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The Influence of Hip Strength and Core Endurance on Recurrent Patella Dislocations: A Pilot Study

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ABSTRACT

BACKGROUND AND PURPOSE: Patellar instability can be a source of pain and functional disability. Aspects of patellar dislocations explored in the literature include demographics, radiographic findings, physical features, and quadriceps and hamstring strength. A lack of information exists on muscular strength as a predisposing factor for recurrent patellar dislocations. The aim of this study was to determine the influence of hip strength and core endurance on recurrent patellar dislocations. It was hypothesized that decreased hip strength and core endurance would be associated with this injury.

METHODS: In this case control study, cases with recurrent patellar dislocation at a rehabilitation clinic were all offered the chance to participate. Healthy controls without any current knee injuries or previous surgeries were matched by sex and age. Participants provided anthropometric and demographic data and filled out the International Physical Activity Questionnaire, KOOS Knee Survey, Kujala Knee Pain Scale, and a patellofemoral instability form. Cases underwent a patellofemoral exam and joint testing protocol. Both groups completed the forward step down test, strength of hip external rotation and abduction using a dynamometer, and bilateral side plank endurance. Recordings of the forward step down test were reviewed by six researchers to determine inter-rater reliability.

RESULTS: Side plank endurance and hip external rotation strength were significantly decreased in the cases compared to the controls. There was no statistical difference for hip abduction strength between the two groups. Moderate to good inter-rater reliability was found for the forward step down test.

CONCLUSIONS: Weak hip external rotators and core endurance could lead to an increased risk for patellar dislocations. While hip abduction strength was not statistically significant between cases and controls, it was 4% less in the case group. The gluteus medius is active during side plank exercise and may contribute to significant results observed in core endurance testing. The forward step down test could be used to assess dynamic weakness in hip abductors and external rotators across providers based on reliability findings. This pilot study was the first to investigate hip strength and core endurance as a risk factor for recurrent patellar dislocations and further research is needed to confirm findings.

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

THE INFLUENCE OF HIP STRENGTH AND CORE ENDURANCE ON RECURRENT PATELLAR DISLOCATIONS: A PILOT STUDY

Submitted by,

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

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Chapter 1: INTRODUCTION

Patella instability is a source of knee pain. Lateral patella dislocations occur when a mechanical injury leads to a lack of bony congruency between the patella and the femur. It can also result from a failure of the soft tissue surrounding the patellofemoral joint to resist the lateral movement of the patella. The severity of patellofemoral joint injuries spans a continuum, ranging from patellofemoral pain syndrome, to patella subluxations and the most severe, patella dislocations. Dislocations can be divided into first time or recurrent injuries, and risk factors may differ between the two groups. Furthermore, studies have found higher rates for potential redislocation after a previous dislocation injury. A study of first time patella dislocation patients by Sillanpaa et al[1] found rates of recurrence as high as 40%. These injuries can be caused by a traumatic event such as a football tackle or by a non-traumatic mechanism such as stepping off of a curb. A study by Maenpaa et al[2] of first time patella dislocators defines a traumatic mechanism as a torsion, blow or kick. One example of a non-traumatic mechanism is femoral rotation during flexion-extension of the lower limb in normal daily activities.[2]

The incidence of patella dislocation is difficult to assess as not every subject that sustains a dislocation will seek care or follow-up treatment. Waterman et al[3] reported an incidence rate of 2.29 patella dislocations per 100,000 people presenting to United States emergency departments from 2003-

2008. Sillanpaa et al[1], in a study of 128,714 male conscripts in the military, found that 278 had patella dislocations during basic training over a 4 year period. Seventy-two of these were first-time, traumatic patella dislocations, resulting in an incidence rate of 77.4 per 100,000 persons per year in this population. Waterman et al[3] reported that half of all patella dislocations occurred during athletic activity with basketball, soccer, and football associated with the highest percentages, respectively. Fithian et al[4], in a study of first time dislocators, supported Waterman's data, finding that 61% of all first-time dislocations occurred during sports.

Current research has examined four areas of risk factors for patella dislocations. The first are demographic and anthropometric risk factors which include: age, gender, race, BMI, height, family history and activity level. The second risk factor area is radiographic findings which include: patella alta, sulcus angle, Laurin angle, congruence angle, lateral patellar overhang, trochlear dysplasia, tibial tuberosity-trochlear groove distance (TT-TG), skeletal maturity, rotational deformity, and patellar tilt. Physical features are the third risk area. These include: limb alignment and Q-angle, ligament laxity and joint mobility, medial patellofemoral ligament (MPFL) and other soft tissue structure characteristics, range of motion, and patella hypermobility and displacement. Finally, muscular strength has been assessed as a risk factor by only a few studies that focused on quadriceps, hamstring, and general whole body strength.

Very few research studies have examined the effect of hip strength and core endurance on patella dislocations. Our hypothesis is that subjects with recurrent dislocations will demonstrate decreased hip strength and core endurance as compared to healthy controls. This hypothesis is based on research demonstrating that patellofemoral pain may be due to decreased hip strength, causing an inward collapse of the knee. This collapse may cause a lateral pull on the patella, possibly increasing susceptibility to patella dislocations. Core endurance is also important to maintain proper knee alignment over a period of time. Without endurance, a person’s maximal strength is not sufficient to sustain correct positioning and could lead to a dislocation. Therefore, the purpose of our study was to determine the influence of hip strength and core endurance on recurrent patella dislocations.

Chapter II: REVIEW OF RELATED LITERATURE

Demographics:

Studies have found conflicting results on the impact of various demographic and anthropometric characteristics as risk factors for first time or recurrent patella dislocations. Many authors have looked at the influence of age, sex, activity level, and race in affecting a person's risk for a patellofemoral injury.[1, 3-10]

Three studies found that the younger population, ages 10-20, had the greatest rates of traumatic dislocation. Waterman et al[3] conducted a large longitudinal prospective study examining all patella dislocations that entered the United States medical system through the ER from 2003-2008. They found that 15-19 year olds were associated with significantly higher rates of dislocation. A prospective cohort study (n=189) looked at patients that supplied convincing subjective history of dislocation or required reduction in the ER. They concluded that the 10-17 age range sustained the most primary patella dislocations with a per capita risk of 29 +/- 8 per 100,000 and a 29 times higher risk than older age groups.[4] Hsiao et al[5] found similar results in their large US military retrospective cohort study that showed the incidence rates were highest among the <20 age group.

Two studies also examined the influence of age on the re-dislocation of the patella after the primary event. Interestingly, Lewellan et al[6,7] found results in their 2015 study that differed from their 2013 study. The 2013 large, retrospective case-control study gathered patient data from the Mayo Medical Index database between1998 to 2010 and found that age was not a significant risk factor for re-dislocation.[7] Thirty-eight percent of the patients treated non-operatively had a subsequent subluxation or dislocation in the follow-up period. However, the inclusion criteria limited the participating patients to 18 years or younger, making it hard to generalize to other age groups like the Sillanpaa et al study above. The 2015 Lewallen et al[6] retrospective cohort study (n=312) found that the <25 age group had a higher likelihood of recurrence compared to other groups. They did not limit the age range in this study but included any patient with a primary traumatic patella dislocation from 1998-2010 seen at Mayo Clinic in Rochester, MN. Additionally, a small, retrospective case-control study by Balcarek et al[8] compared the risk factors of patients who had and had not re-dislocated within two years after their primary traumatic dislocation. The authors found that 71% of participants who experienced their first time dislocation at less than or equal to 16 years old re-dislocated within two years. This contrasts with the 15% of participants older than 16 years that re-dislocated within the two year follow-up period. Although these results agree with the 2015 Lewallan et al study[6], this small study did not have sufficient power. Considering all the above studies, participants between 10-20 years old were found to have the greatest rates of dislocation. These younger patients were also more likely to dislocate again compared to their older counterparts.

Controversy still exists in the literature as to whether sex is a risk factor for first time traumatic patella dislocation. A large prospective, longitudinal epidemiological study found that females did not show a significant overall or age-stratified difference in patella dislocation rates compared to males.[3] However, multiple studies concluded that females had a higher risk for this injury compared to their male counterparts. Hsiao et al[5] found the adjusted incidence rates of 0.63 per 1000 person-years for females and 0.39 for males in the military. However, this specific military population makes it difficult to generalize these results. The retrospective cross sectional study (n=177) by Maenpaa[9] analyzed patients admitted from 1982-1989 at a large hospital for lateral dislocation. Maenpaa et al found that this injury is more common in females, with 58% of the dislocations occurring in their female participants. However, this study did not give explicit inclusion/exclusion criteria and did not clearly separate first time and recurrent dislocations making it difficult to apply to a general population. Fithian et al[4] concluded that the risk of first time dislocation was highest among young females ages ten to 17 years old with a 33% greater risk compared to males in the same age bracket. These females also had a risk that was three times greater for redislocation compared to their male counterparts. However, these results were found to not be statistically significant. The prospective cohort study by Atkin et al[10] gathered data from 1992-1994 on patients in the Kaiser Health Plan program who experienced a traumatic first time patella dislocation. This study corrected for over- or under-represented segments of the population by calculating risk based on the actual number of patients within each demographic category and found that there is an increased risk for females aged 10-20 but not in later years.

Three studies looked at sex as a risk factor for recurrence of patella dislocation. Both the Lewallan et al[6,7] studies concluded that sex had no significant effect on re-dislocation. Additionally, a retrospective case-control study by Balcerek et al[8] found no difference between sex when they compared the risk factors of patients who had and had not re-dislocated within 2 years after their first traumatic dislocation.

Race and family history have also been studied as risk factors for first time patella dislocations. A large US military retrospective cohort study by Hsiao et al[5] found that Caucasian and African American service members were 65% and 59% more likely to sustain a patella dislocation, respectively, than people in the "other" race category. Furthermore, they concluded that African Americans have equal rates to their Caucasian counterparts. Waterman et al[3] also found that African Americans and Caucasians are at a higher risk for patella dislocation when compared with the Hispanic race. Maenpaa et al[9] examined the impact of family history as a risk factor. This retrospective cross sectional study (n= 177) found that only 4% of first time dislocators had a family history of patella dislocation compared to 23% of those with recurrent dislocations. Although this study supports the idea that family history is a weak risk factor for first time traumatic dislocation, the lack of explicit inclusion/exclusion criteria and not clearly separating first time and recurrent dislocations decreases the strength of these results. In Atkin et al[10], only 9% of patients reported a family history of patella dislocation in the questionnaire.

Many articles analyzed the participants' activity levels when they experienced their first patella dislocation. Several studies found that there is a higher risk by participating in soccer, football, gymnastics and dance compared to other sports. Waterman et al[3] found that there is a higher risk during basketball, soccer and football. In his study, 51.9% of patella dislocations occurred during athletic activity, with the highest rate of 18.2% in basketball. Maenpaa et al[9] found that 44% of these injuries occurred as a result of athletic performance. Soccer, gymnastics and ice hockey were the most commonly injurious; all popular sports in Finland where this study was done. Fithian et al[4] found that 61% of their subjects experienced a first-time dislocation during a sport and an additional 9% while dancing. Atkin et al[10] found 72% of their subjects were injured during sports activities compared to non-sport activities and two-thirds of these injuries occurred during cutting or pivoting sports. In Silanpaa et al[1], 63% of the injuries occurred in unspecified sports activities and the remaining 37% in military training, which is presumably active in nature. In the 2013 study by Lewallen et al[7], 71.2% of the subjects were involved in sports at the time of the injury. They also assessed sports involvement as a risk factor for recurrent dislocation but did not find it to be statistically significant. Balcarek et al[8] examined the impact of activity level on the recurrence of patella dislocation.

This retrospective case-control study concluded that approximately 70% of participants were involved in sports at the time of dislocation, but it was not found to be a statistically significant risk factor for redislocation.

Radiographic Findings

Studies have examined various radiographic findings as risk factors for patellar instability and dislocation. These include patella alta, sulcus angle, Laurin angle, congruence angle, lateral patellar overhang, trochlear dysplasia, tibial tuberosity-trochlear groove distance (TT-TG distance), skeletal maturity, rotational deformity, and patellar tilt.

Patella alta occurs when the patella sits too high in relation to the femoral trochlea, which leaves the patella vulnerable to dislocation due to lack of a bony restraint. X-ray or MRI measurements are taken to determine the ratio between length of the patellar tendon and the vertical length of the patella. In the prospective cohort study done by Atkin et al[10], first time patella dislocators had x-rays taken of both the injured and uninjured knee. Results determined that 50% of the subjects had patella alta in their injured knee, with no statistic reported for the uninjured knee. A prospective cohort study done by Balcarek et al[11] compared patellar heights in acute patella dislocators, recurrent patellar dislocators, and a healthy control group. It was found that both the acute and recurrent patellar dislocators showed significantly greater patella height than the control group. A retrospective review by Steenson et al[12] of patients undergoing surgical treatment for recurrent patella dislocation compared 60 knees with recurrent dislocation to 120 healthy control knees. It found that 60% of the knees with recurrent dislocation had patella alta, compared to 20.8% of controls, which is statistically significant. However, it is important to consider that the subjects in this study may have different characteristic than typical recurrent dislocators, as they were about to undergo surgery for their condition. Additionally, the retrospective cohort study by Lewallen et al in 2015[6] was done to determine risk factors for recurrent patellar instability. This study found that patella alta was a significant risk factor for recurrent instability, with a five year recurrence-free estimate of 68% without patella alta and 53% with patella alta. Lastly, a prospective cohort study by Dejour et al[13] compared true lateral radiographs between knees with patellar instability, the contralateral knee, and control knees. This study found that 24% of the knees with instability had patella alta, compared to no patella alta in the control knees.

Results from two studies disagree on the role of patella alta as a risk factor. In the 2013 retrospective study by Lewallen et al[7], results showed that patella alta was not a significant risk factor for recurrent instability. The small, retrospective case-control study by Balcarek et al[8] compared subjects who had experienced a recurrent patellar dislocation within 24 months of the initial dislocation and those who did not. It was concluded that patella alta, determined by a sagittal view MRI, was more frequently seen but not significant in the recurrent dislocators. However, this study had low power and follow up may not have been long enough for recurrent dislocations to occur.

Sulcus angle is another radiographic finding that has been studied as a risk factor. It is the angle formed by three points measured on x-ray: the highest points of the medial and lateral condyles and the lowest point of the intercondylar sulcus. Atkin et al[11] looked at sulcus angle as a risk factor for patellar dislocation in first time dislocations. Abnormal was considered to be 150 degrees or greater. Twenty-nine percent of the subjects had an abnormal sulcus angle in the injured knee compared to 26% that had an abnormal sulcus angle in the uninjured knee, with significance not stated. A randomized controlled trial by Palmu et al[14] followed subjects for two years after their initial dislocation to record recurrent dislocations. There was no difference in sulcus angles between the subjects that dislocated once and those with recurrent dislocations. These studies suggest that sulcus angle is not a risk factor for patellar instability or dislocation.

Using x-ray imaging, Atkin et al[11] also looked at the Laurin angle, congruence angle, and lateral patellar overhang as risk factors of traumatic patellar dislocation. Laurin angle is the angle formed by two lines; one running from the femoral condyles and the other line running tangential to the lateral facet of the patella. An abnormal Laurin angle would be 0 degrees or greater, indicating opening medially. It was found that 44% of subjects had an abnormal angle in their injured knee compared to 28% that had it in their uninjured knee; the significance was not stated. Congruence angle is a measurement that splits the sulcus angle in half and is marked with a reference line. The reference line is compared to another line, which runs from the lowest point in the sulcus to the apex of the median patellar ridge. If this line is medial to the reference line, the angle is negative. If it runs lateral to the reference line, the angle is positive, or abnormal. It was found that 69% of first time dislocators had an abnormal congruence angle in their injured knee and 72% had an abnormal congruence angle in their uninjured knee, significance not stated. Lateral patellar overhang is any portion of the patella that hangs lateral to the femoral condyles. An abnormal measurement is anything greater than 0 mm. It was found that 100% of subjects had an abnormal lateral patellar overhang in their injured knee and 97% in their uninjured knee, which was significantly different.

Another risk factor is trochlear dysplasia, a condition when the trochlear groove is too shallow. An MRI reading using the Dejour Method was used to determine the presence of trochlear dysplasia in the Balcarek et al[8] study. This method examines lateral trochlear inclination, trochlear facet asymmetry, and trochlear depth to judge severity of trochlear dysplasia. This study classified existing trochlear dysplasia into two categories: mild and severe. It was found that trochlear dysplasia was significantly associated with an episode of recurrent patellar dislocation. However, all of the subjects presented with at least mild trochlear dysplasia and no differentiation was made regarding the risk of recurrent dislocation for mild versus severe trochlear dysplasia. Another study by Balcarek et al[11] also divided existing trochlear dysplasia into two categories: low-grade and high-grade. It was found that only high-grade trochlear dysplasia was significantly associated with early patellar redislocation. Furthermore, the

2013 study by Lewallen et al[7] found that trochlear dysplasia was strongly associated with recurrent instability, with 58% of knees in the study with recurrent instability having trochlear dysplasia. Results from Lewallen et al 2015[6] agreed with their prior study that trochlear dysplasia is a significant risk factor for recurrent patellar instability, with five year recurrence-free estimates at 75% without trochlear dysplasia and only 40% with. Dejour et al[13] found that 85% of the knees with patellar instability demonstrated trochlear dysplasia. Lastly, Steenson et al[12] found a prevalence of 68.3% of knees with recurrent dislocations having trochlear dysplasia, compared to 5.8% of control knees, which was statistically significant.

In the study by Balcarek et al[8], tibial tuberosity-trochlear groove (TT-TG) distance was observed using MRI to determine if it was a risk factor for recurrent instability. This distance is determined by drawing two parallel lines and measuring the distance between them. The first line runs through the deepest part of the trochlear groove. The other line runs through the most anterior part of the tibial tuberosity. An abnormal TT-TG distance in this study was 16 mm or greater. It was found that an abnormal TT-TG distance was more prevalent in the subjects who had re-dislocated, but it was not a significant difference. However, another study by Balcarek et al[11] found that first time and recurrent patellar dislocators had a significantly greater TT-TG distance as compared to the controls. Dejour et al[13] found that 56% of the patellar instability knees had a TT-TG distance of >20 mm. Steenson et al[12] found that the presence of an abnormal TT-TG distance, defined as greater than or equal to 20 mm, in recurrent patellar dislocators was at 41.7%, compared to 3.3% of control knees. This was found to be statistically significant.

Both Lewallen studies[6,7] examined skeletal immaturity as a risk factor for patella dislocation. In the 2013 study[7], growth plates of subjects were classified as open, closing, or closed. It was found that skeletal immaturity alone was not a risk factor. When combined with trochlear dysplasia, subjects with open or closing growth plates had a risk ratio of 3.3 for recurrent instability compared to a reference group with no trochlear dysplasia and closed physes. Trochlear dysplasia combined with closed growth plates had a risk ratio of 2.2 for recurrent instability compared to the reference group. However, the 2015 study[6] found that immature physes at the distal femur and proximal tibia were a significant risk factor for recurrent instability, with a five year recurrence-free estimate of 74% with a mature physeal status and 44% with an immature physeal status.

Rotational deformity was explored as a risk factor in recurrent patella dislocation by Steenson et al.[12] This is found by examining the tibial tubercle rotation angle. It is measured through MRI, finding the angle between the posterior condylar line of the femur and a line running from a point on the posterior condylar line in the center of the intercondylar notch to the center of the tibial tubercle. Abnormal values had not been previously defined, so these were determined by finding the mean and standard deviation of the control group, and considering anything within plus or minus two standard deviations of the mean as normal. Abnormal values of rotational deformity were present in 68.3% of the knees with recurrent patella dislocation, compared to 5.8% of the control knees, which was considered statistically significant.

Patellar tilt is the last radiographic finding examined by Balcarek et al[8] using the Dejour Method. This is the angle made by two lines: one running through the transverse axis of the patella and the other running just posterior to the femoral condyles. In this study, 20 degrees or greater was considered abnormal. Results of this study showed that high patellar tilt is significantly associated with a recurrent patella redislocation within 24 months. However, some subjects had joint effusion, which may have affected the patellar tilt observed. Patellar tilt was also observed by Dejour et al[13] using CT with the knee in extension. There was a significantly greater patellar tilt in the unstable patella group compared to the control group.

Physical Features

There are many physical features that have been studied to determine if they predispose someone to knee instability or patellar dislocation. These include limb alignment and Q-angle, ligament laxity and joint mobility, the medial patellofemoral ligament and other soft tissue structures, patellar instability and displacement, and BMI.

A prospective cohort study by Atkin et al[10] studied 74 subjects who dislocated their patella for the first time. Participants were measured on risk factors including average quadriceps angle, hip rotation measurements, and standing limb alignments. Quadriceps angle (or Q-angle) was measured in supine with the knee at 30 degrees of flexion and the patella in the femoral trochlea. Hip rotation measurements were taken via the procedure described by Staheli et al[15], and standing limb alignments were taken on the posterior side of the subjects. All measurements were within normal limits. Although there was a wide range of individual differences, there were no differences in the measurements between non-injured and injured legs. A prospective cohort study by Fithian et al[4] reported that there were small differences in Q-angle between two groups: one being first time dislocators and the other recurrent dislocators. The recurrent dislocators had slightly larger Q-angles than the first time dislocators.

Literature on ligament laxity and joint mobility found mixed results. The study by Fithian et al[4] described above found women that were in the first-time dislocator group had more joint mobility than males, as assessed by the thumb test. The thumb test is done by passively moving the thumb towards the forearm and measuring the distance between the two. Research by Nomura et al[16] studied joint laxity and knee hypermobility in recurrent dislocators. This prospective cohort study supported the Fithian et al[4] findings, reporting that ankle hypermobility and knee and elbow hyperextension were significantly greater in the dislocation versus the non-dislocation group. The Nomura et al[16] study also reported that the generalized laxity total score and overall percentage of those with laxity was greater in the dislocation group. In contrast, Atkin et al[10] found that there were no significant differences between the norms for ligament-specific laxity and the leg that experienced the dislocation. A cross sectional study by Sanfridsson et al[17] hypothesized that in recurrent dislocators, there are more genetic factors contributing to patellar dislocation including valgus alignment and joint laxity. The same study also suggested that those with traumatic dislocations injured their ligaments and other soft tissue components during the event, while recurrent, non-traumatic dislocators had genetic predispositions that contributed to having an unstable patella, such as valgus position and joint laxity.

De Oliveira et al[18] conducted an observational, case-control study on 100 controls and 50 participants with patellar instability on a variety of factors, including the medial patellofemoral ligament (MPFL). The MPFL is an important contributor to preventing lateral patellar dislocation. They discovered that MPFL length decreased with older age and that it was thicker in males than in females at the point where it inserts into the femur. Among other findings were that the MPFL was longer for the instability group (a qualification of >60 mm to be considered abnormal), and that the thickness at the insertion was significantly less in the instability group versus the control group. Finally, those who had patellar lateral inclination over 20 degrees and trochlear dysplasia had the greatest differences in the MPFL. All measurements were taken via MRI.

Fithian et al[19] reviewed the impact of soft tissue structures of the knee and patellofemoral joint. In general, soft tissue and bony structures are the two key components that limit “passive mediolateral patellar motion.” As the knee goes into extension, soft tissue stabilizes the patella; as it goes into flexion, the bony structures and “patellofemoral joint geometry” stabilize the patella. De Oliveira et al[18] stated that the MPFL has been consistently demonstrated to be the primary controller for patellar instability. Fithian et al[19] also supports the findings that MPFL size and thickness differ between individuals, citing evidence from cadaver studies. The authors identify the key ligamentous structures involved with patellar instability: medial patellar retinaculum, MPFL, medial patellomeniscal ligament, and medial patellotibial ligament.

A small single group, repeated measures study by Powers et al[20] studied patellar displacement in a group of 6 females who had a lateral patellar subluxation and were also experiencing patellofemoral pain. The authors used kinematic magnetic resonance imaging to study the patellofemoral joint kinematics while in non-weight bearing and weight bearing positions. They found that there is a significant interaction with knee flexion and lateral patellar displacement. Specifically, there is significantly greater lateral displacement in weight bearing as the knee goes from 27 to 21 degrees of extension compared to in non-weight bearing.

The retrospective case-control study by Balcarek et al[8] studied patellar instability. The authors researched risk factors for patellar dislocation and also ranked them by using a patellar instability severity score. They found that subjects with a score of 4 or more on the patellar instability severity score, when compared to subjects with a score of 3 or less, were 4.88 times more likely to have an early episode of patellar redislocation.

Three studies[1,6,7] investigated the impact of BMI and height as a risk factor for first time or subsequent patella dislocations. Sillanpaa et al[1], in their large retrospective cohort study of the Finnish military, concluded that the participants that had patella dislocations were taller than the controls with a mean height of 180.5 +/- 7.3 cm and had a higher mean BMI of 23.6 +/- 3.9 compared to the healthy controls with a mean height of 178.7 +/- 6.6 cm and BMI of 22.9 +/- 3.5. However, neither were found to be statistically significant. Similarly, the two studies by Lewallan et al[6,7] found that BMI was also not a significant risk factor for re-dislocation.

Muscular strength

Little research exists dedicated to examining muscular weakness as a risk factor for patella dislocations. In the military cohort study done by Silanpaa et al[1], generalized strength scores were gathered from all healthy personnel without knee complications or pain. They assessed long jump, sit-up, pull-up, push-up, and back extension that were rated on a score from 0-3 points based on performance. Adding these scores together yielded a maximum score of 15 for their overall strength score. Out of 128,714 male conscripts in the military, 278 sustained patellar dislocations with 72 being first time traumatic dislocators. The median service time before patellar dislocation was 90 days (4-313 days). The study found no significance in mean muscle strength between those that had traumatic patellar dislocations and the healthy controls.

In their cross sectional study (n=82), Maenpaa et al[9] assessed quadriceps and hamstring strength (peak torque) using a Cybex 6000 dynamometer system. All of the patients in the study had a previous unilateral patella dislocation and received conservative treatment at the beginning of the study which had a mean follow up of 10 years. The researchers compared the involved knee to the sound knee with tested speeds of 60 and 180 degrees/second using the dynamometer system. After collecting this data, they divided groups depending on their natural history of recovery. The first group only received conservative treatment; they had no complications or re-dislocation. The second group either continued conservative treatment or received surgical treatment following a re-dislocation. The last group required surgery due to anterior knee pain, subluxations, or other residual complaints. The results showed the group that never experienced any re-dislocations or complications had the best outcomes for muscle torque. There was a statistically significant difference in quadriceps strength between the 3 study groups at both tested speeds of 60°/s and 180°/s, however the tests for hamstring muscle strength did not differ significantly between the study groups. A Pearson correlation coefficient did not show any relationship between quadriceps and hamstring strength in this study. Although it may appear that decreased quadricep strength is a risk factor for this condition, it is unknown if the patella dislocation caused the decreased strength or if the decreased strength was present before the dislocation. The Maenpaa article was included in a systematic review by Smith et al[21] on clinical outcomes; they found that strength generally remained decreased after rehabilitation in patients with patellofemoral dislocations. However, the Smith article did not discuss the potential for decreased muscle strength contributing to patellofemoral dislocations but that strength was generally decreased after a dislocation.

Patellar instability can be viewed on a continuum that includes patellofemoral pain syndrome, patella subluxations, and patella dislocations. All of these diagnoses involve lateralization of the patella at varying levels of severity. However, mechanisms of injury for these different diagnoses have not been fully established in the literature.

Although there are few research articles examining hip muscle strength as a risk factor for patella dislocations, there are multiple studies available on decreased hip strength being a potential risk factor for patellofemoral pain syndrome (PFPS). Hip abduction and external rotation weakness can lead to an inward collapse of the knee (hip adduction and internal rotation) with resulting lateral pull on the patella that can lead to patellofemoral pain or patella dislocations. This lateralization of the patella, due to this hip weakness, could potentially increase the chances of a first time dislocation and also increase the likelihood of recurring incidence. In a systematic review done by Prins et al[22], they found five quality studies on hip strength in patients with PFPS. They found strong evidence in the PFPS participants, compared to healthy controls, of decreased hip external rotation, abduction, and extension strength, with moderate evidence of hip flexion and internal rotation strength deficits, and no evidence for hip adduction strength weakness. However, only weak evidence was found when comparing the unaffected limb to PFPS limbs for the same strength tests. In a second systematic review, with 24 articles done by Rathleff et al[23], the researchers found mixed results on hip strength depending on the type of study performed. Cross-sectional studies suggested that adult men and women with PFPS had decreased hip strength compared to healthy individuals. However, a small number of prospective studies indicated there is not an association between isometric hip strength and a risk for acquiring PFP

As a result, this study concluded that reduced hip strength may be a result of PFPS rather than a risk factor. During this literature review no studies were found on core stability and endurance as potential risk factors for patella dislocations. This core weakness could be a potential risk factor for patella dislocations due to poor proximal stability leading to unstable distal mobility.

While some radiographic findings, such as patella alta, trochlear dysplasia, and tibial tuberosity-trochlear groove, show consistent association with patella instability, other factors such as sulcus angle do not. Given the correlation of hip and core strength with PFPS, more studies need to be done on hip, knee, and core strength as potential risk factors for patellar dislocations.

Chapter III: METHODS

Subjects

Our study compared an age and sex matched healthy control group to a patient population. The patient group consisted of individuals who reported to the clinic following a recent patella dislocation. Patients were assessed by one of two physical therapists with a combined 20 years of experience. Patients were included in the study if they were between 14 and 40 years of age, had a well-documented history of patella dislocation, a physician's diagnosis of patella instability, and were literate in the English language. Controls and patients were matched on age (+/- two years) and sex. Exclusion criteria for control subjects included: currently experiencing low back, hip, or other lower extremity pain, pregnancy, fibromyalgia, cancer, or systemic disease such as rheumatoid arthritis or a history of knee surgery or lower extremity fracture in the past 3 years. Subjects in the healthy control group were recruited through a faculty advisor by word of mouth and were assessed by student researchers. Characteristics of each group can be found in Table 1.

Procedures

Each participant in the patient and control group completed the International Physical Activity Questionnaire (IPAQ). The purpose of the IPAQ is to obtain general data concerning the subject's physical activity. A systematic review by Silsbury et al[24] found that the IPAQ demonstrated good test-retest reliability reporting an ICC = .76 as a self-report physical activity scale. The controls filled out a subjective history form on current activity level.

The patient group filled out the patellofemoral instability history form, KOOS Knee Survey and the Kujala Knee Pain Scale. The patellofemoral instability history form was developed by the researchers of this study. It assesses physical characteristics of the subjects, past knee injuries and treatment, and activity levels. The purpose of the KOOS Knee Survey is to assess symptoms and disability.[25] It focuses on five domains related to pain, symptoms, and activities of daily living with a score of 0% representing maximum pain and/or disability and 100% representing no pain or disability. The KOOS has been shown to have adequate reliability with ICC=0.85-0.93, validity, and responsiveness.[25] The Kujala Knee Pain Scale is designed to assess the level of anterior knee pain. Paxton et al[26] reported a reliability for the Kujala Knee Pain Scale of 0.86 when assessed in a population that had experienced an acute patella dislocation.

After filling out the history, symptom, and functional status measures, the patient group underwent a lower extremity patellofemoral exam. The exam included a general dynamic movement screen consisting of a two legged stance, a two legged squat, a single leg stance and squat on both the right and left legs, and gait observation. After the general exam, a specific patellofemoral joint special testing protocol was performed. The purpose of this was to assess static and dynamic movement of the patella, quadriceps activation, presence of swelling, and tenderness to palpation over specified landmarks.

Lastly, the control and patient group both completed tests and measures that included the forward step down test, femur and tibial length, knee range of motion, strength of hip external rotation and abduction using a dynamometer, and bilateral side planking. The detailed descriptions of each test can be found below.

The forward step down (FSD) test was developed from the modified parameters used by Park et al[27] in his study of 26 females without knee pain. In this study, the forward step down test was determined to have moderate to excellent inter-rater reliability (0.64-.87) between raters. Before testing, a researcher demonstrated the test twice to each control subject to highlight the desired form and speed of each trial. The subjects were told to keep their hands on their hips and slowly tap their heel onto the floor before returning to the stool. The subjects then practiced FSD twice on each leg before completing five video recorded trials on each leg. Bright colored stickers were placed in the middle of the patella on each control to better visualize any atypical knee movements. Subjects were not given any cues to correct their movements throughout the trials. After the five consecutive trials were completed, two examiners independently rated the performance of the subject across all five repetitions of the FSD. Quality was based on the following five criteria with one point given for each strategy observed: Arm strategy: if the subject used an arm strategy to recover balance, one point was given. Because subjects were instructed to keep their hands on their waist, removing their hands from their waist was interpreted as a strategy to recover balance. Trunk movement: if the subject leaned their trunk to either side it was interpreted as recovering balance and one point was given. Pelvic plane: if one side of the pelvis was rotated in the transverse plane or elevated in the frontal plane compared with the other side, one point was given. Knee position: if the knee of the tested limb moved medially in the frontal plane and the tibial tuberosity crossed an imaginary vertical line positioned directly over the second toe of the tested foot, one point was given. Maintenance of a steady unilateral stance: if the subject had to support body weight on the non-tested limb, or the foot of the tested limb moved during testing, one point was given. If there was a discrepancy in scoring between the two examiners, the higher number of errors was used. In addition, inter-rater reliability was assessed by observing the video recordings of each of the subjects and controls. Five physical therapy students and one physical therapist were initially familiarized with the scoring of the FSD test, then watched each trial of five step downs one time. Each examiner then scored the video independently.

Femur and tibial moment arm were measured to determine torque for hip abduction and external rotation. The femur moment arm included the distance from the greater trochanter to 1 inch above the lateral knee joint line. To determine the tibia moment arm measurements were taken from the medial knee joint line to one inch above the medial malleolus.

Hip external rotation and abduction strength were measured with a handheld Microfet ™ (Hoggan Scientific, LLC, Salt Lake City, Utah) dynamometer. Hip abduction was measured bilaterally with the subject in a sidelying position. The participants were brought through their full abduction range of motion to determine the halfway point where the measurement was taken. The hip was brought into slight extension to make sure hip flexors were not activated during testing. The examiner placed the dynamometer 1" proximal to the lateral knee joint and a mobilization belt was strapped around the dynamometer and plinth to increase stability and consistency between measurements. External rotation strength was tested bilaterally in a seated position with a towel placed underneath the distal portion of the thigh. The examiner held the dynamometer just proximal to the medial malleolus and a mobilization belt was strapped around the dynamometer and plinth leg to add stability during measurement. Participants were given one submaximal trial test and then two measurements were taken with maximal external rotation and abduction strength. All strength measurements were taken following the verbal command, "When I say push then push as hard as you can: Push, Push, Push, Push, Push, relax." The best of the two trials was recorded. One study looked at the reliability of hip strength measured by handheld dynamometry used here. This study of healthy subjects found intraclass correlation coefficients between 0.86 and 0.97 for all muscle groups tested, which is considered excellent reliability.[28]

Finally, core endurance was assessed by performing a side plank according to the protocol set forth by McGill et al[29] in his study of 75 subjects, with modifications for foot placement. Patients were instructed to lay on their side with legs extended, top foot on top of bottom foot for support. Patients lifted their hips off of the mat to maintain a straight line over their full body length, while the top arm was resting on their side. The researcher gave each control subject one warning to correct form if needed. The test ended when hips returned to mat. The patients completed a plank on each side with a three minute break between each trial. In this same study, reliability of the side plank was examined by re-testing the subjects over five consecutive days. For both the right and left side plank, excellent reliability was found, with a correlation coefficient of 0.99.

Data Analysis

All statistics were run through NCSS 8 (Kaysville, Utah). Data on age, height, weight, and activity level were used to compare six case subjects to matched controls. Because two of the cases were affected bilaterally, our data on hip strength, core endurance, and the forward step down test compared a total of eight legs between cases and controls. The case subjects were matched with the corresponding leg(s) of the control group for comparison. Descriptive statistics were used to quantify means and standard deviations for demographic data, pain levels, outcome measure scores and objective findings.

The IPAQ was analyzed for all subjects with levels of activity categorized into low, moderate, and high. The low total physical activity level was classified as below 600, the moderate level was equal to or above 600, and the high level was equal to or above 3000 MET-minutes per week. Two sample t-tests were then run for each of the subsections of the IPAQ using the total number of minutes. Chi square was used to determine if a relationship existed between the control group and the case subjects for the forward step down. A moderate to good score was equal to or less than 2 errors and a fair to poor score was greater than 2 errors. This division was chosen due to the small proportion of subjects who scored less than 2 errors serving as an easy divide between low and high scores. Inter-rater reliability of the forward step down test was examined by comparing the assigned total scores among six researchers using the Spearman correlation. Hip external rotation and hip abduction strength results were first divided by body weight to normalize the data. Then, t-tests were run to test for differences between cases and controls on normalized strength measurements and Mann Whitney U was used for data with skewed distributions.

Chapter IV: RESULTS

In Table 1, the mean values and standard deviations for subject demographics and anthropometrics including age, height, weight, and BMI of the cases and controls are displayed. No significant difference between the two groups existed in any category. There was a significant difference ($p = 0.004$) in level of activity, with cases spending more time sitting and less time performing recreational activities.

Table 2 contains information on case subject history. Of the cases, there were two left-sided dislocations, two right-sided dislocations, and two bilateral dislocations. Three had a history of two dislocations, and three had a history of five or more dislocations. Three reported a family history of this injury, two did not, and one subject did not provide this information. A variety of activities were reported to make their pain worse. In five subjects, stairs were reported painful, and in four subjects kneeling and running was painful (or increased pain).

Static patellar positioning was examined in the clinic by a physical therapist. Testing done in full extension showed that there was a lateral tilt present in 7/8 cases (87.5%) of the knees and lateral translation was present in 100% of the knees. In 90 degrees of knee flexion, lateral translation was present in 6/7 (85.7%) of the knees and patella alta in 4/7 (57.1%) of the knees. Patellar tracking with open kinetic chain movement found lateralization in 5/8 cases

(62%) and crepitus in 6/8 cases (75%) of the knees. In the quadrant mobility test, a score of two quadrants was discovered in 6/8 cases (75%) of the knees.

Visible quad atrophy was present in only 1/8 cases (16.6%) while a hip drop was present in 6/8 cases (75%) along with a valgus knee collapse in 4/8 cases (50%). This indicates that hip weakness and lack of neuromuscular control was much more prevalent in cases than quad atrophy. Looking at the case group’s bony alignment in standing with two leg stance, 5/6 (83.3%) had abnormal positioning with 4 having valgus deformity (2 affected limb, 2 bilateral) and 1 had knee squinting. The one leg squat test resulted in 50% of the patients’ involved limbs having knee valgus and 6/8 or 75% having hip drop. Lastly, 2/6 (33%) of the tested limbs had medial arch collapse (pes planus) that could contribute to the patient’s knee valgus.

Bony malalignment during two leg stance was present in five of the six cases, with four cases presenting with genu valgum (two unilateral and two bilateral) and one with knee squinting. Abnormal foot positioning was found in two of the six subjects. Multiple form variations were observed in the one legged-squat with the cases. Four of the eight knees had a trunk lean, six of the eight had a hip drop, and four of the eight had a valgus collapse. Quadriceps atrophy was only found in one of the eight cases, but surprisingly four of the eight legs had normal quadriceps activation and four had good quadriceps activation when tested.

Numeric pain ratings for the cases showed that the average worst pain was 5/10 compared with the usual pain of 1.25/10. Pain with squatting was the second highest at 4/10. A detailed list of pain rating for different activities can be found in Figure 1.

Scores for the five KOOS sub categories ranged from the lowest of 43.7% for quality of life to the highest of 92.16% for activities of daily living. Refer to table 3 for the scores for all categories. These results show that the most affected categories for the case subjects were quality of life and sports and recreation. The Kujala Knee Pain Scale is also scored such that 0% is equal to extreme pain and 100% is equal to no pain. The average score for the case group was 69%.

The results of the IPAQ, stratifying activity levels into low, moderate, or high, can be seen in Table 1. A significant difference between the two groups was found (p=0.04). Three out of five cases (60%) were in the low and two out of five (40%) (one subject did not complete the IPAQ) were in the high total physical activity level category. The controls were evenly divided among the moderate and high total physical activity level category. The results of the five domains of the IPAQ are shown in Table 4. In two of the domains, there was a significant difference found between cases and controls. Cases reported a significantly greater amount of time sitting (p=0.0005) and less time performing recreational activities (p=0.01) compared to controls.

The results of the forward step down test are shown in Table 1. The controls had a slightly larger proportion (62%) that scored good to moderate, compared to 50% of the cases but the difference was not statistically significant (p=0.614).

Hip external rotation and abduction strength and core endurance results are shown in Figures 2 and 3. The results of hip external rotation testing revealed the cases scored 7% lower than controls demonstrating a significant difference (p=0.003). For hip abduction, the cases scored 4.4% lower than the controls but this difference was not significant (p=0.425) between the two groups. The results of the side plank showed there was a significant difference (p=0.008) between the two groups with the cases scoring 48% lower in core endurance.

Chapter V: DISCUSSION

This study was the first to investigate hip strength and core endurance as risk factors for recurrent patellar dislocations. Although limited by the small sample size, the results give more insight into the hypothesis that subjects with recurrent dislocations demonstrate decreased hip strength and core endurance as compared to healthy controls. Hip external rotation was significantly weaker in the case group versus the controls. Weak external rotators can cause excessive internal rotation of the femur during dynamic activities leading to inward collapse of the knee. This can lead to lateral tracking of the patella and PFPS, and with significant force or overuse, could potentially result in dislocation. The second factor leading to inward collapse of the knee is weak hip abductors. Results showed that there was no statistically significant difference for hip abduction strength between the case and control groups; however mean maximal isometric strength was 4% less in the case subjects. If a larger sample were used, hip abduction strength might show statistical significance between the case and control groups. As a result, hip abduction cannot be ruled out at this time due to the low power of the study. The cases also demonstrated decreased core endurance via a significantly decreased side plank hold time. Proximal stability is crucial for distal mobility and if individuals do not have adequate core endurance to stabilize their pelvis they can often develop poor control of lower extremity mechanics. This poor control can lead to continued patellar instability with a potential for recurrent dislocations if not addressed.

It may be surprising that hip external rotation strength between the groups was significantly different but hip abduction strength was non-significant. It could be that hip abduction endurance is more important than hip abduction maximal strength which may be important for athletes performing repetitive lower extremity movements such as jumping, cutting, and running. A study by Ekstrom et al[30] with 30 healthy participants examined muscle activity during side plank exercise using electromyography. The side plank exercise had high activation of gluteus medius along with back and abdominal musculature. Our results suggest the importance of hip abduction and core endurance deficits, rather than maximal strength as a risk factor for patella dislocations. We were not able to assess hip external rotation endurance during this study.

Patella instability may also be related to local knee weakness or lack of proximal stability. In the case group, only 1 out of the 8 knees assessed had quad atrophy although a higher proportion showed hip drop (75%) and knee valgus (50%). These findings could be indicative of a lack of proximal stability instead of quadriceps weakness leading to a higher risk for patella dislocation. It is likely that both play a significant role in patellar instability, however it is unknown how these may influence each other. More studies are warranted to address both proximal instability and knee musculature strength as risk factors for patella dislocations.

Examination of static patellar positioning performed in the case group provided similar findings summarized from articles in the above literature review. Looking at patella translation, 100% of the knees observed in our case group had excessive lateral translation. A previous study also found that subjects with patella dislocations had 100% lateral patella overhang in their involved extremities and 97% in uninvolved extremities.[11] In the current study, lateral patellar tilt was shown in 87.5% of the case group and in a previous study it was shown that a high patella tilt was significant for recurrent patella dislocations.[8] Poor proximal stability has been hypothesized to increase lateral patella tracking and it was expected to see this in case group. A static patellar examination was not completed with the control group so we were unable to compare findings.

There was also a high variation in scores on the KOOS. The activities of daily living average (ADL) subscore was only slightly impacted by patella dislocations. The average ADL subset score for the cases was ~90%, with 100% showing no disability. This could be due to the low level of velocity, joint stress, and muscular control needed to complete these tasks. This contrasts with the higher disability reported for quality of life and sports/recreation at 40-60%. Sports and recreational activities generally require twisting, increased speeds and unpredictable movements that would likely be avoided by a person with symptomatic patellar instability. Furthermore, the inability to complete these sports and recreational activities may decrease the quality of life reported, leading to the ~40% mean scale score.

There was no significant relationship between case-control status and performance of the forward step down test. We expected to see decreased quality of movements of the case group compared to the controls, however, both groups had impaired functional movements. It may be that there is a large percentage of persons with impaired performance even in a normal population, but there are several other potential reasons for this finding. First, if the practice time for each group was increased, the participants may have felt more comfortable and earned a higher score, and this may have benefitted the controls to a greater extent. Secondly, the healthy controls may have been less motivated to perform their best on the test. Thirdly, there are multiple components that lead to a low score in the step down test, such as balance, neuromuscular control, and strength. Both groups had low scores but it may have been for different underlying reasons. Fourth, some of the case subjects were not able to correctly perform a forward step down as required. Rather than using a slow and smooth descent, patients made a rapid descent to the floor with no eccentric control demonstrated. Since they could not perform this slowly, the test may not be sensitive enough and other less demanding tests may be more appropriate for this population. Finally, the forward step down test was only performed for 5 repetitions; if mechanism of injury is due to decreased endurance, a fatigue protocol for this test may show different results.

Lastly, the inter-rater reliability of the forward step down test was determined to be moderate to excellent (0.64-.87). This shows that this test can be used across clinicians when assessing patients in the clinic with confidence of consistent scoring.

Based on the IPAQ, the cases spent significantly more time sitting and less time performing recreational activities. This suggests decreased conditioning which was consistent with the mean disability levels seen on the activities of daily living and sports/recreation scales of the KOOS questionnaire. Decreased conditioning of the case group may lead to the significant findings of decreased hip strength and core endurance, resulting in a potential increased risk for patellar dislocation when activity is increased. Many individuals with patella instability may feel less able to participating recreational activities, as seen from the IPAQ and KOOS scores, and this can directly impact the quality of life of these patients.

Looking at the clinical implications of the results, patient demographics, such as age, sex, and ethnicity along with atypical physical features, such as patella alta, trochlear dysplasia, and limb alignment can increase the risk of having a patellar dislocation. However, the findings of decreased hip strength and core endurance are preventable risk factors. For individuals with patellar instability, addressing hip strength, core endurance, and other impairments with therapeutic exercises can provide a decreased risk of recurrent patella dislocations.

Future research is warranted with a larger sample size to confirm this study’s findings and to address hip abduction strength due to its non-significant findings in this study. Due to the other non-significant findings found with the forward step down test, a different scoring method that is more sensitive and objective to highlight any significant differences between the cases and controls may be helpful. Furthermore, an endurance protocol may be warranted before additional testing is completed to assess the influence of fatigue on results. Clinical tests should be developed that would better show impaired motions in the transverse plane. It is difficult to assess all aspects of motion in this plane during the forward step down test with our eyes. Core and hip endurance testing may be more relevant to the dynamic collapse mechanism leading to dislocation due to prolonged activity. Lastly, future research is needed on foot mechanics to investigate a bottom up mechanism as a risk factor for patellar dislocations.

Limitations of the study include the following points: Due to a small case population, the study had low power that may contribute to the non-significant findings with hip abduction strength and the forward step down test. Since patellar instability is relatively uncommon, involving more therapists in recruitment across multiple sites may increase the recruitment rate. Also, the case control design of the study makes it difficult to determine if decreased strength and endurance seen in the case population causes patellar dislocations or resulted from these injuries. In either case, addressing impaired strength and endurance may help prevent recurrent dislocations and decrease the need for surgical intervention.

Chapter VI: Conclusion

In conclusion, the results of this pilot study show cases had significantly reduced hip external rotation strength and core endurance. There were no significant differences for hip abduction strength, however hip abduction endurance may be a more relevant mechanism for patellar dislocation based on the side plank results. It is recommended that clinicians evaluate hip strength and core endurance for patients with patellar instability and incorporate interventions to address these deficits in their plan of care.

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TABLES

Table 1. Comparison of the Case Subjects and Controls

	Case	Control	p-value
Mean Age, years (sd)	20.3 (6.3)	20.5 (7.2)	0.97
Mean Height, inches (sd)	66.6 (2.7)	66.1(4.1)	0.44
Mean Weight, lbs (sd)	135.5 (20.3)	147.8 (31.8)	0.44
Mean BMI (sd)	21.4 (2.1)	23.6 (3.2)	0.18
Low Activity, n (%)	3 (60%)	0 (0%)	0.04*
Mod. Activity, n (%)	0 (0%)	4 (50%)	
High Activity, n (%)	2 (40%)	4 (50%)	
FSD ≤2	4 (50%)	5 (63%)	0.61
FSD >2	4 (50%)	3 (37%)	

FSD- Forward step-down.
BMI-Body Mass Index
*Cases spent significantly more time sitting (p= 0.004) and significantly less time performing recreation activities (p=0.001)

Table 2. Patient History Information

Case #	Unilateral /Bilateral	Number of Dislocations	Family History	Activities that Make Pain Worse
1	Left	2	M	Running, stairs, kneeling, squatting
2	Right	5	Y	Kneeling
3	Bilateral	5	Y	Running, stairs, kneeling
4	Left	2	Y	Walking, running, stairs, kneeling, squatting, prolonged sitting
5	Bilateral	2	N	Stairs, prolonged sitting
6	Right	5	N	Running, stairs, prolonged sitting

Table 3. The Knee Injury and Osteoarthritis Outcome Score Mean Scores of the Case Subjects

KOOS* Subcategory	Mean Score (sd)
Quality of Life	43.8% (23.4)
Symptoms	63.7% (10.2)
Pain	79.2% (13.3)
ADLs	92.2% (6.1)
Sports and Recreation	54.2% (21.1)

Table 4. International Physical Activity Questionnaire (IPAQ) Scores of the Cases and Controls.

Category	Case	Control	p-value
Occupation MET minutes (sd)	7270.4 (6954.3)	2553.0 (2059.3)	0.145
Transportation MET minutes (sd)	816.8 (617.6)	37.5 (620.1)	0.504
Household MET minutes (sd)	1248.8 (1450.0)	888.0 (1034.2)	0.675
Recreation MET minutes (sd)	761.4 (747.3)	5832.0 (3178.6)	0.010*
Time spent sitting (sd)	2883.6 (866.7)	874.0 (355.6)	0.0005*

FIGURES

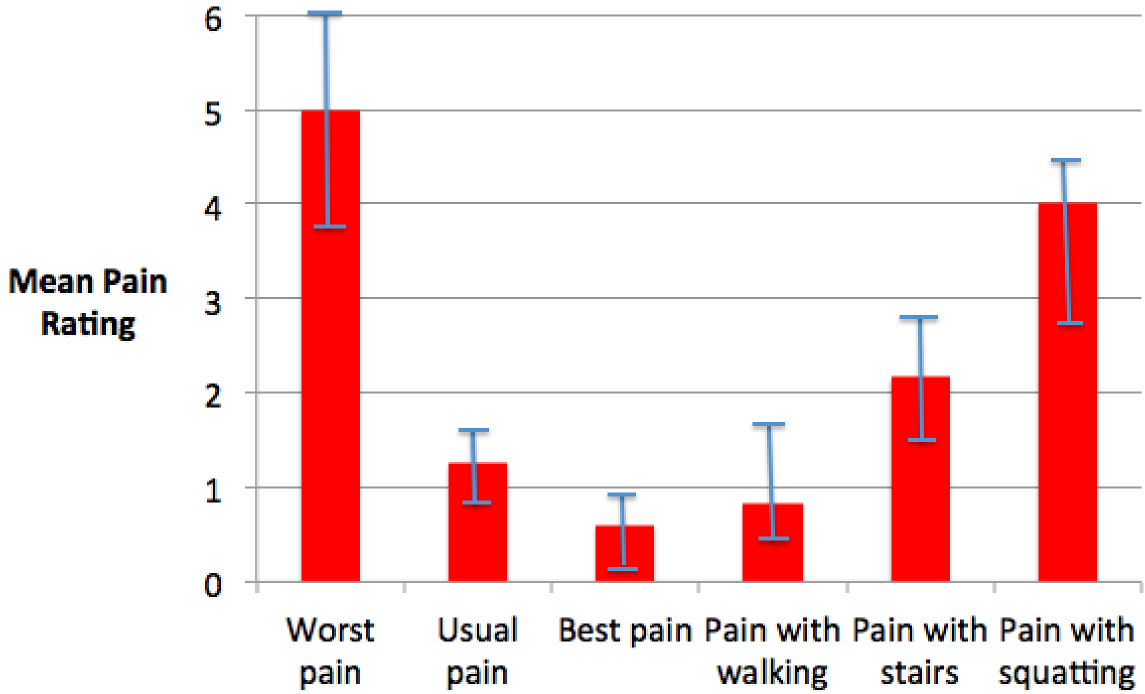

Figure 1: Reported Pain Ratings for Specific Activities. Most participants reported 5/10 pain as their worst and experienced the most pain when squatting.

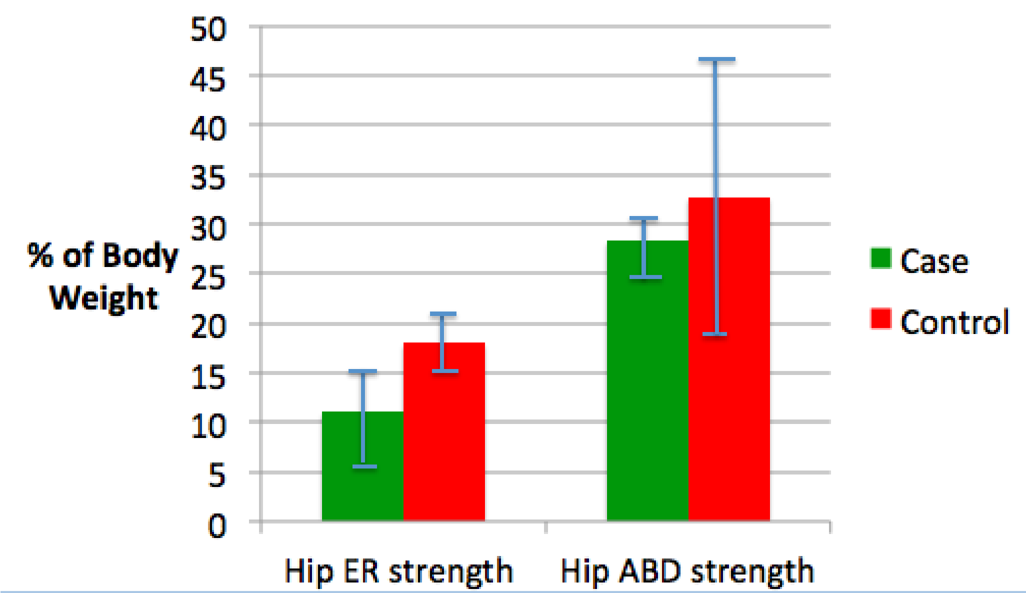

Figure 2: Hip external rotation and abduction strength comparisons between the cases and controls. There was a significant difference between groups for external rotation (p=0.003) but not for abduction (p=0.425).

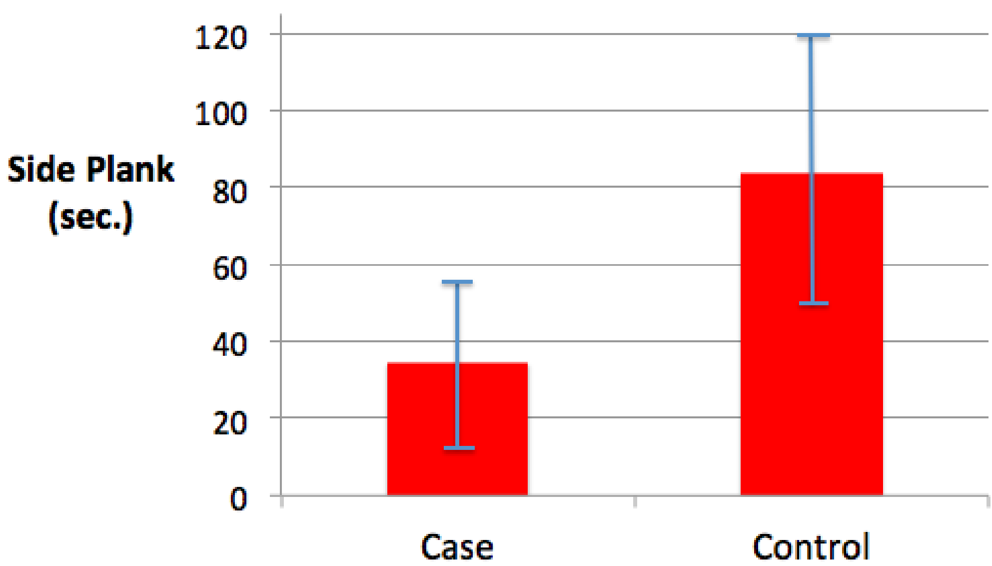

Figure 3: Side plank core endurance comparison between affected leg of cases and corresponding leg of healthy controls. The results of the side plank showed there was a significant difference (p=0.008) between the two groups with the cases scoring 48% lower in core endurance.