ASSOCIATION BETWEEN IMPAIRMENTS AND FUNCTION IN INDIVIDUALS WITH PATELLOFEMORAL PAIN SYNDROME

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of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2005

UNIVERSITY OF PITTSBURGH

FACULTY OF HEALTH AND REHABILITATION SCIENCES

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Purpose: To identify baseline impairments associated with physical function and to identify what changes in impairments are associated with functional outcome in patients with PFPS following a standardized physical therapy (PT) treatment at 2 and 6-month follow-ups.
Subjects: 74 patients diagnosed with PFPS and referred to PT treatment.
Methods: Correlational, predictive design. Baseline measurement session was performed to complete demographic questionnaires, self-reported measures, and undergo a physical exam. Impairments measured during physical exam included quadriceps strength, hip abduction strength, hip external rotation strength, hamstrings length, quadriceps length, plantar flexors length, ITB/TFL complex length, lateral retinacular length, foot pronation, Q-angle, tibial torsion, quality of movement, pain, and anxiety. Following the baseline, subjects participated in a standardized PT program. Then, measurement sessions were performed at 2 and 6-month follow-ups.
Analyses: Association between baseline impairment and function used a stepwise multiple regression in which potential confounder variables (age, sex, activity level, height and weight) were forced into the model as a single block. Then, impairment measures were entered in a stepwise procedure. Function measured by the Activity of Daily Living Scale (ADLS) was the criterion variable. Association between changes in impairment and function outcome was investigated with two stepwise multiple regressions, one with the 2 and the other with the 6-month follow-up data. The criterion variable was the ADLS of the respective follow-up controlled by the baseline ADLS. First, potential confounders were forced into the model as a single block. Then, changes in impairments and baseline pain were entered in a stepwise procedure.
Results and Clinical Relevance: At baseline our study indicates that after controlling the confounders, pain and tightness of lateral retinaculum predicted baseline function. Data suggested that pain may mediate the relationship between anxiety and function in patients with PFPS and the role of pain and anxiety in the prediction of function should be considered together with this population. At the 2 and 6-month follow-ups, after controlling the confounders, increased gastrocnemius length and increased quadriceps length predicted functional outcome, respectively. It seems that clinicians should specifically target impairments of soft tissue length in an attempt to improve functional outcome in patients with PFPS.

TABLE OF CONTENTS

ACKNOWLEDGMENTS x
1. CHAPTER I - INTRODUCTION 1
1.1. STATEMENT OF THE PROBLEM 1
1.2. AIMS AND HYPOTHESES 2
1.2.1. Specific Aim 1 3
1.2.1.1. Hypothesis Aim 1 3
1.2.2. Specific Aim 2 3
1.2.2.1. Hypothesis Aim 2 4
1.3. BACKGROUND 4
1.3.1. Definition, Prevalence and Etiology of PFPS 4
1.3.2. Physical Therapy and PFPS 5
1.3.3. Impairments Associated With the Etiology or the Presence of PFPS 7
1.3.3.1. Quadriceps Muscle Weakness 8
1.3.3.2. Hip Abductors and External Rotators Weakness 8
1.3.3.3. Quadriceps Muscle Tightness 9
1.3.3.4. Hamstrings Muscle Tightness 9
1.3.3.5. Tightness of Plantar Flexor Muscles 10
1.3.3.6. Tightness of Iliotibial Band/Tensor Fascia Lata Complex 11
1.3.3.7. Tightness of Lateral Retinacular Tissues 11
1.3.3.8. Poor Quality of Movement 11
1.3.3.9. Excessive Foot Pronation 12
1.3.3.10. Increased Q-Angle 13
1.3.3.11. Lateral Tibial Torsion 13
1.3.3.12. Increased Femoral Anteversion 14
1.3.3.13. Pain 14
1.3.3.14. Anxiety 14
1.3.4. Steps of This Study 15
2. CHAPTER II – RELIABILITY OF MEASURES OF IMPAIRMENTS ASSOCIATED WITH PATELLOFEMORAL PAIN SYNDROME 16
2.1. INTRODUCTION 16
2.2. METHODS 19
2.2.1. Subjects 19
2.2.2. Procedures 21
2.2.3. Measures 22
2.2.3.1. Hamstrings Length 22
2.2.3.2. Tightness of the Lateral Retinacular Structures 23
2.2.3.3. Q-Angle 23
2.2.3.4. Tibial Torsion 24
2.2.3.5. Quadriceps Length 24

2.2.3.6. Femoral Anteversion ... 24
2.2.3.7. Plantar Flexors Length ... 25
2.2.3.8. Hip External Rotation Strength ... 25
2.2.3.9. Hip Abduction Strength ... 26
2.2.3.10. Length of the Iliotibial Band/Tensor Fascia Lata (ITB/TFL) Complex ... 26
2.2.3.11. Foot Pronation ... 27
2.2.3.12. Quality of Movement during the Lateral Step Down Test ... 28
2.2.4. Data Analysis ... 31
2.3. RESULTS ... 32
2.4. DISCUSSION ... 33
2.5. CONCLUSION ... 39
3. CHAPTER III – PREDICTORS OF PHYSICAL FUNCTION IN PATIENTS WITH PATELLOFEMORAL PAIN SYNDROME ... 41
3.1. INTRODUCTION ... 41
3.2. METHODS ... 47
3.2.1. Subjects ... 47
3.2.2. Measures ... 48
3.2.2.1. Self-Reported Function ... 50
3.2.2.2. Self-Reported Activity Level ... 50
3.2.2.3. Self-Reported Pain ... 50
3.2.2.4. Self-Reported Anxiety ... 51
3.2.2.5. Impairment Measures ... 51
3.2.3. Data Analysis ... 51
3.3. RESULTS ... 53
3.4. DISCUSSION ... 61
3.5. CONCLUSION ... 70
4. CHAPTER IV – CHANGES IN IMPAIRMENT PREDICT FUNCTIONAL OUTCOME AFTER A PHYSICAL THERAPY TREATMENT IN PATIENTS WITH PATELLOFEMORAL PAIN SYNDROME ... 71
4.1. INTRODUCTION ... 71
4.2. METHODS ... 75
4.2.1. Subjects ... 75
4.2.2. Procedures ... 76
4.2.2.1. Physical Therapy Program ... 76
4.2.3. Measures ... 78
4.2.3.1. Self-Reported Function ... 78
4.2.3.2. Self-Reported Activity Level ... 79
4.2.3.3. Self-Reported Pain ... 79
4.2.3.4. Change in Impairment ... 79
4.2.4. Data Analysis ... 80
4.3. RESULTS ... 82
4.3.1. Baseline Characteristics of Patients ... 83
4.3.2. Changes in functional outcome and measures of impairment ... 83
4.3.3. Regression diagnostics of analyses with the 2 and 6-month follow-up data ... 86
4.3.4. Regression analysis with the 2-month follow-up data ... 86
4.3.5. Regression analysis with the 6-month follow-up data ... 89

4.4. DISCUSSION ... 92
4.5. CONCLUSION ... 102
5. CHAPTER V ... 104
5.1. SIGNIFICANCE AND DIRECTION OF FUTURE RESEARCH ... 104
APPENDIX A ... 108
Measurement Techniques of Physical Impairments and Reliability Coefficient of Each Measure ... 108
APPENDIX B ... 111
Physical Therapy Program- Description of Exercises and Progression ... 111
BIBLIOGRAPHY ... 115

LIST OF TABLES

Table 1: Demographic characteristics of the sample. Values represent the mean (Standard Deviation) unless otherwise stated. 20
Table 2: Illustration of the techniques used to measure impairments associated with PFPS. 29
Table 3: Results of the reliability analysis. 33
Table 4. Demographic and history information. Values represent the mean (SD) for variables age, height, and weight. For all other variables, the values represent number of patients per category (percentage). 49
Table 5. Descriptive statistics for the variables used in the multiple regression analysis. Values represent the mean (SD), except where noted otherwise. 54
Table 6. Correlation matrix of variables used in the multiple regression analysis. 58
Table 7. Stepwise multiple linear regression model predicting function. 60
Table 8. Standardized beta coefficients of each variable in the final model. 61
Table 9. Standardized beta coefficients of each regression equation to test the mediator effect of pain in the relationship between anxiety and function. 64
Table 10. Baseline characteristics of patients. 77
Table 11. Reasons for patients dropping out of study at the 2 and 6-month follow-up. 83
Table 12. Baseline characteristics of patients who completed and dropped out study participation at 2-month follow-up, and patients who completed and dropped out study participation at 6-month follow-up. Values represent the mean (SD), except where noted otherwise. 84
Table 13. Descriptive statistics of the variables ADLS score and changes in impairments from the baseline. Values represent the mean (SD), except where noted otherwise. 85
Table 14. Partial correlations of the 2-month follow-up data between the criterion and change in impairments when baseline ADLS score, age, sex, activity level, height, and weight are partialed out. 87
Table 15. Stepwise multiple linear regression predicting functional outcome at the 2-month follow-up. Criterion variable = 2-month Activity of Daily Living Scale (ADLS) score. 88
Table 16. Standardized beta coefficients of each variable in the final model. 88
Table 17. Partial correlations of the 6-month follow-up data between the criterion and change in impairments when baseline ADLS score, age, sex, activity level, height, and weight are partialed out. 90
Table 18. Stepwise multiple linear regression predicting functional outcome at the 6-month follow-up. Criterion variable = 6-month Activity of Daily Living Scale (ADLS) score. 91
Table 19. Standardized beta coefficients of each variable in the final model. 91

LIST OF FIGURES

Figure 1. Flow diagram of patient course during the study period. 82
Figure 2. Histogram of variable 2-month change in gastrocnemius length. 94
Figure 3. Histograms of variables 6-month change in external rotation strength and change in ITB/TFL length. 97

ACKNOWLEDGMENTS

A greatly appreciate the funding from Clinical Research Grant Program, Orthopaedic Section of American Physical Therapy Association, the Pennsylvania Physical Therapy Association Research Fund, and the OPTP and Endura Tape.

Thank you to my dissertation committee: Tony Delitto, the “big boss”. Thank you for believing and taking care of every step that resulted in my inclusion in the doctoral program. Tony sees the big picture of facts and is able to capture what is the best fit for the members of his team. His attitude is always positive towards new endeavors. As an exceptional facilitator, he showed me how to clear obstacles during the journey without having interfered in it. And, better yet, he does all these things without saying many words.

James Irrgang, the first mentor in my journey at Pitt. Thank you for always having 5 min. to discuss any of my doubts, although our discussions invariably ended up longer than that. Doesn’t matter where Jay was, he had the availability and the right answers or the sources that I needed. I don’t know how I would have made through the PhD level research process without Jay. With Jay’s example of hard work I learned that big accomplishments are not supposed to be easy.

Julie Fritz, who taught me to go straight to the point. Thank you for playing an important role in the genesis of this project. I wish we had worked longer together at Pitt. I enjoyed each project we’ve carried out not only for the learning experience but because of the friendship that has grown by sharing the same goals.

Steve Wisniewski, who taught me that meetings should not be scheduled at 12 am. Thank you for offering your expertise in statistical analysis. Your inputs have been invaluable. Your careful scrutiny has contributed to the rigor of this dissertation. I've learned the importance of having an expert as a consultant. I do not want to be an expert is statistics!

Kelley Fitzgerald, I could not have asked for a better mentor. Kelley is my dissertation chair and was my adviser throughout the PhD process. Words will probably not express my gratitude for all he has done. He is responsible for converting my writing skills from almost non-comprehensible to the level it is today. Kelley guided me through each stage of the research process. I highly appreciate his tough critics and strictness (Who said being a doctor would be effortless, anyway?). Through our several scholarly discussion he taught me the rigor of science. Kelley always respected my points of view, even when we radically disagreed. He has been a supportive and genuine friend who has shared his understanding about the importance of balancing family and work, always remembering that the ultimate goal is happiness.

Thank you to friends, colleagues, and family: John Childs, doctoral colleague and best friend during the doctoral degree. John helped me since the beginning of this project. He did not measure efforts to facilitate contact with clinical sites, devoted time to help me training the participating centers, and was always open to new adventures. It has been a fun privilege working with John. His initiative, energy, and vision have inspired me in many ways. However, we do not share his "working machine" capability.

Thanks to all the physical therapists who assisted me with data collection. Your help was crucial to get this work done: David Browder, Scott Jones, Benjamin Hando, and Tony Domenech. Special thanks to Jerry McGinty, who in addition of being an excellent clinician and research enthusiast, is a great friend and was my informal mentor when arriving at Pitt.

To avoid the risk of forgetting names, I would like to thank all my colleagues, friends, and staff of the PT department who have helped me in so many ways. Special thanks to a great clinical mentor and friend Dr. Richard E. Erhard. Thanks to Ray Burdett and Alexandra Gil.

Thanks to my family for their endless support and prayers, even at a long distance. My most sincere gratitude to the one who shared every moment of my journey at Pitt and of my personal life, my loved husband Enio. You gave up many of your priorities to let me pursue my dreams. Thank you for your patience, understanding, support, and love. Enio is the one who kept me going during difficult times. He really adds value to our vows "in sickness and in health, in happiness and…" I can only be a working Mom for Eduardo and Luiza (in the near future) because Enio is the devoted father.

1. CHAPTER I - INTRODUCTION

1.1. STATEMENT OF THE PROBLEM

Patellofemoral pain syndrome (PFPS) is a highly prevalent knee problem and accounts for 10 – 25% of all patients seen in physical therapy (PT).[13,21,62,111,126] Despite the fact that PT is the most frequently used conservative treatment for PFPS,[62,111] studies reported that approximately one fourth of the patients continue to have pain and dysfunction for more than one year after PT has been completed.[24,26,97,137] A review of clinical trials for treatment of PFPS suggested that improvements in pain and function due to PT are only consistent in the short-term and that there is inconclusive evidence to support the superiority of one particular intervention compared to another.[23]

One reason for the limited effectiveness of PT treatments in managing patients with PFPS perhaps has to do with the fact that treatment decisions are often based on improving impairments that have theoretically or experimentally been associated with the etiology or the presence of PFPS, such as muscle weakness, soft tissue tightness, structural alterations of the lower extremities, quality of movement, and pain.[47,117] Although these impairments have been suggested to contribute to the origin or presence of PFPS,[47,117] how these impairments relate to physical function in individuals with PFPS has not been established. We believe that identification of the key impairments related to function is the first step to assist in delineating physical therapy treatment approaches for patients with PFPS.

Another reason for the limited effectiveness of PT treatments may be the lack of awareness whether changes in impairments targeted during the PT treatment are in fact responsible for the improvements in function experienced by these patients. This lack of awareness has probably directed the focus of PT treatment approaches at improving impairments not related to functional outcome. Studies have shown that although the impairments targeted by the PT treatment appear to improve, such improvements do not seem related to improvements in function.[19,95,125] If it can be shown that changes in key impairments predict improvement in function, targeting such impairments may improve the effectiveness of PT for patients with PFPS.

Despite the prevalence of PFPS and the apparent difficulty in selecting effective interventions, there are no studies in the published literature seeking to investigate if baseline impairments are related to function and if changes in physical impairments are associated with functional outcome. This study will investigate if the same impairments related to the origin or the presence of PFPS also relate to physical function in this population and will identify what changes in impairments are associated with functional outcome in patients with PFPS following a standardized PT treatment.

1.2. AIMS AND HYPOTHESES

The overall aim of this study is to explore the association between impairments and function in a cohort of patients with PFPS.

1.2.1. Specific Aim 1

Identify the baseline impairments associated with physical function in a cohort of patients with PFPS, while accounting for age, sex, activity level, height and weight. Impairments explored include quadriceps weakness, hip external rotators weakness, hip abductors weakness, quadriceps tightness, hamstrings tightness, gastrocnemius tightness, soleus tightness, iliotibial band/tensor fascia lata (ITB/TFL) tightness, lateral retinaculum tightness, foot pronation, Q-angle, tibial torsion, femoral anteversion, quality of movement, pain, and anxiety.

1.2.1.1. Hypothesis Aim 1

It is hypothesized that lower baseline levels of function would relate to impairments consisting of decreased muscle strength, decreased soft tissue length, increased foot pronation, increased Q-angle, lateral tibial torsion, excessive femoral anteversion, poor quality of movement, and higher levels of pain and anxiety.

1.2.2. Specific Aim 2

Identify what changes in impairments are associated with functional outcome in a cohort of patients with PFPS following a standardized PT treatment at a 2 and 6-month follow-up, while accounting for age, sex, activity level, height and weight. Change in impairments explored included change in: quadriceps femoris strength, hip abduction strength, hip external rotation strength, hamstrings length, quadriceps length, gastrocnemius length, soleus length, ITB/TFL complex length, lateral retinacular structures length, and quality of movement.

1.2.2.1. Hypothesis Aim 2

It is hypothesized that the level of function at the conclusion of PT would relate to increased muscle strength and soft tissue flexibility, and improvement in quality of movement. It is also hypothesized that a similar relationship between change in impairments and functional outcome exist at the 2 and 6-month follow-up.

1.3. BACKGROUND

1.3.1. Definition, Prevalence and Etiology of PFPS

PFPS is the terminology used for patients with a clinical presentation of anterior knee pain, more typically retropatellar pain, after excluding other sources of anterior knee pain such as intra-articular pathology, peripatellar tendonitis or bursitis, plica syndromes, Sinding Larsen's disease, Osgood Schlatter's disease, neuromas and other rarely occurring pathologies.[43,126] The most common symptoms in patients with PFPS are pain and crepitation in the patellofemoral joint during and after physical activities such as running, walking up/down stairs, and squatting. In addition, pain while sitting with the knees flexed, occasional weakness, giving way, and catching sensations have also been reported.[43,126]

While knee injury is one of the most common reasons active young adults seek medical consultation, PFPS accounts for 20 – 40% of all knee complaints and represents from 10 to 25% of all visits seen in PT clinics.[13,21,62,111,126] The prevalence of PFPS dependents on sex and age, being more prevalent in females and young adults.[13,24,111] Dehaven and Lintner[24] reported that among patients with knee disorders examined in their clinic 18% of males and 33% of females had PFPS. Although PFPS can be observed in individuals as young as 10 years old to adults in the fifth decade of life, the highest incidence occurs in individuals from 13 to 19 years of age.[34]

The etiology pf PFPS is not clearly understood. Because patients with PFPS often place great demands on their knees, overuse is clearly part of the problem.[34] Some have suggested that the pain and discomfort experienced by patients with PFPS is likely the result of abnormal muscular and biomechanical factors that alter the tracking of the patella within the femoral trochlear notch.[47,117] Improper tracking of the patella changes the distribution of shearing and compressive forces on the patellofemoral joint during daily activities.[117] Alteration in patellofemoral tracking may increase patellofemoral contact pressures and contribute to patellar cartilage damage.[43,47] Since articular cartilage is devoid of nerve endings, the pain felt in the patellofemoral joint is suggested to originate from stress on retinacular tissue, subchondral bone irritation, synovitis or other inflammatory responses within the knee.[43]

1.3.2. Physical Therapy and PFPS

Several PT approaches have been proposed for individuals with PFPS.[19,28,32,52,77,91,95,109,110,121,125,143] Evidence to support the effectiveness of these treatments is limited. A review of randomized clinical trials of treatment of PFPS suggested that improvement in pain and function due to PT treatments are only consistent in the short-term follow-up.[23] They reported there is inconclusive evidence to support the superiority of one particular intervention compared to another.[23] We have recently conducted a systematic review of randomized trials and concluded that among the PT treatments used for the general population with PFPS, there are at least some evidence for the short-term improvement of pain and function with the use of quadriceps muscle strengthening combined with patellar taping and lower extremity stretching.[10]

Studies that have investigated the effect of PT treatment at a longer-term follow-up reported that approximately one fourth of the patients continue to have pain and dysfunction for more than one year after rehabilitation has been completed. Nimon et al[97] reported that 27% of the adolescents with idiopathic anterior knee pain treated with PT or immobilization continued to have symptoms for 16 years. Whitelaw et al[137] reported that 32% of patients with anterior knee pain who received PT had pain at an average follow-up of 16 months. Other two studies reported that at the 12-month follow-up 18% and 70%of the patients who received conservative treatment were still symptomatic.[24,26]

One reason for the limited effectiveness of PT treatments in managing patients with PFPS perhaps has to do with the fact that treatment decisions are often based on improving impairments that have theoretically or experimentally been associated with the etiology or the presence of PFPS.[62,126] Although these impairments have been related to the origin or presence of PFPS,[62,126] how these impairments relate to physical function in individuals with PFPS has not been clearly established. We believe that identification of the key impairments related to function is the first step to assist in delineating physical therapy treatment approaches for patients with PFPS. Therefore, it is necessary to determine if the impairments that have been suggested to contribute to the etiology or the presence of PFPS also impact the functional limitations observed in these patients.

Another reason for the limited effectiveness of PT treatments may be the lack of awareness whether changes in impairments targeted during the PT treatment are in fact responsible for the improvements in function experienced by these patients. This lack of awareness has probably directed the PT treatment at improving impairments not related to functional outcome. Several trials have utilized a cumbersome treatment approach addressing simultaneously many of the potential impairments related to the etiology or the presence of PFPS and have reported overall poor outcomes.[19,28,52] Conversely, studies that have targeted only one of the impairments related to PFPS have also reported poor outcomes.[95,110,125] A similarity among these studies is that although the impairments targeted by the treatment appear to improve, such improvements do not seem related to improvements in function.[19,95,125] Perhaps the focus of PT treatment approaches in these studies has not been directed at the proper impairments. If it can be shown that changes in key impairments predict improvement in function, targeting such impairments may improve the effectiveness of PT for patients with PFPS. Therefore, studies should determine whether improvements in impairments targeted during the PT treatment are associated with improvements in function.

1.3.3. Impairments Associated With the Etiology or the Presence of PFPS

To adequately investigate the association between impairments and function, we explored a great variety of impairments that have been related to PFPS. The impairments explored were selected based on either underlying theoretical constructs or on previous research which has demonstrated that several factors or impairments such as muscle weakness, soft tissue tightness, postural alterations of the lower extremities, quality of movement, anxiety, and pain contribute to the origin or the presence of PFPS.[34,43,62,125] We intended to be as exploratory as possible. Therefore, independent of the number of studies that investigated a particular impairment or the level of evidence that linked the impairment with PFPS, when there was at least a sound theory supporting the potential relationship between the impairment and PFPS, the impairment was included in our investigation. Following we provide the theory or findings from previous research about the several impairments we selected to examine in this study.

1.3.3.1. Quadriceps Muscle Weakness

It was suggested that the quadriceps muscles are responsible for the dynamic stabilization of the patella inside the trochlear groove by preventing excessive lateral and medial movement of the patella during knee flexion and extension.[54] Duffey et al[27] demonstrated that runners with anterior knee pain had weaker knee extensors when compared with asymptomatic runners and reported that the decreased quadriceps strength was a predictor of anterior knee pain. Powers et al[104] reported that subjects with PFPS had significantly less knee extensor torque than that of a comparison group without PFPS. Some authors suggested that quadriceps muscles strength was not associated with PFPS. Messier et al[94] compared a non injured group of runners and a group of runners with PFPS and reported that no significant muscular strength discriminators existed between the groups. Witvrouw et al[142] reported non differences in quadriceps strength between an athletic population with PFPS and healthy controls. All the above mentioned studies used sound design and methodology. Despite the controversy as to whether or not quadriceps muscle weakness contributes to PFPS, there is weak evidence that a regimen of quadriceps strengthening may decrease pain and increase function in a short-term follow-up in these patients.[91,121,143]

1.3.3.2. Hip Abductors and External Rotators Weakness

The hip abductors help to control rotational alignment of the limb and maintain pelvic stability in single leg stance.[42] Weak hip abductors may cause a compensatory dynamic valgus knee alignment resulting in increased stress on the iliotibial band. Because the iliotibial band attaches to the lateral surface of the patella, such an alteration may pull the patella laterally and increase the compressive forces on the lateral aspect of the patellofemoral joint potentially contributing to PFPS.[73] Regarding the hip external rotators, some authors have proposed that they help to eccentrically control femoral internal rotation during gait and sport activities.[90] Hip external rotators weakness may increase medial femoral rotation and valgus knee moments during the stance phase of walking.[56] The excessive knee valgus and medial femoral rotation may increase the Q-angle, which may pull the patella laterally and result in increased stresses over the lateral surface of the patellofemoral joint. Ireland et al[63] examined whether females with anterior knee pain are more likely to demonstrate hip abduction or external rotation weakness than a similar, asymptomatic, age-matched control group. They reported that subjects with PFPS demonstrated less hip abduction and hip external rotation strength than the controls.[63] We have performed a cross sectional study and have found that subjects with PFPS were significantly weaker in hip abduction but did not differ in hip external rotation strength when compared to a control group.[100]

1.3.3.3. Quadriceps Muscle Tightness

It is theorized that limited flexibility of the quadriceps muscles may pull the patella superiorly, thus increasing compression of the patellofemoral joint during physical activities.[54] There is a consensus in the literature that quadriceps muscle tightness is related to PFPS. Witvrouw et al[142] have found that, in a young athletic population, subjects that developed PFPS had shorter quadriceps muscles than subjects without PFPS. Using a stepwise logistic regression they identified shortened quadriceps muscles as one of the risk factor for the development of PFPS.[142] Smith et al[118] reported that in adolescent elite figure skaters decreased quadriceps flexibility was associated with PFPS.

1.3.3.4. Hamstrings Muscle Tightness

Authors have theorized that limited hamstring flexibility may contribute to PFPS by either requiring higher quadriceps force production to overcome the passive resistance offered by the hamstrings or by causing a slight knee flexion during physical activities, both which may result in increased patellofemoral joint reaction forces.[54] The evidence to support the above theory is rather contradictory. Smith et al[118] have shown that among adolescent skaters decreased hamstrings flexibility was correlated with PFPS. However, this study has several shortcomings that affects its validity (lack of control of potential confounder variables, tester not masked to subject's condition, and unclear statistical procedure). The only prospective study that investigated factors related to the development of PFPS that investigated this impairment reported that hamstrings tightness was not different between a group that developed PFPS and a group that did not.[142]

1.3.3.5. Tightness of Plantar Flexor Muscles

Plantar flexors tightness may result in limited ankle dorsiflexion, which could be compensated by either excessive subtalar pronation or external rotation of the lower leg to gain additional range of motion for the terminal stance phase of gait. The internal rotation of the lower extremity that accompanies subtalar pronation or the lower leg external rotation may both increase the quadriceps angle and consequently increase patellofemoral stresses. Two studies investigated the association between plantar flexors tightness and PFPS and reported conflicting results. Witvrouw et al[142] used a 2-year prospective study to assess risk factors associated with the development of anterior knee pain. They reported that among the 282 young athletes who were followed over the 2-year period, the individuals that developed PFPS had shorter gastrocnemius muscles than subjects that did not develop anterior knee pain In another study, Messier et al[94] used a cross-sectional design in a group of 20 runners with and 20 runners without PFPS. They found no differences in gastrocnemius length between the two groups. We are not aware of any study that investigated the isolated contribution of soleus muscles tightness on PFPS.

1.3.3.6. Tightness of Iliotibial Band/Tensor Fascia Lata Complex

Because the distal fibers of the ITB/TFL complex attach to the lateral aspect of the patella via the iliopatellar band,[124] it has been theorized that tightness of ITB/TFL complex may pull the patella laterally and increase the stress over the lateral surface of the trochlear groove.[13] Although there is no evidence to support this theory, several experts have proposed to stretch this structure in an attempt to reduce pain in patients with PFPS.[13,138]

1.3.3.7. Tightness of Lateral Retinacular Tissues

Tightness of the lateral retinacular tissues is believed to contribute to PFPS based on studies that theorized that in patients with patellofemoral malalignments there is an adaptative shortening of the lateral retinaculum as a consequence of the lateral displacement of the patella.[76,113] One study suggested that the lateral retinaculum may be the source of pain in patients with PFPS.[113] To date, there is no evidence to support the link between tightness of the lateral retinacular tissues and PFPS.

1.3.3.8. Poor Quality of Movement

Quality of movement, sometimes referred to as neuromotor control or movement coordination, refers to the biomechanics of the lower extremities and the various components of the musculoskeletal system in relationship with its surrounding during the performance of physical activities.[47] Subsequently, poor quality of movement refers to the improper biomechanics of the lower extremities, trunk and arms during physical activities. Because patients with PFPS seem to exhibit maladaptive alterations in lower extremity biomechanics, it was proposed that poor quality of movement may be a factor in the development of PFPS.[47] The alterations observed in individuals with PFPS may be related, in part, to the muscle imbalance caused by the decreased strength, difference in timing between synergic muscle groups or failure in recruitment of the lower extremity muscles.[13,15,142] Muscular imbalance, caused either by weakness or muscle length imbalances, was suggested to alter movement patterns, resulting in abnormal motion of the patella and alteration of the load distribution across the patellofemoral joint.[13,15,142] The alterations in lower extremity biomechanics can probably be identified as movements performed with poor quality.

1.3.3.9. Excessive Foot Pronation

Some authors have theorized a model where a pronated foot would cause compensatory internal rotation of the tibia and femur.[92] The internal rotation of the femur would move the center of the patella to a more medial position in relation to the anterior superior iliac spine, increasing the Q angle and the laterally directed forces on the patella.[42,43] Other authors have rejected the suggestion that a pronated foot causes medial rotation of the tibia and/or femur by showing a lack of relationship between peak foot pronation and the rotation of the tibia and femur.[107]

The evidence to support the theory that increased foot pronation causes PFPS is inconclusive. One study found a significant increase in rearfoot varus in individuals with PFPS compared with the control group.[103] Although rearfoot varus has been associated with overpronation,[35] foot pronation was not investigated in this study.[103] Another study indicated that foot pronation was a predictor of anterior knee pain in runners.[27] However, the amount of pronation was lower in symptomatic runners than in non-symptomatic.[27] Results of a randomized trial offer some support to the association between foot pronation and PFPS.[32] The authors tested the effectiveness of foot orthotics in decreasing pain in females with PFPS who over pronate. The group that received foot orthotics to limit foot pronation reported less pain.[32]

1.3.3.10. Increased Q-Angle

The rationale for quadriceps (Q) angle as a contributor of PFPS is based on the fact that both increases and decreases in the Q-angle measured in vitro in normal human knees were associated with increased peak patellofemoral pressures.[58] Alteration in Q angle may change the contact and pressure patterns of the patellofemoral joint, leading to excessive pressure in locations that are not typically exposed to these stresses.[94] Messier et al[94] have investigated the differences between a non injured control group of runners and a group of injured runners with PFPS. They reported that runners with PFPS had significantly higher values of Q angle (17 ± 0.6 degrees) than the controls (11 ± 0.4 degrees).[94] In addition, they suggested that Q angles in excess of 16 degrees may be significantly associated with PFPS in distance runners. Other researchers failed to find any direct correlation between Q angle and the etiology of PFPS.[27,67,68]

1.3.3.11. Lateral Tibial Torsion

Excessive lateral tibial torsion may contribute to PFPS by increasing tension in the infrapatellar tendon attachment on the patella, pulling the patella laterally and increasing the compression over the lateral patellofemoral joint.[29] Eckhoff et al[29] measured tibial torsion as the angle of static rotation of the tibia with respect to the femur in full knee extension using computed tomography images. They reported that the lateral rotation of the tibia relative to the femur was increased significantly in patients with PFPS (7 ± 1 degree) compared with subjects with no symptoms (1± 0.4 degrees). Another study performed with subjects with knee osteoarthritis suggested an association between lateral torsion of the leg and patellofemoral osteoarthritis.[123]

1.3.3.12. Increased Femoral Anteversion

Increased anteversion of the femur has been suggested to result in a lateral displacement of the patella, increase in the patellofemoral pressure, and contribute to the development of PFPS.[30] One study reported that an increased incidence of patellofemoral osteoarthrosis is associated with increased femoral anteversion.[81] In a series that compared a control group with patients who have failed a conservative treatment for anterior knee pain, Eckhoff et al[30] reported that the patients had significantly higher femoral anteversion (23 ± 12 degrees) than the control group (18 ± 7 degrees). In another study,[29] the same authors compared a control group with patients with PFPS and they reported that the difference in femoral anteversion was not significant.

1.3.3.13. Pain

No study has investigated the contribution of pain experience and PFPS. Although pain accompanies PFPS, perhaps pain should not be seen solely as a symptom of damage to the body. It has to be recognized if other psychological aspects associated with pain such as suffering, anger, pain expectancy, self-efficacy, fear, and depression may also affect function.[131;156;157] Patients with higher pain levels may suffer and because of this suffering, may not be able to perform as much or as well as the patients with less pain. The first step to advance the understanding of pain experience in patients with PFPS is to investigate the effect of pain on function.

1.3.3.14. Anxiety

Anxiety was suggested to contribute to the presence of PFPS.[14] Witonski[141] reported that patients with anterior knee pain manifested more anxiety and stress symptoms, and higher levels of hostility than a control group. Although the clinical significance of anxiety in individuals with

PFPS is not clear, we believe that high levels of anxiety may be associated with function or may influence the response of patients to the treatment of PFPS.

1.3.4. Steps of This Study

Despite the prevalence of PFPS and the apparent difficulty in selecting effective interventions, there are no studies in the published literature seeking to investigate if baseline impairments are related to function and if changes in physical impairments are associated with functional outcome. However, before exploring the associations between impairment and function in patients with PFPS, the reliability and measurement error of these impairment measures in this population has to be established. Reliability and measurement error are essential properties of any measurement that need to be established before the measurement can be considered clinically meaningful and useful.

Therefore, the first step of this study was to determine the inter-tester reliability and measurement error of the abovementioned impairments in patients with PFPS. This step of the study is reported in Chapter II. The second step of this study was aimed to investigate if the same impairments related to the etiology or the presence of PFPS also relate to physical function in PFPS prior to PT treatment (i.e. at baseline). This investigation is reported in Chapter III. In Chapter IV we reported the investigation in which we aimed to identify what changes in impairments are associated with functional outcome in patients with PFPS following a standardized PT treatment (i.e. at the 2 and 6-month follow-ups). In Chapter V we outline the significance of our study and discuss directions of future research.

2. CHAPTER II – RELIABILITY OF MEASURES OF IMPAIRMENTS ASSOCIATED WITH PATELLOFEMORAL PAIN SYNDROME

2.1. INTRODUCTION

Patellofemoral pain syndrome (PFPS) is a common knee problem among young active individuals.[13,24,111] The mechanism of PFPS is not well understood. It has been proposed that PFPS may arise from abnormal muscular and biomechanical factors that alter tracking of the patella within the femoral trochlear notch contributing to increased patellofemoral contact pressures that result in pain and dysfunction.[47,117] Authors have suggested a variety of impairments involved in the etiology of PFPS.[12] However, there is no evidence that these impairments are associated with the patient's functional limitations. In the absence of definitive impairments in which to focus the examination or treatment in patients with PFPS, clinicians tend to perform an extensive physical examination that generally includes a multitude of impairment measures such as[111] muscle weakness, soft tissue tightness, structural or postural alterations, and poor quality of movement.

The reliability and measurement error of several impairment measures used during the clinical examination of patients with PFPS has not been established. In some studies that have investigated the reliability of impairment measures associated with patellofemoral dysfunction, the samples did not include patients with PFPS.[48,50,55,108,114] Reliability and measurement error are essential properties of any measurement that needs to be established before the measurement can be considered clinically meaningful and useful. Reliability is the ability of a test to consistently yield more or less the same results when administered on several occasions to stable subjects, whereas measurement error provides the threshold for interpreting test results being reasonably confident that true change has occurred.[51,74]

Among the measures of muscle strength performed in patients with PFPS, measurement properties of hip abduction and hip external rotation strength tests have not been determined in patients with PFPS. Strength of hip abductors and external rotators are commonly measured in patients with PFPS because weakness of these muscles has been linked with PFPS.[56,90] Authors suggested these muscles help to maintain pelvic stability by eccentrically controlling femoral internal rotation during weight-bearing activities. Weakness may result in increased medial femoral rotation and valgus knee moments, augmenting compressive forces on the patellofemoral joint.[56,90] Current studies suggest that individuals with PFPS have weaker hip muscles when compared to matched control groups.[63,100]

Soft tissue restrictions, such as shortening of the quadriceps, hamstrings, and plantar flexor muscles, shortening of the iliotibial band/tensor fascia lata (ITB/TFL) complex, and shortening of the lateral retinacular structures have all been associated with PFPS and are impairments commonly measured in this population.[54,118,142] It is theorized that tight quadriceps and hamstrings may increase compression of the patellofemoral joint.[54] While two studies agree supporting the association of quadriceps flexibility and PFPS, the same studies conflict regarding the association of hamstrings flexibility and PFPS.[118,142] There is some evidence to support the association between plantar flexors tightness and PFPS.[142] Concerning the ITB/TFL and lateral retinacular tissues, although it has been theorized that tightness of these tissues may displace the patella laterally and increase the stress in the patellofemoral joint or medial retinacular tissue,[13,138] evidence to support such theory does not yet exist. In general, studies that investigated the measurement properties of all the above mentioned soft tissue measures have not used individuals with PFPS, have not determined the measurement error, or have failed to report an acceptable level of reliability.[2,11,31,48,108,120,135,146]

Studies examining the measurement properties of tests used to determine structural or postural alterations in patients with PFPS are also lacking. Some structural or postural alterations that have been linked to PFPS are excessive foot pronation, quadriceps angle (Q-angle), tibial torsion, and femoral anteversion. Evidence to support that increased foot pronation causes PFPS is inconclusive.[27,103] Regarding Q-angle, it was reported that Q-angle is more accentuated in runners with PFPS than in runners without PFPS.[94] To our knowledge, just one study has investigated the relationship between tibial torsion and PFP and reported that the lateral rotation of the tibia relative to the femur was increased in patients with PFP.[29] Studies that investigated the association of femoral anteversion and PFPS have reported conflicting results.[29,30] Although some measures of structural alterations have shown good reliability, [114]sample of patients with PFPS have rarely been used.[50,55,114]

Quality of movement refers to the biomechanics of the lower extremities, trunk and arms in relationship with its surrounding during physical activities.[47] It has been theorized that patients with PFPS exhibit altered movement patterns in the lower extremities that may result in alterations of the load distribution across the patellofemoral joint.[13,15,142] Altered movement patterns may be recognized during physical activities as movements performed with poor quality. We are unaware of studies that investigated the consistency of measures of quality of movement in patients with PFPS.

The purpose of this study was to determine the inter-tester reliability and measurement error of measures of impairments associated with PFPS in a population of patients diagnosed with PFPS. We examined the measurement properties of measures of hip abduction strength, hip external rotation strength, quadriceps length, hamstrings length, plantar flexors length, ITB/TFL complex length, lateral retinacular structures length, foot pronation, Q-angle, tibial torsion, femoral anteversion and quality of movement, because of their frequent use in the examination of individuals with PFPS and the lack of information concerning their reliability and measurement error.

2.2. METHODS

A single group repeated measures design was used in this study. Data for this study was obtained as part of a larger multicenter study that investigated predictors of function in persons with PFPS.

2.2.1. Subjects

Individuals were eligible to participate in this study if they were diagnosed by a physician with PFPS, were between 12 and 50 years of age, had pain in one or both knees, had duration of signs and symptoms greater than 4 weeks, had history of insidious onset not related to trauma, and had pain in the patellar region with at least three of the following: manual compression of the patella against the femur at rest or during an isometric knee extensor contraction, palpation of the postero-medial and postero-lateral borders of the patella, resisted isometric quadriceps femoris muscle contraction, squatting, stair climbing, kneeling, or prolonged sitting.

Exclusion criteria included previous patellar dislocation, knee surgery over the past 2 years, concomitant diagnosis of peripatellar bursitis or tendonitis, internal knee derangement, systemic arthritis, ligamentous knee injury or laxity, plica syndrome, Sinding Larsen's disease, Osgood Schlatter's disease, infection, malignancy, musculoskeletal or neurological lower extremity involvement that interferes with physical activity, and pregnancy. Thirty patients were recruited from 2 clinical sites (Lackland Air Force Base, in San Antonio, TX, and the Centers for Rehab Services that is affiliated with the University of Pittsburgh Medical Center, Pittsburgh, PA). All subjects who agreed to participate signed a consent form approved by the Institutional Review Board of the respective clinical site. Demographic characteristics of the participants are reported in Table 1.

Table 1: Demographic characteristics of the sample. Values represent the mean (Standard Deviation) unless otherwise stated.

Variable (n= 30)	
Age in years	29.1(8.4)
Number of females (%)	17 (59)
Height in cm	171 (11.1)
Weight in kg	79 (18.6)
Body Mass Index as kg/cm^2	.26 (.05)
Numeric Pain Rating Scale score	3.9 (1.9)
Activity of Daily Living Scale score	67.3 (17.3)

2.2.2. Procedures

Subjects had one lower extremity tested. Subjects with bilateral symptoms had the most affected knee selected for testing. The most affected knee was defined by the patient report of most painful knee. Data were collected during one assessment session that lasted approximately 60 minutes. Examiners met once during a 2-hour session before the study was initiated to review operational definitions and practice the procedures to ensure standardization. One meeting was performed at the local site (Pittsburgh) and one at the remote site (San Antonio). Each examiner was provided with the Manual of Standard Operating Procedures of the study, which contained detailed explanations about the performance of each test.

Two pairs of physical therapists with different levels of experience participated in data collection. One pair of testers had 2 and 10 years of clinical practice, whereas the other pair had 3 and 5 years of clinical experience. During each data collection session, the subject remained inside an examination room. To ensure that the examiners remained blinded to each other's assessments, the two examiners entered the examination room independently, performed and recorded the measurements, and then left the room. The results were not shared with the other examiner. The measurements were always performed in the same order. Measures in supine were performed first, followed by prone, side-lying, and standing positions. This was done to avoid the need for subjects to excessively change positions, to ensure that the examiners were performing all tests under the same conditions and that any effect that the order of testing might have on the assessments would be the same for each examiner. The order of the examiners was varied for each new patient.

2.2.3. Measures

Each participant completed a demographic questionnaire and self-reported measures of pain and function before performing the physical exam. Subjects' age, gender, height, weight, prior history of knee problems, mechanism of injury, duration of current episode, and symptom location were recorded.

Pain intensity was measured using an 11-point numeric pain rating scale ranging from 0 (No Pain) to 10 (Worst Imaginable Pain). Patients rated their current, best, and worst level of pain during the last 24 hours. The average of the three ratings was used to represent the patient's overall pain intensity. Numeric pain scales have been shown to be reliable and valid.[65,66,69,122]

The Activity of Daily Living Scale (ADLS) of the Knee Outcome Survey was used as a knee-specific measure of physical function.[64] The ADLS assesses the effects of knee impairment on activities of daily living. The ADLS consists of 14 items that measure the full spectrum of symptoms and functional limitations during activities of daily living that one may experience as a result of a variety of knee pathologies. The ADLS score is transformed to a 0 to 100 point scale with 100 indicating the absence of symptoms and functional limitations. Psychometric testing has demonstrated the ADLS to be reliable, valid and responsive in subjects with PFPS.[64,87]

Measurements performed during the physical examination follow:

2.2.3.1. Hamstrings Length

Length of the hamstrings was determined by measuring the straight leg raise using a gravity goniometer (MIE Medical Research Ltd., Leeks, UK). The subject was in the supine position with the knee being tested extended and the other leg flat on the table to avoid excessive posterior pelvic tilt. Before starting the measurement, the goniometer was zeroed on the lower half of the anterior border of the tibia. Then, the lower extremity was passively lifted to the end range of motion or firm end feel and the measurement recorded in degrees (Table 2). The average measurement of two trials with 5-second pause between trials was recorded.

2.2.3.2. Tightness of the Lateral Retinacular Structures

Tightness of the lateral retinacular structures was assessed with the patellar tilt test.[76] The patellar tilt test was performed with the subject in supine with the knee in full extension and the femoral condyles placed in the horizontal plane. The examiner attempted to lift the lateral edge of the patella from the lateral femoral condyle. The patella was not allowed to move laterally during the measurement (Table 2). The inability to lift the lateral boarder of the patella above the horizontal plane indicated a positive test for tightness of the lateral retinaculum. Adequate length of the lateral retinaculum or negative test was indicated by the ability to lift the lateral boarder of the patella above the horizontal plane. This test was performed once.

2.2.3.3. Q-Angle

Q-angle was measured with the knee in full extension with the subject in supine. The angle formed by the intersection of the line of application of the quadriceps force (line from the anterior superior iliac spine to the center of patella) with the center line of the patellar tendon (line from the center of the patella to the tibial tubercle) was measured in degrees with a universal goniometer (Table 2).[58] The center of the patella and the tibial tubercle were marked with a demographic pencil, which was wiped clean after the measurement. Before the measurement the tester palpated the anterior superior iliac spine and asked the subject to keep his second finger pointing down over this landmark during the measurement. This measurement was performed once.

2.2.3.4. Tibial Torsion

Tibial torsion was measured with a universal goniometer with the participant prone on a low table, and with the knee being tested bent at 90^0. This measurement was performed once. Height of the table was adjusted so the tester could comfortably visualize the plantar surface of the subject's foot. To facilitate visualization, the tester marked the most prominent aspect of the medial and lateral malleolus with a small dot. The examiner measured the angle formed by the axis of the knee (imaginary line from the medial to lateral femoral epicondile) and an imaginary line through the malleoli (Table 2). We elected to measure tibial torsion with the patient in a prone position rather than the position usually described with the patient sitting with knees in 90^o because tibial torsion is a horizontal plane rotational malalignment.[46,49] We believe that using an inferior view of the leg enables better observation of the talocrural joint axis in the horizontal plane.

2.2.3.5. Quadriceps Length

Length of the quadriceps muscle was determined by measuring the quadriceps femoris muscle angle during passive knee flexion with the subject in the prone position. Care was taken to avoid anterior tilting of the pelvis and/or extension of the lumbar spine. The angle of knee flexion in the prone position was measured using a gravity goniometer which was zeroed on a horizontal surface prior to the measurements. The gravity goniometer was placed over the distal tibia (Table 2). The average measurement of two trials with 5-second pause between trials was recorded.

2.2.3.6. Femoral Anteversion

Femoral anteversion was measured using the Craig's test with the participant in prone with the knee flexed to 90^o.[86] This measurement was performed once. Before starting the measurement, the gravity goniometer was zeroed on a vertical surface and placed on the medial surface of the lower leg, just proximal to the medial malleolus (Table 2). The examiner palpated the posterior aspect of the greater trochanter of the femur. The hip was then passively rotated until the most prominent portion of the greater trochanter reached the horizontal plane. The degree of anteversion was then estimated, based on the angle of the lower leg with the vertical (Table 2).

2.2.3.7. Plantar Flexors Length

Length of plantar flexors was determined by measuring the amount of ankle joint dorsiflexion with the knee extended and again with the knee flexed at 90°. Ankle dorsiflexion measured with the knee extended was used to account for the influence of gastrocnemius tightness. Measurement of ankle dorsiflexion with the knee bent was used to detect tightness of joint capsule or soleus muscle. The subject was positioned in the prone position with the foot hanging off the table and the subtalar joint was maintained in the neutral position. Dorsiflexion was measured with a standard goniometer as the angle formed by the lateral midline of the leg on a line from the head of the fibula to the tip of the lateral malleolus and the lateral midline of the foot in line with the border of the rearfoot/calcaneus (Table 2). The average measurement of two trials with 5-second pause between trials was recorded.

2.2.3.8. Hip External Rotation Strength

Strength measures were performed using the Lafayette Manual Muscle Test (MMT) System (Lafayette Instrument, Lafayette, IN). Muscle strength was recorded in terms of force, in kilograms. Hip external rotation strength was examined with the subject positioned in prone on a padded table with the knee being tested flexed to 90° and the hip in neutral rotation. The contralateral lower extremity was positioned with the hip in neutral rotation and the knee in full extension. To obtain optimal mechanical advantage, the examiner stood on the side of the table opposite of the test limb. Subjects exerted an isometric contraction of their hip external rotators for 3-5 seconds in a position of neutral hip rotation. The manual resistance against the external rotation was applied with the MMT just proximal to the medial malleolus (Table 2). To maintain uniformity in the nature of verbal commands provided by the tester during testing, the testers were instructed to always give a strong verbal encouragement during the performance of every maximum effort. The average force of two trials with one minute of rest between trials was recorded.

2.2.3.9. Hip Abduction Strength

Hip abduction strength was measured with the subject in side-lying with the hip being tested positioned superior with respect to the contralateral hip. To restrain body rotation, the subject's lower leg was slightly bent and the pelvis was blocked by the examiner's body. The subject's pelvis was stabilized with the examiner's free hand. Subjects exerted an isometric contraction of their hip abductors for 3-5 seconds in a position of approximately 30° of hip abduction and 5° of hip extension. The manual resistance was applied with the MMT proximal to the lateral malleolus in the direction of adduction (Table 2). To maintain uniformity in the nature of verbal commands provided by the tester during testing, the testers were instructed to always give a strong verbal encouragement during the performance of every maximum effort. The average force of two trials with one minute of rest between trials was recorded.

2.2.3.10. Length of the Iliotibial Band/Tensor Fascia Lata (ITB/TFL) Complex

Length of ITB/TFL complex was examined using the Ober's test.[73] The subject was positioned in side-lying with the leg being tested positioned superior and the lower leg slightly flexed at the hip and knee to maintain stability. The test leg was flexed to a right angle at the knee and grasped just below the knee with the examiner's distal hand. The examiner moved the subject's thigh first in flexion, then through abduction combined with extension until the hip was positioned in mid-range abduction with neutral flexion/extension. From this position the thigh was allowed to drop toward the table until the point were the limb stopped moving towards the table. At that point the measurement was taken. The gravity goniometer was zeroed on a horizontal surface prior to the measurement and was placed over the distal portion of the ITB/TFL complex (Table 2). The result was recorded as a continuous variable. Negative values represent more tightness whereas positive values (below horizontal) represent less tightness. The average measurement of two trials with 5-second pause between trials was recorded.

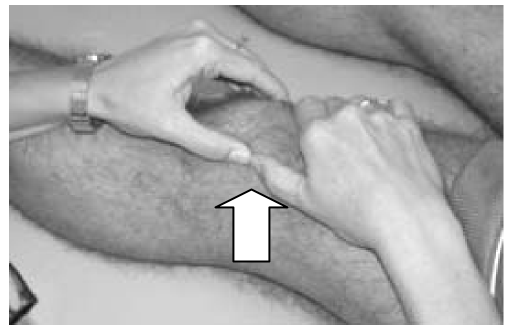
2.2.3.11. Foot Pronation

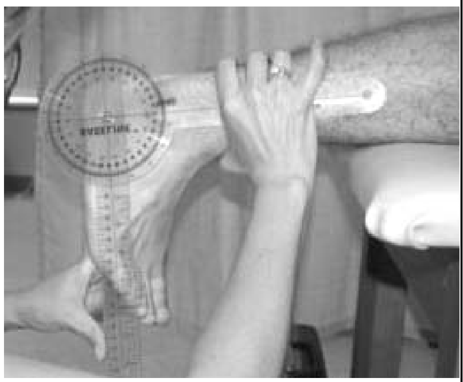
Foot pronation was measured by the navicular drop test.[92,114] Navicular drop test measures the difference between height of the navicular at subtalar joint neutral position and that of the relaxed stance position.[92,114] The subject stood on a high hard surface with his feet shoulder width apart. The examiner stayed behind the subject with the eyes leveled at subject's feet. The examiner marked the subject's navicular tuberosity with a demographic pencil, which was wiped clean after the measurement. The examiner put the subject in the subtalar joint neutral position. Using an index card placed perpendicular to the hard surface, the examiner recorded the distance from the navicular to the floor (Table 2). The subject was then instructed to relax from the subtalar neutral position and the measurement was repeated. Then, with a metric ruler, the distance between the two dots, in the index card (which represents the difference in the position of the navicular tubercle with respect to the floor between the subtalar neutral and relaxed standing positions) was recorded in millimeters. Greater distances between the dots indicate greater pronation. This measurement was performed once.

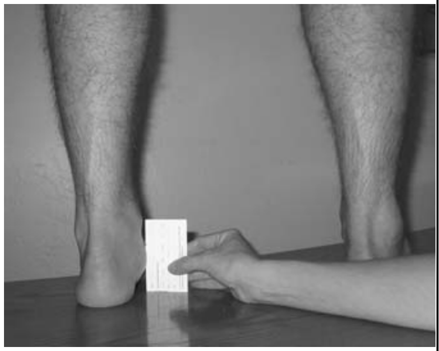
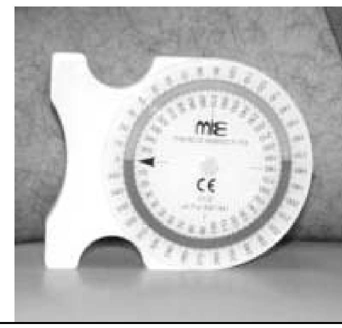
2.2.3.12. Quality of Movement during the Lateral Step Down Test

Quality of movement during the lateral step down test was assessed using a scale designed for this purpose. The subject was asked to stand in single limb support with the hands on the waist with the knee straight close to the edge of a 20 cm high step. The contralateral leg was positioned over the floor adjacent to the step and was maintained with the knee in extension. Subject bent the knee being tested until the contralateral leg gently contacted the floor and then re-extended the knee to the start position. This maneuver was repeated for 5 repetitions. The examiner faced the subject and scored the test based on 5 criteria: 1) Arm strategy. If subject used an arm strategy in an attempt to recover balance, add 1 point (Table 2); 2) Trunk movement. If the trunk leaned to any side, add 1 point; 3) Pelvis plane. If pelvis rotated or elevated one side compared with the other, add 1 point; 4) Knee position. If the knee deviated medially and the tibial tuberosity crossed an imaginary vertical line over the 2nd toe, add 1 point, or, if the knee deviated medially and the tibial tuberosity crossed an imaginary vertical line over the medial border of the foot, add 2 points, and; 5) Maintain steady unilateral stance. If the subject stepped down on the non-tested side, or if the subject tested limb became unsteady (i.e. wavered from side to side on the tested side), add 1 point. Total score of 0 or 1 was classified as good quality of movement, total score of 2 or 3 was classified as medium quality, and total score of 4 or above was classified as poor quality of movement.

Table 2: Illustration of the techniques used to measure impairments associated with PFPS.

ILUSTRATION OF MEASURES OF IMPAIRMENTS	
Hamstrings Length - Straight leg raise test  	**Tightness of the Lateral Retinacular Structures -** Patellar Tilt Test 
Q-Angle 	**Tibial Torsion** Angle formed between inter-epicondilar and intermalleolar lines 

Quadriceps Muscle Length - Quadriceps femoris muscle angle 	**Femoral Anteversion** Craig's Test 
Plantar Flexors Length 	**Hip External Rotation Strength** 
Hip Abduction Strength 	**ITB/TFL Complex Length-** Ober's Test 

Foot Pronation - Navicular Drop Test 	**Quality of Movement** Example of lateral step down test trial using arm strategy 
Technique to zero goniometer on horizontal surface 	**Technique to zero goniometer on vertical surface** 

2.2.4. Data Analysis

Descriptive statistics, including frequency counts for categorical variables and measures of central tendency and dispersion for continuous variables were calculated to summarize the data.

Inter-tester reliability for categorical or ordinal impairment measurements was determined by a Cohen's Kappa statistics and its 95% CI.[22] For continuous measurements an Intra- Class Correlation (ICC) coefficient and its 95% CI was used.[115,116] The ICC model (2, 1) was used when the unit of analysis was a single measurement, and the model (2,k) was used when the unit of analysis represented mean ratings.[115,116] The mean square estimates to calculate the ICC coefficients were obtained from a random effects 2-way analysis of variance with repeated measures.[115]

Calculation of the standard error of measurement (SEM) was used to determine measurement error. Results of the reliability analyses for the continuous measures were used to calculate the SEM. The SEM was calculated as ($SD * \sqrt{1 - r}$), where r is the test-retest reliability coefficient and SD is the standard deviation of the scores.[85,145]

2.3. RESULTS

Results of the reliability analysis are in Table 3. Table 3 shows the means and standard deviations of the continuous variables, the percentage of findings for categorical or ordinal variables, the reliability model used during the analysis, the reliability coefficient with the 95% CI, the standard error of measurement for continuous variables, and percentage agreement of categorical or ordinal variables.

Table 3: Results of the reliability analysis.

Variable (n = 30)	Mean (SD) or percentage of findings	Model Used	Reliability Coefficient	95% CI	SEM or percentage agreement
Hamstrings length (degrees)	81.5 (15.0)	ICC (2, k)	.92	(.82; .96)	4.3
Lateral retinacular length (tight, normal)	83% tight	Kappa	.71	(.57; .86)	93%
Q-angle (degrees)	12.2 (4.3)	ICC (2, 1)	.70	(.46; .85)	2.4
Tibial torsion (degrees)	17.6 (5.4)	ICC (2, 1)	.70	(.45; .85)	2.9
Quadriceps length (degrees)	138.5 (12.3)	ICC (2, k)	.91	(.80; .96)	3.8
Femoral anteversion (degrees)	12.8 (6.1)	ICC (2, 1)	.45	(.10; .70)	4.5
Gastrocnemius length (degrees)	9.3 (5.8)	ICC (2, k)	.92	(.83; .96)	1.6
Soleus length (degrees)	16.0 (6.0)	ICC (2, k)	.86	(.71; .94)	2.2
Hip external rotation strength (Kg)	17.1 (5.2)	ICC (2, k)	.79	(.56; .91)	2.4
Hip abduction strength (Kg)	12.9 (4.6)	ICC (2,k)	.85	(.68; .93)	1.8
ITB/TFL complex length (degrees)	15.5 (11.1)	ICC (2, k)	.97	(.93; .98)	2.1
Foot pronation (mm)	5.9 (2.7)	ICC (2, 1)	.93	(.84; .97)	0.7
Quality of movement (from 0 to 1= good; from 2 to 3 = medium; 4 and above = poor)	33% good 50% medium 17% poor	Kappa	.67	(.58; .76)	80%

2.4. DISCUSSION

Shrout's suggested a classification of reliability coefficients in which values less than 0.10 are considered virtually no agreement; 0.11 to 0.40 indicate slight agreement; 0.41 to 0.60 indicate fair agreement; values between 0.61 and 0.80 indicate moderate; and values greater than 0.81 indicate substantial agreement.[115] Based on this classification the inter-tester reliability coefficients were substantial for measures of hamstrings length, quadriceps length, gastrocnemius length, soleus length, ITB/TFL complex length, hip abductors strength, and foot pronation. Moderate values of reliability were observed for measures of Q-angle, tibial torsion, hip external rotation strength, lateral retinacular tightness, and test of quality of movement. Measurement of femoral anteversion resulted in fair reliability.

We believe that to make valid interpretation of measurements, the measurements must first demonstrate reasonable reliability. Interpretation of the confidence intervals around the values with substantial agreement (above 0.80) leads to the estimation that the inter-tester reliability of these measures falls anywhere between 0.68 and 0.98. Therefore, considering the worst case (lower bound of the 95% CI of hip abduction strength of 0.68), the reliability of these measures are still satisfactory for clinical use. Measures with a moderate level of reliability had their confidence intervals ranging from 0.45 and 0.91, with the lower bound of these intervals ranging from 0.45 to 0.58, which warrants some caution when interpreting the findings of Q-angle, tibial torsion, hip external rotation strength, tightness of lateral retinacular structures, and quality of movement. Regarding the interpretation of femoral anteversion, both the reliability coefficient value and the confidence intervals suggest that interpretation of this test's finding may not be consistent.

We are not aware of prior studies that determined the reliability of measuring hamstrings length using the straight leg raise test in a population of patients with PFPS. The substantial agreement of our results concords with three prior studies and disagrees with one study. Two studies that were performed with healthy adults and used standard goniometer to measure the straight leg raises reported intersession correlation of $r = 0.88$ and an ICC for inter-tester reliability of 0.99 for this measure.[20,57] Another study with a population of patients with low back pain that used a gravity goniometer to perform the measure reported an ICC of 0.87 for the inter-tester reliability and a SEM of 6.4 degrees.[41] Our results disagree with a study by Hunt at al performed with healthy individuals.[59] They reported fair inter-tester reliability, with ICC of 0.54 and 0.48 for the left and right leg respectively.[59] Because Hunt, et al, did not provide a description of subject inclusion criteria or a clear description of the test procedure used in their study,[59] it is not possible to speculate why their measures were less consistent than our findings or those of other studies. We can only suspect that the day-long time interval for inter-tester measures used in Hunt et al's study may have been too long and allowed that true variations in the compliance of these tissues may have happened.

We elected to measure hamstrings length using the straight leg raise test rather than the popliteal angle test to avoid the potential for ceiling effects with the later test.[73] In our clinical experience, the ceiling effect will happen with several patients with PFPS who may completely extend the knee before starting to feel the passive hamstrings resistance during the popliteal angle test. Therefore, in individuals with lesser hamstrings tightness, the popliteal angle will be limited on the ability to pick up subtle tightness.

Our study yielded better reliability for the patellar tilt test than that reported by Watson et al.[135] Watson et al's study included mainly asymptomatic individuals (19 symptomatic and 76 asymptomatic) as subjects and students as testers. They reported inter-tester reliability with Kappa values of .20, .33, and .35 for the three pair of testers, with respective percent agreements of 57%, 47%, and 62%.[135] We believe our study may have had higher reliability because we used experienced therapists who were familiar with the test in clinical practice. Another potential explanation for such difference is the exclusive use of patients diagnosed with PFPS in our study. Having only patients with PFPS may increase the incidence of positive findings and result in a more realistic determination of Kappa values. Watson et al[135] do not report the incidence of positive findings in their study.

Prior studies have reported lower levels of inter-tester reliability for measures of Q-angle than in our study. Tomsich et al. used a sample of healthy young individuals tested by therapists with experience ranging from 2.5 to 5.5 years and reported an ICC of .23 and a SEM of 3.7 degrees.[128] Greene et al. had 25 testers measuring each other's knees, two of whom had patellofemoral pain symptoms. They reported inter-tester reliability with ICC of .20 and .26 for left and right knee respectively.[48] The better reliability in our study could be explained by better standardization of measurements and training of raters, or by the fact that all our subjects were diagnosed with PFPS. As increases and decreases in Q-angle are associated with increased patellofemoral pressures, it is possible that patients with PFPS have more variability in the measures of Q-angle than asymptomatic individuals.[58] The decreased data variability in other studies may have artificially reduced the ICC values.

Our finding indicates a fair to poor reliability of the Craig's test to measure femoral anteversion, which is consistent with prior study that reported Pearson correlation coefficient of r = .47 for inter-tester reliability of this test.[50] The low reliability may be due to the difficulty in accurately palpating the greater trochanter and determining its most lateral position, especially in overweight individuals. To test this hypothesis, we divided the sample according to body mass index (BMI), in which individuals with BMI of .249 or below are classified as normal or underweight, and those with BMI of .25 or above are classified as overweight or obese.[37] The ICC for the 11 individuals with BMI of .249 or below was .81 (95% CI .39; .95), whereas for the 19 individuals with BMI of .25 or above was .20 (95% CI -.30; .60). Therefore, it appears that in overweight individuals measurements of femoral anteversion may be more difficult to perform and consequently less consistent. Until further study investigates the association of BMI and the consistency of femoral anteversion measures we recommend that clinicians make judgements based on the results of this measurement with caution.

Measures of dorsiflexion with the knees extended or flexed at 90^{o} resulted in substantial reliability, which is in disagreement with prior studies. Elvery et al reported ICC of .50 for intertester reliability for ankle passive dorsiflexion.[31] In another study Youdas et al reported and ICC of 0.28 for measurements of active dorsiflexion.[146] We believe our study may have resulted in better reliability for several reasons: 1) We trained the testers to be consistent with positioning the arms of the goniometer; 2) We stabilized the tibia during active dorsiflexion; 3) Measuring active dorsiflexion performed by the subject removes the confounding effect of tester strength that could be a problem if dorsiflexion was measured passively; 4) We used the average of two trials.

Our results are in agreement with previous studies that have indicated good reliability for measures of quadriceps length, hip abduction strength, ITB/TFL complex tightness, and foot pronation. Eng & Pierrynowski have tested the consistency of measures of quadriceps length using the quadriceps femoris muscle angle in a population of female with PFPS and reported and ICC of .94 for intra-tester reliability.[32] A prior study that examined the reliability of measuring hip abduction strength using a hand held dynamometer in runners with iliotibial band syndrome reported substantial inter-tester reliability, with an ICC of 0.96.[39] Another study used Pearson correlation coefficients to determine test–retest reliability using a hand held dynamometer in two boys with muscular dystrophy and reported correlation coefficients of 0.86 for hip abduction strength.[61] In a recent study, Reese & Bandy tested the reliability of measuring ITB/TFL complex in asymptomatic individuals using the Ober test as a continuous measure as we did and reported an ICC of .90.[106] A study that investigated the reliability of measuring foot pronation using the navicular drop test reported an ICC value of 0.73 for the inter-tester reliability.[114]

To our knowledge this is the first study that reports the reliability of measuring tibial torsion, hip external rotation strength, and quality of movement in patients with PFPS. Quality of movement was tested during the lateral step down test. This test was developed by our group based on the maladaptive alterations in lower extremity function that are normally observed during physical examination in patients with PFPS.[13,42,47,127] In addition to the step down test has shown to be reliable, we believe it is able to recognize altered movement patterns commonly observed in this population.[131] Further studies should validate this test against referenced measures of function.

An important element of the validity of measurements, and the subsequent ability to accurately interpret these measurements, relies on the evidence of satisfactory reliability and measurement error.[1] Poor reliability and high levels of measurement error reduce the usefulness of a test and limit the extent to which test results can be generalized.[1] Measurement error, determined in this study by calculating the SEM, refers to the hypothetical difference between an examinee's observed score on any particular measurement and the examinee's true score for the procedure.[1] Calculation of the SEM provides a threshold for interpreting the test results over time. Using this criterion with values of hamstrings length as an example, when the hamstrings length changes more than 4.3 degrees, one can be reasonably confident that true change has occurred, not just noise or measurement error. Further validation might be gained in future studies that determine how responsive to change these measurements are following interventions.

There is currently no consensus regarding the number of SEMs an individual's score must change for that change to confidently exceed measurement error. Previous researchers have reported one SEM as the best measure of meaningful change on health-related quality of life measures.[145] Moreover, the SEM has several properties that make it an attractive statistic for determining clinically meaningful change. First, the SEM accounts for the possibility that some of the change observed with a particular measure may be attributable to random error. Secondly, the SEM is independent of the sample under investigation; that is, the SEM is expected to remain relatively constant for all samples taken from a given population. Third, the SEM is expressed in the original metric of the measure, aiding its interpretation.[145]

To validate the use of the measures of impairments associated with PFPS tested in this study, further research is warranted in a number of areas. It should be determined whether these impairment measurements are related to pain and function in individuals with PFPS. It should also be determined whether these measurements are able to discriminate those with and without PFPS and whether changes in these impairment measurements after completing a rehabilitation program will be associated with improvement of pain and function.

2.5. CONCLUSION

Several of the impairments associated with PFPS had sufficient reliability for clinical use. Inter-tester reliability coefficients were substantial for measures of hamstrings length, quadriceps length, plantar flexors length, ITB/TFL complex length, hip abductors strength, and foot pronation. Moderate values of reliability were observed for measures of Q-angle, tibial torsion, hip external rotation strength, lateral retinacular tightness, and test of quality of movement, which warrants some caution when interpreting the findings of these tests. Measurement of femoral anteversion resulted in fair reliability, suggesting that interpretation of this test may not be consistent. Additional evidence is needed to support their use by testing if these impairment measurements are related to physical function and whether or not they can be used to guide treatment planning which ultimately would result in successful treatment outcomes.

3. CHAPTER III – PREDICTORS OF PHYSICAL FUNCTION IN PATIENTS WITH PATELLOFEMORAL PAIN SYNDROME

3.1. INTRODUCTION

Patellofemoral pain syndrome (PFPS) is characterized by clinical presentation of anterior knee pain after excluding other sources of pain such as intra-articular pathology, peripatellar tendonitis or bursitis, plica syndrome, Sinding Larsen's disease, Osgood Schlatter's disease, neuromas and other rarely occurring pathologies.[125] Symptoms of PFPS are pain and crepitation in the patellofemoral joint during and after physical activities such as running, walking up/down stairs, squatting, pain while sitting with the knees flexed, occasional weakness, giving way, and catching sensations.[125] PFPS is more prevalent in females and young adults and accounts for 20 – 40% of all knee complaints and 10 - 25% of all visits seen in physical therapy clinics.[13,21,62,111,125]

The source of pain in PFPS is likely the result of abnormal muscular and biomechanical factors that alter the tracking of the patella within the femoral trochlear notch.[117;47] Improper tracking of the patella changes the distribution of shearing and compressive forces on the patellofemoral joint during daily activities resulting in increased patellofemoral contact pressures and contributing to patellar cartilage damage.[43,47,117] Since articular cartilage is devoid of nerve endings, the origin of the pain is suggested to originate from stress on retinacular tissue, subchondral bone, synovitis or other inflammatory responses within the knee.[43]

Based on either underlying theoretical constructs or on previous research, several factors or impairments such as muscle weakness, soft tissue tightness, structural and postural alterations of the lower extremities, quality of movement, anxiety, and pain have been suggested to contribute to the origin or the presence of PFPS.[47;117] However, how these impairments relate to physical function in individuals with PFPS has not been clearly established. This study will investigate if the same impairments related to the origin of PFPS also relate to physical function in this population.

Among the active forces that may influence the tracking of the patella, weakness of the quadriceps femoris, hip abductors and hip external rotators muscles are impairments proposed to be associated with PFPS. It was suggested that quadriceps muscles are responsible for the dynamic stabilization of the patella inside the trochlear groove.[54] Some studies demonstrated that individuals with PFPS have weaker knee extensors when compared with asymptomatic controls.[27;104] Other studies have reported that quadriceps strength was not different in individuals with and without PFPS.[94;142] Despite this controversy, there is some evidence that a regimen of quadriceps muscle strengthening help to decrease pain and increase function in a short-term follow-up in patients with PFPS.[91,121,143]

Authors have suggested that the hip abductors aided by the hip external rotators maintain pelvic stability in single leg stance and eccentrically control femoral internal rotation during gait and sport activities.[90;42] Weakness of these muscles may cause a dynamic valgus knee alignment, which may result in increased medial femoral rotation and quadriceps angle. The increased medial femoral rotation and quadriceps angle may result in a laterally displaced patella which, in turn, may increase the stress on the patellofemoral joint.[73;56] Ireland et al examined whether females with anterior knee pain are more likely to demonstrate hip abduction or external rotation weakness than a similar, asymptomatic, age-matched control group.[63] They reported that subjects with PFPS demonstrated less hip abduction and hip external rotation strength than the controls.[63] We have also previously reported that subjects with PFPS were significantly weaker in hip abduction but did not differ in hip external rotation strength when compared to a control group.[100]

Passive forces believed to influence PFPS are tightness of the quadriceps, hamstrings, plantar flexors, iliotibial band/tensor fascia lata (ITB/TFL) complex, and lateral retinacular tissues.[54;118;142] It is theorized that limited flexibility of the quadriceps muscles may pull the patella superiorly, thus increasing compression of the patellofemoral joint during physical activities.[54] Witvrouw et al have found that, in a young athletic population, subjects that developed PFPS had shorter quadriceps muscles than subjects without PFPS.[142] Smith et al reported decreased quadriceps flexibility in adolescent elite figure skaters with PFPS.[118]

Authors have theorized that limited hamstring flexibility may contribute to PFPS by either requiring higher quadriceps force production to overcome the passive resistance offered by the hamstrings or by causing slight knee flexion during physical activities, both which may result in increased patellofemoral joint reaction forces.[54] The limited evidence regarding the contributing role of the hamstrings in PFPS is conflicting. One study demonstrated a relationship between limited hamstrings flexibility and PFPS[118] while another failed to establish any relationship.[142]

Plantar flexor tightness may result in limited ankle dorsiflexion, which could be compensated by either excessive subtalar pronation or external rotation of the lower leg to gain additional range of motion for the terminal stance phase of gait. The internal rotation of the lower extremity that accompanies subtalar pronation or the lower leg external rotation may both alter the quadriceps angle and consequently increase patellofemoral stresses. Two studies investigated the association between plantar flexor tightness and PFPS and reported conflicting results. Witvrouw et al reported that young athletes followed over a 2-year period who developed PFPS had decreased gastrocnemius flexibility.[142] Messier et al used a cross-sectional design to compare ankle dorsiflexion between runners with and without PFPS and found no differences between the two groups.[94]

Because the distal fibers of the ITB/TFL complex attach to the lateral aspect of the patella via the iliopatellar band,[124] it has been theorized that tightness of ITB/TFL complex may pull the patella laterally and increase the stress over the lateral surface of the trochlear groove.[13] Tightness of the lateral retinacular tissues was also suggested to contribute to PFPS.[76,113] Authors have suggested that in patients with patellofemoral malalignments there is an adaptative shortening of the lateral retinaculum as a consequence of the lateral displacement of the patella.[76,113] One study suggested that the lateral retinaculum may have a key role in the origin of patellofemoral pain.[113] To date, there is no evidence to support the link between tightness of the ITB/TFL complex or the lateral retinacular tissues with PFPS.

Some structural and postural alterations of the lower extremities such as excessive foot pronation, quadriceps angle, lateral tibial torsion and femoral anteversion were suggested to contribute to PFPS.[27,54,58,103] The evidence to support the theory that increased foot pronation causes PFPS is inconclusive. One study found a significant increase in rearfoot varus in individuals with PFPS compared with the control group.[103] Although rearfoot varus has been associated with overpronation,[54] foot pronation was not investigated in that study. Another study indicated that foot pronation was a predictor of anterior knee pain in runners.[27] However, the amount of pronation was lower in symptomatic runners than in non-symptomatic runners.[27] Results of a randomized trial offer some support to the association between foot pronation and

PFPS.[32] The authors tested the effectiveness of foot orthotics in decreasing pain in females with PFPS who over pronate. The group that received foot orthotics to limit foot pronation reported less pain.[32]

The rationale for quadriceps (Q) angle as a contributor of PFPS is based on the fact that both increases and decreases in the Q-angle measured in vitro in normal human knees were associated with increased peak patellofemoral pressures.[58] While some researchers reported that runners with PFPS had significantly higher values of Q angle than a control group without PFPS,[94] other researchers failed to find any correlation between Q angle and PFPS.[27,67,68]

Excessive lateral tibial torsion may contribute to PFPS by increasing tension in the infrapatellar tendon attachment on the patella, pulling the patella laterally. Eckhoff et al[29] measured tibial torsion as the angle of static rotation of the tibia with respect to the femur in full knee extension using computed tomography images and reported increased tibial torsion in patients with PFPS compared with subjects with no symptoms.

Evidence regarding the association between femoral anteversion and PFPS is conflicting. One study reported that patients who have failed a conservative treatment for anterior knee pain had significantly higher femoral anteversion than the group who improved with treatment.[30] Another study compared femoral anteversion between an asymptomatic control group and patients with PFPS and reported no significant differences between the groups.[29] A third study reported that higher incidence of patellofemoral osteoarthrosis was associated with increased femoral anteversion.[123]

Some authors have theorized that poor quality of movement may be associated with PFPS, though no scientific evidence has been provided to support this notion.[47,131] Quality of movement, also referred to as neuromotor control, refers to the biomechanics of the lower extremities and the various components of the musculoskeletal system in relationship with its surrounding during the performance of physical activities.[47] It was suggested that patients with PFPS exhibit altered movement patterns related to the muscle imbalance caused by decreased strength, decreased muscle length, or difference in timing between synergic muscle groups of the lower extremity.[13,15,142] The altered movement patterns or poor quality of movement may result in abnormal load distribution across the patellofemoral joint and contribute to PFPS.[13,15,142]

We believe that factors such as anxiety and pain levels may both be associated with function. Anxiety was suggested to contribute to the presence of PFPS.[14] Witonski[141] reported that patients with anterior knee pain manifested more anxiety and stress symptoms, and higher levels of hostility than a control group. Regarding pain, no study has investigated the contribution of pain experience and PFPS. Although pain accompanies PFPS, perhaps pain should not be seen solely as a symptom of damage to the body. It has to be recognized if other psychological aspects associated with pain such as suffering, anger, pain expectancy, and fear of pain may also affect function.[35,40,133] Patients with higher pain levels may suffer and because of this suffering, may not be able to perform as much or as well as the patients with less pain. The first step to advance the understanding of pain experience in patients with PFPS is to investigate the effect of pain on function.

Although all the impairments presented above have theoretically or experimentally been associated with the presence of PFPS, is has not been determined if these same impairments also influence the level of physical function in individuals with PFPS. We believe that identification of the key impairments related to function is the first step to assist in delineating physical therapy treatment approaches for patients with PFPS. Therefore, it is necessary to determine if the impairments that have been suggested to contribute to the presence of PFPS also impact the functional limitations observed in these patients. There may only be a small number of impairments that account for the patient's functional level. Targeting these impairments in the future may improve the effectiveness of rehabilitation for restoring function in patients with PFPS.

The purpose of this study was to explore the relationship between impairments and physical function in patients with PFPS. We hypothesized that lower levels of function would be related to decreased muscle strength, decreased soft tissue flexibility, excessive foot pronation, excessive quadriceps angle, lateral tibial torsion and femoral anteversion, poor quality of movement, and higher levels of pain and anxiety.

3.2. METHODS

A correlational, predictive design was used in this study to explore the relationship between impairments and physical function in a cohort of patients with PFPS.

3.2.1. Subjects

Individuals were eligible to participate in this study if they were diagnosed by a physician with PFPS, were between 12 and 50 years of age, had pain in one or both knees, had duration of signs and symptoms greater than 4 weeks, had history of insidious onset not related to trauma, and had pain in the patellar region with at least three out of the following: manual compression of the patella against the femur at rest or during an isometric knee extensor contraction, palpation of the postero-medial and postero-lateral borders of the patella, resisted isometric quadriceps femoris muscle contraction, squatting, stair climbing, kneeling, or prolonged sitting.

Exclusion criteria included previous patellar dislocation, knee surgery over the past 2 years, concomitant diagnosis of peripatellar bursitis or tendonitis, internal knee derangement, systemic arthritis, ligamentous knee injury or laxity, plica syndrome, Sinding Larsen's disease, Osgood Schlatter's disease, infection, malignancy, musculoskeletal or neurological lower extremity involvement that interferes with physical activity, and pregnancy.

Seventy four patients were recruited across 4 clinical sites in distinct geographical regions in the United States from January 2003 through July 2004. From the 74 patients recruited into the study, 25 were from Minot Air Force Base, ND, 23 from Lackland Air Force Base, in San Antonio, TX, 17 from Travis Air Force Base, in Fairfield, CA and 9 from the Centers for Rehab Services, which is affiliated with the University of Pittsburgh Medical Center in Pittsburgh, PA. Although the majority of subjects came from military sites, some of these subjects were from the civilian population and the greater part of the military personnel was not in active duty. All subjects who agreed to participate signed a consent form approved by the Institutional Review Board of the respective clinical site.

3.2.2. Measures

All subjects completed demographic questionnaires, self-reported measures (function, level of physical activity, pain, and anxiety), and underwent a physical exam performed by a physical therapist. Subject's characteristics recorded in the demographic questionnaire are reported in Table 4.

Table 4. Demographic and history information. Values represent the mean (SD) for variables age, height, and weight. For all other variables, the values represent number of patients per category (percentage).

Variable (n= 74)		
Age in years		29.3 (8.8)
Height in cm		170 (12)
Weight in kg		76 (16)
Number of females (%)		39 (53)
Race (%)	Caucasian	50 (68)
	African-American	8 (11)
	Hispanic	8 (11)
	Asian	3 (4)
	Native-American	1 (1)
	Other	4 (5)
Involved side (%)	Left	14 (19)
	Right	24 (32)
	Bilateral, left most painful	17 (23)
	Bilateral, right most painful	19 (26)
Work activity (%)	Mostly sedentary	18 (24)
	Sedentary, walking required	13 (18)
	Moderately active	34 (46)
	Demanding	9 (12)
Employment Status (%)	Full time	64 (87)
	Part time	2 (3)
	Unemployed	3 (4)
	Homemaker	1 (1)
	Student	4 (5)
Number of patients who use medication for PFPS (%)		43 (58)
Chronicity of pain (%)	1 – 3 months	26 (35)
	4 – 6 months	17 (23)
	7 – 12 months	7 (10)
	13 – 24 months	13 (18)
	> 25 months	10 (14)
Number of prior episode (%)	None	27 (36)
	1	33 (45)
	2 – 3	4 (5)
	4 – 5	5 (7)
	6 or more	5 (7)

3.2.2.1. Self-Reported Function

Function was measured by the Activity of Daily Living Scale of the Knee Outcome Survey (ADLS).[64;12] The ADLS is a knee specific measure of physical function that assesses the effects of knee impairment on activities of daily living. The ADLS consists of 14 items that measure the full spectrum of symptoms and functional limitations during activities of daily living that one may experience as a result of a variety of knee pathologies. Each item is scored on a six-point Likert-type scale. The ADLS score is transformed to a 0 to 100 point scale with 100 indicating the absence of symptoms and functional limitations. Psychometric testing has demonstrated the ADLS to be reliable and valid.[64] A recent study used a population of athletic patients to compare the ADLS with other three knee outcome scales and reported that the ADLS was the most reliable, valid and responsive among the scales investigated.[87]

3.2.2.2. Self-Reported Activity Level

Level of physical activity was measured by the rating of activity of the International Knee Documentation Committee.[53] This rating allows subjects with knee pathologies to record their level of activity using four pre-defined activity levels: 1 - jumping, pivoting, hard cutting, football, soccer; 2 – heavy manual work, skiing, tennis; 3 – light manual work, jogging, running; 4 – activities of daily living, sedentary work.

3.2.2.3. Self-Reported Pain

Pain was measured using an eleven-point numeric pain scale. This scale was anchored on the left with the phrase “No Pain” and on the right with the phrase “Worst Imaginable Pain”. Numeric pain scales were shown to be reliable and valid.[66,69,87] Subjects rated their current level of pain, the worst pain, and the least amount of pain in the last 24 hours, and the ratings were averaged.

3.2.2.4. Self-Reported Anxiety

Anxiety was measured using the Beck Anxiety Index (BAI).[8] The BAI consists of 21 items, each scored 0-3. Possible score ranges from 0 – 63 with higher scores indicating higher levels of anxiety. The BAI has been shown to be a reliable and valid tool to assess the presence and magnitude of anxiety symptoms.[8,119]

3.2.2.5. Impairment Measures

Physical impairments were measured during the physical examination and included quadriceps femoris strength, hip abduction strength, hip external rotation strength, hamstrings length, quadriceps length, gastrocnemius length, soleus length, ITB/TFL complex length, lateral retinacular structures length, foot pronation, Q-angle, tibial torsion, and quality of movement. Subjects had one lower extremity tested. Subjects with bilateral symptoms had the most affected knee selected for testing based on the self-reported pain. Measurement techniques and the reliability coefficient for each measure are provided in Appendix A. With exception of quadriceps femoris strength, all the other impairments measured during the physical examination had their reliability determined during this study. Reliability of measures of quadriceps strength as performed in this study was not investigated because it has been well established.[82,93] Details about the methodology of the reliability component of this study is described in Chapter II.

3.2.3. Data Analysis

The association between impairment and function in patients with PFPS was investigated with a stepwise multiple regression[102] using the ADLS score as the criterion variable. The predictor variables were potential confounding variables (age, sex, activity level, height and weight) and the above mentioned measures of impairments previously associated with PFPS. The measures of impairments were continuous variables, with exception of lateral retinacular length and quality of movement. Lateral retinacular length was a categorical variable (tight or normal) and quality of movement was an ordinal variable with 3 categories (good, medium or poor). Two dummy variables were created for quality of movement.

Age and sex were treated as confounders because prior research has shown that they may affect the association between impairment and function.[34;43] Activity level was a confounder because the development and exacerbation of PFPS is related to increased physical activity and overloading of the patellofemoral joint.[34] Three dummy variables were created for the 4 categories of level of physical activity. Height and weight were treated as confounders to account for the effect of body size on strength and length measurements.

Before performing the stepwise regression, regression diagnostics were performed and measures of impairments were screened based on their reliability. We planned to exclude variables with reliability coefficients below 0.6. Descriptive statistics and bivariate correlations (Pearson product moments and Spearman Rho) among the variables were analyzed. A stepwise multiple regression was performed in two steps. In the first step, potential confounder variables were forced to enter into the model as a single block. In the second step, the block of impairment measures were entered into the model in a stepwise procedure. The probability of the F value for this analysis was set at 0.05 to enter the model, and 0.10 for removal of the model. The stepwise approach was used to determine if the impairments would improve the fit of the regression model after controlling for age, sex, activity level, height and weight. For each impairment accepted into the model the adjusted R^2 value was calculated, reflecting the goodness of fit of the linear model adjusted for the number of predictor variables in the equation. Significance of the linear association of each variable was tested. Standardized beta coefficients for each variable in the final model were calculated and the significance of each was tested under the null hypothesis that the coefficient was not different from zero.[140]

3.3. RESULTS

Femoral anteversion was excluded from the analysis because its reliability coefficient was 0.45 (Appendix A). Other impairment measures had reliability coefficients above 0.6. Descriptive statistics of the variables used in the analysis are summarized in Table 5.

Bivariate correlations between the variables are shown in Table 6. Only the predictor variables lateral retinacular tightness, pain and anxiety demonstrated significant relationships with the criterion variable ADLS score. Implications of these findings will be examined in further detail in the discussion. The bivariate correlations among the confounders supported controlling for these variables: The negative association between activity level and ADLS suggested that more active individuals had better function. Age was negatively associated to pain, suggesting that younger individuals had higher magnitude of pain. Sex was positively associated with hamstrings length, soleus length, and Q-angle, indicating that females had greater flexibility of the hamstrings and soleus muscles, and higher Q-angle. Sex was negatively associated with height, weight, quadriceps strength, hip abduction strength, hip external rotation strength, and tightness of lateral retinaculum, indicating that females were shorter, lighter, had weaker quadriceps and hip muscles, and had less tightness of lateral retinaculum than males. The positive association between height, weight, and the three measures of strength indicated that

Table 5. Descriptive statistics for the variables used in the multiple regression analysis. Values represent the mean (SD), except where noted otherwise.

Variable (n = 74)			**Actual Range Minimum-Maximum**
Activity of Daily Living Scale score		66 (17)	29- 96
Age in years		29 (9)	12.0 - 50.0
Female (%)		39 (53)	
Activity level – patients per category (%)	Jumping, pivoting, cutting, football, soccer	9 (12)	
	Heavy manual work, skiing, tennis	6 (8)	
	Light manual work, jogging, running	22 (30)	
	Act. of daily living, sedentary work	37 (50)	
Height in cm		170 (12)	135 to 198
Weight in kg		76 (16)	43 to 114
Quadriceps strength in Nm		192 (73)	55 to 385
Hip ABD strength in Kg		12 (4.4)	4.4 to 26.6
Hip ER strength in Kg		15 (5.5)	5.6 to 27.5
Hamstrings length in degrees		78 (12.2)	49 to 117
Quadriceps length in degrees		132 (11.4)	110 to 166
Gastrocnemius length in degrees		7.4 (5.6)	-5 to 29
Soleus length in degrees		14.8 (5.4)	2 to 31
Iliotibial band/ tensor fascia lata length in degrees		13.7 (9.6)	-10 to 37
Lateral retinacular structures length -positive test (%)		54 (73)	
Foot pronation (Navicular drop test) in mm		6.3 (3.6)	0.0 to 17.0
Q-angle in degrees		14.4 (5.4)	5.0 to 28.0
Tibial torsion in degrees		17.7 (4.9)	10.0 to 32.0
Quality of movement –patients per category (%)	Good	16 (22)	
	Medium	47 (64)	
	Poor	11 (14)	
Numeric Pain Rating Scale score		3.8 (1.9)	0.0 to 7.0
Beck Anxiety Index		4.9 (6.7)	0.0 to 28.0

Table 6. Correlation matrix of variables used in the multiple regression analysis.

n = 74	Age	Sex	AL	Height	Weight	Quadr strength	Hip ABD strength	Hip ER strength	Hamst length	Quadr length	Gastroc length	Soleus length	ITB/TFL length	LRS length	Foot pronation	Q-angle	Tibial torsion	Quality of mvmt	Pain	BAI
ADLS	.09	-.17	-.23*	-.00	-.03	.04	.06	.09	-.11	.10	.15	-.13	-.12	.22*	-.03	.06	.11	-.07	-.62**	-.45**
Age	-	-.07	.05	-.04	.17	.03	-.11	.07	.18	-.09	.12	.14	.14	.11	.00	-.03	.03	.06	-.22*	-.15
Sex		-	.00	-.66**	-.72**	-.60**	-.42**	-.66**	.38**	.12	.03	.20*	-.04	-.21*	-.01	.40**	.12	.16	-.09	.09
AL			-	-.06	-.01	.04	.07	.05	.00	.10	-.21	-.16	-.09	-.19	-.10	-.08	.01	-.10	.10	.05
Height				-	.69**	.45**	.31**	.42**	-.28**	-.20*	-.06	-.14	.02	.11	-.00	-.33**	-.10	-.04	.19*	.03
Weight					-	.61**	.27**	.58**	-.28**	-.40**	-.10	-.20*	.01	.21*	-.02	-.24*	-.09	-.02	.12	.00
Quadr strength						-	.44**	.67**	-.03	-.15	.16	.02	-.06	.14	.02	-.28**	-.15	-.24*	.05	.00
Hip ABD strength							-	.67**	-.08	.03	-.01	-.16	-.30**	.21*	-.07	-.02	.12	-.05	.04	-.17
Hip ER strength								-	-.22	-.04	.12	-.14	-.05	.26*	-.03	-.16	-.05	-.11	-.04	-.11
Hamst length									-	.19	.27*	.33**	.13	-.11	-.02	.03	.09	.06	-.19	-.05
Quadr length										-	.37**	.39**	.21*	.08	.02	-.06	.11	-.03	.02	.01
Gastroc length											-	.49**	.30**	.18	.00	.06	.13	.00	-.14	-.04
Soleus length												-	.26*	.08	.14	-.03	-.05	.11	.01	.15
ITB/TFL length													-	.06	-.03	-.19	-.24*	-.14	.14	.02
LRS length														-	-.15	-.02	-.01	.03	.14	-.23*
Foot pronation															-	.07	-.13	.21*	-.05	.05
Q-angle																-	.20	.17	-.13	-.02
Tibial torsion																	-	.24*	-.18	-.09
Quality of mvmt																		-	-.03	-.04
Pain																			-	.34**

* Significant at $p \leq .05$; ** Significant at $p \leq .01$; ADLS- activity of daily living scale; AL- activity level; Quadr- quadriceps; ABD- abduction; ER – external rotation; Hamst – hamstrings; Gastroc – gastrocnemius; ITB/TFL- ileotibial band/tensor fascia lata; LRS – lateral retinacular structures; Q- quadriceps; Mvmt- movement; BAI- Becky Anxiety Index.

taller individuals were heavier and had stronger quadriceps and hip muscles. Height and weight were both negatively associated with hamstrings length, quadriceps length, and Q-angle, suggesting that taller and heavier individuals had shorter muscles in front and back of the thighs and smaller Q-angle. Height was also positively associated with pain, indicating that taller individuals had more pain. Weight was positively associated with lateral retinaculum tightness and negatively associated with soleus length, suggesting that heavier individuals had tighter lateral retinaculum structures and tighter soleus muscles.

The three strength measures, quadriceps strength, hip abduction and hip external rotation strength, were all positively related to each other, indicating that individuals with stronger quadriceps also had stronger muscles around the hip. Quadriceps strength was also negatively associated with Q-angle and quality of movement, indicating that individuals with weaker quadriceps had higher Q-angle and had more difficulty performing the step down test. The negative correlation between hip abduction strength and ITB/TFL length suggests that individuals with stronger hip abductors had tighter ITB/TFL complex. The negative association between hip external rotation strength and hamstrings length indicates that individuals with stronger hip external rotators had tighter hamstrings. Hip abduction and hip external rotation strength were both positively associated with lateral retinaculum tightness, suggesting that individuals with stronger hip muscles had tighter lateral retinaculum.

Gastrocnemius length was positively associated with soleus length and these two variables were positively associated with hamstrings and quadriceps length. Therefore, individuals with tighter calf muscles had tighter muscles in the posterior and anterior thigh. Gastrocnemius and soleus length were positively associated with ITB/TFL length, indicating that individuals with tighter calf muscles had tighter ITB/TFL complex. ITB/TFL length was also positively associated with quadriceps length and negatively associated with tibial torsion, indicating that individuals with tighter ITB/TFL had tighter quadriceps and higher magnitudes of lateral tibial torsion. Quality of movement was positively associated with foot pronation and tibial torsion, indicating that individuals with higher magnitudes foot pronation and lateral tibial torsion had more difficulty performing the step down test. Anxiety was negatively associated with lateral retinacular tightness and positively associated with pain, suggesting that more anxious individuals had less tightness of the lateral retinaculum and more pain.

The results of the stepwise multiple regression on ADLS scores indicated that the addition of pain and lateral retinacular length did improve the model fit after controlling for age, sex, level of physical activity, height and weight (Table 7). The overall model accounted for 56% of variation in function. The three models created during the analysis and their respective R^2 change indicates that when having the confounders controlled, pain and lateral retinacular length accounts for 34% and 7% of the variation in function, respectively.

Table 7. Stepwise multiple linear regression model predicting function.
Criterion variable = ADLS score.

Model - Variables entered	Total R^2	Adjusted R^2	ΔR^2	*df*	*F* change	*p*
I - Age, Sex, AL, Height, Weight	.15	.06	.15	7, 66	1.7	.136
II - Age, Sex, AL, Height, Weight, Pain	.49	.43	.34	1, 65	43.6	<.001
III - Age, Sex, AL, Height, Weight, Pain, LRSL	.56	.50	.07	1, 64	9.8	.003

AL= activity level; LRSL= lateral retinacular structures length

Table 8 shows the standardized beta coefficients of each variable in the final model and their significance. Variables sex, weight, pain and lateral retinacular length had beta coefficients different from zero.

Table 8. Standardized beta coefficients of each variable in the final model.

Standardized coefficient		Beta	*p*
Age		-.060	.508
Sex		-.344	.010
AL	Dummy 1	.100	.278
	Dummy 2	.069	.438
	Dummy 3	.004	.967
Height		.062	.627
Weight		-.286	.042
Pain		-.669	<.001
LRSL		.287	.003

AL= activity level; LRSL= lateral retinacular structures length

The variance inflation factor had values not higher than 2.8, suggesting no collinearity problems. Assessment of the Jackknife residual plot and the box-plot of the standardized residuals determined that the data fit reasonably well with the linear model assumptions.

3.4. DISCUSSION

The purpose of this study was to explore the relationship between impairments and physical function in patients with PFPS. The results have shown that although all the impairments explored have been theoretically or experimentally related to the presence of PFPS, after controlling for the potential confounders, only the impairments pain and tightness of lateral retinacular structures predicted levels of function in our cohort of patients with PFPS. Findings of this study did not support our hypothesis that lower levels of function would be related to decreased muscle strength, decreased soft tissue flexibility, excessive foot pronation, quadriceps angle, lateral tibial torsion and femoral anteversion, poor quality of movement, and higher levels of pain and anxiety.

This is the first study that we are aware of that investigated the relationship of function and psychosocial variables such as pain and anxiety in patients with PFPS. In patients with other musculoskeletal conditions such as knee osteoarthritis and low back pain, pain has been shown to be a predictor of function/disability.[60,79,136,140] In patients with PFPS pain has been usually seen as a symptom of unhealed damage to the patellofemoral joint or surrounding structures. The suffering and affect involved in the pain experience have been typically neglected. We believe our result warrants further speculation about the relationship pain and function. One possible explanation of this relationship may be that pain may influence one's belief in the ability to execute physical tasks, which in turn influences motivation to perform tasks.[3,4,79] Patients with PFPS may judge their functional capabilities on the basis of pain intensity. If pain negatively affects self efficacy and motivation, task performance is likely to be weakest for patients who equate their pain with their functional limitations.[3,79] Future studies should investigate the association between the emotional or psychosocial aspects of pain and function in individuals with PFPS.

Some may argue that because pain is the main symptom of patients with PFPS perhaps we should have used pain as the criterion variable of our analysis. Alternatively, one may suggest that the high correlation between pain and function may have hidden the predictor capability of the other physical impairment variables. To address these issues we performed two additional analyses with our data. In the first analysis we performed the stepwise regression in the same way as we did for this study with the following changes: pain was the criterion variable and ADLS was not in the model. The model explained 22% of the variation in pain. The confounders accounted for 12% and anxiety accounted for 10% of variation in pain. In the second analysis the stepwise regression had ADLS as the criterion and the variable pain was excluded from the model. The regression model without pain explained 30% of the variation in function, with the confounders and anxiety accounting each one for 15% of the variation in function. In both analyses no other physical impairment variable was accepted into the models. Therefore, the arguments to use pain as the predictor or take pain out of the model to clarify the role of physical impairments did not result in the emergence of any new predictor variables.

We found it interesting that in the above mentioned analyses anxiety was the only impairment that predicted pain and function. Observing the correlation matrix, anxiety was significantly correlated with ADLS ($R = .45$, $R^2 = .20$), indicating that individuals with higher anxiety levels had less function. However, when pain was in the multiple regression model the significance of the contribution of anxiety was decreased, indicating that pain could potentially be a mediator in the relationship between anxiety and function. To test the mediator effect of pain we performed three regression equations.[7] First, we determined if anxiety was a predictor of pain. Second, we determined if anxiety was a predictor of function. Third, we determined if both pain and anxiety predicted function. The conditions for a mediator effect of pain in the relationship between anxiety and function would be confirmed if: 1) the standardized beta coefficients of the three first regression equations were significant, and, 2) in the third equation where pain was present, the beta coefficient of the effect of anxiety on function was less than in the second equation, where pain was not part of the model.[7] As Table 9 shows, because the contribution of anxiety was lower when pain was in the model, we concluded that pain mediated the relationship between anxiety and function.

Table 9. Standardized beta coefficients of each regression equation to test the mediator effect of pain in the relationship between anxiety and function.

Standardized coefficient	**Beta**	***p***
Anxiety = Pain	.338	.003
Anxiety = Function	-.446	< .001
Pain + Anxiety = Function		
Pain	-.527	< .001
Anxiety	-.268	.006

Although the results suggest that pain is a better predictor of function than anxiety alone, negating the contribution of anxiety to the prediction of function may misguide clinicians. Therefore, it seems that anxiety and pain should be investigated together when considering targeting these factors to improve patients' function. Perhaps interventions such as coping strategies to deal with pain may affect the association anxiety and function and be more effective to reduce functional limitations than interventions aimed to reduce the pain as a symptom (i.e. modalities or analgesics).

While prior studies in patients with different painful conditions confirmed the association between pain and anxiety,[16,35,45,132,134] further studies are needed to confirm the association between pain, anxiety, and function in patients with PFPS. The clinical implication of the relationship between pain, anxiety, and function in this population is unknown. Witonski suggested that the anxiety of patients with PFPS may modify the perception of pain, and may exacerbate or even cause the sensation of pain.[141] Carlsson et al suggested that if patients with PFPS do not improve as expected, referral to a pain clinic with psychological expertise should be considered.[14] Our results suggest that perhaps emphasizing clinical intervention for pain may affect the link between anxiety and function. Psychological treatment for pain prior or during physical therapy treatment may enhance outcome in terms of the ability to manage pain. Improving self-efficacy for pain reduction prior to a painful experience has shown to lower reports of pain.[83] Since patients with more confidence in a given situation will experience less anxiety in that situation, it is possible that the lower reports of pain be due in part to a simultaneous reduction in anxiety.[35] Therefore, treatment approaches such as relaxation techniques, breathing techniques, and distraction techniques, which were demonstrated to be effective in treating chronic pain,[72,105] may also be helpful to manage anxiety and improve function in patients with PFPS.

In patients with low back pain, psychosocial variables such as pain and anxiety, fear-avoidance beliefs, depressive symptoms, catastrophizing behavior, and feelings of appraisal of control have been shown to predict disability.[11,40,129,130,133] Changes in some of these factors after receiving a cognitive-behavioral based intervention was related to changes in disability.[144] Previous research also suggested that in patients with low back pain, modest pain intensity reduction can lead to significant functional improvement.[38] Therefore, we believe further research should determine if coping strategies for pain and anxiety management may enhance functional outcomes in patients with PFPS. Studies should also investigate if other psychosocial variables that were related to function in other musculoskeletal conditions also relate to function in patients with PFPS.

Tightness of the lateral retinacular structures accounted for 7% of the variance in function in patients with PFPS. The positive relationship between lateral retinacular structures length and the ADLS (i.e. individuals with tighter lateral retinaculum have higher levels of function) was an unexpected finding. Although the evidence regarding the association of tightness of lateral retinacular structures and the origin of PFPS is conflicting, the common held belief is that lateral retinaculum tightness contributes to PFPS.[73] While some authors suggested that in patients with patellofemoral malalignments there is an adaptative shortening of the lateral retinaculum as a consequence of the lateral displacement of the patella,[76;113] findings of another study question such suggestion. Witvrouw et al[142] performed a prospective study to determine factors associated with the development of anterior knee pain. One of the investigated factors was clinical measures of patella mobility.[142] They measured mediolateral mobility of the patella by applying a maximal manual force medially or laterally to the patella with the subject's quadriceps at rest and knees extended. Medial displacement was used to measure tightness of the lateral retinaculum. They noted that although not significant, the values for the medial and lateral patellar mobility were greater in the group of individuals who developed PFPS.[142]

Regardless of the above controversy, this is the first time that a study investigated the relationship of lateral retinacular length and physical function. Our findings indicate that individuals with a tighter lateral retinaculum had better function. We speculate that the direction of this association may be explained by the possibility of having patients with patella hypermobility in our sample. It may be that several of the patients with normal rating during the patellar tilt test had in fact excessive length of the lateral retinacular structures. Excessive length may allow the patella to sublux during physical activity, which in turn may result in decreased function. Although we did exclude patients with history of patellar dislocation, we have not included measures of patella mobility to confirm if we had individuals with patella hypermobility. Further research is needed to clarify this topic.

Perhaps the most surprising result of the present investigation was the lack of contribution of muscle strength in the prediction of function. Based on previous research that showed that quadriceps strength was related to function in populations with other knee pathologies such as knee osteoarthritis,[36,60] we expected to find similar results in our study. We initially thought that the discrepancy in the association between quadriceps strength and function could be explained by patients with PFPS not being weaker than individuals with asymptomatic knees. However, it does not appear to be the case. There seems to be more evidence supporting that individuals with PFPS have weak quadriceps than refuting it. Duffey et al[27] demonstrated that runners with anterior knee pain had weaker knee extensors when compared with asymptomatic runners. Powers et al[104] reported that subjects with PFPS had significantly less knee extensor torque than that of a comparison group without PFPS. Messier et al[94] reported that the strength of knee extensors, whereas lower in the group of runners with PFPS, was not a significant discriminator between groups with and without PFPS. Witvrouw et al[142] reported that in an athletic population the isokinetic strength values of the quadriceps of subjects with PFPS were not significantly lower than in the controls. All these studies used sound design and methodology to test quadriceps muscles strength. Therefore, although patients with PFPS appear to have weak quadriceps, in our study quadriceps weakness did not relate to function.

We are aware of only one study that investigated the correlation between function and quadriceps weakness.[104] Powers et al[104] have used the functional assessment questionnaire[78] to assess functional limitations and reported no correlation between function and quadriceps strength, which is in agreement with our findings. Quadriceps strength values for individuals with PFPS were similar in these two studies, with a mean of 2.4 ± 0.78 Nm/Kg in Powers et al[104] study and 2.5 ± 0.76 Nm/Kg in our study. Relevant to this discussion is the fact that in a population of individuals with deficient or recently reconstructed anterior cruciate ligament, there is also controversy about the relationship between quadriceps strength and function. Some studies reported no association between quadriceps strength and functional tests[18,70] whereas others have reported a significant association.[71,139]

While people with PFPS seem to have weaker muscles around the hip,[63,100] our results indicate a lack of relationship between weakness of the hip aductors and external rotators with function. Although hip abductor and external rotation strength may not relate to function, it may be relevant to the cause of pain and pathology associated with PFPS. Therefore, further study is needed to clearly define the role of muscle strength in the pathology of PFPS. Furthermore, even though muscle strength did not relate to function in our study, future studies should investigate if changes in quadriceps, hip abductors and hip external rotators strength are related to functional outcome in this population.

None of the impairments related to muscle tightness were associated with function. Because the values of muscle tightness in our study were similar to those reported in prior studies, the lack of association with function are not likely to be explained by differences in our sample. For measures of quadriceps tightness in individuals with PFPS one study reported a mean of 124 ± 12^{o},[142] another study reported a mean of 136 ± 16^{o},[143] while we found a mean of 132 ± 11^{o}. For measures of hamstrings tightness using the straight leg raise test one study reported means of 91 ± 20^{o} for individuals that developed PFPS,[142] while we have found a mean of 78 ± 12. We believe our lower values may be explained by the age differences (mean of 29.3 years in our study in opposition to 18.6 years in the other study). There seems to be a negative correlation between age and muscle length.[44] We found one study performed with patients with PFPS that used the same technique to measure ankle dorsiflexion as we did.[94] The study reported a mean of 6.4^{o}, compared to our mean of 7.4^{o}. We are not aware of prior studies performed with PFPS patients that reported measures of ITB/TFL complex tightness. One study used the same technique to measure ITB/TFL complex tightness in asymptomatic individuals and reported a mean of 19 ± 8^{o}.[106] The lower values in our study (14 ± 10^{o}) may be explained by the fact that our study included only subjects who had PFPS.

Variables of postural or structural alterations did not relate to function. The lack of relationship may be explained in part because our sample of patients with PFPS did not appear to have considerable postural and structural alterations. Our values of foot pronation, Q-angle and tibial torsion seem smaller in comparison with the values of other studies. Studies that investigated the navicular drop test in healthy adults reported values from 3.6 ± 3.3 mm[9] to 9.0 ± 4.2 mm.[98] It has been suggested that values between 6 to 9 mm are considered normal.[84] Although we are not aware of previous reports of navicular drop test values in a sample with PFPS, in our study the mean navicular drop test value was 6.3 ± 3.6mm. Our values of Q-angle are consistent with the normative values for healthy individuals of 10^{o} for males and 15^{o} for females.[73] In our study males had 12 ± 4.2^{o} and female 16 ± 5.5^{o}. In a sample of male and female runners with PFPS the Q-angle had a mean of 17^{o} and standard error 0.6^{o}.[94] The mean of our clinical measure of tibial torsion was 17.7^{o}. It has been proposed that normal values of lateral tibial torsion range from 13 to 18^{o}.[86]

Our final regression model accounted for 56% of variation in function. Although we have explored a multitude of factors previously related to PFPS, because approximately half of the variation was unexplained, apparently we still lack knowledge about this multifactorial syndrome. There may exist some other impairments or factors that contribute to function in this population that have not been investigated. Based on our results regarding pain and anxiety, we believe some of the impairments that should be further explored in future research are the psychosocial factors such as suffering, anger, pain expectancy, self efficacy, fear, anxiety, and depression. Furthermore, the cross-sectional nature of the data used in this study allows for an examination of an association between impairments associated with PFPS and function, but not necessarily causation. Longitudinal studies are needed to definitively determine the relationship between changes in impairments and functional outcome in patients with PFPS.

3.5. CONCLUSION

Our study indicates that after controlling age, sex, activity level, height and weight, only the impairments pain and tightness of lateral retinacular structures predicted levels of function in our cohort of patients with PFPS. The other impairment measures of muscle strength, length, postural or structural alterations and quality of movement explored in our study were not associated with function.

Our data also suggested that pain may mediate the relationship between anxiety and function in patients with PFPS and therefore the role of pain and anxiety in the prediction of function should be considered together with this population. We proposed further research should determine if treatments in terms of pain and anxiety management may enhance functional outcomes in patients with PFPS. Future studies should investigate if other psychosocial variables related to function in other musculoskeletal conditions also relate to function in patients with PFPS. The association between tightness of the lateral retinacular structures and function indicated that individuals with tighter lateral retinaculum had higher levels of function. This was an unexpected finding that should be further investigated.

4. CHAPTER IV – CHANGES IN IMPAIRMENT PREDICT FUNCTIONAL OUTCOME AFTER A PHYSICAL THERAPY TREATMENT IN PATIENTS WITH PATELLOFEMORAL PAIN SYNDROME

4.1. INTRODUCTION

Patients with patellofemoral pain syndrome (PFPS) account for 10 – 25% of all physical therapy (PT) visits.[13,17,21] Despite the fact that PT is the most frequently used conservative treatment for PFPS,[62,111] studies reported that approximately one fourth of the patients continue to have pain and dysfunction for more than one year after PT has been completed.[25,26,97,137] A review of controlled clinical trials for treatment of PFPS suggested that improvements in pain and function due to PT are only consistent in the short-term and that there is inconclusive evidence to support the superiority of one particular intervention compared to another.[23] Another systematic review concluded that among the PT treatments used for population with PFPS there are some evidence for the short-term improvement in pain and function with the use of quadriceps muscle strengthening combined with patellar taping and lower extremity stretching.[10] In view of this, it seems essential that the effectiveness of PT for patients with PFPS be enhanced.

We believe one reason for the limited effectiveness of PT treatments in managing patients with PFPS has to do with the impairment-based approach that currently drives treatment planning. Treatment decisions are often based on improving impairments that are believed to influence physical function. However, the key impairments, which when properly treated and improved will influence the outcome of PFPS rehabilitation have not yet clearly been identified.

Research trials have utilized treatment approaches that addressed simultaneously, several of the potential impairments that have been related to the etiology or the presence of PFPS and have reported poor improvement in pain and function. [19,28,52] Studies that have targeted only one of the impairments related to PFPS have also reported poor outcomes.[95,110,125] A similarity among these studies is that although the impairments targeted by the treatment appear to improve, such improvements do not seem related to improvements in function.[19,95,125] Therefore, perhaps the focus of PT treatment approaches in these studies has not been directed at the proper impairments.

To enhance improvements in function, the first step should be to determine whether changes in impairments targeted during the PT treatment are in fact responsible for the improvements in function experienced by these patients. If it can be shown that changes in key impairments predict improvement in function, targeting such impairments may improve the effectiveness of PT for patients with PFPS. Despite the prevalence of PFPS and the apparent difficulty in selecting effective interventions, there are no studies in the published literature seeking to investigate if changes in physical impairments are associated with functional outcome.

Impairments commonly targeted during PT treatment are the ones that have been shown to contribute to the origin or presence of PFPS, such as weakness of the quadriceps, hip abductors, and hip external rotators muscles, tightness of the hamstrings, quadriceps, and plantar flexors muscles, tightness of structures such as the iliotibial band/tensor fascia lata (ITB/TFL) complex and the lateral retinaculum, and poor quality of movement. Weakness of the quadriceps muscles is frequently addressed during PT treatment because there is some evidence that individuals with PFPS have weaker knee extensors than asymptomatic controls.[27,104] Furthermore, studies have demonstrated a small decrease in pain and increase in function in patients who received a regimen of quadriceps muscle strengthening.[91,121,143] Weakness of the hip abductors and external rotators muscles have more recently been suggested as impairments present in patients with PFPS. Studies demonstrated that individuals with PFPS are weaker in these muscles than controls.[63,100] In addition, a report of two cases suggested that strengthening of the musculature around the hip may be a helpful treatment to decrease pain in this population.[88]

Muscle tightness is another impairment targeted during PT treatment.[19] Use of techniques to stretch the quadriceps is based on the evidence that individuals with PFPS have shorter quadriceps muscles than subjects without PFPS.[118,142] Regarding limited hamstring flexibility, the evidence of its contribution to PFPS is conflicting.[118,142] Allthough the evidence conflicts, hamstrings stretching is commonly used based on the theory that tight hamstrings would require higher quadriceps force production to overcome the passive resistance offered by the hamstrings or would cause slight knee flexion during physical activities, both which would result in increased patellofemoral joint reaction forces.[54] Stretch of the plantar flexors are used mainly to increase the ankle dorsiflexion in patients with PFPS. While the studies conflict regarding the association between plantar flexors tightness and the presence of PFPS,[94,142] the theory that the potential compensations of limited ankle dorsiflexion (i.e. excessive subtalar pronation or external rotation of the lower leg) may alter the rotation of the lower extremity and increase patellofemoral stresses provides the rationale to stretch the plantar flexors as part of the PT treatment.

Stretching of structures such as the ITB/TFL complex and the lateral retinaculum are also used in clinical practice with PFPS patients. Regardless of the inexistent evidence of the contribution of the tight ITB/TFL in PFPS, clinicians seem to stretch this structure based on expert's opinion that stretching the ITB/TFL complex may be beneficial in reducing pain in patients with PFPS.[13] Stretching of the lateral retinacular tissues is used in PT practice because authors suggested that in patients with patellofemoral malalignments there is an adaptative shortening of the lateral retinaculum as a consequence of the lateral displacement of the patella, which may potentially be the cause of the patellar pain.[42,113]

Another impairment, although not frequently targeted during PT treatment, but which is believed to contribute to PFPS, is poor quality of movement.[80] Quality of movement, also referred to as neuromotor control, refers to the biomechanics of the lower extremities and the various components of the musculoskeletal system in relationship with its surrounding during the performance of physical activities.[47] It was suggested that the altered movement patterns seen in patients with PFPS may result in abnormal load distribution across the patellofemoral joint and contribute to PFPS.[13,15,142] Poor quality of movement is sometime addressed during PT treatment using movement reeducation or exercises to improve the neuromotor control.

We believe that improvements in some of the abovementioned impairments following PT treatment may predict improvements in function in patients with PFPS. Therefore, we propose to identify what changes in impairments are associated with functional outcome in patients with PFPS following a standardized PT treatment. We hypothesize that the level of function at the conclusion of PT treatment will be associated with increased muscle strength and soft tissue flexibility, and improvement in quality of movement. It is also hypothesized that a similar relationship between change in impairments and functional outcome will exist at a 2-month and 6-month follow-up.

4.2. METHODS

A correlational, predictive design was used to explore the relationship between changes in impairments and functional outcome following PT treatment in a cohort of patients with PFPS.

4.2.1. Subjects

Individuals were eligible to participate in this study if they were diagnosed by a physician with PFPS, were between 12 and 50 years of age, had pain in one or both knees, had duration of signs and symptoms greater than 4 weeks, had history of insidious onset not related to trauma, and had pain in the patellar region with <u>at least three out of the following</u>: manual compression of the patella against the femur at rest or during an isometric knee extensor contraction, palpation of the postero-medial and postero-lateral borders of the patella, resisted isometric quadriceps femoris muscle contraction, squatting, stair climbing, kneeling, or prolonged sitting.

Exclusion criteria included previous patellar dislocation, knee surgery over the past 2 years, concomitant diagnosis of peripatellar bursitis or tendonitis, internal knee derangement, systemic arthritis, ligamentous knee injury or laxity, plica syndrome, Sinding Larsen's disease, Osgood Schlatter's disease, infection, malignancy, musculoskeletal or neurological lower extremity involvement that interferes with physical activity, and pregnancy.

Seventy four patients were recruited into the study from January 2003 through July 2004 from 4 clinical sites (Minot Air Force Base in Minot, ND, Lackland Air Force Base in San Antonio, TX, Travis Air Force Base in Fairfield, CA and the Centers for Rehab Services, which is affiliated with the University of Pittsburgh Medical Center in Pittsburgh, PA). The population was comprised of civilians and military personnel. All subjects who agreed to participate signed a consent form approved by the Institutional Review Board of the respective clinical site.

4.2.2. Procedures

All subjects participated in a baseline measurement session during which they completed demographic questionnaires, self-reported measures (function, activity level, and pain), and underwent a physical examination performed by a physical therapist. Subject's characteristics recorded in the demographic questionnaire are reported in Table 10.

Following the baseline session, subjects participated in a standardized PT program. After the PT program, measurement sessions were performed at the 2 and 6-month follow-up. During the follow-up visits the self-reported measure of function was completed and the physical examination was repeated. Subjects had one lower extremity tested. Subjects with bilateral symptoms had the most affected knee selected for testing based on the self-reported pain measurement.

4.2.2.1. Physical Therapy Program

The PT program consisted of 8 treatment sessions conducted 1-2 times per week. All subjects received the same treatment program. The treatment program was standardized and the content of the treatments was agreed by all the participating sites. Each of the clinical sites had a site coordinator who was trained by the principal investigator in the treatment procedures. The training session included specific training in the exercise program and taping method used in this study to insure the treatment was performed in a very similar fashion across sites.

Table 10. Baseline characteristics of patients.

Variables (n = 74)		Mean (SD) or Number of patients (%)
Age in years		29 (9)
Female (%)		39 (53)
Height in cm		170 (12)
Weight in cm		76 (16)
Race- patients per category (%)	Caucasian	50 (68)
	African-American	8 (11)
	Hispanic	8 (11)
	Asian	3 (4)
	Native-American	1 (1)
	Other	4 (5)
Work activity- patients per category (%)	Mostly sedentary	18 (24)
	Sedentary, some walking	13 (18)
	Moderately active	34 (46)
	Demanding	9 (12)
Use medication for PFPS (%)		43 (58)
Chronicity of pain - patients per category (%)	1 – 3 months	26 (35)
	4 – 6 months	17 (23)
	7 – 12 months	7 (10)
	13 – 24 months	13 (18)
	> 25 months	10 (14)
Activity level - patients per category (%)	Jumping, pivoting, cutting	9 (12)
	Heavy manual work	6 (8)
	Light manual work	22 (30)
	Act. of daily living	37 (50)
Activity of Daily Living Scale score		66 (17)
Numeric Pain Rating Scale core		3.8 (1.9)

The participating sites were provided with a detailed Manual of Standard Operating Procedures that outlined the procedures to be used in this study. The treatment program incorporated strengthening exercises, stretching exercises, and patellar taping. These treatment elements have shown at least some level of evidence to improve pain and function in patients with PFPS.[33,89,91,112,121,143] Patellar taping was applied at the beginning of each treatment session as originally proposed by McConnell.[89] Then, a warm-up took place by having the patient ride a stationary bicycle for 5 minutes. After that, the stretching exercises included quadriceps, hamstrings, and gastrocnemius stretching. Strengthening exercises included quadriceps muscles strength in weight-bearing and non weight-bearing conditions. Subjects were asked to perform a home exercise program 3 times a week during the 8-week treatment period in addition of the exercises completed during the PT session. Compliance with home exercises was self-reported in an exercise log. After the 2-month follow-up subjects were asked to continue with the exercises but compliance was not checked. Detailed description of the PT program and the rules for progressing the treatments can be seen in the Appendix B.

4.2.3. Measures

4.2.3.1. Self-Reported Function

Function was measured by the Activity of Daily Living Scale of the Knee Outcome Survey (ADLS)[12,64] at baseline and at the 2 and 6 month follow-ups. The ADLS is a knee specific measure of physical function that assesses the effects of knee impairment on activities of daily living. The ADLS consists of 14 items that measure the full spectrum of symptoms and functional limitations during activities of daily living that one may experience as a result of a variety of knee pathologies. Each item is scored on a six-point Likert-type scale. The ADLS score is transformed to a 0 to 100 point scale with 100 indicating the absence of symptoms and functional limitations. Psychometric testing has demonstrated the ADLS to be reliable, valid and responsive in subjects with patellofemoral pain.[64,87]

4.2.3.2. Self-Reported Activity Level

Level of physical activity was measured at baseline by the rating of activity of the International Knee Documentation Committee.[53] This rating allows subjects with knee pathologies to record their level of activity using four pre-defined activity levels: 1 - jumping, pivoting, hard cutting, football, soccer; 2 – heavy manual work, skiing, tennis; 3 – light manual work, jogging, running; 4 – activities of daily living, sedentary work.

4.2.3.3. Self-Reported Pain

Pain was measured at baseline using an eleven-point numeric pain scale. This scale was anchored on the left with the phrase "No Pain" and on the right with the phrase "Worst Imaginable Pain". Numeric pain scales were shown to be reliable and valid.[66,69,87] Subjects rated their current level of pain, the worst pain, and the least amount of pain in the last 24 hours, and the ratings were averaged. Pain was measured to test if magnitude of pain at baseline predicted functional outcome following a PT treatment.

4.2.3.4. Change in Impairment

Physical impairments were measured at baseline and at the 2 and 6-month follow-up and included quadriceps femoris strength, hip abduction strength, hip external rotation strength, hamstrings length, quadriceps length, gastrocnemius length, soleus length, ITB/TFL complex length, lateral retinacular structures length, and quality of movement. Change scores (post-treatment score *minus* pre-treatment score) were calculated for each of the physical impairments. Most variables of change in impairment were continuous. Change in lateral retinacular length and change in quality of movement were ordinal with 3 categories (improved, no change, worsened). Two dummy variables were created for each of these later variables. Measurement techniques and the reliability coefficient for each measure are provided in Appendix A. With exception of quadriceps femoris strength, all the other impairments measured during the physical examination had their reliability determined during this study. Reliability of measures of quadriceps strength as performed in this study was not investigated because it has been well established.[82,93] Details about the methodology of the reliability component of this study is described in Chapter II.

4.2.4. Data Analysis

It was not possible to obtain complete data on all those patients who were initially recruited to the study. Because of the predictive nature of the present study only the patients with completed data were included in the analyses. Data were analyzed in three stages. First, a series of analyses were performed to determine whether the baseline characteristics of patients who completed the intervention differed from those who dropped out at each follow-up. Categorical or nominal measures (i.e. sex, race, work activity, use of medication, chronicity of pain, and activity level) were explored using Pearson Chi-Square, whereas continuous measures (age, height, weight, pain, and ADLS score) were explored using Mann-Whitney *U* tests. We used non-parametric analysis due to the unequal sample sizes of the group who dropped out and the group who stayed in the study. Secondly, to determine whether pre to post-treatment changes occurred in function and physical impairment variables, a series of Paired t-Tests were performed with continuous variables, whereas the McNemar Test and McNemar-Bowker Test were used to analyze the change in lateral retinacular length and change in quality of movement, respectively. The probability of error was set at 5% for all the abovementioned analyses. Thirdly, the association between changes in impairment and function outcome in patients with PFPS was investigated with two stepwise multiple regressions, one with the 2-month and the other with the 6-month follow-up data.[102]

The criterion variable of each stepwise multiple regression was the ADLS score of the respective follow-up controlled by the baseline ADLS score. The predictor variables were potential confounders (age, sex, height, weight, and activity level), the changes in impairments, and baseline pain. Age and sex were treated as confounder because prior research has shown that they may affect the association between impairment and function.[34,43] Activity level was a confounder because the stimulus for developing and exacerbating PFPS is related to increased physical activity and overloading of the patellofemoral joint.[34] Three dummy variables were created for the 4 categories of level of physical activity. Height and weight were treated as confounders to account for the effect of body size on strength and length measurements.

Before performing the stepwise regression, regression diagnostics were performed. Descriptive statistics and partial correlation among the variables were analyzed. We calculated partial correlations, instead of zero order correlations, to determine the independent strength of the relationships between the criterion and each change in impairment variable while controlling for the potential confounders and the baseline level of function. The stepwise multiple regression was performed in two steps. First, potential confounder variables and the baseline ADLS score were forced as a block to enter the model. Second, the block of changes in impairments and baseline pain were entered into the model in a stepwise procedure. The probability of the F value was set at 0.05 to enter into and 0.10 to remove from the model.

The stepwise approach was used to determine if changes in impairments would improve the fit of the regression model after controlling for age, sex, activity level, height and weight. For each variable accepted into the model the adjusted R^2 value was calculated, reflecting the goodness of fit of the linear model adjusted for the number of predictor variables in the equation. Significance of the linear association of each variable at each step was tested. Standardized beta coefficients for each variable in the final model were calculated and the significance of each was tested under the null hypothesis that the coefficient was not different from zero.[140]

4.3. RESULTS

The diagram with the overall flow during the study is depicted in Figure 3. Twenty three (31%) of the 74 initially recruited patients dropped from study participation prior to the 2-month follow-up. Sixteen patients (22%) dropped from participation between the 2 and 6-month follow-up, adding up to a total of 39 patients (53%) who dropped from the study at the 6-month timepoint. In addition, at the 6-month follow-up we had missing strength data due to equipment failure in 7 patients, thus resulting in complete data being available for 28 (38%) patients. All drop-outs and the specific reasons for dropping out are reported in Table 11.

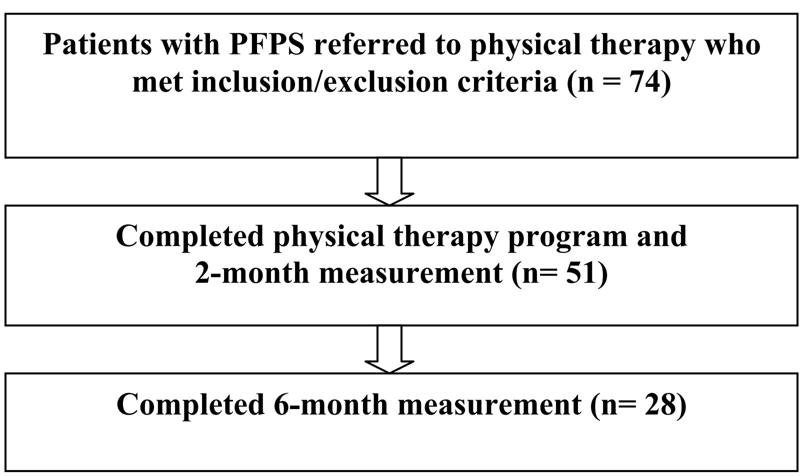


Figure 1. Flow diagram of patient course during the study period.

Table 11. Reasons for patients dropping out of study at the 2 and 6-month follow-up.

Reason – Number of patients	Two-month	Six-month
Moved to another demographic location far from reach	6	3
Sustained a meniscal injury in the affected knee while shooting	1	0
Severe back injury during a fall	1	0
Twisted the knee during ball game and injured ligament	1	0
Excessive time constraints secondary to employment	6	2
Left place of employment or moved away without further information (lost to follow-up)	5	3
Knee stopped hurting after first assessment and patient never started therapy	2	0
Sustained other knee injury and went to surgery	0	2
Health problems at home	1	0
No known reason	0	6
Incomplete data due to equipment failure	0	7
Total	**23**	**23**

4.3.1. Baseline Characteristics of Patients

Table 12 shows that there were no significant baseline differences between those patients who completed the study and those who dropped out at the 2 or 6-month follow-ups.

4.3.2. Changes in functional outcome and measures of impairment

Table 13 highlights the baseline values of the ADLS score and measures of impairment and the mean change of each variable at the 2 and 6-month follow-ups in comparison with the baseline data. The 95% confidence interval and the significance of each change are also shown.

Table 12. Baseline characteristics of patients who completed and dropped out study participation at 2-month follow-up, and patients who completed and dropped out study participation at 6-month follow-up. Values represent the mean (SD), except where noted otherwise.

Variable		Completed 2-month (n = 51)	Dropped at 2-month (n = 23)	*P* value	Completed 6-month (n = 28)	Dropped at 6-month (n = 46)	*P* value
Age in years		29 (9)	31 (9)	.323	27 (7)	31 (10)	.193
Female (%)		28 (55)	12 (52)	.573	15 (54)	24 (52)	.907
Height in cm		169 (10)	169.6 (15)	.981	171 (10)	168 (13)	.205
Weight in cm		74 (15)	81 (16)	.104	75 (16)	77 (16)	.854
Race- PPC (%)	Caucasian	37 (72)	13 (57)	.570	23 (82.5)	27 (59)	.217
	African-American	4 (8)	3 (13)		2 (7)	5 (11)	
	Hispanic	5 (10)	3 (13)		1 (3.5)	7 (15)	
	Asian	1 (2)	1 (4)		1 (3.5)	1 (2)	
	Native-American	0	1 (4)		0	1 (2)	
	Other	4 (8)	2 (9)		1 (3.5)	5 (11)	
Work activity – PPC (%)	Mostly sedentary	11 (21)	7 (31)	.832	5 (18)	13 (29)	.700
	Sedentary, some walking	9 (18)	4 (17)		5 (18)	8 (17)	
	Moderately active	25 (49)	9 (39)		15 (54)	19 (41)	
	Demanding	6 (12)	3 (13)		3 (10)	6 (13)	
Use medication for PFPS (%)		30 (59)	13 (57)	.853	18 (64)	25 (54)	.401
Chronicity of pain – PPC (%)	1 – 3 months	21 (41)	6 (26)	.446	13 (46)	14 (31)	.717
	4 – 6 months	12 (23)	5 (22)		4 (15)	13 (28)	
	7 – 12 months	5 (10)	2 (9)		2 (7)	5 (11)	
	13 – 24 months	9 (18)	4 (17)		6 (21)	7 (15)	
	> 25 months	4 (68)	6 (26)		3 (11)	7 (15)	
Activity level - PPC (%)	Jumping, pivoting, cutting	8 (16)	1 (4)	.571	5 (18)	4 (9)	.138
	Heavy manual work	4 (8)	2 (9)		1 (3)	5 (11)	
	Light manual work	14 (27)	8 (35)		5 (18)	17 (37)	
	Act. of daily living	25 (49)	12 (52)		17 (61)	20 (43)	
Activity of Daily Living Scale score		67 (15)	63 (19)	.347	66 (15)	66 (18)	.982
Numeric Pain Rating Scale score		3.7 (1.7)	4.0 (2.3)	.426	4.1 (1.8)	3.6 (2.0)	.296

PPC – patients per category

Table 13. Descriptive statistics of variables ADLS score and changes in impairments from the baseline and the significance of changes. Values represent the mean (SD), except where noted otherwise.

Variables[a]		Baseline (n = 74)	2-month follow up (n = 51)			6-month follow-up (n = 28)		
			Mean change (SD)	95% CI	*P* value	Mean change (SD)	95% CI	*P* value
ADLS score		66 (17)	10.9 (16)	6.5; 15.3	<.001	17.9 (16)	11.5; 24.3	<.001
Quadriceps strength in Nm		192 (73)	9.4 (31)	0.7; 18.0	.035	-1.5 (32)	-13.8; 10.9	.811
Hip abductors strength in Kg		12 (4)	-.23 (3)	-1.1; 0.6	.590	-.53 (4)	-2.0; 0.9	.454
Hip external rotators strength in Kg		15 (6)	.33 (3)	-0.4; 1.1	.368	.61 (3)	-0.5; 1.7	.253
Hamstrings length (°)		78 (12)	2.9 (9)	0.4; 5.3	.022	2.3 (10)	-1.6; 6.3	.237
Quadriceps length (°)		132 (11)	3.0 (7)	1.1; 4.9	.003	4.2 (8)	0.9; 7.4	.014
Gastrocnemius length (°)		7.4 (6)	1.4 (7)	-0.4; 3.3	.131	3.8 (5)	2.0; 5.7	<.001
Soleus length (°)		14.8 (5)	2.3 (5)	0.9; 3.8	.002	2.1 (4)	0.5; 3.8	.014
ITB/TFL length (°)		13.7 (10)	0.5 (7)	-1.5; 2.5	.661	1.3 (8)	-1.8; 4.5	.395
Lateral retinacular length - patients with tightness		54 (73%)	34 (66%)		.508	20 (71%)		.687
Quality of movement, patients per category	Good	16 (22%)	29 (57%)		.002	14 (50%)		.044
	Medium	47 (64%)	16 (31%)			13 (46%)		
	Poor	11 (14%)	6 (12%)			1 (4%)		

ADLS – Activity of daily living scale; ITB/TFL – iliotibial band/tensor fascia lata
a- All variables used in the analyses shown in this table are normally distributed (i.e. Kolmogorov-Smirnov Z not significant at $\alpha = .05$)

At the 2-month follow-up, significant increases were observed in function, quadriceps strength, hamstrings length, quadriceps length, soleus length, and quality of movement. No significant changes occurred on the measures of hip abduction and external rotation strength, gastrocnemius length, ITB/TFL length, and lateral retinacular length. At the 6-month follow-up, significant increases were observed in function, quadriceps length, gastrocnemius and soleus length, and quality of movement. Measures of muscle strength, hamstrings length, ITB/TFL length, and lateral retinaculum length were not significantly changed.

4.3.3. Regression diagnostics of analyses with the 2 and 6-month follow-up data

The predictor variables used on both regression analyses had Variance Inflation Factors that were considerably less than 10, indicating that the data were not affected by multicollinearity.[75] Visual observation of the plots of Jackknife residuals and the box-plot of the standardized residuals determining that the data fit the linear model assumptions.[75]

4.3.4. Regression analysis with the 2-month follow-up data

Partial correlations between the variables are shown in Table 14. The partial correlations controlled for the effect of baseline ADLS score, age, sex, activity level, height, and weight. Change in gastrocnemius length was positively associated with the criterion variable ADLS score at 2-month, indicating that patients who increased gastrocnemius length also improved function. The association between ADLS score at 2-month and the "dummy 1" of lateral retinaculum length indicates that the patients who increased lateral retinaculum length had better function at the 2-month follow-up. A note of explanation regarding the association between the variable "dummy 1" coded from change in lateral retinaculum length and function at 2-month follows. The variable "change in lateral retinaculum length" was dummy coded in such a way that the reference variable was patients who did not change. As a result, the variable "dummy 1" refers to the patients who improved in reference to the ones who did not change, whereas "dummy 2" refers to the patients who worsened in reference to the ones who did not change.

Table 14. Partial correlations of the 2-month follow-up data between the criterion and change in impairments when baseline ADLS score, age, sex, activity level, height, and weight are partialed out.

n = 51	Δ Quadr strength	Δ Hip ABD strength	Δ Hip ER strength	Δ Hamst length	Δ Quadr length	Δ Gastroc length	Δ Soleus length	Δ ITB/TFL length	Δ LRS length Dummy 1	Δ LRS length Dummy 2	Δ QoM Dummy 1	Δ QoM Dummy 2	Baseline pain
ADLS 2-month	-.04	-.17	.14	-.10	-.09	.35*	.05	-.02	.32*	-.25	-.01	.12	.09
Δ Quadr strength	-	.28	.18	.09	-.04	-.11	-.23	.00	.14	-.11	.10	-.13	.11
Δ Hip ABD strength		-	.37*	.09	-.03	.03	.02	-.19	.14	-.20	-.21	.09	-.15
Δ Hip ER strength			-	.07	.22	.08	-.09	-.03	-.10	.09	.06	-.21	.25
Δ Hamst length				-	.02	-.15	-.09	-.04	.11	.08	.28	-.31*	-.13
Δ Quadr length					-	.15	.17	-.31*	-.26	.37*	.16	-.16	.14
Δ Gastroc length						-	.17	.01	.01	-.25	.08	.12	-.01
Δ Soleus length							-	-.36*	-.04	.06	.06	.15	-.02
Δ ITB/TFL length								-	.14	-.18	-.19	.04	.04
Δ LRS length- dummy 1									-	-.75**	-.15	.17	.00
Δ LRS length- dummy 1										-	.18	-.11	.04
Δ QoM – dummy 1											-	-.77**	.22
Δ QoM – dummy 2												-	-.22

* Significant at p ≤ .05; ** Significant at p ≤ .01; ADLS- activity of daily living scale; Δ - change; Quadr- quadriceps; ABD- abduction; ER – external rotation; Hamst – hamstrings; Gastroc- gastrocnemius; ITB/TFL- iliotibial band/tensor fascia lata complex; LRS – lateral retinacular structures; QoM- quality of movement

The results of the stepwise multiple regression at 2-months indicated that the addition of change in gastrocnemius length did improve the model fit after controlling for baseline ADLS score, age, sex, activity level, height and weight (Table 15). The overall model accounted for 49% of variation in functional outcome. The two models created during the analysis and their respective R^2 change indicates that when having the confounders controlled, increase in gastrocnemius length accounted for 7% of the variation in functional outcome. Table 16 shows the standardized beta coefficients and their significance of each variable in the final model. The baseline ADLS score and change in gastrocnemius length had beta coefficients different from zero.

Table 15. Stepwise multiple linear regression predicting functional outcome at the 2-month follow-up. Criterion variable = 2-month Activity of Daily Living Scale (ADLS) score.

Model – Variables entered	Total R^2	Adjusted R^2	ΔR^2	*df*	*F* change	*p*
I – ADLS at baseline, Age, Sex, Activity Level, Height, Weight	.42	.31	.42	8, 42	3.7	.002
II - ADLS at baseline, Age, Sex, Activity Level, Height, Weight, Change in gastrocnemius length	.49	.38	.07	1, 41	5.9	.020

Table 16. Standardized beta coefficients of each variable in the final model.

Standardized coefficient		Beta	*p*
Activity of Daily Living Scale at baseline		.699	< .001
Age		.116	.347
Sex		.001	.995
Activity Level	Dummy 1	.138	.280
	Dummy 2	-.113	.342
	Dummy 3	-.115	.355
Height		-.175	.364
Weight		-.111	.579
Change in gastrocnemius length		.328	.020

To determine if the stepwise model may have excluded variables which were close to reaching significance but perhaps due to lack of power did not make it into the model, we visually observed the standardized beta coefficients of the variables not entered into the model. The only variable close to reaching significance to enter the model was change in lateral retinacular structures length (Beta = .240, p = .055), indicating that individuals who increased the length of the lateral retinaculum had better function. Implications of this finding will be examined in further detail in the discussion.

4.3.5. Regression analysis with the 6-month follow-up data

Partial correlations between the variables are shown in Table 17. The partial correlations controlled for the effect of variables baseline ADLS score, age, sex, activity level, height, and weight. Change in quadriceps length and change in ITB/TFL length were positively associated with the criterion variable ADLS score at 6-month. The positive association indicates the patients who increased length of these soft tissues also improved function.

Table 17. Partial correlations of the 6-month follow-up data between the criterion and change in impairments when baseline ADLS score, age, sex, activity level, height, and weight are partialed out.

n = 28	Δ Quadr strength	Δ Hip ABD strength	Δ Hip ER strength	Δ Hamst length	Δ Quadr length	Δ Gastroc length	Δ Soleus length	Δ ITB/TFL length	Δ LRS length Dummy 1	Δ LRS length Dummy 2	Δ QoM Dummy 1	Δ QoM Dummy 2	Baseline pain
ADLS 6-month	.18	-.42	-.27	-.16	.53*	.12	.43	.48*	-.23	.14	.13	-.13	-.02
Δ Quadr strength	-	.12	.25	.31	.11	.10	-.23	-.16	.01	-.23	-.04	.20	.15
Δ Hip ABD strength		-	.32	-.14	-.21	.34	.43	-.33	.13	-.19	-.52*	.41	-.13
Δ Hip ER strength			-	.32	.19	.04	-.39	-.31	-.07	.25	.08	.09	-.23
Δ Hamst length				-	-.07	-.13	-.51*	-.31	-.02	-.04	.38	-.37	-.18
Δ Quadr length					-	.33	.29	.27	.14	-.04	.14	-.06	.02
Δ Gastroc length						-	.12	-.25	-.04	.05	.07	-.15	-.21
Δ Soleus length							-	.46*	-.07	.10	.04	-.03	.12
Δ ITB/TFL length								-	.27	-.04	-.19	.11	.14
Δ LRS length- dummy 1									-	-.78**	-.34	.31	.37
Δ LRS length- dummy 1										-	.39	-.44	-.46*
Δ QoM – dummy 1											-	-.87**	-.15
Δ QoM – dummy 2												-	.34

* Significant at p ≤ .05; ** Significant at p ≤ .01; ADLS- activity of daily living scale; Δ - change; Quadr- quadriceps; ABD- abduction; ER – external rotation; Hamst – hamstrings; Gastroc- gastrocnemius; ITB/TFL- iliotibial band/tensor fascia lata complex; LRS – lateral retinacular structures; QoM- quality of movement

The results of the stepwise multiple regression with the 6-month follow-up data indicated that the addition of change in quadriceps length did improve the model fit after controlling for baseline ADLS score, age, sex, level of physical activity, height and weight (Table 18). The overall model accounted for 55% of variation in functional outcome. The two models created during the analysis and their respective R^2 change indicates that when having the confounders controlled, increase in quadriceps length accounted for 18% of the variation in functional outcome. Table 19 shows the standardized beta coefficients of each variable in the final model and the significance of each. The only variable that had beta coefficient different from zero was change in quadriceps length.

Table 18. Stepwise multiple linear regression predicting functional outcome at the 6-month follow-up. Criterion variable = 6-month Activity of Daily Living Scale (ADLS) score.

Model – Variables entered	Total R^2	Adjusted R^2	ΔR^2	*df*	*F* change	*p*
I – ADLS at baseline, Age, Sex, Activity Level, Height, Weight	.37	.10	.37	8, 19	1.4	.264
II - ADLS at baseline, Age, Sex, Activity Level, Height, Weight, Change in quadriceps length	.55	.32	.18	1, 18	7.1	.016

Table 19. Standardized beta coefficients of each variable in the final model.

Standardized coefficient		Beta	*p*
Activity of Daily Living Scale at baseline		.293	.138
Age		.257	.204
Sex		.271	.284
Activity Level	Dummy 1	.383	.055
	Dummy 2	.280	.153
	Dummy 3	.015	.935
Height		-.385	.199
Weight		.171	.656
Change in quadriceps length		.484	.016

To determine if the stepwise model may have excluded variables which were close to reaching significance but perhaps due to lack of power did not make it into the model, we visually observed the standardized beta coefficients of the variables not entered into the model. The variables close to reaching significance to enter the model were change in hip external rotation strength (Beta = -.453, p = .053) and change in ITB/TFL length (Beta = .357, p = .086). The negative relationship between change in hip external rotation strength and function at 6-month indicate that individuals who decreased external rotation strength had better functional outcome. The positive relationship between change in ITB/TFL length and function at 6-month indicates that individuals who increased ITB/TFL also improved function. Implications of these findings will be examined in further detail in the discussion.

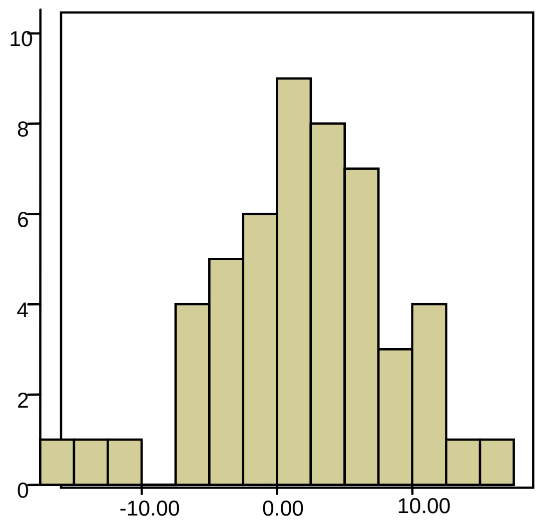
4.4. DISCUSSION

The aim of the present study was to determine if changes in impairments (i.e. weakness of the quadriceps, hip abductors, and hip external rotators muscles, tightness of the hamstrings, quadriceps, gastrocnemius and soleus muscles, tightness of ITB/TFL complex and the lateral retinaculum, and poor quality of movement) are associated with functional outcome following a standardized PT treatment in a cohort of patients with PFPS. The results have shown different predictors at 2 and 6-month follow-up. At the 2-month follow-up, after controlling for age, sex, activity level, height and weight, increased gastrocnemius length accounted for additional 7% of the variance in functional outcome. At the 6-month follow-up, after controlling for the potential confounders, increased quadriceps length accounted for 18% of the variance in functional outcome.

Although gastrocnemius length has been suggested to contribute to the presence of PFPS,[142] this is the first study that investigated the relationship of changes in this impairment and functional outcome in this population. It is theorized that gastrocnemius tightness may cause limited ankle dorsiflexion, which could be compensated by either excessive subtalar pronation or external rotation of the lower leg to gain additional range of motion for the terminal stance phase of gait.[54] The internal rotation of the lower extremity that accompanies subtalar pronation or the lower leg external rotation may respectively decrease or increase the quadriceps angle and consequently increase patellofemoral stresses.[54] Mizuno et al suggested that both increases and decreases in the quadriceps angle could lead to increased patellofemoral contact pressures.[96] Although we do not know from our data, we speculate that perhaps the improvement in function experienced by the patients who increased the length of the gastrocnemius can be explained because increases in gastrocnemius length may normalize the above compensations, decrease patellofemoral stresses, and consequently allow the patients to perform physical activities with less limitations.

It is noteworthy that, although increases in gastrocnemius length was related to functional outcome at the 2-month follow-up, no significant changes were observed in gastrocnemius length after the PT program. It seems that for the relationship between change in muscle length and functional outcome to exist, a reasonable number of patients should have some changes in muscle length. To determine if a reasonable number of patients did change (i.e. several patients increased and several decreased the length of the gastrocnemius), we calculated the dispersion of the data and visually observed the histogram of this variable. The measures of dispersion (SD = 7^o; variance = 45^o ; range 34^o = from -17^o to 17^o) and the histogram of the change in gastrocnemius length (Figure 2) indicate that, although the mean did not significantly change, the spread of the data was considerable. Therefore, the patients that actually increased the length of the gastrocnemius muscle may be the ones who accounted for the improvement in function. We do not believe that the lack of significant changes in gastrocnemius length were due to the PT program. The PT program incorporated gastrocnemius stretching exercises and used a stretching technique which has been shown effective to increase muscle/tendon flexibility.[5,6,101]

Figure 2. Histogram of variable 2-month change in gastrocnemius length.



The effectiveness of gastrocnemius muscle stretching in this population has not been previously investigated. Despite the fact that gastrocnemius stretching is commonly used in daily practice to treat patients with PFPS, studies have incorporated stretching of these muscles only as a small component of the overall treatment program.[19] Having the stretching exercises combined with additional treatment components does not allow for any definitive conclusion of its individual effects. Therefore, further research should determine if specifically incorporating gastrocnemius stretch may enhance functional outcomes in patients with PFPS. Studies should also investigate if there is a certain magnitude of increase in muscle length needed to impact the improvement in function. It may be that only modest increases in muscle length can lead to significant functional improvements.

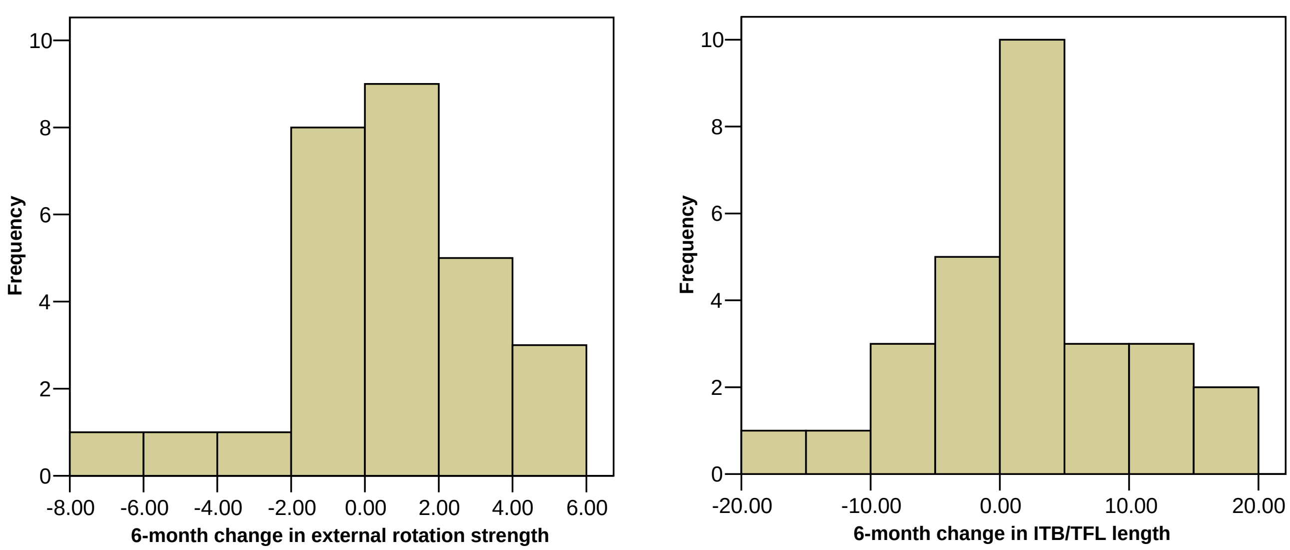
Increase in quadriceps length was the sole predictor at the 6-month follow-up, accounting for 18% of the variation in functional outcome. Although quadriceps length was significantly improved at both, the 2 and 6-month follow-up, change in quadriceps length was not a predictor at the 2-month follow-up. We believe the lack of association between quadriceps length and functional improvement at the 2-month follow-up may probably be explained by the fact that the magnitudes of changes at 6-months were bigger than at the 2-month follow-up. The biological plausibility for the association between quadriceps length and functional outcome may be that since tight quadriceps muscles pull the patella superiorly and increase compression of the patellofemoral joint during physical activities,[54] increasing the length of these muscles may result in less compression of the patellofemoral joint. Less compression of the patellofemoral may reduce the pain and consequently improve function.

There is a consensus in the literature that quadriceps muscle tightness is related to the etiology and the presence of PFPS. Witvrouw et al[142] have found that, in a young athletic population, subjects who developed PFPS over time had shorter quadriceps muscles than subjects without PFPS. Using a stepwise logistic regression they identified shortened quadriceps muscles as one of the risk factor for the development of PFPS.[142] Smith et al[118] reported that in adolescent elite figure skaters decreased quadriceps flexibility was associated with PFPS. Despite the consensus about the association between quadriceps length and PFPS, to our knowledge, no studies have purposely investigated the effectiveness of quadriceps stretching to improve outcomes in patients with PFPS.

Although this study was exploratory in nature, to avoid that spurious variables would enter into the model we set the alpha at 0.05. However, because the dropouts during the study have decreased the sample size particularly at the 6-month follow-up, we were concerned that such a conservative model would reject variables which with a bigger sample would have entered into the model. To determine if variables which were close to reaching significance did not make it into the model we observed the standardized beta and the significance of each variable excluded from the stepwise model. We believe that, although these variables are not considered predictors of functional outcome, clinicians and researchers should be aware of their potential contribution to functional outcome. At the 2-month follow-up the only variable close to reaching significance was change in lateral retinacular structures length, whereas at the 6-month follow-up the variables close to reaching significance were change in hip external rotation strength and change in ITB/TFL length. Interesting to observe is that the partial correlation between change in lateral retinacular length and the 2-month ADLS score was significant (Table 14). In addition, Table 17 shows that the variable change in ITB/TFL length was significantly associated with the 6-month ADLS score. However, the partial correlations have not shown a significant association between change in hip external rotator strength and the 6-month ADLS score (Table 17). The direction of the relationships between these variables and functional outcome indicated that individuals who increased the length of the lateral retinaculum and the ITB/TFL and the ones who decreased the strength of the hip external rotators had better function.

The three abovementioned variables that did not make it into the model did not significantly change from baseline to the specific follow-up. Regarding lateral retinaculum length, among the 51 patients tested at the 2-month follow-up, 6 (12%) improved, 42 (82%) did not change, and 3 (6%) patients worsened in relation to the baseline measures. Patients who had tight lateral retinaculum at baseline and normal measure at the 2-month were considered improved, whereas the ones who had normal lateral retinaculum at baseline and became tight at the 2-month follow-up were considered worsened. Therefore, although the proportion of patients with tight lateral retinaculum did not significantly change, some individual patients did change. Concerning the external rotation strength and ITB/TFL length, although the means of both variables at the 6-month follow-up were not different than the baseline means, to determine if a reasonable number of patients changed we calculated the dispersion of the data and visually observed the histogram of these variables. The measures of dispersion for change in external rotation strength (SD = 3 Kg; variance = 8 Kg ; range 13 Kg = from -7 to 6 Kg) and change in ITB/TFL length (SD = 8^o; variance = 65^o ; range 36^o = from -18^o to 18^o) and the histogram of both variables (Figure 3) indicate that the spread of the data were considerable.

Figure 3. Histograms of variables 6-month change in external rotation strength and change in ITB/TFL length.



We investigated the relationship between functional outcome and lateral retinaculum and ITB/TFL length based on the theory that tightness of the lateral retinacular structures, perhaps as a result of increased tension in the iliotibial band, may adversely pull the patella laterally and alter tracking of the patella in the trochlear groove.[13,113,124] Manual stretching of the lateral retinaculum and the ITB/TFL is the technique generally used to increase the length of these tissues. There is some evidence that manually stretching the lateral retinaculum may decrease patellofemoral pain.[110] There is no such evidence regarding ITB/TFL stretching. Because the PT program used in the present study did not incorporate manual stretching of these structures, we believe that perhaps the performance of stretching exercises for the quadriceps and gastrocnemius muscles (which tense the ITB/TFL by putting the thigh in extension) combined with the use of patellar taping may have contributed to the individual changes in these variables.

We believe that the association between functional outcome and decreased strength of the hip external rotators may have been a spurious finding. Theoretically, the weakness of hip external rotators is believed to cause increased medial femoral rotation during physical activities, which may result in a laterally displaced patella and increased stress on the patellofemoral joint.[42,56,90] Furthermore, studies demonstrated that individuals with PFPS are weaker in these muscles than controls and suggested that strengthening of the musculature around the hip may be a helpful treatment to decrease pain in patients with PFPS.[63,88] Therefore, it seems there is not a reasonable explanation for the negative association between hip external rotation strength and functional outcome. We believe that although hip external rotation strength was not specifically targeted during the PT program, during the double leg squats and the unilateral step down/up exercises the patients had to use these muscles to eccentrically control femoral internal rotation, which may have accounted for the variation in external rotation seen in some patients at the 6-month follow-up.

The two factors that predicted functional outcome in our study are related to soft tissue tightness. So far, we tried to explain the association between increased length of these structures and functional outcome based on previously proposed theories.[13,54,142] As discussed before, lengthening of the gastrocnemius and quadriceps muscles would ultimately decrease patellofemoral contact area, reduce patellofemoral compression, and perhaps normalize tracking of the patella inside the trochlear groove. Reducing the patellofemoral compression would result in pain reduction and consequently improve function. Consequently, using the above model, it seems that in order to these changes to impact on functional outcome, improvement on these impairments should be related to decreased pain. If this rationale is correct, we believe that the increased length of these soft tissues should also predict reductions in pain. To understand if there is a direct relationship between increase in soft tissue length, reduction in pain, and improvement in function, we tested if the outcome of pain could be predicted by any changes in impairments. Thus, we performed two stepwise regression analyses, one with the 2-month and the other with the 6-month follow-up data. The analyses were similar to the ones performed during this study, with only two differences: the criterion variable for each analysis was pain at the respective follow-up adjusted by baseline pain, and the ADLS scores were not entered into the models. The results of both analyses indicated that none of the changes in impairments predicted outcomes of pain. Therefore, perhaps besides decreased patellofemoral compression and reduction in pain, another mechanism may exist to explain improvement in function in patients with PFPS.

We believe that an additional potential explanation for the association between increased soft tissue length and functional outcome may be that the elongation of the gastrocnemius and quadriceps muscles may decrease the passive resistance offered by these muscles and allow more freedom of movement at the joints. The decreased stiffness of the joints directly affected by the increased compliance in these tissues (i.e. patellofemoral, knee, ankle and hip) will result in greater ease of motion during physical activities, which consequently could result in better function, or at least the perception of better function. In this proposed model, elongation of soft tissues would affect physical function directly without necessarily affecting pain.

Although some physical impairments were not improved during the study period, the PT program used in this study seems to have been effective to improve function in our patients with PFPS. Based on the value of the minimum clinically important difference of 7 points in the ADLS, which has been calculated in this sample,[99] at the 2 and 6-month follow-up respectively, 60% and 76% of patients have improved above the minimum clinically important difference. It may be that if we had used a more intense or lengthy program we may have seen bigger changes in the impairments investigated. Bigger changes in impairments would probably result in higher variation in the data, which would maybe increase the likelihood of finding some other predictors.

In our study, increased quadriceps strength did not predict functional outcome in patients with PFPS. Quadriceps weakness was specifically targeted during the PT program and, although the patients significantly increased quadriceps strength at the 2-month follow-up, the increase was not related to functional outcome. Strengthening of the quadriceps muscles has been investigated in several research trials for patients with PFPS. Few randomized trials investigated the isolated effect of quadriceps strengthening in the outcome of patients with PFPS. Two studies investigated the difference in quadriceps training methods (i.e. open kinetic chain, closed kinetic chain, isometric and eccentric exercises).[125,143] Because all the groups in these studies demonstrated some improvement in function and decrease in pain, it suggests there is at least some evidence that quadriceps strength training is useful in the management of PFPS.[125,143] Other studies that investigated the effectiveness of PT programs used quadriceps strengthening as part of a treatment program that included several additional interventions such as education, patellar taping, stretching, orthotics, and patellar mobilization.[19,28,52,109] The combination of multiple treatment approaches does not allow sorting out the effect of quadriceps strengthening in isolation.

The results of our study do not question prior research that found an association between physical impairments and the etiology or the presence of PFPS, nor does it challenge the use of treatment approaches based on such associations.[19,28,52,62,109,125] Rather, we propose that the clinical implications of our results seem to be that clinicians should modify existing interventions for patients with PFPS. We believe that PT treatment should specifically target impairments of soft tissue length in an attempt to improve functional outcome. Although stretching techniques are commonly used during treatment of patients with PFPS, the stretching techniques are generally considered a less important treatment approach. As clinical research is a reflection of clinical practice, the absence of investigations regarding the effectiveness of muscle stretching in this population proves that muscle stretching is neglected in the treatment of these patients. Therefore, further studies are necessary to investigate if PT programs that address stretching of the gastrocnemius and quadriceps muscles will result in improved function.

The present study has some limitations. Due to dropout and incomplete data, data were obtained from 69% of patients at the 2-month and 38% of patients at the 6-month follow-up, which potentially threatens the generalizability of the findings. Nevertheless, no significant differences were evident between the baseline characteristics of those patients who completed the study and those who dropped out. This indicates that the data forming the results of the present study were derived from patients who where representative of the original sample. Furthermore, although our model did fit the assumptions of linear regression, we had a small sample size at the 6-month follow-up, which may have compromised the stability of the regression model. Therefore, future studies should be designed to validate the findings of this study. Finally, because the present study was designed as a predictive study, the use of a control group was not feasible. Not having a control group raises the possibility that the changes observed on the outcome measures might have occurred spontaneously, rather than as a result of the intervention.

4.5. CONCLUSION

Our study indicates that at the 2-month follow-up, after controlling age, sex, activity level, height, and weight, increased gastrocnemius length predicted functional outcome. At the 6-month follow-up, after controlling for the potential confounders, increased quadriceps length was the sole predictor of functional outcome in our cohort of patients with PFPS.

The factors that predicted functional outcome in our study are related to soft tissue tightness. Explanation of the association between increased length of these structures and functional outcome may be that increasing the muscle length may reduce patellofemoral compression, reduce pain, and consequently improve function. Therefore, some level of pain reduction would be necessary to impact on functional outcome. We propose an additional explanation for such association. The elongation of the gastrocnemius and quadriceps muscles may decrease the passive resistance offered by these tissues and allow more freedom of movement at the joints. The decreased stiffness of the joints will result in less difficulty in performance of physical activities, which consequently could result in better function, or at least the perception of better function by the patient. In this proposed model, elongation of soft tissues would affect physical function directly without necessarily affecting pain.

The clinical implications of our results seem to be that clinicians should modify existing interventions for patients with PFPS and specifically target impairments of soft tissue length in an attempt to improve functional outcome. Further studies are necessary to investigate if PT programs that address stretching of the gastrocnemius and quadriceps muscles will result in improvements of function.

5. CHAPTER V

5.1. SIGNIFICANCE AND DIRECTION OF FUTURE RESEARCH

The most common recommended treatment for PFPS is PT. However, evidence for the effectiveness of PT treatment to improve function in patients with PFPS is limited. To try to improve the effectiveness of PT treatment we explored the relationship between impairments and physical function in a cohort of patients with PFPS. This project explored if the impairments related to the etiology and the presence of PFPS are equally associated with physical function prior to PT treatment in a cohort of patients with PFPS. Furthermore, this study identified what changes in impairments are related to functional outcome in response to PT treatment. No study has previously attempted to investigate these questions.

By exploring the relationship between impairments and physical function at baseline this study found that pain predicted levels of function in our patients with PFPS. We believe the relationship between pain and function in this population was not previously investigated because although pain accompanies PFPS, pain has been seen solely as a symptom of damage to the patellofemoral joint or surrounding structures. It has to be recognized if other psychological aspects associated with pain such as suffering, anger, pain expectancy, self efficacy, and fear of pain may also affect function.[35,40,133] One possible explanation of the relationship between pain and function is that pain may influence one's belief in the ability to execute physical tasks, which in turn influences motivation to perform tasks.[3,4,79] If pain negatively affects self efficacy and motivation, task performance is likely to be weakest for patients who equate their pain with their functional limitations.[3,4,79] Therefore, future studies should investigate if other psychosocial variables related to function in other musculoskeletal conditions also relate to function in patients with PFPS.

Our data also suggested that pain may mediate the relationship between anxiety and function in patients with PFPS, indicating that the role of pain and anxiety in the prediction of function should be considered together in this population. This finding suggests that perhaps interventions such as coping strategies to deal with pain may simultaneously reduce anxiety and affect the association anxiety and function and be more effective to reduce functional limitations than interventions aimed to reduce the pain as a symptom (i.e. modalities or analgesics). Therefore, future studies should investigate if the use of treatment approaches used to treat chronic pain may also be helpful to manage anxiety and improve function in patients with PFPS.

The results of the baseline analysis also indicated that lateral retinacular structures length predicted levels of function in PFPS. The association between tightness of the lateral retinacular structures and function indicated that individuals with tighter lateral retinaculum had higher levels of function. This is an unexpected finding that should be further investigated.

Our study indicates that at the 2 and 6-month follow-ups increased gastrocnemius length and increased quadriceps length, respectively, predicted functional outcome in our cohort of patients with PFPS. The physical impairments that predicted functional outcome in our study are related to soft tissue length. Explanation of the association between increased length of these muscles and functional outcome may be that increasing the length of these structures may reduce patellofemoral compression, reduce pain, and consequently improve function. Consequently, it seems that in order for these changes to impact on functional outcome, improvement on these impairments should be related to decreased pain, which was not the case with our data. Therefore, we propose an additional explanation for such association. The elongation of the gastrocnemius and quadriceps muscles may decrease the passive resistance offered by these tissues and allow more freedom of movement at the joints. The decreased stiffness of the joints will result in less difficulty in performance of physical activities, which consequently could result in better function, or at least the perception of better function by the patient. In this proposed model, elongation of soft tissues would affect physical function directly without necessarily affecting pain. The clinical implications of our results seem to be that clinicians should modify existing interventions for patients with PFPS and specifically target impairments of soft tissue length in an attempt to improve functional outcome. Further studies are necessary to investigate if PT programs that address stretching of these soft tissues will result in improvements of function. Studies should also investigate if there is a certain magnitude of increase in muscle length needed to impact the improvement in function. It may be that only modest increases in muscle length can lead to significant functional improvements.

The other impairment measures of muscle strength, length, structural alterations and quality of movement or the changes in these impairments were not associated with function or functional outcome, respectively. Although some physical impairments were not improved during the study period, the PT program used in this study seems to have been effective to improve function in our patients with PFPS. It may be that if we had used a more intense or lengthy program we may have seen bigger improvement in impairments, which would perhaps increase the likelihood of finding other significant predictors. This study served as the first step to identify the key impairments that should be targeted during PT treatment to hopefully improve the effectiveness of PT treatment for patients with PFPS. To validate our findings we propose future investigations replicate this study with a bigger sample or perhaps using a more intense PT program.

Our regression models accounted for an average of 50% of variation in function or functional outcome. Although we have explored a multitude of factors previously related to PFPS, apparently we still lack knowledge about this multifactorial syndrome. Perhaps there are other impairments or factors that may contribute to function in this population and have not been investigated. Based on our results regarding pain and anxiety, we believe some of the impairments that should be further explored in future research are the psychosocial factors such as suffering, anger, pain expectancy, self efficacy, fear, anxiety, and depression.

APPENDIX A

Measurement Techniques of Physical Impairments and Reliability Coefficient of Each Measure

Measurement, Equipment Used, and Reliability	Description
Quadriceps femoris strength Isokinetic dynamometer (Biodex System 3 Pro, Shirley, NY)	Subject is firmly secured on the seat of the dynamometer with the pelvis and thigh secured to the seat using straps to minimize movements of these segments. The hips are flexed to approximately 75°, and the knee to be tested flexed to 75°. The lever arm with the force transducer is strapped to the patient's leg by means of a cushioned shin pad positioned just above the medial malleolus. The axis of rotation of the dynamometer is aligned with the lateral femoral condyle. Subject is instructed to exert as much force as possible using an isometric contraction while extending the knee against the force-sensing arm of the dynamometer. The contraction is repeated for four trials. The maximum torque is recorded.
Hip Abduction Strength Lafayette Manual Muscle Tester (MMT) System (Lafayette Instrument, Lafayette, IN) ICC: 0.85	Measured with the subject in side-lying with the test hip positioned superior with respect to the contralateral hip. Subject exerted an isometric contraction of the hip abductors for 3-5 seconds in a position of approximately 30° of hip abduction and 5° of hip extension. The manual resistance is applied with the MMT proximal to the lateral malleolus in the direction of adduction. To maintain uniformity in the nature of verbal commands provided by the tester during testing, the testers were instructed to always give a strong verbal encouragement during the performance of every maximum effort. The average force of two trials with one minute of rest between trials is recorded. Maximum force in kilograms is recorded.
Hip external rotation strength Lafayette Manual Muscle Tester ICC: 0.79	Subject is positioned in prone on a padded table with the test knee flexed to 90° and the hip in neutral rotation. The contralateral lower extremity is positioned with the hip in neutral rotation and the knee in full extension. To obtain optimal mechanical advantage, the examiner stands on the side of the table opposite of the test limb. Subject exerts an isometric contraction of the hip external rotators for 3-5 seconds in a position of neutral hip rotation. The manual resistance against the external rotation is applied with the MMT just proximal to the medial malleolus. To maintain uniformity in the nature of verbal commands provided by the tester during testing, the testers were instructed to always give a strong verbal encouragement during the performance of every maximum effort. The average force of two trials with one minute of rest between trials is recorded. Maximum force in kilograms is recorded.
Hamstrings Length Gravity goniometer (MIE Medical Research Ltd., Leeks, UK) ICC: 0.92	Determined using the straight leg raise test. Subject in the supine position with the tested knee extended and the other leg flat on the table. Before testing goniometer is zeroed on the lower half of the anterior border of the tibia. The lower extremity is passively lifted to the end range of motion or firm end feel and the measurement recorded in degrees. The average measurement of two trials with 5-second pause between trials is recorded.
Quadriceps Length Gravity goniometer ICC: 0.91	Determined by measuring the quadriceps femoris muscle angle during passive knee flexion with the subject in the prone position. The angle of knee flexion in the prone position is measured. The gravity goniometer is zeroed on a horizontal surface prior to the measurements and is placed over the distal tibia. The average measurement of two trials with 5-second pause between trials is recorded.

Plantar Flexors Length Standard goniometer Dorsiflexion with knee extended ICC: 0.92 Dorsiflexion with knee bent ICC: 0.86	Determined by measuring the amount of ankle joint dorsiflexion with the knee extended and again with the knee flexed at 90°. Ankle dorsiflexion measured with the knee extended is used to account for the influence of gastrocnemius tightness. Measurement of ankle dorsiflexion with the knee bent is used to detect tightness of joint capsule or soleus muscle. Subject is positioned in the prone position with the foot hanging off the table and the subtalar joint maintained in the neutral position. Dorsiflexion is measured as the angle formed by the lateral midline of the leg on a line from the head of the fibula to the tip of the lateral malleolus and the lateral midline of the foot in line with the border of the rearfoot/calcaneus. The average measurement of two trials with 5-second pause between trials is recorded.
ITB/TFL Complex Length Gravity goniometer ICC: 0.97	Determined by using the Ober's test.[73] Subject is positioned in side-lying with the tested leg positioned superior and the lower leg slightly flexed at the hip and knee to maintain stability. The test leg is flexed to a right angle at the knee and grasped just below the knee with the examiner's distal hand. The examiner moves the subject's thigh first in flexion, then through abduction combined with extension until the hip is positioned in mid-range abduction with neutral flexion/extension. From this position the thigh is allowed to drop toward the table until the point where the limb stops moving towards the tables. At that point the measurement is taken. The gravity goniometer is zeroed on a horizontal surface prior to the measurement and during measurement is placed over the distal portion of the ITB/TFL complex. The result is recorded as a continuous variable. Negative values represent more tightness whereas positive values (below horizontal) represent less tightness. The average measurement of two trials with 5-second pause between trials is recorded.
Lateral Retinacular Structures Length Kappa: 0.71	Assessed with the patellar tilt test.[76] Performed with the subject in supine with the knee in full extension and the femoral condyles placed in the horizontal plane. The examiner attempts to lift the lateral edge of the patella from the lateral femoral condyle. The patella is not allowed to move laterally during the measurement. The inability to lift the lateral boarder of the patella above the horizontal plane indicates a positive test for tightness of the lateral retinaculum. Adequate length of the lateral retinaculum or negative test is indicated by the ability to lift the lateral boarder of the patella above the horizontal plane.
Foot Pronation Metric ruler and index card ICC: 0.93	Measured by the navicular drop test.[92,114] It measures the difference between height of the navicular at subtalar joint neutral position and that of the relaxed stance position. Subject stands on a high hard surface with the feet shoulder width apart. Examiner stays behind the subject with the eyes leveled at the subject's feet. The examiner marks the subject's navicular tuberosity and put the subject in the subtalar joint neutral position. Using an index card placed perpendicular to the table, the examiner records the distance from the navicular to the floor. The subject is then instructed to relax from the subtalar neutral position and the measurement is repeated. Then, with a metric ruler, the distance between the two dots, in the index card (which represents the difference in the position of the navicular tubercle with respect to the floor between the subtalar neutral and relaxed standing positions) is recorded in millimeters. Greater distances between the dots indicates greater pronation.
Q-angle Universal goniometer ICC: 0.70	Measured with the knee in full extension with the subject in supine. The angle formed by the intersection of the line of application of the quadriceps force (line from the anterior superior iliac spine to the center of patella) with the center line of the patellar tendon (line from the center of the patella to the tibial tubercle) is measured.[58]
Tibial Torsion Universal goniometer	Subject prone on a low table, and with the tested knee bent at 90^0. Height of the table is adjusted so the tester can comfortably visualize the plantar surface of the subject's foot. To facilitate visualization, the tester marks the most prominent aspect of the medial and

ICC: 0.70	lateral malleolus with a small dot. The examiner measures the angle formed by the axis of the knee (imaginary line from the medial to lateral femoral epicondile) and an imaginary line through the malleoli.
Femoral Anteversion Gravity goniometer ICC: 0.45	Measured with the Craig's test with the participant in prone with the knee flexed to 90^o.[86] Before starting the measurement, the gravity goniometer is zeroed on a vertical surface and placed on the medial surface of the lower leg, just proximal to the medial malleolus. The examiner palpates the posterior aspect of the greater trochanter of the femur. The hip is then passively rotated until the most prominent portion of the greater trochanter reaches the most lateral position or the horizontal plane (parallel with the table). The degree of anteversion is estimated based on the angle of the lower leg with the vertical.
Quality of Movement Kappa: 0.67	Measured during the lateral step down test using a scale designed for this purpose. The subject is asked to stand in single limb support with the hands on the waist with the knee straight close to the edge of a 20 cm high step. The contralateral leg is positioned over the floor adjacent to the step and is maintained with the knee in extension. Subject bend the tested knee until the contralateral leg gently contact the floor and then re-extend the knee to the start position. This maneuver is repeated for 5 repetitions. The examiner faces the subject and scores the test based on 5 criteria: 1) Arm strategy. If subject uses an arm strategy in an attempt to recover balance, add 1 point; 2) Trunk movement. If the trunk leans to any side, add 1 point; 3) Pelvis plane. If pelvis rotates or elevates one side compared with the other, add 1 point; 4) Knee position. If the knee deviates medially and the tibial tuberosity crosses an imaginary vertical line over the 2^{nd} toe, add 1 point, or, if the knee deviates medially and the tibial tuberosity crosses an imaginary vertical line over the medial border of the foot, add 2 points, and; 5) Maintain steady unilateral stance. If the subject steps down on the non-tested side, or if the subject tested limb becomes unsteady (i.e. waves from side to side on the tested side), add 1 point. Total score of 0 or 1 is classified as good quality of movement, total score of 2 or 3 as medium quality, and total score of 4 or above is classified as poor quality of movement.

APPENDIX B

Physical Therapy Program- Description of Exercises and Progression

Subjects completed an exercise program consisting of patellar taping, a strengthening, and a stretching component in the physical therapy clinic for 8 sessions distributed over 2 months (1 or 2 times a week at the therapist's discretion, but not having completed all 8 sessions before 7 weeks). Progression of strengthening exercises was individualized and based on the number of repetitions (maximum of 3 sets of 10 repetitions) and the load used during each exercise. If the patient could not complete the 3 sets of the proposed exercise with 10 repetitions each, the patient started with the maximum number of repetitions that allowed the completion of 3 sets of that number of repetitions.

Patellar Taping Component

Apply the patellar taping at the beginning of each PT session. If needed, reapply or tighten the tape during the PT session. Instruct the patient in how to apply the tape at home and provide the material necessary to perform the taping technique.

Start the taping procedure using the medial glide component. The amount of glide varies depending on the tightness of lateral structures. Use pain reduction as the guide. Use the Endura-Fix underneath the strapping tape (i.e. the "brown Endura tape").	 
If the medial glide is not effective, use the lateral tilt component. Correction of the lateral tilt can be made by firm taping from the midline of the patella medially.	
If both the medial glide and lateral tilt are not effective, try the rotation component. To correct abnormal patellar rotation, apply the tape from either the middle inferior pole upwards and medially (to correct external rotation of the inferior pole), or the middle superior pole downwards and medially (to correct internal rotation of the inferior pole). Typically, it is more common to correct a patella that is externally rotated, thus the need to bring the tape upwards and medially.	

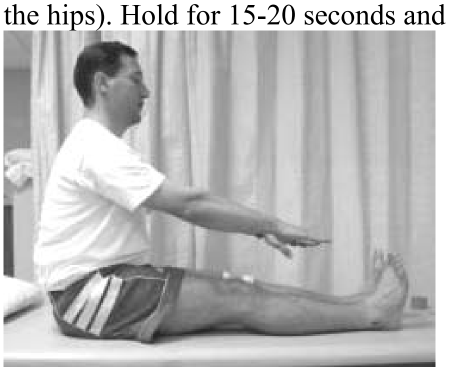
Warm-Up

After taping, have the patient ride a stationary exercise cycle. Start with 3 minutes and progress to a 5-minute warm-up. Start with no resistance and progress with resistance as tolerated by the patient.

Stretching and Strengthening Exercises

Hamstrings stretch

In a sitting position with the knees straight and heels together, bend the ankles so that the toes point toward the face. Then reach forward with the head up and arms straight, attempting to touch the toes without rounding the back (i.e. should only bend at the hips). Hold for 15-20 seconds and repeat 5 times.



Quadriceps stretch

In a standing position, use the arm opposite of the leg being stretched to bring the heel of the side being stretched as close to the buttocks as possible. Do not bend backwards or rotate the hips forward. Hold for 15-20 seconds and repeat 5 times.

Gastrocnemius stretch

In a standing position with both of your hands against a wall, stand with one foot in front of the other such that the leg being stretched is in the back. Bend the forward knee while pushing the heel of the leg in the back (i.e. the leg being stretched) towards the floor, while keeping this knee straight. Keep your hips rotated backwards and your low back relatively flat while you perform the stretch. The stretch should be biased toward the outside of the foot. Hold for 15-20 seconds and repeat 5 times.

Static quadriceps setting

In a supine position, place a rolled tower under the knee being exercised. Attempt to maximally straighten this knee and hold this position as hard as you can for 5 seconds. Repeat 30 times with a 3-second rest interval between repetitions. Rest for 1 minute.

Straight leg raises (SLR)

Affix the appropriate weighted sandbag on the leg being exercised using the Velcro straps. Lie supine. Raise the leg to be exercised by bending your hip to a position where it is around 45°. Perform 3 sets of 10 repetitions each. Rest 1 minute after the conclusion of each set.

When the patient can complete 30 repetitions without pain while using proper technique, progress the weight of the cuff weights. Start at 2lbs and progress by 2-lb increments to a maximum of 10lb. When the patient is able to complete 30 repetitions with 10-lbs, progress to leg extension machine in a short arc movement from 20° of knee flexion to terminal extension.

Double leg squats (0 – 50°), with the feet 4-inches apart

Stand against a wall with the feet approximately 4-inches apart (Feet should be relatively close together.) Squat down by bending at the hips, knees, and ankles, being careful to keep the legs in proper alignment. Squat down until the knees are bent approximately 50°. Return from the squat upon reaching this position (i.e. do not hold the squat). Keep the back against the wall during this exercise but avoid pushing the back against the wall. Perform 3 sets of 10 repetitions each. Rest for 1 minute after the conclusion of each set.

If the patient cannot perform the 50° range, start with a shorter arc of movement and progress accordingly. Progress this exercise by holding dumbbells (one in each hand). When the patient can complete 30 repetitions without pain while using proper technique, progress the dumbbell weight. Start at 2lbs and progress by 2-lb increments to a maximum of 10lbs When the patient is able to complete 30 repetitions with 10lbs, progress the exercise by performing the repetitions at a slower rate.

Double leg squat (0 – 50°), with the feet 12-inches apart

Stand away from the wall with the feet approximately 12-inches apart. (This is approximately shoulder-width apart). Squat down by bending at the hips, knees, and ankles, being careful to keep the legs in proper alignment. Squat down until the knees are bent approximately 50°. Return from the squat upon reaching this position (i.e. do not keep the knee bent in this position by holding the squat). Perform 3 sets of 10 repetitions each. Rest for 1 minute after the conclusion of each set. Use the

Unilateral step-down and step-up exercise

t is 8-12 inches in height with
the step. Bend the affected knee
e foot on the non-affected side
our hips, knee, and foot in
Re-straighten the knee on the
step when the foot on the
non-affected side touches the
floor. Perform a total of 3 sets

weight prescribed by your therapist: If the patient cannot perform the 50° range, start with a shorter arc of movement and progress accordingly. Progress this exercise by holding dumbbells (one in each hand). When the patient can complete 30 repetitions without pain while using proper technique, progress the dumbbell weight. Start at 2lbs and progress by 2-lb increments to a maximum of 10lbs When the patient is able to complete 30 repetitions with 10lbs, progress the exercise by performing the repetitions at a slower rate.  	of 10 repetitions each. For the first set, step down forward on the step. For the second set, step down sideways on the step. For the third set, step down backwards on the step. Rest for 1 minute after the conclusion of each set.   Progress this exercises by holding the dumbbells during all repetitions in each direction. Ensure the patient maintains proper alignment of the hips, knees, and feet. When the patient can complete 30 repetitions without pain while using proper technique, progress the dumbbell weight. Start at 2lbs and progress by 2-lb increments to a maximum of 10lbs When the patient is able to complete 30 repetitions with 10lbs, progress the exercise by performing the repetitions at a slower rate.

Short arc leg extension (from 90 to 50°of flexion)

Start with cuff weights as described above and progress to using a leg extension machine. Initiate leg extension machine with 1 plate. When able to tolerate 3 sets of 10 repetitions with one plate, advance to second plate. The following progression is recommended:

1st set: 10 reps with plate 1; 2nd set 6 – 8 reps with plate 2; 3rd set 5 reps with plate 2.

When tolerating well with plates 1 and 2, add plate 3 as follows:

1st set, 10 reps, plate 1; 2nd set, 6 – 8 reps, plate 2; 3rd set, 5 reps, plate 3.

When tolerating 3 plates as above, advance by adding one plate for each set as follows:

1st set, 10 reps, plate 2; 2nd set, 6 – 8 reps, plate 3; 3rd set, 5 reps, plate 4.

Note: This exercise is not part of the home exercise program.

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