

[RESEARCH REPORT]

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Hip Strength and Hip and Knee Kinematics During Stair Descent in Females With and Without Patellofemoral Pain Syndrome

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Patellofemoral pain syndrome (PFPS) is a common problem experienced by active adults and adolescents³¹; however, its etiology has remained vague and controversial.²² Unlike other knee dysfunctions (eg, anterior cruciate ligament injury), which often have a specific onset and mechanism of injury, patients with PFPS generally report diffuse peripatellar and retropatellar pain of an insidious onset. Dye⁹ has described PFPS as an orthopedic “

enigma” because of the continued misunderstanding of its etiology.

A commonly accepted hypothesis regarding PFPS etiology has been abnormal patella tracking that causes increased lateral compressive patellofemoral joint stress.^{8,13} Researchers^{17,29} have examined the quadriceps angle (Q-angle) to better understand this phenomenon. The Q-angle, formed by drawing a line from the anterior superior iliac spine (ASIS) to the patella's midpoint and another from the patella's midpoint to the tibial tubercle, represents the resultant lateral quadriceps pull. Therefore, an increased Q-angle may predispose the patella to excessive lateral tracking and stress.^{19,29} Mizuno et al²⁰ and Elias et al¹¹ have reported increased patellofemoral joint stress in response to an increased Q-angle.

Many studies have not supported the relationship between an increased Q-angle and PFPS, possibly because of the static nature of this measure.^{14,25} However, Powers²⁵ has described lower limb motions that may increase the Q-angle during dynamic movements. Excessive knee valgus from hip adduction (movement of the femur relative to the pelvis) increases the Q-angle because it displaces

• **STUDY DESIGN:** Cross-sectional.

• **OBJECTIVE:** To determine if females presenting with patellofemoral pain syndrome (PFPS) from no discernable cause other than overuse demonstrate hip weakness and increased hip internal rotation, hip adduction, and knee valgus during stair descent.

• **BACKGROUND:** Historically, PFPS has been viewed exclusively as a knee problem. Recent findings have indicated a possible association between hip weakness and PFPS. Researchers have hypothesized that patients who demonstrate hip weakness would exhibit increased hip internal rotation, hip adduction, and knee valgus during functional activities. To date, researchers have not simultaneously examined hip and knee strength and kinematics in subjects with PFPS to make this determination.

• **METHODS AND MEASURES:** Eighteen females diagnosed with PFPS and 18 matched controls participated. Strength measures were taken for the hip external rotators and hip abduc-

tors. Hip and knee kinematics were collected as subjects completed a standardized stair-stepping task. Independent *t* tests were used to determine between-group differences in strength and kinematics during stair descent.

• **RESULTS:** Subjects with PFPS generated 24% less hip external rotator ($P = .002$) and 26% less hip abductor ($P = .006$) torque. No between-group differences ($P > .05$) were found for average hip and knee transverse and frontal plane angles during stair descent.

• **CONCLUSION:** Subjects with PFPS had significant hip weakness but did not demonstrate altered hip and knee kinematics as previously theorized. Additional investigations are needed to better understand the association between hip weakness and PFPS etiology.

• **LEVEL OF EVIDENCE:** Symptom Prevalence, Level 4. *J Orthop Sports Phys Ther* 2008;38(1):12-18. doi:10.2519/jospt.2008.2462

• **KEY WORDS:** anterior knee pain, hip abduction, hip external rotation, kinematics

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the patella medially relative to the tibial tubercle. Similarly, excessive hip internal rotation positions the patella more medially relative to the tibial tubercle.²⁷ Based on these findings, researchers^{16,25,27,28} have theorized that hip abductor and hip external rotator weakness may cause excessive hip adduction and hip internal rotation, respectively, thus contributing to patellofemoral joint stress. More importantly, recent studies^{18,28,32} have reported favorable outcomes in patients who participated in a rehabilitation program targeting the hip musculature.

Ireland et al¹⁶ and Robinson and Nee²⁸ both have reported hip abductor and hip external rotator weakness in females having an insidious onset of PFPS. Although they concluded that weakness might predispose the patella to lateral tracking, neither investigation examined hip or knee kinematics. It was unknown if subjects actually demonstrated excessive hip adduction, hip internal rotation, and knee valgus during a dynamic activity.

Mascal et al¹⁸ reported hip abductor and hip external rotator weakness in 2 subjects diagnosed with PFPS before and after a 14-week intervention that focused on hip, pelvis, and trunk strengthening. They also measured frontal and transverse plane hip kinematics during a step-down maneuver for 1 of the subjects. At the end of the intervention, the subject who underwent the kinematic assessment showed a 50% and 317% increase in hip abductor and hip external rotator strength. Average hip frontal plane motion changed from 8.7° to 2.3° adduction immediately following the intervention. Hip transverse plane motion changed from 1.4° internal rotation to 2.6° external rotation. Mascal et al¹⁸ concluded that improved kinematics would move the patella lateral relative to the ASIS and decrease the dynamic Q-angle. A limitation of this case report was that they did not examine knee kinematics. It was unclear what effect, if any, hip weakness had on knee valgus. Therefore, additional studies that simultaneously examine hip and knee strength and kinematics are needed to

better understand this interrelationship.

The purpose of this study was to compare hip strength and hip and knee kinematics in subjects with no discernable cause of PFPS, except for overuse, to matched controls. We hypothesized that subjects with PFPS would demonstrate (1) significantly less hip abductor and hip external rotator strength and (2) greater hip adduction, hip internal rotation, and knee valgus angle during stair descent. We chose subjects with no discernable cause of PFPS, except for overuse, because this cohort best represents the majority of people diagnosed with PFPS.¹³

METHODOLOGY

Subjects

RECENT STUDIES^{10,15} HAVE SUGGESTED gender differences associated with strength and kinematics. Therefore, only female subjects were included in this study. All subjects were recruited from the greater Lexington, KY area through various forms of advertisement (flyers posted in area physicians' offices, area physical therapy clinics, athletic health clubs, and University common areas) and reported to the University of Kentucky Biodynamics Laboratory for testing. We recruited 18 females for the experimental group (mean \pm SD age, 24.5 \pm 3.2 years; height, 1.7 \pm 0.1 m; body mass, 63.1 \pm 9.1 kg; duration of symptoms, 14.4 \pm 12.8 months). Each subject in the experimental group was matched with an asymptomatic female with respect to age, height, and body mass. A total of 18 females comprised the control group (mean \pm SD age, 23.9 \pm 2.8 years; height, 1.7 \pm 0.1 m; body mass, 62.1 \pm 8.5 kg).

Females in the experimental group participated in this study if they complained of (1) anterior knee pain during stair descent, (2) pain for a minimum of 1 month, and (3) pain during at least 2 of the following provocative activities: (a) stair ascent, (b) squatting, (c) kneeling, or (d) prolonged sitting. They also rated usual knee pain over the previous week at a minimum of 3 on a 10-cm visual ana-

log scale (VAS).⁵ Six subjects reported bilateral symptoms. In these individuals, the most affected lower extremity was tested.²⁶ Control subjects participated in the study if they had (1) no history or diagnosis of knee pathology, (2) no pain with any of the above-named provocative activities, and (3) no history of hip pathology. The right lower extremity was tested for control subjects.²¹

Subjects were excluded if they had (1) previous knee surgery or significant injury, (2) traumatic patellar dislocation, (3) any neurologic involvement that would affect gait, or (4) previous hip surgery or significant injury. Inclusion and exclusion criteria were consistent with other published literature.^{16,32} No subjects in the experimental group reported episodes of patella instability; all reported symptoms that were consistent with an insidious onset of PFPS from overuse.¹³

Prior to participation, all subjects signed an informed consent approved by the University of Kentucky Institutional Review Board and their rights were protected. All procedures followed were in accordance with the ethical standards of The University of Kentucky Institutional Review Board.

Instrumentation

We assessed pain using a 10-cm VAS.⁴ The extreme left side of the VAS stated "no pain," whereas the extreme right side stated "worse pain imaginable." Subjects drew a perpendicular line on the scale at the position that most likely described their usual pain over the previous week.⁶

All isometric strength testing was performed using the Commander PowerTrack II (J Tech Medical, Salt Lake City, UT) handheld dynamometer (HHD). This digital strain-gauge dynamometer has a maximum load cell capacity of 556.3 N, with a manufacturer-reported accuracy of 99%. The HHD's calibration was confirmed prior to the study by placing known weights on the HHD and comparing this to the HHD's reported weight. Accuracy was verified after every 10th testing session.

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Video data were recorded using a 7-camera video-based motion capture system (Motion Analysis Corporation, Santa Rosa, CA) operating at 60 Hz. A 3-dimensional volume of approximately $2.0 \times 1.2 \times 1.8$ m was calibrated in accordance with manufacturer-recommended procedures, yielding mean residual errors of less than 2.5 mm.

Procedures

First, subjects completed a 10-cm VAS to report the typical pain level during the past week.⁶ Next, we measured the distance from the greater trochanter to the lateral femoral condyle and from the lateral femoral condyle to the lateral malleolus using a cloth tape measure. These distances represented the external moment arm for the applied force (eg, point of application of the HHD) during hip abductor and hip external rotator strength testing, respectively.³⁴ These measures enabled the conversion of the isometric strength measures to units of torque (Nm). Isometric strength measures were taken for the hip abductors and hip external rotators in the same manner described by Ireland et al.¹⁶ For the hip abductors, subjects were positioned on a plinth in side lying (unaffected lower extremity directly on the table), with the test lower extremity in a neutral position by placing pillows between the lower extremities. The HHD was placed over the lateral femoral condyle. An immovable strap was pulled through the HHD and secured around the plinth. For the hip external rotators, subjects sat on the plinth with the hips and knees flexed to 90°. The HHD was placed just proximal to the medial malleolus. An immovable strap was pulled through the HHD and secured around a stationary object (in an opposite line of pull to resist hip external rotation). To minimize substitution of the hip adductors and hip flexors, a towel roll was placed between the subjects' knees and the examiner manually stabilized the thigh during testing (to minimize hip flexion).

For testing, subjects produced a maximum voluntary isometric contraction using the "make test"² to the beat of a

metronome set at 60 beats per minute. They generated maximum force over a 2-second period and maintained this force for an additional 5 seconds. Subjects performed 1 practice trial² and 3 test trials, with a 30-second rest period between trials. A coefficient of variation was calculated and an additional trial was taken, if necessary, to ensure that subjects had 3 measures with variability less than 10%.¹ The order of muscle testing was randomly determined to account for any potential order bias. All measures of force were recorded in Newtons.

Next, retroreflective markers with a diameter of 20 mm were placed on the subjects using a standard Cleveland Clinic marker setup. After collecting an anatomic calibration file, subjects were shown the stair stepping task and allowed 5 practice trials. They were instructed to ascend and descend two 20-cm-high steps, ensuring that the test extremity lifted and lowered the body on the first and third steps, respectively (FIGURE 1). Subjects also took a minimum of 3 strides prior to and immediately following stair stepping to maintain a continuous movement pattern. All subjects performed the task at a standardized rate of 96 beats per minute.⁵

After demonstrating proficiency with the stair-stepping task, subjects performed 10 test trials. Data from the last 5 trials were analyzed because of potential learning effects that might have been associated with earlier trials, even with subjects having performed 5 practice trials. Seven control subjects returned to the laboratory within 5 to 7 days to determine measurement reliability. For this purpose, they completed all procedures in the identical manner as on the initial testing day.

Data Processing

Strength We expressed hip abductor strength in units of torque by multiplying the force recorded on the HHD by the distance from the greater trochanter to the lateral femoral condyle.³⁴ We expressed external rotator strength in units

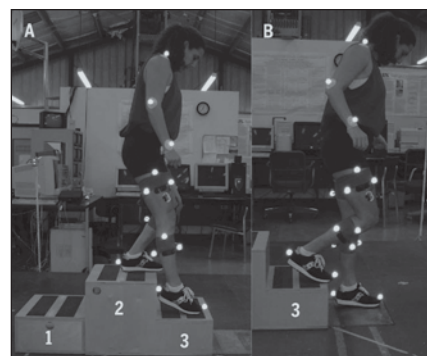


FIGURE 1. Stair descent interval. Stair descent began when the test extremity's foot initially contacted the third step (A) and ended as test extremity's foot was lifted off the third step (B).

of torque by multiplying the force recorded on the HHD by the distance from the lateral femoral condyle to the lateral malleolus.³⁴ The average torque from 3 trials having a coefficient of variation less than 10% was then normalized to subject height and weight ($[\text{torque (Nm)} \div \text{body weight (N)} \times \text{subject height (m)}] \times 100$) to allow for comparison among subjects.¹² The normalization procedure resulted in strength being expressed without units. These values were used for statistical analysis.

Kinematics Video data were tracked and smoothed using a fourth-order Butterworth zero-phase-lag low-pass filter, with a cutoff frequency of 6 Hz, using EVaRT 4.2 software (Motion Analysis Corporation). Hip transverse plane, hip frontal plane, and knee frontal plane angles for the last 5 individual trials were calculated using OrthoTrak 5.0 software (Motion Analysis Corporation). Individual trials were normalized to 100% of the gait cycle and ensemble averaged. Average joint angles during the stance phase of stair descent were used for statistical analysis. The stance phase of stair descent began at the point of initial toe contact on the third step and ended at the point when the toe was lifted off the step (FIGURE 1).³ We determined toe contact when toe velocity was zero.

Statistical Analysis

Independent *t* tests were used to determine group differences for age, height,

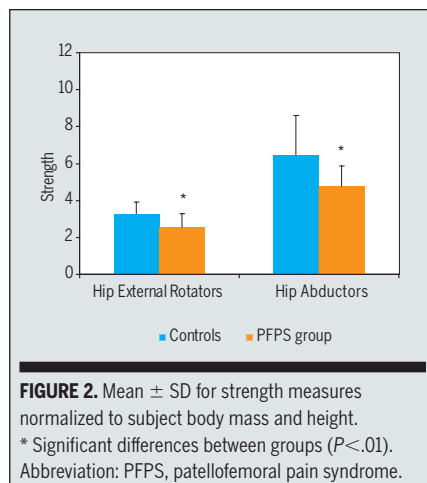
and body mass. Intraclass correlation coefficients³⁰ (ICCs) were used to determine between-day reliability. Standard errors of measurements⁷ (SEMs) were used to determine measurement precision for all dependent measures. The SEM for each measure was calculated using its standard deviation(s) and ICC in the following manner: $SEM = s\sqrt{1-ICC}$.⁷ Based on this equation, measures having limited variability (a small standard deviation) would have a lower SEM. Denegar and Ball⁷ have stated that measures with a relatively lower ICC but a small SEM suggest that the amount of measurement inconsistency would occur in an acceptably small range.

Separate independent *t* tests were used to determine group differences in hip external rotator and hip abductor strength as well as differences in hip and knee joint angles. All statistical analyses were performed using SPSS Version 12.0 (SPSS, Inc, Chicago, IL). Level of significance was established at the .05 level. The Bonferroni correction was used to adjust the level of significance for the independent *t* tests' multiple comparisons to protect against a possible type I error.²⁴ The *P* value for strength values was adjusted to the .025 level and the *P* value for kinematic values was adjusted to the .017 level.

RESULTS

SUBJECTS WITH PFPS RATED USUAL pain over the previous week an average (\pm SD) of 4.4 ± 1.5 cm on the VAS. Independent *t* tests for subject demographics revealed similar age, height, and body mass ($P > .44$) characteristics for both groups. ICC_{3,3} for hip external rotator strength was 0.85 with a SEM of 0.31, and 0.97 with a SEM of 0.46 for hip abductor strength. ICC_{3,5} was 0.75 with a SEM of 4° for the hip transverse plane angle and 0.81, with a SEM of 1° for the hip frontal plane angle. ICC_{3,5} for the knee frontal plane angle was 0.88 with a SEM of 4°.

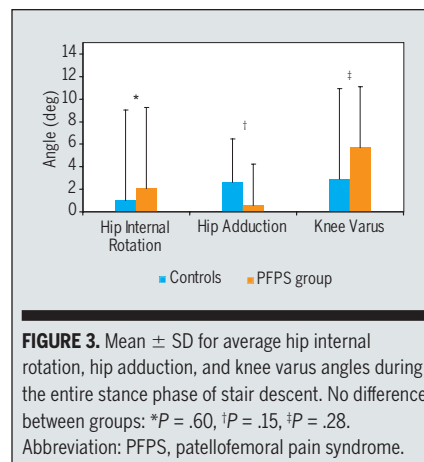
Results from separate independent *t*



tests showed significantly lower hip external rotator strength ($P = .002$) and hip abductor strength ($P = .006$) for subjects with PFPS. On average, these subjects generated 24% less hip external rotator torque and 26% less hip abductor torque compared to controls (FIGURE 2). Subjects with PFPS demonstrated similar hip internal rotation (2.1° compared to 1.0° ; $P = .67$) and hip adduction (1.0° compared to 2.6° ; $P = .15$) to that of controls during stair descent. Although not significantly different, subjects with PFPS maintained the knee in greater varus (5.7° compared to 2.9° ; $P = .28$) than controls (FIGURE 3).

DISCUSSION

THE PURPOSE OF THIS STUDY WAS TO compare hip strength and hip and knee kinematics in subjects with no discernable cause of PFPS, except for overuse, to matched controls. We initially hypothesized that females with PFPS would demonstrate less hip external rotator and hip abductor strength. We also believed that hip weakness would result in greater hip internal rotation, hip adduction, and knee valgus during stair descent. Results from this study partially supported these hypotheses. Subjects with PFPS demonstrated hip external rotator and hip abductor weakness; however, no differences were found with respect to hip internal rotation and hip adduction angles during stair descent.



Moreover, all subjects maintained a knee varus position during stair descent.

Hip Strength

Ireland et al¹⁶ were the first to specifically identify hip external rotator and hip abductor weakness in females diagnosed with PFPS. They reported that subjects with PFPS demonstrated 36% less hip external rotator strength and 26% less hip abductor strength than controls. They expressed strength in N of force (instead of torque) normalized to subjects' weight. Because we positioned subjects in an identical manner (eg, identical hip position and HHD placement) for all strength testing, we were able to conduct a secondary analysis to compare results.

For this purpose, we expressed the force (N) values as a percent of the subjects' body weight (BW). Subjects with PFPS in the current study generated mean \pm SD hip external rotator force equal to $11.1\% \pm 3.1\%$ BW, compared to $10.8\% \pm 4.0\%$ BW in the Ireland et al¹⁶ study. Average \pm SD hip abductor force for our subjects with PFPS was $22.5\% \pm 5.9\%$ BW, compared to $23.3\% \pm 6.9\%$ BW reported by Ireland et al.¹⁶ We also found that subjects with PFPS demonstrated 24% less hip external rotator strength and 26% less hip abductor strength than controls. It was noteworthy that strength values and between-group percent differences from 2 independent investigations were similar for this patient population.

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Robinson and Nee²⁸ assessed hip external rotator and hip abductor strength for the affected and contralateral (unaffected) side of subjects with PFPS and dominant and nondominant side of controls. Subjects with PFPS had mean \pm SD hip external rotator strength values equal to 16% \pm 6% BW, which agreed with the current study and Ireland et al.¹⁶ Subjects with PFPS also exhibited 30% less hip external rotator strength compared to the control group's dominant side and 15% less strength than their contralateral side.

Robinson and Nee²⁸ reported average \pm SD hip abductor strength values of 16% \pm 8% BW. Subjects with PFPS exhibited 27% less hip abductor strength compared to the control group's dominant side and 23% less strength than their contralateral side. These smaller hip abductor strength values, relative to those found in the current study and Ireland et al.,¹⁶ were likely due to the testing methodology. When assessing hip abductor strength, Robinson and Nee²⁸ positioned subjects in a side-lying position, abducted the hip to 30°, and placed the HHD just proximal to the lateral malleolus. This position led to a greater mechanical advantage (greater moment arm) for the tester and also reduced hip abductor muscle fiber length. In summary, Robinson and Nee²⁸ provided additional evidence of a possible association between hip weakness in this patient population. Furthermore, they identified hip strength deficits between the affected and unaffected side in females presenting with unilateral PFPS.

Unlike others,^{16,28} Piva et al.²³ did not report hip external rotator and hip abductor weakness in a similar patient population. A major difference was that the researchers did not secure the HHD to the extremity being tested with an immovable strap. Wikholm and Bohannon³³ and Agre et al.¹ reported that inadequate stabilization can affect a subject's ability to exert a maximum contraction. Another difference resulted from subject position, especially when testing the hip external rotators. Piva et al.²³ assessed subjects in

a prone position with the hip extended and knee flexed to 90°. We chose to assess hip external rotator strength in a sitting position to enable comparison to other studies.^{16,28}

Kinematics

To date, only Mascal et al.¹⁸ have examined the interrelationship between hip strength and hip kinematics. In this case report, the 1 subject who underwent a biomechanical assessment demonstrated improved hip strength and kinematics (eg, less hip internal rotation and hip adduction) during a step-down maneuver following a 14-week core-strengthening intervention. These data provided preliminary evidence to support the theory regarding hip weakness and altered lower extremity kinematics.²⁵

Our study was the first to examine this interrelationship in a larger group of subjects with PFPS. However, our findings did not support this theory,²⁵ as subjects with hip weakness did not demonstrate excessive hip internal rotation, hip adduction, and knee valgus compared to controls. One reason for this finding may have been related to the chosen task. We assessed subjects during stair descent at a rate of 96 beats per minute because it represented an activity associated with PFPS. This task may not have been challenging enough and may have resulted in our subjects with PFPS having sufficient hip strength to maintain similar lower extremity alignment as controls during stair descent. Also, our subjects with PFPS reported on average \pm SD pain duration of 14.4 \pm 12.8 months, indicating a chronic condition. Over the course of time, subjects might have adjusted their movement pattern to avoid pain. We could not conclusively make this determination because pain was not specifically assessed during stair descent.

Although hip weakness has been associated with PFPS, our findings suggest that hip weakness may not necessarily result in altered hip and knee kinematics. Although limited data have inferred this relationship,¹⁸ it remains elusive if

patients demonstrated hip weakness and faulty lower extremity mechanics prior to developing PFPS. Therefore, some of our subjects might have developed PFPS initially from other bony structural factors or soft tissue restrictions that eventually resulted in hip weakness. Prospective studies specifically designed to assess these variables are needed to better understand these influences.

Clinical Implications

Like prior findings,^{16,23,28} subjects with PFPS demonstrated both hip external rotator and hip abductor weakness. These results further support the current trend of incorporating hip strengthening in PFPS rehabilitation, especially for patients with evident hip weakness. Clinicians may use findings from the current study to identify patients with evident hip weakness (hip external rotator force values less than approximately 12% BW and/or hip abductor force values less than approximately 26% BW) that might benefit from this intervention approach. When using these reference values, clinicians must assess patients in the same manner as our study, regarding patient position and location of the applied resistance. Finally, we recommend the use of HHD in conjunction with stabilization straps as differences in examiner resistance can affect these measures.³³

Limitations

This study had several limitations. First, the primary examiner was not blinded to each subject's condition. Bias might have been introduced unintentionally during data collection and analysis. We did minimize potential bias by taking measures in accordance with a standardized protocol. ICCs for all dependent measures exceeded 0.75, which inferred good stability of measures.²⁴ Second, we chose subjects with no discernable cause of PFPS, except for overuse, and inclusion criteria reflected signs and symptoms used clinically to diagnose PFPS.^{13,32} Subjects in the PFPS group might have had other contributing factors. Third, we assessed subjects using

a stair-stepping task representative of a task that provokes patellofemoral joint pain.⁵ The task was relatively simple and subjects might have exhibited altered lower extremity mechanics if assessed during a more challenging maneuver. Fourth, our data had relatively high variability, especially when measuring hip transverse plane motion. Although variability might have represented between-subject differences in motor performance, it likely highlighted the continuing difficulty associated with measuring frontal and transverse plane movement.³⁵ Finally, we did not assess pain during testing. Subjects might have exhibited different kinematics in the presence of pain.

Future Research

Although independent studies have reported hip weakness in this subject population, it remains elusive if such weakness was the cause or the result of PFPS. Prospective studies are necessary for addressing this question. PFPS also is a multifactorial problem and clinicians have used many treatment approaches (eg, patella taping, quadriceps strengthening, bracing) with various level of success. It is unclear if all patients with PFPS will respond favorably to hip strengthening. Future studies should focus on delineating a patient cohort that may respond more favorably to this intervention approach.

CONCLUSION

OUR RESULTS AGREED WITH PRIOR works that have identified hip weakness in females diagnosed with PFPS. However, our subjects with PFPS did not demonstrate excessive hip internal rotation, hip adduction, or knee valgus angle during stair descent. Although hip weakness is a prevalent impairment for this patient population, our findings question an absolute direct association between hip weakness and altered lower extremity mechanics. These incongruent findings support the need for additional research to better understand the relationship between hip weakness, hip

and knee kinematics, and patellofemoral joint pressure. ●

KEY POINTS

FINDINGS: Researchers have identified hip weakness in patients with patellofemoral pain syndrome and suggest that weakness causes excessive hip internal rotation, hip adduction, and knee valgus during functional activities. Although our subjects exhibited hip weakness, they did not demonstrate altered lower extremity kinematics as previously theorized.

IMPLICATION: Findings from this study highlight the need for additional research to establish an absolute direct association between hip weakness and altered lower extremity kinematics.

CAUTION: It has not been determined whether hip weakness is the cause or the result of PFPS.

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