

Impaired muscle capacity of the hip and knee in individuals with isolated patellofemoral osteoarthritis: a cross-sectional study

Cristiano Carvalho , Fábio Viadanna Serrão, Letícia Mancini and Paula Regina Mendes da Silva Serrão

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Abstract

Aims: The aims of this study were to compare the capacity of the knee and hip muscles between individuals with and without isolated patellofemoral osteoarthritis (PFOA) and to evaluate the impact of PFOA on pain, stiffness, and physical function.

Methods: This cross-sectional study evaluated muscle capacity of the hip and knee using an isokinetic dynamometer. The isokinetic variables used in the statistical analysis were peak torque, total work, and average power. Pain, stiffness, and physical function were assessed using questionnaires.

Results: A total of 26 individuals participated in the study (13 with PFOA and 13 controls). The PFOA group exhibited lower peak torque, total work, and average power for knee extension and flexion in the concentric mode ($p \leq 0.01$) as well as lower peak torque and total work for knee extension ($p \leq 0.005$) and lower total work for knee flexion ($p = 0.05$) in the eccentric mode. The PFOA group exhibited lower peak torque of the extensor, abductor, adductor, and internal rotator muscles of the hip ($p \leq 0.05$), less total work of the abductor and adductor muscles ($p \leq 0.04$), and lower average power of eccentric adduction of the hip ($p = 0.01$) compared with the healthy controls. Compared with the control group, the PFOA group had a higher level of pain, stiffness, and compromised physical functioning self-reported ($p \leq 0.005$).

Conclusion: Participants with PFOA exhibited impairments regarding muscle capacity of the hip and knee, higher level of pain and stiffness as well as compromised physical functioning in comparison with healthy controls.

Keywords: dynamometer, isokinetic, knee osteoarthritis, rheumatic diseases, rheumatic diseases muscle, strength muscle

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Introduction

All compartments of the knee can be affected by osteoarthritis (OA), with the patellofemoral compartment being the most frequently affected even before the tibiofemoral compartment.^{1,2} In comparison with medial tibiofemoral OA, individuals with patellofemoral osteoarthritis (PFOA) report more disability and are more prone to suffering the early onset of chronic symptoms, which contributes to the functional limitations associated with the disease.^{3–6}

Although many studies have investigated characteristics of the thigh muscles (especially the quadriceps) in tibiofemoral OA, data on individuals with isolated PFOA are scarce. Three studies showed that isometric weakness of the quadriceps was associated with PFOA.^{7–9} Moreover, a stronger femoral quadriceps seems to protect the patellofemoral joint against the loss of cartilage in the lateral compartment.¹⁰ In a recent prospective cohort study, Culvenor *et al.*¹¹ found that low quadriceps strength increased the

Correspondence to:
**Paula Regina Mendes da
Silva Serrão**
Department of Physical
Therapy, Federal
University of São Carlos,
Rodovia Washington
Luis, km 235–SP-310 São
Carlos, São Paulo 13.565-
905, Brazil
paula.serrao@ufscar.br

Cristiano Carvalho
Fábio Viadanna Serrão
Letícia Mancini
Department of Physical
Therapy, Federal
University of São Carlos,
São Carlos, São Paulo,
Brazil



risk of aggravating cartilage damage in the lateral patellofemoral joint in women but not in men.

The strength of the hip muscles has been underexplored in individuals with PFOA. Knee instability in individuals with OA can also be a consequence of an increase in dynamic valgus,¹² which could be related to hip muscle weakness, especially the gluteus maximus and medius. Dynamic valgus appears mainly during activities with unilateral weight support involving medial rotation and adduction of the hip as well as knee abduction.¹³ The gluteus medius and maximus muscles act eccentrically to control the movements of hip flexion, adduction, and medial rotation during activities with body weight support.¹⁴ Thus, the weakness of these muscles can result in excessive hip adduction and medial rotation during activities with unilateral support, leading to an increase in dynamic valgus of the knee, which results in an increase in the angle of the quadriceps (Q angle) and, consequently, an increase in lateralizing forces acting on the patella, causing greater stress on the lateral patellofemoral joint.¹⁵ This aspect is well established in individuals with patellofemoral pain (PFP) and has been implicated in the development and progression of this syndrome.^{16–18} As PFP seems to be a precursor of PFOA,^{6,19,20} the study of these aspects in PFOA is extremely relevant.

Three previous studies evaluated isometric strength of the hip muscles in patients with PFOA.^{8,21,22} In studies by Pohl *et al.* and Høglund *et al.*, individuals with PFOA exhibited a reduction in the isometric strength of the hip abductors in comparison with the individuals in the healthy control group.^{8,21} Moreover, Høglund *et al.* found that individuals with PFOA had lower isometric strength of the hip extensors.⁸ On the other hand, Macri *et al.* found no difference in isometric strength of the abductors, extensors, and internal hip rotator muscles.²² Furthermore, neither study found a difference in isometric external rotator strength between groups.^{8,21,22} Finally, although the gluteus medius and maximus muscles act eccentrically to control or resist excessive hip adduction and medial rotation during activities with body weight support, no previous study has evaluated the eccentric strength of these muscles in individuals with PFOA.

To the best of our knowledge, no studies have evaluated the eccentric strength of the hip muscles or

the eccentric strength of the knee flexors and extensors in individuals with PFOA compared with healthy individuals. Given the important role of the thigh and hip muscles during the execution of functional tasks, such investigation is extremely important. In parallel to changes in muscle strength, individuals with PFOA may also report pain, stiffness, and deficits in physical function, so investigating these issues is also relevant. Therefore, the aim of the present study was to investigate differences between individuals with isolated PFOA and healthy controls with regards to eccentric and concentric muscle capacity of the knee flexion and extension as well as eccentric muscle capacity of the hip abduction, extension, adduction, internal rotation, and external rotation. Our secondary aim was to describe and compare pain, stiffness, and physical function level self-reported in individuals with PFOA to individually matched controls. The hypothesis of this study is that individuals with isolated PFOA have weaker hip and knee muscles compared with healthy controls. Also, individuals with PFOA will report more pain, stiffness, and greater impairment in physical function compared with healthy individuals.

Materials and methods

Study design

The present cross-sectional study was conducted at the Rheumatology and Hand Rehabilitation Research Lab and the Isokinetic Dynamometry Lab of the Physical Therapy Department of *Universidade Federal de São Carlos* (UFSCar), Brazil. This study followed the recommendations of the STROBE statement and received approval from the UFSCar Human Research Ethics Committee (certificate number: 96324918.4.0000.5504).²³ All participants signed a statement of informed consent. The data were collected between August 2019 and February 2020.

Participants

Individuals from the general community of São Carlos city were recruited through the divulgation of the study on the website of the institution, flyers, as well as local radio, newspapers, and magazines. All participants were submitted to a radiological exam of both knees and the severity of knee OA was graded using the Kellgren and Lawrence (KL) criteria by a specialist.²⁴ The diagnosis of OA was based on the clinical and

radiographic classification criteria of the American College of Rheumatology.²⁵

The participants were divided into two groups: a PFOA group and a control group of healthy individuals. For both groups, men and women between 40 and 65 years of age were recruited. For the PFOA group, the participants needed to have anterior or retro patellar pain ≥ 4 on the 11-point numeric pain scale that is aggravated by two or more activities that place considerable load on the patellofemoral joint, such as climbing stairs, standing up from the sitting position, or squatting²⁶; morning stiffness lasting less than 30 min, joint crepitation²⁵; and evidence of the formation of osteophytes in the patellofemoral joint in radiographs (profile and axial skyline view) through the Grade 2 or 3 KL classification.²⁷ Individuals with unilateral and bilateral symptoms were included in the study. To be included in the control group, the participants could not have any radiographic abnormalities of the knee.

The exclusion criteria for the PFOA group were those used by Pohl *et al.*²¹: previous history of fracture or recurrent subluxation of the patella; bone abnormalities (fracture, osteochondritis dissecans, or bipartite patella); known OA in other weight supporting joints; osteotomy or arthroplasty of the hip, knee, or ankle; arthroscopic surgery or injections in the knee in the previous 3 months; physical therapy in the previous 6 weeks; the use of a cane or other gait-assistance device; and any physical or medical problem that may be a contraindication for the evaluations. Individuals with concomitant tibiofemoral OA (KL grade of ≥ 2 on an antero-posterior radiograph) were also excluded.⁹ The same exclusion criteria applied to the control group. The two groups were matched for sex.

The participants were instructed not to perform any physical activity beyond habitual activity in the 48 h prior to the tests. The dominant lower limb was evaluated in the control group and was determined based on the answer to the following question: "Which leg would you use to kick a soccer ball as far as possible?"²⁸ The affected limb was evaluated in the PFOA group. In cases of bilateral isolated PFOA, the more symptomatic limb was evaluated according to the level of pain verified by the numeric pain rating scale.²⁹

Outcome measures

Western Ontario and McMaster Universities Osteoarthritis Index. All volunteers answered the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), which is a self-report questionnaire specific to patients with knee and/or hip OA composed of three domains: pain (five items), joint stiffness (two items), and physical function (17 items).³⁰ The 72 h prior to the application of the questionnaire were considered for the evaluation. The domains are scored on a five-point scale (none = 0, mild = 1, moderate = 2, intense = 3, and very intense = 4). The maximum score for each domain of the questionnaire were considered, with higher scores denoting worse pain, stiffness, and physical function. A version translated and validated for Brazilian Portuguese language was used.³¹

Anterior knee pain scale. Functioning was evaluated using the Anterior Knee Pain Scale (AKPS), which was developed especially for patients with PFP.³² The score ranges from 0 to 100 (higher scores denote less functional limitation) for the evaluation of pain when squatting, running, jumping, climbing stairs, and after remaining in the sitting position for a prolonged time with the knee flexed as well as the evaluation of the occurrence of claudication, edema, subluxation, atrophy of the quadriceps, deficient knee flexion, and the need for support while walking.³²

Level of physical activity. The level of physical activity of each participant was classified according to the World Health Organization guidelines.³³ Active individuals were those who practiced at least 150–300 min of moderate-intensity aerobic physical activity; or at least 75–150 min of vigorous-intensity aerobic physical activity; or an equivalent combination of moderate and vigorous physical activity throughout the week for substantial health benefits.

Isokinetic assessment of hip and knee. Eccentric torque during hip abduction, extension, and lateral rotation, as well as both concentric and eccentric torque during knee extension and flexion were determined using the Biodex Multi-Joint System 3 isokinetic dynamometer (Biodex Medical Inc., Shirley, NY, USA) and recorded at a sampling frequency of 100 Hz. The isokinetic dynamometer is considered the gold standard for the measurement of muscle strength.³⁴ The

equipment was calibrated prior to the evaluations. All procedures, including correction for the effect of gravity on the torque measurements, were conducted in accordance with the instruction manual of the equipment.³⁵

Prior to each evaluation, the participant was familiarized with the activity, performing three submaximal and two maximal contractions.³⁶ After a 3-min rest, data collection began, which consisted of five repetitions of maximal contraction at a velocity of 30°/s for the assessment of hip torque and 60°/s for the assessment of knee torque.^{37,38} During the evaluations, the participants received standardized, vigorous, verbal encouragement to stimulate a greater production of force during the contractions.³⁹ However, the participants received no visual feedback from the equipment at any time. The order of the muscle groups to be evaluated was randomized. Between each isokinetic assessment, participants were asked if they had knee pain (evaluated using the numeric pain rating scale). None of the participants in this study reported pain during the isokinetic assessments.

Knee extensor and flexor torque. For the determination of knee extensor and flexor torque, the participant was seated with the hips and knees flexed at 90°. The trunk and thigh were stabilized with straps.⁴⁰ The rotation axis of the dynamometer was aligned with the lateral epicondyle of the femur and the lever arm was attached distally to the ankle 5 cm above the medial malleolus.⁴⁰ The range of motion for the evaluations was 20°–90° of knee flexion (complete knee extension = 0°).⁴¹

Hip abductor and adductor torque. For the determination of hip abductor and adductor torque, the participant was positioned in lateral decubitus with the evaluated lower limb positioned parallel to the floor over the non-evaluated limb in neutral medial/lateral rotation and flexion/extension of the hip.³⁷ The hip and knee of the non-evaluated limb were flexed slightly. The trunk and contralateral lower limb were stabilized with straps. The volunteer was instructed not to flex the evaluated limb and maintain the toes facing forward during the tests to avoid any compensation and change in muscle recruitment. The rotation axis of the dynamometer was at a point representing the intersection of two lines: one line

directed downward from the posterosuperior iliac spine toward the knee and another oriented medially and posteriorly to the major trochanter of the femur toward the midline of the body. Resistance was applied to the distal third of the thigh 5 cm above the upper edge of the patella.³⁷ The range of motion of the test was from 0° (neutral position) to 30° of hip abduction.³⁸

Lateral and medial hip rotator torque. For the determination of the torque of the lateral and medial hip rotators, the participant was seated with the hips and knees flexed at 90°. The trunk and thigh were stabilized with straps. The rotation axis of the dynamometer was aligned with the longitudinal axis of the femur³⁷ and the lever arm was fixed 5 cm above the medial malleolus. The range of motion during the evaluation was from 10° of medial rotation to 20° of lateral rotation of the hip.³⁸

Hip extensor torque. For the evaluation of hip extensor torque, the participant was positioned with the trunk at 90° of flexion, arms around the chair of the dynamometer for stabilization, and the non-evaluated limb with contact with the floor supporting the body weight.³⁶ A pelvic strap was used for stabilization. The axis of the dynamometer was aligned with the greater trochanter of the femur and the lever arm was fixed to the distal third of the posterior thigh above the popliteal fold. The participant was instructed to maintain the knee flexed at 90° during the test. The range of motion was 90–60° of hip flexion (neutral position = 0°).³⁶

Statistical analysis

The sample size was calculated with the aid of the G*Power software (version 3.1.9.2; Kiel University, Germany) based on the hip abduction torque in eccentric mode of the first five participants in each group. Considering a significance level of $\alpha=0.05$ and $\beta=0.95$ to detect a difference in hip abduction torque of 24.9 Nm/kg with a standard deviation (SD) of 13.4, 13 participants were needed for each group.

The data were analyzed with the aid of IBM SPSS Statistics (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY, USA). The normality and homoscedasticity of the data were determined using the Shapiro–Wilk test and Levene's

test, respectively. For all normality and homoscedasticity tests, the result was $p > 0.05$, except for the WOMAC domains ($p < 0.001$). The isokinetic variables considered in the statistical analysis were means of peak torque, total work, and average power. All isokinetic variables were normalized by individual body mass (kg) (isokinetic variable/body mass $\times 100$). Student's *t*-test was used for the comparison between groups regarding demographic and anthropometric variables, strength of the hip and knee muscles, and score on the AKPS. Mann-Whitney *U* test was used for the comparison between groups regarding WOMAC domain scores. The effect size (Hedges' *g*) was calculated for each comparison and the interpretation suggested by Cohen 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.⁴² For all analyses, the significance level was set at 5% ($p \leq 0.05$).

Results

From a list of 108 individuals, 82 were excluded based on the exclusion criteria, or failed to return for the subsequent assessments. Of these, 26 participants matched the eligibility criteria. Table 1 displays the anthropometric and clinical characteristics of the sample. Among individuals with PFOA, only one participant had doubtful OA (KL grade 1) in the tibiofemoral compartment. The other 12 participants had isolated PFOA. No differences between groups were found for age or BMI ($p > 0.05$) and no differences were found in terms of physical activity levels. Compared with the control group, the PFOA group had higher scores on all WOMAC domains ($p \leq 0.005$) and greater functional impairment measured using the AKPS ($p < 0.001$).

Regarding the strength of the knee extensors, lower peak torque ($p = 0.004$), total work ($p = 0.01$), and average power ($p = 0.002$) were found during concentric mode in the PFOA group compared with the control group (Table 2). On average, the PFOA group had 29% lower peak torque, 30% less total work, and 36% lower average power regarding concentric extension of the knee. The PFOA group also has lower peak torque ($p = 0.004$) and total work ($p = 0.005$) during eccentric mode, with an average of 23% and 30% less torque and total work, respectively. No

difference in average power during the eccentric mode was found between groups ($p = 0.1$).

Regarding the strength of the knee flexors, lower peak torque ($p = 0.01$), total work ($p = 0.01$), and average power ($p = 0.005$) during concentric mode were found in the PFOA group (Table 2). On average, PFOA group had 28% lower peak torque, 32% less total work, and 36% lower average power regarding concentric flexion of the knee. In eccentric mode, the PFOA group had less total work compared with the control group ($p = 0.05$), exhibiting an average of 25% less total work regarding eccentric flexion of the knee. Although the PFOA group also had lower peak torque ($p = 0.07$) and average power ($p = 0.06$) under this condition, the differences between groups did not achieve statistical significance.

The results of the isokinetic assessment of the hip muscles are displayed in Table 3. The PFOA group had lower peak torque of the extensors, abductors, adductors, and internal rotators compared with the control group ($p \leq 0.05$). On average, the PFOA group had 20% lower extension torque, 18% lower abduction torque, 17% lower adduction torque, and 17% lower internal rotation torque. Lower values were also found for total work of the abductors and adductors in the PFOA group ($p \leq 0.04$), with an average of 28% less total work in eccentric abduction and adduction of the hip. Regarding average power, a difference between groups was found only for the adductor muscles of the hip ($p = 0.01$), with the PFOA group exhibiting 22% less average power in hip adduction.

Discussion

The aim of the present study was to compare the strength of the knee extensors and flexors in concentric and eccentric modes as well as the strength of the extensors, abductors, adductors, external rotators, and internal rotators of the hip in eccentric mode between individuals with and without PFOA. The present results indicate that individuals with isolated PFOA have diminished concentric and eccentric strength of the femoral quadriceps and hamstrings as well as diminished eccentric strength of the hip extensors, abductors, adductors, and external rotators. Regarding the WOMAC questionnaire, significant differences between groups were found for the three

Table 1. Demographic and clinical characteristics of patellofemoral osteoarthritis group and control group.

Characteristics	Mean ± SD		Median (IQR)		Mean difference (95% CI)	p value	Mann-Whitney U	Effect size
	Control (n = 13)	Patellofemoral Osteoarthritis (n = 13)	Control (n = 13)	Patellofemoral Osteoarthritis (n = 13)				
Age (years)	49.5 ± 5	52.5 ± 7.9	-	-	-3 (-8.4 to 2.4)	0.3	-	0.44
BMI (kg/m ²)	26.6 ± 3.7	28.5 ± 2.5	-	-	-1.9 (-4.5 to 0.7)	0.1	-	0.58
Female (n; %)	7 (53.8)	7 (53.8)	-	-	-	-	-	-
Male (n; %)	6 (46.2)	6 (46.2)	-	-	-	-	-	-
Level of physical activity ^a (n; %)								
Active	10 (76.9)	10 (76.9)	-	-	-	-	-	-
Sedentary	3 (23.1)	3 (23.1)	-	-	-	-	-	-
KL classification	Grade 0 = 13	Grade II = 10 Grade III = 3	-	-	-	-	-	-
Anterior knee pain scale score ^b	98.6 ± 3.4	68.7 ± 20.8	-	-	29.9 (17.8–42)	<0.001*	-	1.94
WOMAC scores ^c								
Pain ^d	0.1 ± 0.3	2.8 ± 3.1	0 (0)	1 (6)	-2.7 (-4.5 to -0.9)	0.003* ^g	36,000	1.19
Stiffness ^e	0.2 ± 0.4	1.9 ± 1.6	0 (0.5)	2 (3.5)	-1.7 (-2.6 to -0.8)	0.005* ^g	35,000	1.41
Physical function ^f	0.9 ± 2.2	10.9 ± 10.5	0 (0.5)	9 (14)	-10 (-16.1 to -3.9)	<0.001* ^g	15,000	1.28

^aLevel of physical activity according to WHO.³³
^bRange of possible scores: 0–100.
^cMedians and interquartile ranges for WOMAC domain scores.
^dRange of possible scores: 0–20.
^eRange of possible scores: 0–8.
^fRange of possible scores: 0–68.
^gp values for Mann-Whitney U tests.
*Significant difference; p ≤ 0.05.
BMI, body mass index; IQR, interquartile range; KL, Kellgren and Lawrence; SD, standard deviation; WHO, World Health Organization; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

Table 2. Isokinetic peak torque, total work, and average power (mean \pm SD) for eccentric and concentric knee extension and flexion in patellofemoral osteoarthritis group and control group.

Measures knee motion	Group		Mean difference (95% CI)	p value	Effect size	
	Control (n = 13)	Patellofemoral osteoarthritis (n = 13)				
Peak torque (Nm/kg·100)						
CONC	Extension	203.9 \pm 53.8	145.8 \pm 37.9	58.1 (20.4–95.8)	0.004*	1.21
	Flexion	98.7 \pm 21.8	71.3 \pm 27.9	27.4 (4.1–47.7)	0.01*	1.06
ECC	Extension	268.7 \pm 57.1	207.8 \pm 38.9	60.9 (21.4–100.5)	0.004*	1.21
	Flexion	168.3 \pm 41.7	141.1 \pm 32.1	27.2 (–2.9 to 57.3)	0.07	0.71
Total work (J/kg·100)						
CONC	Extension	826.5 \pm 238.9	579.6 \pm 210.5	246.9 (64.6–429.2)	0.01*	1.06
	Flexion	441 \pm 110.3	300.9 \pm 154.9	140.1 (31.3–249)	0.01*	1.01
ECC	Extension	1,081.5 \pm 283	760.3 \pm 251.2	321.2 (104.6–537.8)	0.005*	1.16
	Flexion	731.9 \pm 204.3	552.5 \pm 210.7	179.4 (11.4–347.4)	0.04*	0.84
Average power (W/kg·100)						
CONC	Extension	128.1 \pm 33.7	82.5 \pm 33.3	45.6 (18.5–72.7)	0.002*	1.32
	Flexion	67.1 \pm 15.4	43.3 \pm 22.9	23.8 (8–39.6)	0.005*	1.18
ECC	Extension	82.8 \pm 31.1	61.7 \pm 30.8	21.1 (–4 to 46.2)	0.1	0.66
	Flexion	114.7 \pm 33.3	91.4 \pm 27.7	23.3 (–1.5 to 48.1)	0.06	0.74
*Significant difference; $p \leq 0.05$. CI, confidence interval; CON, concentric; ECC, eccentric; J, Joules; kg, kilograms; Nm, Newton meters; SD, standard deviation; W, Watts.						

Table 3. Isokinetic peak torque, total work, and average power (mean \pm SD) for eccentric hip extension, abduction, adduction, external rotation, and internal rotation in patellofemoral osteoarthritis group and control group.

Measures hip motion	Group		Mean difference (95% CI)	p value	Effect size
	Control (n = 13)	Patellofemoral osteoarthritis (n = 13)			
Peak torque (Nm/kg·100)					
Extension	250.5 \pm 54	201.5 \pm 57.3	49 (3.9 to 94.1)	0.03*	0.85
Abduction	191.7 \pm 38.8	157.4 \pm 30.4	34.3 (6.1 to 62.5)	0.02*	0.95
Adduction	203.4 \pm 42.9	169.4 \pm 41.6	34 (-0.2 to 68.2)	0.05*	0.78
External rotation	70.9 \pm 28	64.2 \pm 11.9	6.7 (-10.7 to 24.1)	0.4	0.30
Internal rotation	131.4 \pm 21.9	108.8 \pm 24.7	22.6 (3.7 to 41.5)	0.02*	0.93
Total work (J/kg·100)					
Extension	444.7 \pm 115.1	358.5 \pm 135.9	86.2 (-15.7 to 188.1)	0.09	0.66
Abduction	324.9 \pm 101.5	234.8 \pm 103.7	90.1 (7 to 173.2)	0.04*	0.85
Adduction	424.2 \pm 103.8	304.4 \pm 113.5	119.1 (31.8 to 207.8)	0.01*	1.07
External rotation	132.8 \pm 62.5	104.1 \pm 35.1	28.7 (-12.3 to 69.3)	0.16	0.55
Internal rotation	209.6 \pm 58.5	176.8 \pm 78.5	32.8 (-23.2 to 88.8)	0.24	0.46
Average power (W/kg·100)					
Extension	35.9 \pm 14	30.3 \pm 13.6	5.6 (-5.6 to 16.8)	0.3	0.43
Abduction	23 \pm 11.4	18.4 \pm 11.1	4.6 (-4.5 to 13.7)	0.3	0.40
Adduction	79.1 \pm 16.3	62 \pm 15.7	17.1 (4.2 to 30.1)	0.01*	1.03
External rotation	24.8 \pm 11.1	20.4 \pm 6.1	4.4 (-2.9 to 11.7)	0.2	0.48
Internal rotation	22.5 \pm 7.7	17.5 \pm 8.2	5 (-1.4 to 11.4)	0.1	0.62
*Significant difference: $p \leq 0.05$. CI, confidence interval; J, Joules; kg, kilograms; Nm, Newton meters; W, Watts.					

domains (pain, stiffness, and physical function) and the total score, indicating a reduction in the quality of life of individuals with PFOA. Moreover, these individuals reported greater functional impairment measured using the AKPS.

The PFOA group exhibited lower peak concentric and eccentric torque of the knee compared with the control group of healthy individuals. These findings are compatible with data described

by Baker *et al.* and Høglund *et al.*, who also identified a reduction in isometric strength of the quadriceps in patients with PFOA compared with control subjects.^{7,8} One should bear in mind that Culvenor *et al.* found that concentric weakness of the quadriceps increased the risk of cartilage damage in the lateral patellofemoral joint in women.¹¹ Accordingly, Amin *et al.* found that a concentrically stronger femoral quadriceps seems to protect the patellofemoral joint from the loss of cartilage in the lateral compartment.¹⁰ Thus, we

may infer that the weakness in the volunteers of the present study could be a factor contributing to the progression of the disease.

These findings are not in agreement with those of Macri *et al.*,²² who found no differences between individuals with and without PFOA for knee extensors isokinetic strength. This latter study also evaluated the quadriceps muscle isokinetic strength in patients with knee PFOA using an isokinetic dynamometer. However, our eligibility criteria differ. They included individuals with PFOA grade ≥ 1 according to the KL classification, i.e., at least doubtful narrowing of the joint space with possible osteophyte formation on radiographic, while in our study we included only individuals with PFOA grades 2 or 3, i.e., definite osteophyte formation and possible or definite narrowing of the joint space with some sclerosis, and possibly deformity of bony ends on radiographs. Besides, Macri *et al.* do not mention the relative and absolute frequency of the PFOA degree of their included individuals.²² Perhaps, this may have influenced the comparison of the results of both studies.

To the best of our knowledge, no previous studies have compared the eccentric strength of the femoral quadriceps between individuals with and without PFOA. Functionally, the femoral quadriceps acts eccentrically to decelerate knee flexion during the period of lower limb support in the load response subphase.⁴³ Hinman *et al.* found that impairments in quadriceps activity and the kinematics of the knee of individuals with knee OA when going down stairs may be associated with changes in the joint load.²⁹ Thus, we may suggest that the deficits in eccentric knee strength found in the present study reduced the normal impact absorption action of the joint, which may also be a factor contributing to the progression of the disease.

Peak concentric knee flexor torque was 28% lower in the PFOA group. This finding is compatible with the results of previous studies, in which individuals with knee OA had less knee flexion strength.^{44,45} Hurley and Newham report arthrogenic muscle inhibition in the femoral quadriceps in patients in the early stages of knee OA.⁴⁶ Callaghan *et al.*⁴⁷ also found arthrogenic muscle inhibition in the femoral quadriceps in individuals with PFOA. As arthrogenic muscle inhibition compromises the muscles around the

affected joint and considering the fact that the hamstrings have insertions in the tibia and fibula,⁴⁸ the inhibition of these muscles may also exert an influence on joint degeneration in individuals with isolated PFOA.

We also found that individuals with isolated PFOA exhibit less total work and lower average power in the concentric mode and less total work in the eccentric mode of knee extension as well as less total work and lower mean power in the concentric mode of knee flexion. However, no deficit in peak torque or average power was found in the knee flexor in eccentric mode, although a deficit in total work was found. Thus, the present results suggest that the ability of individuals with PFOA to produce concentric knee flexor strength seems to be more compromised than the production of strength under eccentric conditions. Meireles *et al.*⁴⁹ found that patients with rheumatoid arthritis exhibit less total work of the knee extensors and flexors, which the authors attributed to inflammatory manifestations and atrophy. Thus, lower total work and muscle power values may clinically represent a change in muscle functioning, which may also stem from the inflammatory process and the atrophy of muscle fibers found on knee OA.^{50–52}

The reduction in muscle power may be more critical than the loss of muscle strength in older patients, specifically with regards to the capacity to recover from a sudden trip, as this strategy depends on the power and coordination of the lower limb muscles.^{53–55} Thus, as muscle power is already compromised in individuals with PFOA, it is important for interventions to include high-velocity power training with the aim of enhancing this capacity and improving physical functioning. In individuals with knee OA, the power deficit of the quadriceps and hamstrings is associated with a poorer functional performance and self-reported functioning.^{56–58} Therefore, we encourage studies to explore the potential benefits of exercises with the aim of improving deficits in the muscle power of the knee in individuals with PFOA.

Peak eccentric hip extensor torque was 20% lower in the PFOA group. Høglund *et al.* found a 28% deficit in isometric hip extensor strength in individuals with PFOA.⁸ A systematic review with meta-analysis found moderate evidence indicating less isometric hip extensor strength in individuals with PFP and strong evidence in women with PFP.¹⁷

Although we found no significant difference between groups regarding eccentric knee flexor torque, a difference was found regarding eccentric hip extensor torque. As the knee flexors play a role in the extension of the hip, the reduction in eccentric hip extensor torque must be due to weakness in the monoarticular extensors of the hip – in this case, the gluteus maximus. Eccentric contraction of the hip extensors is necessary during the support phase of the gait cycle. Powers suggests that the weakness of these muscles causes excessive anterior pelvic tilt, resulting in the posterior displacement of the center of mass and an increase in the external flexor moment of the knee.¹⁵ This posterior displacement of the center of mass during functional activities increases the moment of knee flexion and the demand on the knee extensors, resulting in an increase in stress in the patellofemoral joint. Thus, hip extensor weakness may be related to an increase in patellofemoral stress. Crossley *et al.* found that individuals with PFOA have greater anterior pelvic tilt throughout the support phase of the gait cycle as well as greater lateral pelvic tilt, greater hip adduction, and less hip extension during the late support phase.²⁶ Although the researchers did not perform an analysis of hip muscle strength in individuals with PFOA, we may infer that the weakness in the hip extensors and abductors found in the present study could contribute to these possible kinematic abnormalities.

Peak eccentric hip abductor torque was 18% lower in the PFOA group compared with the control group. Comparing isometric strength of the hip abductor in individuals with PFOA with a control group, Pohl *et al.* and Høglund *et al.* found lower strength in those with the disease, which is in agreement with the present findings.^{8,21} In contrast, Macri *et al.* found no differences between individuals with and without PFOA for isometric strength of the hip abductors.²²

The gluteus medius is the main abductor of the hip. The eccentric action of this muscle controls the adduction movement of the hip on the frontal plane during activities with body weight support.¹⁴ Thus, weakness of the gluteus medius can result in excessive hip adduction during activities with unilateral body weight support. Moreover, although this muscle does not directly act on the position of the knee on the frontal plane, Ford *et al.* found a positive correlation between the

adduction movement of the hip and abduction of the knee.⁵⁹ As excessive hip adduction and knee abduction have been related to an increase in patellofemoral stress due to the increase in the lateralizing forces that act on the patella,^{15,60} it is possible that the individuals in the PFOA group of the present study exhibited an increase in patellofemoral stress due to eccentric weakness of the abductor muscles of the hip. Høglund *et al.* found that an increase in the peak angle of tibial abduction during the task of sitting down and standing up from a chair was moderately correlated with reductions in the isometric strength of the hip abductors in 15 individuals (8 with PFOA and 7 controls).⁸

Studies involving individuals with PFP found that excessive contralateral pelvic drop due to weakness of the gluteus medius can lead to compensations, with the ipsilateral tilt of the trunk.^{61,62} Biomechanically, this ipsilateral tilt displaces the vector resulting from the ground reaction force laterally to the center of the knee joint, with the consequent creation of an external abductor moment in the knee. Although we also found a reduction in the strength of the hip abductor in the PFOA group, it is not yet clear whether this strength deficit is accompanied by changes in the kinematics of the lower limbs leading to an increase in hip adduction during functional activities involving weight support and ipsilateral tilt of the trunk. These issues should be investigated in future studies.

The PFOA group also had lower eccentric hip adductor torque in comparison with the control group. Baldon *et al.* report similar results in patients with PFP compared with control subjects.³⁷ In contrast, Rathleff *et al.* found no difference in isometric hip adductor strength between adolescents with and without PFP.⁶³

The posterior fibers of the gluteus medius produce external rotation of the hip.⁶⁴ However, with hip flexion more than 50°, a change in the action of these fibers occurs due to the change in the moment arm, and the fibers then contribute to internal hip rotation.⁶⁵ Thus, the position of the test could have exerted an influence on the results, as we evaluated internal hip rotation torque with the participants sitting on the chair of the equipment with the knee and hip flexed at 90°. Due to the position during the test, the

fibers of the gluteus medius could have been assisting in internal rotation, which may explain why we found a significant difference in the strength of the internal hip rotators between the groups. Thus, the strong gluteus medius in the control group is believed to have contributed positively to this evaluation, whereas the weak gluteus medius in the PFOA group contributed negatively to the generation of internal rotation strength, resulting in lower internal rotator torque in this group.

No difference between groups was found regarding the strength of the external hip rotators. Likewise, Pohl *et al.*, Hoglund *et al.*, and Macri *et al.* also found no significant difference in external hip rotation strength evaluated isometrically between individuals with and without PFOA.^{8,21,22} The weakness of the gluteus medius may have contributed to the deficit in internal rotation of the hip in the PFOA group compared with the control group, but the same was not found regarding external hip rotation, as the posterior fibers of the gluteus medius would not contribute to external rotation due to the positioning on the test (volunteers seated with hip and knee flexed at 90°). Pohl *et al.* and Hoglund *et al.* also performed the evaluation of external hip rotation strength with the individuals sitting with the hip and knee flexed at 90°.^{8,21}

Besides the deficits in muscle strength, the individuals with PFOA also had a higher level of pain and stiffness as well as compromised physical functioning. The PFOA group had higher values than the control group for all three domains of the WOMAC questionnaire and a lower score on the AKPS. These findings indicate an altered perception of pain as well as compromised joint mobility and physical functioning stemming from the disease. Similar results are described in the literature, as individuals with knee OA report more pain, stiffness, and compromised physical functioning.^{66,67}

The present findings are relevant, indicating that individuals with isolated PFOA have impaired muscle strength of the knee and hip. Moreover, the contribution of a possible muscle inhibition resulting in a reduction in the strength of the knee flexors and extensors as well as the hip extensors, abductors, adductors, and external rotators implies an impaired capacity for activities of daily

living in individuals with PFOA. Therefore, evaluation of this musculature is important in clinical practice, in addition to incorporating strengthening approaches to these muscular groups during treatment regimens. Weakness of the gluteus medius and maximus muscles can result in excessive adduction and medial rotation of the hip during activities with unilateral support, leading to an increase in the dynamic valgus of the knee and, consequently, an increase in the lateralizing forces acting on the patella, causing greater joint stress and possible worsening of the symptoms. Also, our results suggest that individuals with PFOA do not present alterations in the strength of the hip lateral rotator muscles. However, the approach to assess this muscle group needs to be further investigated.

Future investigations are also needed to study the relationship between concentric and eccentric knee torque, eccentric hip torque and the pelvis, and hip and knee kinematics in individuals with PFOA. Also, there is a need to better understand whether the addition of exercises that address the strength deficits of this musculature in individuals with PFOA improves pain and physical function. Strong and high-quality evidence recommends strengthening the muscles of the hip and knee in the conservative treatment of people with knee OA.⁶⁸⁻⁷⁰ In PFOA, there is a lack of randomized clinical trials on the effects of a program to strengthen the muscles of the lower limb. However, the results of a pilot feasibility study suggest that hip strengthening and a core stabilization program may be beneficial in improving symptoms, function, and physical performance in people with PFOA.⁷¹ These findings are preliminary but promising, and further clinical studies will determine which muscle group should be addressed and whether concentric, eccentric, and/or isometric strengthening is more effective in improving pain symptoms, especially during functional activities, in the rehabilitation program for patients with PFOA.

This study has limitations that should be considered. Although strength deficits were found in the hip and knee muscles of the individuals with PFOA, we cannot relate these findings to the progression of the disease. Thus, prospective studies are needed for a better follow-up of the role of functional changes in the knee and hip muscles in the pathogenesis of PFOA. Moreover, considering

the changes in function and strength in this population, studies involving the rehabilitation of individuals with isolated PFOA are essential to clinical practice. Finally, we evaluated several characteristics of muscle capacity, which is a highlight of the study since little is known about these characteristics in PFOA, especially about the peak concentric and eccentric torque of the lower limb muscles as well as total work and average power. However, as it is an exploratory study, we chose not to adjust the results for multiple testing to avoid power reduction and minimize type II error.^{72,73} Although correction for multiple comparisons can reduce the likelihood of spurious findings (type I error), it can also increase the likelihood of false negatives (type II error), i.e., truly important differences are considered non-significant.^{72,73} Thus, the results of this study should be considered in this context.

Conclusions

In the present study, the individuals with isolated PFOA exhibited a reduction in muscle capacity of the knee extensors and flexors as well as the hip extensors, abductors, adductors, and external rotators in comparison with healthy controls. The individuals with PFOA also had high levels of pain and stiffness as well as compromised physical functioning.

Conflict of interest statement

The authors declare that there is no conflict of interest.

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Ethical approval statement

This study was approved by the Human Research Ethics Committee of Federal University of São Carlos (certificate number: 96324918.4.0000.5504).

ORCID iD

Cristiano Carvalho  <https://orcid.org/0000-0003-1174-0015>

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