

Outcomes of a Weight-Bearing Rehabilitation Program for Patients Diagnosed With Patellofemoral Pain Syndrome

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ABSTRACT. Boling MC, Bolgla LA, Mattacola CG, Uhl TL, Hosey RG. Outcomes of a weight-bearing rehabilitation program for patients diagnosed with patellofemoral pain syndrome. *Arch Phys Med Rehabil* 2006;87:1428-35.

Objective: To determine the effects of a weight-bearing rehabilitation program on quadriceps and gluteus medius electromyographic activity, pain, and function in subjects diagnosed with patellofemoral pain syndrome (PFPS).

Design: Pretest and posttest 6-week intervention study.

Setting: Musculoskeletal research laboratory.

Participants: Fourteen subjects diagnosed with PFPS and 14 healthy control subjects volunteered to participate in this study. No subjects withdrew from the study because of adverse effects.

Intervention: Subjects diagnosed with PFPS participated in a 6-week rehabilitation program. The rehabilitation program consisted of weight-bearing exercises that focused on strengthening the quadriceps and hip abductor musculature.

Main Outcome Measures: Electromyographic onsets of the vastus medialis oblique (VMO) and vastus lateralis and onset and duration of the gluteus medius were collected during a stair-stepping task that was performed during the pretest and posttest. A visual analog scale (VAS) and Functional Index Questionnaire (FIQ) were administered at pretest and posttest and each week of the intervention.

Results: Vastus lateralis and VMO onset timing differences (vastus lateralis electromyographic onset minus VMO electromyographic onset) and VAS and FIQ scores significantly improved for patients diagnosed with PFPS. Vastus lateralis and VMO onset timing in the PFPS group were significantly different from those in the control group at baseline and were not significantly different from the control group after the intervention. We did not find differences in gluteus medius onsets or duration of activity.

Conclusions: Subjects diagnosed with PFPS responded favorably and quickly to a therapeutic exercise program that incorporated quadriceps and hip musculature strengthening. The efficacy of the therapeutic exercise program used in this study should be further investigated in a larger subject population.

Key Words: Electromyography; Exercise; Knee; Pain; Rehabilitation.

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PATELLOFEMORAL PAIN SYNDROME (PFPS) is among the most common causes of knee pain in the United States. One of the most commonly accepted etiologies of PFPS is abnormal tracking of the patella within the femoral trochlea.¹ A cause of this abnormal tracking may be a delayed onset of the vastus medialis oblique (VMO) relative to the vastus lateralis.^{2,3} If the vastus lateralis contracts before the VMO, a temporary imbalance in mediolateral force may occur, causing abnormal tracking of the patella.⁴

Researchers have previously investigated the onset times of the VMO and vastus lateralis in patients with PFPS; however, a consensus has not been made. Some researchers have reported no significant differences in the onset times of the VMO and vastus lateralis in patients with PFPS compared with controls when performing weight-bearing and non-weight-bearing exercises.⁴⁻⁶ However, other researchers have reported that the vastus lateralis was activated significantly sooner than the VMO in patients with PFPS compared with control subjects during a reflex activation.^{7,8} Recent literature has determined that the vastus lateralis and VMO onset timing difference (vastus lateralis onset minus VMO onset) is altered in patients with PFPS compared with controls.^{2,3} Because of differing results in the literature, this topic warrants further investigation.

Cowan et al⁹ investigated the effect of a rehabilitation program on timing of the VMO relative to the vastus lateralis using the McConnell-based rehabilitation program. The McConnell-based rehabilitation program incorporates quadriceps strengthening, patellar taping, and weight-bearing exercises that influence the hip musculature. After this intervention, subjects reported decreased pain and had improved vastus lateralis and VMO onset timing differences.⁹ These findings suggest that subjects had improved quadriceps neuromuscular control. The researchers, however, did not examine possible influences of the hip musculature.

Weak hip musculature is also thought to contribute to abnormal tracking of the patella.¹⁰⁻¹² Ireland et al¹⁰ found that women with PFPS are 26% weaker in hip abduction and 36% weaker in hip external rotation compared with healthy controls. Such weakness may cause an increase in both hip internal rotation and the valgus force vector at the knee, a combination that may further facilitate lateral patella tracking.¹ Limited research exists on the temporal characteristics of the gluteus medius in patients with PFPS. Brindle et al¹² investigated the temporal characteristics of the gluteus medius in patients with and without PFPS and reported a delay and shorter duration of gluteus medius activation during a stair-stepping task in patients with PFPS.¹² They concluded that temporal differences in gluteus medius activation may contribute to PFPS.

Most patients with PFPS respond favorably to conservative intervention,^{1,13,14} with the most common treatment being quadriceps strengthening using non-weight-bearing and weight-bearing exercises. Weight-bearing exercises are more functional than non-weight-bearing exercises because they require multijoint movement, facilitating a functional pattern of muscle recruitment, and stimulate proprioceptors.¹⁵⁻¹⁷ Because of these advantages, clinicians often recommend weight-bearing exercises in the rehabilitation of PFPS patients.^{15,18}

Based on previous research, we theorized that exercises emphasizing neuromuscular control of both the quadriceps and hip musculature may benefit patients diagnosed with PFPS. Although Cowan et al⁹ have quantified VMO and vastus lateralis timing differences, no researchers have determined the effect weight-bearing rehabilitation may have on electromyographic timing characteristics of the hip musculature and surrounding knee musculature. Therefore, the purpose of this study was to investigate the effects of a weight-bearing rehabilitation program in patients diagnosed with PFPS on (1) the electromyographic onset timing of the VMO, vastus lateralis, and gluteus medius during a stair-stepping task; (2) the duration of gluteus medius activity during a stair-stepping task; (3) subjective pain; and (4) perceived function.

METHODS

Participants

Twenty-eight subjects (14 controls, 14 experimental) between the ages of 18 and 42 years were recruited. For the experimental group, we recruited 5 men and 9 women (age, 24±6y; height, 167.5±10.1cm; weight, 71.6±12.2kg; duration of symptoms, 22±25mo) from the University of Kentucky Clinic and general campus population. Inclusion criteria were (1) anterior or retropatellar knee pain reported during at least 2 of the following activities: ascending and descending stairs, hopping and running, squatting, kneeling, and prolonged sitting; (2) insidious onset of symptoms not related to trauma; (3) pain with compression of the patella; (4) pain on palpation of patellar facets; and (5) involvement in at least 30 minutes of physical activity 3 days a week. Subjects were excluded for the following reasons: (1) symptoms present for less than 2 months; (2) self-reported clinical evidence of other knee pathology; (3) history of knee surgery; (4) self-reported history of patella dislocations or subluxations; and (5) current significant injury affecting other lower-extremity joints.

For the control group, we recruited 5 men and 9 women (age, 23±2y; height, 170.9±7.3cm; weight, 72.4±15.6kg) from the University of Kentucky general population. Exclusion criteria were (1) history of knee surgery, (2) clinical evidence of other knee pathology, and (3) current significant injury affecting other lower-extremity joints.

Instrumentation

We collected surface electromyographic muscle activity using bipolar Ag-AgCl surface electrodes^a and a 16-channel Myopac electromyography system.^b All electromyography channels were amplified at a gain of 2000 by a portable transmitter attached to each subject's waist. Electromyographic data were sampled at 1000Hz and transmitted via a fiber optic cable to a 12-bit analog-to-digital board. This system also had a common mode rejection ratio of 90dB. The raw electromyographic data were stored on a personal computer for analysis with Datapac software.^b

A footswitch^b was placed in each subject's shoe of the lower extremity being tested to determine heel strike synchronously

with the collection of electromyographic activity. The gain was set at 1000 for the footswitch.

Procedures

On arrival to the Musculoskeletal Research Laboratory, all subjects were screened based on the inclusion and exclusion criteria and signified their voluntary decision to participate by signing a university-approved informed consent form. Next, they completed the visual analog scale (VAS) and Functional Index Questionnaire (FIQ).¹⁹ The VAS and FIQ have previously been reported as reliable for patients diagnosed with PFPS^{19,20} (.70 and .96, respectively). We used a 10-cm VAS to determine subjects' worst pain in the knee during the previous week. The FIQ is a 16-point questionnaire used to determine changes in function, with a higher score representing greater perceived function.

The affected, or most affected, lower extremity of each subject diagnosed with PFPS and the right lower extremity of each control subject were used for electromyographic data collection. Each subject's skin was shaved, abraded, and cleaned with isopropyl alcohol before application of surface electrodes. Surface electrodes, measuring 5mm in diameter with an interelectrode distance of approximately 20mm, were placed in parallel arrangement over the muscle bellies of the VMO, vastus lateralis, and gluteus medius. The electrode for the VMO was placed approximately 4cm superior to and 3cm medial to the superomedial border of the patella and oriented 55° to the long axis of the femur.⁹ The electrode for the vastus lateralis was placed approximately 10cm superior and 7cm lateral to the superior border of the patella and oriented 15° to the long axis of the femur.⁹ The electrode for the gluteus medius was placed approximately halfway between the iliac crest and greater trochanter.²¹ Specific electrode placements for the VMO, vastus lateralis, and gluteus medius were documented for each subject so that the placements could be replicated for the posttest. We confirmed electrode placements with manual muscle testing and verified that there was no discernable cross talk.

Electromyographic activity of the VMO, vastus lateralis, and gluteus medius were recorded when subjects performed 5 trials of the stair-stepping task. The stair-stepping task consisted of walking to a stair platform, ascending 2 stairs, and descending 2 stairs (figs 1, 2). Each step was 20cm in height. The stair-stepping task was performed at a rate of 96 steps/min.^{3,22} Subjects stood approximately 1.5m away from the stair platform so that they could take 2 steps before reaching the platform. The principal investigator instructed subjects to use the instrumented lower extremity to ascend and descend the

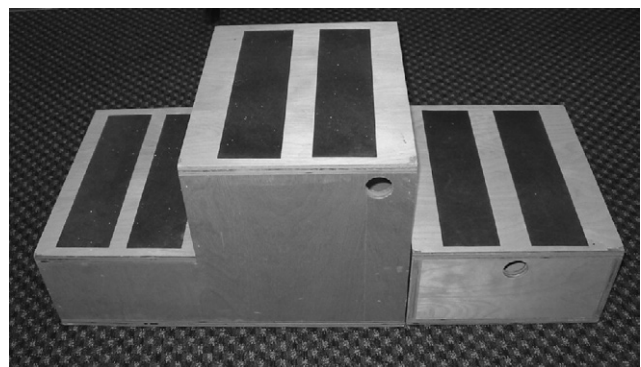


Fig 1. The stair platform.

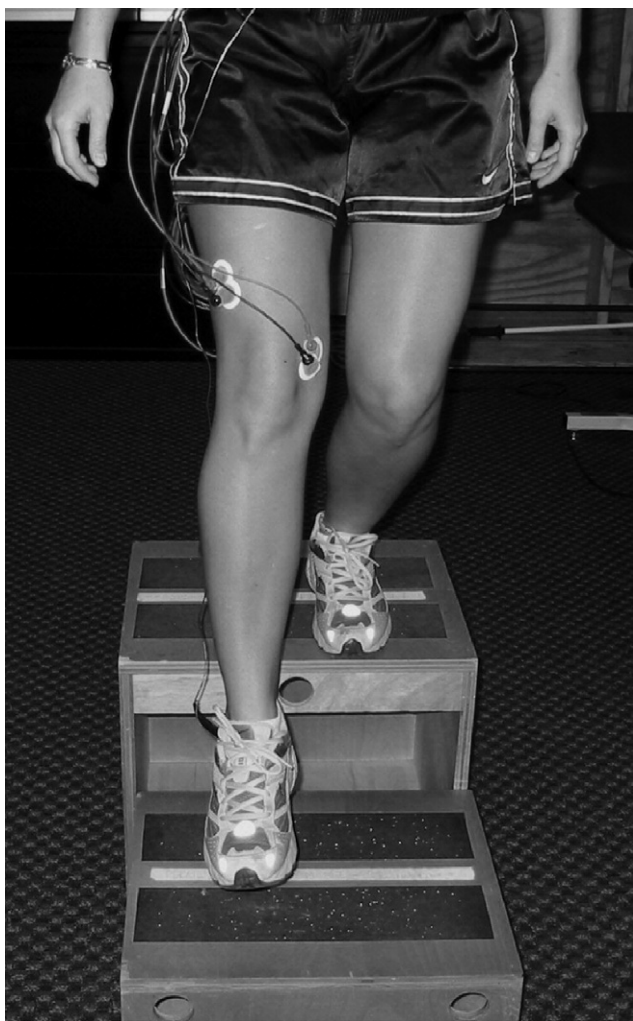


Fig 2. The descent phase of the stair-stepping task.

first and last steps, respectively. Subjects performed a minimum of 5 practice trials before data collection to familiarize themselves with the stair-stepping task. They performed 5 test trials with 10 seconds of rest between each trial.

After the testing procedures, the principal investigator instructed subjects diagnosed with PFPS on the first phase of rehabilitation exercises. The components of the rehabilitation program included stretching, balancing, and strengthening exercises. All subjects with PFPS received an exercise video, exercise instruction booklet, and exercise log to complete each week to facilitate program compliance. Subjects with PFPS documented the sets and repetitions for all exercises performed at home in the exercise log. Subjects with PFPS were also asked to not take any nonsteroidal anti-inflammatory drugs 24 hours before a rehabilitation or testing session and to not change their training regimens drastically during study participation. They performed rehabilitation exercises 1 day a week with the principal investigator and 2 days at home, for a total of 3 exercise sessions a week. During weekly supervised sessions, the principal investigator introduced new exercises and ensured that subjects performed them in a pain-free manner. If subjects could not perform the exercises or a specific exercise without pain, they were instructed to perform the exercise(s)

from the previous week until the next training session with the principal investigator. The rehabilitation exercises focused on quadriceps strengthening, gluteus medius strengthening, and lower-extremity neuromuscular control. Appendix 1 provides a detailed description of the rehabilitation program.

All subjects (PFPS, control) completed a VAS and FIQ every week for 6 weeks. At the end of the 6-week period, subjects repeated the stair-stepping task to determine changes in the electromyography-dependent measures.

Data Reduction

Electromyographic data were sampled at 1000Hz and band-pass filtered between 20 and 500Hz. Data were then full wave-rectified and low-pass filtered at 50Hz. This processing duplicated methods used by Cowan et al⁹ and enabled comparison between results. Muscle onset was determined when electromyographic activity increased above a threshold at least 3 standard deviations (SDs) above electromyography data for a standing resting interval of 200ms and remained above this threshold for at least 25ms. The muscle was considered off when it fell below this threshold for more than 50ms. The vastus lateralis, VMO, and gluteus medius onsets and gluteus medius durations were determined by using the procedures described above. The time of onset for each muscle was determined relative to activation of the footswitch during the ascent and descent phases of the stair-stepping task. The duration of gluteus medius activation was defined as the time from gluteus medius onset to the time the gluteus medius turned off for each phase of the stair-stepping task. The ascent phase was the period from when a subject stepped up onto the first stair with the instrumented leg until the foot of this leg lifted off the first stair. The descent phase was the period when a subject stepped down onto the third stair with the instrumented leg until the foot of this leg lifted off the third step. The vastus lateralis and VMO onset timing difference was quantified by subtracting the VMO onset from the vastus lateralis onset from each stage of the stair-stepping task.²² A zero difference indicated that the vastus lateralis and VMO were activated simultaneously, a negative value indicated that the vastus lateralis was activated before the VMO, and a positive value indicated that the VMO was activated before the vastus lateralis. We averaged the vastus lateralis onsets, VMO onsets, VMO and vastus lateralis onset timing differences, gluteus medius onsets, and gluteus medius durations for the 5 stair-stepping trials and used these values for data analysis.

Statistical Analysis

Separate 3-way analysis of variance (ANOVA) procedures with repeated measures were performed to determine differences between the vastus lateralis and VMO onset timing differences, onset of vastus lateralis, onset of VMO, onset of the gluteus medius, and duration of gluteus medius activity. The model included 1 between-subjects factor (group: PFPS, controls) and 2 within-subjects factors (test: pre, post; step phase: ascent, descent). The intraclass correlation coefficient (ICC_{2,1}) was used to determine intrarater reliability for the vastus lateralis and VMO onset timing difference, gluteus medius onset, and gluteus medius duration across 10 randomly selected control subjects. We compared values for the dependent variables measured during the pretest and posttest in 10 randomly selected control subjects. The ICC_{2,1} and standard error (SE) of measurement are reported for each electromyographic variable in the results section.

Two separate 2-way repeated-measures ANOVA procedures were performed to determine differences for VAS and FIQ

Table 1: Electromyographic Values for the PFPS and Control Group

Muscle	PFPS		Control	
	Pretest	Posttest	Pretest	Posttest
Vastus lateralis and VMO onset timing difference				
Ascending	-22.36±29.06	40.83±50.53	61.81±68.70	34.94±22.68
Descending	-50.56±81.98	37.26±45.15	56.97±54.76	41.04±39.48
Vastus lateralis onset				
Ascending	-153.4±156.26	-128.91±156.49	-93.34±55.19	-91.68±40.96
Descending	-197.34±56.92	-160.70±72.38	-169.96±66.29	-164.22±62.84
VMO onset				
Ascending	-131.04±143.71	-169.74±188.56	-155.16±87.58	-126.63±53.66
Descending	-146.76±75.40	-197.96±70.43	-226.93±59.88	-197.07±43.25
Gluteus medius onset				
Ascending	-81.64±153.33	-49.56±131.67	-19.54±52.21	-32.38±41.34
Descending	-158.93±69.30	-133.76±96.17	-154.26±58.70	-131.95±59.94
Gluteus medius duration				
Ascending	631.67±74.03	578.48±148.17	621.77±152.34	606.64±154.35
Descending	329.64±85.85	303.24±125.31	363.43±145.72	357.46±165.35

NOTE. Values are mean ± SD (in milliseconds).

scores. The model used for these 2 measures was 1 between-subjects factor (group: PFPS, controls) and 1 within-subjects factor (time: baseline, weeks 1, 2, 3, 4, 5, 6). Significant differences from each ANOVA were examined further using a Bonferroni post hoc analysis. We analyzed all data using SPSS^c with the level of significance set at the .05 level.

RESULTS

Means and SDs for each electromyographic variable are presented in table 1.

Vastus Lateralis and VMO Onset Timing Difference

Post hoc analysis showed that the PFPS group had vastus lateralis and VMO onset timing differences that were significantly lower than those of the control group at the pretest during the ascent and descent phases ($F_{1,26}=23.377, P=.001$; effect size, 1.9) (fig 3). At the initial testing, subjects diagnosed with PFPS activated the VMO 36ms later than the vastus lateralis, and subjects in the control group activated the VMO 59ms earlier than the vastus lateralis. The PFPS group's vastus lateralis and VMO onset timing difference significantly increased after the intervention ($F_{1,26}=23.377, P=.001$; effect size, 1.9). The VMO was activated 39.04ms earlier than the vastus lateralis in the posttest condition (see fig 3). Intrarater reliability for vastus lateralis and VMO onset timing ± SE of measurement was $0.73±12.17$ ms for the ascent phase and $0.49±33.01$ ms for the descent phase of the stair-stepping task.

Vastus Lateralis Onset and VMO Onset

The vastus lateralis onset did not change significantly from pretest to posttest in the PFPS or control groups ($F_{1,26}=.482, P=.494$). The VMO onset was significantly earlier after the rehabilitation program in the PFPS group ($F_{1,26}=7.391, P=.012$). Across groups, the vastus lateralis onset ($F_{1,26}=10.00, P=.004$) and VMO onset ($F_{1,26}=6.365, P=.018$) were both significantly earlier during the descent phase of the stair-stepping task compared with the ascent phase of the stair-stepping task.

Gluteus Medius Onset and Duration

Gluteus medius onset occurred significantly earlier during the descent phase of the stair-stepping task compared with the ascent phase of the stair-stepping task ($F_{1,26}=20.651, P=.001$).

The gluteus medius duration during the concentric phase (609.64ms) was significantly longer than gluteus medius duration during the eccentric phase (338.43ms) of the stair-stepping task ($F_{1,26}=202.524, P=.001$).

The pretest and posttest values for both gluteus medius onset ($F_{1,26}=3.396, P=.077$) and gluteus medius duration ($F_{1,26}=.934, P=.343$) did not differ significantly. Also, gluteus medius onset ($F_{1,26}=.776, P=.386$) and gluteus medius duration ($F_{1,26}=.514, P=.480$) did not differ significantly between the PFPS and control groups. Intrarater reliability for gluteus medius onset ± SE of measurement was $0.41±42.56$ ms for the ascent phase and $0.65±34.75$ ms for the descent phase of the stair-

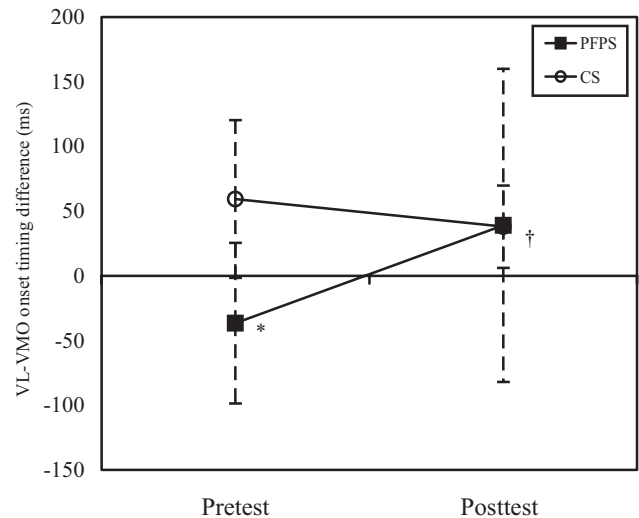


Fig 3. Mean vastus lateralis (VL) and VMO onset timing difference pretest and posttest for subjects with PFPS and control subjects (CS). Timing differences are significantly different at pretest and are similar at posttest. Positive values indicate VMO activation before vastus lateralis activation. Error bars refer to SDs for the vastus lateralis and VMO onset timing differences in each group during the pretests and posttests. *Significant difference ($P<.05$) between control group and PFPS group pretest. †Significant difference ($P<.05$) between PFPS group pretest and posttest.

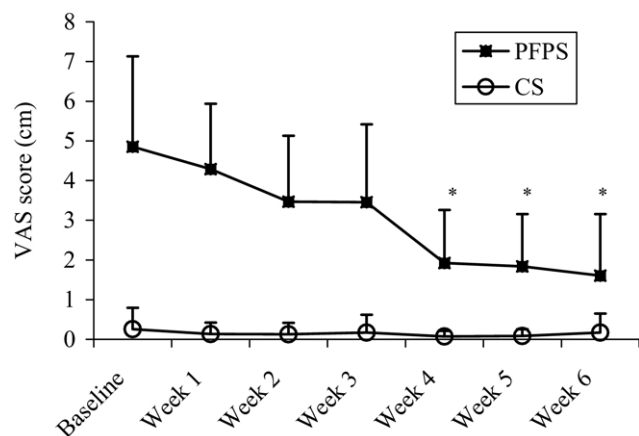


Fig 4. Mean VAS scores for subjects with PFPS and control subjects. Pain was significantly different between baseline and weeks 4 to 6 for subjects with PFPS. Error bars refer to SDs for the VAS scores in each group over the 6-week intervention. *Significant difference ($P < .05$) from baseline in the PFPS group.

stepping task. Intrarater reliability for gluteus medius duration \pm SE of measurement was 0.85 ± 61.97 ms for the ascent phase and 0.49 ± 118.63 ms for the descent phase of the stair-stepping task.

Pain and Function

A significant test by group interaction effect was present for VAS scores ($F_{6,6} = 10.33$, $P = .001$). The PFPS group had significantly lower pain starting at week 4 of the rehabilitation program (fig 4). A significant test by group interaction effect was present for function as measured by the FIQ ($F_{6,6} = 18.01$, $P = .001$). Post hoc analysis showed a significant increase in FIQ scores for the PFPS group from baseline starting at week 2 (fig 5). Post hoc analyses also showed that the control group's VAS scores and FIQ scores did not significantly change during this investigation.

Rehabilitation Compliance

Based on subject documentation in the exercise log, the PFPS group had 98.3% compliance for the rehabilitation program.

DISCUSSION

The results of this study indicate that subjects with PFPS had decreased pain, increased function, and altered vastus lateralis and VMO onset timing differences after the weight-bearing rehabilitation program. These results are similar to those reported by Cowan et al⁹ after a McConnell-based rehabilitation program.

This investigation differed from a few of the previous investigations because there was no focus on specific VMO activation.^{9,23-28} This program integrated balance, stretching, and strengthening exercises to affect pain, function, and muscle activation patterns. These results suggest that a weight-bearing rehabilitation program normalized the onset of the VMO relative to the vastus lateralis, decreased pain, and increased function in subjects diagnosed with PFPS.

Vastus Lateralis and VMO Onset Timing Differences

As stated previously, VMO and vastus lateralis neuromuscular timing in patients diagnosed with PFPS has been a

controversial area in the literature. Researchers⁷ have stated that the VMO should activate earlier than or at the same time as the vastus lateralis because a delay in VMO activation may lateralize the patella and result in PFPS. Neptune et al²⁹ stated that as little as a 5-ms delay in VMO activation may cause an increase in the compressive forces on the lateral patellofemoral joint.

Results from the present study agree with the findings of Cowan et al.^{2,3,9} Our symptomatic subjects had vastus lateralis and VMO onset timing difference changes from -22.36 ms to 40.83 ms during the ascent phase and -50.56 ms to 37.26 ms during the descent phase of the stair-stepping task after the intervention program. Proposed mechanisms for the changes in the motor recruitment pattern of the VMO and vastus lateralis are discussed below.

Recent research^{11,30-32} has suggested the importance of gluteus medius strengthening in the rehabilitation of knee dysfunction. These researchers believe that gluteus medius weakness increases both femoral internal rotation and knee valgus angle. Although we did not measure the strength or activation amplitude of the gluteus medius, improvements in these parameters may have a meaningful effect on knee kinematics by improving patellar tracking on the femur and thus reducing pain caused by abnormal tracking. Therefore, a decrease in pain might have reversed possible VMO inhibition³³ that subjects experienced at the beginning of the intervention. We did not examine these parameters specifically; therefore, future studies should investigate influences from the hip musculature.

Motor unit synchronization may be another mechanism that contributed to the change in vastus lateralis and VMO onset timing difference in our study. Duchateau and Enoka³⁴ defined motor unit synchronization as a measure of the correlation in the discharge times of action potentials by pairs of motor units. When surface electromyography is used, compound motor unit action potentials are being measured. The computer algorithm that we used to determine the onset of electromyographic activity depends on a certain number of simultaneous motor unit activations to reach onset criteria. If a lower number of motor units did not activate simultaneously at the pretest because of muscle inhibition, they might not have met the threshold for muscle activation, thereby delaying the detection of

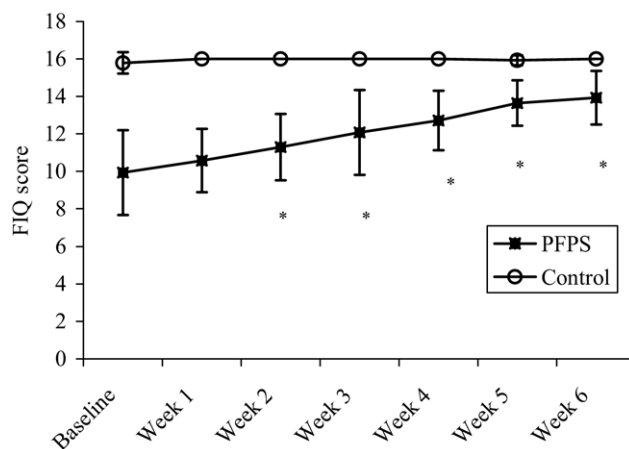


Fig 5. Mean FIQ scores for subjects with PFPS and control subjects. Function was significantly better from baseline at weeks 2 to 6 for subjects with PFPS. Error bars refer to SDs for the FIQ scores in each group over the 6-week intervention. *Significant difference ($P < .05$) from baseline in the PFPS group.

electromyographic onset. If this occurred at the pretest, it may account for the delayed onset of the VMO compared with the onset of the vastus lateralis.

The decrease in pain that subjects with PFPS reported may be the most viable mechanism for the change in the vastus lateralis and VMO onset timing difference. Researchers have reported an association between increased pain and quadriceps muscle inhibition in subjects with PFPS.^{33,35} If our subjects with PFPS experienced less pain during the posttest, which they reported, they may have had less VMO inhibition, which would account for the changes in the vastus lateralis and VMO timing differences. Unfortunately we do not know if muscle pattern changes occurred before or after changes in pain, because we collected electromyographic data only during the pretest and posttest.

Gluteus Medius Onset and Duration

Previous research has reported subjects with PFPS have weak hip musculature and altered timing characteristics of the gluteus medius compared with healthy people.^{10,12} Subjects in our investigation performed a stair-stepping task similar to the task described by Brindle et al.¹² Our results, however, indicated that gluteus medius electromyographic timing characteristics were not altered in subjects diagnosed with PFPS at the pretest compared with control subjects. The gluteus medius concentric and eccentric onsets reported by Brindle¹² in the PFPS group were similar to those in our PFPS group, but we did not find a significant difference between our PFPS group and control group. One explanation for the differing results from Brindle¹² is that we controlled the speed at which subjects performed the stair-stepping task. We controlled for speed during the stair-stepping task because the speed at which a task is performed can affect the timing of muscle activation. Another explanation is that the variability of this measure may have accounted for the finding of no differences. Because Brindle¹² is the only study to report this, further replication is necessary to support this finding.

Our results also indicated that gluteus medius onset and duration were not altered after a weight-bearing rehabilitation program. We cannot determine from this investigation why the gluteus medius onset and duration did not change and the vastus lateralis and VMO onset did change after the weight-bearing rehabilitation program. However, as stated previously, pain inhibits muscle activation. In patients diagnosed with PFPS, pain in the hip is not a common complaint. Therefore, if pain is not inhibiting the activation of the gluteus medius, we may not find a change in gluteus medius onset or duration after the weight-bearing rehabilitation program.

Subjective Pain

Because of the subjective nature of PFPS diagnosis, previous investigators^{9,23,24,26-28} have used a VAS scale to monitor pain throughout a rehabilitation program, consistent with the methods used in our investigation. Our results showed that VAS scores improved from 4.85 to 1.92 after 4 weeks of rehabilitation, which is consistent with other investigations. Other researchers^{24,27} have also reported a significant decrease in scores on the VAS after 4 weeks of rehabilitation.

Perceived Function

Researchers^{23,24,27} have used the FIQ to determine changes in function during rehabilitation programs for subjects with PFPS. Our results indicate that function significantly increased from baseline measures at week 2 and for the remainder of the study. Rehabilitation studies that used the FIQ for a measure of

function report significant improvements in FIQ scores ranging from 4 weeks up to 12 months.^{23,24,27} One reason our findings differed may be due to the frequency of our assessments. Subjects in the present study completed the VAS and FIQ each week, whereas previous researchers did not reassess these parameters until 4 weeks into the rehabilitation program.

Study Limitations

The present study has limitations. One limitation of this study is the moderate reliability of the electromyographic measures. This may reduce the credibility of our results; however, we calculated an effect size of 1.9 for the interaction effect of the vastus lateralis and VMO onset timing difference. This provides support for the significant change in vastus lateralis and VMO onset timing difference from pretest to posttest in patients with PFPS.

Another limitation of this study is the lack of a control group who had PFPS. Future investigations should perform a randomized controlled trial to determine if the rehabilitation is effective in altering electromyographic measures, reducing pain, and increasing function in patients with PFPS. Although we believe the rehabilitation program was effective in altering the timing characteristics of the vastus lateralis and VMO, patients with PFPS who do not perform rehabilitation may also show changes in the timing characteristics of the vastus lateralis and VMO after a 6-week period.

Clinical Implications

The use of non-weight-bearing and weight-bearing exercises for the rehabilitation of patients diagnosed with PFPS has been widely discussed in the literature.^{9,23-28} We decided to use only weight-bearing exercises for our rehabilitation program because patellar compressive forces are decreased in the first 40° of knee range of motion.^{16,16,36} Weight-bearing exercises in this range of knee flexion also simulate everyday functional tasks and require activation of additional musculature other than the quadriceps.¹⁶ The findings of decreased pain and increased function in our subjects support the use of weight-bearing exercises for the rehabilitation of PFPS.

With the rising costs of health care, home exercise programs supervised by a qualified health care provider may become a necessity for patients who require rehabilitation. Roddey et al³⁷ concluded that no differences exist between self-reported outcomes for rotator-cuff repair patients participating in a home rehabilitation program using video instruction or personal instruction from a therapist. Harrison et al²⁴ also compared a home rehabilitation program with supervised treatment. Harrison concluded that the home rehabilitation program was as effective as the supervised treatment for the improvement of symptoms and function in patients with PFPS.

Subjects in our investigation performed the exercises once a week under the supervision of the principal investigator and twice a week at home. They received a video and written instruction of all the exercises in the rehabilitation program. Our findings of decreased pain and increased function after the rehabilitation program provided additional evidence for the effectiveness of a supervised home rehabilitation program. These findings also suggested that 6 weeks of supervised home rehabilitation provided sufficient time to decrease pain and increase function in patients diagnosed with PFPS.

CONCLUSIONS

Our investigation has provided evidence that the vastus lateralis and VMO onset timing difference may change after a

weight-bearing rehabilitation program. This investigation also showed the effectiveness of a supervised home rehabilitation program to decrease pain and increase function in subjects diagnosed with PFPS. Future research should investigate the different components of a rehabilitation program (quadriceps strengthening, gluteus medius strengthening, lower-extremity neuromuscular control) and its effect on the change in vastus lateralis and VMO onset timing difference. Monitoring changes in

electromyographic activity weekly would aid in determining if a decrease in pain is responsible for the alteration of the vastus lateralis and VMO onset timing difference in subjects with PFPS.

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APPENDIX 1: PFPS WEIGHT-BEARING REHABILITATION PROGRAM

Activity	Duration
Stretches (All exercise sessions)	
• Sitting hamstring stretch	5 repetitions/20-s hold
• Standing quadriceps stretch	
• Standing calf stretch	
Week 1 Exercises	
• Wall slides (0°–40° of knee flexion)	15 repetitions/5-s hold
• Lateral step downs off 4-in step	3 sets of 10 repetitions
• Single-leg heel raises	3 sets of 10 repetitions
• Thera-band ^d front pull (subjects perform a single-leg stance on injured limb and perform standing, resisted hip flexion with the contralateral limb)	3 sets of 10 repetitions
Week 2 Exercises	
• Wall slides (0°–40° of knee flexion) with Thera-band resistance around knees	15 repetitions/5-s hold
• Single-leg heel raises on Airex ^e balance pad	3 sets of 10 repetitions
• Lateral step down off 6-in step	3 sets of 10 repetitions
• Thera-band diagonal pull (subjects perform a single-leg stance on injured limb and perform standing resisted hip flexion in a diagonal pattern)	3 sets of 10 repetitions
Week 3 Exercises	
• Wall slides (0°–40° of knee flexion) standing on Airex balance pad with Thera-band resistance around knees	15 repetitions/5-s hold
• Mini-squat (0°–30° of knee flexion)	3 sets of 10 repetitions
• Lateral step down off 4-in step with Thera-band resistance behind knee pulling anteriorly	3 sets of 20 ball tosses
• Single-leg stance on Airex balance pad bouncing ball off wall	
Week 4 Exercises	
• Mini-squat (0°–30° of knee flexion) on Airex balance pad	3 sets of 10 repetitions
• Lateral step down off 6-in step with Thera-band resistance behind knee pulling anteriorly	3 sets of 10 repetitions
• Backward walk with Thera-band resistance around ankles (subjects stand with slight knee flexion and take steps backward with resistance between ankles)	3 sets of 10 repetitions
• Forward lunges onto 8-in step without push-off (subjects lunge onto 8-in step to 40° of knee flexion)	3 sets of 10 repetitions
Week 5 Exercises	
• Single-leg mini-squat (0°–30° of knee flexion)	3 sets of 10 repetitions
• Lateral step down off 4-in step standing on Airex balance pad with Thera-band resistance behind knee pulling anteriorly	3 sets of 10 repetitions
• Side stepping with Thera-band resistance around ankles (subjects stand with slight knee flexion and take steps laterally with resistance between ankles)	3 sets of 10 repetitions to left and right
• Forward lunges onto 8-in step with push-off (subjects lunge onto step to 40° of knee flexion and push off to starting position)	3 sets of 10 repetitions
Week 6 Exercises	
• Single-leg mini-squat (0°–30° of knee flexion) standing on Airex balance pad	3 sets of 10 repetitions
• Lateral step down off 6-in step standing on Airex balance pad with Thera-band resistance behind knee pulling anteriorly	3 sets of 10 repetitions
• Monster walks with Thera-band resistance around ankles (subjects stand with 30° of knee flexion and walk forward with resistance between ankles)	3 sets of 10 repetitions
• Forward lunges to ground level (subjects lunge on level surface to 40° of knee flexion)	3 sets of 10 repetitions

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Suppliers

- a. Medicotest, 1775 Winnetka Cir, Rolling Meadows, IL 60008.
- b. Run Technologies, 22702 Via Santa Maria, Mission Viejo, CA 92691.
- c. Version 12.0; SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.
- d. Hygenic Corp, 1245 Home Ave, Akron, OH 44310.
- e. Alcan Airex AG, Specialty Foams, CH-5643 Sins, Switzerland.