The Effect of Valgus Control Instruction Exercises on Pain, Strength, and Functionality in Active Females With Patellofemoral Pain Syndrome

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Background: Patellofemoral pain syndrome (PFPS) is sometimes related to excessive hip adduction and internal rotation, as well as knee valgus during weightbearing activities in females. Research on injury prevention and rehabilitation strategies has shown the positive effects of valgus control instruction (VCI) exercise programs in training.

Hypothesis: A VCI program would result in a positive change in pain, eccentric hip muscle torque, and performance in females with PFPS.

Study Design: Controlled laboratory study.

Level of Evidence: Level 1.

Methods: Sixty-four amateur female volleyball players from our university (age, 18-25 years) with PFPS and equal years of exercise experience were randomly divided into VCI (n = 32; age, 22.1 ± 5.88 years) and control (n = 32; age, 23.1 ± 6.49 years) groups. Function (single, triple, and crossover hops), strength (hip abductor and external rotators), pain (visual analog scale), and knee valgus angle (single-leg squat) were assessed at baseline and after intervention.

Results: There was a significant difference before and after implementation of the VCI program with regard to pain (49.18% ↓, $P = 0.000$), single-leg hop test (24.62% ↑, $P = 0.000$), triple-hop test (23.75% ↑, $P = 0.000$), crossover hop test (12.88% ↑, $P = 0.000$), single-leg 6-m timed hop test (7.43% ↓, $P = 0.000$), knee dynamic valgus angle (59.48% ↓, $P = 0.000$), peak abductor to adductor eccentric torque ratio (14.60% ↑, $P = 0.000$), peak external (59.73% ↑, $P = 0.023$) and internal rotator (15.45% ↑, $P = 0.028$) eccentric torques, and the ratio of peak external to internal rotator eccentric torque (40.90% ↑, $P = 0.000$) ($P < 0.05$).

Conclusion: PFPS rehabilitation and prevention programs should consider VCI exercises to decrease pain, improve strength, and increase athletes' functional performance.

Clinical Relevance: This study investigated the effect of VCI exercises on knee valgus angle, pain, and functionality of individuals with PFPS. The VCI program improves performance, knee dynamic valgus angle, and strength in participants with PFPS. A controlled and optimal knee valgus angle during a functional task is the most important factor for injury prevention specialists. VCI training can be used as a supplemental method to prevent and treat lower extremity injury in patients with PFPS.

Keywords: patellofemoral pain syndrome; female athletes; instruction; strength; performance

Patellofemoral pain syndrome (PFPS) is the most common cause of knee pain in female athletes and results from force imbalances in patellar tracking during knee flexion and extension.[32]

Excessive hip adduction and internal rotation during weightbearing could cause medial knee rotation, tibia abduction, and foot pronation, leading to dynamic knee valgus. Excessive knee valgus is related to diminished hip muscle

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strength[6,18,21,39] and is implicated in numerous knee injuries, including anterior cruciate ligament tears[17] and patellofemoral joint dysfunction.[28]

Patients with PFPS exhibit abnormalities in the mechanics and dynamic control of lower limbs. However, few studies have used neuromuscular training as a treatment strategy, and there is insufficient evidence regarding the influence of this intervention on the biomechanics of patients with PFPS.

Salsich et al (2012) suggested that correcting the dynamic alignment of the lower limbs could be an important component in rehabilitation of patients with PFPS.[35] However, until now, only 3 studies have investigated this factor, and 2 only assessed the influence of correcting gait mechanics.[26,35,41] The third study compared a program that used hip muscle strengthening exercises with training to control the movement of the trunk and lower limbs with a program that only focused on strengthening the quadriceps.[3]

Many studies focus on exercise with and without instruction on PFPS. Instructions that catch and direct the athlete's attention to a specific aspect of the movement are called internal focus (IF) instructions.[6] IF instructions are directed toward the execution of movements such as "keep the knee over the toe" or "land with a flexed knee."[18,21] IF instructions limit the patient's ability to use his or her motor skills to quickly respond and react. Conversely, an external focus (EF) instruction is directed toward the outcome or effects of the movement (eg, landing from a jump: "try to land on the markers on the floor"). EF instructions facilitate motor learning more effectively by using unconscious or automatic processes.[39] According to a systematic review, using EF resulted not only in better motor performance but also in better movement technique (increased retention) when compared with IF.[23] Real-time feedback on contraction time resulted in the ability to perform exercises more closely to prescribed dose and also induced larger strength gains.

In line with prior studies investigating instruction in PFPS exercise programs, this study focused on evaluating the effect of valgus control instruction (VCI) exercises on performance and the kinetic and kinematic factors associated with lower extremity function in landing. The primary hypothesis was that VCI exercises can decrease pain and knee valgus angle in individuals with PFPS. Our secondary hypothesis was that VCI exercises could improve performance through hop tests, and third, that VCI exercises could improve eccentric peak torque of the hip abductor, adductor, and external rotators in individuals with PFPS.

METHODS

Study Design

This was a pre- and posttest, matched control, single-blinded study performed at the Physical Education and Sport Sciences Laboratory of Kharazmi University.

Patients were recruited through the university physical therapy clinic. Eligible patients attended a baseline assessment, followed by a 6-week intervention. All patients read and signed an informed consent form approved by the university ethics committee. Figure 1 shows the CONSORT (Consolidated Standards of Reporting Trials) flow diagram.

Participants

The sample size was chosen based on a power analysis (β = 0.829) of the hip external rotation peak torque variable, which indicated a minimum of 16 athletes were needed for the study.

The athletes were 64 amateur female university volleyball players with equal years of exercise experience, ages 18 to 25 years (body mass index, 18.5-24.9 kg/m^2). After baseline testing, patients were randomly assigned to VCI (n = 32) and control (n = 32) groups by an investigator. Randomization was performed in blocks of 4. Consecutively numbered, opaque envelopes were randomly assigned by a computer-generated table of random numbers. An individual blinded to patient data performed the randomization and provided the group assignment to a physical therapist. To ensure that participants were unaware of the exercises performed by the other group, the groups were given program instructions separately. The experimental group underwent a total of 18 supervised training sessions over a 6-week period.

Patients were included in the study if they had anterior knee pain of 3 or greater on a 10-cm visual analog scale (VAS)[8,36] for a minimum of 8 weeks before the assessment or anterior or retropatellar knee pain during at least 3 of the following activities: ascending/descending stairs, squatting, running, kneeling, jumping, and prolonged sitting. Patients also must have presented with an insidious onset of symptoms unrelated to trauma and positive Clark test.[11,24]

Exclusion criteria included intra-articular pathology, patellar instability, Osgood-Schlatter or Sinding-Larsen-Johansson syndrome, hip pain, knee joint effusion, and previous surgery in the lower limb. Patients were also excluded if palpation of the patellar tendon, iliotibial band, or pes anserinus tendons reproduced the pain.[8,24]

Outcome Measures

Patients completed self-report questionnaires and functional, isokinetic, and lower extremity kinematic evaluations both at baseline and after 6 weeks of intervention. All assessments were performed by an experienced expert.

Pain

Pain intensity was assessed as the worst knee pain experienced in the previous week using a 10-cm VAS, with 0 indicating no pain and 10 indicating extremely intense pain. This pain scale has been shown to be reliable, valid, and responsive in assessing individuals with PFPS.[9]

Function

Physical function was measured using lower extremity performance tests (single-leg hop test, triple-hop test, crossover hop test, and single-leg 6-m timed hop test).[34] To perform these tests, patients jumped 3 consecutive times on the affected limb, covering the greatest distance possible, while keeping their

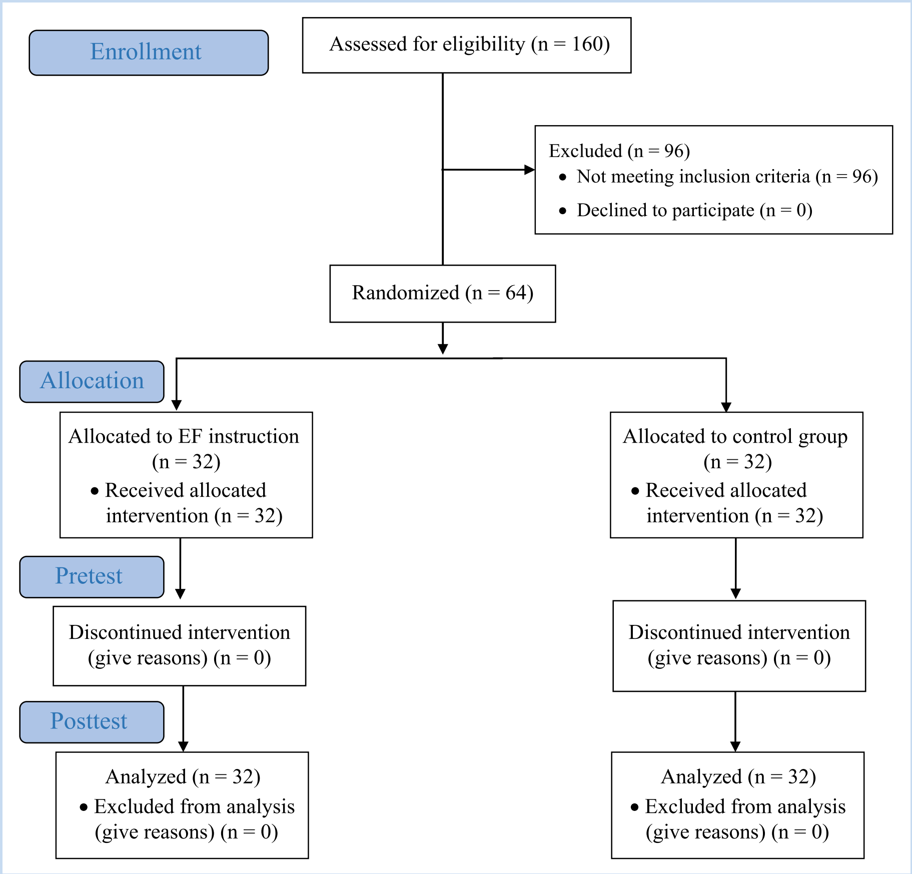


Figure 1. CONSORT (Consolidated Standards of Reporting Trials) flow diagram. EF, external focus.

arms behind their back during the test. Participants initially performed 1 submaximal-effort and 1 maximal-effort trial, with 1 minute of rest between trials, to acquaint themselves with the test activity. Subsequently, after 2 minutes of rest, the patients performed 2 maximal-effort trials with 2 minutes of rest between trials. The test was repeated if patients used their arms for propulsion or lost balance during the test. The longest distance jumped (in meters) of the 2 peak-effort trials was used for statistical analyses. A previous study has shown excellent reliability for this test and a standard error of the mean (SEM) of 0.92 and 0.15 m, respectively.[2]

Two-Dimensional Video Camera for Kinematic Data (Knee Valgus Angle Measurement)

A 2-dimensional video camera has been shown to be reliable for measuring kinematic data of the lower extremity, with an intraclass correlation coefficient (ICC) of 0.92.[10] In this study, the pilot tests were conducted for intraclass reliability of the examiner, resulting in a correlation coefficient of approximately 0.91.

Fifteen anatomical landmarks were identified with retroreflective markers and secured to the patient's skin using double-sided adhesive tape: 1 at the sternoclavicular notch, 1 on each acromioclavicular joint, 1 on each anterior superior iliac spine, 1 on each medial joint line of the knee, 1 on each lateral joint line of the knee, 1 on each medial malleolus, 1 on each lateral malleolus, and 1 on each base of the fifth metatarsal. Retroreflective markers were affixed by the same clinician for each participant, with a level of accuracy of less than 8 mm. Two-dimensional videos of the single leg squat were captured using 3 Canon Vixia HF R42 digital cameras (Canon USA). Each camera was placed on a tripod at a height of 1.2 m from the floor and 2.4 m from the participant. One camera was placed in the sagittal plane and 2 were placed in the frontal plane (1 anterior, 1 posterior). Each camera was leveled using the Bubble Level application (v2.1; Lemondo Entertainment), with a sampling rate of 60 frames per second.[37]

Two-dimensional videos were processed using Kinovea Software (v0.8.15; Kinovea Open Source Project, www.kinovea.org). For each trial, 2 still images were created in the frontal and sagittal planes (1 standing, 1 at peak knee flexion).

Peak Torque and Time to Peak Torque

Each participant completed a 5-minute submaximal warm-up on a cycle ergometer (Ergo 167 Cycle; Ergo-Fit). Next, baseline procedures of eccentric hip abduction and adduction and hip external and internal rotation torque tests were conducted in a random order among the participants. If the test began with the eccentric hip abduction and adduction torque tests, the participant assumed the side-lying position[5] with the nontested hip and knee flexed and fixed with straps. The rotation axis of the dynamometer was aligned with a point on the participant, representing the intersection of 2 straight lines. One line was directed inferiorly from the posterior-superior iliac spine toward the knee, and the other line was medially directed from the greater trochanter of the femur toward the midline of the body. The lever arm of the dynamometer was attached with straps 5 cm above the superior border of the patella. The hip was placed in a position that was neutrally aligned in all 3 planes.

Participants were instructed to keep their toes pointed forward and not bend their knees to help prevent alterations in muscle recruitment and compensation during testing. The range of motion for the test was from 0° (neutral position) to 30° of hip abduction. Participants initially performed 2 series of 5 submaximal and 1 series of 5 maximal reciprocal eccentric hip adduction and abduction contractions, with 1 minute of rest between the 2 series. After a 3-minute rest interval, participants then performed 2 sets of 5 repetitions at their maximal eccentric voluntary effort, with 3 minutes of rest between sets. Next, the eccentric hip external and internal rotation procedures and torque tests were performed. External and internal hip rotation and isokinetic eccentric peak torque were measured with the participant seated and the hip and knee flexed to 90°.[23] The axis of the dynamometer was aligned with the long axis of the femur. The range of motion of the test was from 0° (neutral position) to 30° of external hip rotation.

Verbal encouragement was provided during all maximal eccentric hip torque tests. The movements were performed at an angular speed of 30 deg/s.[13] To correct the influence of gravity effect torque on the data, the limb was weighed following the instructions from the dynamometer's operations manual. Test results were automatically corrected in the software for gravity effect torque. All repetitions were visually analyzed to identify and exclude potential repetitions that could have influenced the mean value. The repetition was excluded if the participant was not able to initiate or execute the movement through the total range of motion during the eccentric torque test or if the torque value was inferior to 80% of the peak torque values of the last 5 repetitions.

We excluded 2 repetitions from the hip abduction torque test, 3 repetitions from the hip external rotation torque test, and 1 repetition from the hip internal rotation torque test based on the criteria described. We used the peak torque value of the last 5 maximal eccentric contractions to calculate the mean peak torque value, but if a repetition had been excluded, the mean peak torque value was calculated using the peak torque value from the last 4 repetitions of the test. We also used the peak torque values of the last 5 maximal eccentric contractions to calculate the mean peak torque value. Nine participants were tested on 2 occasions, with 1 week between test days. The random order of the tests was matched between test days. We used an ICC (3,1) to evaluate the intrarater reliability, and the SEM was used to describe the precision of the measurement. The results expressed as ICC (3,1) (SEM) were 0.97 (0.07 N·m/kg) for abduction, 0.78 (0.16 N·m/kg) for adduction, 0.87 (0.07 N·m/kg) for external rotation, and 0.92 (0.11 N·m/kg) for internal rotation.[2]

Interventions

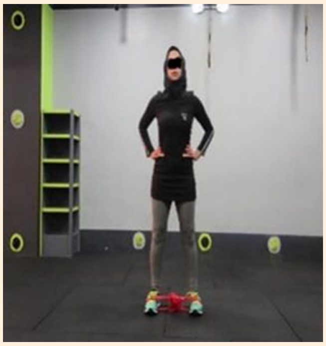
The VCI exercise training protocol of this study was based on the feedback methods and neuromuscular training used in previous studies by Prentice,[29] Rabelo et al,[30] and Baldon Rde et al.[3] Verbal and visual (a mirror)[31] feedback methods were used to control movement of the pelvis and the knee in the frontal plane. Before beginning the exercises, the correct and incorrect execution of each exercise was demonstrated to the patients. The patient was encouraged to perform an exercise correctly and control pelvic and knee movements by applying instructions like "keep your knees toward the toes," "stop your knees from rotating internally," and "keep the pelvis at a symmetric level." Verbal feedback was given by the examiner only at the beginning of each training session, but it was repeated if the person did not maintain the correct position during the exercise.

Feedback during the last 4 sessions was eliminated to improve the learning process by encouraging self-correction. The experimental group performed the training protocol 3 times per week for 6 weeks, with at least 24 hours between intervention sessions. Each training session included 15 minutes of simple aerobic movements to warm up and cool down and about 45 minutes of prescribed exercise time.

The intensity of exercise was increased every 2 weeks. Usually, each exercise was performed in 3 sets, and for the first week, each new exercise was repeated 6, 8, and 4 times per set to familiarize the patient with the correct technique. After learning the correct technique, the volume and intensity of the exercise increased based on the VCIs (Table 1).

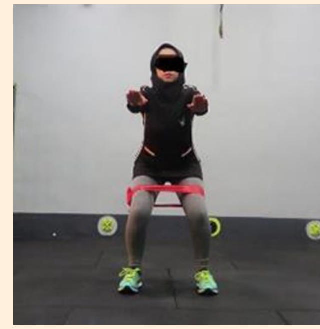
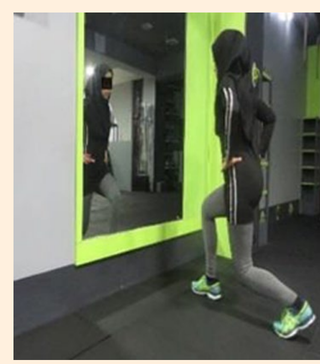
The EF exercise progressions presented in this study are organized into the 3 major neuromuscular, strength and stability, and mobility limitations (or deficit) categories. In the current study, we propose associated progressive exercises to target each specific deficit category (neuromuscular, strength and stability, and mobility) for each criterion. Each proposed exercise is supplemented with a description of the desired exercise technique.

Table 1. Valgus control instruction intervention

Squat in front of mirror (0°-60° of knee flexion, performed in front of mirror to ensure the knee does not exceed the midfoot)		
• 2 sets of 10 repetitions, with 5-second isometric contraction • Exercise progression: increasing 2-second hold	Weeks 1 and 2	
• 3 sets of 12 repetitions, with 10-second isometric contraction • Resistance: holding weights • Initial load: 10% of body mass • Exercise progression: increasing 5% of body mass	Weeks 3 and 4	
• Not performed	Weeks 5 and 6	
Squat (0°-60° of knee flexion)		
• 2 sets of 20 repetitions, with 5-second isometric contraction • Exercise progression: increasing 2-second hold	Weeks 1 and 2	
• 3 sets of 12 repetitions, with 10-second isometric contraction • Resistance: holding weights • Initial load: 10% of body mass • Exercise progression: increasing 5% of body mass	Weeks 3 and 4	
• Not performed	Weeks 5 and 6	
Lateral walk with elastic resistance around the forefoot		
• 2 sets of 20 repetitions, with 5-second isometric contraction • Resistance: elastic band • Initial load: 2 elastic resistance levels lower than 1 RM • Exercise progression: increasing 1 elastic resistance level	Weeks 1 and 2	
• 3 sets of 12 repetitions • Initial load: 1 elastic resistance level lower than 1 RM • Exercise progression: increasing 1 elastic resistance level	Weeks 3 and 4	
• Not performed	Weeks 5 and 6	
Strengthening the hip abductors with weightbearing (Trendelenburg)		
Pelvic drop while standing		
• Not performed	Weeks 1 and 2	
• 3 sets of 12 repetitions • Resistance: ankle weight • Initial load: 75% of 1 RM • Exercise progression: increasing 1 to 2 kg	Weeks 3 and 4	
As in weeks 3 to 4	Weeks 5 and 6	

(continued)

Table 1. (continued)

Squat with elastic resistance (0°-60° of knee flexion, resistance placed around the knees, stimulating the constant activation of the hip abductors and lateral rotators during task execution; relatively stable terrain)		
• Not performed	Weeks 1 and 2	
• 3 sets of 12 repetitions, with 10-second isometric contraction • Resistance: holding weights • Initial load: 10% of body mass • Exercise progression: increasing 5% of body mass	Weeks 3 and 4	
As in weeks 3 to 4	Weeks 5 and 6	
Squat on BOSU ball (BOSU) (0°-60° of knee flexion)		
• Not performed	Weeks 1 and 2	
• 2 sets of 20 repetitions, with 5-second isometric contraction • Exercise progression: increasing 2-second hold	Weeks 3 and 4	
• 3 sets of 12 repetitions, with 10-second isometric contraction • Resistance: holding weights • Initial load: 10% of body mass • Exercise progression: increasing 5% of body mass	Weeks 5 and 6	
Forward lunge in front of mirror (exercise performed in front of the mirror, single-leg balance at 30° of knee flexion on stable terrain)		
• Not performed	Weeks 1 and 2	
• 3 sets of 12 repetitions • No load • Hip flexion and forward trunk lean emphasized	Weeks 3 and 4	
• Not performed	Weeks 5 and 6	
Forward lunge (single-leg balance at 30° of knee flexion on stable terrain)		
• Not performed	Weeks 1 and 2	
• 3 sets of 12 repetitions • No load • Hip flexion and forward trunk lean emphasized	Weeks 3 and 4	
As in weeks 3 to 4	Weeks 5 and 6	

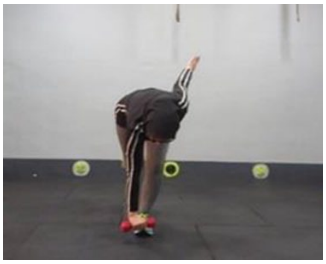
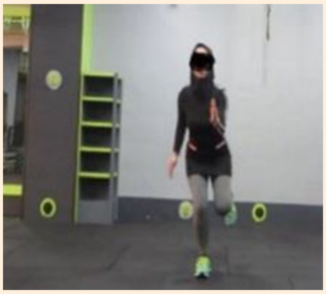
(continued)

Table 1. (continued)

Balance exercise on BOSU ball		
• Not performed	Weeks 1 and 2	
• 3 sets of 20 seconds • Each leg exercised	Weeks 3 and 4	
• 3 sets of 30 seconds • Each leg exercised	Weeks 5 and 6	
Single-leg balance at 30° of knee flexion (performed on stable terrain)		
• Not performed	Weeks 1 and 2	
• Not performed	Weeks 3 and 4	
• 3 sets of 12 repetitions • No load • Hip flexion and forward trunk lean emphasized	Weeks 5 and 6	
Squat with elastic resistance around the knees		
• Not performed	Weeks 1 and 2	
• Not performed	Weeks 3 and 4	
• 3 sets of 12 repetitions • No load • Squat with elastic resistance around the knees stimulating the constant activation of the hip abductors and lateral rotators during task execution, performed on unstable terrain	Weeks 5 and 6	
Unipodal squat on BOSU ball (keep the pelvis balanced and avoid excessive pronation of the foot)		
• Not performed	Weeks 1 and 2	
• Not performed	Weeks 3 and 4	
• 3 sets of 12 repetitions • No load • Squat with elastic resistance around the knees stimulating the constant activation of the hip abductors and lateral rotators during task execution, performed on unstable terrain	Weeks 5 and 6	

(continued)

Table 1. (continued)

Modified forward lunge with elastic around the knee that is ahead (constant muscle activation of abductors and lateral rotators of the hip and training of motor control during the execution of the activity, performed on stable terrain)		
• Not performed	Weeks 1 and 2	
• Not performed	Weeks 3 and 4	
• 3 sets of 12 repetitions • No load • Exercise performed in the mirror with elastic resistance around the knee of the anterior limb to encourage hip abduction and lateral rotation • Hip flexion and forward trunk lean emphasized	Weeks 5 and 6	
Romanian deadlift		 
• Not performed	Weeks 1 and 2	
• Not performed	Weeks 3 and 4	
• 3 sets of 12 repetitions • Resistance: elastic band • Initial load: 1 medicine ball then 1 RM • Exercise progression: increasing 1 level	Weeks 5 and 6	
Lateral sliding without jumping		 
• Not performed	Weeks 1 and 2	
• Not performed	Weeks 3 and 4	
• 3 sets of 12 repetitions • Resistance: elastic band • Initial load: 1 medicine ball then 1 RM • Exercise progression: increasing 1 level	Weeks 5 and 6	

(continued)

Table 1. (continued)

Hip lateral rotation		
• Not performed	Weeks 1 and 2	
• Not performed	Weeks 3 and 4	
• 3 sets of 12 repetitions • Resistance: elastic band • Initial load: 1 medicine ball then 1 RM • Exercise progression: increasing 1 level	Weeks 5 and 6	

	Neuromuscular	Strength/Stability	Mobility
Deficit	Active valgus during squats/lunges; increased hip adductor activation and increased coactivation of the gastrocnemius and tibialis anterior muscles lead to valgus	Passive valgus during squat motions	Joint hypomobility causing altered front plane position (ie, valgus) during squats/ lunges
Targeted correction	Remove tendency to use active valgus strategy during squats/ lunges	Improve hip abductor, hamstring, and gluteus strength to reduce medial knee displacement	Improve range of motion of hip adductors and hip internal rotators
Specific instructions	Push yourself as hard as possible off the ground after landing on the ground. Point knee caps straight ahead/push knees outward/lead with your hips when descending/keep nonlunging leg straight/land with knees apart/point knee straight/maintain upright posture.		

RM, repetition maximum.

All sessions were supervised by the same investigator.

During the study, the patients were asked not to seek any other type of treatment for anterior knee pain and to maintain their regular daily activities.

Control Group

The control group (n = 32) received written instructions that included postural corrections and tips for improving general health. The control group came to the clinic for pre- and posttesting. They were asked to come to the clinic once or twice a week and received heat or ice treatment according to their needs.

Statistical Analysis

Normality and variance homogeneity of data were tested using the Shapiro-Wilk and Levene tests, respectively. The effects of the intervention on the outcome measures were assessed by repeated-measures analysis of variance. The outcomes were analyzed with a 2-by-2 analysis of variance (2 groups and 2 time points). When significant group-by-time interactions were found, planned pairwise comparisons with paired *t* tests were used to determine between-group and within-group differences. SPSS version 23 software was used to analyze the data.

The effect size (ES) (Cohen *d*) was calculated to determine the standardized mean difference for each variable. ESs were classified as small (*d* = 0.20), medium (*d* = 0.50), or large (*d* = 0.80).[27]

RESULTS

The VCI and control groups had a participation rate of 100% during the study period.

The results of the Shapiro-Wilk test indicated normal data distribution (Table 2). Demographic data did not differ between the groups ($P > 0.05$).

Analysis of variance with a Greenhouse-Geisser test showed significant group interactions over time for all variables (Tables 3-6). Pretest comparisons revealed no significant differences between groups at baseline testing for all variables.

Pain

There was a statistically significant difference in pain within the experimental group (49.18% ↓, $P = 0.000$). There was no statistically significant difference within the control group in pain (0.459) (Table 3). However, based on the independent *t* test, there was a statistical difference between the experimental and control groups for pain ($P = 0.001$, ES = 0.621) (Table 3).

Performance

There was a statistically significant difference for performance, including single-leg hop test (24.62% ↑, $P = 0.000$), triple-hop test (23.75% ↑, $P = 0.000$), crossover hop test (12.88% ↑, $P = 0.000$), and single-leg 6-m timed hop test (7.43% ↓, $P = 0.000$), within the experimental group. There was no statistically significant difference within the control group for performance (Table 4). However, based on the independent *t* test, there was a statistically significant difference between the experimental and control groups for performance, including single-leg hop test ($P = 0.003$, ES = 0.676), triple-hop test ($P = 0.002$, ES = 0.641), crossover hop test ($P = 0.005$, ES = 0.572), and single-leg 6-m timed hop test ($P = 0.003$, ES = 0.151) (Table 4).

Dynamic Knee Valgus Angle

There was a statistically significant difference in knee dynamic valgus angle within the experimental group (59.48% ↓, $P = 0.000$). There was no statistically significant difference within the control group for knee dynamic valgus angle (5.82% ↓, $P = 0.239$) (Table 5). However, based on the independent *t* test, there was a statistical difference between the experimental and control groups for knee dynamic valgus angle ($P = 0.004$, ES = 0.720) (Table 5).

Strength

There was a statistically significant difference in strength, including ratio of peak abductor to adductor eccentric torque (14.60% ↑, $P = 0.000$), peak external rotator eccentric torque (59.73% ↑, $P = 0.023$), peak internal rotator eccentric torque (15.45% ↑, $P = 0.028$), and ratio of peak external to internal rotator eccentric torque (40.90% ↑, $P = 0.000$), within the experimental group. There was no statistically significant difference in strength within the control group (Table 4). However, based on the independent *t* test, there was a statistically difference between the experimental and control groups for strength, including peak adductor eccentric torque ($P = 0.034$, ES = 0.371), ratio of peak abductor to adductor eccentric torque ($P = 0.005$, ES = 0.120), peak external rotator eccentric torque ($P = 0.005$, ES = 0.864), peak internal rotator eccentric torque ($P = 0.002$, ES = 0.270), and ratio of peak external to internal rotator eccentric torque ($P = 0.003$, ES = 0.840) (Table 6).

DISCUSSION

The results of this study showed that 6 weeks of VCI exercises significantly improved performance and strength and decreased pain and knee valgus angle in individuals with PFPS.

Effect of VCI Exercises on Abductor and Adductor Torques and Their Ratio

There were statistical differences within the experimental group and between the experimental group and the control group for the ratio of the peak abductor to adductor eccentric torque after treatment (14.60% ↑, $P = 0.000$ and $P = 0.005$, ES = 0.120, respectively).

The study findings are consistent with that of Nakagawa et al.[24] In their study, patients showed decreased pain levels during functional activity, improved eccentric extensor torque, and improved electromyography of the gluteus medius through hip muscle strengthening intervention; however, the peak hip abductor and external rotator torque did not change. This difference of results may be due to the study's focus on hip muscle training, lack of verbal feedback, and minimal use of structured, supervised testing sessions, while instead allowing participants to perform most sessions at home during the intervention.[35]

Our results are not consistent with those of Ferber et al,[14] Baldon Rde et al,[3] Dolak et al,[12] Rabelo et al,[41] Khayambashi et al,[28] Willy and Davis,[40] Boling et al,[4] and Herman et al.[16] This could be due to the differing exercise protocols, prescribed training doses, and types of strength measurement used in our study. Additionally, these previous researchers used manual dynamometers to measure strength, whereas as an isokinetic dynamometer was used in our study.

The abnormal eccentric muscle strength of the abductor and external rotators in the lower extremities seems to be lower in individuals with PFPS than in healthy participants, increasing the possibility of internal hip rotation during functional movements.[20,33] The absence of sufficient hip muscle strength, especially abductor and external rotator muscle strength, could increase the possibility of knee valgus during weightbearing activities.[20,38] Studies have demonstrated that improving hip muscle strength can help patients maintain control of the lower limbs in the frontal and transverse planes during dynamic

Table 2. Demographic characteristic of participants

	Experimental (n = 32)	Control (n = 32)	*P*
Age, y	22.1 ± 5.88	23.1 ± 6.49	0.647
Weight, kg	59.6 ± 3.66	58.6 ± 5.02	0.598
Height, cm	162.5 ± 7.60	164.4 ± 8.09	0.693
Body mass index, kg/m^2	22.1 ± 1.61	21.2 ± 1.00	0.438
Exercise experience, y	6.4 ± 1.4	5.8 ± 1.3	0.651

Table 3. Comparison of pain variable pretest and posttest[a]

Variable	Group	Pretest, Mean ± SD	Posttest, Mean ± SD	Δ, %	Within-Group Difference, *P*	Between-Group Difference, *P*	Effect Size
Pain, VAS (0-10)	Experimental	6.1 ± 1.18	3.1 ± 1.61	49.18 ↓	0.000	0.001	0.621
	Control	6 ± 1.35	6.1 ± 1.12	—	0.459		

VAS, visual analog scale.
[a]↓ indicates decrease and ↑ indicates increase.

Table 4. Comparison of performance variable pretest and posttest[a]

Variable	Group	Pretest, Mean ± SD	Posttest, Mean ± SD	Δ, %	Within-Group Difference, *P*	Between-Group Difference, *P*	Effect Size
Single-leg hop test, cm	Experimental	112.43 ± 9.60	140.12 ± 11.50	24.62 ↑	0.000	0.003	0.676
	Control	118.60 ± 14.01	117.50 ± 13.05	0.92 ↓	0.157		
Triple-hop test, cm	Experimental	308.31 ± 58.44	381.54 ± 33.40	23.75 ↑	0.000	0.002	0.641
	Control	343.18 ± 42.66	324.12 ± 35.22	5.55% ↓	0.063		
Crossover hop test, cm	Experimental	301.25 ± 14.63	340.06 ± 18.95	12.88 ↑	0.000	0.005	0.572
	Control	306.37 ± 40.47	299.62 ± 36.25	2.20 ↓	0.637		
Single-leg 6-m timed hop test, cm	Experimental	10.90 ± 0.60	10.09 ± 0.62	7.43 ↓	0.000	0.003	0.151
	Control	10.16 ± 0.44	10.29 ± 0.67	1.27 ↑	0.090		

[a]↓ indicates decrease and ↑ indicates increase.

Table 5. Comparison of knee dynamic valgus pretest and posttest[a]

Variable	Group	Pretest, Mean ± SD	Posttest, Mean ± SD	Δ, %	Within-Group Difference, *P*	Between-Group Difference, *P*	Effect Size
Knee dynamic valgus angle, deg	Experimental	18.81 ± 2.66	7.62 ± 2.04	59.48 ↓	0.000	0.004	0.720
	Control	17.52 ± 8.51	16.50 ± 2.01	5.82 ↓	0.239		

[a]↓ indicates decrease and ↑ indicates increase.

activities.[7,9,38] In this study, an increase in hip and knee muscle strength was likely an important factor in improving the kinematics of the lower extremity as well as knee stability, thereby reducing knee abduction movements. However, it seems that the applied protocol influenced neuromuscular control more than strength variables. It could be concluded that the duration of the protocol was too short to affect the peak eccentric abductor torque, and the protocol only influenced the muscle coordination between the 2 groups of abductor and adductor muscles.

The significant improvement in the ratio of eccentric torque of the abductor to the hip adductor from baseline indicates VCI exercises have the potential to help correct patellar tracking issues. Furthermore, the contact surface of the patella and the hip joint levels were reduced, which likely explains the reduction of pain and valgus angle in the experimental group. The observed changes likely result from improved musculoskeletal system function.

Effect of VCI Exercises on External and Internal Rotator Torques and Their Ratio

There were statistically significant differences within the experimental group and between the experimental group and the control group, which favored the experimental group, for the peak external and internal rotator eccentric torques and the ratio of the peak external to internal rotator eccentric torque throughout the study.

This study is consistent with the studies by Ferber et al,[14] Baldon Rde et al,[3] Rabelo et al,[30] Khayambashi et al,[28] and Willy and Davis[40] in these variables.

Baldon Rde et al[3] showed that neuromuscular control could enhance the effects of the strength exercises on pain, performance, and kinematic performance after 8 weeks of intervention and 3 months of follow-up. Ferber et al[14] and Baldon Rde et al[3] did not accompany their protocols with any feedback. Rabelo et al[30] reported that neuromuscular exercises are effective in increasing the strength of the abductor, external rotator, and extensor muscles.

The present study was not consistent with Nakagawa et al,[25] who investigated the effect of added strength exercises on hip abductor and lateral rotator muscles in PFPS in a randomized, controlled pilot study.

Effect of VCI Exercises on Performance and Pain Variables in People With PFPS

In the present study, there was a statistically significant improvement in pain within the experimental group ($P = 0.000$), whereas there was no statistically significant improvement in the control group ($P = 0.459$). Also, there was a significant change ($P = 0.001$, ES = 0.621) between the experimental and control groups, favoring the experimental group. This change could be due to an increase in the ratio of peak abductor to adductor eccentric torque and in the ratio of external to internal rotator torque of the hip within the experimental group. With the reduction in pain, the experimental group could perform significantly better in the single-leg hop test, triple-hop test, crossover hop test, and single-leg 6-m timed hop test.

The present study agreed with the results of Riel et al,[31] Hwangbo,[19] Baldon Rde et al,[3] Herman et al,[16] and Khayambashi et al.[22]

Aghapour et al[1] showed improved performance and reduction of pain in patients with PFPS when using Kinesio tape (Kinesio). In the present study, VCI exercises in the experimental group made it possible to control dynamic knee valgus.

Hwangbo[19] used visual feedback to improve the influence of squat exercises on activity of the vastus lateralis and medialis muscles, which prevented the occurrence of PFPS.

Khayambashi et al[22] demonstrated that both hip and quadriceps muscle strengthening exercises could reduce pain and improve performance of patients with PFPS; however, hip muscle strengthening exercises were more effective.

Effect of VCI Exercises on the Knee Valgus Angle of Individuals With PFPS

In addition, there were statistically significant differences within the experimental group ($P = 0.000$) and between the

Table 6. Comparison of peak torque and torque ratio variables pretest and posttest[a]

Variable	Group	Pretest, Mean ± SD	Posttest, Mean ± SD	Δ, %	Within-Group Difference, *P*	Between-Group Difference, *P*	Effect Size
Peak abductor eccentric torque, N·m/kg	Experimental	97.75 ± 7.22	98.54 ± 6.70	0.80 ↑	0.100	0.127	0.264
	Control	94.16 ± 4.41	92.62 ± 13.72	1.63 ↓	0.132		
Peak adductor eccentric torque, N·m/kg	Experimental	106.78 ± 11.06	95.87 ± 9.31	10.28 ↓	0.982	0.034	0.371
	Control	106.86 ± 8.59	103.67 ± 10.17	2.98 ↓	0.072		
Ratio of peak abductor to adductor eccentric torque	Experimental	0.89 ± 0.063	1.02 ± 0.81	14.60 ↑	0.000	0.005	0.120
	Control	0.88 ± 0. 52	0.88 ± 0.07	—	0.453		
Peak external rotator eccentric torque, N·m/kg	Experimental	40.83 ± 5.75	65.22 ± 6.30	59.73 ↑	0.023	0.005	0.864
	Control	45.75 ± 6.30	43.16 ± 6.50	5.66 ↓	0.127		
Peak internal rotator eccentric torque, N·m/kg	Experimental	45.93 ± 7.20	53.03 ± 7.87	15.45 ↑	0.028	0.002	0.270
	Control	50.91 ± 10.49	47.27 ± 12.17	7.14 ↓	0.123		
Ratio of peak external to internal rotator eccentric torque	Experimental	0.88 ± 0.078	1.24 ± 0.148	40.90 ↑	0.000	0.003	0.840
	Control	0.88 ± 0.062	0.90 ± 0.046	2.27 ↑	0.730		

[a]↓ indicates decrease and ↑ indicates increase.

experimental group and the control group ($P = 0.004$, ES = 0.720). However, there was no significant change in the control group.

This study agrees with the results of Riel et al,[31] Hwangbo,[25] Baldon Rde et al,[3] Fukuda et al,[15] and Herman et al.[16] Herman et al[16] investigated the effect of strengthening hip and thigh muscles but reported no reduction in the risk of the noncontact injury after training. Through VCI and low-load exercises, motor control could be reestablished, resulting in more controlled knee movements and reduction of knee valgus in functional tasks.

Limitations

There were limitations in the current study. The exercise program used in this study was only performed for 6 weeks; therefore, the long-term effects of this program could not be determined. In addition, the patients with PFPS experienced fatigue easily and were not able to perform the sets as previously determined, which made the duration of exercise longer in some cases than originally stated. To validate and confirm the VCI exercises, future research must be performed over a longer period and consider follow-up results. Although a 2-dimensional video camera (knee valgus angle measurement) has been shown to be reliable for measuring kinematic data of the lower extremity, a 3-dimensional assessment would deliver a more detailed kinematic image of the performance.

CONCLUSION

Improved dynamic knee performance and reduction in knee valgus angle during functional situations could lead to improvement in the ratio of the abductor to adductor eccentric torque and the ratio of the peak external rotator and internal rotator eccentric torques in patients with PFPS.

VCI exercises can correct knee valgus angle through re-education of motor controls. Thus, the VCI exercise protocol can be recommended for patients with PFPS and for noncontact anterior cruciate ligament injury prevention.

These results indicate a medium (0.50) to large (0.80) ES for the variables in our study, suggesting that use of a VCI exercise protocol in the clinical setting may selectively improve patient pain and strength, as well as knee valgus angle and performance.

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