinical School of Physiotherapy of ULBRA - Torres Campus, from March to November 2016.

To reach this sample size, the variable "gait speed" was used as the primary outcome of the study and, based on the study by Sagawa Jr Y, *et al.* (2013) [10], we estimated the mean and standard deviation of the variation in knee flexion in subjects with severe OA as 46.57 ± 8.55 ; and the mean and standard deviation of the variation in knee flexion in control subjects as 54.28 ± 4.27 post intervention. With a study strength of 80%, a significance level of 95% and a sample size ratio of 1:1 (intervention group:control group), the estimated number of 14 subjects for each intervention group was reached. Believing that the losses and refusals would be around 30%, we reached the final number of 19 healthy subjects and 19 subjects with OA, totaling 38 subjects.

Women aged between 40 and 75 years, both healthy and ambulatory with unilateral or bilateral knee OA (grade I-III, according to the radiological classification of Kellgren-Lawrence [11]), were included.

The following subjects were excluded from the study: women with grade IV knee osteoarthritis according to Kellgren-Lawrence radiological classification, as confirmed by an orthopedic surgeon; non-ambulatory; with neurological diseases leading to cognitive deficits; with psychiatric disorder; with symptomatic heart disease; patients with clinical manifestations making it impossible to perform the tests; with previous history of corticoid infiltration in knee joints or use of viscosupplementation in the last three months; with history of knee trauma or surgery in the last six months; and making use of some type of anti-inflammatory and/or analgesic medication during the study period.

Initially, all eligible subjects were invited to participate in the study. They were then oriented on the objectives and methodologies of the study. Participants signed the Free and Informed Consent Term (FICT). After signing the term, all subjects were evaluated.

The evaluation began with the anthropometric analysis of the sample.

Angular gait analysis was performed by computerized bio-photogrammetry. Spherical white self-adhesive markers (13 mm in diameter) were placed in anatomical bone points. The markers were placed on the acromion (anterior, medial and posterior), anterosuperior

iliac spines (ASIS), posterosuperior iliac spines, major trochanter of the femur, lateral condyle of the femur, anterior tibial tuberosity (ATT), lateral malleolus of the fibula and head of the fifth metatarsal.

Image collection was performed using two Sony® digital camcorders (20.1 megapixels) with a photographic tripod at a height of 80 cm from the ground, positioned 2 meters away from a five-meter path where the subjects deambulated. The camcorders were positioned in the midline beside and in front of the path.

For this step and stride evaluation, participants deambulated on a brown paper walkway (10 m x 0.6 m) with their feet painted with gouache to mark the plantar region. After this procedure, the analysis of the parameters of step and stride was performed taking into account all phases of the gait. Step length was obtained by the distance in centimeters from the calcaneus of one foot to the calcaneus of the opposite foot. Stride length was obtained by the posterior perpendicular distance from the heel of one foot to the posterior end of the same heel. These measurements were obtained using a tape measure.

The study participants were filmed in the frontal (anterior and posterior) and lateral (right and left) planes during gait. The distance to be covered was 10 meters, where the first and last meters were disregarded in order to disregard acceleration and deceleration values. From the dynamic images collected, the videos were edited in Movie Maker® software. The dynamic images were transformed into static images (frames) at the initial moment of each phase of the gait. Afterwards, the frames were transferred to Corel Draw X6®, where angular analyses were performed (Table 1).

Analysis Plan	Measured angle	Anatomical Points Of Reference
Front	Lateral trunk tilt angle	Right Anterior Acromion x Left Anterior Acromion x Orthogonal Horizontal Axis
	Lateral pelvic tilt angle	Right Asis x Left Anterior Asis x Orthogonal Horizontal Axis
	Angle of knee valgus/varus	Asis x Att x Orthogonal Vertical Plane
Side	Compensatory trunk bending angle	Lateral Acromion X Greater Tuberosity Of The Femur x Orthogonal Vertical Plane
	Angle of movement of hip, knee and ankle	Hip - Greater Tuberosity x Orthogonal Vertical Plane Knee - Greater Tuberosity x Lateral Condyle x Lateral Malleolus Ankle - Lateral Condyle x Lateral Malleolus x Head Of 5 th Metatarsal

Table 1: Angular analyses performed on frontal and sagittal planes.

ASIS: Anterosuperior Iliac Spine; ATT: Anterior Tibial Tuberosity

Step and stride lengths were measured. The participant was asked to deambulate on a brown paper walkway (10 m x 0.6 m) fixed to the ground with crepe tape so there were no slides during the procedure. At the beginning of the path, the feet were painted with gouache. Then, the patient was asked to deambulate on brown paper. Step and stride lengths were obtained at the same gait phase, and the phase showing the lowest distance was collected.

For functional analysis, the six-minute walk test (6MWT) and the Timed “Up & Go” test (TUG) were used.

SPSS (Statistical Package for the Social Sciences) version 17.0 was used as database and statistical package. Data were double-typed in order to avoid typing errors and expressed as mean and standard deviation. Subsequently, they were analyzed statistically by unpaired parametric tests (Student’s t-tests) to analyze the variables between the groups. For non-parametric variables, Mann-Whitney test was used between the groups. For the correlation between degree of development of OA and step and stride length, Pearson’s correlation test was used. The significance level established for the statistical test was $p < 0.05$.

Results

We present the results of a cross-sectional study with 38 women, being 19 knee OA patients, aged 52.30 ± 17.13 years and 19 healthy women, aged 50.58 ± 6.10 years. 63.2% of women had knee OA classified as grade II on the Kellgren-Lawrence radiological scale. 57.9% presented OA in both knees. Women with knee OA consumed significantly more cigarettes than the control group. The groups were homogeneous regarding anthropometric characteristics, skin color and occupation (Table 2).

Variable	ControlGroup (n = 19)	Osteoarthritis Group (n = 19)	P value
Age, years (mean \pm SD) [§]	50.58 \pm 6.10	52.30 \pm 17.13	0.165
Skin color, n (%) [#]			0.311
White	19 (100.0)	18 (94.7)	
Black	0 (0.0)	1 (5.3)	
Occupation, n (%) [#]			0.210
Housewife	7 (36.8)	4 (21.1)	
Professor	3 (15.8)	1 (5.3)	
Merchant	2 (10.5)	1 (5.3)	
Retired	2 (10.5)	9 (47.4)	
Others	5 (26.4)	4 (20.9)	
Time of pain, years (mean \pm SD) [§]	-	5.26 \pm 4.21	-
Kellgren-Lawrence, n (%) [#]			-
Grade I	-	2 (10.5)	
Grade II	-	12 (63.2)	
Grade III	-	5 (26.3)	
AffectedKnee, n (%) [#]			-
Right	-	4 (21.1)	
Left	-	4 (21.1)	
Both	-	11 (57.9)	
Smoking, n (%) [#]			0.034
Yes	0 (0.0)	4 (21.1)	
No	19 (100.0)	15 (78.9)	
Weight, kg (mean \pm SD) [§]	66.90 \pm 11.96	73.18 \pm 14.69	0.157
Height, cm (mean \pm SD) [§]	157.92 \pm 5.87	157.36 \pm 6.43	0.411
BMI, kg/cm ² (mean \pm SD) [§]	26.78 \pm 4.29	29.76 \pm 6.49	0.105

Table 2: Characterization of the study sample (n = 38).

Chi-square test; § Student's t test

Angle analysis of the right hip showed significant differences between the groups in the heel strike and double stance phases. In the heel strike phase, the control group presented a hip flexion of 19.47 ± 4.13 degrees, while the OA group presented a hip flexion of 23.29 ± 4.26 degrees ($p=0.008$). In the double stance phase, the right hip of the control group presented a flexion of 16.17 ± 6.12 degrees, while the OA group showed a flexion of 20.41 ± 4.75 degrees ($p = 0.023$). The other phases did not present significant differences (Figure 1).

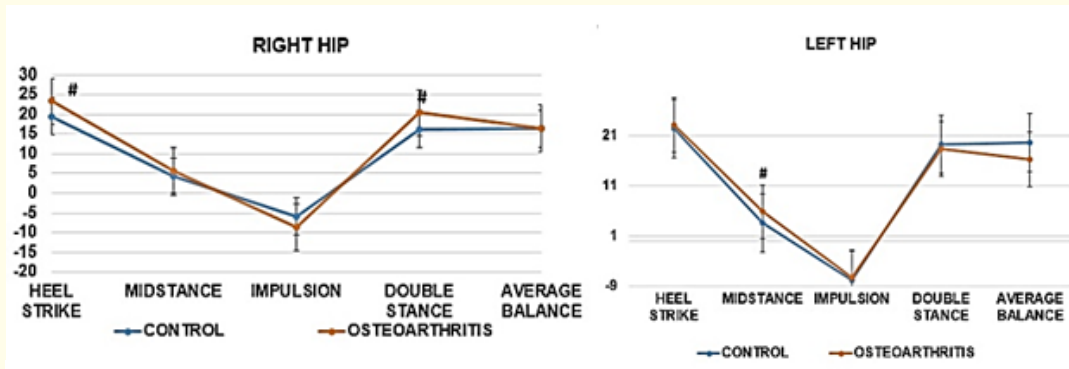


Figure 1: Hip angle analysis in the various gait phases.

$p < 0.05$ in relation to the control group. Student's *t* test.

Angle analysis of the left hip showed significant difference only in the midstance phase. The OA group had significantly greater hip flexion than the control group. The left hip flexion of the control group was 3.66 ± 2.55 degrees, while the OA group showed a flexion of 5.82 ± 3.65 degrees ($p = 0.041$) (Figure 2).

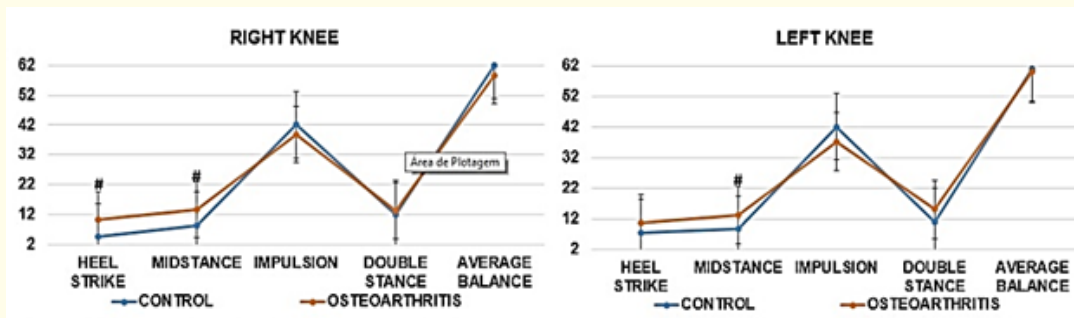


Figure 2: Knee angle analysis in the various gait phases.

$p < 0.05$ in relation to the control group. Student's *t* test.

In the angle analysis of the right knee, the heel strike and midstance phases showed significant differences between the groups. In the heel strike phase, the control group presented a knee flexion of 4.60 ± 4.88 degrees while the OA group presented flexion of 10.32 ± 7.44 degrees ($p = 0.009$). In the midstance phase, the control group presented knee flexion of 8.51 ± 6.52 degrees, while the OA group presented a semiflexion of 13.77 ± 8.16 degrees ($p = 0.035$) (Figure 3).

Angle analysis of the left knee demonstrated a significant difference between the groups only in the midstance phase. Subjects in the control group presented a flexion of 8.81 ± 5.36 degrees, while subjects with OA presented a flexion of 13.3 ± 6.52 degrees ($p = 0.026$).

There was an angular difference between the study groups regarding the angle analysis of the right ankle in the heel strike and double stance phases. In the heel strike phase, the control group presented a plantar flexion angle of 7.98 ± 5.46 degrees, while the OA group presented 13.2 ± 8.2 degrees of ankle plantar flexion ($p=0.009$). In the double stance phase with lower limb support, the control group performed an ankle plantar flexion of 12.10 ± 6.32 degrees, while the OA group performed 17.24 ± 6.24 degrees of flexion ($p = 0.016$).

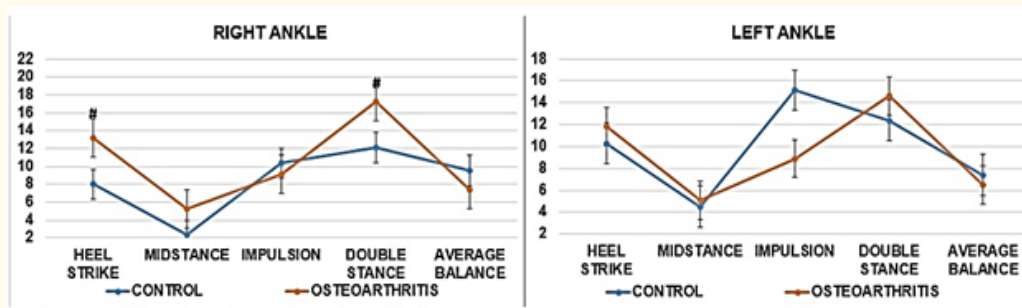


Figure 3: Ankle angle analysis in the various gait phases.
$p < 0.05$ in relation to the control group. Student's *t* test.

No differences were found between the groups in any of the gait phases regarding the left ankle.

There were no significant differences between the groups regarding trunk and pelvis angles, valgus angle and trunk flexion angle, both with right lower limb and left lower limb support (Table 3).

Variable	Control Group (n = 19)	Osteoarthritis Group (n = 19)	p value
Trunk tilt angle, degrees (mean ± SD)			
RLLsupport	2.70 ± 1.68	2.68 ± 1.76	0.966
LLLsupport	3.30 ± 1.64	2.59 ± 1.33	0.172
Pelvic tilt angle, degrees (mean ± SD)			
RLL support	2.63 ± 1.43	2.75 ± 1.75	0.831
LLL support	3.22 ± 2.05	2.81 ± 1.69	0.527
Maximum valgus angle, degrees (mean ± SD)			
RLL support	7.69 ± 1.83	6.85 ± 2.83	0.291
LLL support	6.82 ± 2.78	6.79 ± 2.66	0.976
Trunk flexion angle, degrees (mean ± SD)			
RLL support	4.87 ± 1.81	4.90 ± 2.90	0.964
LLL support	14.55 ± 25.99	6.24 ± 3.74	0.184

Table 3: Trunk angle analysis, pelvic angle analysis and valgus measurements in the study groups (n = 38).

RLL: Right lower limb; LLL: left lower lim.

The OA group presented a significantly longer Timed “Up & Go” test compared to the control group. The control group performed the Timed “Up & Go” test in 7.94 ± 1.12 seconds, while the OA group performed the test in 10.04 ± 2.65 seconds ($p = 0.004$) (Figure 4).

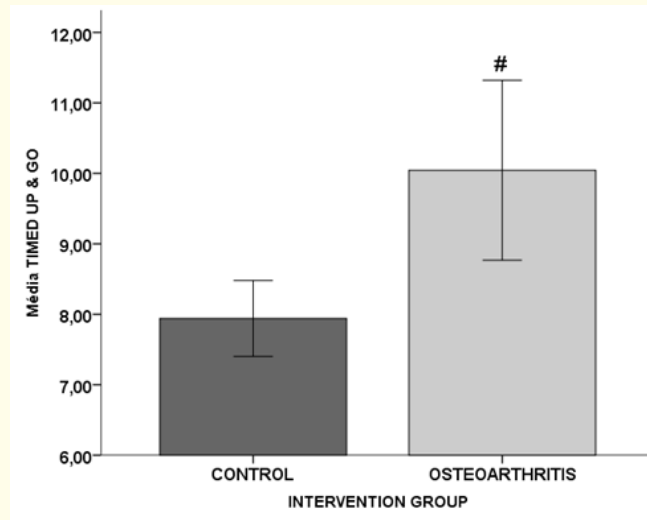


Figure 4: Timed “Up & Go” test results in the study groups (n = 38).
p < 0.0; Student’s t test.

Analyzing the results of balance and coordination through the six-minute walk test, subjects from the OA group walked a distance significantly less than the distance covered by the control group. The control group covered the distance of 374.9 ± 62.42 meters, while the OA group covered the distance of 322.95 ± 63.96 meters ($p = 0.016$) (Figure 5).

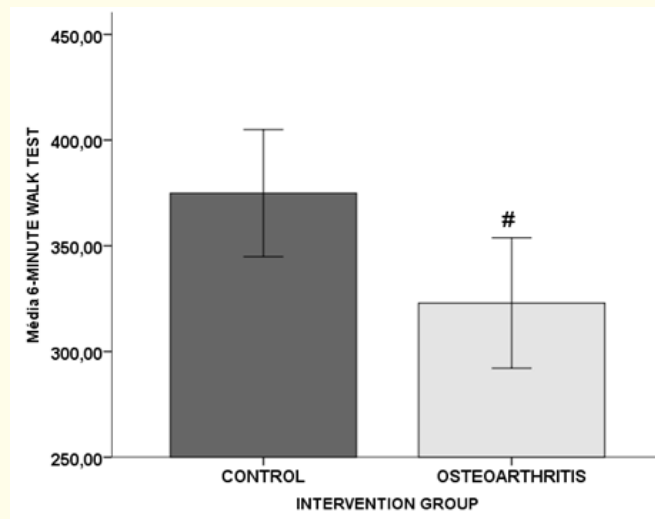


Figure 5: Results of the 6-Minute Walk Test in the study groups (n=38).
p<0.05; Student’s t test.

An inverse significant correlation was found between the classification presented on the Kellgren-Lawrence radiological scale and the step length. As the degree of OA progression increased, there was a significant decrease in step length ($p = 0.05$) (Figure 6).

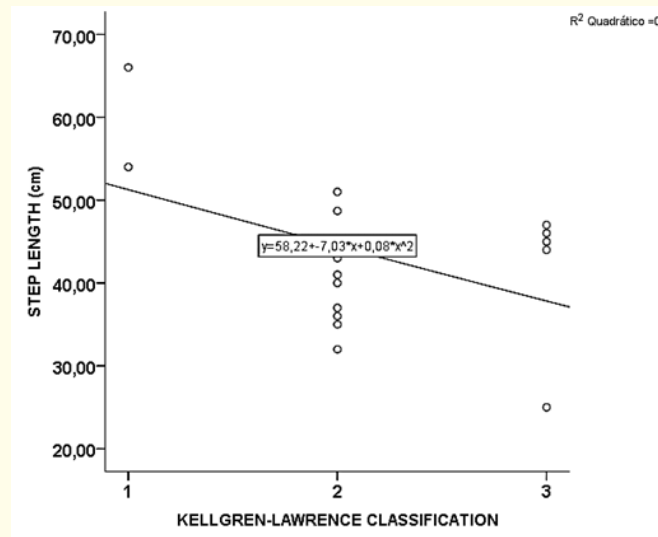


Figure 6: Analysis of the correlation between step length and the Kellgren-Lawrence classification in the osteoarthritis group ($p < 0.05$). Pearson's correlation.

Step length evaluation showed a significant difference between the control group and the OA group. While the control group had a step length of 47.53 ± 4.56 centimeters, the OA group had a step length of 43.43 ± 8.8 centimeters ($p = 0.003$).

Analyzing the stride length of subjects with OA in relation to the Kellgren-Lawrence radiological classification, an inverse significant correlation was found. As the degree of OA progression increased, there was a significant decrease in stride length ($p=0.009$) (Figure 7).

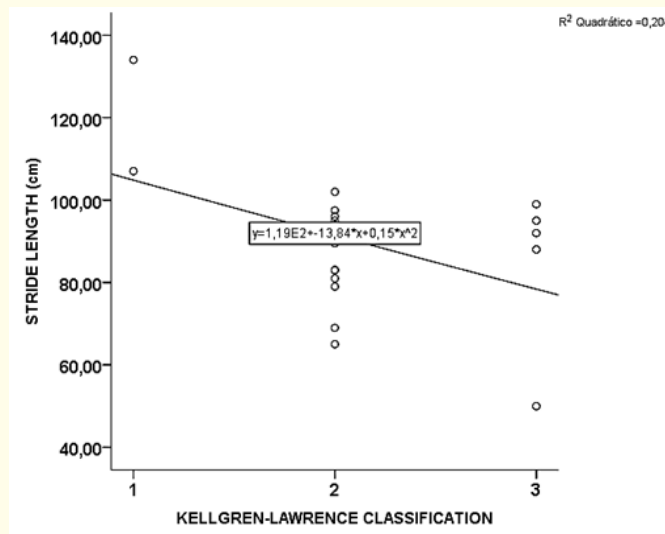


Figure 7: Analysis of the correlation between stride length and the Kellgren-Lawrence classification in the osteoarthritis group ($p < 0.05$). Pearson's correlation.

The control group had a significantly greater stride length compared to the OA group. The control group had a 95.52 ± 8.73 cm stride length, while the OA group presented a 89.42 ± 17.6 cm stride length ($p = 0.019$).

Discussion

In this study, we sought to evaluate the gait parameters of women with knee OA compared to healthy women without OA. The study refers to a sample of 38 patients with a mean age of 55.92 ± 8.08 years. Both groups were homogeneous regarding anthropometric characteristics, skin color and occupation.

Step length was significantly lower in the OA group. It was found that women with greater degree of joint damage, assessed through the Kellgren-Lawrence radiological scale, demonstrated significantly smaller step length. Turcot, *et al.* conducted a study with 86 participants, of whom 60 had severe OA, divided into 46 with knee varus and 14 with knee valgus, and 26 were healthy subjects. Subjects with knee varus presented a significant decrease in step length in relation to the varus group and the control group [12]. Kiss, *et al.* reported that patients with knee OA have a decrease in the amplitude of angular parameters on the affected side, which leads to a decrease in the consistency of lower limbs movements, with a decrease in step and stride length [13].

Regarding stride length, the OA group presented a significantly smaller length in relation to the control group. It was verified in the OA group that the greater the evolution of joint damage, assessed through the Kellgren-Lawrence radiological scale, the smaller the stride length. Kirkwood, *et al.* [14] evaluated 78 women, being 38 elderly (69.6 ± 8.1 years) with knee OA and 40 asymptomatic women of the same age group. As in our study, they found a significant difference in stride length between the groups, and the OA group presented significantly lower values. Arantes, *et al.* [15] also found a significant decrease in the OA group compared to a control group. Astephen, *et al.* carried out a study with 91 people of both sexes, being 30 healthy people (control group), 30 people with moderate knee OA and 31 with severe OA. The study compared the stride length between the groups. It has been shown that subjects of the severe OA group demonstrated a significantly lower stride length than those of the moderate OA group and control group [16]. Serkan, *et al.* [2] also compared the stride length in the different phases of OA and, as in our study, found a significant difference between the results, from 1.13 ± 0.10 in the control group to 0.99 ± 0.18 in the group with OA classified as grade III by the Kellgren-Lawrence scale.

The OA group presented a significantly longer time in the TUG compared to the control group. Analyzing the results of balance and coordination through the 6MWT, subjects in the OA group covered a distance significantly less than that covered by the control group. Unlike our results, Mattos, *et al.* [17] performed a study with 33 subjects, being 15 patients with OA and 18 asymptomatic patients. No significant differences were found for TUG between the groups. Laufer, *et al.* [18] carried out a study with 63 elderly patients with osteoarthritis, where the participants were divided into two groups: exercise group and exercise + NMES group. Both groups performed an initial evaluation containing the TUG test. The authors obtained the value of 13 seconds in the exercise group and 12.9 seconds in the exercise + NMES group. Differently from this finding, our study obtained a value of 10.04 ± 2.65 . Neto, *et al.* [19] carried out a study with 35 elderly patients diagnosed with knee OA, where the participants were divided into two groups: obese and non-obese. The study compared the results of TUG and 6MWT between the groups [19]. The result showed that non-obese subjects performed the TUG in a shorter time and walked a greater distance in the 6MWT [19]. Regarding the 6MWT, in our study, healthy women covered a distance of 374.9 ± 62.42 meters. Alves, *et al.* in their study, evaluated 33 healthy women and 10 healthy men with a mean age of 64 years and observed, in the women group, the value of 530 ± 79 meters [20].

No significant differences were found in the values of knee valgus/varus in the studied sample. Silva, *et al.* evaluated 21 individuals diagnosed with OA of the medial compartment of the knee compared to 16 people in the control group. The peaks of the dynamic varus angle of subjects with OA were higher than in the control. These OA patients presented a four times higher knee adduction (varus) compared to the control group, which presented a discrete dynamic varus. This reinforces the precept that individuals with varus malalignment have high degrees of dynamic varus related to high peak knee adduction moment values [21]. The literature shows that both normal individuals and, mainly, individuals with medial knee OA with varus alignment tend to go into knee adduction; however, the intensity is about three times higher for individuals with the pathology [22].

In this study, the gait phases that presented higher angular impairment in the OA group were the heel strike, midstance and double stance phases. OA women had significantly higher hip and knee flexion angles than healthy women. Arantes, *et al.* [14], in a comparative study between elderly women with OA and the control group, concluded that the elderly women in the OA group deambulated with a significantly lower hip extension ROM in the stance period compared to the asymptomatic subjects, corroborating our findings in the stance and double stance phases. The study also reports that the decrease in hip ROM during the stance phase of gait of elderly women with knee OA indicates that gait changes in these women are not limited to the knee joint. Weidow, *et al.* [23] evaluated two groups of elderly with OA, being one group with OA of the medial compartment and another with lateral compartment disease. The two groups of patients showed decreased hip extension, and this decrease was more pronounced in OA of the lateral femorotibial compartment.

Regarding knee angle analysis, significant differences were found in the heel strike and midstance phases. Silva, *et al.* found that, in the sagittal plane, the OA group presented a higher flexor moment in relation to the control group. This pattern, of lower variation in flexion-extension values, represents the start of the joint stiffness pattern. This stiffness shows a tendency of the affected knee to continue more in flexion, characterized mainly by the higher flexor peaks of the OA group in the stance phase [21]. This tendency toward rigidity and flexed gait is also represented by the decrease in gait speed and the change of the loading axis from the frontal plane to the sagittal plane. This is characterized by the highest flexor peak moment, increasing the tendency to a flexed gait, which produces a kinetic adaptation with transfer of part of the load from the frontal plane to the sagittal plane [23]. Evidence has shown that patients with OA exhibit small knee extensor moment and that gait speed affects more the moments in the sagittal plane [19]. Knee flexion in OA is greater, that is, the knee is less extended compared to healthy individuals, and this parameter shows higher values in more advanced degrees of OA compared to patients with moderate OA [24-25]. Kirkwood, *et al.* [14] evaluated two groups of elderly women, one with women with OA and another with healthy women, and observed that between the midstance (30 and 50% of the cycle) and swing (60 and 80 % of the cycle) phases, the OA group had lower angular values in relation to the asymptomatic group. Differing from these findings, we did not find significant differences between the groups in the midswing phase. Arantes, *et al.* [15] evaluated muscle activation in OA and asymptomatic elderly women. The elderly women with knee OA had no significant difference in the intensity of activation of the quadriceps, femoral biceps, anteriortibial, gastrocnemius and soleus muscles during gait when compared to the asymptomatic elderly women. The authors suggest that gait changes can occur without strength decrease; not with standing, unlike our findings, they did not find significant differences in the midstance phase.

In our study, it was found that women with OA presented a greater plantar flexion than healthy women in the heel strike and double stance phases. Arantes, *et al.* did not find, in their study, a significant difference in ankle joint ROM between OA and asymptomatic elderly women. Ankle kinematics do not appear to be involved in compensatory changes in the gait of elderly women with knee OA [15]. Farrokhi, *et al.* [26] compared two groups of elderly with OA, divided according to their knee joint stability (unstable and stable). The study assessed the gait characteristics of the subjects. The authors concluded that the unstable knee group also walked with significantly lesser activation of the ankle plantar flexors during the initial knee extension phase of gait compared to subjects with good knee stability.

Conclusion

The results suggest that knee OA causes different changes in gait, such as decreased step and stride length (especially as the disease levels increase, as assessed by Kellgren-Lawrence grading), increased TUG time, and decreased 6MWT walking distance in relation to the control group. However, we did not find significant differences between valgus/varus between the groups.

Knee OA also causes angular changes in gait, not only in the knee, but in the hip and ankle. The changes were significant in the different stance phases.

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