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Original Article

Comparison of open and closed kinetic chain exercises on vastus medialis and vastus medialis oblique in patellofemoral pain syndrome: A randomized, single-blinded, prospective study

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ABSTRACT

Objectives: The aim of this study was to compare the effect of open and closed kinetic chain exercises on pain, thickness of vastus medialis (VM) and vastus medialis oblique (VMO) muscle, and VMO architecture.

Patients and methods: The randomized single-blind prospective was conducted between January 2022 and September 2023. Thirty patients (11 males, 19 females; mean age: 37.5±8.8 years; range, 18 to 50 years) with patellofemoral pain syndrome (PFPS) were randomized into two groups. Fifteen patients in the first group (23 knees) received open kinetic chain exercises, and 15 patients in the second group (22 knees) received closed kinetic chain exercises (CKCE) as a six-week home exercise program. The following variables were measured before and after the exercise program: Visual Analog Scale , Q angle, and ultrasonographic measurements. In ultrasonographic measurements, the thickness of the VM and VMO muscles and the VMO fiber angle was evaluated.

Results: Both groups showed statistically highly significant improvement in all evaluation parameters in inter- and intragroup comparisons (p<0.001). Before treatment, there was no statistical difference in Visual Analog Scale scores between the two groups. However, a significant decrease was observed in favor of the CKCE group after treatment (p=0.037). There was no statistically significant difference between the groups in terms of VMO, VM muscle thickness, and fiber angle changes (p=0.26, p=0.28, and p=0.28, respectively).

Conclusion: The thickness of the VM and VMO muscles, the angle of the VMO fibers, and the pain scores improved both exercise groups in patients with PFPS. However, CKCE proved to be superior for pain reduction. Both open and closed kinetic chain exercises can be beneficial for PFPS management, with CKCE potentially being more appropriate for patients with prominent pain.

Keywords: Exercise, patellofemoral pain, ultrasound, vastus medialis.

Patellofemoral pain syndrome (PFPS) is a prevalent musculoskeletal disorder, clinically defined by anterior knee pain.[1] Patellofemoral pain syndrome is more common in females, affecting 15 to 33% of the active adult population and 21 to 45% of adolescents.[2,3] Approximately two-thirds of patients diagnosed with PFPS can be successfully treated with appropriate rehabilitation programs.[4]

Among the causes of PFPS are biomechanical, anatomical, psychosocial, and behavioral factors.[5] Biomechanical factors play an important role in etiology, including lower limb alignment abnormalities, and muscle imbalances. Increased femoral anteversion, genu valgum, knee hyperextension, increased Q angle, and increased foot pronation are factors contributing to lower limb alignment abnormalities. Weakness in the knee extensor and hip muscles, as well as imbalance between the vastus medialis oblique (VMO) and vastus lateralis (VL), can contribute to the development of PFPS. Atrophy of the VMO or impaired motor control of this muscle often disrupts the balance between the vastus medialis (VM) and VL, leading to lateral deviation

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of the patella.[6] An excessively laterally deviated patella rubbing against the lateral femoral condyle can cause degeneration and pain on the articular surface.[7]

Conservative treatment of PFPS includes patient education, exercise, taping, orthotic approach, soft tissue manipulation, acupuncture, and other adjunctive therapies.[8] However, optimizing the muscle imbalance between VM and VL should constitute the first step of the conservative treatment approach.[6] In this context, the most effective conservative treatment approach is exercise training.[9] However, there is no consensus on which type of exercise will strengthen VM muscle more effectively. When we look at the literature, the results obtained from studies on which type of exercise is more beneficial for strengthening the WMO in patients with PFPS are contradictory.[10,11]

Kinetic chain exercises are divided into two types: open kinetic chain (OKC) exercises (OKCE), if the distal end of the limb is free during movement and closed kinetic chain (CKC) exercises (CKCE) if it is fixed to a surface. Open kinetic chain is considered less functional than CKC, but it plays a significant role in enhancing muscle strength during the rehabilitation process in patients with restricted range of motion.[12] It also increases muscle strength of all muscle components that make up the quadriceps.[13] Closed kinetic chain exercises are similar to many activities in daily life that can be performed in weight transfer position and in which lower extremity muscle groups work synergistically. Since they cause less patellofemoral joint reaction force formation than OKCE, CKCE are recommended to be used during periods of severe pain.[14]

Ultrasonography (USG) has gained an important place in musculoskeletal imaging because it is noninvasive, reliable, inexpensive, and easily accessible. Ultrasound measurements of WM thickness have been shown to be as valid as magnetic resonance imaging and can be used to objectively assess the muscle.[15]

When the literature is examined, there are studies comparing the effects of open and closed chain exercises on VMO thickness by USG measurement, and these studies were performed in healthy volunteers.[16,17] We believe that this study will make a significant contribution to the existing literature, as it is the first to compare the effects of OKCE and CKCE on the VM and VMO muscles using US in patients with PFPS. The aim of this study was to compare the effects of open and CKCE on pain, ultrasonographically measured VM and VMO muscle thickness, and VMO architecture in patients with PFPS.

PATIENTS AND METHODS

This randomized single-blind prospective study evaluated 48 patients diagnosed with PFPS at the Physical Medicine and Rehabilitation outpatient clinic of Eskişehir Osmangazi University Faculty of Medicine between January 2022 and September 2023. The diagnosis of PFPS was based solely on clinical signs and symptoms consistent with patellofemoral pain, in the absence of other identifiable pathological conditions, similar to those in previous studies.[18,19] The study included patients with PFPS who had pain in the peripatellar or retropatellar region for at least three months during at least two of the following activities: sitting with bent knees for an extended period, running, squatting, jumping, kneeling, climbing stairs, and tenderness on patellar facet palpation during examination. Patients with a history of previous knee surgery, evidence of ligament, meniscus, or bone injury, history of trauma or fracture, patellofemoral dislocation or subluxation, knee pathology such as knee osteoarthritis, Osgood-Schlatter or Sinding-Larsen-Johansson syndrome, pain radiating to the knee from lumbar spine, hip or ankle lesions, history of intra-articular injection within one year, and those who underwent any physical therapy rehabilitation program for PFPS in the last one year were excluded. The use of nonsteroidal anti-inflammatory drugs was restricted until the completion of the study. Forty-one patients who met the inclusion criteria and agreed to participate in the study were randomly divided into two groups: the OKCE group and the CKCE group. Fifteen of 20 patients in the OKCE group and 15 of 21 patients in the CKCE group were able to complete the study by performing home exercise programs. Hence, the final analysis was conducted with a total of 30 patients (11 males, 19 females; mean age: 37.5±8.8 years; range, 18 to 50 years) (Figure 1). Written informed consent was obtained from the patients. The study protocol was approved by the of Eskişehir Osmangazi University Clinical Research Ethics Committee (date: 17.03.2022, no: E-80558721-050.99-307260). The research was guided in accordance with the principles of the Declaration of Helsinki.

The patients were separated into two distinct groups through the utilization of the sealed envelope

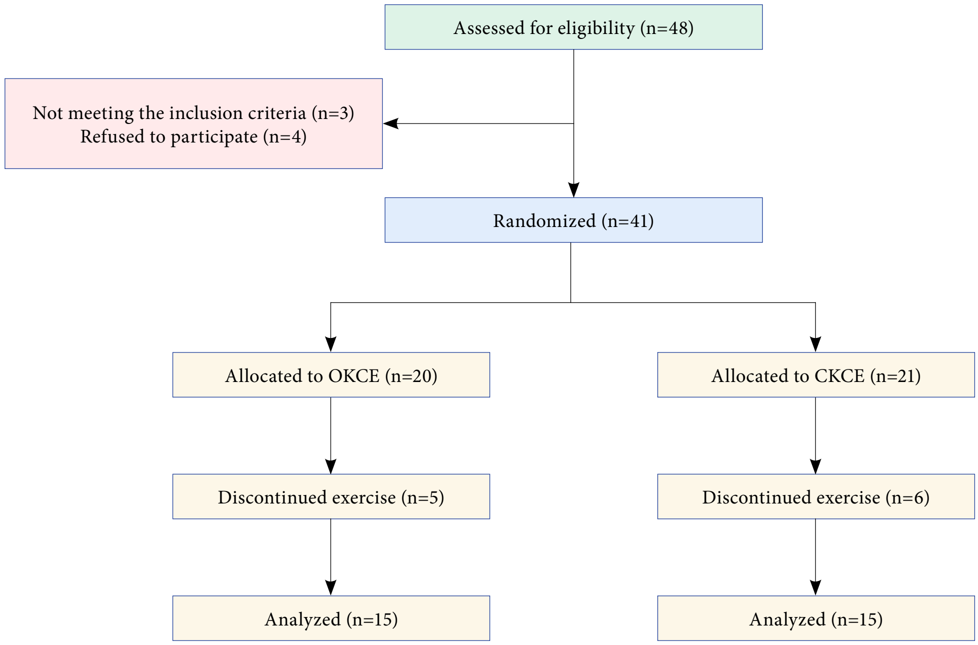

Figure 1. Study flowchart.

OKCE: Open kinetic chain exercise; CKCE: Closed kinetic chain exercise.

method, which is a simple randomization method. Patients were asked to choose closed envelopes with OKCE and CKCE written on them. The physician opened the selected envelope and proceeded to elucidate the details of the home exercise program.

A blinded physiatrist demonstrated and explained the group-specific exercises to the patients and these exercises were given as brochures. The patients were asked to perform the exercises as a home exercise program three times a day with 10 repetitions of each exercise, every other day for six weeks. Patients were told to stop the exercise that day if they felt pain during exercise. Patients were called by phone once a week to check whether they continued their exercises.

For OKCE, patients were asked to perform straight leg raises and two different isometric quadriceps strengthening exercises as a home exercise program. During the straight leg raising exercise, patients were asked to raise their leg in supine position with only hip flexion in knee extension and then lower it after waiting for 10 sec. During the isometric quadriceps strengthening exercises, patients were asked to place a pillow under the knee while lying supine with the knee slightly flexed. They were asked to push the pillow with the knee for 10 sec until the knee reached full extension. In the same way, this time the pillow was placed under the ankle, and the patient was asked to push the pillow with the ankle for 10 sec with the knee in extension (Figure 2).

Closed kinetic chain exercises included squats with isometric hip adduction, a semi-squat exercise, and a step-down exercise. During squats with isometric hip adduction, patients were asked to place a pillow between their knees with the knee on the medial joint line. Patients were asked to squat with their back against the wall, without dropping the pillow, bringing their knees to 45° flexion. During the semi-squat exercise, patients were asked to stand on one leg while holding on to a fixed surface, with the painful knee in full extension and the other knee in 90° flexion. Then the patients were asked to squat while standing on one leg with the painful knee at 20° flexion and stay in this position for 5 sec. During the step-down exercise, patients were asked to step on two feet on a step not higher than 10 cm. While the painful knee was flexed on the step, the other foot was asked to slowly touch the ground. After the foot touched the ground, they were asked to return to the starting position (Figure 3).

Patients' pain were assessed by the Visual Analog Scale (VAS). Patients were asked to express the pain felt using on a scale of 0 to 10, where 0 indicated no pain and 10 indicated the most severe pain faced throughout their life.

Figure 2. Open kinetic chain exercises.

Figure 3. Close kinetic chain exercises.

The Q angle, defined as the angle between two lines (the midpoint of the patella and the spina iliaca anterior superior and the midpoint of the patella and lines drawn through the tuberositas tibia), was assessed. The measurement was made with a goniometer (1° interval) in the supine position while lying down.

All USG measurements were performed using a B-mode and linear array transducer (Samsung L5-12/50 model, 7.5 MHz) of the ultrasound device (Samsung Sonoace X7; Samsung, Seoul, Korea) by a blinded physiatrist. The measurements were all taken by a physical therapist who had received specialized training in using real-time ultrasound. Measurements were performed in the supine position with the patient lying supine, preventing external rotation of the hip. Muscle thickness was measured. Measurements were repeated three times for each muscle. The measurements were mean averaged.

For the thickness measurements of the VM and VMO muscles , the locations were determined using data from the research conducted by Kawakami et al.[20] For localization of the vastus medialis, the distance between the top of the patella and the spina iliaca anterior superior was measured with a tape measure. Twenty percent of the measured distance was marked from the distal part on the same line. For the VMO, 2 cm above the upper end of the patella was marked. To calculate the medial position of the VM and VMO, 12.5% of the thigh circumference was determined medially at the marked level.[19] Ultrasonographic images of VM and VMO muscle thickness measurements are shown in Figures 4a and 4b.

For the VMO fibre angle measurement, the ultrasound probe was positioned at the lower edge of the patella on the inner side of the knee, then moved upwards until the VMO fibers were visible on the screen. The probe was then rotated to align the VMO fibers parallel to each other. Both ends of the probe were marked with a pencil by placing a point on the patient's skin. After that, the probe was removed, and a line was drawn connecting those two points and extended to intersect the femoral axis. The angle between the line and the femoral axis was measured with a goniometer to represent the VMO fiber angle and noted (Figure 4c). The ultrasonographic measurement technique was performed using a method previously shown to be statistically reliable.[21]

Statistical analysis

The data were analyzed using IBM SPSS version 21.0 software (IBM Corp., Armonk, NY, USA). To determine the suitability of variables for normal distribution, the Shapiro-Wilk test was utilized. The independent samples t-test and Mann-Whitney U test were utilized in the comparison of independent groups (OKCE and CKCE groups) according to the distribution forms. The paired samples t-test and Wilcoxon signed-rank test were utilized to compare dependent means according to the distribution forms. Chi-square tests were used to examine the cross tabulations. Analysis of covariance was performed using postexercise outcomes as the dependent variable when comparing preexercise and postexercise changes between groups.[22] In summarizing the data, number (%) statistics were used for qualitative data, and mean ± standard deviation (SD) or median (interquartile range) statistics were used for quantitative data. A p-value <0.05 was considered statistically significant.

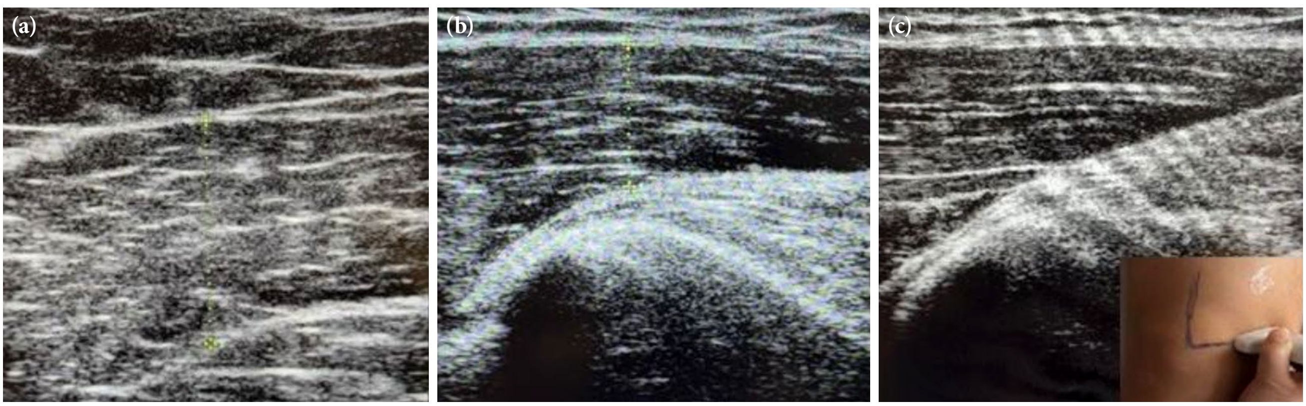

Figure 4. Ultrasonographic images of **(a)** vastus medialis, **(b)** vastus medialis oblique muscle 23 thickness and **(c)** vastus medialis oblique fibre angle measurements.

TABLE 1
Demographics feature of groups

	OKCE group (n=15)				CKCE group (n=15)				
	n	Mean±SD	Median (25-75%)	Min-Max	n	Mean±SD	Median (25-75%)	Min-Max	*p*
Age (year)		37.8±8.2				37.1±9.7			0.840*
BMI (kg/m²)		24.68±2.49				26.78±3.78			0.082*
Sex									0.705#
Females	10				9				
Males	5				6				
Dominance side									0.483#
Right	15				13				
Left	0				2				
Affected side									0.883#
Right	3				3				
Left	3				5				
Bilateral	9				7				
Duration of symptom (month)			12	8-24			12	5-60	0.950**

OKCE: Open kinetic chain exercise; CKCE: Closed kinetic chain exercise; SD: Standard deviation; BMI: Body mass index; * Analyzed by independent samples t-test; ** Analyzed by Mann-Whitney U test; # Analyzed by the chi-square tests; P<0.05: significant.

The sample size and power analysis were conducted using G*Power version 3.1.9.2 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), with consideration given to achieving 80% power and a 5% type 1 error rate. In the power analysis determined by using the mean differences of VMO fiber angle before and after kinetic chain exercises obtained from a pilot study,[17] it was determined that at least 12 patients per group were needed. However, to increase the power of the study, the study was completed with 15 participants each in the OKCE and CKCE groups.

RESULTS

There was no statistical difference between the two groups in terms of age, sex, body mass index, symptom duration, dominance, and affected side (p=0.840, p=0.705, p=0.082, p=0.950, p=0.483, and p=0.883, respectively; Table 1). Both groups showed statistically highly significant improvement in all evaluation parameters in inter- and intragroup comparisons (p<0.001; Table 2).

When VAS scores were evaluated, there was no statistical difference between the two groups before treatment, but there was a significant decrease in favor of the CKCE group after treatment (p=0.037). Vastus medialis oblique muscle thickness was significantly less in the OKCE group before treatment (p=0.042), while no difference was detected after treatment (p=0.547). In the Q angle, VM muscle thickness, and VMO fiber angle measurements, there was no significant difference between the groups before and after treatment (p=0.513, p=0.628, and p=0.991 before exercise; p=0.874, p=0.364, and p=0.205 after exercise, respectively; Table 2).

When the changes in the assessment parameters between pre- and postexercise were compared between the groups, it was found that only the VAS scores improved significantly more in the CKCE group (p=0.006). There were no differences between the groups in terms of changes in the Q angle, the VMO, the VM muscle thickness, and the fiber angle (p=0.095, p=0.209, p=0.140, and p=0.179, respectively; Table 3).

DISCUSSION

This study was designed to investigate the effect of OKCE and CKCE on pain, VM and VMO muscle thickness, and VMO architecture. The results of the study showed a significant improvement in the thickness of VM and VMO muscles, VMO fiber angle values, and pain scores in both exercise groups. Pain scores (VAS) improved more in the CKCE group compared to the OKCE group after treatment. Although VMO thickness was significantly less in the OKCE group before treatment, VM and

TABLE 2
Intra- and intergroup comparisons of assessment parameters

	OKCE group (n=23)			CKCE group (n=22)			
	Mean±SD	Median (25-75%)	Min-Max	Mean±SD	Median (25-75%)	Min-Max	*p*
VAS							
Pre-exercise	5.39±2.17			5.59±2.17			0.76*
Post-exercise	3.69±2.30			2.27±2.16			**0.037***
p value		<0.001†			<0.001†		
Q angle (°)							
Pre-exercise	12.08±2.02			11.73±2.64			0.513*
Post-exercise	12.04±1.72			12.14±2.17			0.874*
p value		0.75†			0.103†		
VMO (mm)							
Pre-exercise		15.3	14.3-16.2		15.75	15.28-17.93	**0.042****
Post-exercise		17.1	15.9-18.4		17.40	16.58-18.28	0.547**
p value		<0.001‡			<0.001‡		
VM (mm)							
Pre-exercise	23.34±2.72			23.73±2.67			0.628*
Post-exercise	26.17±1.56			25.60±1.86			0.364*
p value		<0.001†			<0.001†		
Fiber angle (°)							
Pre-exercise		53	51-55		52.5	50-55.5	0.991**
Post-exercise		56	54-59		56	55-60.5	0.205**
p value		<0.001‡			<0.001‡		

OKCE: Open kinetic chain exercise; CKCE: Closed kinetic chain exercise; SD: Standard deviation; VAS: Visual Analog Scale; VMO: Vastus medialis oblique; VM: Vastus medialis; p value: indicates a significant difference between pre- and post-intervention within the group; * Analyzed by independent samples t-test; ** Analyzed by Mann-Whitney U test; † Analyzed by the paired samples t test; ‡ Analyzed by the Wilcoxon signed-rank test; P<0.05: significant; n: Number of knee diagnosed patellofemoral pain syndrome.

VMO thickness, and VMO fiber angle changes were similar in both groups.

The priority in the treatment of PFPS is to correct the muscle imbalance between VM and VL.

TABLE 3
Analysis of covariance of postexercise outcomes adjusted for preexercise outcomes

	OKCE and CKCE group least squares	
Dependent variables	Mean±SD	*p*
VAS postexercise	1.548±0.536	**0.006**
Q angle postexercise	−0.371±0.217	0.095
VMO postexercise	0.462±0.362	0.209
VM postexercise	0.621±0.413	0.140
Fiber angle postexercise	−1.317±0.965	0.179

OKCE: Open kinetic chain exercise; CKCE: Closed kinetic chain exercise; SD: Standard deviation; VAS: Visual Analog Scale; VMO: Vastus medialis oblique; VM: Vastus medialis; P<0.05: significant.

Strengthening of the VM muscle prevents lateral deviation of the patella. Open and closed kinetic chain exercises that strengthen the VMO muscle provide appropriate and coordinated contraction of the muscle, correcting patellar malalignment and reducing the load on the knee joint. Thus, joint functions are improved and pain is reduced.[23] In the literature, conflicting results were obtained in studies comparing the effects of OKCE and CKCE on pain.[23-25] In our study, at the end of the six-week home exercise program, a significant decrease in pain was observed in both groups, and pain decreased more in the CKCE group than in the OKCE group. The possible mechanism of this result is that, although OKC exercises provide isolated quadriceps contraction, the agonist contraction of hamstrings and quadriceps in CKC exercises provides a better functional effect on the tibiofemoral joint.[26] In addition, CKC exercises may be more effective in pain reduction because they apply less stress on the patellofemoral joint than OKC exercises.[24]

Fredericson and Yoon[27] evaluated physical examination signs in PFPS. They found that goniometric measurements were essential to quantify the abnormal Q angle commonly associated with PFPS. In a review on PFPS, it was stated that a large Q angle is a predisposing factor for patellofemoral pain.[28] However, some studies have reported no association between the Q angle and patellofemoral joint symptoms. The Q angle in PFPS patients is frequently reported to be less than 15°.[29] In another study, there was no difference between patients with PFPS and healthy individuals in terms of the Q angle.[30] Accordingly, measuring the Q angle has declined in popularity among clinicians because it does not provide information about patient management.[27,31] In our study, the Q angles of the patients in both exercise groups were found to be below 15°, and there was no significant change in the Q angle after exercise applications.

In addition, Q angle measurements were made in different positions such as standing and supine positions in different studies, which may have contributed to conflicting findings. In our study, to maximize external rotation of the tibia and its tubercle, and for clinical simplicity, we chose to measure the Q angle in full knee extension and in the supine position, as described by Aglietti et al.[32]

In the literature, electromyography studies proving muscle imbalance in the quadriceps have found lower VMO to VL electromyography activity ratio in patients with PFPS compared to healthy volunteers.[33,34] Another study found that VMO muscle thickness was less in USG measurements in patients diagnosed with PFPS compared to healthy volunteers.[35] Differently, there was no significant difference in muscle thickness between symptomatic limbs of patients with PFPS and healthy volunteers in the study by Giles et al.,[19] but there was a notable decrease in quadriceps muscle thickness between symptomatic and asymptomatic limbs of patients with PFPS.

In a study by Cheon et al.,[16] in which OKC and CKC exercises were performed using an exercise machine in healthy young adults, the muscle thickness of all parts of the quadriceps were ultrasonographically evaluated before and after exercise, and while all muscle thicknesses increased in both exercise groups, VMO thickness increased more in the CKC group. Similarly, in our study, VM and VMO muscle thicknesses increased significantly in both exercise groups compared to pretreatment, but there was no difference between the two groups in terms of thickness changes.

It is reported that the VMO fiber angle in healthy individuals is between 50° and 60°. The medial stabilization force of the patella decreases at low VMO fiber angle.[36,37] In a study in which VMO fiber angles were evaluated ultrasographically in patients with PFPS, compared to the control group, fiber angles were significantly lower.[35] In this study, VMO fiber angles were slightly more than 50° in both groups, as in other similar studies.[35,38] Different results were obtained in studies investigating the effects of open and closed chain exercises on fiber angle of the VMO. In the study conducted by Elniel et al.[17] in asymptomatic young people, similar improvement in VMO fiberangle was observed in both groups in participants who underwent six-week OKC and CKC exercises. A study with 21 healthy male participants found that six weeks of quadriceps strengthening exercises, one of the OKCE, caused a significant increase in VMO fibre angle.[21] In contrast, Honarpishe et al.[39] applied a quadriceps exercise protocol consisting of open and closed chain exercises for four weeks to patients diagnosed with PFPS, but no statistical difference was detected in VMO fiber angle compared to the control group. Our study found significant improvement in VMO fiber angle in both exercise groups, but no difference between exercise groups.

The study had some limitations. Although participants were called by phone to encourage and follow-up home exercise practices, it could not be determined whether each participant performed home base exercises effectively. Furthermore, since USG measurements were taken at rest, the relationship between VMO and VM morphology may be different during contraction. Another limitation was that the Q angle was not evaluated dynamically. Although the sample size was adequately powered by statistical analysis, studies with larger numbers of participants, long-term exercise protocols, and follow-up are needed.

In conclusion, this study demonstrated that both OKCE and CKCE were effective in reducing pain and increasing the thickness of the VM and VMO muscles in patients with PFPS. While the CKCE group demonstrated a more pronounced reduction in pain, no significant differences were observed between the two groups in terms of muscle thickness and VMO fiber angle changes. The findings of this study suggest that both types of exercise are beneficial for addressing muscle imbalances associated with PFPS; however, further studies with larger sample sizes and long-term follow-up are needed to confirm the long-term effectiveness of these interventions and to better understand their impact on the dynamic function of the quadriceps muscles.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Concept, materials, data collection and/or processing, literature search: B.A., O.A.; Design, writing: B.A., F.B.; Supervision, analysis and/or interpretation, critical reviews: B.A., F.B., O.A.

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