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Pain and Hip Lateral Rotator Muscle Strength Contribute to Functional Status in Females with Patellofemoral Pain

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Abstract

Background and Purpose—Patellofemoral pain (PFP) is a common musculoskeletal pain condition, especially in females. Decreased hip muscle strength has been implicated as a contributing factor, yet the relationships between pain, hip muscle strength, and function are not known. The purpose of this study was to test the hypothesis that pain and hip muscle strength explain unique portions of variance in the functional status of females with PFP.

Design: An observational, cohort study.

Subjects: Twenty-one females with PFP (age: 26±7 yrs; height: 163±4 cm, and body mass: 62±10 kg,). Subjects had a minimum pain duration of two months (mean pain duration: 4.9±3.6 years).

Main Measures: Pain during a unilateral squat measured with a visual analog scale (VAS); isometric muscle force of gluteus medius, gluteus maximus, and hip lateral rotators; Kujala score (self-report measure of function).

Statistical Analysis: Hierarchical multiple regression analysis was performed with Kujala score as the dependent variable. Pain and hip lateral rotator muscle strength were independent variables, entered in that order. Other strength measures were not correlated with the Kujala score, and as such, were not used in the analysis.

Results—Pain explained 22% of the variance in the Kujala score (p=.03). Hip lateral rotator strength explained an additional 14% of the variance, after accounting for pain level (p=.06).

Conclusions—Pain and hip lateral rotator strength contributed to the functional status of females with PFP. Improving pain and hip lateral rotator muscle strength may improve function in females with this common pain condition.

Keywords

Visual Analog Scale; Kujala Score; Hand-held Dynamometry; Knee Pain

INTRODUCTION

Patellofemoral pain (PFP) is one of the most common musculoskeletal pain conditions (Grady et al., 1998; Sanchis-Alfonso et al., 1999; Taunton et al., 2002), especially in active females (DeHaven and Lintner, 1986; Taunton et al., 2002). Prevailing theories regarding the mechanism of PFP suggest that pain develops in response to elevated patellofemoral

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joint stress (force per unit area) (Seedhom et al., 1979; Goodfellow et al., 1976; Grana and Kriegshauser, 1985). Faulty hip kinematics during weightbearing (e.g. increased hip adduction and medial rotation) are proposed to contribute to increased stress and PFP due to the resultant increase in quadriceps angle (Q-angle), which reflects the lateral component of the quadriceps muscle force. An increased Q- angle has been reported to increase patellofemoral joint stress (Huberti and Hayes, 1984; Ramappa et al., 2006), and increased medial femoral rotation has been shown to decrease patellofemoral joint contact area (Lee et al., 1994; Fuchs et al., 1999).

Given the theoretical link between faulty frontal and transverse plane hip kinematics during weightbearing and altered patellofemoral joint mechanics, investigators have begun to explore whether hip muscle strength is a contributing factor in PFP. Ireland and colleagues (Ireland et al., 2003), Bolgla et al (Bolgla et al., 2008), and Willson et al (Willson et al., 2008) used handheld dynamometry to assess hip muscle strength in females with and without PFP, and all reported decreased hip abductor and lateral rotator muscle strength in females with PFP compared to pain free subjects. Robinson and Nee (Robinson and Nee, 2007) reported decreased hip abduction, extension and lateral rotation strength in females with PFP, and Cichanowski and colleagues (Cichanowski et al., 2007) reported generalized decreased hip muscle strength (flexion, extension, abduction, medial and lateral rotation) in collegiate female athletes with PFP compared to control subjects. Souza and Powers (Souza and Powers, 2008) tested hip muscle strength using an isokinetic device and reported decreased isometric hip abduction, extension and lateral rotation strength, decreased eccentric hip abduction strength, and decreased concentric hip extension strength in females with PFP compared to controls.

Despite the evidence of reduced hip muscle strength in females with PFP, the relationships between pain, hip muscle strength, and functional status are unclear. Furthermore, no study has explored the individual contributions of pain and hip muscle strength to function. Knowledge of the unique contributions of pain and hip muscle strength to function would provide insight into factors contributing to impaired function in individuals with PFP and help inform rehabilitation strategies for this common pain condition. The purpose of this study was to test the hypothesis that pain assessed during a weightbearing task and hip muscle strength (gluteus medius, gluteus maximus, and hip lateral rotators) would explain unique portions of variance in functional status in females with PFP.

METHODS

Design

The study was an observational, cohort study.

Subjects

Twenty-one female subjects with patellofemoral pain participated. The average age of the subjects (mean±SD) was 26±7 years. Average height was163±4 cm, and average body mass was 62±10 kg. Patellofemoral pain was defined as pain originating from the patellofemoral articulation (retropatellar, peripatellar) that was readily reproducible with two of the following provocation tests: resisted non-weightbearing quadriceps contraction, unilateral squat, and step-down (McConnell, 1986). An additional inclusion criterion was a minimum pain duration of two months, to eliminate subjects who may have had pain develop from an isolated bout of intense activity. Pain duration was 4.9±3.6 years, on average. Exclusion criteria were: a history (or current report) of knee ligament, tendon or cartilage injury, traumatic patellar dislocation, or prior knee surgery. Patellar instability was not an exclusion criterion; four subjects reported a history of patellar instability. Subjects were recruited from local universities, community centers, physicians' offices, and word-of-mouth referrals. Approval for this study was granted from the Institutional Review Board at Saint Louis University. Written informed consent was obtained from all subjects and the rights of the subjects were protected.

Materials and Procedures

All measures were collected during a single session. Subjects underwent a clinical examination of the knee joint by the principal investigator (a physical therapist with 20 years of experience). Palpation was performed to rule out pain originating from associated structures (patellar tendon, quadriceps tendon, tibiofemoral joint and meniscii, synovial plicae). Subjects completed a visual analog pain scale (VAS) (Carlsson, 1983) in response to the pain provocation tests to verify that the pain inclusion criterion (pain/no pain) was met. The VAS was a 100 mm horizontal line with left and right anchors representing "no pain" and "worst imaginable pain", respectively. Subjects marked the point on the line that corresponded to their pain level during the provocation tests. The VAS has been shown to be a valid measure for detecting clinical change in individuals with PFP (Chesworth et al., 1989).

Pain Assessment—Subjects' pain level during the unilateral squat provocation test was chosen for analysis because the unilateral squat is a task that theoretically could be impacted by weakness of the gluteus medius, gluteus maximus and hip lateral rotator muscles. Subjects were asked to stand on one leg (painful side) and perform a partial squat to approximately 60 degrees of knee flexion. Upper extremity support was allowed for balance only. Immediately following the activity subjects marked the point on the VAS line that corresponded to the pain level experienced during the task. VAS scores were computed by measuring the length of the line from the left anchor to the subject's mark in millimeters.

Hip Muscle Strength Assessment—Gluteus medius, gluteus maximus, and hip lateral rotator muscle strength was assessed on the involved side using a hand-held dynamometer (Hogan Industries, Draper, UT) and the manual muscle testing procedures described by Kendall (Kendall et al., 1993). To test the gluteus medius subjects were positioned on a plinth, lying on their non-involved side. The non-involved hip and knee were flexed to provide trunk stability. The trunk and pelvis were placed in a neutral position, and the pelvis was stabilized manually by the examiner. The involved limb was placed in slight hip abduction, extension and lateral rotation and subjects were told to "hold the position and don't let me move you." The dynamometer was placed 2 cm proximal to the lateral malleolus, and the examiner applied force perpendicular to the limb segment in the direction of hip adduction and flexion. The force was increased until the subjects' resistance was "broken", signified by movement of the limb out of the test position. The breaking force was recorded and the test was repeated two additional times. The average force value over the three tests was computed and expressed as a percentage of the subject's body weight in Newtons.

Gluteus maximus strength was assessed with subjects in the prone position. The involved knee was flexed to ~90° and the involved hip was extended as far as possible without allowing the subject to extend the trunk. The pelvis was stabilized manually by the examiner and the dynamometer was placed on the posterior thigh, just proximal to the knee joint. The subject was asked to hold the position while force was applied perpendicular to the limb in the direction of hip flexion. Three trials were performed and the average force value over the three trials was computed and expressed as a percentage of the subject's body weight in Newtons. One subject was unable to complete the test procedures for gluteus maximus strength; as a result, gluteus maximus data was available for only 20 subjects.

To test lateral rotator strength, subjects assumed a seated position with the hips and knees flexed to 90 degrees. A small towel was placed under the knee to align the knee joint center with the hip joint center. The subject's involved limb was placed in lateral rotation while the examiner stabilized the femur. The dynamometer was placed 2 cm proximal to the medial malleolus and the subject was asked to hold the position while the examiner applied force perpendicular to the limb in the direction of medial rotation. Three trials were performed and the average force value over the three trials was computed and expressed as a percentage of the subject's body weight in Newtons.

Reliability of the strength measures was determined on a sample of eight subjects who were not included in the main study sample. Measurements were taken for right and left lower extremities as described on two separate occasions, one day apart. Intrarater reliability was determined using the intraclass correlation coefficient ($ICC_{(3,3)}$). The ICC values were .80 and .88 for right and left gluteus medius strength, .64 and .51 for right and left gluteus maximus strength, and .95 and .87 for right and left lateral rotator strength, respectively.

Functional Status Assessment—The Anterior Knee Pain Questionnaire developed by Kujala, et al (Kujala et al., 1993) was used to assess functional status. The 12-item questionnaire evaluates subjective symptoms and functional limitations associated with anterior knee pain. The multiple choice questionnaire addresses issues of pain, swelling, patellar subluxations, quadriceps atrophy, knee flexion deficiency and limitations associated with walking, stairs, squatting, running, jumping, and sitting. The composite score ranges from 0 to 100, with 100 indicating no functional limitation. The Kujala questionnaire has demonstrated a high test-retest reliability ($ICC_{(2,1)} = .95$.) and a minimal detectable change of 13 points in a group of subjects with patellofemoral pain (Watson et al., 2005). Subjects were given the questionnaire at the beginning of the testing session, and any questions were clarified by the principal investigator, after which subjects completed the questionnaire independently.

Data Analysis

All statistical analyses were performed using SPSS software (version 13, SPSS, Inc., Chicago, IL). Descriptive statistics (mean, standard deviation, range) were calculated for VAS, gluteus medius, gluteus maximus, and hip lateral rotator strength, and Kujala score. Pearson correlation matrices were constructed using the same variables. A hierarchical multiple regression analysis was conducted using Kujala score as the dependent variable. The strength of hierarchical regression is that the order of entry of independent variables is based *a priori* on sound theory or knowledge of published data, and thus reflects causal hypotheses (Cohen and Cohen, 1983). The independent variables were selected for entry if they had a significant zero-order correlation with the dependent variable (Table 2), and the order of entry was prioritized according to the impact each independent variable likely would have on the dependent variable. As such, VAS was entered first, followed by hip lateral rotator strength.

At each step in the analysis a regression equation was generated, R^2 was computed and the change in R^2 was calculated. Significance of the change in R^2 was determined using an F test (alpha=.05). If the change in R^2 was not statistically significant, the contribution of that independent variable was evaluated for its clinical significance (whether or not it explained at least 10% of variance in Kujala score) prior to the next step of the analysis. Residual plots were examined and the Durbin-Watson statistic (Field, 2005) and Cook's distance (Field, 2005) were computed to determine if the assumptions of linear regression had been met. In addition, to check for normality of the residuals a histogram of the standardized residuals was compared to a normal distribution, and a normal probability (P-P) plot of the observed cumulative proportions vs. the expected cumulative proportions was generated to see how closely the data approximated the diagonal (Field, 2005).

RESULTS

Descriptive statistics for pain during unilateral squat (VAS), hip muscle strength, and Kujala score are displayed in Table 1. Pearson correlations for the same variables are displayed in Table 2. A positive correlation was found between hip lateral rotator muscle strength and Kujala score (r= .40, p= .04). A negative correlation was found between pain during a unilateral squat and Kujala score (r= −.47, p=.02). There was no correlation between hip lateral rotator strength and pain. Neither gluteus medius strength nor gluteus maximus strength was correlated with pain or function.

The results of the hierarchical regression analysis are displayed in Table 3. Pain during the unilateral squat explained 22% of the variance in the Kujala score (p=.03). When hip lateral rotator strength was added, the change in R^2 was .14, indicating that the unique portion of variance in Kujala score explained by hip lateral rotator strength, after accounting for pain level, was 14% (p=.06). Because 14% was considered to be a meaningful amount of variance (>10%), hip lateral rotator strength was left in the equation even though the alpha level was greater than .05. In the final equation, VAS and hip lateral rotator strength together explained 37% of the variance in Kujala score.

The assumptions of linear regression were met based on the following findings: a plot of the standardized residuals versus the standardized predicted residuals revealed no particular pattern (i.e. data were randomly distributed around 0), no more than 5% of cases had a standardized residual absolute value above 2, there were no cases that had a Cook’s distance above 1, indicating that no case had an undue influence on the model (Field, 2005), and the Durbin-Watson statistic was 2.47 (between 1.5 and 2.5), indicating that the residuals were uncorrelated (Field, 2005). Furthermore, the histogram of the standardized residuals approximated the normal curve, and the P-P plot showed the data closely clustered around the diagonal, indicating a normal distribution of the residuals (Field, 2005).

DISCUSSION

We hypothesized that pain and hip muscle strength would explain unique portions of variance in function as measured by the Kujala score. Together, pain and hip lateral rotator muscle strength explained 37% of the variance in Kujala score. Gluteus medius and maximus strength measures were not associated with function, and none of the strength measures was associated with pain. The use of hierarchical regression analysis strengthens the interpretation of the association between variables in that it provides a causal direction for the relationships investigated. As such, the finding that pain and hip lateral rotator strength explained unique portions of variance in the Kujala score suggests that pain and hip lateral rotator strength contribute to function and that improving pain and strength might improve the functional status of females with PFP. Another positive aspect of the study was the use of typical clinical assessment measures of strength, pain and function. Although the subjects were tested in a laboratory setting, the findings are generalizable to clinical settings and thus have relevance for practice.

In addition to strengths of the study, there are several limitations to acknowledge. The reliability of the gluteus maximus strength measurement was less than .75, a threshold for “good” reliability (Portney and Watkins, 2000). Inadequate reliability could have affected the precision of the measurement and the ability to detect significant relationships. It is possible that the lack of association between gluteus maximus strength and pain or function was the result of low reliability. A second limitation pertains to the regression analysis. A single measure of function (Kujala score) was used as the dependent variable and the independent variables included only two domains (pain and muscle strength). This may be one reason why only 37% of the variance in function was explained. We attempted to be parsimonious in our design, given the limited number of subjects, and thus chose variables that 1) had a plausible biomechanical link to PFP (hip muscle strength), and 2) would likely affect functional status (pain level).

Pain during the unilateral squat explained 22% of the variance in function, suggesting that the level of pain a person has during this weightbearing task influences her functional status. This finding is not surprising, given that the Kujala questionnaire includes questions about pain and its impact on tasks such as stair climbing, running, jumping, and squatting. However, that only 22% of the variance in function was explained by pain suggests that factors other than pain have an impact on function. Other investigators have reported similar findings. Juhakoski and colleagues (Juhakoski et al., 2008) studied factors associated with pain and physical function in 118 subjects with hip osteoarthritis. The authors reported that performance measures were better predictors of physical function than pain.

Hip lateral rotator muscle strength explained an additional 14% of the variance in Kujala score, beyond the variance already explained by pain. This finding supports the theory linking decreased hip lateral rotator muscle strength and PFP and is consistent with previous studies that have reported decreased lateral rotator muscle strength in females with PFP (Ireland et al., 2003; Bolgla et al., 2008; Willson et al., 2008; Robinson and Nee, 2007; Cichanowski et al., 2007; Souza and Powers, 2008). The mechanism by which decreased lateral rotator muscle strength impacts function is unclear; however, it is possible that this strength deficit results in abnormal hip kinematics (e.g. increased medial rotation) during weightbearing tasks. Several studies have reported improved hip kinematics after weightbearing hip strengthening programs (Myer et al., 2006; Mascal et al., 2003; Pollard et al., 2006). Future studies should assess whether increasing hip lateral rotator strength results in improved hip kinematics and function in females with PFP.

To our surprise, hip lateral rotator strength was the only strength variable associated with function. The lack of a relationship between gluteus medius or maximus strength and function is in contrast to reports in the literature of decreased hip abduction and extension strength in females with PFP (Robinson and Nee, 2007; Cichanowski et al., 2007; Souza and Powers, 2008). This finding may be explained in part by the methods used to assess strength. While several investigators used handheld dynamometers similar to ours (Ireland et al., 2003; Bolgla et al., 2008; Willson et al., 2008; Robinson and Nee, 2007; Cichanowski et al., 2007), we employed a “break” test using manual resistance, whereas others used a strap or other type of external resistance to devise a “make” test (Ireland et al., 2003; Willson et al., 2008; Bolgla et al., 2008; Cichanowski et al., 2007). It is possible that our break test had a ceiling effect that was influenced by the level of resistance applied by the investigator. We tried to minimize the ceiling effect by assuring that the examiner exerted increasing force to the point where the limb just started to move out of position. It is possible, however, that limb movement did not occur for every subject on every repetition. Another explanation for the lack of correlation between gluteus medius and maximus strength and function is that non-weightbearing, isometric measures of muscle strength may not capture the aspects of muscle performance that are most critical for engaging in functional activities. In addition, the test positions for gluteus medius and maximus emphasize the abductor and extensor components of these muscles, respectively, but fail to capture their contribution as lateral rotators. Perhaps other measures of muscle performance such as concentric or eccentric muscle force, torque or power, or rate of force/torque development are more closely related to function. Future studies should incorporate multiple measures of muscle performance.

None of the strength variables was associated with pain level. This finding is contrary to the proposed mechanism of pain development, and as above, one explanation for this finding may be that non-weightbearing isometric hip muscle force has little to do with patellofemoral joint mechanics or pain during weightbearing tasks. Altered hip kinematics have been reported in single leg squats, running and jumping (Willson and Davis, 2008), dynamic activities that require hip muscles to contract eccentrically and concentrically. Abnormal hip motion during such tasks, therefore, is most likely a function of some other aspect of muscle performance. Testing muscle performance during weightbearing tasks would be more reflective of activities that are commonly painful and would allow gluteus medius and maximus to contribute to lateral rotation, thereby capturing more accurately the force generating potential of these muscles in the transverse plane.

Together, pain and hip lateral rotator strength explained less than 40% of variance in function. This finding suggests that there are additional factors, possibly from other domains, that impact function in individuals with PFP. Reports in the literature suggest that quadriceps strength (Natri et al., 1998), patellofemoral joint crepitus (Natri et al., 1998), vastus medialis response time (Witvrouw et al., 2002), and duration of symptoms (Witvrouw et al., 2002) are related to functional outcomes in individuals with PFP. Given that the mechanism of PFP is multifactorial, it is possible that other domains (bony structure, joint alignment, joint flexibility, etc.) influence function. Future studies should incorporate a multivariate analysis with a larger sample size to address this question. Increasing the sample size also would increase the generalizability of the findings to larger populations. In addition, using a performance-based measure of function instead of a self-report measure would more accurately capture a person’s true functional status and could result in a greater percentage of variance being explained by physical impairment measures.

IMPLICATIONS

Pain during a unilateral squat and hip lateral rotator muscle strength contributed to functional status in females with patellofemoral pain, suggesting that rehabilitation strategies aimed at improving pain and increasing hip lateral rotator strength may improve functional outcomes in females who have this common pain condition.

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Table 1

Descriptive Statistics: Hip Muscle Strength, Pain, Function

	Mean	Standard Deviation	Range
Gluteus Medius Strength (% BW)* n=21	10.3	3.9	5.3–19.1
Gluteus Maximus Strength (% BW)* n=20	21.3	6.0	11.4–36.6
Hip Lateral Rotator Strength (% BW)* n=21	14.0	3.4	8.4–23.2
VAS§ (mm) n=21	31.2	17.0	4.0–63.0
Kujala Score£ n=21	76.3	11.8	40.0–93.0

*resistance force in Newtons as percentage of body weight in Newtons

§Visual Analog Scale (0 = no pain, 100 = severe pain)

£Kujala Total Score (100 = no functional limitation)

n = number of subjects in analysis

Table 2

Pearson Correlation Matrix

	Gluteus Maximus Strength	Hip Lateral Rotator Strength	VAS	Kujala Score
	r (*p*-value)*	r (*p*-value)*	r (*p*-value)*	r (*p*-value)*
Gluteus Medius Strength	.68 (<.001) n=20	.48 (.01) n=21	.24 (.15) n=21	.01 (.49) n=21
Gluteus Maximus Strength		.76 (<.001) n=20	.02 (.47) n=20	.18 (.21) n=20
Hip Lateral Rotator Strength			−.04 (.43) n=21	.40 (.04) n=21
VAS				−.47 (.02) n=21

*1-tailed

VAS = Visual Analog Scale

n = number of subjects in analysis

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Table 3

Regression Analysis

Step	Predictors	R^2	R^2 Change	F	Degrees of Freedom	*p*-value
1		.223	.223	5.443	1, 19	.031
	(Constant)					
	VAS					
2		.366	.143	4.074	1, 18	.059
	(Constant)					
	VAS					
	Hip LR Strength					

VAS= Visual Analog Scale

LR= Lateral Rotator

* Dependent Variable: Kujala Score