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An Evaluation of Hip Strength and Femoral Structure in Women With and Without Patellofemoral Pain

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Background: Recent studies have suggested that excessive hip internal rotation during dynamic tasks may be associated with patellofemoral pain. Although diminished hip-muscle strength and altered femoral morphologic characteristics have been implicated in abnormal hip rotation in persons with patellofemoral pain, no study has confirmed this hypothesis.

Hypothesis: Women with patellofemoral pain would demonstrate increased average hip internal rotation, decreased hip-muscle performance, and abnormal femoral shape compared with controls. Furthermore, measures of hip strength and femoral shape are predictive of average hip internal rotation during running.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Nineteen women with patellofemoral pain and 19 pain-free controls participated. Lower extremity kinematics during running, hip-muscle performance, and femoral morphologic characteristics on magnetic resonance imaging were quantified. Independent *t* tests were used to assess group differences. Stepwise linear regression was used to determine whether measures of strength and/or structure were predictive of average hip internal rotation during running.

Results: Participants with patellofemoral pain demonstrated significantly greater average hip internal rotation (8.2° ± 6.6° vs 0.3° ± 3.6°; $P < .001$), reduced hip-muscle strength in 8 of 10 hip strength measurements, and greater femoral inclination (132.8° ± 5.2° vs 128.4° ± 5.0°; $P = .011$) compared with controls. Stepwise regression revealed that isotonic hip extension endurance was the only predictor of average hip internal rotation ($r = -.451$; $P = .004$).

Conclusion: Abnormal hip kinematics in women with patellofemoral pain appears to be the result of diminished hip-muscle performance as opposed to altered femoral structure. The results suggest that assessment of hip-muscle performance should be considered in the evaluation and treatment of patellofemoral joint dysfunction.

Keywords: biomechanics; hip; medical imaging; motion analysis

It has been suggested that abnormal hip kinematics may play a role in the development of patellofemoral pain (PFP).[23] In particular, excessive hip internal rotation is thought to contribute to patellofemoral joint malalignment[27] and increased patellofemoral joint stress.[15] Diminished hip-muscle strength and abnormal femoral structure have been proposed as contributing to abnormal hip kinematics in persons with PFP.[11,23]

Given the proposed link between hip-muscle performance and PFP, several studies have investigated hip-muscle strength in this population. In 2003, Ireland et al[11] reported decreased hip abductor and external rotator strength in female subjects with PFP when compared with a control group. These findings have been confirmed in subsequent investigations by Robinson and Nee,[28] Cichanowski et al,[4] and Bolgla et al.[2] However, a limitation of these studies is that hip strength was quantified using a handheld

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dynamometer during isometric contractions. Given that the gluteus maximus and gluteus medius act eccentrically to control hip adduction and internal rotation during weightbearing, it would appear that a more thorough assessment of hip-muscle performance may provide additional insight into the relationship between hip strength and PFP.

With respect to femoral structure, 2 abnormalities are thought to be related to PFP: (1) femoral inclination (ie, coxa valga/coxa vara) and (2) femoral anteversion.[6,23] More specifically, greater degrees of femoral inclination and femoral anteversion are thought to influence lower extremity alignment as well as hip-muscle moment arms.[1,13,21] In a computational modeling study investigating the influence of abnormal femoral morphologic characteristics in children with cerebral palsy, Arnold et al[1] reported that a 20° increase in femoral inclination (coxa valga) reduced the gluteus medius moment arm by 26%. As a result, it has been postulated that abnormal femoral inclination may contribute to functional weakness of the hip abductors, resulting in excessive hip adduction and dynamic knee valgus during weightbearing activities.[23] To date, no studies have investigated femoral inclination in a PFP population.

In contrast to femoral inclination, individuals with PFP have been reported to have higher degrees of femoral anteversion.[6] Excessive femoral anteversion has been associated with greater degrees of passive and dynamic hip internal rotation.[13,30,31] In addition, simulated femoral anteversion has been shown to increase patellofemoral joint stress in an in vitro study.[15] Furthermore, it has been reported that a combination of excessive anteversion and inclination may lead to a 69% reduction in the gluteus medius moment arm.[1]

Although diminished hip strength and altered femoral morphologic characteristics have been hypothesized to contribute to abnormal hip kinematics and PFP, it is not known how these factors relate to dynamic function. For example, do measures of strength and/or structure predict hip kinematics? The purpose of the current study was to determine if hip-muscle performance and femoral structure differ between women with PFP and pain-free controls, and to determine to what degree these measures predict average hip internal rotation during running. Given the previous work in this area, it was hypothesized that women with PFP would demonstrate increased average hip internal rotation, decreased hip-muscle performance, and abnormal femoral shape when compared with a control group. Furthermore, it was hypothesized that measures of hip strength and femoral structure would be predictive of average hip internal rotation during running.

MATERIALS AND METHODS

Participants

Two groups of participants were recruited for this study. Nineteen women with a diagnosis of PFP composed the experimental group, while 19 pain-free women served as a control group (Table 1). Only female participants were included because of the higher incidence of PFP in women and because of potential differences in hip structure between genders.[5,8,17,34] Individuals over 45 years of age were excluded from the study to control for the possible effects of overt degenerative joint disease. Participants in the PFP group were recruited from local physical therapy and orthopaedic clinics in the Los Angeles area. Controls were selected from a group of approximately 60 women who responded to a university-wide recruitment effort (posted flyers). In general, participants in both groups were young, active individuals.

TABLE 1
Participant Characteristics[a]

	Patellofemoral Pain (N = 19)	Controls (N = 19)	*P* Value
Age (y)	27 ± 6	26 ± 4	.35
Height (m)	1.69 ± .08	1.68 ± .06	.71
Weight (kg)	64.7 ± 10.4	62.9 ± 6.8	.45

[a]Mean ± standard deviation.

Assignment to the PFP group was established based on symptoms and physical examination results. Candidates were screened through physical examination to rule out ligamentous or meniscal injury, patellar tendinitis, and large knee-joint effusion.[24,25] Only those candidates meeting the following criteria were admitted to the experimental group: (1) pain originating specifically from the patellofemoral articulation (vague or localized); (2) readily reproducible pain (3 of 10 based on a visual analog scale), with at least 2 of the following functional activities commonly associated with PFP—stair ascent or descent, squatting, kneeling, prolonged sitting, or isometric quadriceps contraction; and (3) reports of pain greater than 3 months in duration.[26] The PFP patients were excluded from participation if they reported having any of the following: (1) previous history of knee surgery, (2) history of patellar instability, or (3) neurologic involvement that would influence gait. Approximately 50% of individuals who were screened were included in the study. The most common reasons for exclusion included pain in the patellar tendon (as opposed to the patellofemoral joint) and the lack of pain reproduction with aggravating tasks.

The control group was selected based on the same criteria as the experimental group, except that controls had none of the following: (1) history or diagnosis of knee lesion or trauma, (2) current knee pain or effusion, (3) knee pain with any of the activities described for the PFP group, or (4) limitations that would influence gait.

Instrumentation

Three-dimensional motion analysis was performed using a computer-aided video motion analysis system (Vicon, Oxford Metrics Ltd, Oxford, England). Kinematic data were sampled at 120 Hz. Reflective markers placed on specific anatomic landmarks (see below for details) were used to quantify lower extremity kinematics. Ground-reaction forces were obtained using 3 AMTI force plates (Model #OR6-6-1, Advanced Mechanical Technology, Inc [AMTI], Watertown, Massachusetts) at a rate of 1560 Hz.

Strength testing was performed using a Primus RS multimodal dynamometer (BTE Technologies, Hanover, Maryland). Measurement capabilities of this device include position, torque, and power during isometric, isokinetic, and isotonic testing. As a result of the flexibility permitted in the orientation of the torque sensor, the Primus RS is capable of measuring torque data in a variety of testing positions.

Femoral shape was quantified using MRI. Images of the proximal and distal femur were acquired using a 1.5-T magnetic resonance system (GE Healthcare, Milwaukee, Wisconsin) using a pulse sequence optimized to visualize bony structure (see below for details).

Procedures

All participants underwent 3 data collection sessions. First they underwent kinematic evaluation during running. Next, participants underwent hip-muscle performance testing. Finally, they underwent MRI to assess femoral morphologic characteristics. Kinematic analysis and strength testing was performed at the Musculoskeletal Biomechanics Research Laboratory. Imaging was performed at the University of Southern California Imaging Science Center. Before testing, all procedures were explained and each participant signed a human subject's consent form as approved by the Institutional Review Board of the University of Southern California. After the candidate agreed to participate, age, height, and weight were recorded. For participants with unilateral symptoms (n = 14), only the painful limb was tested. In cases of bilateral pain (n = 5), the most painful side at the time of testing (as determined by self-report) was tested.

Kinematic Evaluation

As reported in previous publications,[7,19] reflective markers (14-mm spheres) were placed over the following bony landmarks: the first and fifth metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles, the joint space between the fifth lumbar and the first sacral spinous processes, and bilaterally over the greater trochanters and iliac crests In addition, triads of rigid reflective tracking markers were placed on the lateral surfaces of the participant's thigh, leg, and heel counter of the shoe. Once all markers were secured, a standing calibration trial was captured. After the calibration trial, anatomic markers were removed. The tracking markers remained on the participant throughout the entire data collection session. All markers were placed by a single investigator who demonstrated acceptable reliability for the primary variable of interest (hip rotation) in a pilot study (intraclass correlation coefficient [ICC] = 0.93; standard error of the mean [SEM] = 1.3º).

Practice trials of walking and running allowed participants to become familiar with the instrumentation. Kinematic data were collected during a fixed running velocity (180 m/min ± 5%) along a 15-m walkway.[20] A trial was considered successful if the participant's instrumented foot landed within the borders of 1 of the force plates. Three trials of data were obtained for each participant.

Muscle Performance Testing

On a separate day, participants returned for hip-muscle performance testing. This was done to minimize the influence of fatigue on the kinematic evaluation. Strength testing for the control group was matched for side with participants in the PFP group. Hip strength was performed in 4 different positions: standing pelvic drop, seated hip external rotation, prone hip extension, and side-lying hip abduction.

Standing Pelvic Drop. Testing for the standing pelvic drop task was performed as described by Bolgla and Uhl.[3] This testing position was evaluated under 3 conditions: isometric, isokinetic, and isotonic endurance. Participants stood on a step while the contralateral extremity (nonpainful side for the PFP group) was positioned off the step and remained unsupported. A support beam was provided for "fingertip" balance (Figure 1A). The resistance pad was secured around the participant's non-weightbearing ankle, just superior to the malleoli. The torque arm was attached to the resistance pad and positioned so that it was parallel to the participant's neutral pelvis position (Figure 1A). For isometric testing, the torque arm was locked. Participants were instructed to elevate the non-weightbearing lower extremity (ie, hip hike) by abducting the stance-limb hip. Each participant was monitored to ensure that her hips and knees remain extended so that the superiorly directed force was a result of pelvic elevation.

For isokinetic testing, patient positioning remained the same as described above. A 20° range of motion was set as assessed by a goniometer (10° of hip adduction to 10° of hip abduction). The dynamometer was programmed to allow motion at 10 deg/s. Participants were instructed to maximally resist the motion of the dynamometer during both the concentric and eccentric phases of motion. One trial of 10 repetitions was recorded.

For isotonic endurance testing, the testing position and range of motion remained the same as described for isokinetic testing. Resistance was set at 25% of the participant's body weight. Participants were instructed to contract against the resistance throughout the desired arc of motion. Each repetition (concentric and eccentric phases) was performed in 2.5 seconds. Participants were instructed to perform as many repetitions as possible at the set speed. Performance of each repetition was monitored through the dynamometer power output. A successful repetition consisted of completing the entire arc of motion in the time allotted. When this criterion was not achieved, the dynamometer power output would drop. A drop of ≤75% power output (as compared with the first repetition) was considered a failed repetition. The test was terminated after 2 successive failed repetitions or the participant achieved exhaustion and refused to continue.

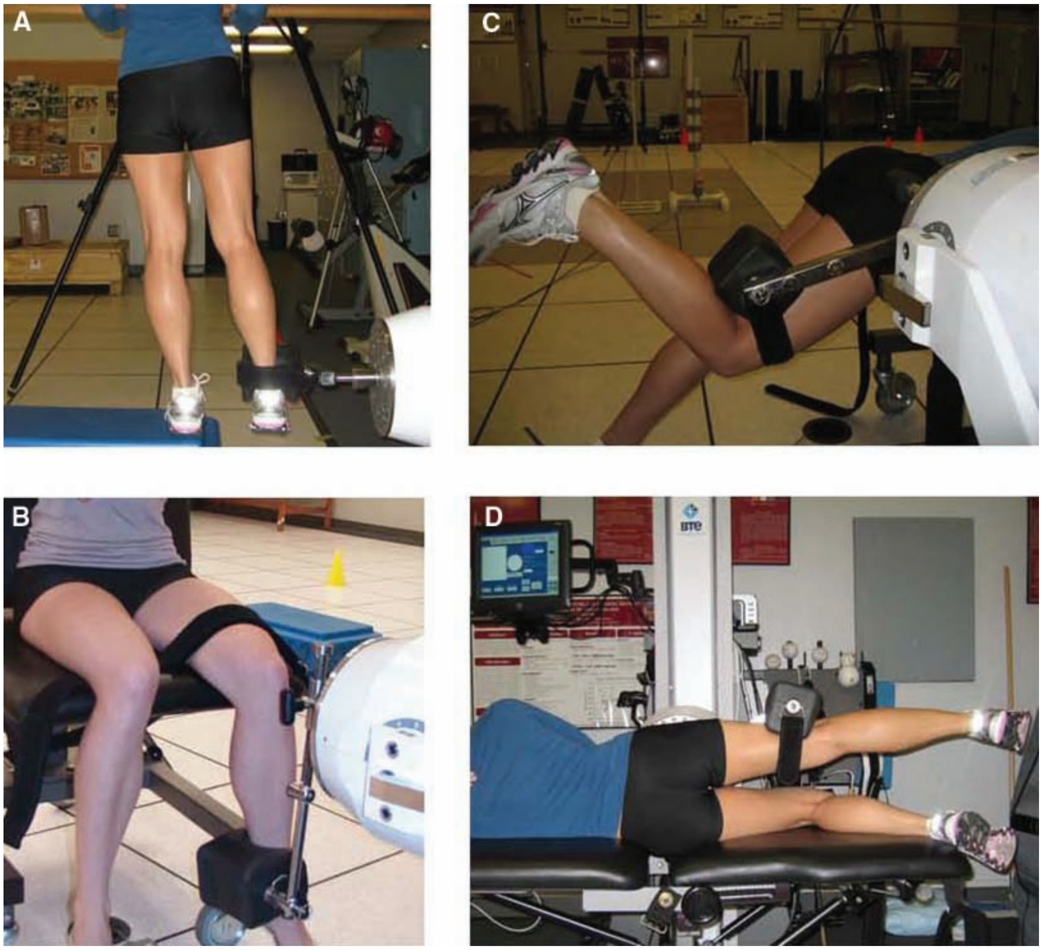

Figure 1. Hip-muscle performance testing positions: A, standing pelvic drop; B, seated hip external rotation; C, prone hip extension; and D, side-lying hip abduction.

Seated Hip-External Rotation. Hip external rotator strength testing was performed in the seated position.[11,16] This testing condition was evaluated only isometrically. The hips and knees were positioned in 90° of flexion and the distal femur of the tested limb was secured to the dynamometer chair with stabilization straps. The dynamometer head was aligned with the hip-joint center of the tested limb (Figure 1B). The resistance pad was positioned just superior to the medial malleolus. For isometric testing, the dynamometer arm was locked in place to prevent motion. participants were instructed to cross their arms over their chest during all trials.

Prone Hip Extension. Hip extension strength was assessed in the prone position under 3 conditions: isometric, isokinetic, and isotonic endurance. For isometric testing, participants were positioned prone with both lower extremities off the edge of the dynamometer table (Figure 1C). The axis of rotation of the dynamometer was aligned with the hip-joint center in the sagittal plane. The resistance pad was positioned just superior to the popliteal space. The knee of the tested extremity was flexed to 90° (Figure 1C) and the hip was positioned in 30° of hip flexion. For isometric testing, the dynamometer arm was locked to prevent any motion and the participant was instructed to extend the hip while keeping the knee flexed.

For isokinetic testing, a 40° range of motion was set (30° of hip flexion to 10° of hip extension). The dynamometer was programmed to allow motion at 10 deg/s. Participants were instructed to resist the motion of the dynamometer during both the concentric and eccentric phases of motion. One trial of 10 repetitions was recorded.

For isotonic endurance testing, the same positioning and range of motion as described for isokinetic testing was used. Participants performed hip extension repetitions using the same termination criteria described for the standing pelvic drop position.

Side-Lying Hip Abduction. For hip abduction strength testing, participants were placed side-lying on the dynamometer testing table. Side-lying abduction was assessed only isometrically. The target hip was placed superior and positioned in a neutral position (0° of flexion, 0° of

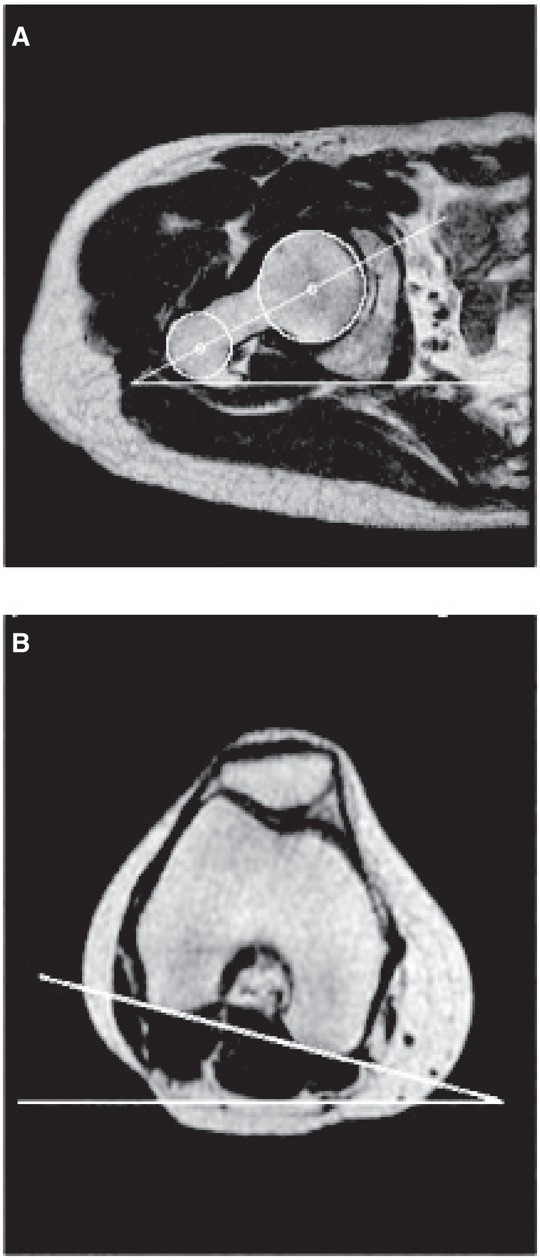

Figure 2. Method to quantify femoral anteversion using separate images visualizing the femoral neck axis (A) and posterior condylar axis (B) (see text for details).

abduction, 0° of rotation). The axis of the dynamometer was aligned with the hip joint center in the frontal plane. The resistance pad was positioned at the participant's lateral femoral epicondyle and was locked in place to prevent motion (Figure 1D).

For all testing positions, 3 trials of isometric torque testing were performed with 1 minute of rest between each trial. A 2-minute rest was permitted between testing conditions and testing modes. For all trials, participants received oral encouragement throughout.

Magnetic Resonance Imaging

Coronal T1-weighted images of the femur were acquired to quantify femoral inclination (repetition time [TR], 600 ms; echo time [TE], 12.6 ms; field of view, 48 × 48 cm; matrix, 512 × 512; slice thickness, 5 mm). Images were considered acceptable if the femoral neck axis and the long axis of the femoral shaft were identifiable. The imaging time for femoral inclination was approximately 3 minutes.

Two series of images were required to quantify femoral anteversion. Using a frontal plane image, a single T1-weighted axial oblique image was acquired parallel to the femoral neck, bisecting its superior and inferior borders (Figure 2A). Next, a second T1-weighted axial oblique image was acquired through the epicondylar axis (Figure 2B). These 2 images were obtained using the following imaging parameters: TR, 450 ms; TE, 8.1 ms; field of view, 24 × 24 cm; matrix, 256 × 256; and slice thickness, 5 mm. Imaging time for femoral anteversion was 3 minutes.

Data Analysis

Reflective markers were identified manually within the Vicon workstation software and then imported into Visual3D (C-Motion, Rockville, Maryland). This biomechanical analysis software was used to quantify three-dimensional kinematics of the hip based on standard anatomic conventions (ie, relative motion between the pelvis and thigh segments). The kinematic variable of interest was average hip internal rotation angle during the first 50% of the stance phase of running. This portion of the running cycle was chosen as this is the time when the hip musculature must decelerate the mass of the body and control hip flexion and internal rotation. The stance phase was identified as the period from initial contact of the foot of interest until toe-off (as determined by the force-plate data).

Torque data were transferred from the BTE dynamometer computer to a personal computer and imported into Excel software (Microsoft Office 2003, Microsoft, Redmond, Washington). For isometric and isokinetic testing, peak torque values were identified and normalized to body mass. For all isometric tests, the average of the 3 trials was used for statistical analysis. For isokinetic testing, the average torque for the 10 repetitions was calculated and recorded (concentric and eccentric phases were analyzed separately). For isotonic endurance testing, the number of repetitions completed at the designated power output was recorded.

Magnetic resonance images of the proximal femur were analyzed using Image J software (National Institutes of Health, Bethesda, Maryland). Femoral inclination was quantified as described previously.[12,14,29] Using the frontal plane image, the femoral neck axis and long axis of the femoral shaft were identified (Figure 3A). To define the femoral neck axis, the head of the femur was fitted with an ellipsoid and the centroid of the femoral head was calculated (Figure 3B). Next, the femoral neck was fitted with a rhomboid, and its centroid was calculated (Figure 3C). A line connecting the centroids of the femoral head and neck was used to define the femoral neck axis (Figure 3D). The

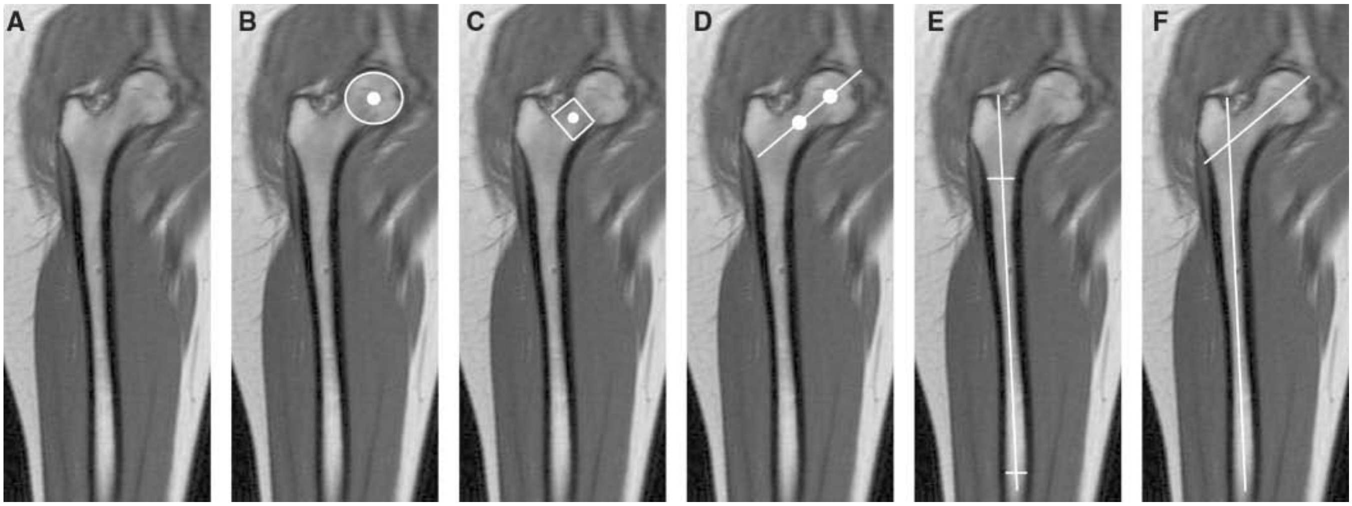

Figure 3. Method to quantify femoral inclination from a frontal plane image (see text for details).

long axis of the femur was defined by bisecting the proximal and distal femoral shaft and drawing a line connecting the bisected points (Figure 3E). Femoral inclination was defined as the angle formed by the line defining the femoral neck axis and the line defining the femoral shaft axis (Figure 3F). All inclination measurements were made by a single investigator who demonstrated excellent reliability in a pilot study (ICC = 0.96; SEM = 1.9º).

Quantification of femoral anteversion was performed using the method described by Tomczak et al.[33] First, the image oriented parallel to the femoral neck was analyzed to determine the femoral neck angle with respect to the horizontal (as referenced by the image field of view). The femoral head was outlined with an ellipse and the centroid was determined. Next, the femoral shaft was outlined with an ellipse and its centroid was established. A line connecting the centroids defined the femoral neck axis in the transverse plane (Figure 2A). Next, the angle between the femoral neck axis and a horizontal line drawn in the image field of view was measured (Figure 2A). The angle was considered positive if the femoral head was anterior to the femoral shaft and negative if it was posterior to the femoral shaft.[33]

The axial oblique image through the femoral condyles was used to determine the femoral condylar axis. The most posterior aspect of each femoral condyle was defined and a line connecting the 2 was drawn (Figure 2B). This line defined the femoral condylar axis in the transverse plane and was referenced to a horizontal line in the image field of view (Figure 2B). The condylar axis angle was positive if the lateral condyle was anterior to the medial condyle (indicating an internally rotated position) and negative if the lateral condyle was posterior to the medial condyle (indicating an externally rotated position).[33] To determine femoral anteversion, the femoral neck axis angle (with respect to the image field of view) was added to the femoral condylar angle (with respect to the image field of view).[33] All measurements of anteversion were made by a single investigator who demonstrated excellent reliability in a pilot study (ICC = 0.94; SEM = 1.6º).

Statistical Analysis

Group differences in average hip internal rotation, measures of hip-muscle performance, and femoral morphologic characteristics were assessed using independent *t* tests. The association between each of the strength and structural measures (dependent variables) and average hip internal rotation (independent variable) was assessed using Pearson correlations. All variables that were found to be significantly correlated with average hip internal rotation were used in a stepwise multiple regression model to determine the best combination of predictive variables. All correlation and regression analyses were performed using data for both groups combined. All statistical analyses were performed using SPSS statistical software (SPSS Inc, Chicago, Illinois), with a significance level of $P < .05$.

RESULTS

Hip Kinematics

On average, the PFP group demonstrated significantly greater average hip internal rotation during running when compared with the control group (8.2° ± 6.6° vs 0.3° ± 3.6°; $P < .001$).

Hip-Muscle Performance

Eight of 10 strength variables were found to be significantly different between groups ($P < .05$) (Table 2). For all isometric tests performed, participants with PFP had significantly lower peak torque values. For the isokinetic tests, eccentric

TABLE 2
Comparison of Hip Strength, Endurance, and Femoral Structure Between Groups[a]

	Patellofemoral Pain (N = 19)	Controls (N = 19)	*P* Value
Isometric (Nm/kg)			
Pelvic drop	1.86 ± 0.48	2.34 ± 0.35	0.001[b]
Hip external rotation	0.56 ± 0.13	0.69 ± 0.11	0.002[b]
Hip extension	1.98 ± 0.50	2.35 ± 0.38	0.01[b]
Side-lying abduction	1.39 ± 0.41	1.62 ± 0.26	0.04[b]
Isokinetic (Nm/kg)			
Pelvic drop concentric	1.10 ± 0.33	1.27 ± 0.35	0.14
Pelvic drop eccentric	1.17 ± 0.40	1.50 ± 0.45	0.02[b]
Hip extension concentric	0.78 ± 0.28	0.94 ± 0.15	0.03[b]
Hip extension eccentric	0.87 ± 0.34	0.92 ± 0.27	0.59
Isotonic endurance (repetitions)			
Pelvic drop	42.1 ± 23.3	68.7 ± 34.2	0.008[b]
Hip extension	16.6 ± 7.5	31.9 ± 7.8	<0.001[b]
Femoral structure (deg)			
Femoral anteversion	19.5 ± 9.9	19.6 ± 10.2	0.96
Femoral inclination	132.8 ± 5.2	128.4 ± 5.0	0.01[b]

[a]Mean ± standard deviation.
[b]Significant ($P < .05$).

TABLE 3
Relationship Between Hip Variables and Hip Internal Rotation During Running

	Pearson *r*	*P* Value
Isometric		
Pelvic drop	–.256	.06
Hip external rotation	–.145	.19
Hip extension	–.269	.05[a]
Side-lying abduction	–.167	.16
Isokinetic		
Pelvic drop concentric	–.135	.21
Pelvic drop eccentric	–.302	.03[a]
Hip extension concentric	–.027	.44
Hip extension eccentric	–.019	.46
Isotonic endurance		
Pelvic drop	–.251	.06
Hip extension	–.451	.002[a]
Femoral structure		
Femoral anteversion	.204	.11
Femoral inclination	.213	.10

[a]Significant ($P < .05$).

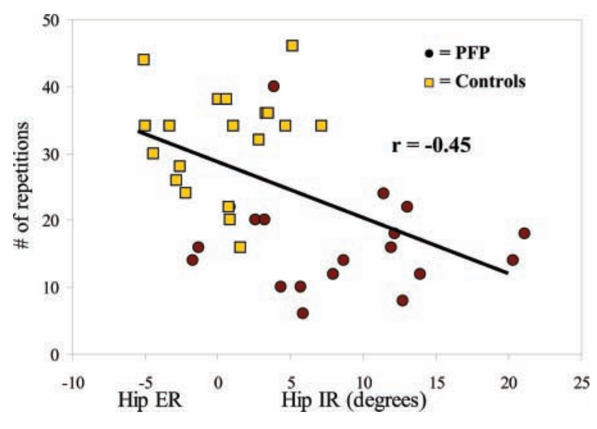

Figure 4. Relationship between prone hip extension endurance and average hip internal rotation during running. PFP, patellofemoral pain group; ER, external rotation; IR, internal rotation.

standing pelvic drop and concentric prone hip extension were significantly lower in the PFP group ($P < .05$) (Table 2). In addition, those with PFP had diminished pelvic drop and hip extension isotonic endurance values when compared with the control group ($P < .05$) (Table 2). No group differences were found for concentric standing pelvic drop and eccentric prone hip extension ($P > .05$) (Table 2).

Femoral Structure

Subjects with PFP had significantly greater degrees of femoral inclination when compared with the control group (132.8° ± 5.2° vs 128.4°± 5.0°; $P = .01$) (Table 2). However, no difference in femoral anteversion was observed between groups ($P > .05$) (Table 2).

Predictors of Average Hip Internal Rotation During Running

Correlation analysis revealed that 3 variables were significantly associated with average hip internal rotation: isometric hip extension torque ($r = –.27$; $P = .046$), hip extension endurance ($r = –0.45$; $P = .002$), and average eccentric isokinetic torque during the pelvic drop test ($r = –.30$; $P = .03$) (Table 3). When these 3 variables were entered into the stepwise multiple regression model, only hip extension endurance emerged as a significant predictor of average hip internal rotation during running ($r = -.45$; $P = .004$) (Figure 4).

DISCUSSION

Consistent with the hypothesis proposed, we found that women with PFP demonstrated increased average hip internal rotation during running, decreased hip-muscle strength, and differences in femoral structure. The increased average hip internal rotation observed in the PFP group is consistent with previous investigations linking abnormal femur rotation and PFP. Using dynamic MRI, Powers et al[27] reported that lateral patellar tilt and lateral patellar displacement during a single-limb squat was the result of internal rotation of the femur as opposed to movement of the patella. Although direct comparisons between the current investigation and the study by Powers et al[27] cannot be made, our findings support the premise that hip motions may influence patellofemoral joint mechanics.

Our finding of greater average hip internal rotation in persons with PFP is in contrast to recent studies by Willson and Davis[35] and Bolgla et al.[2] Willson and Davis[35] found less hip internal rotation in female subjects with PFP compared with a control group during running, hopping, and a single-legged squat. These authors hypothesized that the observed decrease in hip internal rotation in the PFP group may have been the result of a compensatory strategy to limit potentially painful motion. Bolgla et al[2] investigated hip kinematics in female subjects with PFP during stair descent and found no differences in hip kinematics despite significant differences in hip strength. They stated that a lack of group differences in hip kinematics may have been related to the fact that a relatively low-demand task was evaluated in their study.

With respect to the current investigation, the observed increase in average hip internal rotation in the PFP group was accompanied by decreased hip-muscle performance. This was evident in 8 of the 10 conditions evaluated. More specifically, women with PFP demonstrated a 21% deficit in muscle performance when averaged across all strength-testing conditions. Our findings are consistent with those of previous authors who have reported similar ranges of hip-strength deficits (18% to 38%).[3,4,11,28]

The largest deficits in hip-muscle performance were observed in the tests of muscular endurance. On average, women with PFP performed 49% less hip extension repetitions and 40% less pelvic drop repetitions when compared with the control group. These findings may help to explain clinical reports of increased symptoms during repetitive activities such as running. More specifically, poor muscle endurance may result in a reduced ability to control lower extremity motions during prolonged bouts of exercise.

In the current study, we observed significantly greater femoral inclination in women with PFP when compared with the control group. As mentioned above, excessive degrees of inclination may influence patellofemoral mechanics by altering lower extremity alignment and/or influencing hip-muscle moment arms.[1,9] With respect to the relationship between femoral inclination and lower extremity alignment, it has been proposed that increased femoral inclination is associated with genu varum.[9] Such an alignment would be detrimental to the patellofemoral joint as in vitro studies have shown that a varus alignment of the knee can lead to significant increases in patellofemoral joint contact pressures.[10]

Femoral inclination also has been shown to affect hip-muscle moment arms.[1] A reduction in hip abductor moment arm would decrease the gluteus medius torque-generating potential and may lead to functional weakness and altered hip kinematics. Although the PFP group was found to have significantly greater femoral inclination than the control group, it should be noted that the average difference was only 4.4°. Whether such a difference would result in meaningful changes in knee alignment and/or changes in moment arms remains to be seen.

With regard to femoral anteversion, we did not detect differences between groups. On average, group means were nearly identical (19.5° vs 19.6°) and fell within the range of "normal," which has been reported to be between 8° and 30°.[22] Our findings are in contrast to those of Eckhoff et al,[6] who reported higher degrees of femoral anteversion in a group of patients with patellofemoral symptoms. It should be noted, however, that Eckhoff et al[6] studied an equal distribution of males and females, whereas the current study only included females. In addition, Eckhoff et al[6] only included patients in whom conservative treatment had failed. Another difference between the 2 studies is that the current investigation excluded persons with patellar instability, which was not a criterion used by Eckhoff et al.[6] It is possible that subjects with recurrent dislocations may have structural abnormalities not observed in the current study.

Three hip-muscle performance measures were found to be significantly correlated with average hip internal rotation during running. Of the 3 strength variables, 2 were related to gluteus maximus strength and 1 was related to gluteus medius strength. All 3 correlations were negative, indicating that decreases in hip-muscle strength were associated with greater degrees of average hip internal rotation. Contrary to our hypothesis, neither femoral inclination nor femoral anteversion was found to be correlated to average hip internal rotation during running.

When all 3 significant predictors were entered into a stepwise multiple regression, isotonic hip extension endurance emerged as the best predictor of average hip internal rotation during running. This finding is logical, as the primary hip extensor (ie, the gluteus maximus) also is the primary external rotator of the hip.[21] The gluteus maximus acts eccentrically during the weight-acceptance phase of running to control hip flexion and internal rotation, and acts concentrically in late stance to extend the hip prior to toe-off.[32] The fact that our isotonic endurance testing protocol incorporated both eccentric and concentric muscle activities suggests that this mode of testing may provide a better assessment of extensor muscle performance compared to more traditional approaches (ie, isometric strength testing).

A potential limitation of our study is that measures of femoral structure were obtained using MRI as opposed to the more traditional method of CT. Although previous studies have shown that the MRI method to quantify anteversion is reliable and comparable with measurements obtained from CT,[33] no studies have compared MRI and CT measurements of femoral inclination. Given as such, the inclination values reported in the current study should be viewed with caution. Nonetheless, we believe our group comparisons for femoral inclination are valid given the fact that the SEM for this measure was quite small (1.6º).

In summary, our results add to the growing body of literature supporting the link between abnormal hip function and PFP. Although women with PFP demonstrated diminished hip-muscle strength in 8 of 10 strength variables and differences in femoral structure compared with a control group, isotonic hip extension endurance was the only significant predictor of average hip internal rotation during running. Our results suggest that assessment of hip-muscle performance should be considered as part of the evaluation and treatment of patellofemoral joint dysfunction. Future studies should be conducted to determine whether improving strength and/or endurance of the hip musculature will result in improvements in hip rotation during running.

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