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ORIGINAL ARTICLE

Three-dimensional kinematics of the trunk, pelvis, hip, and knee during the single-leg squat and hip torque in subjects with isolated patellofemoral osteoarthritis compared to individually matched controls: Preliminary results

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ABSTRACT

Objectives: This study aimed to compare three-dimensional kinematic of the trunk, pelvis, hip, and knee during the single-leg squat and hip torque in individuals with and without isolated patellofemoral osteoarthritis (PFOA).

Patients and methods: This cross-sectional study evaluated trunk, pelvis, hip, and knee kinematics at 30°, 45°, and 60° knee flexion during the single-leg squat using the Vicon motion capture and analysis system, the Nexus System 2.1.1, and 3D Motion Monitor software. Sixteen individuals (8 males, 8 females; mean age: 49.3±6.2 years; range 40 to 61 years) participated in the study, of which eight were PFOA patients and eight were healthy controls. Isometric hip abductor, extensor, and external rotator torques were evaluated using a handheld dynamometer.

Results: The PFOA group exhibited greater hip adduction at 30° ($p=0.008$), 45° ($p=0.005$), and 60° ($p=0.008$) knee flexion in the descending phase of the single-leg squat, as well as at 60° ($p=0.009$) and 45° ($p=0.03$) knee flexion in the ascending phase. No significant differences were found between groups for other kinematic variables ($p>0.05$). The PFOA group exhibited lower isometric hip abductor ($p=0.02$), extensor ($p<0.001$), and external rotator ($p=0.007$) torques.

Conclusion: Individuals with PFOA exhibited excessive hip adduction that could increase stress on the lateral patellofemoral joint at 30°, 45°, and 60° knee flexion during the single-leg squat and exhibited weakness of the hip abductors, extensors, and external rotators in comparison to healthy controls.

Keywords: Kinematics, knee, muscle strength, osteoarthritis, rheumatic diseases, rheumatology.

Osteoarthritis (OA) is the most common joint disease in the world, with the knee being the most frequently affected, and it is associated with high costs to health and society.[1,2] OA is characterized by articular cartilage degradation, synovial inflammation, bone remodeling, and osteophyte formation, leading to pain, swelling, stiffness, functional disability, and impact on quality of life.[3,4]

Although the patellofemoral compartment of the knee is also affected by OA in approximately 20%,[5] patellofemoral OA (PFOA) is little studied. Investigations of knee OA tend to focus on individuals with OA in the tibiofemoral compartment or both compartments. Furthermore, compared to medial tibiofemoral OA, individuals with PFOA report more disability[6,7] and are more likely to experience an early onset of chronic symptoms.[6,8]

Weakness of the hip muscles exerts an influence on the kinematics of the trunk and lower limbs. The gluteus medius and maximus muscles are important dynamic hip stabilizers, contributing to the control of the movements of flexion, adduction, and medial rotation of the hip joint during weight-bearing activities.[9] Thus, weakness of these muscles can result in excessive adduction and medial rotation of the hip during activities involving unilateral body weight support. Although these muscles do not directly contribute to the position of the knee on the frontal plane, Ford et al.[10] found that greater hip adduction is associated with greater knee abduction. Excessive hip adduction, medial rotation, and knee abduction are related to an increase in patellofemoral stress.[11] An increase in the dynamic valgus of the knee results in an increase in the quadriceps angle (Q angle) and, consequently, an increase in the lateralizing forces that act upon the patella, provoking greater stress on the lateral patellofemoral joint.[12] Moreover, excessive internal rotation causes a reduction in the area of patellofemoral contact,[13] resulting in an increase in stress in this joint.

Gluteus medius muscle weakness may also be associated with excess movement of the pelvis on the fontal plane, with consequent compensations of the trunk and an increase in loading on the patellofemoral joint. A common compensation for excessive contralateral pelvic drop is ipsilateral lean of the trunk.[14,15] However, this ipsilateral lean can laterally displace the resulting vectors of the ground reaction forces to the articular center of the knee, with the consequent creation of an external abductor moment in the knee,[16] thereby increasing patellofemoral stress. In turn, a compensatory strategy for the weakness of the gluteus maximus muscle is trunk extension.[17] This strategy is used to reduce the demand on the weak gluteus maximus muscle during weight-bearing activities. However, it increases the demand on the knee extensor muscles[12] and, therefore, the patellofemoral stress.[18]

Some studies have evaluated hip adduction and knee abduction kinematics during functional tasks in individuals with PFOA;[19-22] however, the findings are inconsistent. Regarding the movement of the hip on the transverse plane, previous studies found no difference between groups on the task of walking on a treadmill, during gait, or during the sit-to-stand task.[19,20,23] However, it is possible that the low demand of the tasks studied may have resulted in the absence of differences regarding the kinematic outcome of internal hip rotation between groups. Thus, studies are needed to investigate this variable on a task with a greater demand, such as the single-leg squat. Moreover, to the best of our knowledge, no study evaluated the kinematics of the trunk on the sagittal plane during the single-leg squat task. Considering its influence on patellofemoral stress, it is important to assess this segment during this task.

Individuals with PFOA could have weakness of the hip extensors, abductors, and external rotators.[24,25] The weakness of these muscles may be related to kinematic changes. However, trunk, pelvis, hip, and knee strength and kinematics have rarely been evaluated in a single study involving people with isolated PFOA.[19,22,23] Thus, it is important to investigate whether the strength deficits of people with PFOA are accompanied by kinematic changes during tasks with greater functional demand, such as the single-leg squat.

Therefore, the aim of the present study was to investigate the three-dimensional kinematics of the trunk, pelvis, hip, and knee at 30°, 45°, and 60° knee flexion during the descending and ascending phases of the single-leg squat and determine the isometric strength of the hip muscles in individuals with isolated PFOA compared to controls. We hypothesized that individuals with isolated PFOA would exhibit greater trunk extension, ipsilateral trunk lean, contralateral pelvic drop, hip adduction, internal hip rotation, and knee abduction during the descending and ascending phases of the single-leg squat and would have weaker isometric hip torque.

PATIENTS AND METHODS

The present cross-sectional study was conducted at the Department of Physical Therapy, Federal University of São Carlos between July 2019 and February 2020. All participants were recruited through the divulgation of the study on the website of the university, flyers, local radio, newspapers, and magazines. Males and females between 40 and 65 years of age composed the sample and were divided into two groups: the PFOA group and the control group of healthy individuals. The eligibility criteria for the PFOA group were the same as those used by Carvalho et al.[26] anterior patellar or retropatellar pain of at least 4 on the 11-point numerical pain scale ranging from 0 (absence of pain) to 10 (worst pain possible); pain aggravated by two or more activities involving load on the patellofemoral joint; joint crepitus and morning stiffness lasting less than 30 min; evidence of the formation of osteophytes in the patellofemoral joint in lateral and skyline axial views (Grade 2 or 3 of KL classification). Individuals with unilateral or bilateral symptoms were included in the study. For inclusion in the control group, the individuals could not have any radiographic abnormalities of the knees and could not have had lower limb pain in the previous six months. The two groups were individually matched for sex and physical activity level. From a list of 108 subjects, 92 were excluded based on the exclusion criteria or did not return for subsequent assessments. Thus, the study included 16 participants (8 males, 8 females; mean age: 49.3±6.2 years; range 40 to 61 years), of which eight were in the PFOA group and eight were in the control group. This study followed the recommendations of the STROBE statement.[27]

The volunteers were submitted to a radiological exam of both knees, and OA severity was graded using the Kellgren and Lawrence (KL) criteria.[28] The diagnosis of OA was based on the clinical and radiographic classification criteria of the American College of Rheumatology.[29] PFOA was defined by a KL score ≥2 on the skyline view or the presence of a definite superior or inferior osteophyte on the patella surface of the lateral view.[30] The evaluation of the radiographs was performed by the same evaluator with 16 years of experience. Kappa coefficients were used to determine the test-retest reliability of KL scores. Kappa was 0.92 (95% confidence interval [CI], 0.78-1.07).

The affected lower limb was evaluated in the PFOA group. In cases of bilateral isolated PFOA, the more symptomatic limb (higher pain level determined using the numerical pain classification scale) was evaluated.[31] The dominant lower limb was evaluated in the control group, which was determined by the answer to the following question: “What leg would you use to kick a ball as far as possible?”[32] The participants were instructed not to perform any physical activity beyond their habitual activity in the 48 h prior to the tests.

Physical activity level was classified according to the guidelines of the World Health Organization.[33] Individuals who practiced at least 150 to 300 min of aerobic physical activity of moderate intensity or at least 75 to 150 min of vigorous aerobic activity or a combination of moderate and vigorous physical activity every week for substantial health benefits were considered physically active. In contrast, those who practiced an intensity lower than that recommended by the World Health Organization were classified as sedentary.

Kinematic evaluation of single-leg squat

Three-dimensional kinematics of the trunk, pelvis, hip, and knee were evaluated using the Vicon motion capture and analysis system (Vicon Motion Systems Ltd, Oxford, UK), the Nexus System 2.1.1 (Vicon Motion Systems Ltd, Oxford, UK), and 3D Motion Monitor software (Innovative Sports Training Inc., Chicago, IL, USA). Six Bonita 10 cameras (Vicon Motion Systems Ltd, Oxford, UK) were used to capture the trajectories of the markers at a sampling frequency of 90 Hz.

Twenty-eight reflective markers (diameter: 14 mm) were positioned on each volunteer on the following anatomic structures: jugular notch, both acromial processes, spinous processes of the seventh cervical and 10th thoracic vertebrae, iliac crest (bilaterally), anterior superior iliac spine and posterior superior iliac spine (bilaterally), first sacral vertebra, greater trochanter (bilaterally), medial and lateral femoral condyles (bilaterally), medial and lateral malleoli (bilaterally), immediately over the second metatarsal head on the shoe (bilaterally), immediately over the calcaneus on the shoe (bilaterally), and the lateral side of the foot on the shoe (on both feet but at different distances; immediately over the fifth metatarsal head on the right foot and base of the fifth metatarsal on the left foot). Moreover, four clusters (each comprising four noncollinear markers affixed to a rigid base) were attached to the participants using Velcro straps on the lateral face of the thigh and leg bilaterally. The participants were evaluated wearing shorts, a top (females) and athletic shoes (Asics model GEL Equation 5; ASICS Brasil Distribuição e Comércio de Artigos Esportivos Ltda., São Paulo, BRA), which were provided by the researcher.

Static data collection was performed to determine the joint angles of the trunk, pelvis, hip, and knee at rest and to align the neutral position of the participant with the system of coordinates of the lab. The participants were then given the opportunity to practice the single-leg squat. Each participant was instructed to squat beyond 60° knee flexion during a 2-sec period and return to the initial position in another 2-sec period, which was marked using a metronome.[34] Thus, each squat lasted four seconds. Participants were instructed to cross their arms in front of their chest, look straight ahead, and perform a single-leg squat for 4 sec. To accomplish the desired knee flexion angle, an adjustable support was put beside the participants at a height that represented the distance from the floor to the greater trochanter of the needed femoral mark.[35] Familiarization was performed prior to the test. A repetition was considered valid when the participant performed the single-leg squat with knee flexion of at least 60° within a 4-sec period without losing balance.[34] If a repetition was not considered valid, another was performed. Five valid repetitions were collected for analysis, with a 1-min rest period allotted between repetitions.

Determination of isometric hip torque

Isometric hip abductor, extensor, and external rotator torques were determined using a handheld dynamometer (Lafayette Manual Muscle Test System; Lafayette Instruments, Lafayette, IN, USA). Isometric hip abductor torque was measured with the participant in lateral decubitus on the examining table with the tested lower limb on top.[36] A cushion was positioned between the legs so that the hip of the tested lower limb remained at approximately 10° abduction.[37] A nonelastic step was positioned immediately above the iliac crest and attached firmly around the examining table to stabilize the trunk.[36] The dynamometer was positioned 5 cm proximal to the lateral joint line of the knee and attached by a nonelastic strap positioned around the leg and around the table (Figure 1a).[36] The command was given during the test for the volunteer to perform "maximum strength lifting the leg."[14]

Maximum isometric hip extensor torque was measured with the participant in the prone position, hip in the neutral position, and the knee of the lower limb being evaluated flexed at 90° so that the action of the hamstring muscles was minimized during hip extension.[38] A nonelastic step was positioned immediately above the iliac crest and around the examining table to stabilize the pelvis.[39] The handheld dynamometer was positioned in the posterior region of the thigh 5 cm proximal to popliteal fossa and attached by a second strap around the table to resist hip extension (Figure 1b).[39] The command was given during the test for the volunteer to perform "maximum strength raising the foot toward the ceiling."

Maximum isometric hip external rotator torque was measured with the participant sitting on the edge of the examining table with the

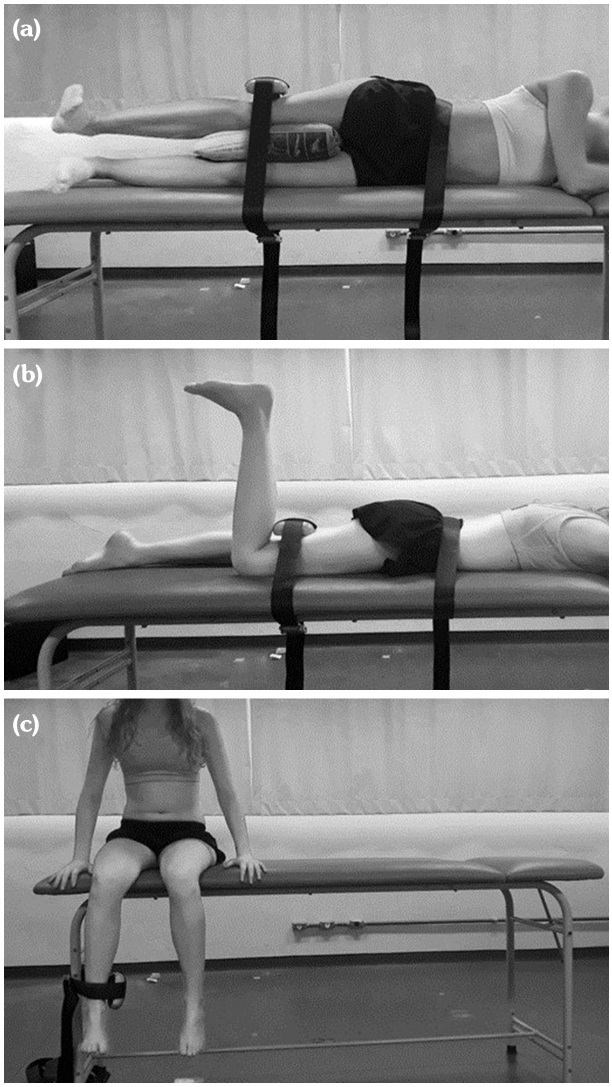


Figure 1. Test position for the evaluation of isometric **(a)** hip abductor torque, **(b)** hip extensor torque, and **(c)** hip external rotator torque.

hips and knees flexed at 90°.[40] The handheld dynamometer was positioned 5 cm above the medial malleolus and attached with a strap around the table (Figure 1c).[40] The command was given during the test for the volunteer to perform "maximum strength bringing the leg and foot inward."

Prior to the evaluations, three submaximal isometric contractions and one maximum isometric contraction were performed to familiarize the participant with the procedures.[36] Next, three 5-sec maximum voluntary isometric contractions (peak value recorded in kilograms) were performed, with a 2-min rest period allotted between trials.[32] The order of the torque evaluations was randomized.

For the purposes of statistical analysis, the average of three trials with less than 10% variability was considered. When a difference greater than 10% occurred between trials, a fourth trial was performed.[41]

Prior to the study, to establish test-retest reliability of the isometric hip torque measurement, eight participants were tested on two occasions separated by three to five days. The intraclass correlation coefficient (ICC3,1) and standard error of measurement were 0.97 and 0.95 Nm/kg for hip abduction torque, 0.99 and 0.66 Nm/kg for hip extensor torque, and 0.95 and 0.55 Nm/kg for hip external rotator torque.

Assessment of kinematic and torque data

The kinematic data were processed using the 3D Motion Monitor software. All kinematic data were filtered using a fourth-order, low-pass, zero-lag Butterworth filter at 12 Hz.[42] Euler angles were calculated using the joint coordinate system recommended by the International Society of Biomechanics in relation to quiet standing.[43,44] Kinematics of the hip and knee were calculated as the movement of the distal segment in relation to the proximal reference. Angles of the pelvis and trunk were calculated as the movement of the segment in relation to the global coordinate system. The articular center of the knee was defined as the midpoint between the medial and lateral epicondyles. The articular center of the hip was determined using the method described by Bell et al.[45]

Kinematic variables were analyzed using a personalized program created in Matlab (Mathworks, Natick, MA, USA). The kinematic variables of interest were trunk flexion (+)/extension (–), ipsilateral (+)/contralateral (–) trunk lean, contralateral pelvic elevation (+)/drop (–), hip flexion (+)/extension (–), internal (+)/external (–) hip rotation, and hip and knee abduction (+)/adduction (–) at 30°, 45°, and 60° of knee flexion during the descending and ascending phases of the single-leg squat.

For isometric hip torques, the results of all trials (kg) were converted into Newtons (strength [N] = strength [kg] × 9.81) to obtain a unit of force.[46] Newtons were then converted into torque (torque [Nm] = force [N] × action length [m]).[46] The length measured between the greater trochanter and lateral epicondyle of the femur was used as the action length for hip abductor and extensor torques.[36,39] The length measured between the lateral epicondyle of the femur and lateral malleolus was used as the action length for hip external rotator torque.[47] All the torque (Nm) data were normalized by body mass (normalized torque [Nm/kg] = torque (Nm) ÷ body mass [kg]).

Statistical analysis

The sample size was calculated with the aid of the G*Power software version 3.1.9.2 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) based on hip internal rotation angle during the single-leg squat at 60° knee flexion in the descending phase of the first four participants in each group. Considering a significance level of α=0.05 and β=0.95 to detect a difference in hip internal rotation angle of 15.2° with a standard deviation of 7.1°, six participants were needed for each group.

The data were analyzed with the aid of IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). The Shapiro-Wilk and Levene tests were used for the determination of normality and homoscedasticity, respectively. Data with nonnormal distribution were log transformed (external hip rotator torque; trunk flexion/extension angles at 30°, 45°, and 60° knee flexion; trunk lean at 60° knee flexion; hip internal/external rotation and abduction/adduction at 30° knee flexion in the descending phase of the single-leg squat; trunk flexion/extension and lean at 60° and 45° knee

Table 1. Demographic and clinical characteristics of the PFOA group and the control group

	PFOA group (n=8)			Control group (n=8)						
	n	%	Mean±SD	n	%	Mean±SD	Mean difference	95% CI	*p*	Effect size
Age (year)			52.3±6.0			46.4±5.1	5.9	−0.07 to 11.9	0.053	1.00
Body mass index (kg/m²)			27.4±2.3			25.1±2.6	2.3	−0.3 to 4.9	0.07	0.89
Sex										
Male	4			4	50	-	-	-	-	-
Female	4			4	50	-	-	-	-	-
Level of physical activity[a]										
Active	6	75		6	75	-	-	-	-	-
Sedentary	2	25		2	25	-	-	-	-	-
Kellgren & Lawrence classification										
Grade 0	-			0						
Grade 2	6			-						
Grade 3	2			-						

PFOA: Patellofemoral osteoarthritis; SD: Standard deviation; [a] Level of physical activity according to World Health Organization.

flexion in the ascending phase of the single-leg squat). Mixed two-way analysis of variance (group * knee flexion angle) was used for the kinematic variables considering the knee flexion angle as repeated measures. The Bonferroni test was used when significant differences were found. Student's t-test for independent samples was used for the comparison of the demographic and anthropometric variables as well as isometric hip torques. The effect size (Hedges' g) was calculated for each comparison, and the interpretation suggested by Cohen[48] was used for the classification of the standardized mean difference, with 0.8, 0.5, and 0.2 indicative of large, medium, and small effect sizes, respectively. The significance level was set at p≤0.05 for all analyses.

RESULTS

The demographic and anthropometric characteristics of the groups are displayed in Table 1. The results of the kinematic analysis are displayed in Table 2 and Figure 2. The PFOA group had a significantly larger hip adduction angle at 30° (mean difference ± SD [95% CI]= 7.38°±3.78° [1.55-13.21°]), 45° (mean difference ± SD [95% CI]= 9.91°±3.71° [3.51-16.31°]) and 60° (mean difference ± SD [95% CI]= 10.6°±2.68° [3.2-18°]) of knee flexion in the descending phase of the single-leg squat and at both 60° (mean difference ± SD [95% CI]= 9.36°±0.4° [2.75-15.97°]) and 45° (mean difference ± SD [95% CI]= 6.81°±0.4° [0.61-13.01°]) of knee flexion in the ascending phase. No significant differences between groups were found for other kinematics variables at 30°, 45°, and 60° knee flexion in the descending and ascending phases of the single-leg squat (p>0.05).

The PFOA group exhibited lower isometric hip abductor (mean difference: −0.44 Nm/kg; 95% CI: −0.79 to −0.09 Nm/kg), extensor (mean difference: −0.50 Nm/kg; 95% CI: −0.68 to −0.32 Nm/kg), and external rotator (mean difference: −0.33 Nm/kg; 95% CI: −0.46 to −0.10 Nm/kg) torques compared to the control group (Table 3).

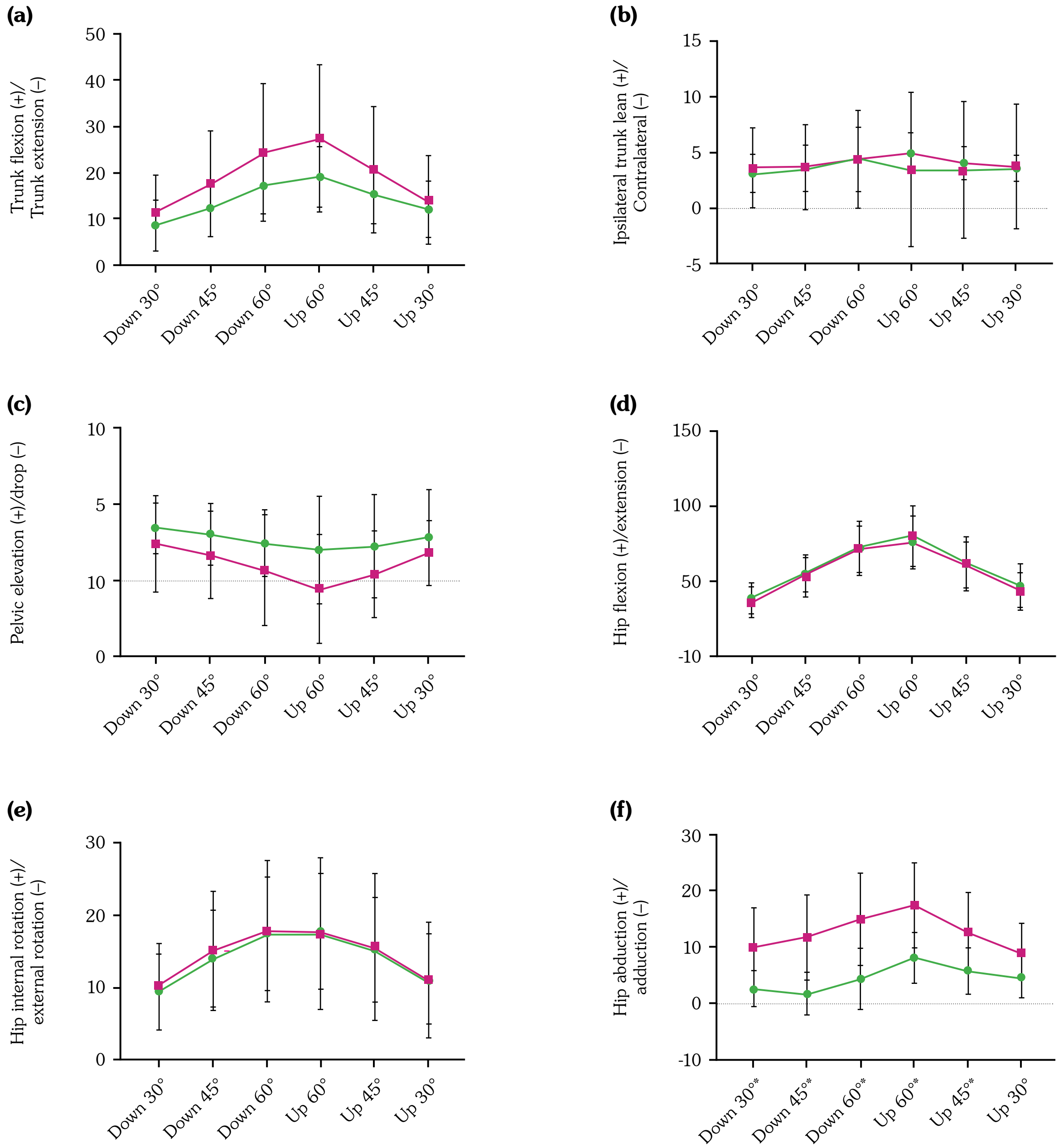
DISCUSSION

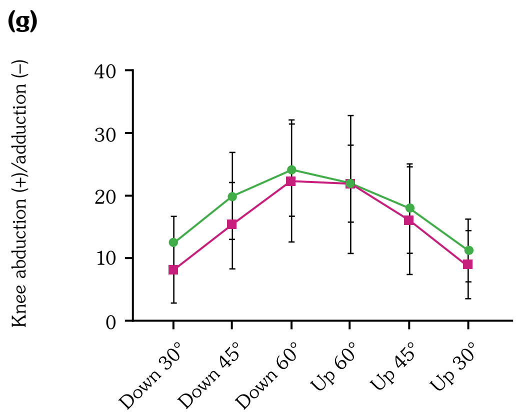
The aim of the present study was to investigate the three-dimensional kinematics of the trunk, pelvis, hip, and knee at 30°, 45°, and 60° knee flexion during the descending and ascending phases of the single-leg squat and determine isometric hip adductor, extensor, and external rotator torques in individuals with isolated PFOA, comparing the results to those found in controls. The findings partially confirm

Table 2. Between-group comparisons of trunk, pelvis, hip, and knee joint angles during single-leg squat (in degrees)

	PFOA group (n=8)	Control group (n=8)				
Variables	Mean±SD	Mean±SD	Mean difference	95% CI	*p*	Effect size
Kinematics (Descending phase)						
Trunk flexion (+)/trunk extension (–)						
Knee flexion at 30°	11.38±8.08	8.60±5.44	2.78	–4.61 to 10.17	0.53	0.38
Knee flexion at 45°	17.58±11.51	12.24±5.85	5.34	–4.45 to 15.13	0.34	0.55
Knee flexion at 60°	24.51±14.90	17.26±6.03	7.25	–4.94 to 19.44	0.35	0.60
Ipsilateral trunk lean (+)/contralateral (–)						
Knee flexion at 30°	3.64±3.62	3.14±1.70	0.50	–2.53 to 3.53	0.73	0.17
Knee flexion at 45°	3.72±3.85	3.60±2.07	0.12	–3.19 to 3.43	0.94	0.04
Knee flexion at 60°	4.45±4.35	4.38±2.87	0.07	–3.88 to 4.02	0.54	0.02
Pelvic elevation (+)/drop (–)						
Knee flexion at 30°	2.42±3.14	3.44±1.66	–1.02	–3.71 to 1.67	0.43	0.38
Knee flexion at 45°	1.72±2.83	3.06±1.99	–1.34	–3.96 to 1.28	0.29	0.52
Knee flexion at 60°	0.74±3.62	2.44±2.17	–1.70	–4.90 to 1.50	0.27	0.54
Hip flexion (+)/extension (–)						
Knee flexion at 30°	36.52±10.05	39.31±10.31	–2.79	–13.71 to 8.13	0.43	0.26
Knee flexion at 45°	54.08±14.16	55.05±11.46	–0.97	–14.78 to 12.84	0.88	0.07
Knee flexion at 60°	72.61±17.92	71.77±15.50	0.84	–17.13 to 18.81	0.92	0.05
Hip abduction (+)/adduction (–)						
Knee flexion at 30°	–9.98±6.99	–2.60±3.21	7.38	1.55 to 13.21	0.008*	1.28
Knee flexion at 45°	–11.73±7.52	–1.82±3.82	9.91	3.51 to 16.31	0.005*	1.57
Knee flexion at 60°	–14.94±8.11	–4.34±5.43	10.60	3.20 to 18.00	0.008*	1.45
Hip internal rotation (+)/external rotation (–)						
Knee flexion at 30°	10.15±5.96	9.55±5.14	0.60	–5.37 to 6.57	0.89	0.10
Knee flexion at 45°	15.03±8.21	14.00±6.71	1.03	–7.01 to 9.07	0.79	0.13
Knee flexion at 60°	17.74±9.74	17.49±7.85	0.25	–9.24 to 9.74	0.96	0.03
Knee abduction (+)/adduction (–)						
Knee flexion at 30°	8.02±5.13	12.50±4.25	–4.48	–9.53 to 0.57	0.08	0.90
Knee flexion at 45°	15.25±6.83	19.96±6.99	–4.71	–12.12 to 2.70	0.19	0.64
Knee flexion at 60°	22.32±9.75	24.08±7.46	–1.76	–11.07 to 7.55	0.69	0.19
Kinematics (Ascending phase)						
Trunk flexion (+)/trunk extension (–)						
Knee flexion at 30°	27.46±16.07	19.11±6.54	8.35	–4.81 to 21.51	0.37	0.64
Knee flexion at 45°	20.58±13.74	15.33±6.43	5.25	–6.25 to 16.75	0.61	0.46
Knee flexion at 60°	14.09±9.49	12.06±6.15	2.03	–6.55 to 10.61	0.62	0.24
Ipsilateral trunk lean (+)/contralateral (–)						
Knee flexion at 30°	3.48±6.94	4.91±1.85	–1.43	–6.88 to 4.02	0.29	0.27
Knee flexion at 45°	3.43±6.11	4.07±1.51	–0.64	–5.41 to 4.13	0.36	0.14
Knee flexion at 60°	3.77±5.54	3.63±1.13	0.14	–4.15 to 4.43	0.95	0.03
Pelvic elevation (+)/drop (–)						
Knee flexion at 30°	–0.55±3.58	2.00±3.54	–2.55	–6.37 to 1.27	0.17	0.68
Knee flexion at 45°	0.42±2.85	2.25±3.37	–1.83	–5.18 to 1.52	0.26	0.55
Knee flexion at 60°	1.88±2.06	2.83±3.14	–0.95	–3.80 to 1.90	0.49	0.34
Hip flexion (+)/extension (–)						
Knee flexion at 30°	80.45±20.16	76.32±17.32	4.13	–16.02 to 24.28	0.67	0.21
Knee flexion at 45°	62.03±18.10	61.43±15.55	0.60	–17.49 to 18.69	0.95	0.03
Knee flexion at 60°	43.99±12.38	47.36±14.46	–3.37	–17.80 to 11.06	0.62	0.24
Hip abduction (+)/adduction (–)						
Knee flexion at 30°	–17.46±7.52	–8.10±4.41	9.36	2.75 to 15.97	0.009*	1.44
Knee flexion at 45°	–12.64±7.12	–5.83±4.01	6.81	0.61 to 13.01	0.03*	1.11
Knee flexion at 60°	–9.04±5.06	–4.66±3.61	4.38	–0.33 to 9.09	0.07	0.94
Hip internal rotation (+)/external rotation (–)						
Knee flexion at 30°	17.51±10.43	17.80±7.94	–0.29	–10.23 to 9.65	0.95	0.03
Knee flexion at 45°	15.67±10.14	15.29±7.23	0.38	–9.06 to 9.82	0.93	0.04
Knee flexion at 60°	11.04±7.97	11.19±6.22	–0.15	–7.82 to 7.52	0.97	0.02
Knee abduction (+)/adduction (–)						
Knee flexion at 30°	21.82±11.06	21.89±6.15	–0.07	–9.67 to 9.53	0.99	0.01
Knee flexion at 45°	16.00±8.64	17.94±7.16	–1.94	–10.45 to 6.57	0.63	0.23
Knee flexion at 60°	8.93±5.46	11.12±4.96	–2.19	–7.78 to 3.40	0.42	0.40

PFOA: Patellofemoral osteoarthritis; SD: Standard deviation; * Significant difference: $p \leq 0.05$.





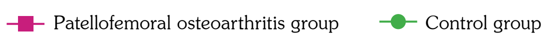


Figure 2. Mean ± standard deviation of trunk flexion/extension **(a)**, ipsilateral trunk lean/contralateral **(b)**, pelvic elevation/drop **(c)**, hip flexion/extension **(d)**, hip internal/external rotation **(e)**, hip abduction/adduction **(f)**, and knee abduction/adduction **(g)** excursions at 30°, 45°, and 60° of knee flexion, in the downward (Dow) and upward (Up) phases of the single-leg squat in the PFOA and control groups.

* PFOA significantly greater than controls ($p \leq 0.05$).

Table 3. Between-group comparisons of normalized isometric hip torques (Nm/kg)

	PFOA group (n=8)	Control group (n=8)				
Isometric torques	Mean±SD	Mean±SD	Mean difference	95% CI	*p*	Effect size
Hip abductor	1.20±0.33	1.64±0.33	−0.44	−0.79 to −0.09	0.02*	1.26
Hip extensor	0.63±0.12	1.13±0.21	−0.50	−0.68 to −0.32	<0.001*	2.76
Hip external rotator	0.48±0.16	0.81±0.25	−0.33	−0.46 to −0.10	0.007*	1.49

PFOA: Patellofemoral osteoarthritis; SD: Standard deviation; * Significant difference: p≤0.05.

our hypotheses, demonstrating that individuals with symptomatic, radiographic PFOA have larger hip adduction angles at 30°, 45°, and 60° knee flexion during the descending phase of the single-leg squat as well as at 60° and 45° knee flexion during the ascending phase and have less capacity to generate isometric hip adductor, extensor, and external rotator torque compared to individually matched controls. All significant effect sizes were large, suggesting possible clinical importance.

The individuals with PFOA evaluated in the present study had larger hip adduction angles at 30°, 45°, and 60° knee flexion in the descending phase of the single-leg squat as well as at 60° and 45° knee flexion in the ascending phase compared to controls. Similar results were found by Crossley et al.[20] their subjects with PFOA had greater hip adduction angles in the late stance phase of gait. Hip adduction and knee abduction are the main components of dynamic knee valgus on the frontal plane,[49] and an excessive hip adduction and knee abduction can have harmful effects on the patellofemoral joint, causing greater stress on the lateral patellofemoral joint.[12] Thus, the greater hip adduction in individuals with PFOA can be an aggravating factor of symptoms and even the progression of the disease. However, prospective studies are needed to confirm this hypothesis.

We found no significant differences between groups regarding the kinematics of the trunk and pelvis on the frontal plane. Our hypothesis was that individuals with PFOA would exhibit greater contralateral pelvic drop and greater ipsilateral trunk lean during the task due to weakness of the ipsilateral gluteus medius. A greater contralateral pelvic drop and ipsilateral trunk lean during the single-leg squat and lower hip abductor torque were found in individuals with patellofemoral pain.[34] In our study, the PFOA group had a 26.8% deficit in isometric hip abductor torque, but this deficit did not result in changes in the kinematics of the pelvis and trunk. The absence of differences between groups for trunk and pelvis kinematics may be due to a type 2 error. Thus, future studies with a larger sample size could confirm our results.

We also found no significant difference between groups regarding the movement of the knee on the frontal plane. In contrast, Hoglund et al.[19] found greater knee abduction in individuals with PFOA during the Sit-to-Stand task. Trunk movement on the frontal plane can alter the loading on the knee as well as knee position. Excessive ipsilateral trunk lean laterally displaces the vector of the ground reaction force to the knee, producing an external abductor moment in the joint,[12] which may contribute to an increase in abduction.[16,50] Thus, the lack of a difference in the trunk movement on the frontal plane in the present study may explain the similarity between groups regarding knee movement.

We also found no significant differences between groups regarding the kinematics of the trunk on the sagittal plane. Likewise, Fok et al.[51] found no difference between the PFOA and control groups regarding trunk flexion during stair ambulation. Our hypothesis was that individuals with PFOA would exhibit smaller trunk flexion angles during the single-leg squat task, as trunk extension may be a compensation for hip extensor weakness.[17] However, although the PFOA group had a 44.2% deficit in isometric hip extensor torque, this deficit did not result in changes in the kinematics of the trunk on the sagittal plane. Analyzing healthy runners, Teng and Powers[52] found that running with trunk extension significantly increased the internal extensor moment of the knee and patellofemoral stress compared to self-selected and flexed positions of the trunk. Although no difference between groups was found regarding the trunk flexion angle in the present study, individuals with PFOA seem to have greater trunk flexion angles during the single-leg squat. This is an important aspect, as stress on the patellofemoral joint was lower in the flexed trunk position in healthy runners.

No difference was found between groups for internal hip rotation. Pohl et al.,[23] Hoglund et al.,[19] and Crossley et al.[20] also found no difference between groups for this variable when walking on a treadmill, during the sit-to-stand task, and when walking, respectively. Although the PFOA group in the present study had a 40.7% deficit in isometric external hip rotator torque, this deficit did not result in changes in the kinematics of the hip on the transverse plane.

The study has some limitations that should be considered. The small sample size may account for the lack of differences between groups regarding kinematic variables of the trunk, pelvis, and knee (type 2 error). Unfortunately, the data collection had to be suspended due to the COVID-19 (coronavirus disease 2019) pandemic; therefore, it was not possible to evaluate the entire sample according to the sample calculation. However, significant differences were observed with large effect sizes for hip adduction during the single-leg squat and for hip isometric torque measurements. Future studies with a larger sample size are encouraged to confirm these differences. Another limitation of this study was that it did not evaluate the strength of the trunk muscles. Considering that the action of the trunk muscles can alter the position of this segment in the sagittal plane and, consequently, patellofemoral stress, future studies should consider the evaluation of these muscles in individuals with PFOA.

In conclusion, the individuals with isolated PFOA exhibited an increase in hip adduction at 30°, 45°, and 60° knee flexion in the descending phase of the single-leg squat and at 45° and 60° knee flexion in the ascending phase compared to healthy controls in the present study. The individuals with PFOA also demonstrated less capacity to generate isometric hip abductor, extensor, and external rotator torque. Although it is not possible to establish a cause-and-effect relationship, the results of the present study can assist in guiding treatment programs for individuals with isolated PFOA.

Ethics Committee Approval: The study protocol was approved by the Federal University of São Carlos Ethics Committee (date: 10.10.2018, no: 96324918.4.0000.5504). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Contributing to the conception and design, collecting data, analyzing and interpreting data, drafting the article and revising it critically for important intellectual content, and approving the final version to be published: C.C.; Contributing to the conception and design, interpreting data, drafting the article and revising it critically for important intellectual content, and approving the final version to be published: F.V.S.; Contributing to the collecting data, analyzing and interpreting data, drafting the article and revising it critically for important intellectual content, and approving the final version to be published: A.F.M.; Contributing to the conception and design, interpreting data, drafting the article and revising it critically for important intellectual content, and approving the final version to be published: P.R.M.D.S.S.

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