

A Proximal Strengthening Program Improves Pain, Function, and Biomechanics in Women With Patellofemoral Pain Syndrome

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Background: It is hypothesized that patients with patellofemoral pain syndrome (PFPS) have hip and core muscle weakness leading to dynamic malalignment of the lower extremity. Thus, hip strengthening is a common PFPS treatment approach.

Purpose: To determine changes in hip strength, core endurance, lower extremity biomechanics, and patient outcomes after proximally focused rehabilitation for PFPS patients.

Study Design: Case series; Level of evidence, 4.

Methods: Nineteen women (age, 22.68 ± 7.19 years; height, 1.64 ± 0.07 m; mass, 60.2 ± 7.35 kg) with PFPS participated in an 8-week program to strengthen the hip and core muscles and improve dynamic malalignment. Paired *t* tests were used to compare the dependent variables between prerehabilitation and postrehabilitation. The dependent variables were pain; functional ability; isometric hip abduction and external rotation strength; anterior, lateral, and posterior core endurance; joint range of motion (ROM; rearfoot eversion, knee abduction and internal rotation, and hip adduction and internal rotation); and peak internal joint moments (rearfoot inversion, knee abduction, and hip abduction and external rotation) during the stance phase of running.

Results: Significant improvements in pain, functional ability, lateral core endurance, hip abduction, and hip external rotation strength were observed. There was also a significant reduction in the knee abduction moment during running, although there were no significant changes in joint ROM.

Conclusion: An 8-week rehabilitation program focusing on strengthening and improving neuromuscular control of the hip and core musculature produces positive patient outcomes, improves hip and core muscle strength, and reduces the knee abduction moment, which is associated with developing PFPS.

Keywords: PFPS; hip; strengthening; knee; patella; women

Patellofemoral pain syndrome (PFPS) is an overuse injury characterized by aching pain in the peripatellar area that is exacerbated by physical activities such as climbing stairs, squatting, jumping, and running and/or by sitting with the knees flexed for prolonged periods of time. The prevalence of this problem is high because it can occur in patients with a wide range of physical activity levels.

Symptoms often cause disability with physical activity, exercise participation, and activities of daily living. Patellofemoral pain syndrome is one of the most common knee disorders, accounting for 25% of all knee injuries seen in athletes in a sports medicine clinic.¹⁸ It has been reported as the cause of 20% to 40% of all visits to physical therapy clinics as a result of knee pain,^{17,30} 10% of total visits to musculoskeletal physical therapy clinics,³⁰ and is the most common injury in runners.⁵² Patellofemoral pain syndrome is the most common cause of knee pain in adolescents³ and has a much higher incidence in women than men.^{1,2,23} There are myriad factors that can lead to the development of PFPS symptoms, which makes diagnosing the cause of the symptoms and designing a rehabilitation program extremely difficult.

One etiological theory of PFPS is that poor proximal neuromuscular control and/or weakness of the hip musculature may lead to poor control of frontal and transverse plane motions of the hip during single-legged stance.⁴¹ Several observational studies have described this pattern

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The authors declared that they had no conflicts of interests in their authorship and publication of this contribution.

TABLE 1
Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria (as determined by physical examination)
Aged 16-40 years	Meniscal or other intra-articular injury
Insidious onset of symptoms, present for at least 4 weeks	Cruciate or collateral ligament laxity or tenderness
Peripatellar knee pain during at least 3 of the following:	Patellar tendon, iliotibial band, or pes anserine tenderness
During or after activity	Positive patellar apprehension sign
Prolonged sitting	Osgood-Schlatter or Sinding-Larsen-Johanssen syndromes
Stair ascent or descent	Evidence of effusion
Squatting	Hip or lumbar referred pain
Active at least 30 minutes per day, most days of the week	History of recurrent patellar subluxation or dislocation
	Known articular cartilage damage (from previously obtained imaging)
	Previous surgery to the patellofemoral joint
	Prolonged nonsteroidal anti-inflammatory drug or corticosteroid use
	History of head injury or vestibular disorder within the last 6 months
	Pregnancy
	Trauma to the knee joint

of dynamic malalignment as femoral adduction and internal rotation, valgus collapse at the knee, tibial internal rotation, and foot pronation.^{28,41,43,55} The relationship between hip muscle function and a variety of lower extremity injuries has been supported by empirical research.^{4,21,22,28,29,32,37} Prospectively, Leetun et al³² reported that participants who became injured displayed weakness in hip abduction and external rotation during preparticipation examination. Female participants were also found to be weaker in hip external rotation and abduction and core muscle endurance assessments compared with male participants. A recent systematic review describes strong evidence that PFPS patients have deficits in hip abduction, extension, and external rotation strength and moderate evidence for a decrease in adduction and internal rotation strength compared to healthy controls.⁴²

Although there is strong evidence to support the theory that hip weakness is found in patients with PFPS, there is mixed evidence to support the theory that hip weakness leads to dynamic malalignment or biomechanical changes in gait. Willson et al⁵⁶⁻⁵⁸ have consistently reported the finding of increased hip adduction angle in patients with PFPS compared with healthy controls. However, other studies have reported no difference in hip adduction angles between injured and uninjured groups.^{6,47} Differences in hip internal rotation have also been inconsistent, with some studies reporting increased hip internal rotation in PFPS patients,^{47,48} other studies reporting decreased hip internal rotation,^{56,57} and yet others reporting no difference.⁶ While these studies have begun to examine the causes of dynamic malalignment and PFPS, none have reported the changes in biomechanics before or after a rehabilitation program.

Several studies have been conducted evaluating the outcomes of rehabilitation programs that include or focus on the proximal hip musculature. Sahrmann⁴⁵ reported that exercise programs focusing on correcting dysfunctional movement patterns seemed to be effective in treating overuse injuries. A rehabilitation program focused on proximal and core strengthening has been effective for 3 patients with PFPS and notable proximal weakness. The patients

had reduced symptoms and increased function, and one patient was evaluated kinematically and showed improvement in dynamic alignment.^{10,33} More recent studies incorporating hip strengthening, stretching, and balancing exercises have also demonstrated a significant improvement in pain and function in patients with PFPS.^{7,35,53} However, no biomechanical or movement analyses were conducted in these studies.

Although there is some evidence connecting hip weakness and dynamic malalignment to PFPS symptoms, there are few studies comprehensively evaluating the outcomes of a rehabilitation program to correct the dysfunction. The inclusion of biomechanical analysis of movement has been lacking in the current outcomes studies. Therefore, the purpose of this study was to determine if a proximally focused rehabilitation program for women with PFPS would (1) decrease pain and increase function, (2) increase hip strength and core muscle endurance, and (3) improve lower extremity biomechanics during running. On the basis of previous literature and clinical expertise, we hypothesized that pain and functional ability would improve, hip and core strength would increase, and joint angles and moments that are associated with dynamic malalignment will be reduced after the rehabilitation program.

MATERIALS AND METHODS

Participants

This study utilized a case series design, occurring in both a research laboratory and rehabilitation clinic setting. Potential participants were evaluated by a sports medicine physician and/or certified athletic trainer during their self-referred visit to a local sports medicine clinic, or university student health center, with a chief complaint of knee pain. If the inclusion criteria (Table 1) were met, the study was described to the patient, and they were referred to the principal investigator for further information. Based on a significant change in hip abduction strength of 3% body

weight with a moderate effect size (0.68), and α set a priori at $<.05$, a sample of $n = 13$ was determined to be necessary to achieve adequate statistical power.⁴⁶

The age range was 16 to 40 years and was chosen because the majority of women have been through pubescent changes by age 16 years, and after 40 years, there is an increased prevalence of hormonal changes and arthritis development. There is little consensus on a standard diagnostic test for PFPS, and costly and invasive diagnostic testing is not indicated for most patients with the stereotypical signs and symptoms of PFPS.¹⁵ Therefore, for the purposes of this study, the diagnosis of PFPS was based on classic signs and symptoms. The inclusion and exclusion criteria can be found in Table 1 and are typical of those used in previous PFPS research.^{15,53,54} If physical examination indicated that intra-articular injury or cartilage damage must be ruled out, then images were obtained, and the participant was excluded as necessary. Twenty-eight women volunteered to participate. Nine participants did not complete the study (5 because of time constraints, 2 because of secondary injury, and 2 were unable to be contacted). Therefore, 19 women completed the study (age, 22.68 ± 7.19 years; height, 1.64 ± 0.07 m; mass, 60.2 ± 7.35 kg). The average duration of symptoms was 17 months (range, 1-60 months). Five participants were currently high school or collegiate athletes (soccer, basketball, cross country, gymnastics, cheerleading), 4 were dancers (competitive or studying dance), and the remaining participated in a variety of recreational exercise and/or sports between 3 to 12 hours per week.

Preliminary Testing Procedures

All participants provided informed consent as approved by the university and hospital institutional review boards before participating. Participants under the age of 18 years were not allowed to participate unless a parent or guardian also provided informed consent.

The Kujala Anterior Knee Pain Scale (AKPS) questionnaire is a self-reporting tool used to assess the functional activity level of patients with PFPS.³¹ The visual analog scale (VAS) is a reliable and valid tool in assessing clinical changes in PFPS patients.⁹ Participants marked their usual pain in a day. The VAS and the AKPS have been found to be reliable, valid, and responsive tools for outcomes assessment in PFPS.¹⁴ These tools were used as the primary outcome measures for the study. Crossley et al¹⁴ reported that a combination of outcome measures of VAS and AKPS are the most valid and responsive outcome measures for PFPS clinical trials. Clinically meaningful improvement in the VAS pain score was >20 mm and in the AKPS function score was 8 points. A successful outcome was considered to be any patient who improved >20 mm on the VAS or >8 points on the AKPS.

Three-dimensional joint angle data were collected using a 7-camera Motion Analysis Eagle motion capture system (Motion Analysis Corp, Santa Rosa, California), and ground-reaction force (GRF) data were recorded by a force plate (model OR-6-1, AMTI Inc, Watertown, Massachusetts)



Figure 1. Marker location during standing calibration trial.

mounted in the center of the runway flush with the floor. Ground-reaction force and joint angle data were used in the calculation of internal joint moments, and these data were collected synchronously at 1000 Hz and 200 Hz, respectively.

During testing, participants wore a T-shirt, tight-fitting shorts, and standard athletic shoes (model W801GB, New Balance Athletic Shoes Inc, Boston, Massachusetts). If participants had bilateral knee pain, the leg with more pain was tested, although the rehabilitation was done bilaterally in these participants. Reflective marker clusters (4 markers each) were affixed to the thigh and leg using Velcro® (Velcro USA Inc, Manchester, New Hampshire) straps, and a cluster with 3 markers was affixed to the posterior shoe of the test leg. Additional single markers were placed to define segment alignment and coordinate systems during the standing trial and removed before testing (Figure 1). During the running trials, participants ran straight ahead down a runway at a set speed of 4.0 to 4.5 m/s. Participants were allowed several practice trials to ensure proper foot contact on the force plate. Five subsequent trials were recorded capturing 3-dimensional movement of the hip, knee, and ankle and GRF data.

Hip strength and core endurance measures were counterbalanced to prevent fatigue. Hip external rotation and abduction strength were assessed following the protocol of Leetun et al.³² A handheld dynamometer (model 01136, Lafayette Instruments, Lafayette, Indiana) and straps were used to facilitate maximal isometric contractions. Testing positions for hip strength testing are presented in Figure 2. Two practice trials and 3 experimental trials were performed with 15 seconds of rest between trials. The maximal force value (Kg) of the experimental trials was normalized to body mass (Kg; % body weight [%BW]) and used as the dependent variable for analysis. Normalization was

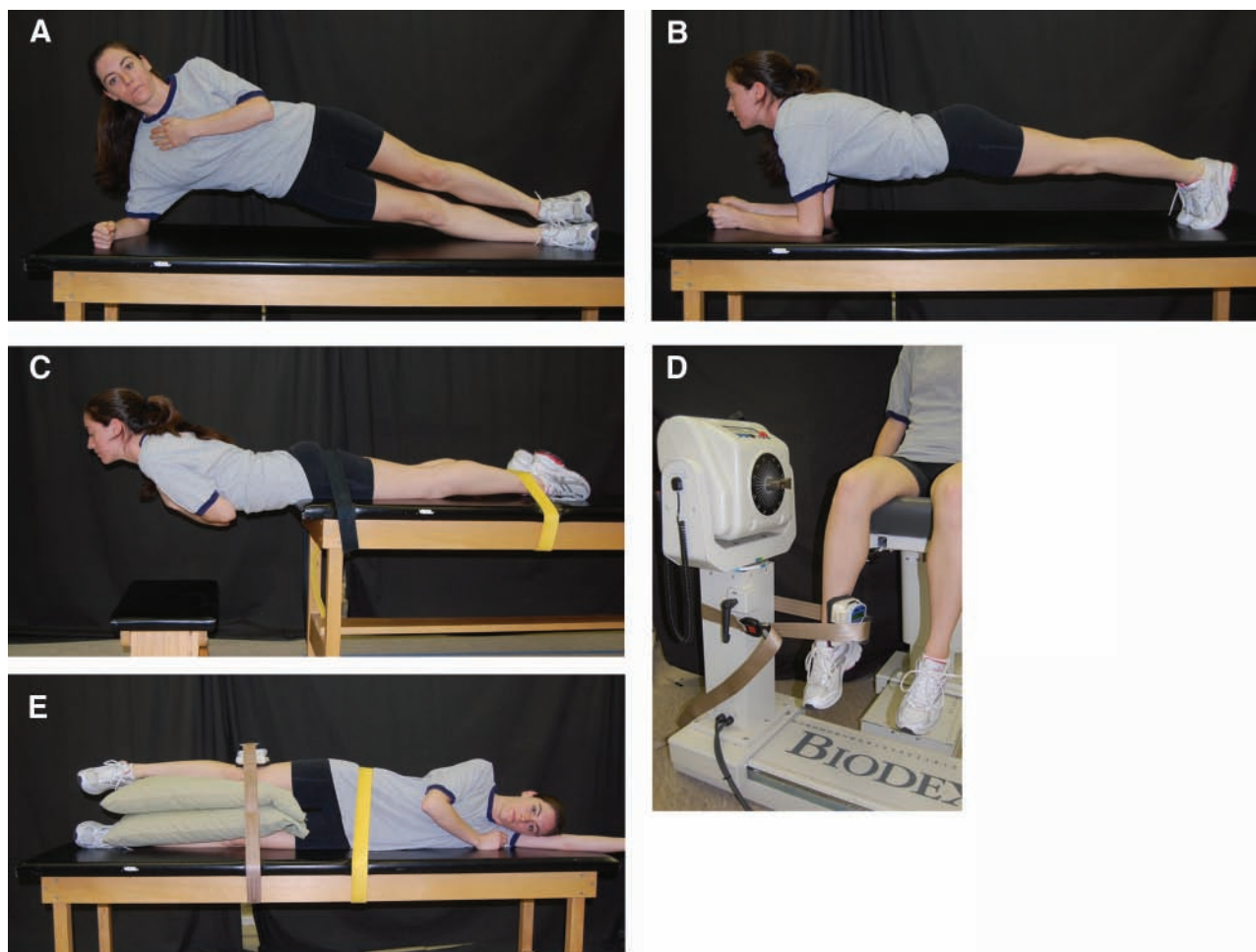


Figure 2. Testing positions for lateral core endurance (A), anterior core endurance (B), posterior core endurance (C), hip external rotation strength (D), and hip abduction strength (E).

performed to allow direct comparison with previously published hip strength data.

Core muscle endurance was defined as the duration of time a patient could hold a static position and was measured using the techniques described by McGill et al³⁴ (Figure 2). For the posterior core, the horizontal extension test was used. For the lateral core, the side bridge exercise was used. It has been shown that there is no difference between right and left side bridge endurance times.³⁴ Therefore, the injured leg was the top leg in the side-lying position so as to not place additional stress on the knee. For the anterior core, the front plank test was used. A single trial of each position was performed with 1 to 2 minutes of rest between positions. The duration of time (seconds) that the participant could hold the position was used as the dependent variable for analysis.

Rehabilitation Intervention

After the initial testing session, participants began the 8-week "proximal stability program." Participants attended

8 to 15 rehabilitation sessions in the clinic, each lasting 30 to 60 minutes. These visits were spread over the 8-week rehabilitation period at the discretion of the treating clinician based on the patient's needs. Each rehabilitation session was supervised by a certified athletic trainer or physical therapist. In addition to the clinical visits, participants performed the exercises at home at least 3 times per week and recorded any exercises, symptoms, and activities in a home exercise diary. Compliance was monitored by attending all scheduled rehabilitation sessions and by random telephone calls to each participant to verify that home exercises were being performed. Participants were asked to refrain from any other weight training during the study and were allowed to maintain their current activity level as tolerated. Besides the exercise program, no other therapeutic interventions were used (ie, taping, bracing, orthoses, modalities, medication). Ice was used as needed to alleviate pain.

The proximal stability program was designed with input from previous research^{33,51} and clinical expertise and followed a neuromuscular retraining paradigm (Table 2). In phase 1 of the program, the participant focused on learning

TABLE 2
Proximal Stability Program

Phase 1 (weeks 1-2)
GOAL: Improve volitional control of the hip and core muscles ^a
• Abdominal draw-in exercises • Side-lying clamshells • Side-lying straight-leg raises • Supine arm/leg extensions • Quadruped arm/leg extensions • Isometric single-legged stance (SLS) • Hamstring stretch • Quadriceps stretch • Calf stretch
Phase 2 (weeks 3-5)
GOAL: Restore reflex contractions to perturbations
• Isometric SLS with hip abduction • Single-legged cable column exercise ◦ Facing toward weights ◦ Facing away from weights ◦ Beside weights • SLS quick kicks • Prone plank exercise • Side plank exercise • Bilateral minisquat • Hamstring stretch • Quadriceps stretch • Calf stretch • Iliotibial band “pretzel” stretch
Phase 3 (weeks 6-8)
GOAL: Restore pattern-generated movements
• “Monster walks” • SLS with sport-specific upper body movement • Minisquat progression (minilunge → SLS → step down) • Hamstring stretch • Quadriceps stretch • Calf stretch • Iliotibial band “pretzel” stretch

^aProgression criteria: dynamic exercise progression: 3 sets × 10 reps → 3 sets × 15 reps → 3 sets × 20 reps; isometric exercise progression: 2 sets × 15 reps × 10-second hold; within each phase, progress by adding weight (2.5-5 lb) or resistance (up one level/color of theraband); and ability to maintain proper alignment during standing exercises (maintain the knee over the second toe, maintain a level pelvis, do not allow the knee to migrate medial of the foot).

to volitionally contract the pelvic- and hip-stabilizing muscles such as the transverse abdominus, gluteus medius, and gluteus minimus. As strength and control of the proximal muscles improved, phase 2 began, and more dynamic exercises were added. Participants were instructed on proper lower extremity alignment and told to concentrate on maintaining proper alignment during the exercises, ultimately progressing to maintaining joint stability during perturbations. Proper alignment was defined as maintenance of the knee over the second toe, maintaining a level pelvis, and not allowing the knee to migrate medial to the foot during a single-legged stance. The final goal was for the maintenance of posture and alignment to become subconscious so more complex functional tasks could be added.²⁶

Pain and functional outcomes, biomechanical analysis, and strength measurements were all recorded upon

completion of the 8-week rehabilitation program. As a follow-up analysis, the VAS and AKPS questionnaire were sent to all participants 6 months after completion of the rehabilitation program.

Data Processing

Three-dimensional coordinate data were low-pass filtered using a fourth-order, zero-lag, recursive Butterworth filter with a cut-off frequency of 12 Hz.⁴⁶ Hip, knee, and ankle joint angles were calculated using a joint coordinate system approach.²⁴ Net joint moments were estimated using a Newton-Euler inverse dynamics analysis⁸ and are reported as internal joint moments (those created by the body in response to externally applied moments). All data were extracted during the stance phase (initial contact to toe off) and time normalized to 101 data points. Because of the relatively small sample size, and to protect statistical power, we selected only the kinematic and kinetic variables that have been most associated with poor dynamic alignment. Kinematic dependent variables were joint range of motion (ROM; defined from initial contact to peak angle) of rear foot eversion, knee abduction, hip adduction, and hip internal rotation. Joint ROM was chosen as the dependent variable because it has been shown to be more reliable between days than peak angles.²⁰ The kinetic dependent variables were peak ankle inversion, knee abduction, and hip abduction and external rotation internal joint moments.

Statistical Analysis

Paired *t* tests were used to compare the dependent variables for strength, joint ROM, and joint moment variables between prereshabilitation and postrehabilitation testing. The 2 subjective outcome variables (VAS and AKPS scores) were compared using the nonparametric Wilcoxon signed-rank statistic. A nonparametric test was chosen because subjectively rated pain and functional ability are not normally distributed variables. The α level was set a priori at .05. The effect size for each variable was calculated using Cohen *d* to give an indication of the magnitude of the effect of the exercise intervention (>0.8 large effect, 0.5 moderate effect, <0.3 small effect).¹²

RESULTS

Most participants completed at least one supervised rehabilitation session per week with a certified athletic trainer or physical therapist, with a range of 8 to 15 sessions. The average number of days the home exercise program was completed was 28, with a range of 19 to 40. Two participants only completed 6 weeks of rehabilitation before their posttest because of their return to college away from the area.

A significant improvement was found in both VAS pain rating score ($Z = -3.823$, $P < .0005$) and AKPS functional

TABLE 3
Mean $\pm$ Standard Deviation of Variables Measured Prerehabilitation and Postrehabilitation Program^a

	Prerehabilitation	Postrehabilitation	P Value	Effect Size
Pain (VAS), mm	40 $\pm$ 18	5 $\pm$ 7	<.0005	2.7
Function (AKPS)	70.4 $\pm$ 11.2	83.7 $\pm$ 11.2	<.0005	1.7
Anterior core, s	72 $\pm$ 33	83 $\pm$ 39	.06	0.5
Posterior core, s	107 $\pm$ 58	127 $\pm$ 53	.10	0.5
Lateral core, s	48 $\pm$ 30	73 $\pm$ 49	.001	1.2
Hip abduction strength, kg/kg ^b	0.34 $\pm$ 0.07	0.38 $\pm$ 0.07	.008	0.8
Hip external rotation strength, kg/kg ^b	0.12 $\pm$ 0.04	0.14 $\pm$ 0.04	.03	0.7
Joint angle ROM, deg				
Rear foot eversion	-15.2 $\pm$ 5.3	-14.8 $\pm$ 5.6	.58	0.1
Knee abduction	-1.46 $\pm$ 1.0	-1.54 $\pm$ 1.8	.86	0.1
Hip adduction	9.1 $\pm$ 3.5	9.7 $\pm$ 3.2	.41	0.2
Hip internal rotation	2.0 $\pm$ 2.5	3.2 $\pm$ 2.9	.12	0.7
Joint moments, N·m				
Rear foot inversion	16.2 $\pm$ 15.6	14.8 $\pm$ 12.4	.61	0.1
Knee abduction	-70.2 $\pm$ 51.4	-54.0 $\pm$ 22.6	.05	0.4
Hip abduction	-142.5 $\pm$ 62.5	-121.1 $\pm$ 29.5	.06	0.5
Hip external rotation	-5.6 $\pm$ 3.8	-4.4 $\pm$ 2.4	.20	0.5

^aVAS, visual analog scale; AKPS, Anterior Knee Pain Scale; ROM, range of motion.

^bForce in kg normalized to body mass.

score ($Z = -3.342$, $P = .001$) (Table 3). Of the 19 participants who completed the study, 15 participants had an improvement of >20 mm on the VAS pain rating and were determined to have a successful outcome. Two patients had VAS improvements of <20 mm but AKPS improvements of >8 points and were also considered to have a successful outcome. Two patients did not meet either of the criteria for a successful outcome and were therefore considered to be unsuccessful. Figure 3 presents the changes in VAS of all the participants.

Peak internal knee abduction moment was significantly reduced after the rehabilitation program ($t_{1,16} = -2.13$, $P = .05$) (Figure 4). There were no other significant changes in joint moments or joint ROM (Table 3).

Lateral core endurance significantly improved ($t_{18} = 4.035$, $P = .001$). There were no significant changes in anterior or posterior core endurance. There were also significant improvements in hip abduction ($t_{18} = 2.979$, $P = .008$) and external rotation ($t_{18} = 2.320$, $P = .032$) strength (Table 3).

DISCUSSION

Patient Outcomes

After the completion of the proximal stability program, women with PFPS had significant improvement in pain and functional ability. They also had significantly stronger hip abductors and external rotators and greater endurance of the lateral core muscles, and knee abduction moments were reduced. The improvement in outcomes and strength measurements indicates that the rehabilitation protocol effectively reduced the symptoms of PFPS and had a positive effect on proximal strength. The reduction in knee

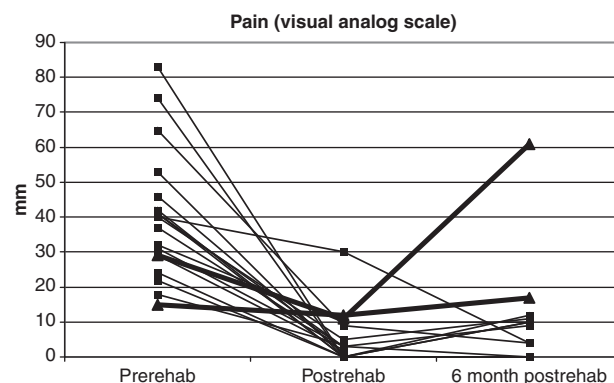


Figure 3. Patient-reported pain (visual analog scale) prerehabilitation, postrehabilitation ($n = 19$), and 6 months after the end of rehabilitation ($n = 13$). Thin lines represent patients with a successful outcome, and thick lines represent patients with an unsuccessful outcome.

abduction moment is important because high abduction moments have been prospectively related to the development of PFPS.⁵⁰

The conservative standard of care for treating PFPS has been focused on open and closed chain quadriceps strengthening and often includes patellar taping, orthoses, and stretching.^{5,16,36} While there is moderately strong evidence that some type of exercise intervention is effective in the treatment of PFPS,^{5,16,25} it is not clear if one form of exercise is superior to another. Furthermore, the recurrence rate of PFPS symptoms is very high, with studies reporting a range of recurrence between 25% and 91% with patients reporting continuing symptoms several years after their rehabilitation.^{18,27,39,49,59} The multifactorial

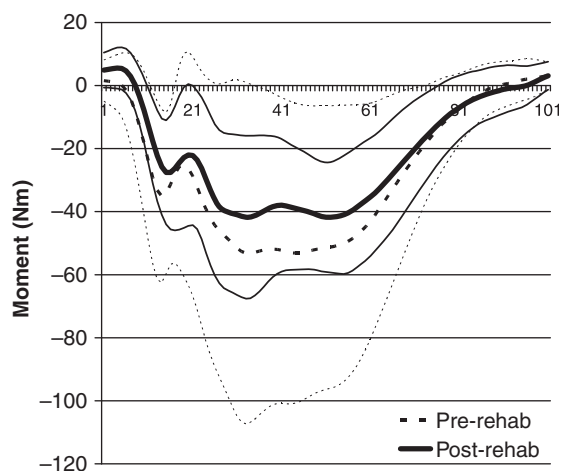


Figure 4. Ensemble average of frontal plane hip moment (N·m). Thick dotted/solid lines represent the means, and thin lines represent the respective standard deviations.

causes of PFPS make isolating and treating the cause of the symptoms very difficult, and it is possible that the causes of some patients' symptoms are not addressed by the current standard of care. Research has revealed that hip muscle dysfunction exists in PFPS patients,^{6,11,28,44} so an alternative approach to quadriceps strengthening has been a hip-focused strengthening program. Despite increasing clinical use of hip strengthening for treating PFPS, and a growing body of literature supporting its effectiveness, there are no randomized clinical trials to support the approach. Before conducting a costly and extensive randomized clinical trial, it is necessary to demonstrate the effectiveness of a proximal approach to PFPS rehabilitation. The current study demonstrates the positive effects of proximal rehabilitation on patient outcomes, strength, and lower extremity biomechanics and is an important step toward conducting clinical trials comparing a proximal strengthening approach to other forms of rehabilitation.

Seventeen of 19 participants had a successful outcome after the rehabilitation program, as defined by improvements in VAS and/or AKPS.¹⁴ Two participants had very small changes in VAS pain score but larger changes in AKPS functional score. These patients had very low pain scores to begin with and thus little room for improvement. Closer examination of the 2 participants with unsuccessful outcomes is warranted to identify any unique characteristics that may have led to their lack of success. Participant "A" had VAS, AKPS, core endurance, and hip strength values that were very much in line with the group means. This was the only participant who had a positive Ober test result initially, perhaps indicating that her issue was more related to iliotibial band tightness. On visual examination, she displayed fairly "normal" alignment, and her biomechanical measures were consistent with the group means. Participant "B" also had preliminary scores that were in line with the group means. This participant did have the highest degree of hip adduction seen in the group, and there was no change in hip adduction

angle after the rehabilitation. One finding to note is that this participant had no improvement in hip strength or core endurance. While she reported consistently performing the strengthening exercises, it is possible that they were not being done correctly or with enough load. It is also possible that these individuals had additional factors that contributed to their knee pain, such as abnormal foot structure, abnormal patellar alignment, or quadriceps imbalance, that were not addressed as part of this rehabilitation program. Future research should be conducted to further examine subgrouping PFPS patients based on their impairments and symptoms and applying rehabilitation paradigms specific to those causes.

The magnitude of pain improvement in patients in the current study is in the range of previously reported studies of proximally focused rehabilitation for PFPS^{7,33,35,53} and in the range of previous studies using multimodal treatment paradigms including quadriceps strengthening, patellar taping, and neuromuscular retraining.^{13,15} Because this was a single-cohort observational study design, no conclusions can be made about the effectiveness of the proximal stability program compared with other forms of PFPS rehabilitation. What can be concluded is that the rehabilitation program used in this study produces primary outcomes that are similar to those from previously published programs and that are similar to the classic rehabilitation of quadriceps strengthening. This information provides the necessary evidence to continue to evaluate the effectiveness of the proximal stability program in a future clinical trial.

Thirteen participants returned the 6-month follow-up questionnaire, for a response rate of 68%. Of those who responded, 4 participants reported continued decrease in pain, and 4 reported slight increases in pain yet remained below their prerehabilitation values. The 2 unsuccessful cases both responded with one having a large increase in pain and the other having no change from original values. These should be considered "medium-range" outcomes and indicate that about 50% of the successful outcomes were starting to redevelop symptoms. This is consistent with the literature on the recurrence rate for PFPS and further illustrates the need for clinical trials that are more focused on etiological subgroups of PFPS patients.

Hip and Core Strength

Several studies have used hand-held dynamometry to measure hip strength in women with PFPS and have reported between 16% and 29% BW for hip abduction (HABD) and 11% and 21% BW for hip external rotation (HER).^{6,11,28,40,44} Before the start of the rehabilitation program, participants in this study had an average of 33.7% BW for isometric hip abduction strength and 12% BW for hip external rotation strength. Although the hip abduction value is slightly higher than that previously reported in patients with PFPS, it is lower than what has been reported for uninjured control participants: hip abduction 22% to 37% BW and external rotation 15% to 23% BW.^{6,11,28,40,44} It appears from these data that the

participants in this study did demonstrate hip weakness, and thus the proximal stability program was an appropriate intervention. No normative data could be found describing "normal" hip strength and core endurance values; thus, determining if our participants were "weak" is difficult.

Patients in this study displayed significant improvements in both hip abduction strength (12% increase) and hip external rotation strength (16% increase). Nakagawa et al³⁵ compared a quadriceps plus hip strengthening program (intervention) to a quadriceps-only strengthening program (control) and reported increases in eccentric isokinetic peak torque of 14% for HABD and 7% for HER in the intervention group and 5% for HABD and 4% for HER in the control group, although these increases were not statistically significant. Mascal et al³³ reported on 2 case studies having a 50% and 90% increase in isometric HABD force and a 317% and 15% increase in HER force as measured with hand-held dynamometry. Tyler et al⁵³ reported that after a rehabilitation program focusing on the hip, patients with a successful outcome had a 28% increase in HABD strength, while those with an unsuccessful outcome had an 18% increase in HABD strength. The difference in strength increases between groups was not statistically significant. Data from the current study add to the evidence that exercise programs focusing on the hip muscles can have a positive effect on strength. It is difficult to directly compare these values to those previously reported because of the different measurement and normalization techniques that have been used. Further study is needed to determine which characteristic of muscle function (strength, endurance, isokinetic, isometric, eccentric, concentric, etc) is most related to PFPS and which is related to decreased pain and improved function.

Although abdominal core muscle "weakness" has been related to developing lower extremity injury,³² none of the previous studies on hip strengthening and PFPS have included these measurements. In this study, a 51% increase in lateral core endurance was found; however, no significant increases occurred in anterior or posterior core endurance. There was a trend toward a significant increase in anterior core endurance ($P = .06$). It was not unexpected that posterior core endurance did not change as this muscle group was not directly trained, as were the anterior and lateral core muscles. Ekstrom et al¹⁹ reported high levels of gluteus medius activity during the side plank exercise (lateral core endurance test), and participants' increased strength in this muscle group could have contributed to their improved performance in the lateral core endurance test. Participants reported the lateral core endurance test to be the most difficult, and it resulted in the shortest hold times of any of the tests. Another interesting comment from the participants was that many of them experienced significant discomfort in their shoulder while holding the side plank position. It is possible that some participants ended the side plank test because of the pain in their shoulder rather than because of abdominal muscle fatigue. Additional research should be conducted to evaluate alternative methods of assessing abdominal core muscle function and its relationship to PFPS.

Biomechanical Changes

A significant decrease in the knee abduction moment was seen after the rehabilitation program. Runners with PFPS have previously been reported to have increased knee abduction impulse (the area under the joint moment-time curve) compared with uninjured runners, and high knee abduction impulse is predictive of development of PFPS symptoms in runners.⁵⁰ Increased hip adduction, contralateral pelvic drop, or lateral trunk lean could all contribute to increasing the knee abduction moment arm and thus the abduction moment. In addition, Snyder et al⁴⁶ reported that the knee abduction moment was significantly reduced in uninjured runners after a 6-week hip-strengthening exercise program. Limited evidence shows that a large knee abduction moment is related to the development of PFPS and that hip strengthening can lead to a reduction in this moment. Although no changes in kinematics were seen in the current study, the decreased knee abduction moment can be viewed as a positive finding and should be further investigated in a large-scale clinical trial.

The theoretical basis for proximal strengthening in the treatment of PFPS is that hip weakness causes dynamic malalignment of the lower extremity, causing increased stress at the patellofemoral joint and therefore pain.⁴¹ Our hypothesis that movements associated with dynamic malalignment would be improved after hip strengthening was not supported. No significant differences in hip adduction, internal rotation, knee abduction, or rear foot eversion ROM were seen. There are several possible explanations for this finding. We chose to examine joint excursion (ROM) during the stance phase because this variable has been shown to be the most reliable when comparing between days.²⁰ A possible issue with this approach is that the direction of the change in ROM could be different for different subjects yet appear as the same amount of ROM (ie, small internal rotation plus large external rotation could have the same ROM value as large internal rotation plus small external rotation). There are some limitations in the precision and reliability of 3-dimensional motion capture in the frontal plane, and therefore, small changes might not be able to be detected with the current technology. Other techniques such as examining joint coupling patterns or joint position during the loading response of gait should be examined in future studies. Another explanation is that not all of the participants had dynamic malalignment at the onset of the study. Therefore, the exercise program may have been attempting to "correct" a malalignment pattern that was not present. There were several participants who displayed one or more large joint angles associated with the pattern of dynamic malalignment. One participant in particular displayed large peak hip adduction and internal rotation, knee adduction, and ankle eversion angles. After the rehabilitation program, this participant displayed decreases in these angles. As PFPS is multifactorial in nature, some participants could have had other factors causing their knee pain. This is a limitation that is common in the PFPS rehabilitation literature. Future studies should attempt to categorize

participants by etiological subgroup and then examine a specific intervention in that subgroup.

Finally, after interventions such as shoes, orthoses, and/or lower extremity strengthening, the body may attempt to maintain the same pattern of motion that is most efficient and alter the neuromuscular activation of muscles and therefore joint moments in response to the intervention to do so.³⁸ This may be another explanation why joint moments were affected by the strengthening program while joint motions were not.

Limitations and Future Research

The primary limitation of this study is that no control group was used in the study design. As new approaches are being explored, it is important to establish the primary effects of a rehabilitation approach before embarking on a costly and time-consuming randomized clinical trial. The findings of this study support that a proximal strengthening approach to treating PFPS does cause positive patient outcomes and positively changes hip strength and lower extremity mechanics. This serves as the foundation for future research in this area. Another limitation is the relatively small sample size. Although appropriate statistical power was obtained, confirmatory studies with larger samples should be performed. Future clinical trials should be conducted to further examine the effectiveness of the proximal stability program using a paradigm in which PFPS patients are included based on the cause of proximal weakness and dynamic malalignment. Finally, because data were only collected at the beginning and end of the 8-week protocol, we cannot determine when the improvement occurred and subsequently if 8 weeks are needed to achieve a positive outcome. Additional studies that track the duration of the response and long-term outcome are also necessary.

CONCLUSION

An 8-week exercise-only rehabilitation program focusing on strengthening and improving neuromuscular control of the hip and core musculature produces positive patient outcomes, improves the hip and core muscle strength, and reduces the knee abduction moment, which are all theorized to be associated with developing PFPS. Physicians, athletic trainers, and physical therapists can use this information to make evidence-based decisions on the type of exercises to include in a rehabilitation program for PFPS.

ACKNOWLEDGMENT

The authors acknowledge Carrie Truebenbach, MS, PT, John Lachacz, PT, ATC, John Ochwenwald, MS, ATC, Becky Worman, ATC, Julie Bonner, MD, and Sarika Monteiro, MS, for their contributions to this project. Funding for this study was provided by the University of

Wisconsin–Milwaukee College of Health Sciences and the Medical College of Wisconsin Department of Orthopedics.

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