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# Iliotibial Band Length and Patellofemoral Pain Syndrome: Relationship Between Two Measurement Techniques

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**Iliotibial Band Length and Patellofemoral Pain Syndrome:  
Relationship Between Two Measurement Techniques**

Duane Scotti

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Doctor of Philosophy in Physical Therapy

4/24/2017

## Approval Page

We hereby certify that this dissertation, submitted by Duane M. Scotti, conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirement for the degree of Doctor of Philosophy in Physical Therapy.

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## Abstract

**Purpose:** To determine the relationship between iliotibial band (ITB) length and the presence of patellofemoral pain syndrome (PFPS), compare the difference in ITB length between the painful knee and the non-painful knee in subjects with unilateral PFPS, determine the test-retest reliability, standard error of measurement (SEM), and minimal detectable change (MDC) of the Ober test and modified Thomas test, and explore the relationship between the Ober test and the modified Thomas test in measuring ITB length. **Subjects:** Forty-eight subjects were recruited (PFPS group n=24, control group n=24) from three different outpatient physical therapy clinics. **Methods:** The Ober test and modified Thomas test was conducted on both legs of each subject to determine ITB length with the use of a digital inclinometer. Examiners were blinded to group assignment and an independent observer recorded all the results. **Results:** The mean values for hip adduction during the Ober test were 7.2 degrees in the control group and 2.3 degrees in the PFPS group. One way ANOVA revealed a significant difference between groups ( $p = .011$ ). There were clinically significant differences in ITB length comparing the painful knee to the non-painful knee for the Ober test due to the 3.0 degree mean difference exceeding the MDC of 1.91 degrees. The ICC values calculated for the test-retest reliability were .95 for the Ober test and .86 for the modified Thomas test. Pearson correlational analysis revealed a weak negative correlation ( $r = -.40$ ,  $p = .005$ ) between the Ober test and modified Thomas test on the left side and no correlation on the right side. **Discussion and Conclusion:** The Ober test is better at distinguishing between a PFPS group and a control group than the modified Thomas test supporting the clinical utility of the Ober test. The use of a digital inclinometer for both the Ober test and modified Thomas test appears to be a reliable method for the measurement of ITB

length. However, given the lack of relationship found between the two tests, the two examination procedures should not be used interchangeably for the measurement of ITB length.

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## CHAPTER 1: INTRODUCTION

### Introduction

Patellofemoral pain syndrome (PFPS) is the most common source of knee pain in active adolescents and adults.<sup>1</sup> The etiology of this condition is considered to be multifactorial in nature with several causative factors relating to altered lower extremity kinematics described in the literature.<sup>2-6</sup> Historically, local influences relating to patellofemoral malalignment have been proposed with a more recent shift toward distal and proximal influences noted as an etiological factor.<sup>5</sup> For example, altered or excessive foot pronation can lead to excessive tibial rotation and resultant knee valgus stress.<sup>7</sup> Similarly, alterations in frontal and transverse plane motions at the hip can affect lateral patellar forces.<sup>7</sup> Decreased iliotibial band (ITB) length has also been theoretically described as a causative factor that can affect the local and proximal influences associated with PFPS. In fact, most treatment paradigms include mobilizing and stretching tight lateral structures to improve their length.<sup>7-11</sup>

Numerous randomized controlled trials have demonstrated positive outcomes in patients with PFPS that include ITB stretching as part of a comprehensive intervention program to improve its length.<sup>7-11</sup> However, the inclusion of ITB stretching is based on weakly proven assertions, thereby validating need for testing and further analysis of this belief. This dissertation determined the relationship between ITB length and PFPS by examining concurrent validity. The difference in ITB length between painful and non-painful knees was also determined for subjects with unilateral PFPS. The test-retest reliability, standard error of measurement, and minimal detectable change were examined for the Ober and modified Thomas tests. In addition, convergent validity was assessed to determine the relationship between the Ober and modified Thomas tests.

## Problem Statement and Goal

The ITB is a thickening of the fascia on the lateral aspect of the proximal lower extremity that is made up of the muscular fascia of the gluteus maximus, gluteus medius, and tensor fascia lata (TFL) muscles.<sup>12</sup> Distally, the fibers of the ITB separate into two distinct bands at the knee with the iliotibial tract attaching to Gerdy's tubercle on the lateral proximal aspect of the tibia as a continuation of the ITB.<sup>13</sup> The iliopatellar band interdigitates with the vastus lateralis contributing to its role as a dynamic stabilizer of the patellofemoral joint.<sup>14</sup> Additionally, the iliopatellar band of the ITB indirectly acts as a passive restraint to medial patella glide and aids in lateral stabilization through its attachments to the lateral border of the patella via the lateral retinaculum.<sup>13</sup>

Tightness of the ITB has been correlated with abnormal kinematics, with increased ITB loads increasing patellar lateral tracking and tilting through parts of the flexion cycle.<sup>4</sup> These increased loads result in physically small but statistically significant changes in patellofemoral and tibiofemoral kinematics suggestive of increased lateral cartilage pressure.<sup>4</sup> Furthermore, increased ITB tension has been shown to have a significant effect on patellar position, affecting translation.<sup>13</sup> Several studies support an association between abnormal kinematics and knee pain.<sup>2,3,15</sup>

Anterior knee pain is the most common knee complaint encountered within orthopedic practice and is the hallmark sign of PFPS.<sup>16</sup> Historically known as chondromalacia of the patella, the etiology is recognized as being multifactorial in nature.<sup>1,7,14</sup> Many associated factors have been reported, though a lack of understanding of the underlying causative factors prevents consensus on the condition's etiology.<sup>5</sup> The proposed factors include: malalignment of the lower extremity, patella maltracking, muscular imbalance, cartilage disruption, increased Q-angle,

dynamic movement disorders, abnormal hip mechanics, overuse and lateral retinaculum tightness.<sup>16</sup> The ITB, through its direct attachments to the lateral retinaculum, can also be considered an etiological consideration in the presence of tightness.<sup>11,14,17</sup> In fact, interventional studies have commonly targeted ITB stretching as a component of a comprehensive treatment program for PFPS.<sup>8-10,18</sup> Increased ITB flexibility in conjunction with improved hip flexor strength has been associated with excellent results in individuals with PFPS who underwent an intervention program consisting of ITB stretching and hip strengthening.<sup>11</sup>

Ober originally described a test for TFL/ITB contractures by assessing lumbopelvic position in patients with low back pain in which he went on to perform surgical fasciotomies.<sup>19</sup> This description has led to the contemporary use of the Ober test to indirectly measure the length of the TFL/ITB complex.<sup>12-14,20-23</sup> The modified Thomas test, used to assess for tightness of the iliopsoas has more recently been suggested to examine the length of the TFL/ITB complex.<sup>24</sup> This newer measurement technique, unlike the Ober test, lacks substantive evidence supporting its use in determining ITB length.

Additional research examining ITB length as measured by the Ober test and modified Thomas test can assist in guiding clinical decisions specifically for the PFPS population. Therefore, the primary purpose of this dissertation study was to examine concurrent validity and determine the relationship between ITB length and the presence of PFPS. Secondary purposes included determining the difference in ITB length between painful and non-painful knees for subjects with unilateral PFPS. In addition, the study sought to determine the test-retest reliability, standard error of measurement, and minimal detectable change of the Ober and modified Thomas tests. Lastly, convergent validity was assessed to determine if the Ober and modified Thomas tests correlated as an indirect measure of ITB length.

## Relevance and Significance

Hudson and Darthuy<sup>14</sup> demonstrated that individuals with PFPS present with tighter iliotibial bands than do individuals without PFPS. This condition is the most common source of knee pain in the physically active population and those under fifty years.<sup>25,26</sup> Incidence rates for PFPS within the general population is still unknown but have been reported to be 25% to 43% in sports medicine and basic military training.<sup>26</sup> The prevalence of PFPS has been reported to be 15% and 12% in females and males, respectively.<sup>27</sup> Myer et al<sup>3</sup> report similar results with a cumulative incidence risk of 9.66 per 100 athletes. Although, epidemiological incidence data remains limited for this population.<sup>28</sup> Females are 2.23 times more likely to develop PFPS compared to their male counterparts.<sup>27</sup> Furthermore, middle and high school female athletes sports specialization has been associated with PFPS with a 16% prevalence. Single sport female adolescent athletes have a 1.5 fold greater risk of developing PFPS than those participating in multiple sports.<sup>29</sup>

Current evidence contradicts the assertion that PFPS is benign and runs a self- limiting course. In fact, the effects of PFPS can be quite devastating secondary to high reoccurrence rates and limitations on performance of physical activities.<sup>6</sup> More than 90% of individuals with PFPS go on to develop chronic pain. A retrospective case-control analysis of 22 patients with PFPS reported 91% still having knee pain following initial examination conducted between four and eighteen years previously.<sup>30</sup> Of those, 68% were female patients with PFPS restricted physical activity found in 36% of the 22 patients.<sup>26</sup>

Individuals with chronic PFPS are at greater risk for developing patellofemoral joint osteoarthritis (OA) later in life.<sup>31</sup> Utting et. al<sup>31</sup> demonstrated that PFPS in adolescents or early adulthood is a likely contributor to long term patellofemoral joint OA. Utting's findings of

patellofemoral joint OA were supported in a recent study examining the prevalence of patellofemoral joint OA in 224 volunteers with chronic PFPS.<sup>32</sup> Radiographic patellofemoral osteoarthritis was prevalent in both the medial and lateral compartments in 70% of the individuals greater than 40 years old. Based on these findings, PFPS could be considered a public health concern secondary to its detrimental effect on physical activity and its association with patellofemoral osteoarthritis.<sup>6</sup> The development of effective interventional programs may be an effective strategy to decrease the occurrence of PFPS and, in turn, the occurrence of patellofemoral osteoarthritis. Identifying contributing causative factors associated with PFPS may likely improve outcomes and decrease incidence.

Theoretical models have proposed tightness of the ITB could result in lateral patellar tracking, lateral patellar tilt and lateral patella compression contributing to PFPS.<sup>14,33</sup> This malalignment and maltracking of the patella can create overloading of subchondral bone due to continuous impact load as the patella re-engages with the femur, resulting in pain. Sheehan et al<sup>17</sup> support this theory by demonstrating a direct correlation between the level of pain and patellofemoral kinematics. Patella malalignment and maltracking that occurs with PFPS can lead to shortening of the lateral retinaculum and/or ischemia resulting in secondary nerve changes and subsequent pain.<sup>34</sup>

Although many interventional studies include ITB stretching as a component of a comprehensive treatment program for PFPS, there are conflicting findings on whether subjects with PFPS have decreased ITB length. A case control study of thirty subjects with PFPS did not demonstrate a correlation, as they found no differences in flexibility of the ITB between the PFPS group and a control group utilizing the Ober test.<sup>33</sup> In a more recent case control study done in 2009 with improved methodology, Hudson and Darthuy<sup>14</sup> found a relationship between

tightness of the ITB as measured by the Ober test and those that had patellofemoral syndrome. Furthermore, a cohort interventional study reported successful PFPS outcomes that were correlated with improved hip flexor strength, ITB flexibility, and iliopsoas flexibility.<sup>11</sup>

High quality randomized clinical trials have demonstrated favorable outcomes for patients with PFPS undergoing a comprehensive interventional program including quadriceps strengthening and lower extremity flexibility that includes ITB stretching.<sup>8,9</sup> However, these current interventions for PFPS only demonstrate short term outcomes with respect to pain and function with less compelling long term efficacy.<sup>5</sup> This finding is evidenced by the high reoccurrence rate seen in retrospective studies.<sup>5,30</sup> A possible explanation for these poor long term outcomes could be the lack of focus on addressing the underlying contributing factors to PFPS. Additional research examining ITB length as a contributing factor measured by the Ober and modified Thomas test may assist in guiding future clinical decisions specifically for the PFPS population. Decreased ITB length has been the framework that has guided treatment paradigms despite the gap in the literature demonstrating a direct relationship with PFPS. Due to unclear and conflicting findings regarding the relationship between PFPS and ITB length, the primary purpose of this study was to determine the relationship between ITB length and PFPS.

### **Research Questions**

The research questions that were answered with this dissertation study included:

- R1:** Is there a relationship between ITB length and the presence of PFPS?
- R2:** Is there a difference in ITB length between the painful knee and the non-painful knee in subjects with unilateral PFPS?
- R3:** What is the test-retest reliability, standard error of the measurement, and minimal detectable change of the Ober test and modified Thomas test?
- R4:** Is there a relationship between the Ober test and modified Thomas test in measuring ITB length?



## Definitions of Terms

**Kinematics:** The measurement of joint angles of motion. Altered lower extremity kinematics have been linked to PFPS.<sup>7</sup>

**Iliotibial band (ITB) length:** The overall length of the TFL/ ITB complex, which is assessed indirectly with the Ober or modified Thomas test.

**Iliotibial Band Syndrome (ITBS):** Leading cause of lateral knee pain in runners and believed to be the result from friction of the ITB as it slides over the lateral femoral condyle.<sup>15</sup>

**Iliotibial band (ITB) tightness:** Strong influence on patellar position due to anatomical influence contributing to patellar malalignment.<sup>13</sup> Associated with decreased muscle length and measured indirectly with a positive test on the Ober or modified Thomas test within the literature.

**Maltracking:** Abnormal repetitive movements of the patella (pathomechanics) re-engaging with the femur. Supported as the primary theory leading to patellofemoral pain syndrome as a result of overloading the underlying subchondral bone.<sup>5</sup>

**Modified Thomas test:** Orthopedic special test to indirectly measure the length of the hip flexor muscle group. For this dissertation, a modification for assessing TFL/ITB length is described. This modification was performed with the subject sitting at the edge of the examination table. The primary examiner assisted the subject in slowly rolling backward onto the table as the subject grasped underneath both thighs until a supine position was achieved with both knees in toward their chest.<sup>35</sup> The primary examiner assisted in flexing the opposite hip by bringing their knee further toward their chest until full motion was obtained to ensure the lumbar spine was in contact with the table. Next, the primary examiner slowly lowered the testing limb into hip extension maintaining a hip neutral position preventing abduction of the thigh.<sup>35</sup> The final test position was reached when full hip extension range of motion was obtained while maintaining the low back, sacrum, and pelvis in contact with the table. The primary examiner instructed the recording examiner to place the digital inclinometer on the thigh with the digital readout facing away from the primary examiner.<sup>12</sup> The recording examiner placed the digital inclinometer at the midpoint between the anterior-superior iliac spine and the patella on the anterior aspect of the thigh. The recording examiner read and recorded the hip extension measurement as a continuous variable to the nearest .1 degree on the data collection form. Next, the primary examiner positioned the limb into full hip abduction and the recording examiner read and recorded the hip extension angle as a continuous variable once again. During both measurement positions; if the limb was horizontal, it was considered to be at zero degrees; if it was below horizontal (extended), the angle was recorded as a positive number; and if it was above horizontal (flexed), the angle was recorded as a negative number. The differences between the two hip extension measures (hip neutral and hip abducted) were used to determine ITB length as a continuous variable during analysis. Decreased ITB length was present when the second measurement of hip extension was greater than the first measurement as a result of placing the ITB in a slackened position.<sup>12</sup> Each measurement was repeated two times with a 5-second pause between each measurement and the procedure was repeated on the opposite limb.

Ober test: Orthopedic special test to indirectly measure the length of the TFL/ ITB. Performed with the subject positioned in sidelying with the primary examiner standing posteriorly. The lower leg was flexed to 45 degrees at the hip and knee to maintain stability and to restrain body rotation.<sup>14,20</sup> The primary examiner used their distal hand to cradle the test limb supporting just above the knee with the knee flexed to 90 degrees. The proximal hand was positioned on the subject's posterior pelvis, which served to block extraneous posterior movement of the pelvis.<sup>33</sup> The examiner lifted the test limb into slight hip flexion, abduction and then extension in order to pass the ITB over the greater trochanter.<sup>36</sup> This was performed while maintaining pelvic stabilization with the examiner's proximal hand and 90 degrees of knee flexion with the examiner's distal hand. Next, the examiner allowed the limb to drop toward the table into hip adduction, attempting to control for any unwanted hip rotation. The position of measurement was determined by the point at which the limb stopped moving toward the table.<sup>13,36</sup> The recording examiner placed the digital inclinometer at the midpoint between the anterior-superior iliac spine and the patella on the lateral aspect of the thigh.<sup>12,22</sup> The recording examiner read the angle of hip adduction with the digital readout facing away from the primary examiner and then recorded the measurement as a continuous variable to the nearest .1 degree on the data collection form.<sup>12</sup> If the limb was horizontal, it was considered to be at zero degrees; if it is below horizontal (adducted), the angle was recorded as a positive number; and if it is above horizontal (abducted), the angle was recorded as a negative number.<sup>13</sup> The greater angle of maximum adduction indicated longer ITB length.<sup>13</sup> Decreased ITB length was present if the limb had a decreased angle of maximum adduction (relative abduction). Each measure was repeated two times with a 5-second pause between each measurement and the procedure was repeated on the opposite limb.

Patellofemoral Pain Syndrome (PFPS): Diffuse retropatellar or peripatellar pain during activities such as running, ascending and descending stairs, squatting, and sitting with flexed knees for prolonged periods of time.<sup>7</sup>

## Summary

PFPS is a common musculoskeletal disorder related to malalignment of altered lower extremity kinematics due to numerous causative factors. Increased lateral cartilage pressure and altered patellofemoral kinematics have been demonstrated with increasing ITB loads. Decreased ITB length has been the framework that has guided treatment paradigms despite the gap in the literature demonstrating a direct relationship with PFPS. This led to the primary purpose of the current study to investigate concurrent validity and determine if there is a relationship between ITB length and PFPS. Secondary purposes of the study include determining the difference in

ITB length between painful and non- painful knees for subjects with unilateral PFPS, determining the test-retest reliability, standard error of measurement, and minimal detectable change of the Ober and modified Thomas tests, and determining convergent validity investigating the relationship between the Ober and modified Thomas tests. The primary and secondary purposes did answer the four research questions previously described that provided the framework for the methodology used in this study. The significance of fostering knowledge on the relationship between ITB length and PFPS can provide insight into the utilization of the Ober test for assessment and determining outcomes during intervention studies. Furthermore, examining the modified Thomas test as a newer measurement technique in addition to the Ober test provides knowledge to assist with future examination and treatment both clinically and for research purposes for individuals with PFPS.

## CHAPTER 2: REVIEW OF THE LITERATURE

### Introduction

This chapter begins with a historical overview of PFPS including the various etiological mechanisms. Specifically, the local, proximal, and distal influences on PFPS are examined with particular attention paid to the ITB as a local influence. The theoretical model as well as the current literature to support decreased ITB length as a contributory factor to patellar maltracking and malalignment are described in detail. Various methods to assess for ITB length are also examined with considerations given for differing operational definitions during measurement. Reliability, validity, and normative criteria for both the Ober test and the modified Thomas test are presented. A summary of what is known and unknown within the literature with current case control trials examining ITB length within the PFPS population are also detailed. Finally, the importance this study and its contribution to the field of orthopedic physical therapy is discussed.

### Historical Overview of Patellofemoral Syndrome and Etiological Theory

The most common knee complaint within physically active individuals is anterior knee pain, which is the hallmark sign of PFPS.<sup>1</sup> This musculoskeletal disorder most commonly affects individuals 15-30 years old and is frequently seen clinically with a reported prevalence rate of 15% and 13% in females and males, respectively.<sup>7,37</sup> Typically pain is exacerbated with descending stairs, prolonged sitting, and squatting.<sup>17</sup> These signs are supported by a recent systematic review that determined the best diagnostic accuracy for PFPS screening and diagnosis is the clinical findings of pain with stair climbing, prolonged sitting, and squatting.<sup>1</sup> Cook et al<sup>16</sup> reported a positive likelihood ratio of 4.0 when clustering positive examination findings of pain with resisted knee extension, patellar palpation, and squatting. This results in a moderate shift toward a diagnosis of PFPS once competing sources have been ruled out. Most of these cases

are classified as having chronic idiopathic PFPS without a known source of their pain.<sup>5</sup> Despite this, PFPS is widely agreed to be multifactorial with pain occurring through various mechanisms.<sup>7</sup> The most substantiated etiological mechanism relates to patella malalignment and maltracking, creating overloading of underlying subchondral bone resulting in pain.<sup>5</sup> Support for this etiological mechanism was given in a recent study that found a direct correlation between patellofemoral joint kinematics and level of pain.<sup>17</sup> Another potential PFPS pain pathway results from abnormal pathomechanics related to a shortened lateral retinaculum with subsequent ischemia creating secondary nerve damage and pain.<sup>5</sup> In summary, the underlying etiology of PFPS is multifactorial with several causative factors purported within the literature that can lead to patellar malalignment and maltracking.<sup>7</sup> These can be subgrouped into proximal, distal, and local influences.<sup>5</sup>

Proximal influences on patella malalignment and maltracking occur in weight bearing and are caused by femoral internal rotation as opposed to lateral tilt of the patella that occurs locally.<sup>5</sup> In fact, biomechanical studies have demonstrated abnormal frontal and transverse plane hip movements in patients with PFPS.<sup>7</sup> These abnormal movements result in excessive femoral internal rotation during the stance phase of gait altering patellofemoral joint kinematics.<sup>7</sup> This excessive dynamic valgus movements have been gender specific with activities such as running and squatting.<sup>38</sup> Females have demonstrated excessive hip adduction mechanics and less knee adduction compared to their male counterparts with PFPS.<sup>38</sup>

Distally, altered or excessive foot pronation can result in compensatory tibial internal rotation with increased valgus stress creating similar patella malalignment and maltracking concerns.<sup>7</sup> Barton et al<sup>39</sup> supported a biomechanical link reporting increased pronated foot postures statically using the foot posture index that was associated with earlier peak rearfoot

eversion dynamically in 26 individuals with PFPS in comparison to a control group. The pronated foot posture and earlier peak rearfoot eversion support the biomechanical model of PFPS, though causation cannot be established due to the retrospective nature of this study.

Local etiological influences contributing to patellar malalignment and maltracking include quadriceps muscle function, hamstring muscle length, and ITB muscle length.<sup>5</sup> Normally, quadriceps stabilization occurs as the patella glides through the femoral groove. An imbalance between quadriceps forces may lead to lateral displacement of the patella, resulting in stress to the lateral facet of the patellofemoral joint.<sup>7</sup> In fact, a recent systematic review concluded there is strong evidence to include quadriceps strengthening in conjunction with other PFPS interventions.<sup>40</sup> This review included seven randomized controlled trials with good to excellent methodological quality using the Physiotherapy Evidence Database critical appraisal tool.<sup>40</sup> These studies supported improved efficacy in terms of pain and function utilizing quadriceps strengthening as opposed to advice and information alone. In addition, pain was significantly reduced with quadriceps strengthening combined with other interventions immediately following intervention and maintained at 12 month follow up.<sup>40</sup> This lends support for impaired quadriceps muscle function as an etiological factor.

### **Iliotibial Band length as an Etiological Factor**

In addition to quadriceps weakness, other potential local etiological considerations include tightness of the hamstrings, patella retinaculum and ITB.<sup>7</sup> Decreased ITB length can lead to altered patellar position affecting joint kinematics supporting its local influence on PFPS etiology. Kang et al<sup>13</sup> used the Ober test in a similar fashion to the current study to measure ITB length in 40 healthy Korean volunteers (22 males, 18 females). A similarity to the current study

is the utilization of a digital inclinometer to measure hip adduction angle in order to improve precision of measurement.<sup>13</sup>

The Ober test can be technically challenging to execute properly due to unwanted movement of the pelvis as the limb is positioned in multiple planes of motion. Proper pelvic stabilization or monitoring is essential in order to achieve reliable measurements. There are a number of studies that have attempted to control for unwanted lateral pelvic motion in the frontal plane during the Ober positioning by using a spirit level that is attached to the subject in order to improve reliability.<sup>14,41</sup> Herrington et al<sup>42</sup> was the first to publish the use of a pressure biofeedback cuff to detect pelvic motion during the Ober test. Kang et al<sup>13</sup> utilized the same Ober test procedures and found an altered patella position in subjects with ITB tightness.<sup>13</sup> Previous to Kang's study, patellar position had been determined by palpating and tracing bony landmarks, which resulted in poor correlations between patellar position and ITB tightness.<sup>42</sup> Herrington et al<sup>36</sup> measured the patella-condyle distance (PCD) using ultrasonography (US). This less invasive, albeit more expensive, method of determining patellar position demonstrated excellent reliability with strong criterion validity when compared to the gold standard MRI measures.<sup>36</sup> Intratester reliability for PCD was reported using ICC= .93 (p< .001) with a standard error of measurement (SEM) of .31 mm and minimal detectable change (MDC<sub>90</sub>) of .72mm. A smaller PCD with increased lateral patellar translation was found at 20 degrees of hip adduction in subjects with ITB tightness compared to those without tightness.<sup>13</sup> In addition, within the tightness group, the ITB length was moderately correlated with PCD at 20 degrees adduction of the hip and strongly negatively correlated with lateral patellar translation, thereby establishing a relationship between ITB length and patellar position.<sup>13</sup> The results of decreased ITB length and patellar position should be used with caution given the subject population used in

Kang et al's study were asymptomatic Korean volunteers as opposed to patients referred for physical therapy with PFPS that were used in this current study. Therefore, results may not be generalizable to the subjects collected in this study. A limitation of Kang et al's study was not testing the reliability of their methods. This is especially important given the use of extra equipment to monitor lateral pelvic motion from the traditional Ober test operational definitions.

### **Patellar Maltracking**

In addition to patellar position, abnormal kinematics has been correlated with tightness of the ITB.<sup>4</sup> Merican et al<sup>4</sup> used nine fresh-frozen cadaveric knees to understand the effects of a tight ITB. Specifically, the authors used a Polaris optical system to capture orientation of trackers on the bones and the raw data was processed by Visual3D software in order to determine the effects of increased ITB force on patellofemoral kinematics. Similar to Kang's findings, it was determined that increased lateral patellar translation and tilting occurred with increased ITB loading through parts of the flexion cycle.<sup>4</sup> The patella translated laterally by 0.8 and 1.4mm with 60 and 90N of load compared to the ITB unloaded condition.<sup>4</sup> Additionally, the patella became more laterally tilted with increased ITB loads by 0.7 degrees, 1.2 degrees, and 1.5 degrees for 20, 60, and 90N respectively.<sup>4</sup> These increased loads resulted in physically small but statistically significant changes in patellofemoral and tibiofemoral kinematics, suggestive of increased lateral cartilage pressure. However, Merican's study does present with inherent limitations due to the in vitro nature of its methods. It is not known how well the elderly knees used in this study extrapolate to the general population, specifically a young active adult population with PFPS. Another significant limitation of this study is the results replicated open chain loading and it is not known how the patellar kinematics would be affected with weight-bearing gait analysis. This is particularly important as the majority of PFPS patients do



experience pain with weight bearing activities such as squatting and stair-climbing.<sup>1,17</sup>

Additionally, it is not known how these findings relate to symptoms in living patients.

Nonetheless, the results can help explain the clinical findings of patellar maltracking and pain as a result of decreased ITB length.

Dynamically, Sheehan et al<sup>17</sup> documented the existence of maltracking in 30 mainly female knees diagnosed with PFPS using dynamic MRI to investigate 3-dimensional patellofemoral kinematics. Maltracking has been reported to occur in a specific subset of patients with PFPS and can potentially lead to the development of patellofemoral joint osteoarthritis.<sup>31</sup> These patients experience overload of the patellofemoral joint cartilage from continuous impact load of the patella re-engaging with the femur.<sup>17</sup> This maltracking is a likely primary impairment that can lead to overloading of the underlying subchondral bone, resulting in pain. This Merican study provides the most current substantiated evidence supporting the malalignment and maltracking etiology of PFPS.

Noehren et al<sup>15</sup> found increased hip adduction and knee internal rotation kinematics in individuals with knee pain. This prospective study collected bilateral frontal and transverse plane 3D lower extremity kinematics and kinetics data using a 6 camera motion analysis system. Subjects consisted of 400 female recreational runners who ran at least 20 miles per week and were followed over the course of two years. 18 subjects developed iliotibial band syndrome (ITBS) and were compared to age and mileage matched healthy controls. The findings of increased hip adduction and knee internal rotation kinematics were consistent with previous retrospective studies analyzing lower extremity kinematics in runners with this condition. This finding is significant as it supports the notion that runners may not change their mechanics as a result of their pain but rather develop pain due to abnormal mechanics. However, this study was

performed on patients with ITBS and not PFPS. Nevertheless, parallels can be made as both are common among active individuals, occur as a result of overuse, and have similar underlying etiological impairments. In fact, the authors' conclusions recommend techniques and exercise to improve hip abductor strength and ITB flexibility for individuals with ITBS, which are analogous to PFPS treatment paradigms.<sup>5,7,8</sup>

Myer et al<sup>3</sup> established altered biomechanics in female basketball players who prospectively went on to develop PFPS. Frontal plane knee loading was investigated in 240 middle and high school aged basketball players during a drop vertical jump. Increased knee abduction moments were found during initial contact on the symptomatic side compared to their asymptomatic teammates.<sup>3</sup> These results support the hypothesis that dynamic knee abduction moment during landing contributes to the onset of PFPS. Similar to Noehren et al<sup>15</sup>, both prospective studies serve as a benchmark for establishing cause and effect relationships and further strengthens the argument for altered biomechanics as an etiological influence on PFPS.

### **ITB stretching as an Intervention for PFPS**

The influence of ITB length as an etiological factor for PFPS may be indirectly supported within the interventional literature. Conclusions based on evidence recommend strengthening and flexibility may be an important consideration in the evaluation and intervention of PFPS.<sup>11</sup> Recent high quality randomized controlled trials include ITB stretching as part of a multicomponent treatment in the management of PFPS.<sup>7-11</sup> However, within the interventional literature, ITB stretching is always utilized in combination with other forms of treatment and never has been based upon evidence in support of ITB stretching as a single intervention. Song et al<sup>9</sup> utilized simple leg press training from 45 degrees to zero degrees knee extension in addition to quadriceps, hamstring, calf, and ITB stretching for eight weeks. Positive outcome

measures included VMO hypertrophy, improved knee function, and reduction in pain for 89 patients with PFPS.<sup>9</sup> Similarly, Fukuda et al<sup>8</sup> demonstrated reduced pain and function for 70 females with PFPS following 4 weeks of strengthening of the hip abductor and lateral rotator muscles in combination with the same lower extremity stretches as the previous study.

Investigations comparing selective VMO training versus general quadriceps strengthening also include ITB stretching as a component of the intervention.<sup>10</sup> Both strengthening approaches were recommended for PFPS rehabilitation following eight weeks of intervention, demonstrating short term improvements in pain, function, and quality of life.<sup>10</sup> Long term findings, including similar methodology, have demonstrated improvements in pain and function at 3 months and 12 months compared to usual care.<sup>18</sup> These interventional studies demonstrate improved outcomes in individuals with PFPS utilizing a multimodal approach including ITB stretching despite the lack of substantive evidence to support decreased ITB length as a etiological factor to PFPS.

Tyler et al<sup>11</sup> also demonstrated improvements in pain and function following a six week protocol focusing on strength and flexibility of the hip in 35 patients with PFPS. In this study, 39 of 43 lower extremities had a positive Ober test prior to treatment as defined as the extremity was above horizontal. Following six weeks of intervention, 24 results normalized and 83% (20 of 24) were associated with a successful outcome. Successful outcome was determined by statistically significant improvements in pain as measured by the Visual Analog Scale (VAS) with activities of daily living and with exercise. Conversely, 15 extremities continued to have a positive Ober test following the intervention period and only 4 of 15 (27%) had a successful outcome. In addition to ITB flexibility, improvements in hip flexor strength and iliopsoas flexibility were also correlated with successful PFPS outcomes.<sup>11</sup> Tyler et al utilized the same Ober test procedure to determine ITB length that was performed in the current study.<sup>11</sup> The

findings by Tyler et al demonstrate successful outcomes with improvements in ITB length. This supports the need to determine the relationship between ITB length and PFPS that was explored in the current study.

### **Use of Ober test to assess ITB Length**

The Ober test is a well-known orthopedic special test used to indirectly measure the length of the ITB. The specific procedure of the test has been well documented with slight variations depending on the method of measurement to quantify the results.<sup>11-14,20,22,23,41,43,44</sup> Most authors have studied healthy volunteers with relatively small sample sizes.<sup>11,13,14,20,41,43</sup> Additionally, several discrepancies exist within the literature regarding positioning, method of measurement, and criteria used for a positive Ober test.<sup>12</sup> Historically, ITB tightness has been determined subjectively, relying on observation to quantify the results with a positive test indicated by the inability of the thigh to adduct beyond the horizontal.<sup>11</sup> A negative test indicates the patient has ideal muscle length with a positive test confirmed if the relaxed and extended hip fell below horizontal in adduction. According to Kendall et al,<sup>45</sup> ITB tightness is defined as the thigh does not reaching 10 degrees of hip adduction from the horizontal plane.<sup>45</sup>

Advances in measurement have led to the use of a bubble or fluid filled inclinometer as a more objective method than observation to quantify the results of the Ober test.<sup>14,20,41,43,46</sup> The inclinometer is placed on the lateral thigh just proximal to the lateral femoral condyle and the measurement is taken as a continuous variable with positive numbers indicating the limb is below horizontal (adduction) and negative numbers indicating above horizontal (abduction). Therefore, negative values represent more tightness whereas positive values represent less tightness.<sup>14,20,43</sup> More recently, a digital inclinometer has been placed at the midpoint between the anterior-superior iliac spine and the patella as a new method of measurement to enhance

accuracy and specificity of measurement.<sup>12,13,22</sup> The digital inclinometer instrumentation will be used during all measurements for this current study in order to enhance precision.

In addition to variability in the measurement device utilized during the Ober testing procedure, researchers have focused on limiting the amount of pelvic motion that occurs during the test.<sup>13,14,41,42</sup> In fact, inability to control pelvic movement has brought about the greatest variability in results seen in the literature with the Ober test.<sup>43</sup> Monitoring pelvic motion is technically challenging and involves knowing at what point the end range of motion has been reached when bringing the limb into hip adduction. Oftentimes, the pelvis will tilt or rotate thereby affecting the measurement and potentially limiting reliability.

The use of a spirit level has been utilized in which a level is placed horizontally on the level of the PSIS in standing and secured with tape.<sup>14,41</sup> The level is then checked when the subject is in side lying to ensure no lateral or anterior posterior tilting of the pelvis has occurred throughout the measurement procedure.<sup>14,41</sup> Melchione and Sullivan<sup>41</sup> were the first authors to attempt to standardize the position of the pelvis secondary to ambiguity of Ober's original description, which noted the examiner steadies the pelvis during the procedure but did not describe how this was done.<sup>41</sup> To standardize the process, Melchione and Sullivan specially designed a pelvic level utilizing a ruler and two spirit levels that was attached to the posterior superior iliac spines (PSIS) and secured with a Velcro strap. The authors attached the spirit levels to 5 male and 5 female subjects with PFPS (average age 23 years old) in order to monitor lateral pelvic motion during the testing procedure. In addition to controlling for unwanted pelvic motion, the authors' main purpose was to modify the position of the knee to mimic lower extremity positioning that occurs with gait. Therefore, the actual test position that was performed by Melchione and Sullivan was later considered to be the modified Ober test utilizing

a slightly flexed knee position. Excellent intrarater reliability (ICC= .94) was established, however, only good interrater reliability (ICC= .73) was reported.<sup>41</sup> The SEM values were determined 1 degree and 2 degrees for intrarater and interrater reliability, respectively.<sup>41</sup> An explanation for the limited interrater reliability could be attributed to the complexity of the patient setup in order to detect pelvic motion and therefore was not utilized in the methods of the current study.

Hudson and Darthuy<sup>14</sup> utilized a similar pelvic level procedure; however, applied it to the original Ober test with the knee flexed to 90 degrees. The aim of their study was to use the Ober test to investigate whether subjects with PFPS have a tighter ITB compared to subjects without pain. Hudson and Darthuy's study included 12 subjects with PFPS and 12 asymptomatic subjects (16 men, 8 women) with an average age of 31 years old. The authors utilized a similar pelvic monitoring protocol with a spirit level that was taped to the subjects PSIS. Two examiners carried out the procedure in order to blind the positioning examiner from the readings of the bubble inclinometer. Limitations of this study included taking only one measurement and not establishing examiner reliability. The Hudson and Durthuy study provided a framework for this current study as it is the only study that demonstrated decreased ITB length in a PFPS group as compared to a control groups of subjects without PFPS.

Herrington et al<sup>42</sup> introduced a pressure biofeedback unit as a simpler procedure to detect the onset of pelvic motion during the Ober test. This study investigated the relationship between ITB length as measured by the Ober test and patellar position in 80 asymptomatic subjects (37 male, 43 female) with a mean age of 21.5 years old.<sup>42</sup> Measurement was recorded at the onset of excessive lateral pelvic tilt during the testing procedure, measurement defined as the moment in which an increase greater than 5 mmHg from the baseline of 40 mmHg was detected by the

biofeedback unit. At that point, the test was halted and a measurement was recorded.<sup>42</sup>

Intrarater reliability was established on five subjects with an ICC= .96 and a SEM of 1.3 degrees.

In a more recent study, Kang et al<sup>13</sup> utilized the same pelvic monitoring procedure with a biofeedback unit, however did not measure examiner reliability. Due to the limited established reliability and lack of MDC reporting using the biofeedback unit, this procedure warranted further investigation and was examined during the pilot work for this dissertation study.

Noehren et al,<sup>22</sup> in recent study, investigated ITB length in 34 male runners utilizing the Ober test. Results indicated a group with ITBS exhibited decreased ITB length compared to age matched controls. While statistically significant, this was not considered clinically meaningful since the between group differences (1.2 degrees) did not exceed the MDC (3.8 degrees). During the testing procedure, the examiner's knee provided stabilization in order to prevent the subject from rolling backward. Similarly, stabilization for the current study was provided by the examiner's hand in order to prevent rolling backward and did not rely on external aides to monitor pelvic motion. Another similarity to this dissertation study was the use of a digital inclinometer to record the measurements. Critics of the use of external aides to assist in pelvic controlling procedures note the increased complexity required, introducing a potential form of measurement error.<sup>43</sup> This was evident in early pilot study testing for this dissertation resulting in significantly decreased interrater reliability (ICC= .52) utilizing a pressure biofeedback cuff to monitor pelvic motion. This provided the rationale to perform the measurement procedure without the use of an external device to monitor pelvic motion during the main dissertation study and was consistent with previous studies.<sup>12,22,33,43</sup>

Reliability and measurement error are critical features of measurement and must be established prior to a test being considered clinically meaningful garnering widespread usage.<sup>20</sup>

Excellent intratester reliability (ICC= .90) with the use of a bubble inclinometer on distal lateral thigh to measure hip adduction angle in 61 asymptomatic individuals (17 males, 44 females) has been established for the Ober test.<sup>43</sup> The mean age of the subjects was 24.2 years and three examiners performed the measurement protocol in order to ensure blinding of examiners. Examiner 1 was responsible for performing the Ober test, examiner 2 placed the inclinometer on the limb and examiner 3 read the number and recorded the data. An average of 2 measurements was used for later analysis and the measurements were repeated on the same subjects the following day in order to establish intrarater reliability.<sup>43</sup>

Piva et al<sup>20</sup> is the only study that has investigated interrater reliability of the Ober test with a PFPS population during pilot study testing for their larger multicenter study with the use of a bubble inclinometer. 30 patients (17 females, 13 males) with PFPS with an average age of 29 years old underwent a repeated measures design with two pairs of physical therapists measuring various strength and flexibility impairments. Excellent interrater reliability was obtained (ICC= .97) measuring hip adduction angle with a SEM of 2.1 degrees.<sup>20</sup> Strengths of this study included proper pelvic stabilization by the examiner that was consistent with the testing procedure for this study. However, significant limitations include lack of examiner blinding from group allocation and from the readings from the inclinometer. This could potentially introduce significant examiner bias. The present study had two examiners for all measurements, one to position the limb and one to place the digital inclinometer on the limb and read and record the number.

Several studies suggest the subjective nature of categorizing the ITB as flexible or inflexible may be replaced with a more objective simple tool such as the digital inclinometer that was utilized as part of this current study.<sup>12,13,22</sup> Normative values and critical criteria for ITB



flexibility have been established combining both subjective assessments and instrumented measurements for the Ober test.<sup>12</sup> Ferber et al<sup>12</sup> was the first to use the digital inclinometer as a new measurement technique in order to improve precision and foster evidence- based determinations on ITB length. He compared the continuous measurement with the dichotomous subjective assessment of ITB length. This study was unique in studying ITB length as it was the only one that used a large sample size, included healthy and injured participants, and examined interrater percentage of agreement. This cross- sectional study included 300 recreational athletes (125 men, 175 women) who volunteered for participation for a total of 600 limbs analyzed. The recreational athlete definition was described as completing at least 30 minutes of activity, 3 times per week. Within those 300 participants, 50 participants were recruited who were uninjured in order to act as controls. Inter- rater reliability was examined by percentage of agreement for the subjective assessment of the Ober test between two clinicians and found to be 97.6% agreement. The average inclinometer angle for the Ober test was 24.6 degrees of hip adduction below the horizontal.<sup>12</sup>

A significant limitation of this study was the primary examiner supported the limb with one hand and then placed the inclinometer with the other hand, lacking any pelvic stabilization. This limitation is heightened by lack of test-retest reliability of the newer digital inclinometer measurement device and procedures utilized prior to study implementation. In addition, interrater reliability of the objective assessment from the continuous variable measured with the digital inclinometer was not reported. There are only three studies (Ferber et al<sup>12</sup> , Kang et al<sup>13</sup> , and Noehren et al<sup>22</sup> ) that used a digital inclinometer during the Ober test and none have reported reliability with this newer measurement device, demonstrating a gap in the current literature.

This dissertation study established test-retest reliability, SEM, and MDC of the newer measurement device using both the Ober and modified Thomas test procedures.

Hudson and Darthuy<sup>14</sup> found similar hip adduction measurement angles as Ferber et al<sup>12</sup>, despite utilizing a bubble inclinometer. The aim of their study was to use the Ober test to investigate whether subjects with PFPS have a tighter ITB compared to subjects without pain. Hudson and Darthuy's study included 12 subjects with PFPS and 12 asymptomatic subjects (16 men, 8 women) with an average age of 31 years old. The findings for hip adduction ranged from 20.3 degrees to 21.4 degrees for the control group and 14.9 degrees to 17.3 degrees for the PFPS group. These results were similar to Herrington et al<sup>42</sup> who found an average angle of 16.2 degrees utilizing a bubble inclinometer in asymptomatic subjects. In addition, Hudson and Darthuy<sup>14</sup> found a trend toward decreased ITB length in the non-painful knee of the PFPS group compared to both knees in the control group. Their results provided preliminary support to the causative model as a result of PFPS commonly occurring bilaterally. Using the causative model, Hudson and Darthuy<sup>14</sup> theorized the ITB had not become sufficiently tight for the subjects to develop symptoms on the contralateral side for the unilateral cases. Using similar methods, Dheeraj and Arora<sup>21</sup> recently compared ITB length between right and left sides in subjects with unilateral sciatica utilizing the Ober test with a bubble inclinometer and did not find significant differences between sides. These findings were tested in the current study by comparing the ITB length of the painful knee to the non-painful knee in subjects with unilateral PFPS.

### **Validity of Assessment Measures**

There are limited evidence that demonstrates the validity of the Ober test, however, many studies support ITB stretching for individuals with PFPS syndrome.<sup>2,8-11,18</sup> A cross sectional ultrasonographic study conducted on 36 asymptomatic subjects with an average age of 24 years

old examined the width of the ITB with stretching. Manual stretching of the ITB was performed in the Ober position with short term deformation of the ITB was found, leading the authors to conclude the Ober position is effective in stretching the ITB.<sup>47</sup> Another study supported short term deformation of the ITB during commonly performed ITB stretches in 5 healthy male elite-level distance runners.<sup>48</sup> This Stanford University biomotion laboratory study captured subject's biomechanics with a 4-camera gait acquisition system including force plate. The ITB deformation was calculated using an indirect analysis of kinematic and kinetic data.<sup>48</sup> Results showed adding an overhead arm extension to the commonly prescribed ITB standing stretch produced the greatest change in ITB length.<sup>48</sup> However, no study has yet to investigate the long-term effects of ITB stretching and mobilization on ITB length.<sup>14</sup>

### **Assessment of ITB Length with the Modified Thomas Test**

The modified Thomas test is a test that has also been recommended to examine TFL/ITB length, though far less frequently than the Ober test.<sup>24</sup> The Thomas test was originally developed to assess for a hip flexor contracture or tightness of the iliopsoas muscle with the subject positioned in supine with the hip joint on the table. This test created difficulty obtaining hip extension measurements and was shortly modified to have the subject positioned with the hip joint over the edge of the table.<sup>35</sup> This modification of the Thomas test has been investigated extensively throughout the literature and is the version commonly used in clinical practice.<sup>12,35,49,50</sup> The modified Thomas test is utilized to examine the length of one- joint and two- joint hip flexor musculature depending on whether the measurement is taken at the hip or the knee.<sup>35</sup> The iliopsoas, rectus femoris, and TFL are the three hip flexor muscles that can be assessed with the modified Thomas test.<sup>50</sup> However, there is a substantial lack of evidence supporting the theoretical assumption that this test can determine TFL/ITB length. The current

study determined the relationship between the Ober test and modified Thomas test in measuring ITB length.

Ferber et al<sup>12</sup> established normative and critical criteria for iliopsoas flexibility using the standard operating procedure for the modified Thomas test in which the subject is positioned with the hip joint over the edge of the table. During this test the subject flexes the hip, bringing the knee to the chest and holding it while the low back, sacrum, and pelvis remain horizontal and are stabilized by the examiner. Inability of the opposite thigh to extend to a neutral position or drop below the horizontal constitutes a positive test for decreased iliopsoas length.<sup>12</sup>

Sahrmann<sup>24</sup> describes using the modified Thomas test to assess the length of the iliopsoas as well as the TFL/ITB. Shortness of the ITB can be detected in the presence of a positive modified Thomas test in which there is increased hip extension range when the hip is placed in a position of abduction. This abducted position places the TFL/ITB on slack and presumably results in improved hip extension range of motion in the presence of a short TFL/ITB.<sup>24</sup> This provided the methods that were carried out in the current study to determine ITB length utilizing the modified Thomas test. Sahrmann also describes a positive modified Thomas test for shortness of the TFL/ITB when excessive external tibial torsion is observed during lowering of the limb into hip extension.

Based upon the current evidence, Harvey<sup>49</sup> was the only study that has attempted to quantify TFL/ITB length utilizing the modified Thomas test. However, his methods were different from those proposed by Sahrmann<sup>24</sup> and the procedure carried out in the current study. Harvey<sup>49</sup> measured the hip abduction angle relative to the femur and angle of the pelvis as opposed to a change score in hip extension angle. The results by Harvey<sup>49</sup> provided objective data for 117 elite athletes using a different procedure to determine ITB length than the one that

will be utilized in the current study. This dissertation study measured the angle of hip extension in two different hip positions; neutral position of hip adduction and then hip abduction to determine ITB length. Harvey<sup>49</sup> found an average of 15.6 degrees of hip abduction to be the resting position of the hip in the modified Thomas position in elite athletes. This result questioned the standardized description of the hip resting in neutral femoral abduction when performing the modified Thomas test. Of note, there were no differences in ITB muscle length found between sport, gender, or limb. Therefore, the author concluded sufficient flexibility is necessary to perform specific sports and any asymmetries that exist between limbs should be addressed.

Harvey's results may also be interpreted from an ITB length perspective, which could potentially be a limiting factor in obtaining neutral abduction of the femur during the modified Thomas test. Nevertheless, this study contained several limitations including poor description of subjects and procedures, lack of blinding, lack of pelvic stabilization, and extrapolation of joint angles in determining flexibility of soft tissues. In part because of the methodological flaws of the Harvey<sup>49</sup> study the investigator of the current study selected an alternative procedure to measure ITB length via hip extension angle in two different positions during the modified Thomas test that was utilized in this current study.

The hip extension angle is the most common measurement recorded within the literature when determining muscle length during the modified Thomas test. Clapis et al<sup>35</sup> examined interrater reliability of hip extension measures during the modified Thomas test in 42 healthy subjects (16 males, 26 females) with an average age of 22 years old. Comparison was made between two measurement instruments, the universal gravity inclinometer and standard goniometer. High interrater reliability (ICC= .91-.93) was determined for both instruments.

High intrarater parallel- forms reliability was also found between the instruments (ICC= .91-.93).<sup>35</sup> Therefore, it was concluded that the two instruments can be used interchangeably for measuring hip extension flexibility during the modified Thomas test. This is similar to the examination of the relationship during this dissertation in determining if the Ober test and modified Thomas test can be used interchangeably for measuring ITB length. Clapis et al<sup>35</sup> study's procedure differed from this dissertation study in that only one hip extension measurement was taken with the hip in neutral, thereby potentially assessing the length of all three two joint hip flexor muscles. This dissertation study measured hip extension angle in both a hip neutral position and hip abducted position in order to quantify TFL/ITB tightness during the modified Thomas test.

In a recent study, Kim and Ha<sup>50</sup> measured the knee flexion angle in 13 Korean subjects (10 males, 3 females) and found very high test- retest reliability (ICC= .97-.99) when utilizing lumbo- pelvic stabilization during the modified Thomas test. This study differed in procedure investigating reliability during three different conditions: the standard position, active lumbo-pelvic stabilization, and passive lumbo-pelvic stabilization. The measurement method was also different in that photographs were taken utilizing a digital camera and the angles were measured with motion analysis software.<sup>50</sup> Limitations of this study include measuring knee flexion angle as opposed to the hip, lack of specific details regarding the testing procedures, small sample size, and the use of young healthy subjects limiting generalizability. Lumbo-pelvic stabilization was not passively held or accomplished with a pressure biofeedback device but was monitored during the modified Thomas test procedures for this current study.

Prior to this study, reliability, normative values, and critical criteria have not been established for the modified Thomas test in investigating TFL/ITB length utilizing the specific

testing procedure as part of this study. Specifically, this study measured the angle of hip extension in both a hip neutral position and then again in a hip abducted position. However, normative values and critical criteria for iliopsoas flexibility have been established for the modified Thomas test utilizing a digital inclinometer.<sup>12</sup> Ferber et al<sup>12</sup> used the digital inclinometer as a new measurement technique to foster evidence- based determinations during the modified Thomas test just as he did with the previously described robust methods for ITB flexibility with the Ober test. This cross- sectional study included 300 recreational athletes (125 men, 175 women) who volunteered for participation for a total of 600 limbs analyzed. The recreational athlete definition was described as completing at least 30 minutes of activity, 3 times per week. Within those 300 participants, 50 participants were recruited who were uninjured in order to act as controls. Interrater reliability was examined by percentage of agreement for the subjective assessment of the modified Thomas test between two clinicians and found to be 95% agreement.

A separate examiner determined comparisons of continuous measurements with the dichotomous subjective assessment of iliopsoas length. Ferber et al<sup>12</sup> was unique in studying muscle length of the iliopsoas as it was the only one that used a large sample size, included healthy and injured participants, and examined interrater percentage of agreement. The average inclinometer angle for the modified Thomas test was 10.6 degrees of hip extension below the horizontal.<sup>12</sup> Limitations of this study included lack of reporting test-retest reliability, interrater reliability, and failing to adjust for chance agreement utilizing the newer digital inclinometer measurement device. The current study determined test-retest reliability of the digital inclinometer during the modified Thomas test including SEM and MDC.

## Patellofemoral Pain Syndrome and ITB Length

There is substantial evidence supporting the use of ITB stretching as a component of a comprehensive exercise programs the program for persons with PFPS. However, the contribution of stretching is not clearly defined within the literature. Furthermore, there are conflicting findings whether subjects with PFPS have decreased ITB length. A case control study by Piva et al<sup>33</sup> performed numerous muscle strength and soft tissue length clinical tests in order to determine whether differences exist between patients with PFPS and age- and gender-matched controls. The inclusion criteria for the PFPS group consisted of patients referred to physical therapy with a diagnosis of PFPS between the ages of 20 to 42 years old and provided the framework for the inclusion methods of this current study.<sup>33</sup> Other inclusion criteria included no history of trauma, duration of symptoms greater than 4 weeks due to insidious onset and pain with at least 3 of the following tests: Clarke's sign, palpation of posteromedial or posterolateral borders of the patella, resisted isometric quadriceps muscle contraction at 60 degrees of knee flexion, squatting, stair climbing, kneeling, or prolonged sitting.<sup>33</sup> Piva et al<sup>33</sup> determined thirty subjects with PFPS (17 males, 13 females) with an average age of 25.8 years did not demonstrate a correlation between ITB flexibility of the PFPS group and the control group, utilizing the Ober test.<sup>33</sup>

A limitation of this study included a difference in activity level between the two groups with the PFPS group being more active. However, the authors did not find a significant association between activity level and magnitude of flexibility and therefore decided not to control for this variable during their analysis.<sup>33</sup> Another limitation was a lack of examiner blinding to the subject's condition. This may have produced an unintentional bias during the ITB length measurement especially given that the same examiner who positioned the limb was



the same examiner who read the measurement from the inclinometer. The strengths of this study included a larger patient population (60 total subjects) than the work of Hudson and Darthuy<sup>14</sup> and the use of validated physical functional assessment measures.

In a more recent case control study, Hudson and Darthuy<sup>14</sup> used improved methodology from the Piva et al<sup>33</sup> study and found a relationship between ITB tightness measured by the Ober test and the presence of PFPS, which provided the theoretical framework for this current study.<sup>14</sup> The average age of the subjects in this study<sup>14</sup> was 30.6 and 32.9 for the control and PFPS group respectively, which was similar to the subject population utilized by Ferber et al<sup>12</sup> in determining normative criteria for the Ober and modified Thomas test with the digital inclinometer. The testing instrument used by Hudson and Darthuy<sup>14</sup> was a bubble inclinometer with extraneous pelvic motion controlled by the use of a spirit level that was attached to the subject's pelvis. The tester was not blinded to the group assignment but was blinded to the readings from the inclinometer at the time of testing as an independent examiner recorded the results. The mean hip adduction values in the left and right legs for the control group were 21.4 ( $\pm 4.9$ ) and 20.3 ( $\pm 3.8$ ) degrees respectively. The PFPS group was 17.3 ( $\pm 6.1$ ) and 14.9 ( $\pm 4.2$ ) in the non-painful leg and painful leg, respectively. The one-way ANOVA revealed significant difference between groups ( $p = .008$ ). Post hoc analysis revealed no significant difference between left and right legs in the control as well as no difference between painful and non-painful legs in the PFPS group. There was a significant difference between the painful leg in the PFPS group and the left and right legs in the control group ( $p = .002$  and  $.009$ ).<sup>14</sup> Limitations of this study include only performing one measurement on each of the limbs, not testing reliability, smaller sample size, lack of manual pelvic stabilization, utilizing a bubble inclinometer, and lack of blinding from group allocation.

Ferber et al<sup>12</sup> also obtained similar measures to Hudson and Darthuy<sup>14</sup> for hip adduction despite using the newer digital inclinometer as a measurement instrument. The average angle of hip adduction found by Ferber et al<sup>12</sup> was 24.6 degrees for all subjects with the use of the digital inclinometer.<sup>51</sup> The current study utilized the same digital inclinometer as the Ferber et al<sup>12</sup> study. Therefore, the current study used an instrument that found similar hip adduction measures to Hudson and Darthuy<sup>14</sup>, which was the only case control study that did find a difference in ITB length between controls and PFPS.

In contrast, Piva et al<sup>33</sup> utilized a slightly younger subject population with an average age of 25.7 and 25.8 for the control and PFPS group respectively. Piva et al<sup>33</sup> found different hip adduction measurements during the Ober test despite using the same bubble inclinometer as Hudson and Darthuy.<sup>14</sup> The mean and standard deviation of hip adduction angle for the control and PFPS group was 15.0 ( $\pm 5.6$ ) and 11.7 ( $\pm 10.2$ ), respectively.<sup>33</sup> The conflicting findings between Hudson and Darthuy<sup>14</sup> and Piva et al<sup>33</sup>, which are the only two studies that have compared ITB length in a PFPS population and a control group could be attributed to the differences in sample size (24 subjects compared to 60 subjects), mean age of subjects (32 years old compared to 25 years old), number of measurements taken during procedure (average of two measurements as opposed to one time measurement), and different levels of pelvic stabilization during the procedures. Other differences could be attributed to the lack of examiner blinding from inclinometer readings as well as group allocation creating examiner bias in the Piva et al<sup>33</sup> study. In addition, Hudson and Darthuy's<sup>14</sup> subjects were older and therefore may have had time to acquire tightness in the ITB as opposed to the younger patient population recruited by Piva et al.<sup>33</sup>

## Summary of What is Known and Unknown About PFPS and ITB Length

Anterior knee pain is the most common knee pain complaint encountered within everyday practice that is collectively diagnosed as PFPS.<sup>7</sup> This occurs as a result of maltracking and malalignment of the patella with an underlying etiology that is multifactorial in nature including local, proximal, and distal influences.<sup>5,17</sup> Additionally, altered kinematics and biomechanics have been detailed for the ITBS and PFPS populations, respectively.<sup>3,15</sup> Historically, tightness of the ITB has been theoretically identified as one of those local influences due to its intimate attachments to the lateral retinaculum. Recently, the literature has demonstrated altered patellar position and kinematics in the presence of ITB tightness.<sup>4,13,42</sup>

The Ober test is the primary clinical test utilized to indirectly measure ITB length with proven reliability and published normative values.<sup>12,20,41,43</sup> Variations exist during performance of the test specifically with regard to monitoring excessive pelvic motion. As noted previously, several authors have utilized a spirit level attached to the patient's pelvis to monitor for any extraneous motion.<sup>14,41</sup> More recently, a pressure biofeedback cuff has been used during the Ober test to allow for control of unwanted pelvic motion.<sup>13,42</sup> Other authors do not advocate introducing another source of measurement error due to the complexity of the procedure.<sup>20,22,33,43</sup>

The modified Thomas test has also been advocated to assess for ITB length, though there is significantly less research for this method compared with the Ober test.<sup>24</sup> The modified Thomas test has been determined to be reliable with published normative data for assessing iliopsoas length with hip extension measurements.<sup>12</sup> This test has yet to be studied specifically for ITB length measuring the hip extension angle in two different hip positions including, hip neutral and hip abduction. Within the literature, differences in measurement instruments exist

for both the Ober and modified Thomas test with improved precision advocated with the use of a digital inclinometer.<sup>12,13</sup>

There are conflicting case control studies that have investigated whether patients with PFPS have ITB tightness as measured by the Ober test. Differences in sample size, mean age of subjects, measurement procedure, and number of measurements taken during procedure could explain these differences in results. The concurrent validity of the modified Thomas test in determining if there is a relationship between ITB length and the presence of PFPS is not known. Furthermore, the Ober and modified Thomas test have not been studied for convergent validity in order to determine if these two tests correlate as an indirect measure of ITB length.

### **Contribution to the Field**

A recent systematic review identified a number of high quality randomized clinical trials that have demonstrated favorable outcomes for patients with PFPS undergoing a comprehensive interventional program including quadriceps strengthening and lower extremity flexibility that includes ITB stretching.<sup>7</sup> However, these interventions for PFPS only demonstrate short term outcomes with respect to pain and function with less compelling long term efficacy.<sup>5</sup> This is evidenced by the high reoccurrence rate of pain seen in retrospective studies.<sup>5,30</sup> A possible explanation for these poor long term outcomes could be the lack of focus on addressing the underlying contributing factors to PFPS. Research examining ITB length as a contributing factor measured by the Ober and modified Thomas test can assist in guiding future clinical decisions specifically for the PFPS population. The Ober test, an established reliable tool that indirectly measures ITB length, in conjunction with the newer modified Thomas test can provide a framework to improve efficacy of PFPS treatments. Therefore, using reliable tests to establish a

relationship between ITB length and PFPS could serve as an initial step in developing future interventional studies investigating ITB length and causation.

Clinicians are in need of clinical diagnostic tests that differentiate the potential pathological parameters associated with PFPS. Specifically, a system of relatively simple clinical tests for the classification of individuals with PFPS needs to be developed to facilitate targeted patient-specific treatment options. Understanding the relationship between the Ober and modified Thomas test will serve as an initial step in meeting this need. Powers et al<sup>5</sup> have recommended that future interventional studies allow for broad subgrouping of subjects. A flexibility group classification consisting of subjects with primary flexibility impairments will allow for a targeted intervention approach, resulting in improved power during future trials. Devising a targeted interventional program for this homogeneous subgroup of PFPS patients with primary flexibility impairment may directly impact outcomes. Conversely, a heterogeneous population of PFPS patients may likely continue to yield inadequate outcomes. Furthermore, the absence of classification may also serve as an explanation as to why previous interventional studies have lacked sustainable positive long term outcomes.<sup>8-10</sup>

## **Summary**

This chapter provides the historical overview of PFPS including the various etiological mechanisms including local, proximal, and distal influences. The theoretical model as well as the current literature to support decreased ITB length as a local influence on patellar maltracking and malalignment are described. The Ober test and modified Thomas test are two methods to assess ITB length with varying operational definitions throughout the literature. Reliability, validity, and normative criteria for both the Ober test and the modified Thomas test were described. The Ober test is the primary clinical test utilized to indirectly measure ITB length

with proven reliability and published normative values.<sup>12,20,41,43</sup> However, variations exist during performance of the test specifically with regard to monitoring excessive pelvic motion and the measurement instrument utilized. The modified Thomas test has also been advocated to assess for ITB length, however this test has yet to be studied specifically for ITB length measuring the hip extension angle in two different hip positions including, hip neutral and hip abduction.<sup>24</sup> The importance in determining the relationship between ITB length and PFPS and its contribution to the field of orthopedic physical therapy was also outlined.

## CHAPTER 3: METHODOLOGY

### Introduction

This chapter describes the specific methods implemented in determining the relationship between ITB length and PFPS. Specifically, the strategy utilized to achieve the primary and secondary objectives is delineated. A detailed description of subjects, examiners, and equipment is provided. Additionally, the specific procedures, reliability of the examiners, and data analysis is described.

### Subjects

A total of 48 individuals were recruited for the main dissertation study: 24 patients with knee pain referred for physical therapy with a diagnosis of PFPS and 24 age- and gender-matched control subjects that did not have PFPS. A sample of convenience was used to recruit the first 24 consecutive PFPS patients and 24 control subjects from three different outpatient physical therapy clinics in the state of Connecticut. A power analysis was performed to determine a sample of 48 subjects based upon previously published data.<sup>14</sup> Hudson et al<sup>14</sup> found a difference of 5 degrees (SD=4) in hip adduction between controls and PFPS on the Ober test. Assuming a similar size effect using a two-sided test with an alpha level of 0.05, it was calculated that a sample of 48 subjects (24 per group) would yield a power of 0.99 to detect a statistically significant difference. Additionally, Hudson et al<sup>14</sup> found a difference of 2.5 degrees between the symptomatic (pain) and asymptomatic (no pain) sides within the PFPS subjects. Assuming a similar size effect and a correlation of 0.7 between sides a sample of 24 PFPS subjects would have power slightly above 0.80 using a paired samples test.

Inclusion criteria for the PFPS subjects were male or female between 18-50 years of age with a diagnosis of knee pain, patellofemoral pain, or chondromalacia patella. All patients

reported an insidious onset of unilateral or bilateral knee pain greater than four weeks duration and were willing to participate in the research study. Subjects were also required to report pain with two or more of the following: stair climbing, squatting, kneeling, running, or sitting still for a minimum of 20 minutes.<sup>20</sup> Diagnostic inclusion criteria was defined by recent interventional PFPS randomized controlled trials.<sup>9,10,18,52</sup>

Additional inclusion criteria for PFPS subjects required at least one of the following positive tests on physical examination: full knee range of motion restricted by pain, pain on palpation of posteromedial or posterolateral patellar borders, positive Clarke's test, pain on isometric resisted knee extension at 60 degrees of flexion, or gluteus medius insufficiency performing a single leg squat.<sup>12,14,16</sup> Gluteus medius insufficiency was determined subjectively by assessing for internal rotation and adduction of the femur between 30 degrees and 60 degrees of knee flexion.<sup>14</sup>

Inclusion criteria for the control group consisted of patients referred for outpatient physical therapy with a diagnosis relating to pain in the neck or upper extremity region. Additional inclusion criteria for the control group required subjects to be age and gender matched to the PFPS group with age being matched within  $\pm 2$  years.<sup>33</sup>

Exclusion from participation in the study for both groups included any of the following: history of trauma, current lower back, hip or ankle pain, history of back, hip, or knee surgery within the past twelve months, history of patellar dislocation, infection of the knee, cancer, concomitant musculoskeletal or neurological impairment of the lower extremity that influenced gait requiring an assistive device, and if the subject was pregnant.<sup>12,14</sup> Subjects were also excluded in either group if they had less than 80 degrees of knee flexion while in the modified Thomas test position due to decreased rectus femoris length. Additional exclusion criteria for



subjects in the control group required those subjects did not have signs and symptoms of PFPS, including knee pain with all of the following: stair climbing, squatting, kneeling, running, or sitting still for a minimum of 20 minutes.

Subjects in both groups were tested for ITB length impairment utilizing the Ober and modified Thomas test in both lower extremities. The patient's self-reported most painful side was considered the involved side for the subjects with bilateral symptoms.<sup>33</sup> Thus, if a subject's most painful side was the right knee then the right knee of the age-matched control subject was used during data analysis. Leg dominance was utilized for demographic data and determined by which leg would be used to kick a ball per patient report.<sup>14</sup> All subjects who met inclusion/exclusion criteria and agreed to participate signed a consent form approved by Nova Southeastern University Institutional Review Board and Quinnipiac University Institutional Review Board (Appendix C).

### **Examiners**

This cross-sectional study was conducted at three outpatient orthopedic physical therapy and sports medicine clinics within the state of Connecticut. As the primary site examiners, three board certified clinical specialists in orthopedic physical therapy performed all measurement procedures. The primary site examiners had a mean of 17 years (range, 11-24 years) of clinical experience in the outpatient orthopedic physical therapy setting and were blinded to group allocation. Three other examiners who were licensed physical therapists performed the initial inclusion testing as the screening examiner. These examiners conducted a screening examination on familiar patients who were currently receiving physical therapy services under their care and who were not blinded to group allocation. The recording examiner was a physical

therapy aide whose role was to place the digital inclinometer on the limb and write the numerical value onto the data collection form. The recording examiner was blinded to group allocation.

All twelve examiners underwent training provided by the lead investigator (13 years clinical experience and an orthopedic clinical specialist) prior to beginning the study. The training session included instruction in the administrative aspects of the study (informed consent, subject recruitment, randomization, blinding, etc.) and specific training on the performance of the screening examination and measurement procedures as noted above. Hands-on practice and review of the Ober and modified Thomas Test was provided to the examiners by the primary researcher, who also provided the examiners with a manual of standard procedures (Appendix D) that included the operational definitions for the Ober and modified Thomas test. The purpose of the training was to ensure measurement procedures were performed in a standardized fashion across all 3 data- collection sites. The primary researcher conducted a hands-on skills post test with the examiners to determine examiner competency in the testing procedures.

### **Instrumentation/ Measures**

A digital inclinometer (Pro 360 digital protractor; SmartTool Technology, Inc. Okalahoma City, OK; accuracy =  $\pm 0.1$  degrees, maximum resolution = 0.1 degrees) was the measurement instrument used to indirectly measure ITB length (Figure 1). Specifically, the inclinometer measured hip adduction angle for the Ober test and hip extension angle for the modified Thomas test in order to improve accuracy and specificity of measurement. This instrument has been shown to be reliable and valid during the Ober and modified Thomas test in 300 recreational athletes.<sup>12</sup> There were three digital inclinometers used for the study, one for each site and each was calibrated against a known standard, ensuring that the angular measure

was the same for the 3 different devices. These devices were supplied by Quinnipiac University and were made available for use to the primary researcher for the three primary examiners.



**Figure 1: Digital Inclinometer**

Subjects in both groups completed a demographic and health history questionnaire, which included age, gender, height, weight, current duration and location of symptoms, mechanism of injury, prior episodes of knee pain, past medical history, past surgical history, and level of physical activity (Appendix E).<sup>33</sup> This information was used to assist in detecting differences between the controls and cases. The International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form was also completed by both groups to determine current level of physical activity of the sample (Appendix F). The questionnaire contains a self-report measure of physical activity level that has been shown to be reliable, valid, and responsive for a variety of knee pain patients including PFPS.<sup>53</sup> Normative data has been published for age and gender matched individuals.<sup>54</sup> The subjects rated their highest level of activity without significant knee pain on a 5-point Likert scale: (4) Very strenuous activities like jumping or pivoting as in basketball or soccer; (3) Strenuous activities like heavy physical work, skiing or tennis; (2) Moderate activities like moderate physical work, running or jogging; (1) Light activities like walking, housework or yard work; (0) Unable to perform any of the above

activities due to knee pain. This information was used to determine activity level between both groups in addition to quantifying the level of activity for subjects recruited within the sample.

Subjects in the PFPS group completed two additional questionnaires for the purpose of obtaining descriptive baseline pain and functional status data for this specific sample. This data was used to determine severity of PFPS condition and its impact on function. These self-report measures of pain and function took place prior to undergoing a physical screening examination to determine inclusion. The VAS is a self-report measure used to evaluate pain intensity along a horizontal line. A 100-mm VAS was used to measure the worst pain experienced in the previous week.<sup>55</sup> This established and reliable tool is widely used for assessing knee pain.<sup>9</sup> The Activity of Daily Living (ADLS) of the Knee Outcome Survey<sup>33</sup> was utilized as a knee specific measure (Appendix G). This survey measures 14 items that include a full spectrum of symptoms and functional limitations that one may experience with knee pathologies during activities of daily living. ADLS scores were then transformed to a 0 to 100 point scale with 100 indicating the absence of symptoms and functional limitations. Psychometric testing of the ADLS has been demonstrated to be reliable, valid, and responsive in subjects with PFPS.<sup>56</sup>

## **Procedures**

Data for each subject was collected at one of three outpatient physical therapy clinics. Each center had three examiners who completed the procedure; screening examiner, primary examiner, and recording examiner. The screening examiner was a physical therapist who communicated with all potential participants and was not blinded to group assignment. They obtained informed consent and performed the screening examination, which included collection of questionnaire data as well as conducting the physical examination to determine inclusion for the PFPS group. The screening examiner also recruited and screened potential subjects to

determine inclusion for the age matched control group. They then scheduled the measurement session with the primary examiner and instructed the subject to wear shorts. The screening examiner also communicated the order of testing based on randomization procedure. This scheduled measurement session occurred within the subjects' first three treatment sessions. Randomization on testing order (Ober or modified Thomas test) and leg tested (right or left) was performed using the random number generator in Microsoft Excel.

The physical examination was conducted on both groups (48 subjects) by the screening examiner and consisted of five tests (Appendix H). These tests were conducted on subjects familiar to the screening examiner as those subjects would currently be receiving physical therapy services under their care. Knee flexion and extension range of motion was assessed with the subject lying supine. The examiner passively flexed and extended the knee with pain and limited knee range of motion being recorded as a positive test. Limited knee range of motion was determined by any deviation from the normal 0 degrees to 135 degrees. Next, the examiner palpated the posteromedial and posterolateral borders of the patella with the subject lying supine with the quadriceps relaxed.<sup>57</sup> Any report of pain during palpation was recorded as a positive test.

The third test was the Clarke test and was performed with the subject lying supine with the affected limb supported on a towel roll in slight flexion.<sup>58</sup> While the subject was relaxed, the examiner placed his hand on the superior border of the patella and pressed the patella distally and then asked the subject to contract their quadriceps muscle.<sup>58</sup> A positive test was considered if the subject's pain was reproduced. Next, the subject was positioned in short sitting over the edge of a table. The examiner resisted isometric knee extension with the knee flexed to 60 degrees. The examiner applied the resistance to the distal tibia after giving the command to "hold strong and

don't let me push your leg down". A positive test was recorded if it reproduced the subject's familiar pain. Lastly, the subject stood up and performed a single leg squat.<sup>12,14,16</sup> A positive test during the squat for gluteus medius insufficiency was determined subjectively by observing for internal rotation and adduction of the femur between 30 degrees and 60 degrees of knee flexion.<sup>14</sup>

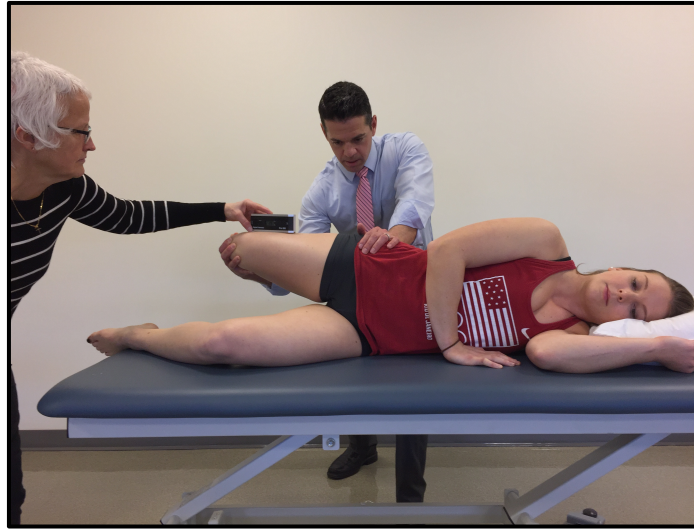
The screening examiner notified the primary examiner to perform either the Ober or modified Thomas test as well as left or right limb based on randomization. This was written on the measurement data collection form (Appendix I). The primary examiner and the recording examiner were both blinded to group assignment and conducted all measurement procedures. The primary examiner was also blinded to the inclinometer readings at the time of testing.<sup>14</sup> The primary examiner positioned the limb in the test position and then communicated to the recording examiner when to place the digital inclinometer on the limb. The recording examiner then read and recorded the number without sharing information findings with the primary examiner.

The recording examiner was a physical therapy aide who was trained by the primary researcher in reading the number from the digital inclinometer and recording it on the measurement data collection form. The primary examiner made the decision of when to place the digital inclinometer on the limb and obtain the reading. The average of two trials was taken with a 5-second rest interval in between trials recorded.<sup>20,43</sup> A reliability procedure was carried out for the first eight subjects of either the PFPS group or control group that were measured by each of the three primary examiners from each site. Following the initial measurement session, subjects rested in a sitting position for 5 minutes and then the same measurement procedure was repeated in order to determine test-retest reliability.

## Ober Test

The Ober test and side to be tested was performed based upon random order with the subject positioned in sidelying with the primary examiner standing posteriorly (Figure 2). The lower leg was flexed to 45 degrees at the hip and knee to maintain stability and to restrain body rotation.<sup>14,20</sup> The primary examiner used their distal hand to cradle the test limb supporting just above the knee with the knee flexed to 90 degrees. The proximal hand was positioned on the subject's posterior pelvis, which served to block extraneous posterior movement of the pelvis.<sup>33</sup> The examiner lifted the test limb into slight hip flexion, abduction and then extension in order to pass the ITB over the greater trochanter.<sup>36</sup> This was performed while maintaining pelvic stabilization with the examiner's proximal hand and 90 degrees of knee flexion guided by the examiner's distal hand. Next, the examiner allowed the limb to drop toward the table into hip adduction, attempting to control for any unwanted hip rotation. The position of measurement was determined by the point at which the limb stopped moving toward the table.<sup>13,36</sup>

The recording examiner placed the digital inclinometer at the midpoint between the anterior-superior iliac spine and the patella on the lateral aspect of the thigh.<sup>12,22</sup> The recording examiner read the angle of hip adduction with the digital readout facing away from the primary examiner and then recorded the measurement as a continuous variable to the nearest .1 degree on the data collection form.<sup>12</sup> If the limb was horizontal, it was considered to be at zero degrees; if it was below horizontal (adducted), the angle was recorded as a positive number; and if it is above horizontal (abducted), the angle was recorded as a negative number.<sup>13</sup> The greater angle of maximum adduction indicated longer ITB length.<sup>13</sup> Whereas the smaller angle indicated decreased ITB length. Each measure was repeated two times with a 5-second pause between each measurement with the procedure repeated on the opposite limb.



**Figure 2: Ober Test**

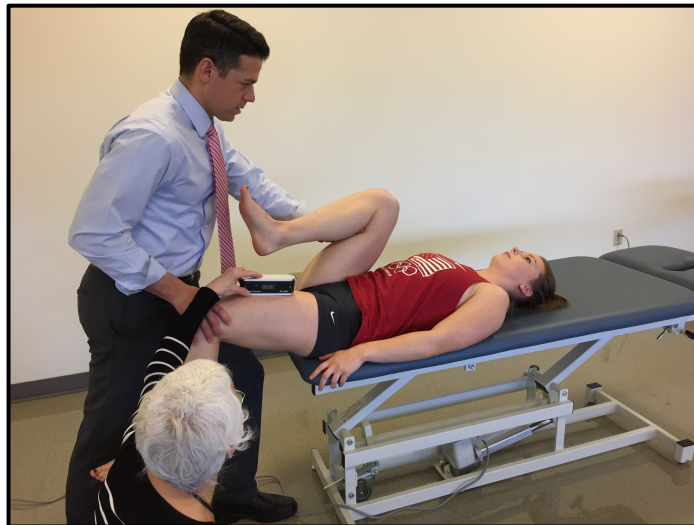
### **Modified Thomas Test**

The modified Thomas test and side to be tested was performed, based upon random order, with the subject sitting at the edge of the examination table (Figure 3). The primary examiner assisted the subject in slowly rolling backward onto the table as the subject grasped beneath both thighs until a supine position was achieved with both knees pulled toward the subject's chest.<sup>35</sup> The primary examiner assisted in flexing the subject's opposite hip by bringing the knee further toward their chest until full motion was obtained to ensure the lumbar spine was in contact with the table. Next, the primary examiner slowly lowered the testing limb into hip extension maintaining a hip neutral position preventing abduction of the thigh.<sup>35</sup>

The final test position was reached when full hip extension range of motion was obtained while maintaining the low back, sacrum, and pelvis in contact with the table. The primary examiner instructed the recording examiner to place the digital inclinometer on the thigh with the digital readout facing away from the primary examiner.<sup>12</sup> The recording examiner placed the digital inclinometer at the midpoint between the anterior-superior iliac spine and the patella on



the anterior aspect of the thigh. The recording examiner read the inclinometer and recorded the hip extension measurement as a continuous variable to the nearest .1 degree on the data collection form. Next, the primary examiner positioned the limb into full hip abduction and the recording examiner read and recorded the hip extension angle as a continuous variable once again. During both measurement positions; if the limb was horizontal, it was considered to be at zero degrees; if it was below horizontal (extended), the angle was recorded as a positive number; and if it was above horizontal (flexed), the angle was recorded as a negative number. The differences between the two hip extension measures (hip neutral and hip abducted) were used to determine ITB length as a continuous variable during analysis. Decreased ITB length was present when the second measurement of hip extension was greater than the first measurement as a result of placing the ITB in a slackened position.<sup>12</sup> Each measurement was repeated two times with a 5-second pause between each measurement with the procedure repeated on the opposite limb.



**Figure 3: Modified Thomas Test**

## Reliability of the Examiners

Reliability analysis of the three primary site examiners performing the methods was conducted through a pilot study at Quinnipiac University in North Haven Connecticut. This was necessary to determine the interrater reliability of the 3 primary examiners, measurement procedure, and instrumentation given the multicenter design. Convenience sampling of 17 (14 female, 3 male) healthy graduate physical therapy students with a mean age of 23 years were recruited for the pilot study (Appendix A). Following signed written informed consent (Appendix B), two trials of the Ober test and modified Thomas test were performed on both legs of each subject by all 3 examiners (Table 1). Interrater reliability, using average measures and model ICC (2,k), demonstrated good reliability ( $> .75$ ) on the left side for both the Ober and Thomas test and moderate reliability (.50- .74) on the right side for both the Ober and modified Thomas tests.<sup>59</sup> The SEM and MDC for interrater reliability were analyzed following the pilot measurement study and can be viewed in Table 1.

**Table 1: Interrater reliability of the Ober and Modified Thomas Test**

Test		Mean (degrees)	SD (degrees)	Interrater (ICC)	95% CI		SEM (degrees)	MDC <sub>90</sub> (degrees)
					Lower	Upper		
Ober Test	Right	8.50	5.92	.62	.15	.85	3.65	5.16
	Left	7.65	5.54	.77	.48	.91	2.66	3.76
Thomas Test	Right	3.27	3.45	.72	.37	.89	1.83	2.58
	Left	2.87	3.33	.76	.46	.91	1.63	2.31

*Abbreviations: SD, standard deviation; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; MDC<sub>90</sub>, minimal detectable change at the 90% level of confidence*

## Data Analysis

An analyst blinded to the data collection process performed the analysis. Descriptive statistics were used to summarize baseline demographic data. Measures of central tendency and dispersion were used for continuous variables such as age, height, weight, body mass index

(BMI), VAS knee pain rating, pain duration, and ADLS score. Frequency counts and percentages were used for categorical variables such as gender, leg dominance, prior episodes of knee pain, side of pain, and current activity level. Baseline demographics were compared between the PFPS group and the control group using an independent *t*-test for all continuous data, and chi-square test for all categorical data. The Kolmogorov-Smirnov test was applied to all data sets to test for normality of distribution. A one-way ANOVA was used for the primary aim of the study in determining the relationship between ITB length and the presence of PFPS. Means and standard deviations were calculated for each group and the painful or most painful knee in the PFPS subject was compared to the same knee in the matched control participant. For the PFPS group, the painful knee was also compared to the non-painful knee for the 18 subjects with unilateral PFPS for both the Ober and modified Thomas test. Differences were considered significant at  $p < .05$ .

Test-retest reliability, standard error of measurement (SEM), and minimum detectable change (MDC) was calculated for both the Ober test and modified Thomas test. In order to determine the test-retest reliability, Intraclass correlation coefficient ICC (2,k) was utilized to calculate test-retest reliability of the first 8 subjects collected by each of the three examiners. ICC (2,k) was also used on the data collected during the pilot measurement study on 17 physical therapy students. This was used to establish interrater reliability by taking the averaged measurements of the 2 trials that each of the three raters measured on each side (left and right) for each subject. ICC values of .75 and above represent good reliability, those between .50 and .74 represent moderate reliability, and those below .50 indicate poor reliability.<sup>59</sup> Portney and Watkins<sup>59</sup> suggest ICC values should exceed .90 for clinical tests such as the Ober and modified Thomas tests in order to ensure reasonable validity.<sup>59</sup> SEM is a distribution- based method

reflecting the extent of expected error in the three examiner scores and was used to calculate responsiveness and clinical significance of the results. SEM is also used to determine if a patient's performance has truly changed from trial to trial. The formula that was utilized to calculate this was  $SEM = SD \times (\sqrt{1 - ICC})$ . SEM data was calculated separately for each leg based upon reliability analysis performed for each individual leg. This was essential for the PFPS group since the majority of subjects had pain only on one side. The MDC was used to calculate the smallest change representative of true change and not measurement error alone with the following formula:  $MDC_{90} = 1.65 \times SEM \times \sqrt{2}$ .<sup>59</sup>

Pearson correlations were also used to examine the relationship between the Ober and modified Thomas tests in measuring ITB length in determining convergent validity. The correlation coefficient (r) statistic was used to quantify the relationship between the Ober test and the modified Thomas test scores for the right knee and for the left knee separately. To compare differences between groups throughout the study a  $p < .05$  level of significance was used. All statistical analysis was performed using SPSS for Windows, Version 19 software (SPSS Inc, Chicago, IL).

## Summary

A specific description of the methods that were implemented to determine the relationship between ITB length and PFPS has been presented. Specifically, a strategy to achieve the primary and secondary objectives of this study has been delineated. The subjects, examiners, and equipment were described for this multicenter study. Additionally, the specific procedures to be employed, data analysis, and resources required were presented.

## CHAPTER 4: RESULTS

### Introduction

This chapter includes the sample demographics, data analysis, research findings, and summary of results. Descriptive tables and figures will be used to complement the data analysis and research findings. The data analysis and research findings will be presented together for each of the three specific research questions. These results will be used to meet the primary and secondary objectives of this dissertation.

### Sample Demographics

The sample was comprised of patients from three different outpatient physical therapy clinics in the state of Connecticut that were recruited from March 2016 to September 2016. The PFPS group consisted of 24 patients with anterior knee pain who satisfied the inclusion criteria and the control group included 24 patients with neck pain or upper extremity pain. All subjects from both groups were physician referred from diverse physician specialties, including primary care, orthopedists, and physiatrists. Baseline demographic and clinical characteristics of the PFPS and the matched control groups are reported in Table 2. Both groups contained 17 female and 7 male participants with an age range between 18 and 50 years. Independent samples t-tests showed no significant differences ( $p > .05$ ) in age, height, weight, or body mass index (BMI) between the two groups. The two groups had a BMI considered to be borderline between normal and overweight. A chi-square analysis showed no significant differences in leg dominance between both groups. However, a chi-square analysis demonstrated the two groups were significantly different ( $p < .05$ ) in their level of physical activity in which the control group performed higher levels of physical activity than the PFPS group. In the PFPS group, 41.7% of

subjects reported prior episodes of knee pain. The majority of subjects had experienced symptoms less than 5 months (minimum 1 month, maximum 18 months). All data sets obtained for hip adduction and hip extension angles indicated no serious violation of normality according to the Kolmogorov-Smirnov test, therefore parametric analysis was conducted.

**Table 2: Demographic characteristics of the sample**

Subject Description	PFPS (n = 24)	Control (n = 24)	P Value
Gender			
Female	17 (70.8%)	17 (70.8%)	1.00 <sup>‡</sup>
Male	7 (29.2%)	7 (29.2%)	
Age (years)*	33.3 ± 11.8	33.6 ± 11.9	.933 <sup>†</sup>
Height (cm)*	170.4 ± 11.7	166.3 ± 8.8	.174 <sup>†</sup>
Weight (kg)*	74.5 ± 18.3	67.7 ± 13.5	.148 <sup>†</sup>
BMI (kg/cm <sup>2</sup> )*	25.8 ± 7.2	24.4 ± 4.1	.405 <sup>†</sup>
Leg Dominance			
Right Side	23 (95.8%)	22 (91.7%)	.551 <sup>‡</sup>
Left Side	1 (4.2%)	2 (8.3%)	
Current Activity Level			
Jumping, pivoting, basketball, soccer	0 (0.0%)	20 (83.3%)	<b>&lt;.001<sup>‡</sup></b>
Heavy physical work, skiing, tennis	3 (12.5%)	0 (0.0%)	
Moderate physical work, jogging	8 (33.3%)	4 (16.7%)	
Light activities, walking, housework	10 (41.7%)	0 (0.0%)	
Unable to perform any activities above	3 (12.5%)	0 (0.0%)	
Prior Episodes			
Yes	10 (41.7%)	N/A	...
No	14 (58.3%)	N/A	
Painful Knee <sup>§</sup>			
Right	11 (45.8%)	N/A	...
Left	13 (54.2%)	N/A	...
VAS Knee Pain Rating (cm)*	4.1 ± 2.5	N/A	...
Pain Duration (mo)*	4.3 ± 4.0	N/A	...
ADLS** Score*	72.3 ± 14.7	N/A	...
<p><i>Abbreviations: PFPS, Patellofemoral Pain Syndrome; BMI, Body Mass Index; VAS, Visual Analog Scale; ADLS, Activities of Daily Living Scale.</i></p> <p><i>* Data are mean ± SD.</i></p> <p><i><sup>†</sup>Independent-samples t-tests.</i></p> <p><i><sup>‡</sup>Chi-square analysis.</i></p> <p><i><sup>§</sup> Most painful knee for bilateral cases (n = 6).</i></p> <p><i>** ADLS ranges from 0-100% with 100% indicating absence of symptoms and functional limitations.</i></p>			

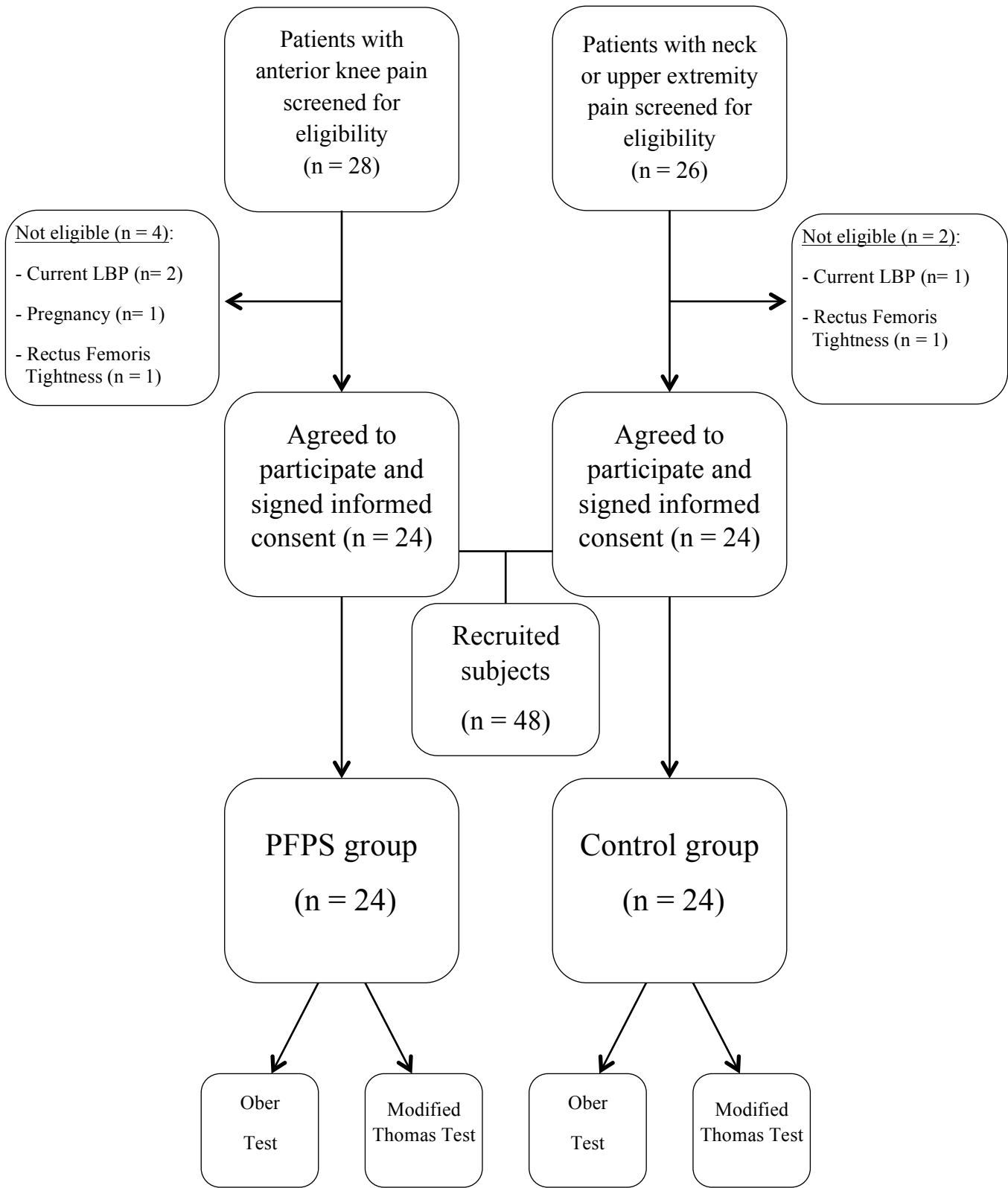


Figure 4: Flow Diagram of Subject Recruitment

### Relationship between ITB length and the presence of PFPS (R1)

A one-way ANOVA was conducted to determine the relationship between ITB length as measured by the Ober and modified Thomas tests and the presence of PFPS. The means and standard deviations of the ITB length data for the Ober and modified Thomas test for the two groups are reported in Table 3.

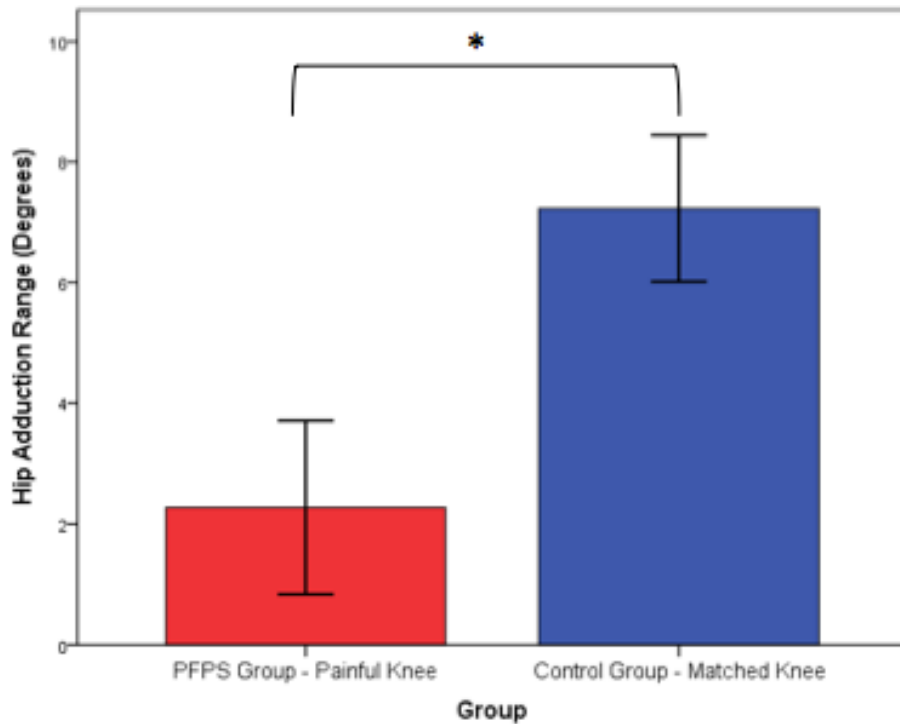
**Table 3: Iliotibial band length measurements of painful or most painful knee in 24 subjects with PFPS and same knee in 24 matched control subjects.**

Test	PFPS Group*	Control Group*	P Value <sup>†</sup>
Ober Test (degrees)	2.3 ± 7.0	7.2 ± 5.9	.011
Modified Thomas Test (degrees)	3.2 ± 3.9	1.3 ± 2.8	.055

*Abbreviations: PFPS, Patellofemoral Pain Syndrome*  
*\* Data are mean ± SD.*  
*† One-way ANOVA.*

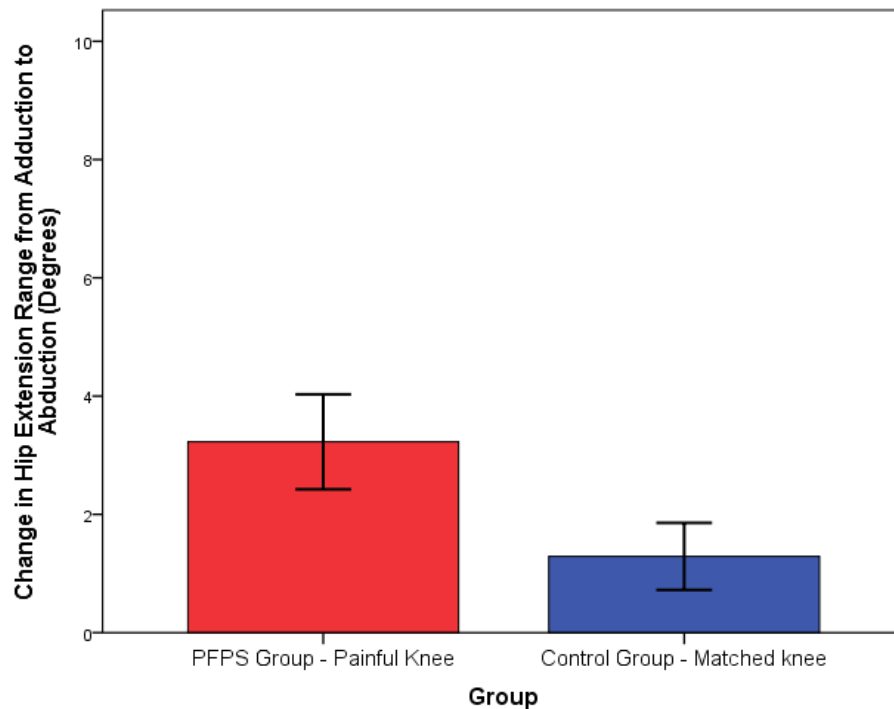
The painful or most painful knee in the PFPS subject was compared to the same knee in the matched control subject, using both the Ober and the modified Thomas test. For the Ober test, the mean value of hip adduction was 2.3 degrees ( $\pm 7.0$ ) for the PFPS group's painful knee or most painful knee and 7.2 degrees ( $\pm 5.9$ ) for the control group's same knee. The one-way ANOVA revealed a difference in mean hip adduction that was significant ( $p < .05$ ) as shown in Figure 5.





**Figure 5: Mean values of hip adduction range as measured by the Ober test for both groups. Error bars represent 1 standard error. ( $P < .05$ )**

The mean value of change in hip extension range from a position of hip adduction to hip abduction using the modified Thomas test was 3.2 degrees ( $\pm 3.9$ ) for the PFPS group's painful knee or most painful knee and 1.3 ( $\pm 2.8$ ) for the control group's same knee. The PFPS group had a greater degree of change during the modified Thomas test score that approached significance as compared to the control group ( $p > .05$ ) as represented in Figure 6.



**Figure 6: Mean values of change in hip extension range from adduction to abduction as measured by the modified Thomas test for both groups. Error bars represent 1 standard error. ( $P > .05$ )**

### **ITB length between the painful knee and the non-painful knee (R2)**

A comparison of ITB length was conducted between the painful knee and the non-painful knee for 18 subjects with unilateral PFPS for both the Ober and modified Thomas test using dependent *t*-tests. The mean difference and significance of the difference in ITB length measured between each knee for the Ober and modified Thomas test can be seen in Table 4.

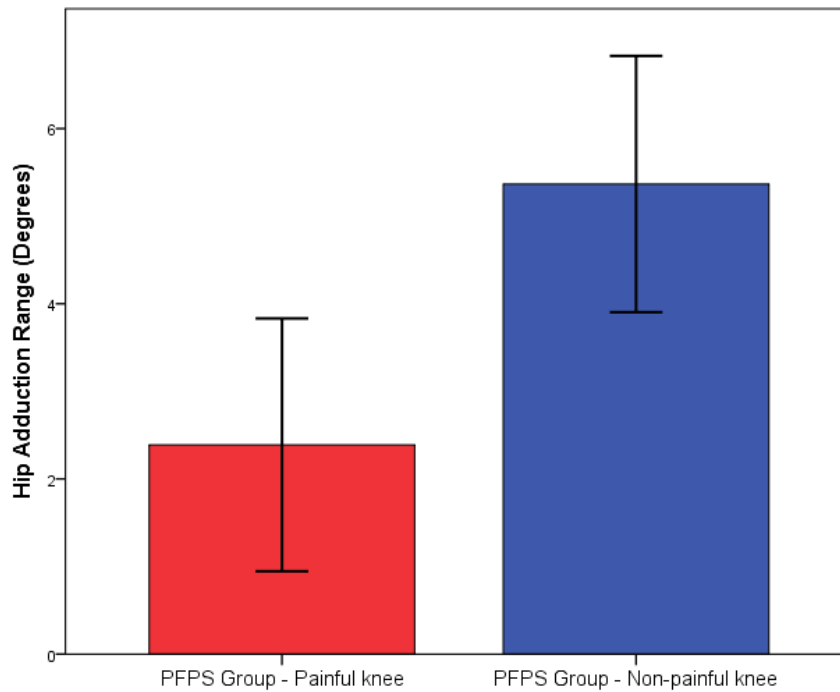
**Table 4: Paired Samples Test. Iliotibial band length measurements for the Ober and modified Thomas test in 18 subjects with unilateral PFPS**

Pair		Mean ITB Length (degrees)	Mean Difference (degrees)	SD	95% CI of the Difference		t	P
					Lower	Upper		
Pair 1: Ober Test	Painful knee	2.4	-3.0	7.1	-6.5	.6	-1.8	.094
	Non-painful knee	5.4						
Pair 2: Thomas Test	Painful knee	3.0	.02	3.3	-1.6	1.7	.02	.978
	Non-painful knee	3.0						

*Abbreviations: PFPS, Patellofemoral Pain Syndrome; ITB, Iliotibial Band; SD, Standard Deviation; CI, Confidence Interval.*

**Pair 1: Ober Test**

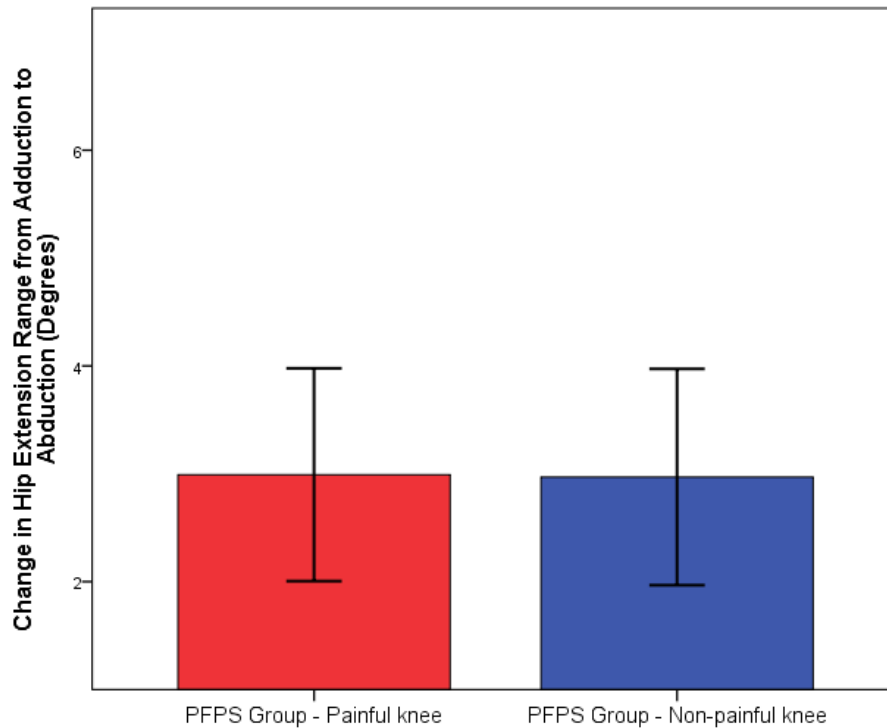
Pair 1 represents the comparison between the mean degrees of hip adduction for the Ober test performed on the painful and non-painful knees of subjects with PFPS. The Ober test ITB length was less in the painful knee compared to the non-painful knee and is represented in Figure 7. There was no significant difference between the two knees.



**Figure 7: Mean values of hip adduction range as measured by the Ober test for the PFPS group. Error bars represent 1 standard error (P>.05)**

## Pair 2: Modified Thomas Test

Pair 2 represents the comparison between the mean degrees of hip extension for the modified Thomas test on the painful and non-painful knees seen in Figure 8. The modified Thomas tests' ITB length was the same in comparing the painful knee to the non-painful knee. There was no significant difference between the two knees.



**Figure 8: Mean values of change in hip extension range from adduction to abduction as measured by the modified Thomas test for the PFPS group. Error bar represent 1 standard error.**

## Test-retest reliability of the Ober test and Modified Thomas test (R3)

Test-retest reliability was conducted on a sample of 24 subjects comprised of 11 PFPS subjects and 13 control subjects. The demographic characteristics of this sample were similar to the full sample of 48 subjects used in the current study. Test-retest reliability was performed

with a repeat measurement of both the Ober test and Modified Thomas test taken after subjects rested in a sitting position for 5 minutes following initial data collection. Each examiner performed these repeated measures for the first 8 subjects from either the PFPS group or control group (Table 5). Test-retest reliability, using average measures and model ICC (2,k), was excellent during the Ober test and modified Thomas test. The SEM and MDC for test-retest reliability were analyzed as well and can be viewed in Table 5.

**Table 5: Test-retest reliability of Ober test and modified Thomas test.**

Test		Mean (SD)	Mean (SD)	(ICC)	95% CI		SEM (degrees)	MDC <sub>90</sub> (degrees)
		Measurement 1	Measurement 2		Lower	Upper		
Ober Test	Right	6.05 (5.33)	6.39 (5.79)	.94	.87	.98	1.35	1.91
	Left	4.19 (6.31)	4.03 (5.85)	.95	.89	.98	1.35	1.91
Thomas Test	Right	2.11 (2.54)	1.93 (2.93)	.92	.81	.96	0.77	1.09
	Left	2.06 (2.96)	1.57 (3.18)	.81	.56	.92	1.33	1.89

*Abbreviations: SD, standard deviation; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; MDC<sub>90</sub>, minimal detectable change at the 90% level of confidence*

#### **Relationship between the Ober test and Modified Thomas test (R4)**

A correlational analysis was conducted to determine the relationship between the Ober test and the modified Thomas test scores for each knee. The results are shown in a scatterplot (Figure 9 and Figure 10) in which each dot represents each subjects' degree of motion during the Ober test and modified Thomas test. Figure 9 depicts the left knee measurements and illustrates the correlation between the Ober test and the modified Thomas test ( $r = -.40$ ,  $p = .005$ ). The right knee measurements are depicted in Figure 10 and reveals the Ober test did not show significant correlation with the modified Thomas test ( $r = .07$ ,  $p = .638$ ).

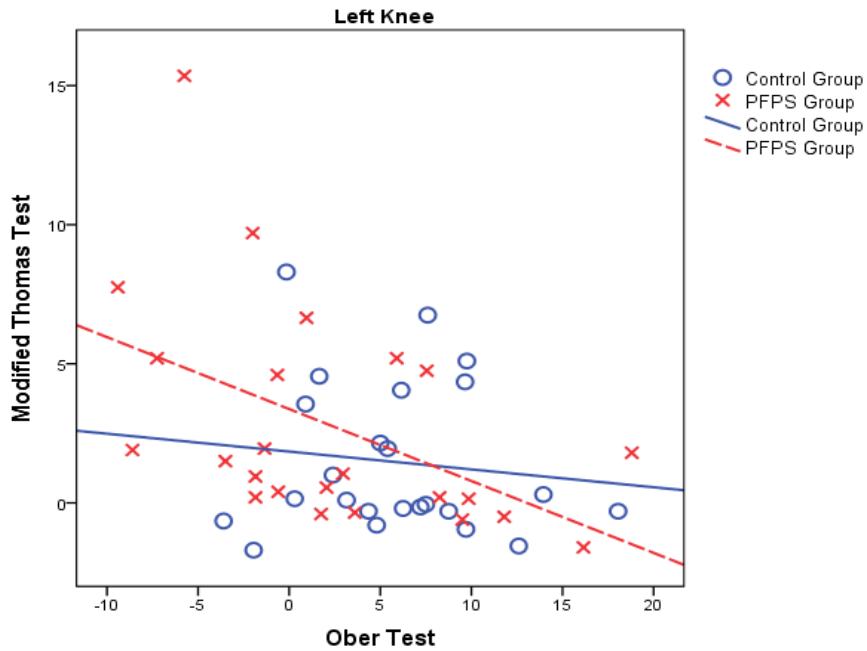


Figure 9: Pearson's Correlation. Correlation between the Ober test and modified Thomas test of the left knee.

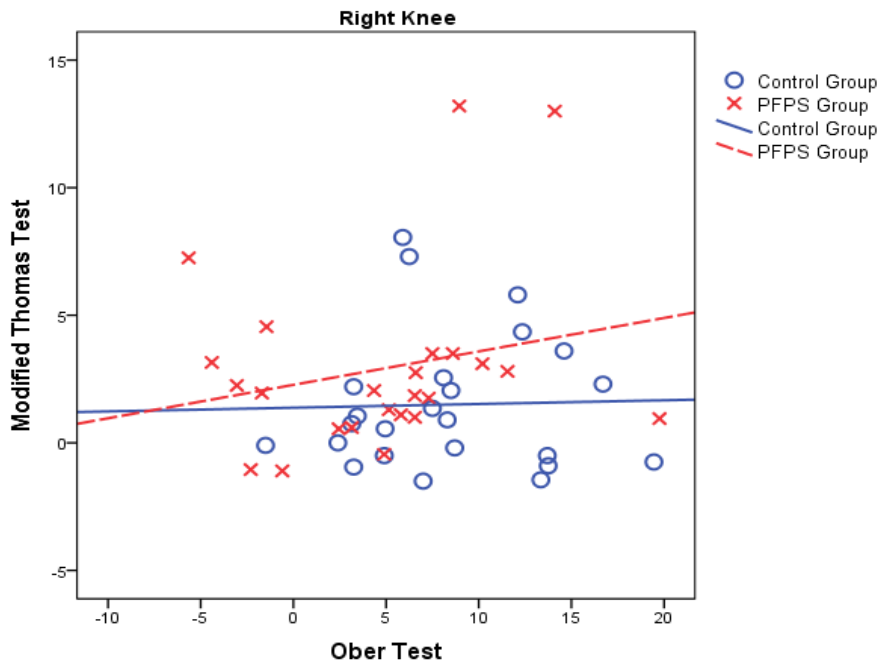


Figure 10: Pearson's Correlation. Correlation between the Ober test and modified Thomas test of the right knee.

## Summary of Results

The sample (n=48) was comprised of patients from three different outpatient physical therapy clinics in the state of Connecticut. Twenty-four patients with PFPS and 24 patients with neck pain or upper extremity pain acting as controls participated in the study. The groups were matched for age and gender and did not differ in height, weight, BMI, or leg dominance. The groups differed in current activity level with the PFPS group being less active. The PFPS subjects on average reported knee pain lasting 4 months, moderate pain levels, and a 30% limitation in functional activities.

Results showed significance for the PFPS group having decreased ITB length compared to the control group as measured by the Ober test. The mean value for hip adduction was 7.2 degrees in the control group and 2.3 degrees in the PFPS group. Results of the modified Thomas test also demonstrated decreased ITB length in the PFPS group as compared to the control group, although that change was not significant. The mean value for change in hip extension was 1.3 degrees in the control group and 3.2 degrees in the PFPS group. The Ober test for the PFPS group demonstrated decreased ITB length in comparing the painful knee to the non-painful knee, whereas the Thomas tests' ITB length was the same in comparing the painful knee to the non-painful knee. The differences in ITB length detected between the painful knee and the non-painful knee with the Ober test were not statistically significant.

Both the Ober and Thomas test demonstrated excellent test-retest reliability using all three examiners and the SEM and MDC were reported for each test. A weak negative correlation was found between the Ober test and modified Thomas test for the left knee. No correlation was found between the Ober test and modified Thomas test for the right knee.

## CHAPTER 5: DISCUSSION

### Introduction

This chapter includes the interpretation, examination, and qualification of the study results. The strengths and weaknesses of the study will be delineated. Inferences will be drawn when discussing the implications of the research findings to the physical therapy community. Recommendations for further research, limitations, and delimitations that may have affected the study will also be detailed. Lastly, a summary of the dissertation will be presented. Discussion of findings will be presented for each of the four research questions.

### Relationship between ITB length and the presence of PFPS (R1)

The primary purpose of this study was to determine the relationship between ITB length and the presence of PFPS. The results of the research demonstrated decreased ITB length in the PFPS group compared to the control group, with a significant difference found when utilizing the Ober test. Significant difference between the PFPS and the control group was not found when utilizing the modified Thomas test. This finding is in agreement with the work of Hudson and Darthuy<sup>14</sup>, which was the only other study that found decreased ITB length in individuals with PFPS compared to aged matched controls utilizing the Ober test. However, limitations in Hudson and Darthuy<sup>14</sup>, such as a small sample size of 24 and only one examiner performing the measurements who was not blinded to group allocation may have introduced examiner bias. The Hudson and Darthuy<sup>14</sup> study also used a bubble inclinometer as the measurement instrument, did not test reliability of that instrument, took one measurement trial as compared to the current study, where three-experienced board certified orthopedic clinical specialists were blinded to group allocation and blinded to readings of the digital inclinometer at the time of testing served as primary examiners. The recording examiner was also blinded to group allocation at the time



of testing. Thus, the current study was able to replicate the findings of decreased ITB length in a PFPS group compared to a control group utilizing the Ober test of Hudson and Darthuy<sup>14</sup> with the use of a digital inclinometer, double the sample size, and improved methodology.

The decreased ITB length findings during the Ober test between groups are in contrast to the work of Piva et al<sup>33</sup> who found no significant differences between a PFPS and control group utilizing the Ober test. Disparity in testing protocols and subject demographics could explain the differences between studies. In the study by Piva et al<sup>33</sup>, the examiners were not blinded to the subject's condition. This may have produced an unintentional bias during the ITB length measurement given that the examiner who positioned the limb was the examiner that read the measurement from the inclinometer. Therefore, lack of blinding to group allocation and lack of blinding from readings of inclinometer were methodological flaws threatening validity. In addition, Piva et al<sup>33</sup> recruited a younger sample with a mean age of 25 years old. This is in contrast to the mean age of 33 years old recruited in the present study and the mean age of 32 years old studied by Hudson and Darthuy.<sup>14</sup> Therefore, age may have been a confounding factor as the subjects in the present study as well as Hudson and Darthuy's<sup>14</sup> may have had time to acquire changes in ITB length as opposed to the younger patient population recruited by Piva et al.<sup>33</sup>

Significant variability was found in hip adduction mean values measured during the Ober test in this study as compared with previous literature (Table 6). Ferber et al<sup>12</sup> obtained normative values of hip adduction with the Ober test utilizing the same digital inclinometer and the same subject demographic (32 years of age) as used in this study as well as that use by Hudson and Darthuy<sup>14</sup>. The study of Ferber et al reported a mean value of hip adduction of 24.6 ( $\pm 7.3$ ) degrees on 300 recreational athletes, which was similar to the results of Hudson and

Darthuy of 20.9 ( $\pm 4.3$ ) degrees for controls and 16.1 ( $\pm 5.2$ ) degrees for PFPS subjects.<sup>12</sup> More recently, Noehren et al<sup>22</sup> published mean values of hip adduction for the Ober test of 8.8 ( $\pm 4.0$ ) degrees for controls and 17.6 ( $\pm 4.7$ ) for ITBS subjects. The significant difference between this study and the previous studies is the position of the knee during testing. Noehren et al<sup>22</sup> performed the Ober test with the knee only slightly flexed (10-15 degrees), which would be considered the modified Ober test.<sup>43</sup> Previous research has demonstrated significantly greater hip adduction values with the modified Ober test compared to the Ober test and concluded these tests should not be used interchangeably.<sup>43</sup>

**Table 6: Ober test mean hip adduction values (degrees)**

Study	Control Group Means (SD)	PFPS Group Means (SD)
Current Study	7.2 (5.9)	2.3 (7.0)
Hudson and Darthuy <sup>14</sup>	20.9 (4.3)	14.9 (4.2)
Piva et al <sup>33</sup>	15.0 (5.6)	11.7 (10.2)
Noehren et al <sup>15</sup>	18.8 (4.0)	17.6 (4.7) <i>ITBS group</i>
Kang et al <sup>13</sup>	27.6 (4.0)	4.0 (3.4)
Park et al <sup>23</sup>	14.0 (7.9)	N/A
Ferber et al <sup>12</sup>	24.6 (7.2)	N/A
Reese & Bandy <sup>43</sup>	18.9	N/A

Piva et al<sup>33</sup> also found greater mean values of hip adduction, though less than the previously mentioned studies; 15.0 ( $\pm 5.6$ ) degrees for controls and 11.7 ( $\pm 10.2$ ) for PFPS. Park et al<sup>23</sup> is the only other study that found similar values to the current study and Piva et al<sup>33</sup>, with Park et al<sup>33</sup> reporting 14.0 ( $\pm 7.9$ ) degrees of hip adduction for healthy subjects utilizing the Ober test. One possible explanation for less hip adduction range of motion with the Ober test consistent with the current study and in contrast to previous studies, may relate to the ability to

control the pelvis. In the current study, the examiner provided adequate force applied to the posterior aspect of the pelvis in an anterior direction during the testing procedure. This positioning allowed for proper pelvic stabilization by maintaining the hip in an extended position during lowering of the limb into hip adduction. Without proper pelvic stabilization, the pelvis rolls posteriorly and the hip joint is positioned in a relatively flexed position. This position of the hip places the TFL/ITB structure on slack and therefore could allow for increased hip adduction values when measured.

Piva et al<sup>33</sup> and Park et al<sup>23</sup> are the only studies that performed the Ober procedure by stabilizing the pelvis with the examiner's free hand and could explain the decreased hip adduction mean values compared to previous literature. Some authors did not position their hand on the pelvis at all or used their hand only to place the inclinometer on the limb.<sup>12,36</sup> Other authors do not adequately describe proper pelvic stabilization in their testing procedures supporting the variation in findings seen in the literature and the current study.<sup>13,14</sup> Proper pelvic stabilization was critical in supporting the primary purpose of the current study, namely to determine the relationship between ITB length and the presence of PFPS.

### **ITB Length between the painful knee and the non-painful knee (R2)**

A secondary purpose of this study was to determine the difference in ITB length between painful and non-painful knees in subjects with unilateral PFPS. The results of the current study, did not demonstrate statistically significant differences between painful and non-painful sides utilizing the Ober test. However, analysis was slightly underpowered due to 18 subjects having only unilateral pain. Results were approaching significance ( $p = .094$ ) and would have been significant ( $p < .05$ ) if conducted on 24 subjects. More importantly, clinical interpretation revealed a 3.0 degree mean difference between painful and non-painful knees, which exceeded

the MDC value of 1.91 degrees. This is in contrast to the conclusions drawn by Hudson and Darthuy<sup>14</sup>, who found a trend toward decreased ITB length in the non-painful knee of the PFPS group compared to both knees in the control group.

In the current study, a direct analysis of painful side compared to non-painful side was conducted in the PFPS group and revealed a 3.0 degree mean difference as opposed to Hudson and Darthuy,<sup>14</sup> who found a 2.5 degree difference between non-painful and control group. Although the magnitude of differences was similar, the analysis used by Hudson and Darthuy<sup>14</sup> was different in that they compared the non-affected side to each side of the control group. Therefore, the interpretation of results differs based on the comparisons used for analysis; painful side versus right and left sides of the control group. In the current study, there were clinically meaningful differences between painful and non-painful side, which indicates the non-painful side differed in ITB length compared to the painful side.

### **Reliability of the Ober test and Modified Thomas test (R3)**

In the clinic, therapists should use reliable tests, which are free from error, both those that may be attributed to the clinician and those related to the measurement instrument. Three studies that have used the digital inclinometer as a measurement instrument to record the values of the Ober test as a continuous variable. However, none have tested reliability using the measurement procedure conducted in this study. This gap in the literature was addressed with the analysis of test-retest reliability, SEM, and MDC in the current study. The test-retest reliability of the Ober test was excellent (ICC= .94 and .95). This finding is in agreement with previous literature evaluating the Ober test with the use of a bubble inclinometer that also found excellent reliability.<sup>43</sup> Although Reese and Bandy reported excellent reliability (ICC=.90 ) using the Ober test, several differences exist between their study and the current study. First, the measurement

instrument used by Reese and Bandy was a bubble inclinometer as opposed to the digital inclinometer that was used in the current study.<sup>43</sup> Additionally, the Reese and Bandy procedures were carried out on healthy subjects without knee pain as opposed to the mix of healthy subjects and PFPS population used in this study.<sup>43</sup>

The MDC statistic assists clinicians in distinguishing between real change and nonmeaningful fluctuation, providing a representation of reliability in terms of measurement error.<sup>59</sup> The MDC represents the minimal change required to be 90% confident that the difference between individual pre and post measures in interventional studies is due to a real change. Therefore, the results of the current study indicate 1.9 and 1.49 degrees would be the minimal amount of change required to detect true change in ITB length for the Ober and modified Thomas test respectively. Noehren et al,<sup>22</sup> utilizing a digital inclinometer reported MDC results of 3.8 degrees for the Ober test in assessing length of the ITB in ITBS subjects and controls.

Recent studies have advocated for the use of pelvic monitoring devices such as a pelvic level or biofeedback cuff during the Ober test procedure.<sup>13,14,41,42</sup> However, these studies did not examine reliability or those that did consisted of small sample sizes of 5 and 10 subjects. The present study showed excellent test- retest reliability for the Ober test using a technique that was simple and easy to use.

Reliability has not been previously established for the modified Thomas test procedure used to assess ITB length as performed in this study. Specifically, the current study measured the angle of hip extension in both a hip neutral position and then again in a hip abducted position. The difference of these two measurements was analyzed to determine ITB length. The test-retest reliability of the modified Thomas test was excellent (ICC= .92) on the right side and

slightly less when testing the left side (ICC= .81). These results were in agreement with Clapis et al<sup>35</sup> (ICC= .91-.93); however, Clapis et al evaluated interrater reliability and used a bubble inclinometer as the measurement instrument.

A recent study has demonstrated improved reliability with the use of an active lumbopelvic stabilization technique using a biofeedback pressure cuff to minimize measurement error.<sup>50</sup> Although Kim and Ha<sup>50</sup> reported excellent reliability (ICC=.99 ) using an active stabilization technique compared to a standardized procedure, several differences exist between the Kim and Ha study and the present one. First, the knee flexion angle was measured with motion analysis equipment as opposed to the hip extension angle with the use of a digital inclinometer that was used in the present study. Additionally, the procedures were carried out on a small sample (n= 13) of young healthy subjects without knee pain. The results of the present study demonstrate excellent test-retest reliability for the modified Thomas test using a novel technique to evaluate ITB length that can be reproduced clinically.

#### **Relationship between the Ober test and Modified Thomas test (R4)**

The final purpose of this study was the assessment of convergent validity to determine correlation of Ober and modified Thomas test as an indirect measure of ITB length. It was hypothesized that decreased ITB length would be associated with decreased hip adduction values during the Ober test, but increased change in hip extension values shown during the modified Thomas test thus, reflecting a negative relationship. The results of this study indicated a statistically significant negative correlation between the Ober test and modified Thomas test for the left knee. However, no correlation was found between the Ober test and modified Thomas test for the right knee. This supports the notion that the tests cannot be used interchangeably to assess for ITB length.

The discrepancy between right and left sides, in particular the right knee, was an area of interest, as it did not demonstrate a correlation between tests. One explanation for the differences in correlation seen between sides is rater error. During the pilot study conducted on 17 healthy subjects, it was noted that the interrater reliability between the three primary examiners was lowest and considerably different for the Ober test on the right side (ICC= .62) compared to the Ober test on the left side (ICC= .77) and the modified Thomas test on both sides (ICC= .72 and .76). To test this explanation, further analysis was conducted examining the relationship between the Ober and modified Thomas test for each individual examiner. The results of the correlational analysis for each individual examiner on the left side ( $r = -.47$ ,  $r = -.56$ ,  $r = -.53$ ) and the right side ( $r = -.13$ ,  $r = .26$ ,  $r = .04$ ) reveal a measurement range rater of .36 on the right side versus .09 on the left side.

The variability in examiner measurement lends credence to the possibility that decreased interrater reliability on the right side during the Ober test influenced the relationship between the Ober and modified Thomas test on the right side. One rationale for the decreased interrater reliability of the Ober test occurring only on the right side could be related to lack of pelvic stabilization with the examiner's non-dominant arm. When performing the Ober test on the right limb, the examiner needs to provide adequate pelvic stabilization in an anterior direction to prevent the pelvis from rolling posterior with their left (non-dominant) arm. If this is not conducted properly by one of the examiners then the hip will be allowed to move into flexion placing the ITB on slack, thereby increasing the hip adduction values. This theory is supported by the trend of increased hip adduction values on the right side (6.5 degrees) versus the left (4.0 degrees) for both PFPS and control groups regardless of group assignment. Future research can

test this handedness hypothesis by determining interrater reliability of the Ober test on the right side between a left hand dominant examiner and a right hand dominant examiner.

## **Implications**

### **Contributions to Knowledge**

Angular measures obtained from the Ober test are commonly used to assess the length of the ITB. Recent studies have utilized a digital inclinometer as a new measurement instrument for determining ITB length to enhance accuracy and specificity of measurement.<sup>12,13,21</sup> In the current study, the digital inclinometer produced reliable results and was easy to use in a clinical setting. Therefore, this study is one of the first investigations to quantify the measurement of ITB length using the Ober test and the modified Thomas test with a digital inclinometer. It is also the first to perform these procedures on a PFPS patient population while comparing it to a control group in which examiners were blinded to group assignment.

The Ober test as an indirect measure of ITB length was more sensitive than the modified Thomas test in detecting the decrease in ITB length between groups. The observed difference between the groups during the Ober test was 4.9 degrees, which exceeded the MDC score of 1.9 degrees supporting the clinical significance of the results. This finding is in contrast to Noehren et al,<sup>22</sup> who concluded their results were not clinically significant due to the difference between groups for the Ober test (1.2 degrees) not exceeding the MDC score (3.8 degrees). Hudson and Darthuy<sup>14</sup> is the only study that found a significant difference in ITB length using the Ober test in subjects with PFPS compared to controls, although they did not report test-retest reliability, SEM, and MDC. Therefore, this current study is the first that has found a statistically significant difference in ITB length between a PFPS group and a control group that is considered clinically



meaningful due to exceeding the MDC score. The current study also had a larger sample size, used multiple examiners, and used a more precise measurement instrument, the digital inclinometer. Results of this study add to the body of knowledge supporting decreased ITB length as one of the many associated factors of PFPS.

The modified Thomas test has commonly been utilized clinically to evaluate the muscle length of the iliopsoas muscle.<sup>12,35,49,50</sup> At the present time, the current study is the first to use the modified Thomas test to evaluate ITB length as a continuous variable by taking the difference in hip extension range of motion from a neutral hip position to a hip abducted position as recommended by Sahrman<sup>24</sup>. The mean values for change in hip extension while using the modified Thomas test for the PFPS group and the control group, neared significance. However, the results cannot be considered clinically significant since the difference between groups for the modified Thomas test (1.9 degrees) is considered borderline with the MDC score (1.5 degrees). Nonetheless, both the PFPS group and the control group demonstrated increased hip extension range of motion when the hip was positioned into abduction during the second part of the test. This finding supports the theory that the TFL/ITB is one of the three hip flexor muscles assessed with the Thomas test since it is the only muscle that is placed in a position of slack when the hip is abducted. However, other factors such as capsular tension or patient relaxation cannot be ruled out as an explanation for the improvement in hip extension range of motion seen in the hip abducted position.

The mean hip adduction values obtained with the Ober test in this study challenges the traditional definition of what is considered a positive test as a result of values being less than previously published studies using similar methodology.<sup>12,14,22,33</sup> Traditionally, the operational definition of the Ober test for decreased ITB length was considered positive by the inability of

the thigh to adduct beyond the horizontal.<sup>19</sup> Kendall et al<sup>45</sup> defined tightness of the ITB as less than 10 degrees of hip adduction during the Ober test. In the current study, the mean value of hip adduction was 7.2 ( $\pm 5.9$ ) degrees and 2.3 ( $\pm 7.0$ ) degrees for the control group and PFPS groups, respectively.

Conclusions related to results for the Ober test in this current study along with previous literature relate to standardization of procedures and definition of a positive test result. Performing the Ober test as a continuous measure with an inclinometer has significant limitations using one examiner secondary to inadequate pelvic stabilization. There are a number of studies that have attempted to control for unwanted pelvic motion during the Ober positioning either by using a spirit level attached to the subject or a biofeedback pressure cuff under the pelvis.<sup>13,14,41,42</sup> However, this only addresses movement of the pelvis in the frontal plane monitoring lateral pelvic tilt of the pelvis and is still not preventing the compensatory posterior roll of the pelvis placing the ITB on slack as previously described. In fact, one author developed an alternative prone ITB length assessment because of the difficulty of maintaining the hip in 0 degrees extension while at the same time attempting to examine the amount of hip adduction.<sup>60</sup> Nonetheless, lack of pelvic manual stabilization or relying on external pelvic monitoring methods could significantly affect results. The importance of stabilization is supported by the variability seen in hip adduction values between previous studies and the current study and the work by Piva and colleagues.<sup>33</sup> In the current study, three different examiners demonstrated reliable procedures with proper manual pelvic stabilization without the need to introduce extraneous complicated procedures such as a spirit level or biofeedback cuff.

The results of the current study as well as the previous literature challenge the accepted clinical definition of a positive Ober test. Every study that investigated the Ober test reported

positive values of hip adduction in control and patients presenting with knee pain, therefore none of these subject cohorts would be considered to have a positive test indicative of decreased ITB length. The results of this current study and the work of Hudson and Darthuy<sup>14</sup> demonstrate significant differences in mean hip adduction angles between PFPS and controls indicating decreased ITB length. These results lend support to adopting a definition similar to Kendall and colleagues that less than 10 degrees of hip adduction would be considered a positive test.

### **Contributions to Professional Practice**

PFPS is the most common source of knee pain in the physically active population and those under fifty years old.<sup>25,26</sup> Clinicians are in need of clinical diagnostic tests that differentiate the potential pathological parameters leading to PFPS. Specifically, a system of relatively simple clinical tests for the classification of individuals with PFPS needs to be developed to facilitate targeted patient-specific treatment options. The current study provides an understanding of the relationship between ITB length and PFPS, which may serve as an initial step in meeting this need. The sample of patients in the current study who presented to physical therapy services with PFPS demonstrated decreased ITB length compared to controls. The relationship found in this study is further strengthened with the use of reliable, precise, and rigorous measurement procedures. The current study provides the magnitude of measurement error, allowing for clinical interpretation of results for the Ober and modified Thomas test measurements utilizing data from test-retest reliability, SEM, and MDC. The results of the current study support the use of the Ober test to determine ITB length in clinical practice, however the data does not support the use of the modified Thomas test.

The clinical utility of the Ober test will enhance the current body of knowledge and allow clinicians to determine whether a patient's clinical state has altered. In addition, using reliable

tests that minimize measurement error, as demonstrated in this study with the Ober and modified Thomas test will allow researchers to identify the extent of true change in patient status during interventional studies.

The continued evolution of healthcare accountability has resulted in increased productivity and outcome demands for physical therapists practicing within an outpatient orthopedic setting.<sup>61</sup> Having examination procedures that provide reliable information can help to meet increased demands for effective and efficient outcomes. This study provides evidence that supports the use of the Ober test as a reliable outcome measure for ITB length. Having reliable measures of ITB length are essential to investigate the long-term effects of ITB stretching and mobilization on ITB length for clinicians and researchers during intervention studies with PFPS populations. Additionally, the Ober test was able to discriminate between the PFPS and control groups during evaluation of ITB length to a greater extent than was the modified Thomas test. Therefore, the Ober test is regularly recommended in clinical practice to assess the length of the ITB.

This practice is supported by this study's findings of the lack of relationship found between the Ober test and modified Thomas test. This lack of convergent validity suggests these tests should not be used interchangeably within clinical practice. One explanation is the two tests are not measuring the same construct of ITB length, lacking construct validity. The modified Thomas test may assess a different component of the ITB and may be positive in determining ITB tightness for specific individuals with PFPS. Thereby, a positive test may implicate the proximal muscular fibers as opposed to the distal fascial fibers of the ITB. Nevertheless, the Ober test is more time efficient as a clinical assessment since it is a single measure test as opposed to the two-measurement method of evaluating ITB length with the

modified Thomas test. This further supports the use of the Ober test to assess ITB length in the current high demand healthcare arena.

Clinical applicability of the results of this study is further strengthened secondary to the rigorous methodology utilized. The internal validity threats were minimized by blinding the primary examiner to group allocation as well as to the readings of the inclinometer at the time of testing. The recording examiner was also blinded to group allocation at the time of testing. In addition, the multicenter design of this study improves generalizability of the results to patients presenting to physical therapy clinics with PFPS.

Powers et al<sup>5</sup> recommend future intervention studies allow for broad subgrouping of subjects. A flexibility group classification consisting of subjects with primary flexibility or mobility impairments may allow for a targeted intervention approach, resulting in improved power during future clinical trials. Results of this study that demonstrate decreased ITB length in PFPS as compared to a control group provides support for such a classification. Devising a targeted interventional program for this homogeneous subgroup of PFPS patients with primary flexibility impairment may directly impact outcomes and improve previous studies that have lacked sustainable positive long term outcomes.<sup>8-10</sup>

### **Implications for Future Research**

The relationship between ITB length and PFPS has been established with the use of the Ober test in this cross sectional study. Decreased ITB length was found in subjects with PFPS as compared to subjects without PFPS when measured using the Ober test. The methods used to assess ITB length can be used in future studies investigating PFPS risk factors. This could be accomplished by conducting prospective studies in which asymptomatic individuals are evaluated for ITB length and then followed prospectively to determine which subjects develop

PFPS. This would provide further insight as to whether decreased ITB length is a causative factor to developing PFPS or if the pain associated with PFPS alters the tracking of the patella and length of the ITB. Identifying ITB length as a risk factor might then encourage the ITB to be targeted in injury prevention programs to decrease the incidence of chronic PFPS. Due to variability in reporting mean hip adduction angles as a continuous variable with the Ober test, future studies are needed to determine specific cut off points in order to determine what a true positive test is in determining decreased ITB length. These studies should include the same reliable measurement procedure that was outlined in this study in order to appropriately identify a positive test during patient assessment.

This study also provides evidence to support the Ober test as a reliable assessment of ITB length. Having reliable measures of ITB length are essential to investigate the long-term effects of ITB stretching and mobilization on ITB length during interventional studies for patients with PFPS. Therefore, future studies should investigate the efficacy of stretching and mobilizing an ITB that has decreased length in patients with PFPS as demonstrated in this study. This study provides the framework to utilize the Ober test as an outcome measure in order to evaluate changes in ITB length during interventional studies.

### **Recommendations**

It is recommended that two examiners be used when performing the Ober test as a continuous measure with the use of an inclinometer to allow for adequate pelvic stabilization. This recommendation is supported by the reliability attained in this current study between three examiners utilizing sufficient manual pelvic stabilization without the need to introduce extraneous complicated procedures such as a spirit level or biofeedback cuff. It is also recommended the tibia be prevented from excessive external tibial torsion by stabilization during

the procedures for the modified Thomas test. This could place the ITB in a position of slack, thereby creating a false negative result as demonstrated by no change in hip extension measure between the hip neutral and hip abducted positions.

### **Limitations**

The research study is not free of limitations or factors beyond the control of the primary researcher that may have affected the results. Certain barriers and current issues relative to this study will be detailed. First, the sample population did not include adolescents, which make up a large majority of PFPS patients seen clinically. This is an important consideration given PFPS is the leading source of knee pain in active adolescents and adults.<sup>5</sup> Therefore, the decreased ITB length found in this study using a mean age of 35 year old may not be generalizable to the adolescent PFPS population. Another limitation relating to the sample is 70% of the subjects were female. Sample representation consistent with the general PFPS population could be viewed as a strength, as females are 2.23 times more likely to develop PFPS compared to their male counterparts.<sup>27</sup> However, there may be different causative factors related to PFPS between genders, which may limit generalizability of the results of this study.

Willy et al<sup>38</sup> demonstrated excessive dynamic valgus movements have been gender specific with activities such as running and squatting.<sup>38</sup> Females have demonstrated excessive hip adduction mechanics and less knee adduction compared to their male counterparts with PFPS.<sup>38</sup> This excessive dynamic valgus motion has also been correlated with lateral maltracking of the patella.<sup>3,15,17</sup> Kang et al<sup>13</sup> demonstrated an association between decreased ITB length and lateral maltracking of the patella. Therefore, the differences in ITB length may have been even greater if this study include only female participants.

Another limitation relates to cross-sectional research design, which limited the ability to explicitly establish a cause-and-effect relationship between ITB and PFPS. Several studies have reported PFPS could be related to deficits in lower limb strength and flexibility.<sup>5</sup> These cross-sectional studies suggest active individuals with PFPS may present with length deficits in their quadriceps<sup>33</sup> or ITB<sup>14</sup> compared with individuals without PFPS. However, there have been no prospective studies to date and the possibility cannot be ruled out that the length deficits in individuals with PFPS may be the result of pain rather than a cause. This has recently been demonstrated with strength deficits associated with PFPS. Two prospective studies investigating a start-to-run program demonstrated that 21 runners who developed PFPS did not have a lower limb strength deficit to those muscle groups prior to their initiation of the training program.<sup>62,63</sup> Thus, it can be hypothesized that strength or length deficits associated with PFPS may be the result of pain rather than a cause, which may have occurred with the decreased ITB length finding in this current study.

Results of reliability evaluations must be interpreted with respect to the period of time between measurements and the skill-level of the clinician.<sup>59</sup> In order to minimize the clinicians being influenced by their memory of the result from their first measurement, a 5 minute rest period was instituted after the series of measurements conducted for both the Ober and modified Thomas tests on both sides. Examiner blinding from the results of the measurements also minimized this source of bias. All measurements were conducted by three experienced physical therapists (mean experience of 17 years) who were orthopedic clinical specialists, selected to improve the reliability and strengthen the internal validity. This was essential to execute the multicenter design with the goal of improved generalizability of results. However, these findings may not generalize to less experienced clinicians that may not be as reliable in performing the



Ober and modified Thomas test procedures, specifically in stabilizing the pelvis accurately during the Ober test. Therefore, skill-level of the clinician is an important factor to consider when interpreting these results.

The Ober and modified Thomas test are indirect measures of muscle length requiring positioning in one plane of motion and then measuring in another plane of motion. This positioning can be technically challenging to ensure proper stabilization and isolation of the motion of measurement. This was minimized with the use of a manual of standard procedures, examiner training, and the evaluation of interrater reliability during pilot study testing and test-retest reliability during data collection for the main study. Nonetheless, the Ober test requires the hip to be positioned into extension prior to taking a hip adduction measurement. Similarly, the modified Thomas test was modified for this study to evaluate ITB length.<sup>24</sup> This unique measurement procedure for determining ITB length required the hip to be placed in two different positions; hip neutral followed by abduction prior to taking the hip extension measurement.

The requirement for taking two measures of hip extension in both hip positions introduces increased measurement and statistical error in determining ITB length. Furthermore, the ITB length was not an actual value in degrees of hip extension measured from the digital inclinometer but a difference between two values of hip extension or a change in number of degrees from the two hip positions. In addition, measuring ITB length with the Ober and modified Thomas test in non-weight-bearing positions does not necessarily reflect how this structure functions during dynamic tasks and its effect on patellar tracking for patients with PFPS.

From a clinical perspective, the need for two examiners to perform the measurement procedure to prevent examiner bias during testing may create scheduling limitations for a busy

outpatient orthopedic clinic. All measurements in this current study were conducted with the use of a digital inclinometer to improve accuracy and strengthen internal validity of the study. However, that device is not commonly found in clinical settings due to perceived cost barriers. Therefore, one cannot generalize results to measurements that would occur with a bubble inclinometer.

Timing of the measurement may have also be a potential confounding factor in terms of how many sessions of physical therapy treatment the patients in the PFPS received prior to measurements. Attempts to minimize this limitation were made in that all subjects were measured during their first three sessions and the timing of the measurement session was always before their treatment session began for that day.

### **Delimitations**

Delimitations that may have occurred during the measurement procedure for the Ober test was lack of adequate pelvic stabilization or monitoring for excessive external tibial torsion. Inadequate pelvic stabilization during the Ober test is supported in the side-to-side differences in interrater reliability of the Ober test during the pilot study suggesting technique error when testing the right side. Park et al<sup>23</sup> demonstrated varying positions of tibial rotation can change Ober test results and can affect reliability of ITB length measurements. Specific monitoring of tibial rotation was not part of the measurement procedure and therefore can be a delimitation of the present study. Another potential delimitation may be inadvertent muscle activity of the subject during the testing procedures, thereby confounding results. In an effort to minimize this, subjects were instructed to relax their leg as much as possible during testing procedures.

A delimitation that may have occurred during the measurement procedure for the modified Thomas test was lack of monitoring for excessive tibial rotation during the

performance of the test. This potentially could have resulted in a false negative test in the presence of decreased ITB length. Sahrman<sup>24</sup> describes a positive modified Thomas test for shortness of the TFL/ITB by the observation of excessive external tibial rotation during lowering of the limb into hip extension. Therefore, in the presence of decreased ITB length, the tibia may have been externally rotated. The external rotation may, in turn, have placed the ITB in a lengthened position, causing shortening of its hip attachment and ultimately, less degrees of hip extension during the test. This would result in decreased change in hip extension measurement from the hip neutral position to a hip abducted position resulting in a less significant decrease in ITB length contribution. This consequence may explain the finding of decreased ITB length for the modified Thomas test between the PFPS and control group that was near statistical significance, but did not reach a statistically significant level as found with the Ober test.

## **Summary**

PFPS is the leading source of knee pain in active adolescents and adults with an etiology recognized to be multifactorial in nature.<sup>5</sup> Decreased ITB length is considered to be one of those factors through its direct attachments to the lateral retinaculum affecting patella position and tracking. However, the inclusion of ITB stretching is based on weakly proven assertions relying on anatomical and biomechanical models. Previous studies relating intrinsic factors to the development of PFPS have only examined multiple factors concurrently, as opposed to a single factor such as ITB length in isolation.<sup>7</sup>

In the current study, a comparison of ITB length was explored between patients presenting to physical therapy with PFPS and matched controls with the intent of determining the relationship between ITB length and PFPS. Additionally, ITB length between the painful knee

and the non-painful knee, test-retest reliability of the Ober test and modified Thomas test, and relationship between the Ober test and modified Thomas test were also explored.

The sample of subjects was comprised of patients from three different outpatient physical therapy clinics in the state of Connecticut. The PFPS group consisted of 24 patients with anterior knee pain who satisfied the inclusion criteria and the control group that included 24 patients with neck pain or upper extremity pain. Each center had three examiners who completed the procedure; screening examiner, primary examiner, and recording examiner. The screening examiner performed the initial physical exam to determine inclusion and was not blinded to group assignment. The primary examiner and the recording examiner were blinded to group assignment and the primary examiner was blinded to readings during the measurements. Randomization on testing order (Ober or modified Thomas test) and leg tested (right or left) was utilized. All subjects were tested for ITB length by the Ober test and modified Thomas test utilizing a digital inclinometer as the measurement instrument. A reliability procedure was carried out for the first eight subjects from the PFPS or control group measured by each of the three primary examiners from each side. This procedure was conducted to determine test-retest reliability, SEM, and MDC of the procedures.

The results of the research demonstrate decreased ITB length in the PFPS group as compared to the control group; however, it was only found to be different utilizing the Ober test and not the modified Thomas test. The results also demonstrate decreased ITB length in comparing the painful knee to the non-painful knee when using the Ober test that was near statistical significance, however was found clinically relevant based upon the results exceeding the MDC findings. Additionally, the test-retest reliability of the Ober and modified Thomas test was determined to be excellent in evaluating ITB length that can be reproduced clinically.

Finally, results indicate a statistically significant negative correlation between the Ober test and modified Thomas test for the left knee of subjects. However, no correlation was found between the Ober test and modified Thomas test for the right knee subjects.

The modified Thomas test has commonly been utilized clinically to evaluate the muscle length of the iliopsoas muscle.<sup>12,35,49,50</sup> At the present time, this current study is the first to use the modified Thomas test to evaluate ITB length as a continuous variable by taking the difference in hip extension range of motion from a neutral hip position to a hip abducted position as recommended by Sahrman<sup>24</sup>. The use of a digital inclinometer for the measurement of ITB length using both the Ober test and the modified Thomas test has been found to be reliable in the current study. However, given the Ober and modified Thomas test were not found to correlate, the two examination procedures should not be used interchangeably for the measurement of ITB length.

The results of this cross sectional study demonstrate decreased ITB length in PFPS subjects as measured with the Ober test. This study does not conclude decreased ITB length as the only causative factor of PFPS. However, it concludes decreased ITB length might be one of the significant contributing factors for the occurrence of PFPS. This finding adds to the current body of knowledge and lends support to the subgrouping of classification systems for PFPS with primary flexibility impairment. The study serves as an initial step in developing future intervention studies to investigate ITB length and causation in order to improve efficacy of PFPS treatments.

## APPENDICES

### Appendix A- Recruitment e-mail for Pilot Study

Subject: Research Study Participation

I am conducting a study investigating two different measurement techniques for assessing the length of the iliotibial band (i.e., tissue on the lateral aspect of the hip and thigh). I am looking for male or female volunteers between the ages of 20-25 years of age without current reports of lower back or lower extremity pain. The study will require you to attend one measurement session that will last approximately 90 minutes. During this session your legs will be placed in positions designed to stretch your iliotibial band and measurements will be taken. You will be compensated \$10 for your participation and all activities will be performed in the physical therapy labs located on the third floor of building MNH at Quinnipiac University. The study has been approved by the Nova Southeastern University IRB and Quinnipiac University HEC/IRB committee. If you have any further questions and are interested in participating in this opportunity, please contact:

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## Appendix B- Pilot Study Informed Consent

IRB protocol # 20115

*Title Project:* Inter-rater Reliability of the Ober Test and modified Thomas Test Using a Digital Inclinometer

*Investigators:* Duane Scotti, PT, MPT, OCS, Katherine Grevelding, PT, DPT, OCS, ATC, Jason Myerson, PT, DPT, DMT, OCS, CMT, FAAOMPT, Eric Stearns, PT, MS, OCS, CIDN

The following description is designed to provide you with information about this study that will allow you to decide if you would like to participate or not. You have been invited to participate in this study because you are between 20-25 years old and you do not have lower back or lower extremity pain

*Purpose:* The primary purpose of this study will be to determine the inter-rater reliability of the Ober test and modified Thomas test as two measures of iliotibial band (ITB) tightness.

*Study Location:* The measurement session will take place in the physical therapy laboratory classrooms (MNH 380, 385) on the North Haven campus at Quinnipiac University.

*Number of Sessions and Duration of Each Session:* One measurement session lasting approximately 60 minutes in duration.

*Examination:* The Ober Test will be utilized to determine the muscle length of the TFL/ITB. This will be performed with you lying on your side and the examiner will position your leg in the stretch position. A digital inclinometer will be placed at the midpoint between the anterior-superior iliac spine and the patella on the lateral aspect of the thigh. The examiner will measure the angle of hip adduction. This will be repeated two times following a 5-second rest period. The modified Thomas test will also be used to determine TFL/ITB length. You will be instructed to sit on the edge of a plinth and roll back, bringing both knees to your chest. The knee of the nontest leg will be held to your chest while the test leg is slowly lowered into hip extension with the knee flexed to 90° and without allowing for any pelvic rotation or hip abduction. The examiner will position a digital inclinometer over the anterior thigh midway between the ASIS and proximal edge of the patella to take a measurement. Next, the examiner will bring your leg out to the side into abduction and repeat the measurement. Both measurements will be performed two times on each side by each of the three examiners.

*Potential Risks and Benefits:* The risks in this study are minimal. There is a small risk of muscle stretch soreness that participants could experience approximately 12-24 hours following the testing procedures. This soreness is similar to what an individual experiences following a mild stretching exercise. Taking measurements at the point in the range when the participant reports a mild stretch sensation minimizes the risk. Several resting periods and the number of repetitions has been minimized to reduce this risk. Compensation in the amount of ten dollars is provided for your participation in this study. Federal regulation requires that all subjects be informed of the availability of medical treatment or financial compensation in the event that physical injury resulting from your participation in this research project. Quinnipiac University cannot provide either medical treatment or financial compensation for any physical injury resulting from their

participation in this study. In the event of an injury occurring during the course of this study, you would be referred to the appropriate medical services.

Confidentiality & Voluntary Participation: All research data will be coded by number and maintained for three years after the study has been completed. Only members of the research team will know your name. Should this research be published, you will not be personally identified in any way. Your decision whether or not to participate in this study will not affect your present or future relationship with Quinnipiac University. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without penalty.

If you have any questions regarding this project or if you have any discomfort following the measurement session, please contact Duane Scotti at (203) 582-7730 (Duane.Scotti@quinnipiac.edu). If you have any questions regarding your role as a human subject, please contact Dr. Richard Feinn, Chairman of Quinnipiac's Human Experimentation Committee/Institutional Review Board (HEC/IRB), at (203) 582-6583 or email at [Richard.Feinn@quinnipiac.edu](mailto:Richard.Feinn@quinnipiac.edu).

Other Considerations:

If the researchers learn anything which might change your mind about being involved, you will be told of this information.

Voluntary Consent by Participant:

By signing below, you indicate that

- this study has been explained to you
- you have read this document or it has been read to you
- your questions about this research study have been answered
- you have been told that you may ask the researchers any study related questions in the future or contact them in the event of a research-related injury
- you have been told that you may ask Institutional Review Board (IRB) personnel questions about your study rights
- you are entitled to a copy of this form after you have read and signed it
- you voluntarily agree to participate in the study entitled *The Opinions of Patients on their Treatment*

Participant's Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Participant's Name: \_\_\_\_\_ Date: \_\_\_\_\_

Signature of Person Obtaining Consent: \_\_\_\_\_

Date: \_\_\_\_\_

Subject Number \_\_\_\_\_



## Appendix C- Informed Consent

Consent Form for Participation in the Research Study Entitled  
*Iliotibial Band Tightness and Patellofemoral Pain Syndrome:  
Relationship between Two Measurement Techniques*

Funding Source: None.

IRB protocol #

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If you have any questions regarding your role as a human subject, please contact Dr. Richard Feinn, Chairman of Quinnipiac's Human Experimentation Committee/Institutional Review Board (HEC/IRB), at (203) 582-6583 or email at [Richard.Feinn@quinnipiac.edu](mailto:Richard.Feinn@quinnipiac.edu).

Human Research Oversight Board (Institutional Review Board or IRB)  
Nova Southeastern University  
(954) 262-5369/Toll Free: 866-499-0790  
[IRB@nsu.nova.edu](mailto:IRB@nsu.nova.edu)

Site Information  
Integrated Rehabilitation Services  
586 East Middle Turnpike  
Manchester, CT 06040

OSM Therapy Center  
100 Beard Sawmill Road  
Shelton, CT 06484

Physical Therapy and Sports Medicine Centers  
97 Barnes Road  
Wallingford, CT 06492

### **What is the study about?**

You are invited to participate in a research study. The goal of this study is to determine if there is a relationship between iliotibial band tightness (ITB) and condition of knee pain known as patellofemoral pain syndrome. The secondary goal is to determine if there is a relationship between two different measurement tests that are used to determine ITB tightness.

### **Why are you asking me?**

We are inviting you to participate because you are currently being seen by a physical therapist and either have knee pain or do not have knee pain. There will be 48 participants in this research study.

### **What will I be doing if I agree to be in the study?**

You will answer questions on 5 different questionnaires. You will also undergo a brief interview and physical examination by the researcher. You will be asked questions about your general health history and activities that may increase your knee pain if you do have knee pain. You will not be asked questions related to the current physical therapy treatment you are receiving. The questionnaires should take you no more than 15 minutes to complete. The interview and physical examination will last no more than 10 minutes. If during the interview the researcher learns that you have a medical condition that makes you ineligible for the study, they will end the interview. You then will undergo two tests designed to evaluate the length of the ITB.

The Ober Test will be performed with you lying on your side and the examiner will position your leg in the stretch position. A digital inclinometer will be placed at the midpoint between the anterior-superior iliac spine and the patella on the lateral aspect of your thigh. The examiner will measure the angle of hip adduction. This will be repeated two times following a 5-second rest period. The second test will be the modified Thomas test and you will be instructed to sit on the edge of a plinth and roll back, bringing both knees to his or her chest. The knee of the nontest leg will be held to your chest while the test leg will be slowly lowered into hip extension with the knee flexed to 90° and without allowing for any pelvic rotation or hip abduction. The examiner will position a digital inclinometer over your anterior thigh midway between the ASIS and proximal edge of the patella to take a measurement. Next, the examiner will bring your leg out to the side into abduction and repeat the measurement. Both measurements will be performed two times on each side and then the tests will be repeated one more time following a 5 minute rest period sitting in a chair.

### **Is there any audio or video recording?**

No

### **What are the dangers to me?**

Risks to you are minimal. There is a small risk of muscle stretch soreness that participants could experience approximately 12-24 hours following the testing procedures. This soreness is similar to what an individual experiences following a mild stretching exercise. Taking measurements at the point in the range when the participant reports a mild stretch sensation minimizes the risk. Several resting periods and the number of repetitions has been minimized to reduce this risk. In the event of an injury occurring during the course of this study, your researcher will try to help you. If you need further help, they will suggest someone you can see

but you will have to pay for that yourself. If you have questions about the research, your research rights, or if you experience an injury because of the research please contact Duane Scotti at (203) 376-6514 about your research rights.

**Are there any benefits to me for taking part in this research study?**

There are no benefits to you for participating.

**Will I get paid for being in the study? Will it cost me anything?**

There are no costs to you and you will not be compensated for your participation in this study.

**How will you keep my information private?**

The questionnaire will not ask you for any information that could be linked to you. All information obtained in this study is strictly confidential unless disclosure is required by law. The IRB, regulatory agencies, or Dr. Litwin may review research records.

**What if I do not want to participate or I want to leave the study?**

You have the right to leave this study at any time or refuse to participate. If you do decide to leave or you decide not to participate, you will not experience any penalty or loss of services you have a right to receive. If you choose to withdraw, any information collected about you **before** the date you leave the study will be kept in the research records for 36 months from the conclusion of the study and may be used as a part of the research.

**Other Considerations:**

If the researchers learn anything, which might change your mind about being involved, you will be told of this information.

**Voluntary Consent by Participant:**

By signing below, you indicate that

- this study has been explained to you
- you have read this document or it has been read to you
- your questions about this research study have been answered
- you have been told that you may ask the researchers any study related questions in the future or contact them in the event of a research-related injury
- you have been told that you may ask Institutional Review Board (IRB) personnel questions about your study rights
- you are entitled to a copy of this form after you have read and signed it
- you voluntarily agree to participate in the study entitled *Iliotibial Band Tightness and Patellofemoral Pain Syndrome: Relationship between Two Measurement Techniques*

Participant's Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Participant's Name: \_\_\_\_\_ Date: \_\_\_\_\_

Signature of Person Obtaining Consent: \_\_\_\_\_ Date: \_\_\_\_\_

## Appendix D- Manual of Standard Procedures

### *Physical Screening Examination:*

Knee Range of Motion: The test will begin with the subject lying in the supine position. The examiner will passively flex and extend the knee and reports of pain or limited knee range of motion is considered a positive test. Limited knee range of motion will be determined by any deviation from the normal 0 degrees to 135 degrees.

Patellar Palpation: The subject will be lying supine and the examiner will palpate the posteromedial and posterolateral borders of the patella with the quadriceps relaxed. Any report of pain during palpation will be considered a positive test.

Clarke Test: The subject will be lying supine with the affected limb supported on a towel roll in slight flexion. While the subject is relaxed, the examiner will place his hand on the superior border of the patella and press the patella distally and then ask the subject to contract their quadriceps muscle. A positive test will be considered if the subject's pain is reproduced.

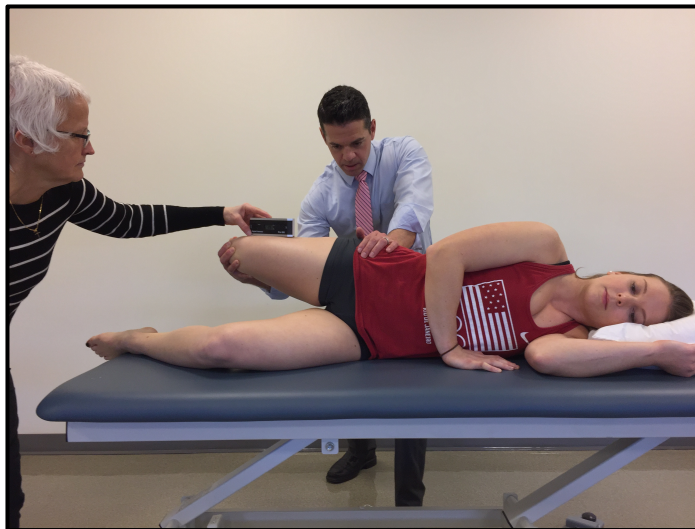
Resisted Knee Extension: The subject will be positioned in short sitting over the edge of a table. The examiner will position the knee at a 60 degree angle and apply resistance to the distal tibia after giving the command to "hold strong and don't let me push your leg down". A positive isometric test will be recorded if it reproduces the subject's familiar pain.

Single Leg Squat: The subject will be in a standing position and will be asked to perform a squat standing on the affected leg. A positive test for gluteus medius insufficiency will be determined subjectively by observing internal rotation and adduction of the femur between 30 degrees and 60 degrees of knee flexion.

## Measurement Procedures:

### Ober Test:

The Ober test is performed with the subject positioned in sidelying with the primary examiner standing posteriorly. The lower leg is flexed to 45 degrees at the hip and knee to maintain stability and to restrain body rotation.<sup>14,20</sup> The primary examiner uses their distal hand to cradle the test limb supporting just above the knee with the knee flexed to 90 degrees. The proximal hand is positioned on the subject's posterior pelvis, which served to block extraneous posterior movement of the pelvis. The examiner lifts the test limb into slight hip flexion, abduction and then extension in order to pass the ITB over the greater trochanter. This is performed while maintaining pelvic stabilization with the examiner's proximal hand and 90 degrees of knee flexion with the examiner's distal hand. Next, the examiner allows the limb to drop toward the table into hip adduction, attempting to control for any unwanted hip rotation. The position of measurement is determined by the point at which the limb stops moving toward the table.<sup>13,36</sup> The recording examiner places the digital inclinometer at the midpoint between the anterior-superior iliac spine and the patella on the lateral aspect of the thigh. The recording examiner reads the angle of hip adduction with the digital readout facing away from the primary examiner and then records the measurement as a continuous variable to the nearest .1 degree on the data collection form. If the limb is horizontal, it is considered to be at zero degrees; if it is below horizontal (adducted), the angle is recorded as a positive number; and if it is above horizontal (abducted), the angle is recorded as a negative number. The greater angle of maximum adduction indicates longer ITB length. Decreased ITB length is present if the limb has a decreased angle of maximum adduction (relative abduction). Each measure is repeated two times with a 5-second pause between each measurement and the procedure is repeated on the opposite limb.



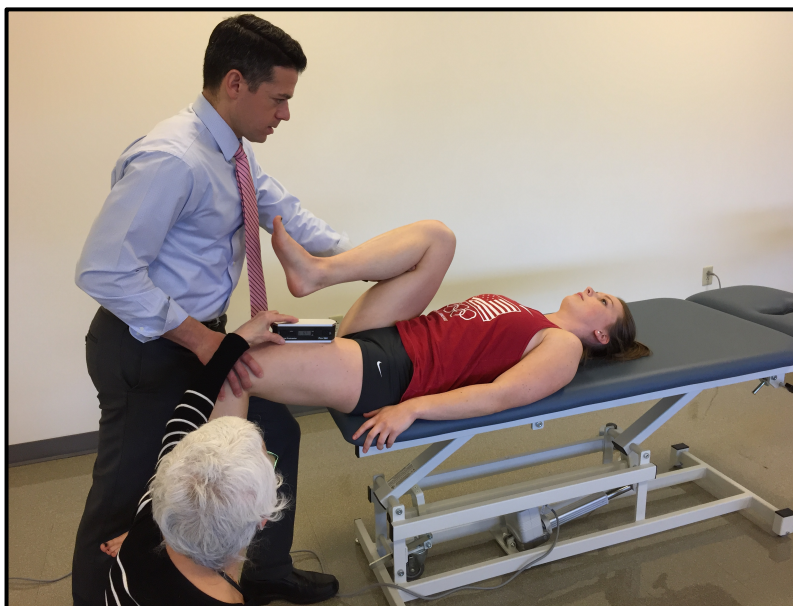
**Ober Test**



**Digital Inclinometer**

### Modified Thomas Test:

The modified Thomas test is performed with the subject sitting at the edge of the examination table. The primary examiner assists the subject in slowly rolling backward onto the table as the subject grasps underneath both thighs until a supine position is achieved with both knees in toward their chest. The primary examiner assists in flexing the opposite hip by bringing their knee further toward their chest until full motion is obtained to ensure the lumbar spine is in contact with the table. Next, the primary examiner slowly lowers the testing limb into hip extension maintaining a hip neutral position preventing abduction of the thigh. The final test position is reached when full hip extension range of motion is obtained while maintaining the low back, sacrum, and pelvis in contact with the table. The primary examiner instructs the recording examiner to place the digital inclinometer on the thigh with the digital readout facing away from the primary examiner. The recording examiner places the digital inclinometer at the midpoint between the anterior-superior iliac spine and the patella on the anterior aspect of the thigh. The recording examiner reads and records the hip extension measurement as a continuous variable to the nearest .1 degree on the data collection form. Next, the primary examiner positions the limb into full hip abduction and the recording examiner reads and records the hip extension angle as a continuous variable once again. During both measurement positions; if the limb is horizontal, it is considered to be at zero degrees; if it is below horizontal (extended), the angle is recorded as a positive number; and if it is above horizontal (flexed), the angle is recorded as a negative number. The differences between the two hip extension measures (hip neutral and hip abducted) are used to determine ITB length as a continuous variable during analysis. Decreased ITB length is present when the second measurement of hip extension is greater than the first measurement as a result of placing the ITB in a slackened position. Each measurement is repeated two times with a 5-second pause between each measurement and the procedure is repeated on the opposite limb.



**Modified Thomas Test**

## Appendix E- Health History Questionnaire

Name: \_\_\_\_\_

Subject # \_\_\_\_\_

Date: \_\_\_\_\_

Age: \_\_\_\_\_

Gender: \_\_\_\_\_

Height: \_\_\_\_\_

Weight: \_\_\_\_\_

1. Are you currently experiencing any knee pain (within the past 48 hours)? \_\_\_\_\_

If no, please skip down to question #6

2. If yes, how long have you been experiencing this current episode of knee pain?

\_\_\_\_\_ months

3. Where is your knee pain located? \_\_\_\_\_

4. How did you injure your knee? \_\_\_\_\_

5. Please circle all of the activities in which you experience knee pain:

Stair climbing

Squatting

Kneeling

Running

Sitting still for a minimum of 20 minutes

6. Have you had any prior episodes of knee pain? \_\_\_\_\_

7. Please list your current medical problems (list the conditions you currently are being treated for):

8. Past medical history: list all hospitalizations, major illnesses and surgeries:

9. Which foot would you use to kick a ball? (circle one)

Right

Left

## Appendix F- IKDC Subjective Knee Evaluation Form

Subject # \_\_\_\_\_

### 2000 IKDC SUBJECTIVE KNEE EVALUATION FORM

Your Full Name \_\_\_\_\_

Today's Date: \_\_\_\_/\_\_\_\_/\_\_\_\_  
Day Month Year

Date of Injury: \_\_\_\_/\_\_\_\_/\_\_\_\_  
Day Month Year

#### **SYMPTOMS\*:**

\*Grade symptoms at the highest activity level at which you think you could function without significant symptoms, even if you are not actually performing activities at this level.

1. What is the highest level of activity that you can perform without significant knee pain?

- 4  Very strenuous activities like jumping or pivoting as in basketball or soccer
- 3  Strenuous activities like heavy physical work, skiing or tennis
- 2  Moderate activities like moderate physical work, running or jogging
- 1  Light activities like walking, housework or yard work
- 0  Unable to perform any of the above activities due to knee pain

2. During the past 4 weeks, or since your injury, how often have you had pain?

- |       |                          |                          |                          |                          |                          |                          |                          |                          |                          |                          |                          |          |
|-------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|----------|
| Never | 0                        | 1                        | 2                        | 3                        | 4                        | 5                        | 6                        | 7                        | 8                        | 9                        | 10                       | Constant |
|       | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |          |

3. If you have pain, how severe is it?

- |         |                          |                          |                          |                          |                          |                          |                          |                          |                          |                          |                          |                       |
|---------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|-----------------------|
| No pain | 0                        | 1                        | 2                        | 3                        | 4                        | 5                        | 6                        | 7                        | 8                        | 9                        | 10                       | Worst pain imaginable |
|         | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |                       |

4. During the past 4 weeks, or since your injury, how stiff or swollen was your knee?

- 4  Not at all
- 3  Mildly
- 2  Moderately
- 1  Very
- 0  Extremely

5. What is the highest level of activity you can perform without significant swelling in your knee?

- 4  Very strenuous activities like jumping or pivoting as in basketball or soccer
- 3  Strenuous activities like heavy physical work, skiing or tennis
- 2  Moderate activities like moderate physical work, running or jogging
- 1  Light activities like walking, housework, or yard work
- 0  Unable to perform any of the above activities due to knee swelling

6. During the past 4 weeks, or since your injury, did your knee lock or catch?

- 0  Yes    1  No

7. What is the highest level of activity you can perform without significant giving way in your knee?

- 4  Very strenuous activities like jumping or pivoting as in basketball or soccer
- 3  Strenuous activities like heavy physical work, skiing or tennis
- 2  Moderate activities like moderate physical work, running or jogging
- 1  Light activities like walking, housework or yard work
- 0  Unable to perform any of the above activities due to giving way of the knee



**SPORTS ACTIVITIES:**

8. What is the highest level of activity you can participate in on a regular basis?

- 4  Very strenuous activities like jumping or pivoting as in basketball or soccer
- 3  Strenuous activities like heavy physical work, skiing or tennis
- 2  Moderate activities like moderate physical work, running or jogging
- 1  Light activities like walking, housework or yard work
- 0  Unable to perform any of the above activities due to knee

9. How does your knee affect your ability to:

		Not difficult at all	Minimally difficult	Moderately Difficult	Extremely difficult	Unable to do
a.	Go up stairs	4 <input type="checkbox"/>	3 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	0 <input type="checkbox"/>
b.	Go down stairs	4 <input type="checkbox"/>	3 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	0 <input type="checkbox"/>
c.	Kneel on the front of your knee	4 <input type="checkbox"/>	3 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	0 <input type="checkbox"/>
d.	Squat	4 <input type="checkbox"/>	3 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	0 <input type="checkbox"/>
e.	Sit with your knee bent	4 <input type="checkbox"/>	3 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	0 <input type="checkbox"/>
f.	Rise from a chair	4 <input type="checkbox"/>	3 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	0 <input type="checkbox"/>
g.	Run straight ahead	4 <input type="checkbox"/>	3 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	0 <input type="checkbox"/>
h.	Jump and land on your involved leg	4 <input type="checkbox"/>	3 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	0 <input type="checkbox"/>
i.	Stop and start quickly	4 <input type="checkbox"/>	3 <input type="checkbox"/>	2 <input type="checkbox"/>	1 <input type="checkbox"/>	0 <input type="checkbox"/>

**FUNCTION:**

10. How would you rate the function of your knee on a scale of 0 to 10 with 10 being normal, excellent function and 0 being the inability to perform any of your usual daily activities which may include sports?

FUNCTION PRIOR TO YOUR KNEE INJURY:

Couldn't perform daily activities	0	1	2	3	4	5	6	7	8	9	10	No limitation in daily activities
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

CURRENT FUNCTION OF YOUR KNEE:

Can't perform daily activities	0	1	2	3	4	5	6	7	8	9	10	No limitation in daily activities
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

## Appendix G- Knee Outcome Survey Activities of Daily Living Scale

Subject # \_\_\_\_\_

### Knee Outcome Survey Activities of Daily Living Scale (ADLS).

**Symptoms:** To what degree does each of the following symptoms affect your level of activity? (check one answer on each line)

	I do not have the symptom	I have the symptom, but it does not affect my activity	The symptom affects my activity slightly	The symptom affects my activity moderately	The symptom affects my activity severely	The symptom prevents me from all daily activity
Pain						
Stiffness						
Swelling						
Giving way, buckling, or shifting of the knee						
Weakness						
Limping						

**Functional Limitations With Activities of Daily Living:** How does your knee affect your ability to: (check one answer on each line)

	Activity is not difficult	Activity is minimally difficult	Activity is somewhat difficult	Activity is fairly difficult	Activity is very difficult	I am unable to do the activity
<u>Walk</u>						
Go up stairs						
Go down stairs						
Stand						
Kneel on front of your knee						
Squat						
Sit with your knee bent						
Rise from a chair						

## Appendix H- Physical Screening Examination Data Collection Form

Subject # \_\_\_\_\_

### IKDC Subjective Knee Evaluation Form:

Sports Activities:

8. What is the highest level of activity you can participate in on a regular basis?

- <sub>4</sub> Very strenuous activities like jumping or pivoting as in basketball or soccer  
<sub>3</sub> Strenuous activities like heavy physical work, skiing or tennis  
<sub>2</sub> Moderate activities like moderate physical work, running or jogging  
<sub>1</sub> Light activities like walking, housework or yard work  
<sub>0</sub> Unable to perform any of the above activities

+ = Positive test

- = Negative test

Test	+	-
<p>1. <u>Knee Range of Motion:</u></p> <p>The test will begin with the subject lying in the supine position. The examiner will passively flex and extend the knee and reports of pain or limited knee range of motion is considered a positive test. Limited knee range of motion will be determined by any deviation from the normal 0 degrees to 135 degrees.</p>		
<p>2. <u>Patellar Palpation:</u></p> <p>The subject will be lying supine and the examiner will palpate the posteromedial and posterolateral borders of the patella with the quadriceps relaxed. Any report of pain during palpation will be considered a positive test.</p>		
<p>3. <u>Clarke Test:</u></p> <p>The subject will be lying supine with the affected limb supported on a towel roll in slight flexion. While the subject is relaxed, the examiner will place his hand on the superior border of the patella and press the patella distally and then ask the subject to contract their quadriceps muscle. A positive test will be considered if the subject's pain is reproduced.</p>		
<p>4. <u>Resisted Knee Extension:</u></p> <p>The subject will be positioned in short sitting over the edge of a table. The examiner will position the knee at a 60 degree angle and apply apply resistance to the distal tibia after giving the command to "hold strong and don't let me push your leg down". A positive isometric test will be recorded if it reproduces the subject's familiar pain.</p>		
<p>5. <u>Single Leg Squat:</u></p> <p>The subject will be in a standing position and will be asked to perform a squat standing on the affected leg. A positive test for gluteus medius insufficiency will be determined subjectively by observing internal rotation and adduction of the femur between 30 degrees and 60 degrees of knee flexion.</p>		

## Appendix I- Measurement Data Collection Form

Subject # \_\_\_\_\_

Test	Right	Right	Left	Left
	Trial 1	Trial 2	Trial 1	Trial 2
	(0.1°)	(0.1°)	(0.1°)	(0.1°)
<p>Ober Test</p> <p>Below horizontal = (+) Above horizontal = (-)</p>				
<p>Modified Thomas Test</p> <p>Position 1: <b>Hip Adduction</b></p> <p>Below horizontal = (+) Above horizontal = (-)</p>				
<p>Modified Thomas Test</p> <p>Position 2: <b>Hip Abduction</b></p> <p>Below horizontal = (+) Above horizontal = (-)</p>				

## Reference List

1. Cook, C, Mabry, L, Reiman, M, Hegedus, E. Best tests/clinical findings for screening and diagnosis of patellofemoral pain syndrome: A systematic review. *Physiotherapy*. 2012;98(2):93-100.
2. Salsich, G, Long-Rossi, F. Do females with patellofemoral pain have abnormal hip and knee kinematics during gait? *Physiother Theory Pract*. 2010;26:150-159.
3. Myer GD, Ford KR, Barber Foss KD, et al. The incidence and potential pathomechanics of patellofemoral pain in female athletes. *Clin Biomech (Bristol, Avon)*. 2010;25(7):700-7.
4. Merican, A, Amis, A. Iliotibial band tension affects patellofemoral and tibiofemoral kinematics. *J Biomech*. 2009;42(10):1539-46.
5. Powers CM, Bolgla LA, Callaghan MJ, Collins N, Sheehan FT. Patellofemoral pain: Proximal, distal, and local factors, 2nd international research retreat. *J Orthop Sports Phys Ther*. 2012;42(6):A1-54.
6. Boling MC, Padua DA, Marshall SW, Guskiewicz K, Pyne S, Beutler A. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: The joint undertaking to monitor and prevent ACL injury (JUMP-ACL) cohort. *Am J Sports Med*. 2009;37(11):2108-16.
7. Clijsen R, Fuchs J, Taeymans J. Effectiveness of exercise therapy in treatment of patients with patellofemoral pain syndrome: Systematic review and meta-analysis. *Phys Ther*. 2014;94(12):1697-1708.
8. Fukuda TY, Rossetto FM, Magalhaes E, Bryk FF, Lucareli PR, de Almeida Aparecida Carvalho N. Short-term effects of hip abductors and lateral rotators strengthening in females with patellofemoral pain syndrome: A randomized controlled clinical trial. *J Orthop Sports Phys Ther*. 2010;40(11):736-742.

9. Song CY, Lin YF, Wei TC, Lin DH, Yen TY, Jan MH. Surplus value of hip adduction in leg-press exercise in patients with patellofemoral pain syndrome: A randomized controlled trial. *Phys Ther.* 2009;89(5):409-418.
10. Syme G, Rowe P, Martin D, Daly G. Disability in patients with chronic patellofemoral pain syndrome: A randomised controlled trial of VMO selective training versus general quadriceps strengthening. *Man Ther.* 2009;14(3):252-263.
11. Tyler TF, Nicholas SJ, Mullaney MJ, McHugh MP. The role of hip muscle function in the treatment of patellofemoral pain syndrome. *Am J Sports Med.* 2006;34(4):630-6.
12. Ferber R, Kendall KD, McElroy L. Normative and critical criteria for iliotibial band and iliopsoas muscle flexibility. *J Athl Train.* 2010;45(4):344-8.
13. Kang SY, Choung SD, Park JH, Jeon HS, Kwon OY. The relationship between length of the iliotibial band and patellar position in asians. *Knee.* 2014;21(6):1135-1138.
14. Hudson Z, Darthuy E. Iliotibial band tightness and patellofemoral pain syndrome: A case-control study. *Man Ther.* 2009;14(2):147-51.
15. Noehren B, Davis I, Hamill J. ASB clinical biomechanics award winner 2006 prospective study of the biomechanical factors associated with iliotibial band syndrome. *Clin Biomech (Bristol, Avon).* 2007;22(9):951-6.
16. Cook C, Hegedus E, Hawkins R, Scovell F, Wyland D. Diagnostic accuracy and association to disability of clinical test findings associated with patellofemoral pain syndrome. *Physiother Can.* 2010;62(1):17-24.

17. Sheehan FT, Derasari A, Fine KM, Brindle TJ, Alter KE. Q-angle and J-sign: Indicative of maltracking subgroups in patellofemoral pain. *Clin Orthop Relat Res.* 2010;468(1):266-75.
18. van Linschoten R, van Middelkoop M, Berger MY, et al. Supervised exercise therapy versus usual care for patellofemoral pain syndrome: An open label randomised controlled trial. *BMJ.* 2009;339:b4074.
19. Ober F. Back strain and sciatica. *JAMA.* 1935;104(18):1580-1583.
20. Piva SR, Fitzgerald K, Irrgang JJ, et al. Reliability of measures of impairments associated with patellofemoral pain syndrome. *BMC Musculoskelet Disord.* 2006;7:33.
21. Dheeraj L, Ishita A. Relationship between iliotibial band tightness and occurrence of low back pain and sciatica. *Indian Journal of Physiotherapy & Occupational Therapy.* 2014;8(2):17-22.
22. Noehren B, Schmitz A, Hempel R, Westlake C, Black W. Assessment of strength, flexibility, and running mechanics in men with iliotibial band syndrome. *J Orthop Sports Phys Ther.* 2014;44(3):217-222.
23. Park JH, Kang SY, Choung SD, Jeon HS, Kwon OY. Effects of tibial rotation on ober's test and patellar tracking. *Knee.* 2016;23(4):600-603.
24. Sahrman S. *Diagnosis and treatment of movement impairment syndromes.* St. Louis: Mosby; 2002.
25. Dolak, K.L., Silkman, C., Mckeon, J., Hosey, G., Lattermann, C., Uhl, T. Hip strengthening prior to functional exercises reduces pain sooner than quadriceps strengthening in females with patellofemoral pain syndrome: A randomized clinical trial. *Journal of Orthopaedic and Sports Physical Therapy.* 2011;41(8):560-570.
26. Lankhorst, N, Bierma-Zeinstra, S, Van Middelkoop, M. Risk factors for patellofemoral pain syndrome: A systematic review. *J Orthop Sports Phys Ther.* 2012;42(2):81-95.

27. Boling M, Padua D, Marshall S, Guskiewicz K, Pyne S, Beutler A. Gender differences in the incidence and prevalence of patellofemoral pain syndrome. *Scand J Med Sci Sports*. 2010;20(5):725-730.
28. Roush JR, Curtis Bay R. Prevalence of anterior knee pain in 18-35 year-old females. *Int J Sports Phys Ther*. 2012;7(4):396-401.
29. Hall R, Barber Foss K, Hewett TE, Myer GD. Sports specialization is associated with an increased risk of developing anterior knee pain in adolescent female athletes. *J Sport Rehabil*. 2014.
30. Stathopulu, E, Baildam, E. Anterior knee pain: A long term follow-up. *Rheumatology*. 2003;42:380-382.
31. Utting MR, Davies G, Newman JH. Is anterior knee pain a predisposing factor to patellofemoral osteoarthritis? *Knee*. 2005;12(5):362-5.
32. Hinman RS, Lentzos J, Vicenzino B, Crossley KM. Is patellofemoral osteoarthritis common in middle-aged people with chronic patellofemoral pain? *Arthritis Care Res (Hoboken)*. 2014;66(8):1252-1257.
33. Piva SR, Goodnite ES, Childs JD. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. *Journal of Orthopaedic and Sports Physical Therapy*. 2005;35(12):793.
34. Sanchis-Alfonso V, Rosello-Sastre E, Revert F, Garcia A. Histologic retinacular changes associated with ischemia in painful patellofemoral malalignment. *Orthopedics*. 2005;28(6):593-9.
35. Clapis PA, Davis SM, Davis RO. Reliability of inclinometer and goniometric measurements of hip extension flexibility using the modified thomas test. *Physiother Theory Pract*. 2008;24(2):135-41.



36. Herrington L, McEwan I, Thom J. Quantification of patella position by ultrasound scanning and its criterion validity. *Ultrasound Med Biol.* 2006;32(12):1833-1836.
37. Boling M, Padua D, Marshall S, Guskiewicz K, Pyne S, Beutler A. Gender differences in the incidence and prevalence of patellofemoral pain syndrome. *Scand J Med Sci Sports.* 2010;20(5):725-30.
38. Willy RW, Manal KT, Witvrouw EE, Davis IS. Are mechanics different between male and female runners with patellofemoral pain? *Med Sci Sports Exerc.* 2012;44(11):2165-2171.
39. Barton CJ, Levinger P, Crossley KM, Webster KE, Menz HB. Relationships between the foot posture index and foot kinematics during gait in individuals with and without patellofemoral pain syndrome. *J Foot Ankle Res.* 2011;4:10-1146-4-10.
40. Kooiker L, Van De Port IG, Weir A, Moen MH. Effects of physical therapist-guided quadriceps-strengthening exercises for the treatment of patellofemoral pain syndrome: A systematic review. *J Orthop Sports Phys Ther.* 2014;44(6):391-B1.
41. Melchione WE, Sullivan MS. Reliability of measurements obtained by use of an instrument designed to indirectly measure iliotibial band length. *J Orthop Sports Phys Ther.* 1993;18(3):511-5.
42. Herrington, L., Rivett, N., Munro, S. The relationship between patella position and length of the iliotibial band as assessed using ober's test. *Manual Therapy.* 2006;11:182-186.
43. Reese NB, Bandy WD. Use of an inclinometer to measure flexibility of the iliotibial band using the ober test and the modified ober test: Differences in magnitude and reliability of measurements. *J Orthop Sports Phys Ther.* 2003;33(6):326-30.
44. Herrington L, Law J. The effect of hip adduction angle on patellar position measured using real time ultrasound scanning. *Knee.* 2012;19(5):709-712.

45. Kendall F, McCreary E, Provance P, Rodgers M. *Muscles testing and function with posture and pain*. 5th edition ed. Philadelphia: Lippincott Williams & Williams; 2005.
46. Tenney HR, Boyle KL, Debord A. Influence of hamstring and abdominal muscle activation on a positive ober's test in people with lumbopelvic pain. *Physiother Can*. 2013;65(1):4-11.
47. Wang TG, Jan MH, Lin KH, Wang HK. Assessment of stretching of the iliotibial tract with ober and modified ober tests: An ultrasonographic study. *Arch Phys Med Rehabil*. 2006;87(10):1407-11.
48. Fredericson, M., White, J.,J., macMahon J.M., Andriacchi, T.,P. Quantitative analysis of the relative effectiveness of 3 iliotibial band stretches. *Arch Phys Med Rehabil*. 2002;83(5):589-592.
49. Harvey D. Assessment of the flexibility of elite athletes using the modified thomas test. *Br J Sports Med*. 1998;32(1):68-70.
50. Kim GM, Ha SM. Reliability of the modified thomas test using a lumbo-plevic stabilization. *J Phys Ther Sci*. 2015;27(2):447-449.
51. Ferber R, Noehren B, Hamill J, Davis IS. Competitive female runners with a history of iliotibial band syndrome demonstrate atypical hip and knee kinematics. *J Orthop Sports Phys Ther*. 2010;40(2):52-8.
52. Baldon Rde M, Serrao FV, Scattone Silva R, Piva SR. Effects of functional stabilization training on pain, function, and lower extremity biomechanics in women with patellofemoral pain: A randomized clinical trial. *J Orthop Sports Phys Ther*. 2014;44(4):240-A8.
53. Irrgang JJ, Anderson AF, Boland AL, et al. Responsiveness of the international knee documentation committee subjective knee form. *Am J Sports Med*. 2006;34(10):1567-1573.

54. Anderson AF, Irrgang JJ, Kocher MS, Mann BJ, Harrast JJ, International Knee Documentation Committee. The international knee documentation committee subjective knee evaluation form: Normative data. *Am J Sports Med.* 2006;34(1):128-135.
55. Crossley KM, Bennell KL, Cowan SM, Green S. Analysis of outcome measures for persons with patellofemoral pain: Which are reliable and valid? *Arch Phys Med Rehabil.* 2004;85(5):815-822.
56. Marx, RG, Jones EC, Allen AA, Altchek DW, O'brien SJ, Rodeo SA, Williams RJ, Warren RF, Wickiewicz TL. Reliability, validity, and responsiveness of four knee outcome scales for athletic patients. *Journal of Bone and Joint Surgery.* 2001;83-A:1459-1469.
57. Naslund J, Naslund UB, Odenbring S, Lundeberg T. Comparison of symptoms and clinical findings in subgroups of individuals with patellofemoral pain. *Physiother Theory Pract.* 2006;22(3):105-118.
58. Nijs J, Van Geel C, Van der auwera C, Van de Velde B. Diagnostic value of five clinical tests in patellofemoral pain syndrome. *Man Ther.* 2006;11(1):69-77.
59. Portney L, Watkins M. *Foundations of clinical research: Applications to practice.* Third ed. Upper Saddle River, New Jersey: Pearson Education; 2009.
60. Gautam VK, Anand S. A new test for estimating iliotibial band contracture. *J Bone Joint Surg Br.* 1998;80(3):474-475.
61. Lubiani GG, Okunade AA. Production cost structure in US outpatient physical therapy health care. *Health Econ.* 2013;22(2):212-223.
62. Finnoff JT, Hall MM, Kyle K, Krause DA, Lai J, Smith J. Hip strength and knee pain in high school runners: A prospective study. *PM R.* 2011;3(9):792-801.

63. Thijs Y, Pattyn E, Van Tiggelen D, Rombaut L, Witvrouw E. Is hip muscle weakness a predisposing factor for patellofemoral pain in female novice runners? A prospective study. *Am J Sports Med.* 2011;39(9):1877-1882.