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Hip Strength and Core Endurance in Female Adolescent Runners With and Without Knee Pain

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ABSTRACT

BACKGROUND AND PURPOSE: Patellofemoral pain syndrome (PFPS) is one of the most prevalent orthopedic conditions affecting young athletes today. Epidemiological studies have reported PFPS to be the most common injury seen in runners. Deficits in hip strength have been identified in runners with PFPS, but core endurance in relation to knee pain has not been well documented. The primary purpose of our study was to investigate differences in hip strength and core endurance between female, adolescent runners with PFPS and their age matched controls. The secondary purpose of our research was to examine any correlations between hip strength and core endurance in our participants.

METHODS: A cross sectional design was used. We recorded pain, Kujala score, hip strength and endurance and core endurance in 34 adolescent female cross country runners. Cases with PFPS were defined as young female runners with a minimum three month history of anterior knee pain of insidious onset and had a most severe knee pain rated 3/10 or higher. Control subjects had no history of knee surgery, traumatic knee injuries, patellar instability, or neurologic conditions. Between-group differences and correlations were calculated between age-matched cases and controls using t-tests. Pearson correlation coefficients were used to determine associations for selected measures.

RESULTS: No significant differences were observed between cases and controls for hip strength and endurance. However, there was a large percent difference between cases and controls in selected core endurance measures. It was found that all hip strength and core endurance results had low correlations (≤ 0.28). Among cases with PFPS, a strong and significant, negative correlation was found between subjects' reported worst pain and Kujala score ($r=-0.79$, $p<0.05$)). A non-significant moderate negative correlation between side plank endurance and usual pain was found ($r=-0.49$).

CONCLUSION: There were minimal differences noted in isometric strength tests between groups. There was a clear difference noted with endurance testing between groups. However, this difference was not found to be significant, which could be due to low number of subjects with PFPS. The differences in endurance between athletes with PFPS and their pain free counterparts merit further investigation and research. Of note, it was found that strength and endurance had a minimal correlation; this indicates that clinically, endurance cannot be inferred from isometric strength testing. Therefore, we recommend clinicians perform specific measures of endurance when attempting to identify impairments in runners with PFPS.

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

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CHAPTER I: INTRODUCTION

Patellofemoral pain syndrome (PFPS) is one of the most prevalent orthopedic conditions affecting athletes today. Those affected by PFPS complain of retropatellar or anterior knee pain that is exacerbated with activities such as squatting or running. Epidemiological studies have reported PFPS to be the most common injury seen in runners.[1-2] These studies indicate that females appear to be at a higher risk for developing PFPS than males and that adolescents are also commonly at risk.[3]

While it is widely acknowledged that PFPS is a common orthopedic injury, the exact magnitude of the problem has only been thoroughly researched in recent years. In 2009, Oakes et al[4] performed an exhaustive review of the literature to determine PFPS prevalence. They examined studies that spanned from 1984-2006 and found an overall prevalence, across all populations, of PFPS of 8.75-17%.[4] However, in 2015 Rathleff et al[5] reported the prevalence of PFPS among adolescents to be 6-7% and that within the adolescent population, females were 2.3 times more likely to develop PFPS than males. In a study by Taunton et al[2] 2002 patients were referred to a facility at the University of British Columbia and underwent a biomechanical and physical examination by sports medicine physicians for their running injuries. From their analysis, it was determined that PFPS was the most common running injury affecting 16.5% of this population, with IT band syndrome and plantar fasciitis as the next two most prevalent conditions, respectively. This retrospective, case control study researched both males and females and did not specify whether adolescents were included in the analysis.[2]

Numerous studies over many decades have investigated the etiological factors leading to PFPS. However, the cause of pain is still not completely known and is believed to be multifactorial. Previous research has found several diverse factors as potential causes for PFPS including, but not limited to, knee strength, Q angle, gait abnormalities, training errors and decreased flexibility.[2,6] Specifically, an abundance of research has focused on knee strength as a risk factor for PFPS. Many prospective studies indicate that decreased knee extensor and flexor strength are associated with patellofemoral pain.[7-9] Yet, a retrospective study by Rathleff et al[10] in 2013 observed no differences in knee strength between those with PFPS and their age matched controls. In addition to knee strength, weakness and instability in the hip and core, as well as kinematic deficits have also been proposed mechanisms for PFPS.[10-17]

Within the last two decades the top-down mechanism has been researched as a potential cause for PFPS.[18] The top-down mechanism can be explained as a mechanism in which strength deficits combined with altered timing of activation of proximal hip and core muscles lead to dynamic valgus at the knee.[18] Dynamic valgus or inward collapse of the knee joint is defined by excessive internal rotation and adduction of the hip. The proposed mechanism for dynamic valgus involves weak hip abductors and external rotators, resulting in poor eccentric control of hip adduction and internal rotation. The resulting dynamic valgus increases compressive forces at the patellofemoral joint theoretically leading to patellofemoral pain. It is important to note in relation to the top-down mechanism, that because of its role as an external rotator, weakness and poor endurance of the gluteus maximus may also lead to inward collapse of the knee. The gluteus maximus is a significant shock absorber during running. Thus with a weak gluteus maximus, other shock absorbers such as the quadriceps have to compensate to absorb excess shock. Excessive use of quadriceps is also a proposed mechanism for patellofemoral pain.

The top-down mechanism as a cause for patellofemoral pain in the adolescent, female population was first pioneered by Ireland et al[19] in 2003 when the authors investigated the relationship between deficits in hip strength and PFPS. This cross-sectional study demonstrated significantly lower isometric strength of hip abductors and external rotators of participants with PFPS on their injured leg compared to healthy controls. Over the last 13 years since this study, more evidence has been amassed which demonstrates there is a relationship between hip weakness and PFPS in the adult population. Yet, very few studies since Ireland et al[19] have focused exclusively on female adolescents, which leaves room for the expansion of data on this demographic. The current discrepancy in research is that cross-sectional, retrospective studies generally indicate a relationship between PFPS and hip strength deficits [15-16,19-20] , while prospective studies do not.[8-9,21-22]

There has also been some evidence to indicate that participating in either a hip or knee strengthening program may help to decrease PFPS. Of four randomized control trials reviewed, all demonstrated some improvement in resolution of the symptoms associated with PFPS[17,23-25] The length of these interventions ranged from 6-9 weeks and varied between exclusively a hip strengthening program, knee strengthening program or both. The results of these studies suggest that if strengthening improves PFPS symptoms then weakness may be a causative factor for this condition.

Inadequate core stability has also been identified as a potential risk factor for PFPS and is included in the top-down mechanism, but there is currently minimal literature to corroborate this hypothesis. The studies that have been completed in this area found that, in those with patellofemoral pain, there was a different pattern of core muscle recruitment, increased core activation and increased trunk displacement when exposed to perturbations compared to healthy controls.[12-13] Also, a study by Earl and Hoch in 2011[14] found that an improvement in core endurance led to a decrease in patellofemoral pain. These studies on core and endurance in relation to patellofemoral pain did not use adolescent, female athletes as their participants.

Within the last decade kinematics imaging methods, including three dimensional motion analysis, have been used to investigate potential causes for PFPS. There is currently limited research in this field. Cross sectional kinematic studies indicate that there is increased hip internal rotation in runners with PFPS compared to their healthy controls.[15-16] Furthermore a cross sectional study in 2013, Rathleff et al[26] found that knee injuries were associated with increased lateral trunk displacement. Also, two randomized control trials focusing on hip strengthening programs, found both knee abduction moments and internal rotation were decreased over the course of eight to nine weeks.[14,17]

The review of the literature will now go further into current knowledge in the areas of hip strength, core stability and endurance, and kinematics. Due to the gap in literature regarding hip strength in female adolescent athletes and the general lack of literature regarding core and endurance, the primary purpose of our study was to investigate differences in hip strength and core endurance between female, adolescent runners with PFPS and their age matched controls. The secondary purpose of our research was to examine any correlations between hip strength and core endurance in our participants. Our hypothesis was that there would be deficits in strength and endurance observed in cases with patellofemoral pain. Additionally, we hypothesized that our participants' strength would be directly correlated with their endurance.

CHAPTER II: REVIEW OF RELATED LITERATURE

Research has been conducted examining factors at the knee which may contribute to the risk of developing PFPS, including knee strength. Prospective research conducted by Duvigneaud et al[7] in 2008 and Boling et al[8] in 2009 on military recruits who developed PFPS during training both found significantly lower knee extensor strength at baseline when compared to recruits who did not develop PFPS. Additionally, Boling et al[8] found lower baseline knee flexor strength in recruits who developed PFPS. In contrast with these results, a case-control cross-sectional study performed by Rathleff et al[10] in 2013 found that in adolescent females with PFPS, there was no difference in knee flexor or extensor strength when compared to their peers without PFPS. However, a separate study published by Rathleff et al[11] in 2013 found that adolescent females with PFPS demonstrated less knee extensor torque when compared to their peers without PFPS. A prospective study published by Leudke et al[9] in 2015 investigated 47 female and 21 male high school cross country runners. Results demonstrated that runners who developed anterior knee pain during the cross-country season were classified only into the weakest tertiles of knee extensor and knee flexor isometric strength, as measured prior to the season starting.[9]

Over the past decade it has been proposed that the strength and endurance of hip musculature through the top down mechanism may have an effect on the knee, thus playing a role in the risk for PFPS. Research published by Ireland et al[19] demonstrated significantly less hip abduction and external rotation isometric strength of the symptomatic leg of young, physically active females with PFPS when compared to age and gender-matched controls. Based on these results, many studies since have examined the relationship between hip strength and PFPS. These studies can be classified into the categories of restrospective, cross sectional studies [11,15-16,19-20]or prospective cohort studies[8-9,22] with the two study types producing different results.

In general, retrospective, cross-sectional studies have found that deficits in hip strength are correlated with PFPS. In 2009, Prins and Van der Wurff[20] conducted a systematic review, including only retrospective studies examining hip strength in females ages 16-27 with PFPS. Of the five studies included in the systematic review, four found significantly less hip abductor strength and external rotation strength in participants with PFPS compared to asymptomatic controls.[20] Furthermore, a systematic review completed by Rathleff et al[11] in 2014 found moderate evidence for lower isometric hip abduction and extension in several studies in those with PFPS compared to controls. This systematic review also found a trend towards deficits in isometric hip external rotation as well. Included in the systematic review by Rathleff et al[11] in 2014 were two different studies published by Souza and Powers in 2009 which examined hip strength in physically active young adult females with PFPS.[15-16] One of their studies demonstrated significantly less hip external rotator, abductor, and extensor strength in subjects with PFPS when compared to those without[15]; the other study found subjects with PFPS to have significantly less hip abductor and extensor strength than their peers without PFPS.[16]

While the majority of cross-sectional studies have found an association between decreased hip strength and PFPS, others did not discover significant differences in these measures when compared to healthy controls. In a study including 12-16 year old subjects (N=40), Rathleff et al[10] in 2013 found no significant differences in hip abduction, adduction, external rotation, and internal rotation strength between the PFPS and healthy control groups. However, the authors of this study concluded that the discrepancies observed between their study and others' might be due to age, as this study is one of the first since Ireland et al[19] in 2003 to focus on subjects of this age group. They further theorized that there may be a difference in etiology of PFPS between adolescents and adults or that adolescents and adults represent the same pathology at two distinctly different stages.

A cross-sectional study performed by McMoreland et al[27] involving female university subjects aged 18-35 produced similar findings as Rathleff et al[10] (2013); in 12 subjects with PFPS and 12 healthy controls, no differences in hip external rotation, internal rotation, or abduction isometric strength were found. However, the small sample size of this study limits its statistical power and generalizability.

In contrast to cross-sectional study results, prospective cohort studies generally have not found a relationship between deficits in hip strength and PFPS. The systematic review by Rathleff et al[11] found that in three high quality studies there was moderate to strong evidence to suggest that deficits in isometric hip strength were not related to the development of PFPS. This systematic review included a prospective study by Thijs et al[22], which examined 77 previously sedentary female adult runners, mean age 38, initiating a 10-week running program. In this study 16 runners were diagnosed with PFPS. No significant difference was found in any measure of hip strength between participants who did and did not develop PFPS.

The majority of prospective research indicates that there is no relationship between deficits in hip strength and PFPS, yet a few studies have reported conflicting findings. Results from research performed on a cohort of 513 female and 806 male freshmen at the US Naval Academy (USNA) by Boling et al[8] demonstrated significantly less hip abductor strength at baseline in recruits who developed PFPS. Boling et al[8] also found recruits who developed PFPS to have significantly greater hip internal rotator strength at baseline than those recruits who were asymptomatic. Of note, all recruits at the USNA are required to participate in varsity or intramural sports in addition to their regular military fitness training. Specific age ranges were not reported in Boling et al's[8] research.

Finoff et al[21] in 2011 investigated 98 male and female adolescent high school runners and Leudke et al[9] in 2015 investigated 47 female and 21 male high school cross country runners. Finoff et al[21] found that runners who developed PFPS during their season demonstrated a significantly lower ratio of hip external to internal rotator strength at baseline compared to their peers who did not develop PFPS, as well as a significant decrease in hip abductor and external rotator strength from baseline to time of PFPS diagnosis. Leudke et al[9] found those with the weakest isometric hip abductor strength developed anterior knee pain.

Decreased hip endurance has also been implicated in the development of PFPS. Endurance, as determined by work output during 30 consecutive maximal concentric contractions at 30°/sec and 75% of full range of motion, was assessed by McMoreland et al.[27] The study concluded that there were no significant differences between the PFPS and control group. Therefore, the results of these studies leave some question as to whether hip strength and endurance deficits contribute to the development of PFPS.

Many studies have investigated the results of starting a strengthening program to reduce the symptoms of PFPS. Four randomized controlled trials (RCTs) found positive results on reducing symptoms of PFPS from a hip and/or knee strength training program.[17,23-25] In their RCT (N=28), Khayambashi et al[23] demonstrated that an 8-week hip strengthening program is more effective than no strength training at improving pain (VAS), health status (Western Ontario & McMaster Universities Osteoarthritis Index), and hip strength in females with PFPS. Ismail et al [24] found comparable results from their study (N=19) with an 8-week hip and core musculature strengthening program. When compared to the baseline measures, significant improvements in pain, functional ability, core endurance, hip abduction, and hip external rotation strength were observed at the end of the 8 weeks. In a large RCT (N=199), Ferber et al[25] studied the effectiveness of a 6-week hip or knee strengthening program in the management of PFPS symptoms. Regardless of which group the subjects were assigned to, hip or knee protocol, improvements of pain (VAS and Anterior Knee Pain Scale) and strength were observed, with no between group statistical differences in VAS or AKPS at 6 weeks. However, subjects in the hip strengthening group had resolution of symptoms one week earlier than those in the knee strengthening protocol. A small RCT (N=7) of 12-18 year old subjects with PFPS found that a 9-week strengthening program was effective at increasing hip strength.[17] The authors noted a significant decrease in pain from pre- to post-intervention.

Impairments in core stability are also thought to be a contributing factor in the development of PFPS. The core musculature is key for all kinetic chain activity and is activated before all activities to provide balance and stability to the trunk and extremities.[12-13] In the lower extremity, if core musculature is not activated properly or with enough force, instability may be present, leading to incorrect mechanics or increased activation of other muscles to compensate. Deficits in core musculature activation and endurance can result in knee valgus or tibial internal rotation during times of single limb stance as a way to provide increased stability to the lower extremity.[14] Over time, this change in mechanics may lead to pain at the knee joint, especially in those with highly repetitive movements, such as runners.[14]

There is limited research available about the relationship between core weakness and PFPS, especially with regards to which occurs first. In a case-control study, Shirazi et al[12] found that subjects with PFPS had a different pattern of core muscle recruitment and increased core muscle activation duration time when exposed to external perturbations as compared to healthy subjects. Participants with PFPS also demonstrated delayed activation of the gluteus medius when compared to healthy controls. In a case series study, Earl and Hoch[14] found that subjects with PFPS who improved lateral core endurance reported a decrease in pain, and also experienced a smaller knee abduction moment during running. This study suggests that improvements in core endurance resulted in improved running mechanics at the knee joint. In all of these studies, the subjects had already developed PFPS prior to participating, so it is unclear if the impaired core activation or weakness is a cause or an effect of PFPS. Zazulak et al[13] examined the relationship between trunk displacement in response to an external force and the development of knee injuries during the three year follow-up. Subjects who developed knee injuries over the course of the follow up were found to have increased lateral trunk displacement with external perturbation, as compared to healthy subjects. This study, however, was not specific to PFPS, but rather knee pain and lower extremity injury in general.[13]

Researchers have also used kinematics and different imaging methods to look at the risk factors for PFPS. In two different studies from 2009, Souza and Powers et al[15-16] examined hip and knee motions using three dimensional motion analysis. Both studies found that hip internal rotation was significantly increased, during running, a jump drop and step down maneuver, in women with PFPS, which they hypothesized was a result of weak external rotators, mainly gluteus maximus and medius. In 2013, Rathleff et al[26] looked at trunk displacement as it related to knee injuries using movement sensors to detect displacement after a sudden force application to the subjects. They found that athletes with more movement of the trunk specifically in a lateral direction had a higher chance of sustaining a knee injury. Earl and Hoch[14] in 2011 performed a study using three dimensional joint movement analysis, and found that after an eight week strengthening program including key hip musculature, knee abduction moments during running were reduced. Similarly, in 2014 Provance et al[17] found that after a 9 week protocol focusing on strengthening and neuromuscular control of hip external rotators, abductors, and extensors led to decreased hip internal rotations during running. This knee abduction, along with the previously mentioned hip internal rotation, have both been hypothesized to increase the likelihood of developing PFPS in women.

CHAPTER III: METHODS

Study Design

A cross sectional study design was used. Subjects were recruited through local high school cross country teams. Data collection occurred across four sessions during pre-season training, mostly prior to or during practice sessions. Some data collection occurred after subjects had participated in warm-ups or relay events. All participants under the age of 18 were required to have a signed consent form from a parent or guardian and assent was obtained from all athletes. This study was approved by the St. Catherine University Institutional Review Board.

Participants

All subjects were female cross country runners between the ages of 12 and 18 years old. Cases were considered if they had experienced symptoms of patellofemoral pain syndrome such as anterior or retropatellar knee pain for at least the three months prior to enrolling in the study. This pain needed to be provoked by at least two activities that decrease the patellofemoral space such as sitting, kneeling, squatting, running, or when using the stairs. Additionally, subjects had to rate their usual knee pain at greater than or equal to 30/100 mm on the visual analog scale.

Subjects were excluded as cases or controls if they had a history of surgery or trauma to their knees, lumbar spine, hips or ankles, or any neurologic disorder that may affect their gait pattern. Furthermore subjects were excluded if they had any patellar instability or were experiencing any knee pain not related to patellofemoral pain syndrome.

Procedures

Baseline Data- Prior to strength and endurance testing, subjects completed surveys describing their sports participation and their typical training schedule in miles run per week. Anthropometric measurements of height and weight were collected. Femur and tibia moment arms were measured for all subjects. Femur moment arms were measured from greater trochanter to 5 cm above the lateral knee joint line and tibia moment arms were measured from the lateral knee joint line to 5 cm above the lateral malleolus. Additionally, cases with knee pain were asked to rate their usual and worst knee pain over the past week, and knee pain with running on a visual analog scale 10 cm line. Cases were also asked to fill out a Kujala Anterior Knee Pain scale**.** This scale asks subjects to rate their knee pain and level of disability with various activities. A total of 100 points are possible on this scale, and a score of 100 points indicates no pain or difficulty. The Kujala Anterior Knee Pain scale has been found to have excellent test-retest reliability and responsiveness in people with PFPS.[28] Furthermore, this test has been found to be an effective screening device for PFPS in adolescent females.[29]

Strength Testing

For strength testing, all subjects were tested bilaterally, and the order for both motion and leg tested first was randomized. Strength measurements were recorded using a Microfet Hand Held dynamometer, (Hoggan Health, West Jordan, Utah). The dynamometer was held in place with the use of reinforcing straps attached to the table. This method has been found to have good to excellent interrater and intrarater reliability for testing lower extremity strength.[30] All strength testing was completed prior to endurance testing to reduce the risk of the endurance test creating fatigue and impacting strength performance. All subjects were given the same instructions for testing and were allowed to complete one practice trial at half strength. For testing trials, subjects were told to push as hard as they could against the device for five seconds, and the better of two trials was used. A 30 second rest break was given between trials.

Hip Abduction*:* Hip abduction testing was performed in sidelying, in the standard manual muscle testing position.[31] The dynamometer was placed just proximal to the knee joint. The strap was wrapped around the table and tension was applied to the strap while the hip was in slight abduction. Figure 1 shows the correct positioning for hip abduction strength testing.

Hip External Rotation: Hip external rotation testing was performed seated, in the standard manual muscle testing position.[31] The dynamometer was placed just proximal to the medial malleolus. The strap was attached to the leg of the table and tension was applied with the leg in neutral rotation. Figure 2 shows the correct positioning for hip external rotation strength testing.

Endurance Testing

To test core endurance, subjects completed side planks and single leg bridges for time. The side plank has been found to have high inter-rater reliability and intra-rater reliability as a measure of core endurance.[32] The side plank was also found to have a reliability coefficient of .97 when tested over a five day period and at an eight week follow up.[33] According to an EMG study, side plank and single leg bridge were found to have equal activation of the lumbar extensor and stabilization muscles of longissimus thoracis and lumbar multifidus. Side plank was found to have increased activation of gluteus medius and external oblique muscles compared to single leg bridge, while single leg bridge was found to have greater activation of gluteus maximus and hamstrings.[34] Again, all subjects were tested bilaterally, and order for endurance test and leg tested first were randomized. Subjects were instructed in the correct form and then were allowed to complete a five second practice trial to ensure understanding of the testing position. All subjects were then instructed to hold the position as long as possible and every 20 seconds were given reminders to hold as long as they could. Additionally, subjects were allowed one cue about form if they fell out of the correct position. Time was started once the subject reached the correct position and stopped once the subject was unable to hold the correct form. Each side was tested only once, and a two minute rest break was given between testing trials on each side.

Side Plank. Figure 3 shows the testing position for the side plank. Subjects were instructed to keep their top arm along the side of their body and feet stacked on top of each other. Furthermore, subjects were to keep their shoulders, hips and feet in a straight line, with minimal rotation at the spine.

Single Leg Bridge. Figure 4 shows the testing position for the single leg bridge. Subjects were instructed to bridge with both legs, and then to lift their foot off of the ground. Subjects were instructed to keep their thighs parallel and to keep their knees, hips and shoulders in a straight line. Additionally, subjects were to keep their pelvis level and limit any rotation at the hips.

Statistical Analysis

Age-matching of case and control subjects was performed to minimize confounders due to developmental level; each painful case was matched with 3 control subjects. Descriptive statistics including VAS pain and Kujala score were assessed for the case group; VAS pain was expressed on a 10.0cm scale and Kujala scale was expressed on a 100 point scale. Height, weight, age, and moment arm for the femur and tibia was gathered at baseline for each subject; these values were reported as mean±SD for each group. Between-group differences in height, weight, BMI, age, and moment arm of the femur and tibia were determined using 2-sample t-tests.

Hip strength was reported as percentage of each subject's body weight and core endurance was reported as time to failure for each testing position. Between-group differences in hip strength and core endurance were calculated using 2-sample t-tests and reported as mean±SD Pearson product-moment correlational statistics were used to assess for associations between measures of hip strength and core endurance for all subjects' bilateral lower extremities; the same statistic was used to assess for associations between hip strength, core endurance, VAS pain, and Kujala score in the painful subjects' affected or most painful lower extremity only. All calculations were performed using NCSS8 Statistical Software (Kaysville, Utah).

CHAPTER IV: RESULTS

Thirty-three participants were recruited for this study, and five participants were excluded from data analysis following data collection; two subjects were excluded due to history of orthopedic issues not meeting inclusion criteria, and three control subjects were excluded as they did not meet criteria for matching with case subjects. Twenty-eight participants, aged 12-18, were included in data analysis. Seven participants met the criteria for inclusion in the case group, and 21 participants met the matching criteria for inclusion in the control group.

Demographics of each group are illustrated in Table 1. A two-sample t-test found no statistically significant differences between groups for age, height, weight, body mass index, or femur and tibia moment arms.

Between-Group Differences

Between-group differences in hip strength and core endurance are displayed in Figures 5-8. For hip abductor strength, the case group produced a mean force of 30.5±8.2% of body weight and the control group produced a mean force of 32.1±6.4% of body weight (Figure 5); these values were not significantly different (p=0.61). For hip external rotator strength, the case group produced a mean force of 15.2±2.7% of body weight and the control group produced a mean force of 14.1±3.1% of body weight (Figure 6); these values also were not significantly different (p=0.41).

The control subjects' mean side plank endurance times were 14.1s longer than those of the cases; however, this difference did not achieve statistical significance (p=0.23) despite a modest effect size of 0.51. Similarly, the control subjects' single leg bridge endurance times were 14.2s longer than those of the cases. While the single leg bridge task also achieved a medium effect size at a value of 0.54, this between-group difference did not achieve statistical significance (p=0.24).

Correlational Statistics

Weak correlations between measures of hip strength and core endurance were found with all subjects pooled as a group (Table 2); scatter plots depicting the distribution of these data are displayed in Figures 9-12. Correlations between measures of hip strength, core endurance, pain, and function for the case group are listed in Table 3. Of note, a moderate negative correlation was found between VAS usual pain and side plank time for the case group, though this did not achieve statistical significance (r=-0.49, p=0.26). A strong negative correlation was found between Kujala score and VAS usual pain (r=-0.79, p=0.03). In contrast, statistically insignificant and weak negative correlations between Kujala score and VAS worst pain (r=-0.27, p=0.56) and VAS pain with running (r=-0.33, p= 0.48). Interestingly, a strong positive correlation was found between VAS worst pain and single leg bridge endurance (r=0.65, p=0.11), though this did not achieve statistical significance.

CHAPTER V: DISCUSSION

Demographics

A total of twenty-eight participants were included in this research study - 21 controls and 7 cases. Data analysis revealed no significant differences between the two groups. The controls and cases were similar in age, BMI, and femur and tibia moment arms reducing the potential for these factors confounding our results.

Between-group Comparisons – Endurance

Although non-significant, marked differences were observed in regards to core endurance between the cases and controls. Relative to the controls, the PFPS group demonstrated mean endurance scores 21% lower for side plank and 19% lower for single-leg bridge. Medium effect sizes were observed for side plank (0.51) and single-leg bridge (0.54); that is, mean differences for these variables were over one-half of a standard deviation lower for the PFPS group. A power analysis was performed revealing that a minimum of 60 cases and matched controls would have been required to achieve significance. Therefore, this study lacked the power to recognize significance in the observed differences.

Considering the top-down mechanism of injury for PFPS once again, dynamic valgus or inward collapse of the knee joint is thought to be caused by weakness or poor endurance of musculature surrounding the hip. Previous research found non-significant differences in endurance of isolated hip muscle groups between females with and without PFPS;[27] however, no other studies analyzed core endurance in adolescent female runners with PFPS. A study by Ekstrom et al utilizing electromyography (EMG) technology determined the primary muscles activated during a side plank to be gluteus medius and external oblique while gluteus maximus and the hamstrings were the primary muscles activated for a single-leg bridge.[34] Extrapolating from the EMG study by Ekstrom et al, poor endurance of the previously mentioned muscles may lead to the inward collapse of the knee joint in adolescent female runners, however, further prospective research with larger sample sizes is required to determine cause and effect.

Between-group Comparisons – Strength

Minimal and non-significant differences in isometric strength between the cases and controls were observed in this study. Our findings contradict the majority of relevant literature which is most generalizable to the adult population with relatively few studies isolating adolescent female runners. As such, the focus of our comparison was with those studies with similar populations. Ireland et al studied PFPS in females aged 12-21. Subjects in this study had a mean age of 15.7 +/- 2.7 which was therefore non-significantly different from subjects in our study. Ireland et al found deficits in hip abduction of 26% and in hip external rotation of 36% for subjects with PFPS.[19] A potential explanation for the observed differences between our study and Ireland et al. are the athletic characteristics of recruited subjects. Ireland et al recruited female athletes of various sports while our study exclusively looked at long distance runners. This difference is worth noting as long distance runners intuitively rely more heavily on the endurance rather than strength of their lower extremity musculature. Furthermore, these findings seem to suggest that normal isometric strength might not be protective of injury in an endurance sport, and possibly different mechanisms of injury could be implicated in a running population. In another study of similar design, Rathleff et al measured isometric hip strength in active 12-16 year old subjects with and without PFPS and found no significant between-group differences.[10] Although the results and participant age were similar to ours, Rathleff et al. included both males and females. Additionally, the authors did not report specific sport participation of the subjects and it is unlikely that they were all long distance runners. Results from our between-group comparisons therefore suggest that, given the nature of the sport, endurance tests may be more relevant to the running population.

Correlation

This study also examined correlations between different variables in our athletes. Our results indicated there was that there was little to no association between strength and core endurance. All four variables of strength and endurance were examined, and in all cases $r < .30$. The training demands and habits of long-distance running athletes may potentially contribute to these observations as the majority of training is spent improving endurance, particularly of the lower extremity, with less strength training incorporated into their routine.

The second correlation of note in our study was the relationship between a participant's Kujala score and their usual report of pain on a VAS scale. The Pearson r value for this correlation is -.793, with a p-value of .03, indicating significance. The scoring of the Kujala is such that the higher the score, the lower the level of impairment. This is opposite on the VAS scale for pain, which explains the negative correlation. This correlation is further confirmation of the Kujala as a valid measure to assess usual knee pain. This is possibly explained by the variety of questions asked in the Kujala, which would more accurately correlate with usual knee pain, as opposed to worst knee pain or pain with a specific activity such as running.

This study also found moderate correlations (ranging from r =.47 to .66) between external rotation strength and the three pain measures. One possible explanation for why external rotation strength is directly correlated with pain is that athletes with high isometric strength may have proper mechanics initially, but they lose these mechanics quickly due to decreased endurance. Early in their run they depend on their strength to maintain proper form. As they fatigue they lose eccentric control, leading to inward collapse.

There were also limited correlations between pain ratings, when looking at usual pain ratings and worst pain rating, or worst pain rating vs. pain rating with running (r=.36 and r=.48, respectively). This can be explained due to the fact that they measure different aspects of pain; the pain ratings used in this study are meant to be complementary of one another, not redundant. It should be noted that all of the correlations found in our study were found among groups with small sample sizes; further research would need to be done to validate the findings discussed above.

Clinical Relevance

Clinically, our study has several interesting implications. Firstly, athletes and patients that compete in endurance training regularly and present with PFPS may require different assessment measures than a strength screen. If strength and endurance are not correlated, then a manual muscle test cannot be assumed to be a good indicator of endurance. When endurance athletes present with PFPS, it may be appropriate to screen their endurance with side plank and single leg bridge to properly assess their risk factors, given the demands of their sport or activity. Secondly, based on the results of these screens, our recommendation is that the involved musculature (namely gluteus maximus and gluteus medius, as deficits in these muscles would contribute to the “top down” mechanism for PFPS discussed earlier), should be specifically addressed. Previous EMG testing would indicate that poor performance in the side plank and single leg bridge tasks could be due to endurance deficits in the above muscle groups.[33] Therefore, these muscles could be trained for endurance in long distance athletes to alleviate or prevent PFPS. This recommendation is given based both on the differences between groups in our study, as well as previous studies demonstrating improvement in PFPS when athletes consistently performed side plank exercises.

[14] Using clinical reasoning and the current body of research, we hypothesize that improvement in the function of gluteus maximus and medius would decrease the moment of inward collapse at the knee over time, and thus reduce the risk of PFPS in endurance athletes.

Limitations

Several limitations were identified. First, there was a low number of case subjects with PFPS, which reduced the power of the study. This made it difficult to see a statistically significant difference in our data, despite large proportional differences between groups. Secondly, due to the necessity to accommodate several different groups of athletes, practice schedules, and training timelines for the athletes, it was not possible to standardize our testing protocol in regards to the athlete’s training on the day of testing. Finally, the cross sectional design of our research study does not allow us to determine causation; we are limited to finding an association and using our clinical reasoning based on our findings. Further research should focus on prospective studies with athletes of this age group that exhibit endurance deficits, and assess the incidence of knee pain throughout and after the season.

CHAPTER VI: CONCLUSION

We found a roughly 20% deficit for both side plank and single leg bridge in the cases in this study, which may contribute to the development of PFPS in female long distance runners. We also found little to no correlation between hip strength and core endurance in the adolescent female runners. In the clinic, manual muscle tests may not give a clinician information regarding a patient's endurance capacity, which we propose to be one of the causative factors for the development of PFPS in a running population. Larger prospective research studies are needed to establish a relationship between reduced endurance and the onset of pain.

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TABLES

TABLE 1. Group Demographics.

	Control Group	Case Group	p*
N	21	7	---
Age (y)	14.7±2.2	14.6±1.6	0.91
Height (in.)	64.6±2.8	64.6±2.2	1.00
Weight (lb)	120.1±18.3	120.8±15.1	0.92
Body Mass Index (kg/m2)	20.2±2.2	20.4±2.4	0.84
Femur Moment Arm (cm)	37.3±3.6	38.1±2.6	0.58
Tibia Moment Arm (cm)	34.9±3.1	34.1±2.5	0.54
Kujala Score (0-100)	---	81.1±10.1	---
Usual VAS Pain (0-10.0cm)	---	3.1±1.2	---
Worst VAS Pain (0-10.0cm)	---	6.4±1.6	---
VAS Pain with Running (0-10.0cm)	---	4.6±1.7	---

*obtained through independent t-tests

Table 2. Correlations Between Measures of Strength and Endurance for all Pooled Subjects.

	Hip Abduction	Hip External Rotation	Side Plank	Single Leg Bridge
Hip Abduction	1.0 (p=0.0000)	0.45 (p=0.0000)*	0.28 (p=0.021)*	0.19 (p=0.118)
Hip External Rotation	---	1.0 (p=0.0000)	0.06 (p=0.624)	0.02 (p=0.90)
Side Plank	---	---	1.0 (p=0.0000)	0.45 (p=0.000)*
Single Leg Bridge	---	---	---	1.0 (p=0.0000)

* indicates statistical significance.

Table 3. Correlations Between Measures of Strength, Endurance, Pain, and Function for Painful Subjects.

	VAS Usual Pain	VAS Worst Pain	VAS Pain with Running	Kujala Score
Hip Abduction	0.32 (p=0.480)	-0.04 (p=0.931)	-0.07 (p=0.877)	-0.33 (p=0.465)
Hip External Rotation	0.47 (p=0.289)	0.66 (p=0.102)	0.51 (p=0.238)	-0.35 (p=0.442)
Side Plank	-0.49 (p=0.264)	0.21 (p=0.644)	0.26 (p=0.580)	0.16 (p=0.731)
Single Leg Bridge	0.15 (p=0.746)	0.65 (p=0.112)	0.33 (p=0.475)	-0.22 (p=0.634)
VAS Usual Pain	1.0 (p=0.0000)	0.36 (p=0.432)	0.29 (p=0.532)	-0.79 (p=0.033)*
VAS Worst Pain	---	1.0 (p=0.0000)	0.48 (p=0.272)	-0.27 (p=0.561)
VAS Pain with Running	---	---	1.0 (p=0.0000)	-0.33 (p=0.477)
Kujala Score	---	---	---	1.0 (p=0.0000)

* indicates statistical significance.

FIGURES

Figure 1. Position for hip abduction strength testing.

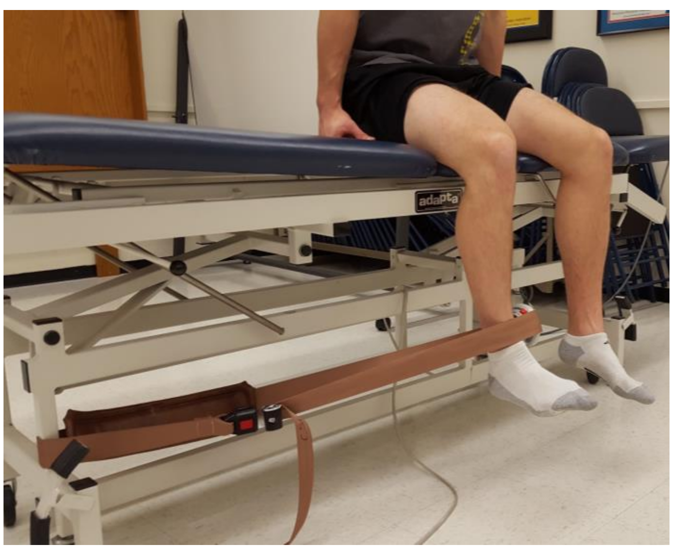


Figure 2. Position for hip external rotation strength testing.

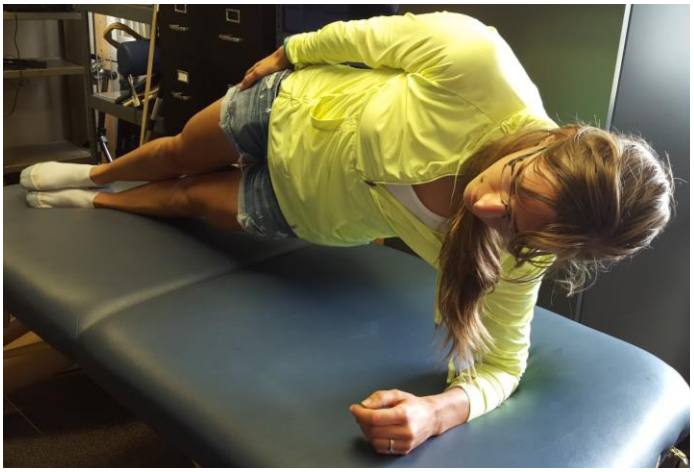


Figure 3. Testing position for side plank.

Figure 4. Testing position for single leg bridge.

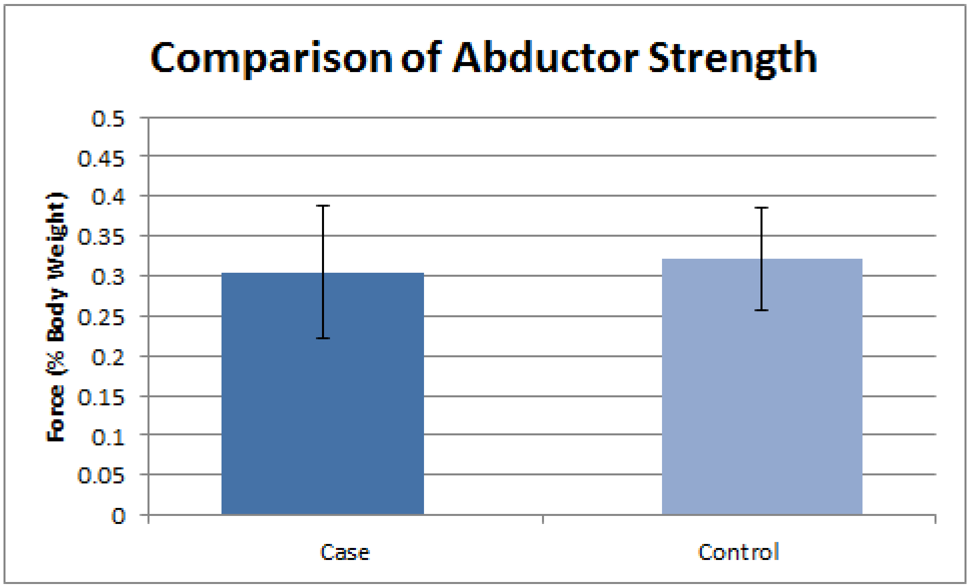


FIGURE 5. Between-group comparison of abductor strength. The case group produced a mean force of 30.5±8.2% of body weight and the control group produced a mean force of 32.1±6.4% of body weight (p=0.61).

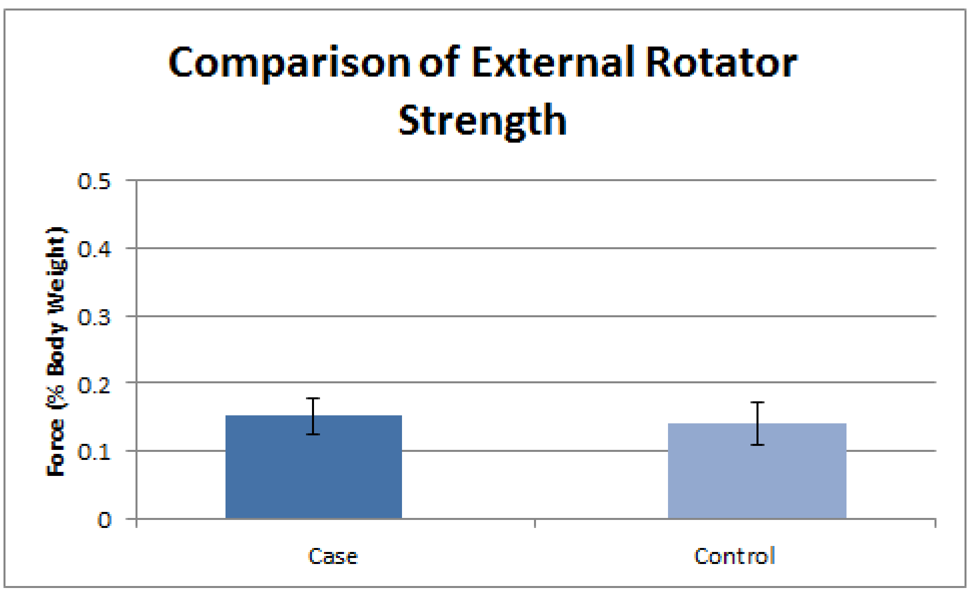


FIGURE 6. Between-group comparison of external rotator strength. The case group produced a mean force of 15.2±2.7% of body weight and the control group produced a mean force of 14.1±3.1% of body weight (p=0.41).

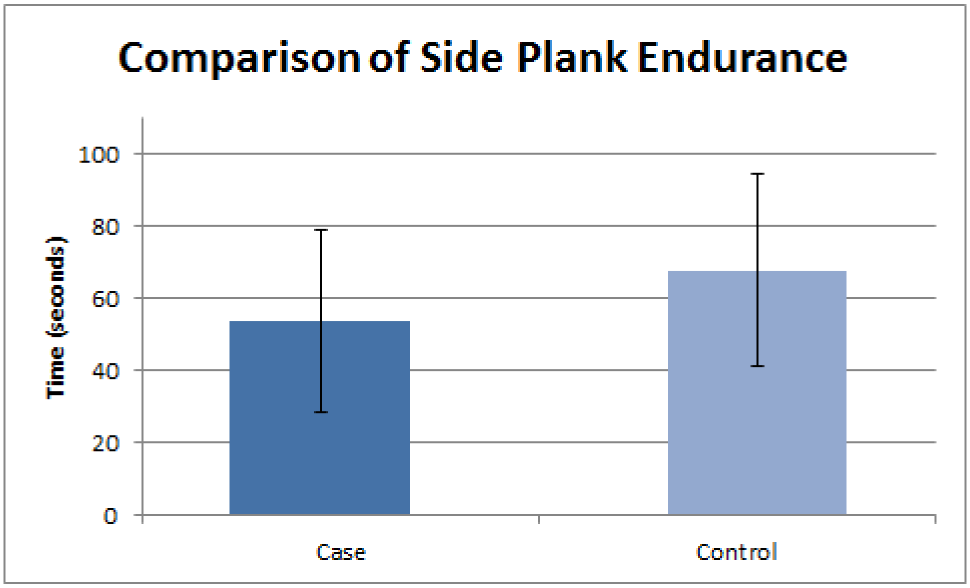


FIGURE 7. Between-group comparison of side plank endurance. The case group performed for a mean of 53.5±25.2s and the control group performed for a mean of 67.6±26.8s (p=0.23).

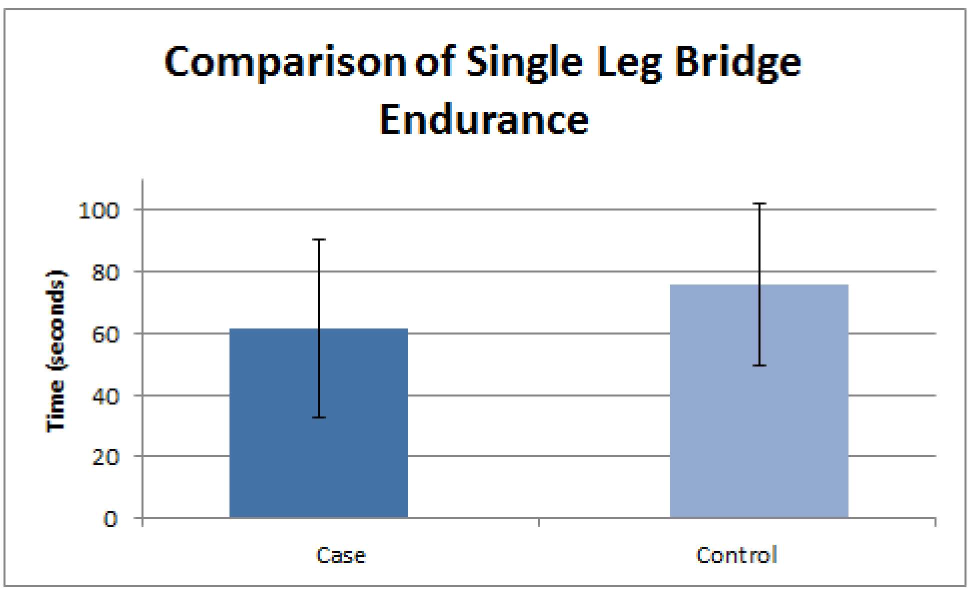


FIGURE 8. Between-group comparison of single leg bridge endurance. The case group performed for a mean of 61.7±29.0s and the control group performed for a mean of 75.9±26.5s (p=0.24).

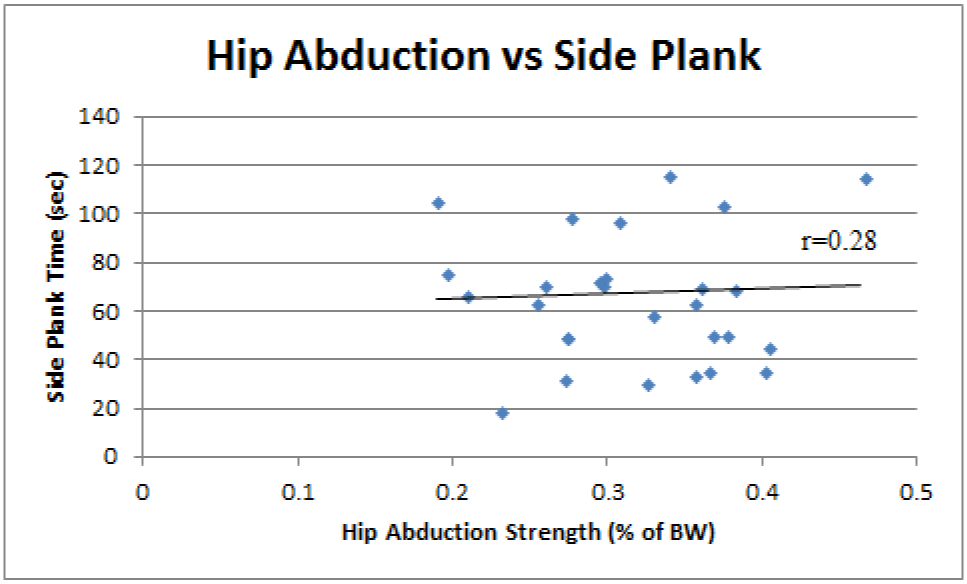


FIGURE 9. Correlation between hip abduction and side plank. A weak but statistically significant correlation exists between the two variables (p=0.021).

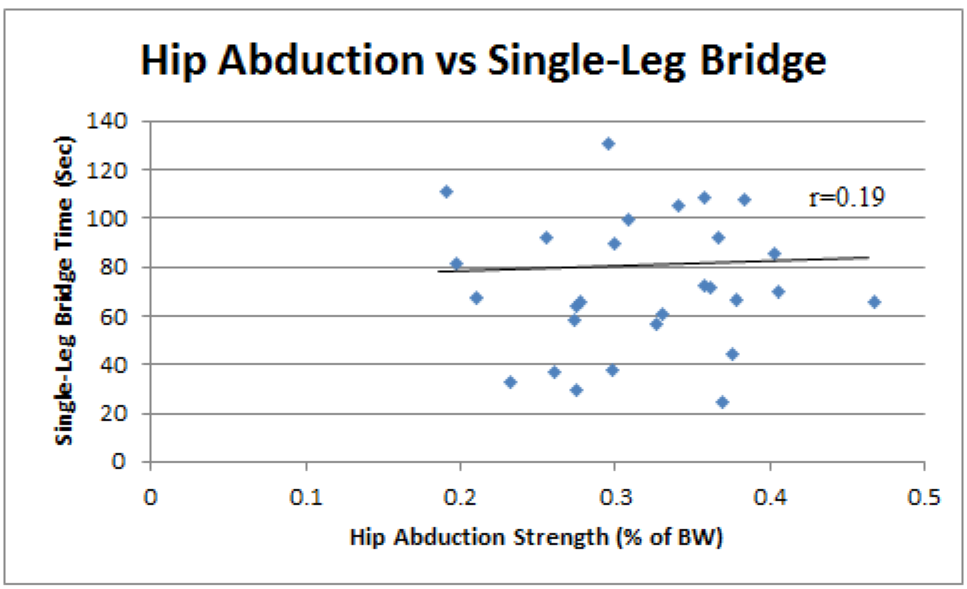


FIGURE 10. Correlation between abduction and single leg bridge. A weak, non-significant correlation was shown between the two variables (p=0.118).

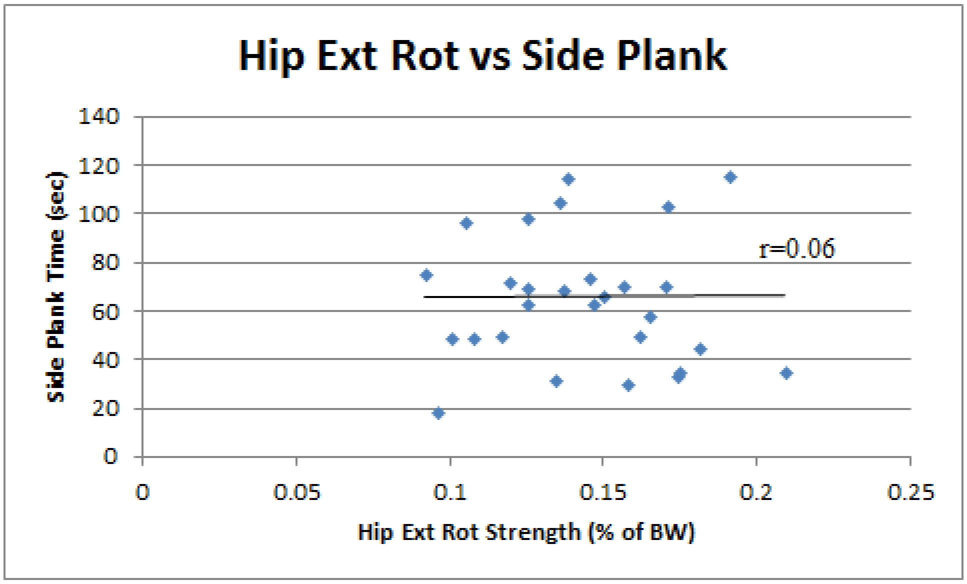


FIGURE 11. Correlation between hip external rotation and side plank. Essentially no correlation exists between the two variables (p=0.624).

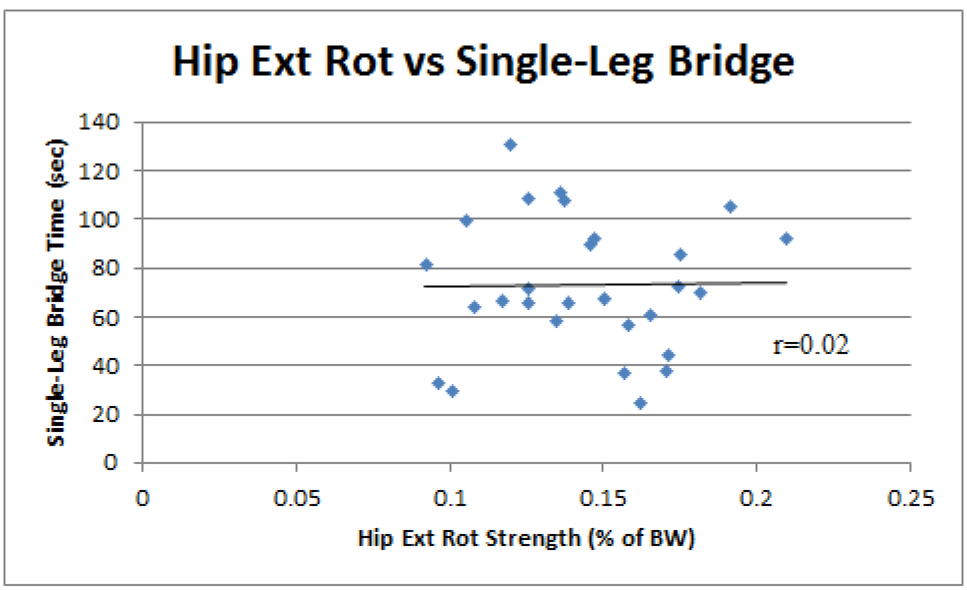


FIGURE 12. Correlation between hip external rotation and side plank. Essentially no correlation exists between the two variables (p=0.900).

APPENDIX A: INSTITUTIONAL REVIEW BOARD APPROVAL

ST. CATHERINE UNIVERSITY

February 26, 2013

John Schmitt, PT, PhD
Saint Catherine University

Re: IRB#13-EXP-07: Hip Strength and Endurance in Young Female Athletes with and without Knee Pain

Dear Professor Schmitt and fellow researchers:

Thank you for your proposal reply to the St. Catherine University Institutional Review Board (IRB). Your project has been reviewed by two IRB members and you have been approved to proceed with your project as was submitted. Good luck on your work!

Please note that all research projects are subject to continuing review and approval. You must notify the IRB of any research changes that will affect the risk to your subjects. You should not initiate these changes until you receive written IRB approval. Also, you should report any adverse events to the IRB. Please use the reference number listed above in any contact with the IRB.

This approval is effective for one year from this date. If the research will continue beyond one year, you must submit a request for IRB renewal. At the end of the project, please complete a project completion form. These forms are available on the St. Catherine University IRB website.

We appreciate your work to ensure appropriate treatment of your research subjects. Good luck with your research.

Sincerely,

John D. Fleming, EdD, OTR/L
Saint Catherine University Institutional Review Board

APPENDIX B: DATA COLLECTION FORM

PFPS Screening Questionnaire 2015

Name____ Age____________
Contact E-mail__________________________________
Phone___________________________
Parent's Name___________________________
Recruited From (school or camp)______________________

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

2) Will you participate in cross country this fall? Y / N If yes, how many seasons have you run cross country before (not including the upcoming season)? Circle one: 0 1 2 3 4 5 6

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

4) How many days do you run in a typical week (circle one): 0 1 2 3 4 5 6 7

5) What is your total running time in a typical week?_____hours and ______minutes

6) How many miles do you run in a typical week? _______________

7) How many months out of the last 12 have you run for exercise?

8) Do you have knee pain? Yes (continue with #7) No (skip to #13)

9) If yes, is it (circle one): Right Left Both

If both, which is worse (circle one): Right Left

10) How long have you had this pain? ___________________

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

Gradually – if yes, list any activity that seemed to cause the pain:________
not sure

12) Where is the pain located?____

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

walking running climbing stairs
kneeling squatting prolonged sitting

14) 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 (circle one)?

0 1 2 3 4 5 6 7 8 9 10
No pain Worse pain

Subject #_____________ (Research Staff)

15) 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

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

17) 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.

K

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**

Subject #____________ (Research Staff)

Pain Rating Scales

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:

Over the past week, when you have had pain:

- How would you rate your *usual* level of knee pain?

No pain at all ●————————————————● Worst pain possible

- How would you rate your ***worst*** level of knee pain?

No pain at all ●————————————————● Worst pain possible

- How would you rate your *usual* level of knee pain while running?

No pain at all ●————————————————● Worst pain possible

Examination and Testing

1. Height (tape measure) in inches: __________

2. Weight (scale) in pounds: ___________

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

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

Leg tested first (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

1. **ABD** in 10° ABD, neutral flexion/extension:

   LEFT Trial 1 ___________ Trial 2 ___________

   RIGHT Trial 1 ___________ Trial 2 ___________

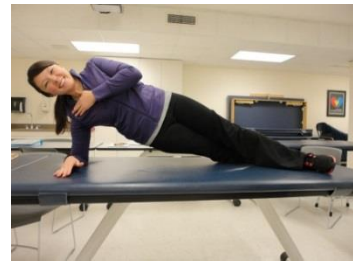
2. **External rotation** in sitting, knees at 90, legs off the ground, arms crossed

   LEFT Trial 1 ___________ Trial 2 ___________

   RIGHT Trial 1 ___________ Trial 2 ___________

Endurance Testing - Commands

- 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"



3. **Side plank**: Straight alignment with neutral trunk, hips.

   Time to fail (sec) Left: ______________ Right: ______________

4. **Single Leg Bridge**:

   Time to fail (sec) Left: ______________ Right: ______________