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ABSTRACT

BACKGROUND AND PURPOSE: Patellofemoral pain syndrome (PFPS) is a common form of knee pain occurring insidiously, and exacerbated by overuse activities. PFPS is common among athletes and adolescent females. Research suggests that hip weakness contributes to the development of PFPS. Similarly, biomechanical reasoning suggests a link between core endurance and PFPS. Few studies have explored these relationships in adolescent females. The purpose of this study was to investigate relationship between hip strength and core endurance in adolescent female athletes with PFPS in comparison to gender and sport matched controls.

SUBJECTS: Female runners age 13-17, 6 with PFPS and 17 without knee pain.

METHODS AND MATERIALS: A case control design was utilized. The Kujala Anterior Knee Pain Scale and multiple Visual Analog Pain Scales were administered prior to testing. Hip external rotation and abduction strength were measured using handheld dynamometers secured with straps. Strength measurements were normalized to body weight. The highest recorded measurement of two trials was utilized for data analysis. Core endurance was assessed with timed lateral planks.

ANALYSES: Number Cruncher Statistical Software 8 was used. Descriptive statistics, t-tests, and Mann-Whitney U tests were utilized to analyze the data. Pearson correlation coefficients were used to assess the degree of relationship among strength, endurance, pain, and Kujala scores for the case group. Effect sizes were calculated for further analysis.

RESULTS: PFPS subjects generated 12% greater median hip abduction and 7% less median hip external rotation strength than controls. In contrast, PFPS subjects demonstrated 22% less median core endurance than the controls. Due to a small sample size, results were not statistically significant.

CONCLUSION: This pilot study indicates further research, with more subjects, is needed to investigate the relationship between hip strength, core endurance, and PFPS in adolescent females.

IMPLICATIONS: Our research suggests that hip and core muscular endurance, in addition to muscular strength should be evaluated in adolescent female runners presenting with PFPS.

The undersigned certify that they have read, and recommended approval of the research project entitled…

HIP STRENGTH AND CORE ENDURANCE AMONG FEMALE ADOLESCENT RUNNERS

Submitted by,

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Angela Everson
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Heidi Sande

in partial fulfillment of the requirements for the Doctor of Physical Therapy Program

Primary Advisor ____________ Date 4-30-14

Co-Advisor ____________ Date 4/30/14

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Chapter I: INTRODUCTION

Patellofemoral pain syndrome (PFPS) is a common source of anterior knee pain characterized by generalized peripatellar and retropatellar pain.[1,2] This pain occurs insidiously, but is exacerbated by overuse activities that place stress on a flexed knee such as squatting, running, jumping, descending stairs, and sitting for prolonged periods of time.[3-5] PFPS is common among athletes and adolescent females.[5,6] It is well documented that approximately 25% of all knee injuries seen in sports related clinics are diagnosed as PFPS.[3,5,6] A study conducted on female basketball players found that 16% suffered from PFPS at the beginning of the season, with an increase to 25% by the end of the season.[7] Similarly, 2.5 million runners are diagnosed with PFPS each year, making up approximately 17% of all running injuries.[7] Despite its high incidence, multiple theories currently exist regarding the cause of PFPS, including abnormal patellar tracking, as well as top down and bottom up mechanisms.[8] The top-down mechanism associates PFPS with a decrease in proximal hip musculature strength, while the bottom-up mechanism refers to the theory that excessive pronation of the foot causes PFPS.[5,9] Excessive pronation at the subtalar joint is believed to be a factor because of the possible contribution to a medial collapse of the knee in the frontal plane and/or an increase in the dynamic Q angle. The dynamic Q angle is potentially increased because the femur internally rotates due to excessive tibial internal rotation during overpronation. Increased strain on soft tissues surrounding the knee is also seen during excessive tibial internal rotation.[8] In support of this theory, a study conducted by McPoil et al, reported that patients with PFPS are four times more likely to have increased foot mobility.[9] Despite these results, other studies have failed to find an association between increased pronation and PFPS.[8] These conflicting theories create challenges for clinicians attempting to provide appropriate treatment plans.

Chapter II: REVIEW OF RELATED LITERATURE

A widely accepted theory regarding the mechanism of PFPS is that the patella tracks abnormally in the intercondylar notch, causing an increase in stress on the lateral aspect of the patellofemoral joint. [1,3,4,6] Research suggests that the cause of this abnormal tracking may be multifactorial. One theory for a cause of PFPS involves the quadriceps muscles. The firing times and patterns of the vastus medialis oblique (VMO) and the vastus lateralis (VL) are considered to be an important influence on patellar tracking. Some clinicians have suggested that the VMO is the first to atrophy, causing an abnormal pull on the patella due to greater relative pull of the VL. This abnormal pull due to muscular imbalance could cause the patella to track too far laterally in the intercondylar notch, leading to PFPS.[10,11] However, subsequent research has suggested that it may not be possible to preferentially strengthen the VMO, leading clinicians to explore other mechanisms that will lead to effective treatments.[12, 13]

Another possible contributor to PFPS is decreased flexibility of the hamstrings and/or quadriceps. Excessively tight quadriceps can increase pressure on the patella as the knee flexes, which may lead to knee pain. Similarly, hamstring tightness causes the knee to bend at heel strike, leading to increased patellar compression forces that could also result in knee pain. Research looking at muscle length as a factor has found there to be significantly less flexibility in the gastrocnemius[10] hamstrings[10], and quardriceps[10,14] in individuals with PFPS.

Some studies also suggest an increased static quadriceps angle (Q angle) as a potential contributing factor for PFPS.[15,16] The Q angle is the angle at which the femur meets the tibia. The theory behind this is that a greater Q angle will cause a greater lateral force on the patella, therefore leading to abnormal patellar tracking. However, some studies have found no significant relationship between an increased Q angle and PFPS.[17]

Hip Weakness

In recent years, research on the cause of patellofemoral pain has shifted away from the knee and focused on the hip, looking at the top down mechanism. In general, it has been proposed that neuromuscular factors of hip weakness can contribute to patellofemoral malalignment due to increased hip internal rotation, hip adduction, and increased knee valgus.[5,6] Research has shown that females with PFPS demonstrate a greater hip adduction moment during peak knee extension than females without PFPS, which may be a factor causing patellofemoral pain due to increased knee valgus.[18] This adduction moment is controlled by proximal hip abductor strength, therefore weakness in these muscles may be a contributor to patellofemoral pain. However, Willson and Davis found a weak correlation between hip external rotation strength and hip internal rotation excursion (r = -.12), abduction strength and hip adduction excursion (r = -.04), and patellofemoral pain. Limitations of this study include using isometric strength testing versus eccentric strength and inability to measure timing and recruitment of the muscle fibers.[19] On the other hand, a study by Cichanowski at el, looked at Division III college athletes and determined that the injured athletes demonstrated significantly weaker hip strength across several muscle groups, than the controls, with the exception of the hip adductors.[6] This study supports the hypothesis that hip weakness is associated with patellofemoral pain.

One of the most common limitations in these studies is the use of a retrospective design. When using a retrospective design, a cause and effect relationship cannot be determined; therefore, these studies don’t clearly determine if the PFPS symptoms are a result of hip weakness. Another frequent limitation is the use of a handheld dynamometer, in which a confounding variable is the strength of the tester. Other common limitations include self-reported subject weight and lack of leg length measurements. These factors affect calculations of strength as normalized to body weight and would not allow researchers to account for torque.

Researchers have studied specific muscle groups of the hip and tested the strength of these muscle groups individually in subjects who have patellofemoral pain. Hip external rotators help to combat the increase in hip internal rotation excursion during many dynamic activities such as running, jumping, and single-leg squats.[19] It is proposed that weak hip external rotators raise the risk for increased internal rotation excursion, which would increase the dynamic Q angle. The study by Cichanowski et al looked at isometric hip external strength using a handheld dynamometer. Researchers compared the affected limb with PFPS to the athlete's uninjured limb. The results indicated the injured leg had significantly weaker hip external rotation strength compared to the uninjured leg ($p = .049$).[6] A study by Magalhaes also used handheld dynamometers to test hip external rotation strength in sedentary individuals with PFPS. A statistically significant difference was found between individuals with unilateral PFPS and the control group ($p=<.01$); however, when comparing side to side differences in the individuals with PFPS there were no significant differences.[2] Ireland et al. also used a dynamometer and stabilizing straps to measure external rotation strength in a slightly younger, female athletic population. Results indicated that subjects with PFPS demonstrated significantly lower strength ($p<.001$), with PFPS subjects demonstrating 36% less external rotation strength than the control group.[5] Willson et al (2008) used straps and a dynamometer and concluded that hip external rotation was 14% ($p=.03$) lower in women with PFPS compared to the control group.[18]

Another muscle group that researchers focus on when looking at the top down method is the hip abductors. Weak hip abductors can lead to excessive adduction and internal rotation of the femur, which increases the lateral patellar contact pressure.[5] With repetitive activities, the malalignment of the femur may lead to retropatellar articular cartilage damage associated with

PFPS. Researchers hypothesized that individuals with PFPS would have significantly weaker hip abductor muscles when compared to their healthy controls. In the Ireland et al study, the maximal abductor muscle contraction measured with a hand-held dyamometer and was recorded and normalized to body weight. Researchers concluded that individuals with PFPS averaged 26% weaker hip abduction strength than their age-matched controls ($p<.001$).[5] Cichanowski et al also measured force with handheld dynamometers which was normalized to body weight, in collegiate female athletes. Results indicated that female collegiate athletes with PFPS had significantly weaker hip abduction strength in their affected leg when compared to their uninjured leg ($p=.003$) as well as to age, gender, and sport-matched healthy controls ($p=.01$).[6] The study by Magalhaes indicated that the PFPS group had 20% significantly weaker hip abductors compared to the control group ($p<.0002$).[2] The injured leg was also compared to the uninjured leg of the PFPS individuals and the results indicated that the injured leg demonstrated 15-20% weaker hip abduction strength ($p<.002$), matching what Cichanowski reported.[2,6] Wilson et al (2009) observed that females with PFPS had 15% weaker hip abduction strength when compared to a control group ($p=.05$).[19] Bolgla et al (2008) matched the results seen by previous studies when looking at the abduction torque produced by the hip abductors of 18 females with PFPS compared to 18 controls. The females with PFPS generated 26% less hip abduction torque ($p=.006$), however there was a lack of blinding during the experiment.[1]

Hip extensor strength is studied less frequently in the PFPS literature examining hip musculature. However, it is important to note that some studies show a correlation between hip extensor strength and PFPS.[3] In a study by Souza and Powers, they reported that the hip extension torque generated by individuals with PFPS was 16% less ($p=.005$) than the control group. This study used dynamometer with stabilization straps to measure hip strength.[20]

Meanwhile, the study by Magalhaes et al reported significant differences in hip extension strength in individuals with PFPS compared to controls, but not compared to the subjects' own uninjured leg. Compared to the control group, hip extension strength was 15% less for the individuals with PFPS (p=.037).[2] Robinson et al conducted a cross-sectional study comparing 20 females, ages 12-35. Strength measurements were normalized to body mass and a handheld dynamometer with manual stabilization was used. He concluded that hip extension strength was 52% less (p=.007) in individuals with PFPS.[3] In contrast, some studies, including a prospective study by Thijs et al, found no hip extensor weakness in individuals with PFPS compared to controls or the uninjured limb.[2,3,6,17]

It has been suggested that there is an association between proximal/core endurance and the occurrence of PFPS pain. Wilson and Davis (2009) found that women with PFPS are 29% weaker in lateral trunk flexion than females without knee pain.[19] It is suspected that this weakness may increase pelvic drop, hip adduction, and internal rotation during dynamic activities[10], leading to abnormal patellar tracking and therefore contributing to PFPS. However, no previous studies have examined core endurance in PFPS population.

Kinematics

In addition to kinetic measures of strength, abnormal femoral kinematics are another potential contributing factor to PFPS. Kinematic studies, including the three discussed below, are typically performed with the assistance of a computer-aided video motion analysis system. These systems utilize multiple cameras and reflective markers in order to help researchers analyze specific motions.[1,21] In a study by Souza and Powers, female subjects with PFPS demonstrated more internal rotation at the hip during activities such as running, jumping and stepping down as compared to age-matched control subjects. It was also discovered that these same PFPS subjects had less hip abduction and extension strength than the healthy controls. Interestingly, PFPS subjects demonstrated higher gluteus maximus maximal voluntary isometric contractions (MVIC) than the control subjects. Souza and Powers concluded that individuals with PFPS demonstrate increased hip internal rotation due to weak gluteus maximus muscles. Considering the gluteus maximus is responsible for hip extension and external rotation, individuals with PFPS are unable to control excessive internal rotation. In an attempt to correct the internal rotation, activation of the weak gluteus maximus is increased, which may explain the high MVIC values present in this study.[21] In a similar study, Bolgla et al found that although subjects with PFPS had decreased hip abduction and external rotation strength, they did not have significantly excessive hip internal rotation, adduction, or knee valgus motions.[1] Although the kinematic results of hip internal rotation contrast those seen in the Souza and Powers study, it should be noted that Bolgla et al chose a step down task that may not have been difficult enough to cause faulty kinematics. Additionally, Bolgla et al only recorded subjects' final five (out of 10) trials, causing the possibility for subjects to adapt a compensatory practice effect in which hip internal rotation was avoided.

Athletes

The Cichanowski et al study and another study by Thijs et al are two of only a few studies to analyze hip musculature strength and PFPS in competitive female athletes.[6, 17] As mentioned above, the Cichanowski et al study reported decreased hip muscle strength in all muscles except for the adductors, in female athletes with PFPS.[6] Because it was suggested that this finding could be a result of deconditioning due to decreased practice time because of injury, researchers also looked at the relationship between affected and unaffected legs of injured subjects. These results showed decreased strength in both the hip abductors and external rotators in the affected legs, suggesting that these muscle groups are important factors in PFPS.[6] However, the prospective study by Thijs et al, concluded that there was no significant difference in hip musculature strength between runners who went on to develop PFPS and runners without PFPS.[17] A drawback of this study is the fact that the authors failed to perform a prospective power analysis. Only 16 of the 77 female subjects developed PFPS, so it is possible that the sample size was not large enough to detect a significant difference in hip muscle strength between the two groups. Despite the results of the study, the authors stressed the importance of assessing hip muscle strength when examining patients with PFPS.[17]

Gender

Most research on PFPS has been conducted using female participants, due to the general acceptance in the literature that there is a significant association between the female gender and PFPS.[5,17,22,23] However, a few studies have directly compared the two genders. Boling and Padua et al followed 1,525 participants from the United States Naval Academy for 2.5 years to monitor the development of PFPS. They found that the females were 2.23 times more likely to develop PFPS than males. The prevalence of PFPS at baseline was also different between the two genders, with a 5% higher prevalence in the female group.[23] Dehaven and Lintner also examined the differences between the two genders. They looked at injured athletes from various professional, intercollegiate, high school, intramural, and unorganized athletic teams. For both sexes the most common areas injured were the knee and ankle, with PFPS accounting for significantly more female injuries (19.6%) than male injuries (7.4%).[24]

Age

The study by Ireland et al investigated the relationship between hip strength and PFPS amongst adolescent female athletes.[5] In addition, Cibulka, published a case report examining the effects of hip musculature strengthening in a 15 year old female runner with PFPS.[25] Aside from these two publications, no other studies to date exist regarding this relationship in a population of adolescent female athletes.

Purpose

Focusing on the top down approach, the purpose of our study was to investigate whether a relationship exists between hip musculature strength and core endurance in female runners between the ages of 12-18 with patellofemoral pain in comparison to healthy age, gender and sport matched controls. We hypothesized that females with PFPS would demonstrate significantly weaker hip abductor and external rotator strength and lower core endurance when compared to the healthy control group.

Chapter III: METHODS

This case control design study investigated whether there is a relationship between hip strength, core endurance and patellofemoral pain syndrome in adolescent, female runners. The Saint Catherine University Institutional Review Board approved the procedures followed in this study.

Subjects

Female runners, ages 12 to 18, were recruited for this study through flyers, emails, and word of mouth. All subjects who participated provided informed consent from a legal parent or guardian. Based on a preliminary power analysis using the data from the Ireland study, it was initially hypothesized that 26 controls and 26 case subjects would be sufficient for 80% power.[5]

Inclusion criteria for the PFPS group included pain in unilateral or bilateral knees with a duration greater than one month, self-reported “worst” Numeric Pain Rating scores of three out of ten or greater in the past week, and pain with at least two of the four following activities: full squat, seated resisted isometric quad contraction at 60 degrees of knee flexion, moderately firm patellar compression while supine with 30 degrees knee flexion, and palpation of the patellar facets while supine with zero degrees knee flexion. For individuals with bilateral knee pain, the self-reported most affected side was used. Females in the healthy control group were age and sport matched to the cases.

Subjects were excluded from participating if they had a history of hip or knee surgery, traumatic patellar dislocation, or a lower extremity fracture in the last three years. Additionally, individuals who reported back, hip, ankle, or foot pain were ineligible. Those who were not able to comfortably assume a prone position, or who reported tenderness with seated palpation of the patellofemoral joint line, patellar tendon, or fat pads were also excluded.

Procedures

All subjects underwent one data collection session. Subjects initially completed a PFPS screening questionnaire which included demographic information, the Kujala knee pain scale and various Visual Analogue Scales (VAS). Upon completion of the form, researchers recorded measurements of each subject's femur and tibia length in centimeters. Femoral measurements were obtained from the greater trochanter to an inch above the lateral joint line of the knee (tibiofemoral joint), while tibial measurements were taken from the lateral joint line of the knee (tibiofemoral joint) to an inch above the lateral malleolus on the affected limb. Subjects then completed a physical exam in which researchers screened for inclusion and exclusion criteria. The exam included a full squat, a seated isometric quad contraction at 30 and 60 degrees of knee flexion, a patellar compression test, and palpations of patellar facets, the tibiofemoral joint line, subpatellar fat pads, and the patellar tendon. Subjects were subsequently asked if each item of the exam caused pain.

Those subjects that passed the inclusion and exclusion criteria continued on to complete the rest of the session. At this time, subjects with knee pain indicated to a researcher, not involved in the strength and endurance tests, which limb was their affected side. For individuals with bilateral knee pain, the knee with the most severe pain was chosen. This same researcher randomly selected a side and then informed control subjects which leg would be tested. Blinded researchers then performed two isometric muscle strength tests and a core muscle endurance test to the subjects specified side.

Tests and Measures

The Kujala knee pain scale is a multiple choice outcome measure consisting of 13 items, which includes questions related to pain, swelling, patellar subluxations, and difficulty with stairs.[26,27] Scores range from zero to 100, with 100 indicating no functional limitation. Research has shown that the Kujala knee pain scale has excellent test-retest reliability (ICC=0.968).[28] The VAS Pain Scale is a ten centimeter, continuous line scale, with zero indicating no pain and ten indicating the worst pain imaginable. This scale was utilized to identify a subject's typical and worst level of pain experienced over the past week, as well as pain intensity with the following activities: walking, ascending and descending stairs, sitting and squatting. The VAS has been shown to be both a reliable and valid measure.[14]

Isometric muscle strength tests of the hip external rotators and abductors were obtained following standard protocols documented by Reese.[29] During the hip external rotator muscle test, subjects were seated at the edge of the plinth with their knees and hips flexed to 90 degrees. A dynamometer was placed one inch proximal to the medial malleolus of the tested leg. A strap was used to hold the dynamometer in place and was attached to the plinth leg at 90 degrees and perpendicular to the tibia. Subjects were instructed to cross their arms over their chest to reduce compensation strategies (Figure 1). For the hip abductor muscle test, subjects were positioned on the plinth in side lying on the non-tested side. The dynamometer was placed one inch proximal to the lateral femoral condyle and a strap was secured perpendicular to the femur around the plinth. The strap was tightened so that during the isometric contraction the subject was positioned in neutral hip alignment (Figure 2).

During both muscle tests, subjects were instructed “push against me as hard as you can.” The researcher gave verbal instructions to push against the dynamometer for a duration of five seconds. Subjects performed two trials with a 30 second rest between each trial. The maximum force was recorded on the dynamometer for each trial and the better of the two trials was submitted for data analysis. When performing the side plank core endurance test, subjects were positioned side lying with their top arm crossed over their body.[30] Researchers instructed subjects to assume the side plank position with their elbow directly under their shoulder. Subjects were asked to hold the side plank "as long as possible" or until they were no longer able to maintain proper form as determined by the researcher (Figure 3).

Analysis

For analysis, Number Cruncher Statistical Software 8 (Kaysville Utah) was used. Means and t-tests were compared for all data with normal distribution, while medians and Mann-Whitney U tests were compared when data were non-normal. Pearson correlation coefficients assessed the degree of relationship among strength, endurance, pain, and Kujala scores for the case group. A significance level of 0.05 was used for all comparisons. Finally, the effect size for core endurance was calculated.

Chapter IV: RESULTS

A total of 30 subjects from local running camps and high school cross country running teams met inclusion criteria to participate in this study. Of the 30 subjects, nine reported knee pain, however two were excluded because their duration of pain was less than one month and an additional subject was excluded due to lack of tenderness on the palpation exam. Therefore, a total of six subjects with knee pain were included in this study. For the 21 subjects who did not report knee pain, three were excluded because they reported other pain in their lower extremities and one reported tenderness during the palpation exam. A total of 17 subjects were ultimately included in this study as control subjects.

Baseline demographic data collected for cases and controls can be seen in Table 1, and no statistically significant differences were found between any of these variables. All subjects were members of either a middle school or high school girls' cross-country running team. All but one subject had right leg dominance. Half of the cases were tested on the right leg, and the other half were tested on the left leg. The control group was similarly divided and tested.

Strength was normalized to body weight, and means of peak hip strength were initially calculated. Medians were also reported due to the presence of outliers. Median peak strength values can be seen in Table 2. The Mann-Whitney U test was used to compare the median peak strength values between groups. No significant differences were found between cases and controls for either strength measurements. However, subjects with patellofemoral pain generated 12% greater median hip abduction strength and 7% less median hip external rotation strength than controls.

Torque was calculated following previous protocol found in Dierks et al. 2008, using median values.[31] No significant differences were found for hip abduction torque ($p = 0.22$) or external rotation torque ($p = 0.64$).

Means and medians were also calculated for lateral core endurance measurements. A Mann-Whitney U test was used to compare the median hold times between groups. No significant differences were found, however the subjects with patellofemoral pain generated 22% less median lateral plank endurance than controls. A moderate effect size was calculated (0.465). Based on this result, a post-hoc power analysis was performed and revealed that 76 cases and 76 controls would be required to achieve significance.

Correlations were calculated between many of the strength, and endurance variables for the entire sample (Table 3). Correlations for pain were additionally calculated for cases. A moderate correlation was found between hip abduction and external rotation isometric strength ($r = 0.49$; $p = 0.02$). Interestingly, no correlation was found between isometric strength and lateral plank endurance ($r < 0.2$). Among the cases with PFPS, strong negative correlations were found between usual pain and Kujala ($r = -0.743$), hip abduction strength and Kujala ($r = -0.800$), and hip external rotation strength and Kujala ($r = -0.678$). Strong positive correlations were found between hip abduction strength and usual pain ($r = 0.745$), and hip external rotation strength and usual pain ($r = 0.945$). Lastly, no correlation was found between lateral core endurance and Kujala ($r = -0.039$).

Chapter V: DISCUSSION

The purpose of our study was to investigate whether a relationship exists between hip musculature strength and core endurance in female runners between the ages of 12-18 with patellofemoral pain in comparison to healthy age, gender and sport matched controls. Our results showed a low correlation between isometric strength and lateral core endurance in this population. Based on these preliminary results, we hypothesize that muscular endurance may be a more important factor than isometric strength in the development of PFPS in adolescent female runners, due to the repetitive nature of the sport. This hypothesis was supported by our data that individuals with PFPS have 22% lower core endurance. The lack of correlation would indicate that isometric strength and lateral core endurance tests are measuring different underlying constructs, and conclusions cannot be drawn about endurance based on measures of isometric strength reported in previous studies. Muscular endurance is particularly important in repetitive athletic activities such as running. Our study is the first to investigate differences in core endurance between runners with knee pain and healthy controls in a population of adolescent females. Our results suggest that, based on a small sample of cases and controls, subjects with patellofemoral pain have lower core muscle endurance than age and sex matched controls.

Additional reasoning for the lack of correlation found between isometric strength and lateral core endurance could be due to the differences in muscles being tested. The lateral core plank requires activation of the obliques, quadratus lumborum, and gluteus medius, while the hip abduction isometric strength mainly attempts to isolate the gluteus medius.[30] The core musculature tested in the lateral plank is important in the stabilization of the pelvis during dynamic activities such as running. Without this stabilization, hip adduction and internal rotation may be increased leading to abnormal patellar tracking, as hypothesized by the top-down mechanism.[10]

The Kujala Anterior Knee Pain Scale and Visual Analog Pain scales are commonly used in the PFPS population, and both demonstrate high reliability. Results from our study found a strong negative correlation between the Kujala and usual pain. This result was expected, as less disability, which is indicated by a higher score on the Kujala, is typically associated with less pain on the VAS pain scale. A strong negative correlation was also found between the Kujala and hip abduction and external rotation strength, which was not expected. Our original hypothesis was that greater hip strength would be associated with less disability, indicated by a higher Kujala score. This result can potentially be explained in a few ways. First, we were unable to recruit enough subjects to accurately assess the relationship between hip strength and patellofemoral pain disability measured by the Kujala. Secondly, it is possible our hypothesis for this adolescent population was incorrect. Previous studies that looked at the adult population revealed low correlations between hip strength and abnormal lower extremity kinematics.[1,19] If we assume abnormal lower extremity kinematics are associated with greater levels of disability, then hip strength is not necessarily associated with abnormal kinematics and therefore disability, which match the results from our study. There is no current literature that examines the relationship between hip strength and disability based on the Kujala that would support our hypothesis for this adolescent population. Interestingly the lateral core endurance test showed no correlation to the Kujala, which again may be due to the small sample size.

Further results found in our study included strong positive correlations between usual pain levels measures on the VAS pain scale and hip abduction and external rotation strength. This result was also unexpected as it is opposite from our original hypothesis. We hypothesized that increased strength would be associated with decreased pain. The small sample size in our study may be a reason for this result. Alternatively, in competitive runners, greater strength may be associated with greater ability and motivation to run through pain.

No current literature addresses the relationship between PFPS and lateral core endurance in the adolescent or adult population. Our study revealed that the PFPS group generated 22% less median lateral plank endurance than the control group, however these results were not found to be significantly different. Once again this may be due to the small sample size in our study. A larger sample size is needed to allow stronger conclusions regarding the role of core endurance in the development of PFPS. Another possibility may be that there is no relationship between core endurance and the development of PFPS; therefore, it would not be expected to see significant differences in core endurance between controls and individuals with PFPS. A larger sample size is needed to allow stronger conclusions regarding the role of core endurance in the development of PFPS.

Lastly, no significant differences were found between the PFPS and control groups for either hip abduction or external rotation strength. These results contradict previous literature which found there to be significant differences between these two groups in hip strength.[1,3,5,6] These previous studies were able to obtain larger sample sizes than our study, therefore, they may have been able to more accurately study these hip strength differences. Also, the subjects in this study were all young runners, whereas other studies have included a mix of athletes or sedentary populations. It is possible that the isometric hip strength of young runners is not related to PFPS, but muscular endurance is instead. In addition, in our study when moment arms were taken into consideration, there were again no significant differences in torque between the two strength measurements. We suspect this result was due to the similar height of subjects in both groups. The median control group height was 65.4 inches and the median case group height was

66.9 inches. Therefore, we can reasonably assume that differences in leg length and torque did not impact the comparisons in strength between the two groups.

The study performed by Ireland et al, used a case control design to analyze hip strength in relation to PFPS. This was one of the first studies to find that subjects with PFPS displayed weakness in hip abduction and external rotation compared to age and sex matched controls, and it is the only study to date with a subject population of adolescent female athletes similar to our study. Due to this similarity, we compared our results to those of the Ireland study. For this comparison we analyzed our strength data as a percentage of body weight. Since our data were not normally distributed, we compared our median strength data to the mean results in Ireland's study (Figure 4). It is interesting to note that our control subjects show less hip abduction and external rotation strength, and our PFPS group show greater hip abduction and external rotation strength than the subjects in Ireland's study. While our data indicates findings opposite those of Ireland's, it is important to remember that our results were not statistically significant and we calculated median values compared to Ireland's mean values, due to the lack of normality in our data.

There are a few notable limitations from our study. The main limitation was the challenge we encountered recruiting subjects. Due to the age requirements in our inclusion criteria, parental consent forms were required. Getting the parental consent forms returned to us prior to testing the subjects was more difficult than we had anticipated. Because of this, many subjects were unable to participate in this study. In particular, subject numbers were more limited in the PFPS groups compared to the control group.

Another limitation was the difficulty interpreting the history items on the subject questionnaire. The subjects in our study were given brief instructions to answer questions regarding their symptoms, pain levels, and disability with different activities. Upon analysis of these questionnaires it appeared the subjects required greater clarification for accurate responses to certain questions. Inferences were then made by the research team as to whether the subjects would be included or excluded, based on whether subjects clearly fit in the case or control group. In the questionnaire we failed to inquire about the individual's running history and training variables. However, all subjects were either members of a high school or junior high cross country running teams. In addition to the questionnaire, the palpation exam that was performed for inclusion and exclusion criteria proved to be difficult to interpret due to unexpected findings. Because of this two subjects were excluded, which may have skewed our results. The palpation exam is accepted based on clinical reasoning, but its validity has not been tested.

An additional limitation was the inconsistency of directions given to the subjects during the side plank core test. Some of the subjects were instructed to stack their feet on top of each other, while others were instructed to place their top foot in front of their bottom. These inconsistencies were due to a lack of consistency among the researchers, which may have impacted our results.

A further limitation was the timing of our data collection relative to the subjects' respective workouts. All subjects but one were tested after running earlier in the day. Differences in training regimen and timing of testing may have had a confounding effect on our results.

Future Research

This study focused on runners to provide consistency and to prevent confounding variables such as differences in sport specific training and conditioning. Since future research in this area warrants a larger sample size in order to reach adequate power, it may be interesting to test subjects from a variety of sports. With an increase in sample size, subjects could be sport-matched to decrease confounding variables. In addition, future research should be performed prospectively, as a retrospective study design does not allow researchers to determine a temporal relationship between risk factors and onset of the overuse injury.

Chapter VI: CONCLUSION

The results of our study indicate that the PFPS group had only 7% less hip external rotation strength and 12% greater hip abduction strength, but they had 22% lower lateral side plank endurance and then control subjects. While not statistically significant, these results suggest that muscular endurance may be a greater factor in the development of PFPS than muscular strength. However, further research with a larger sample size is needed to verify a relationship between hip strength, core endurance and PFPS in adolescent females.

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Tables

Table 1. Baseline Demographic Data

Variable	Control	Case
Age	14.8±1.3	15±1.1
Height (in)	65.4±3.2	66.5±2.0
Weight (lbs)	110.8±18.8	113.3±10.7
BMI	18.1±2.3	18±1.3
Pain Duration (wks)	N/A	83.8±85.9
Worst Pain VAS (cm)	N/A	4.8±3.1
Usual Pain VAS (cm)	N/A	3.1±3.1
Kujala	N/A	84.5±7.3

Table 2. Median Peak Strength Values as Percent of Body Weight

	Hip Abd Strength	Hip ER Strength
PFPS Group	10.9%	29.2%
Control Group	11.7%	25.8%

Table 3. Correlation Data: All Subjects (n=23)

	Age	Hip Abd Strength	Hip ER Strength	Lateral Plank Endurance
Age	1 p=0.000	-0.294 p=0.172	-0.014 p=0.948	-0.247 p=0.260
Height	0.38 p=0.074	0.312 p=0.148	0.138 p=0.530	-0.227 p=0.230
Weight	0.482 p=0.020	0.089 p=0.686	-0.069 p=0.755	-0.119 p=0.590
Hip Abd Strength	-0.294 p=0.173	1 p=0.000	0.489 p=0.018	0.045 p=0.838
Hip ER Strength	-0.014 p=0.948	0.489 p=0.018	1 p=0.000	-0.148 p=0.501
Lateral Plank Endurance	-0.247 p=0.256	0.045 p=0.838	-0.148 p=0.501	1 p=0.000

Table 4: Correlations Among Hip Strength, Core Endurance, Kujala, and Pain Scales Among Cases with Patellefemoral Pain Syndrome (n=6)

	Hip ER Strength	Hip Abd Strength	Lateral Plank Endurance	Kujala Pain Scale	VAS Usual Pain	VAS Worst Pain
Hip ER Strength	1 p=0.000	0.732 p=0.098	-0.305 p=0.556	-0.678 p=0.139	0.945 p=0.004	0.831 p=0.040
Hip Abd Strength	0.732 p=0.098	1 p=0.000	0.151 p=0.775	-0.800 p=0.056	0.745 p=0.090	0.507 p=0.304
Lateral Plank Endurance	-0.305 p=0.556	0.151 p=0.775	1 p=0.000	-0.039 p=0.942	-0.266 p=0.610	-0.420 p=0.407
Kujala Pain Scale	-0.678 p=0.139	-0.800 p=0.056	-0.039 p=0.942	1 p=0.000	0.743 p=0.091	-0.682 p=0.135
VAS Usual Pain	0.945 p=0.004	0.745 p=0.090	-0.266 p=0.610	0.743 p=0.091	1 p=0.000	0.937 p=0.006
VAS Worst Pain	0.831 p=0.040	0.507 p=0.304	-0.420 p=0.407	-0.682 p=0.135	0.937 p=0.006	1 p=0.000

FIGURES

Figure 1. External Rotator Muscle Test: Subjects were instructed to sit with arms across chest to decrease compensatory strategies.

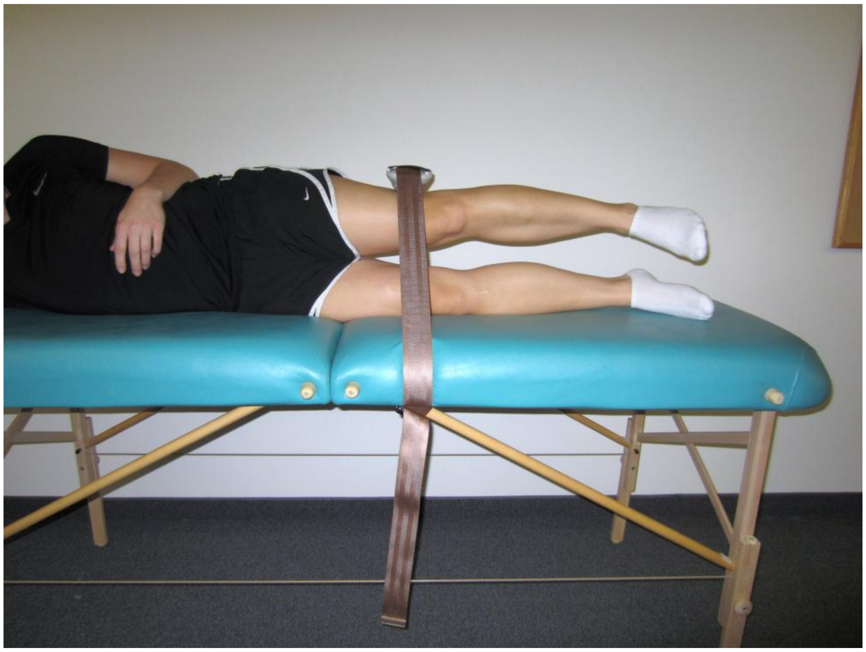


Figure 2. Hip Abductor Muscle Test: Subjects were positioned sidelying with strap secured so that participants could not abduct their leg past neutral.

Figure 3. Side Plank Core Endurance Test: Subjects positioned their feet stacked or one in front of the other, with top arm folded across chest.

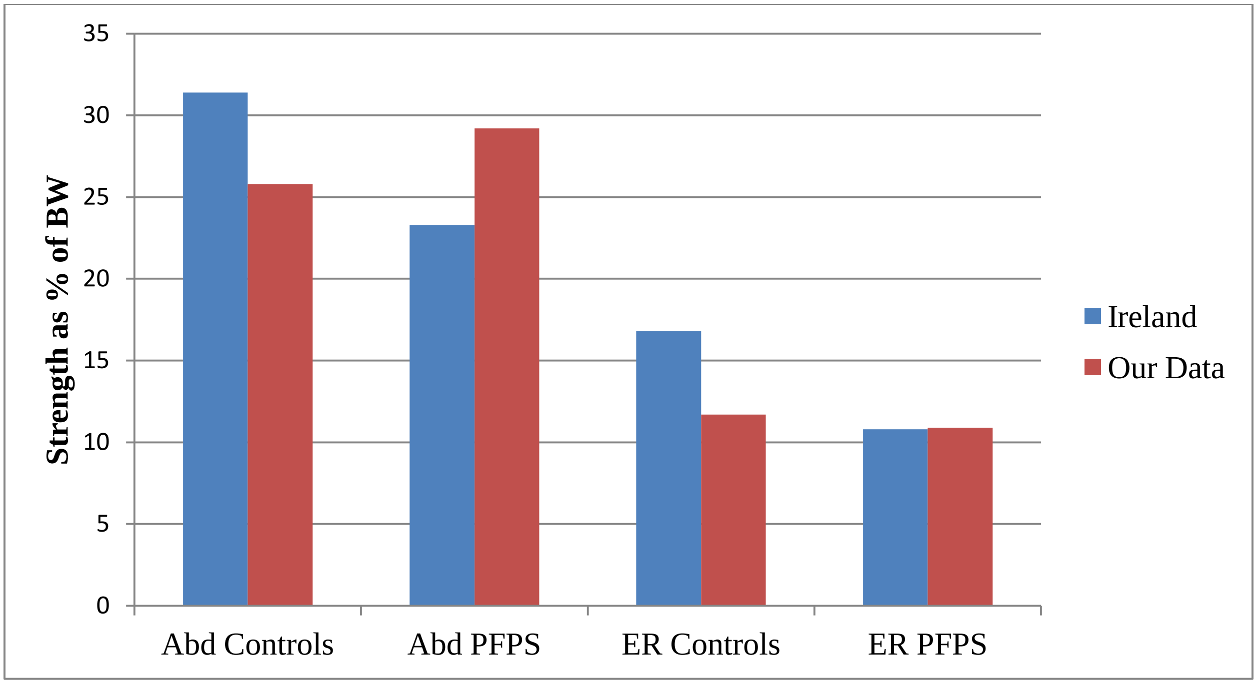


Figure 4. Comparison of strength measurements to Irelands' data.[5]

Appendix A

Hip Strength And Endurance in Girl Athletes With and Without Knee Pain
INFORMATION AND ASSENT FORM

Introduction:
You are invited to participate in a research study about knee pain. This study is being conducted by Jenna Batchelder, Angela Everson, Leah Paquin, Heidi Sande, graduate students at St. Catherine University. They are being helped by two physical therapists and professors, John Schmitt and Kristen Gerlach. We are inviting girls in youth sports that have knee pain to be in our study. We are also asking teammates or friends without knee pain to be in our study, too, so we can compare their strength to the strength of the girls with knee pain. Please read this form and ask questions before you decide if you want to be in the study.

Background Information:
Knee pain is more common in girls than boys and we would like to know why. We will be testing hip muscle strength and endurance for girl athletes with knee pain and without knee pain. We think 40 girls will be in our study by the time we are done.

Procedures:
If you decide to participate, we will either come to your team practice or invite you to be tested at the research lab at St. Catherine University at a time that works well for you.
1. You will need to have a parent or guardian fill out an informed consent form.
2. You will answer some simple questions at the beginning of the research session including questions about your knee pain and ratings of how much pain you have.
3. You will be involved in a quick physical screening session to see which research group you will be put into. The researcher may apply pressure to your knee and ask if it hurts.
4. The researchers will then test your hip strength. For the first hip strength test you will be asked to lie on your side and push your top leg up towards the ceiling as hard as you can against a device that measures force. For the second hip strength test you will be seated at the edge of a table with your feet dangling below you. You will push your leg out to the side as hard as you can against a device that measures force. Each step will be explained to you in a stepwise fashion and a practice strength testing session will be given.
5. For the final test you will lie on your side and lift your hip off the ground for as long as you can.
6. The study will take about 30 minutes.

Risks and Benefits of being in the study:
There are a few risks to think about before you decide whether or not to be in the study. One risk is that you may not want to tell us things about your knee pain, or you may worry that others will learn about your knee pain. We won't tell anyone else what we find. There is a little risk that the tests will hurt, but we want to let you know that the

tests we will do are very common, and they don't usually hurt. If they do hurt, it is usually only a little while.

Being in this study will not really help you in any way. We hope it will help physical therapists and doctors better understand why girls get knee pain so often.

Confidentiality:

We will keep all of your information private and won't tell your coach or anyone else what we find about you, except your parents if they would like to know.

Other things to know about the study:

It is up to you and your parents whether or not you want to be a part of this study. You don't have to, and even if you say you do you can change your mind later. Just let us know if you want to stop. If you do stop we won't be mad or upset at all

If you have questions about the study, please let us know. Your parents also have the researchers' phone numbers if you want to call us.

You may keep a copy of this form.

Statement of Assent (only sign this if you want to be in the study):

I am signing this because I know what I'm being asked to do and I would like to be in the study:

____

Signature of Child age 12-14 Date

____

Signature of Researcher Date

Appendix B

PFPS Screening Questionnaire 2013
Name____
Age____________(eligible if 12-18)   Contact E-mail_________________________________
Phone___________________________
Parent's Name____
Recruited From____

1) What is your main sport?______________   List any other sports that you play competitively:

2) Which leg do you prefer to kick with (circle one)?   Right   Left

3) Do you have knee pain?   Yes (continue with #4)   No (skip to #10)

4) If yes, is it (circle one):   Right   Left   Both   If both, which is worse (circle one):   Right   Left

5) How long have you had this pain? ___________________

6) The pain began (circle one):   from an injury (specify)___________________

   gradually
   not sure

7) Where is the pain located?____

8) I have pain with (circle all that apply):

   walking   running   climbing stairs
   kneeling   squatting   prolonged sitting

9) On a scale of 0-10 with 0 = no pain and 10 = pain that is the worst you can imagine, what would you rate your knee pain when symptoms were at their worst in the past week? (need 3/10 to qualify as a case)

10) Do you CURRENTLY have any of the following: low back pain, hip pain, leg pain below the knee, fibromyalgia, pregnancy, cancer or a systemic disease (e.g. Rheumatoid Arthritis)?   Yes / No

11) Have you ever had knee surgery? Yes / No

12) In the past 3 years, have you had a leg, ankle or foot fracture? Yes / No

If you have knee pain, please continue with the next 3 pages.
If no knee pain, let the researcher know that you are done with the questionnaire.

Subject #_____________ (Research Staff)

Kujala Knee Pain Scale

Knee (circle): Left / Right / Both

For each question, circle the choice which corresponds to your most recent knee symptoms:

1. *How much of a limp do you have?*
   a. *None*
   b. *Slight or occasional / periodical*
   c. *Constant*

2. *How much weight can you bear/support on your leg?*
   a. *Full weight bearing / support without pain*
   b. *Painful with weight bearing / support*
   c. *Unable to support / weight bearing is impossible*

3. *How far can you walk?*
   a. *Unlimited distance*
   b. *More than 1 mile*
   c. *½ to 1 mile*
   d. *Unable to walk*

4. *How would you describe your ability to walk stairs?*
   a. *No difficulty*
   b. *Slight pain when descending.*
   c. *Pain both descending and ascending*

    d. *Unable*

5. *How would you describe your ability to squat?*
    a. *No difficulty*
    b. *Repeated squatting is painful*
    c. *Painful each time I squat*
    d. *Possible only with partial weight bearing on my legs*
    e. *Unable to squat*

6. *How would you describe your ability to run?*
    a. *No difficulty*
    b. *Pain after more than 1 mile*
    c. *Slight pain from the start*
    d. *Severe pain*
    e. *Unable to run*

7. *How would you describe your ability to jump?*
    a. *No difficulty*
    b. *Slight difficulty*
    c. *Constant pain*
    d. *Unable to jump*

8. *How would you describe your ability to sit for a long period with knees bent?*
    a. *No difficulty*
    b. *Painful after exercise*
    c. *Constant pain*
    d. *Pain forces me to straighten my legs temporarily*
    e. *Unable to sit for a long period with knees bent*

9. *How would you describe your pain?*
    a. *None*
    b. *Slight and occasional*
    c. *Interferes with sleep*
    d. *Occasionally severe*
    e. *Constant and severe*

10. *How would you describe the degree of swelling in your knee(s)?*
    a. *None*
    b. *After severe exertion*
    c. *After daily activities*
    d. *Every evening*
    e. *Constant*

11. *How would you describe the degree of abnormal/excessive kneecap movements (subluxations)?*
    a. *None*
    b. *Occasionally in sports activities*
    c. *Occasionally in daily activities*
    d. *At least one documented dislocation*
    e. *More than two dislocations*

12. *How would you describe the degree of loss of muscle size in your thigh?*
    a. *None*
    b. *Slight*
    c. *Severe*

13. *How would you describe any loss of bending motion in your knee?*
    a. *None*
    b. *Slight*
    c. *Severe*

Directions: Please place an "x" on the line to mark your pain rating for each question. If both knees are painful, please answer the question in relation to the knee with the "worst" pain:

1. Over the past week, how would you describe your *usual* level of knee pain?

No pain at all — Worst pain possible

2. Over the past week, how would you describe your *worst* level of knee pain?

No pain at all — Worst pain possible

3. Over the past week, how would you describe your *usual* level of knee pain while walking?

No pain at all — Worst pain possible

4. Over the past week, how would you describe your *usual* level of knee pain while going up and down stairs?

No pain at all — Worst pain possible

5. Over the past week, how would you describe your *usual* level of knee pain while sitting?

No pain at all — Worst pain possible

6. Over the past week, how would you describe your *usual* level of knee pain while squatting?

No pain at all — Worst pain possible

Examination and Testing

Examiner 1

1. Physical Exam Screening Tests: For each test, ask: “Does this cause (your) knee pain?”

__Y __N Full squat: ask patient to perform.

__Y __N Seated max isometric quad, 30, 60^{o} , “Push against me as hard as you can…”

__Y __N Patellar compression – subject supine with knee at 30^{o}, push down firmly with palm on patella

__Y __N Firm palpation of patellar facets – posterior aspect both medially and laterally (supine, knee straight)

__Y __N Firm palpation of tibiofemoral joint line, fat pads, patellar tendon

2. Height (tape measure) in inches: __________

3. Weight (scale) in pounds: ___________

4. Femur moment arm (GT to dynamometer placement – mark in pen) in cm: __________

5. Tibia moment arm (knee center to dynamometer placement – mark in pen) in cm: __________

Examiner 2

1. Leg tested (circle one): Left Right

Isometric testing – Commands

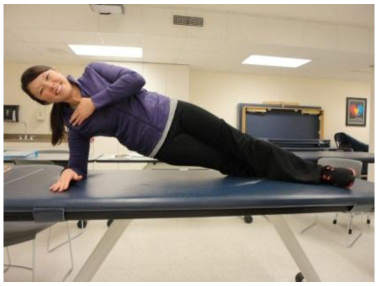
- Practice: Push against me (or the device) with about 1/2 your strength as a warm-up on the count of 3…1, 2, 3 push, push, push, push, push
- Maximum: Push against me (or the device) as hard as you can on the count of 3…1, 2, 3 PUSH, PUSH, PUSH, PUSH, PUSH

2. ABD in 10^{o} ABD, neutral flexion/extension:

   Trial 1 ___________ Trial 2 ___________

3. External rotation in sitting, knees at 90, legs off the ground, arms crossed

   Trial 1 ___________ Trial 2 ___________



4. Side plank: Straight alignment with neutral trunk, hips.

- Ask subject to assume the position for 5 sec to verify understanding, then relax
- "When you are ready, I want you to get in the plank position and hold as long as you can. Go ahead (start

stopwatch when they reach the position). Every 20 sec or so: “Remember, hold it as long as you can”

Time to fail (sec) ________________________________