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Original Article

The effect of shear-wave elastography on functional results and muscle stiffness in patients undergoing non-selective and selective open kinetic chain exercises

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ABSTRACT

Objectives: This study aims to assess the effect of shear-wave elastography (SWE) on vastus medialis obliquus (VMO) and vastus lateralis (VL) muscle performances and functional outcomes of patients with patellofemoral pain syndrome (PFPS) undergoing non-selective open kinetic chain exercises (NSOKCE) and selective open kinetic chain exercises (SOKCE).

Patients and methods: This randomized-controlled clinical trial included a total of 40 patients with PFPS (20 males, 20 females; mean age 46.5±9.8 years, range, 27 to 65 years) and 40 healthy controls (20 males, 20 females; mean age 36.3±11.2 years, range, 23 to 71) between February 2013 and August 2014. The participants in each group were randomized into subgroups according to NSOKCE or SOKCE for six weeks. The VMO and VL muscles were assessed with the SWE, thigh circumferences were measured, and the Visual Analog Scale (VAS) and Lysholm Knee Scale (LKS) scores were obtained.

Results: The OKCE alleviated pain, improved LKS scores, and increased the thigh circumference in PFPS patients. While the healthy controls were able to increase the resting muscle tone of their VMO, the patients with PFPS failed in their both knees. Similarly, resting as well as contracted VMO and VL muscles' functions were improved significantly by both NSOKCE and SOKCE in the healthy controls. The NSOKCE improved the VAS scores in the PFPS group. The increase in the muscle mass of the affected sides of PFPS patients were more evident with NSOKCE.

Conclusion: Our study results show that NSOKCE planning can be preferred over SOKCE, thanks to its contribution to pain improvement and increase in the thigh circumference in the conservative treatment of PFPS.

Keywords: Elastography, exercises, non-selective, pain, patellofemoral.

Patellofemoral pain syndrome (PFPS) manifests with anterior knee pain localized most commonly in the peripatellar and retropatellar areas.[1] Although its pathogenesis has not been thoroughly enlightened, isolated weakness and attenuation and delayed onset of vastus medialis obliquus (VMO) muscle as a component of the extensor mechanism seem to take part in reducing the contact area of patellofemoral joint and, thereby, increasing the contact pressure.[2] Electromyographic (EMG) studies revealed a decline in the activity of the quadriceps muscle, particularly in the VMO relative to vastus lateralis (VL) muscle.[3] Quadriceps setting exercises are routinely included in the conservative treatment of the PFPS, although no consensus has not been reached upon, yet.[4,5]

Closed kinetic chain exercises (CKCE) which are believed to generate least stress over the patellofemoral joint are commonly recommended to PFPS patients.[6,7] However, according to the literature, regardless of whether the extremity bears weight or not, open kinetic chain exercises (OKCE) or CKCE are not superior to one other in strengthening the muscles or relieving

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the pain. Current clinical approaches commonly employ OKCE owing to its selective contribution to VMO muscle and ease of use.[8] While non-selective open kinetic chain exercises (NSOKCE) with the ones that selectively activating VMO muscle are both recommended in the PFPS treatment,[4,9,10] there is still an ongoing debate on the selective activation of the VMO muscle.[4]

Shear-wave elastography (SWE) is a novel method to assess the elasticity of a tissue. This method allows the clinician to examine the contraction and the relaxation of muscles in the real-time setting and it is perfectly feasible in the outpatient clinic setting.[11-13]

The aim of the present study was to assess the stiffness of the VMO and VL muscles using the SWE and to evaluate the outcomes of exercise treatment in pain management, functional scores, and thigh circumferences.

PATIENTS AND METHODS

This randomized-controlled clinical trial included a total of 40 patients with PFPS (20 males, 20 females; mean age 46.5±9.8 years, range, 27 to 65 years) and 40 healthy controls (20 males, 20 females; mean age 36.3±11.2 years, range, 23 to 71) between February 2013 and August 2014. A written informed consent was obtained from each participant. The study was approved by the Istanbul University Cerrahpasa Medical Faculty Local Ethics Committee (05.02.2013 dated and A-15 numbered). The study was conducted in accordance with the principles of the Declaration of Helsinki.

The patients were divided into two groups as the healthy control group (HCG) and the PFPS group (PFPSG). A single sequence of random assignments (i.e., simple randomization method) was used. Both groups were also divided into subgroups as NSOKCE and SOKCE, considering the sex equilibrium between the subgroups. There are no additional exercises in daily life activities of participants in both HCG and PFPSG.

The patients who have met two or more of the following criteria were included in the PFPSG: *(i)* complaining of peripatellar and retropatellar pain that exacerbates particularly during activities such as climbing stairs, crouching, kneeling or prolonged walking or sitting; *(ii)* not having a history of trauma; and *(iii)* having a Visual Analog Scale (VAS) score ≥3 at first admission. Exclusion criteria for the HCG were as follows: *(i)* having a clinically documented diagnosis of PFPS, bursitis around hip or knee or tendinitis; *(ii)* having an history of undergone knee surgery past three months, traumatic hip or knee injury; *(iii)* having documented meniscus lesions, plica syndrome, knee instability, chondropathy, patellar subluxation or dislocation; and *(iv)* having an history of patellar tendon injury, distraction apophysitis around the knee.

An inclusion criterion for both groups was to agree to participate in the study and to sign the informed consent. Healthy volunteers who withdrew their consent at the beginning of the study were excluded. The patients who withdrew their consent following the initial assessment were not included in the statistical analysis; however their treatment was completed.

The height and weight of the participants were recorded, and the Body Mass Index (BMI) was calculated by using the following formula: weight in kg divided by the square of the height in meters (kg/m^2). The thigh circumferences were measured 5 to 10 cm above the upper pole of the patella with a measuring tape.

Interventions

NSOKCE

To perform NSOKCE, all participants were positioned in such a manner that their hip was flexed 90° as they sit in a backed chair and their arms crossed in front of the chest. A rolled towel was placed between the popliteal fossa and the surface of the examination table so that the patient could perform the exercise without any knee contact to the floor. The patient was asked to dorsiflex his/her ankle. The neutral position of the hip joint was maintained by keeping the line connecting both anterior superior iliac spines parallel to the floor and the long axis of the extremity perpendicular to this line. In the neutral position of the hip, all participants were instructed to press the towel against the examination table as strong as they could.[12]

SOKCE

To perform SOKCE, all participants were positioned in such a manner that their lower extremity angles 50° with their trunk as they sit in a backed chair and their arms crossed in front of the chest and their both ankles dorsiflexed. The participants were instructed to perform the exercises with their knee extended and their hip in 15° of adduction.[14]

Exercise program

The exercises were done for both knees in the HCG, and for both diseased (-DS) and healthy (-HS) sides in the PFPSG to avoid asymmetrical strengthening. A daily

program was introduced consisting of five sessions and each session comprised 10 cycles. The knee was kept in full extension and the quadriceps muscle was kept contracted for 10 sec in every cycle. A five-sec rest was put between the cycles. The participants performed their exercises for three days under the supervision of an orthopedic surgeon at the hospital and for two days at home during a total of six weeks.[14] None of the patients received treatment other than the exercises.

The assessment of VMO and VL muscles with SWE was implemented before the beginning of the treatment and at the end of the sixth week. The muscles were examined in both resting and in contraction phases.

Ultrasound (US) measurements

The SWE examinations were performed using a 4 to 15 MHz transducer (Supersonic Imagine, Aix-en-Provence, France) in a quiet, air conditioned room between 10 to 11 A.M. All SWE examinations were performed by a single radiologist experienced in musculoskeletal US for more than 10 years. The SWE examinations for the VMO and VL were performed exactly where the EMG recordings were obtained.[15] These measurement points were used for every participant in during resting or contraction phase of the SWE examination. The SWE studies were performed first during the resting phase. When the study participants contracted their quadriceps muscles for pressing the towel underneath the knee joint, the contraction phase measurements were performed. The US scanner provided a rectangular color map of the scanned area and the quantitative measurements were, then, performed by another experienced radiologist. Image processing for each participant was finished within 15 to 20 min. For each measurement, the area for range of image (ROI) for the color box and circular ROI for the quantitative analysis were equal in size. The circular ROI for the quantitative analysis provided the maximum, minimum, standard deviation, and mean elasticity values in the kilopascal (kPa) unit. A representative example for the SWE measurement is shown in Figures 1 and 2. The mean elasticity values were used for the statistical analysis. All measurements were repeated three times and a mean value was recorded. The mean elasticity value for every muscle in contraction (CP) and resting phases (RP) was accepted as the contraction and resting phases values for that VMO and VL muscles.[12]

VAS and Lysholm Knee Scale (LKS) scores

The VAS was used to assess the pain severity of PFPS and the LKS[16] was used to evaluate the functional outcomes.

Statistical analysis

Statistical analysis was performed using the Number Cruncher Statistical System (NCSS) version 2007 statistical software (NCSS, LLC. Kaysville, Utah, USA). Descriptive data were expressed in mean, standard deviation (SD), median (min-max), number, and frequency for the quantitative data. The Student's t-test was used for the intergroup comparisons of parameters with normal distribution, while the Mann-Whitney U test was used for the intergroup comparisons of parameters without normal distribution. One-way analysis of variance (ANOVA) was used for the comparisons of three or more groups, while the Dunn-Bonferroni adjustment test was used to analyze significant differences between the groups. One-way ANOVA was used for the comparisons of three or more groups with variance homogeneity and

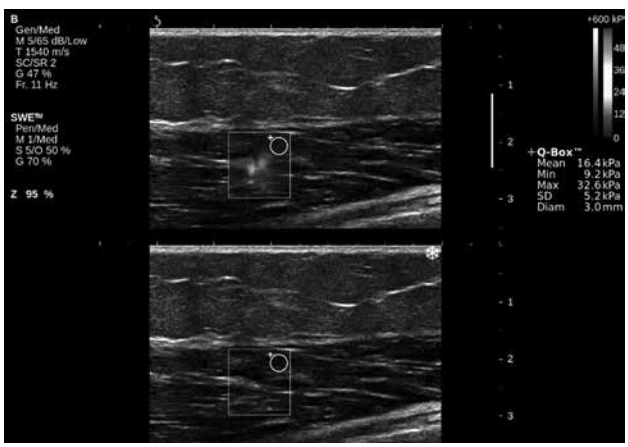

Figure 1. Shear-wave elastographic examination for vastus medialis obliquus muscle in relaxation phase.

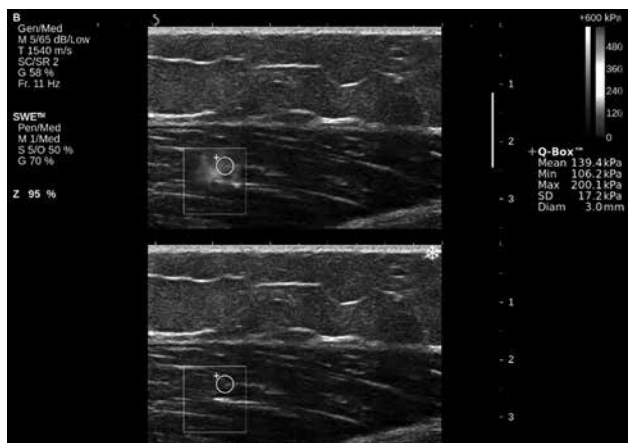

Figure 2. Shear-wave elastographic examination for vastus medialis obliquus muscle in contraction phase.

Table 1. Age, length, weight, Body Mass Index of study participants

	HCG (n=40)			PFPSG (n=40)			
	n	%	Mean±SD	n	%	Mean±SD	*p*†
Age (years)			36.3±11.2			46.5±9.8	0.001*
Sex							1.000‡
Female	20	50.0		20	50.0		
Male	20	50.0		20	50.0		
Length (cm)			170.8±10.0			166.6±10.8	0.073
Weight (kg)			74.7±10.6			74.2±7.7	0.819
BMI (kg/m^2)			25.6±2.8			27.0±4.6	0.093

HCG: Healthy controls group; PFPSG: Patellofemoral pain syndrome group; SD: Standard deviation; † Student-t test; ‡ Pearson chi-square test; * p<0.01; BMI: Body Mass Index; p<0.05.

the Tukey's honestly significant difference (HSD) test was used to analyze significant differences between the groups. The Welch test was used for the comparisons of the groups without variance homogeneity and the Tamhane's test was used to analyze significant differences between the groups. The Kruskal-Wallis test was used for the comparisons of three or more groups without normal distribution, while the Dunn-Bonferroni adjustment test was used to analyze significant differences between the groups. A paired samples t-test was used for intragroup comparisons of parameters with normal distribution and the Wilcoxon signed-rank test was used for intra-group comparisons of parameters without normal distribution. The Pearson's chi-square test was used for the comparison of qualitative data. The Spearman's correlation analysis was used to evaluate the relationships between the parameters. A p value of <0.05 was considered statistically significant.

Power analysis

A post-hoc power analysis was performed using the G*Power version 3.1.7 program (Heinrich-Heine-Universität Düsseldorf, Germany) and the data obtained from the study. When the difference in the VAS scores before and after exercise in the non-selective group comprising of 20 PFPS patients and in the selective group comprising of 20 PFPS patients

Table 2a. Visual Analog Scale and Lysholm Knee Scale scores before and after exercises of non-selective and selective

	Non-selective (n=20)		Selective (n=20)		
	Mean±SD	Median	Mean±SD	Median	*p*†
Visual Analog Scale					
BE	6.6±0.9	7.0	5.8±1.9	6.0	0.025*
AE	2.6±1.1	2.0	3.1±1.5	2.0	0.368
p‡	0.001**		0.001**		
AE-BE difference	-4.0±0.9	-4.0	-2.8±1.5	-2.5	0.002**
Lysholm Knee Scale score					
BE	74.4±9.8	74.0	72.2±15.0	74.0	0.469
AE	81.8±11.3	84.0	77.4±12.7	76.0	0.122
p‡	0.001**		0.002**		
AE-BE difference	7.4±4.7	6.0	5.2±5.3	5.5	0.189

SD: Standard deviation; BE: Before exercises; AE: After exercises; † Mann-Whitney U test; ‡ Wilcoxon signed-rank test; * p<0.05; ** p<0.01.

Table 2b. Visual Analog Scale and Lysholm Knee Scale scores before and after exercises

	Before exercises		After exercises		
PFPS-DS/(n=40)	Mean±SD	Median	Mean±SD	Median	*p*†
Visual Analog Scale	6.2±1.5	6.0	2.8±1.3	2.0	0.001*
Lysholm Knee Scale score	73.3±12.6	74.0	79.6±12.1	81.0	0.001*

PFPS-DS: Patellofemoral pain syndrome diseased side; SD: Standard deviation; † Wilcoxon signed-rank test; * p<0.01.

Table 3. Thigh circumference measurements before and after exercises

	HCG (RS+LS) (n=80)		PFPSG (DS) (n=40)		PFPSG (HS) (n=40)			
TC (n=160)	Mean±SD	Median	Mean±SD	Median	Mean±SD	Median	*p*†	Post Hoc (p)
Visual Analog Scale								
BE	41.8±3.7		44.8±4.5		45.7±4.9		0.001*	1<2, 0.001 1<3, 0.001
AE	42.9±3.8		46.2±4.4		46.7±4.7		0.001*	1<2, 0.001 1<3, 0.001
p‡	0.001*		0.001*		0.001*			
AE-BE difference	1.1±1.0	1.0	1.4±1.0	1.0	1.1±1.0	1.0	0.212**	
10 cm								
BE	44.7±3.7		49.0±5.8		49.8±6.2		0.001*	1<2, 0.001 1<3, 0.001
AE	45.7±4.0		50.3±5.5		50.8±5.9		0.001*	1<2, 0.001 1<3, 0.001
p‡	0.001*		0.001*		0.001*			
AE-BE difference	1.0±1.7	1.0	1.4±1.2	1.2	1.0±1.1	1.0	0.256**	

HCG: Healthy controls group; RS: Right side; LS: Left side; PFPSG: Patellofemoral pain syndrome group; DS: Diseased side; HS: Healthy side; SD: Standard deviation; BE: Before exercises; AE: After exercises; TC: Thigh circumference; † One-way ANOVA test and post-hoc Bonferroni adjustment test; ‡ Paired-samples t-test; * p<0.01; ** Kruskal-Wallis test.

Table 4. Thigh circumference measurements before and after exercises of NSE and SE

		Non-selective (n=40)		Selective (n=40)		
		Mean±SD	Median	Mean±SD	Median	*p*†
HCG-TC/(n=80)	5 cm					
	BE	40.9±2.9		42.6±4.2		0.040*
	AE	42.1±2.6		43.7±4.6		0.056
	‡*p*	0.001**		0.001**		
	AE-BE difference	1.11±1.13	1.0	1.1±0.9	1.0	0.968§
	10 cm					
	BE	43.8±3.0		45.7±4.2		0.018*
	AE	44.8±3.3		46.6±4.5		0.053
	‡*p*	0.003**		0.001**		
	AE-BE difference	1.1±2.2	1.0	0.8±1.1	0.2	0.052‖
PFPSG-DS-TC/(n=40)	5 cm					
	BE	43.6±3.5		46.1±5.1		0.090
	AE	45.5±3.5		47.0±5.1		0.284
	‡*p*	0.001**		0.001**		
	AE-BE difference	1.8±1.1	1.7	0.9±0.6	1.0	0.002**,§
	10 cm					
	BE	47.1±5.6		50.8±5.4		0.044*
	AE	49.3±5.4		51.4±5.6		0.217
	‡*p*	0.001**		0.001**		
	AE-BE difference	2.12±1.17	2.0	0.7±0.7	1.0	0.001**,‖
PFPSG-HS-TC/(n=40)	5 cm					
	BE	44.3±4.0		47.0±5.4		0.079
	AE	45.8±3.9		47.7±5.3		0.190
	‡*p*	0.001**		0.001**		
	AE-BE difference	1.5±1.2	1.0	0.7±0.6	1.0	0.066§
	10 cm					
	BE	48.1±6.3		51.6±5.8		0.073
	AE	49.3±5.7		52.3±5.8		0.109
	‡*p*	0.001**		0.001**		
	AE-BE difference	1.3±1.4		0.8±0.6	1.0	0.262§

NSE: Non-selective; SE: Selective; SD: Standard deviation; BE: Before exercises; AE: After exercises; HCG: Healthy controls group; TC: Thigh circumference; DS: Diseased side; HS: Healthy side; PFPSG: Patellofemoral pain syndrome group; HS: Healthy side; † Student-t test; * p<0.05, ** p<0.01; § Mann-Whitney U test; ‡ Paired-samples t-test; ‖ Pearson Chi-Square Test.

were considered, the effect size and power of the study were found to be d=1.04 and 88% at the α=0.05 level. When the difference values between contraction measurements of the VMO muscle before and after exercise in the HCG comprising of 80 knees, in the diseases group comprising of 40 knees and healthy knee group comprising of 40 knees were considered, the effect size and power of the study were found to be f=0.35 and 98% at the α=0.05 level. When the difference values between 5 cm waist circumferences of the cases before and after exercise in patient group comprising of 20 non-selective and 20 selective individuals were considered, the effect size and power of the study were found to be d=1.05 and 89% at the α=0.05 level. When the difference values between 10 cm waist circumferences of the cases before and after exercise in patient group comprising of 20 non-selective and 20 selective individuals were considered, the effect size and power of the study were found to be d=1.55 and 99.6% at the α=0.05 level.

RESULTS

Both groups were matched in terms of sex distribution and there was no significant difference in the BMI between the groups (Table 1). However, the statistical difference of the NSOKCE was more significant than the SOKCE (Table 2a). Pain decreased significantly with OKCE and a significant functional improvement with an increase in the thigh circumference was observed in all patients. In the PFPSG, the increase in the thigh circumference with NSOKCE was higher than the SOKCE (Table 2b, Tables 3 and 4).

The measurements of elasticity of the VMO muscle at the resting phase was similar in both groups (Table 5). In addition, there was no improvement in the resting phase elasticity in the either affected and healthy sides of PFPSG, although the HCG reported a significant increase with the exercises. The mean VL muscle tone values in the HCG was found to be

Table 5. Elasticity measurements results for VMO and VL muscles in the resting and contraction phase before and after exercises of study participants

		HCG (RS+LS) (n=80)		PFPSG (DS) (n=40)		PFPSG (HS) (n=40)			
	TC (n=160)	Mean±SD	Median	Mean±SD	Median	Mean±SD	Median	*p*†	Post Hoc‡ (p)
VMO (n=160)	Resting phase								
	BE	9.3±3.5	8.6	10.0±3.2	9.8	10.1±3.5	9.7	0.236	-
	AE	10.9±3.7	10.0	11.6±11.1	10.3	10.2±4.1	9.5	0.510	-
	p§	0.001**		0.218		0.282			
	AE-BE difference	1.6±2.4	1.1	1.6±10.6	0.4	0.1±3.3	0.3	0.024*	1>3, 0.048
	Contraction phase								
	BE	144.2±68.5	146.2	95.1±32.3	101.5	124.5±49.2	118.7	0.001**	1>2, 0.001 3>2, 0.017
	AE	197.4±96.1	188.5	120.8±48.1	121.8	141.5±58.4	132.9	0.001**	1>2, 0.001 1>3, 0.007
	p§	0.001**		0.001**		0.001**			
	AE-BE difference	53.2±50.8	41.8	25.6±42.6	18.0	17.1±38.3	16.1	0.001**	1>2, 0.002 1>3, 0.001
VL (n=160)	Resting phase								
	BE	9.6±3.3	9.4	11.3±4.1	10.2	11.4±4.1	10.7	0.024*	1<3, 0.048
	AE	10.9±3.9	10.3	12.8±4.8	12.0	11.8±4.5	11.0	0.089	-
	p§	0.001**		0.139		0.216			
	AE-BE difference	1.3±3.6	0.7	1.5±4.8	0.8	0.3±4.2	0.4	0.501	-
	Contraction phase								
	BE	122.9±77.6	117.5	81.2±29.2	75.7	99.4±31.8	104.3	0.001**	1>2, 0.001
	AE	176.4±102.8	166.3	111.8±35.1	110.0	111.2±42.7	104.3	0.001**	1>2, 0.001 1>3, 0.001
	p§	0.001**		0.001**		0.002**			
	AE-BE difference	53.6±67.2	35.4	30.7±27.8	24.9	11.8±27.5	9.9	0.001**	1>3, 0.001 2>3, 0.008

VMO: Vastus medialis obliquus; VL: Vastus lateralis; HCG: Healthy controls group; RS: Right side; LS: Left side; PFPSG: Patellofemoral pain syndrome group; DS: Diseased side; HS: Healthy side; TC: Thigh circumference; SD: Standard deviation; BE: Before exercises; AE: After exercises; † Kruskal-Wallis test; ‡ Post-hoc Dunn-Bonferroni adjustement test; § Wilcoxon signed-Rank test; *p<0.05; ** p<0.01; The unit for the mean elasticity is kPa (kilopascal).

Table 6. Comparison of the NSE with SE before and after exercises for VMO and VL muscles in the HCG

		Non-selective (n=40)		Selective (n=40)		
		Mean±SD	Median	Mean±SD	Median	*p*†
HCG (n=80) VMO	Resting phase					
	BE	9.1±3.3	8.7	9.5±3.7	8.5	0.908
	AE	10.9±3.7	10.1	10.9±3.7	10.0	0.981
	‡*p*	0.001*		0.001*		
	AE-BE difference	1.7±3.0	1.2	1.4±1.8	1.1	0.743
	Contraction phase					
	BE	143.7±46.5	148.1	144.7±85.6	141.1	0.541
	AE	189.7±72.1	186.6	205.0±115.6	201.0	0.780
	‡*p*	0.001*		0.001*		
	AE-BE difference	46.1±50.1	36.1	60.3±51.3	47.2	0.058
HCG (n=80) VL	Resting phase					
	BE	9.7±3.7	9.5	9.5±2.9	8.9	0.916
	AE	11.0±4.2	10.3	10.8±3.6	10.3	0.996
	‡*p*	0.007*		0.004*		
	AE-BE difference	1.3±3.9	0.8	1.3±3.3	0.5	0.665
	Contraction phase					
	BE	120.7±44.0	122.2	125.0±101.2	111.9	0.271
	AE	173.2±85.6	161.0	179.7±118.6	177.0	0.866
	‡*p*	0.001*		0.001*		
	AE-BE difference	52.5±66.0	41.1	54.7±69.1	27.3	0.795

NSE: Non-selective exercise; SE: Selective exercise; VMO: Vastus medialis obliquus; VL: Vastus lateralis; SD: Standard deviation; BE: Before exercises; AE: After exercises; HCG: Healthy control group; † Mann-Whitney U test; ‡ Wilcoxon signed-ranks test, * p<0.01.

Table 7. Comparison of the NSE with SE before and after exercises for VMO and VL muscles in the PFPSG-DS

		Non-selective (n=20)		Selective (n=20)		
		Mean±SD	Median	Mean±SD	Median	*p*†
PFPSG-DS (n=40) VMO	Resting phase					
	BE	10.6±3.4	11.5	9.4±3.0	9.0	0.297
	AE	12.9±15.4	10.1	10.3±3.2	10.7	0.756
	‡*p*	0.702		0.083		
	AE-BE difference	2.4±14.4	0.2	0.8±4.6	0.7	0.076
	Contraction phase					
	BE	100.0±32.1	104.7	90.2±35.6	90.6	0.256
	AE	133.9±51.5	129.9	107.6±41.5	105.6	0.088
	‡*p*	0.001**		0.021*		
	AE-BE difference	33.8±51.2	16.2	17.4±31.0	23.9	0.914
PFPSG-DS (n=40) VL	Resting phase					
	BE	11.7±4.9	9.9	10.8±3.2	10.6	0.646
	AE	13.8±5.9	12.5	11.8±3.1	11.7	0.499
	‡*p*	0.156		0.456		
	AE-BE difference	2.0±5.4	0.9	0.9±4.1	0.8	0.598
	Contraction phase					
	BE	82.8±28.2	78.8	79.5±30.8	66.8	0.695
	AE	116.3±28.3	110.0	107.4±41.0	109.9	0.516
	‡*p*	0.001**		0.001**		
	AE-BE difference	33.4±29.6	25.6	27.9±26.3	23.6	0.665

NSE: Non-selective exercise; SE: Selective exercise; VMO: Vastus medialis obliquus; VL: Vastus lateralis; PFPSG: Patellofemoral pain syndrome group; DS: Diseased side; SD: Standard deviation; BE: Before exercises; AE: After exercises; † Mann-Whitney U test; ‡ Wilcoxon signed-ranks test. * p<0.05; ** p<0.01.

Table 8. Comparison of the NSE with SE before and after exercises for VMO and VL muscles in the PFPSG-HS

		Non-selective (n=20)		Selective (n=20)		
		Mean±SD	Median	Mean±SD	Median	*p*†
PFPSG-HS (n=40) VMO	Resting phase					
	BE	10.1±2.9	10.1	10.1±4.1	9.5	0.655
	AE	10.3±3.2	9.9	10.1±5.0	9.0	0.351
	‡*p*	0.466		0.421		
	AE-BE difference	0.2±2.7	0.3	0.1±3.8	0.3	0.882
	Contraction phase					
	BE	127.8±59.4	116.3	121.1±37.7	124.1	0.839
	AE	146.2±62.2	129.5	136.9±55.4	140.15	0.914
	‡*p*	0.023*		0.021*		
	AE-BE difference	18.4±34.5	16.1	15.8±42.6	15.2	0.882
PFPSG-HS (n=40) VL	Resting phase					
	BE	11.6±3.5	11.0	11.3±4.8	10.5	0.490
	AE	11.1±3.9	11.0	12.5±5.0	11.0	0.525
	‡*p*	0.737		0.145		
	AE-BE difference	-0.5±4.1	0.4	1.2±4.2	0.7	0.424
	Contraction phase					
	BE	106.6±26.7	111.3	92.3±35.4	81.2	0.062
	AE	117.3±46.4	122.4	105.1±38.9	99.8	0.133
	‡*p*	0.028*		0.028*		
	AE-BE difference	10.7±32.0	11.3	12.8±22.9	7.4	0.957

NSE: Non-selective exercise; SE: Selective exercise; VMO: Vastus medialis obliquus; VL: Vastus lateralis; PFPSG: Patellofemoral pain syndrome group; HS: Healthy side; SD: Standard deviation; BE: Before exercises; AE: After exercises; † Mann-Whitney U test; ‡ Wilcoxon signed-ranks test. * p<0.05.

lower than the PFPSG in the resting phase. However, there was no significant difference in the resting phase measurements of VL muscle between the affected and the healthy sides of PFPS patients, although the mean values were higher than those obtained in the HCG. According to the measurements obtained at the contraction phase, the VL muscles of the HCG benefited from the exercise treatment more than the PFPSG. Nevertheless, the resting tones of VL muscle were found to be similar in both groups at the end of the six-week exercise treatment (Table 5). The efficacy of VL muscle improved with the exercise treatment in both groups and the benefit was maximal in the HCG group (Table 5).

Both SOKCE and NSOKCE positively affected the contractions of VMO and VL muscles in either affected and healthy sides of the PSPFG (Tables 6, 7, and 8).

On the other hand, there was no statistically significant difference in the BMI values and the measurements of pre- and post-exercise thigh

Table 9. Correlation with BMI of the difference of exchange values before and after exercises in the each groups

	Body Mass Index			
	HCG (RS+LS) (n=80)		PFPSG-DS (n=40)	
BE-AE difference values	r	*p*	r	*p*
TC 5 cm	0.089	0.587	0.012	0.939
TC 10 cm	0.167	0.303	-0.027	0.868
VMO RD	-0.280	0.080	-0.089	0.586
VMO CD	0.011	0.948	0.017	0.916
VL RD	-0.001	0.997	0.060	0.714
VL CD	-0.168	0.299	-0.167	0.303

BMI: Body Mass Index; HCG: Healthy control group; RS: Right side; LS: Left side; PFPS: Patellofemoral pain syndrome group; DS: Diseased side; BE: Before Exercises; AE: After exercises; TC: Thigh circumference; VMO: Vastus medialis obliquus; RD: Relaxation difference; CD: Contraction difference; VL: Vastus lateralis; r= Spearman's correlation coefficient; * p<0.05.

circumference, VMO muscle relaxation, VMO muscle contraction, VL muscle relaxation and VL muscle contraction measurements of the diseased knees and healthy knees (Table 9).

DISCUSSION

Exercise treatment is proven to be effective in patients with PFPS.[1,4,5] Quadriceps strengthening exercises increase the muscle contraction strength and, thus, decrease the joint reaction force over the patellofemoral joint. The stress relief over the joint decreases the reflex inhibition and relieves the pain secondary to an increase in endorphins.[17] Our study findings are consistent with aforementioned results, suggesting that OKCE improves the VAS and LKS scores and decreases the pain in the PFPS patients. There is a consensus in the literature on the conservative treatment of PFPS. An activity restriction for the first four weeks followed by a six-week exercise period is the mainstay of a majority of the treatment protocols. The exercises are recommended to be done in five sessions, each of them consisted of at least 10 cycles and during at least six weeks, which was also the protocol employed in our study.[15]

The atrophy of the quadriceps muscles as assessed by US has been documented in PFPS patients in previous studies. It has been also shown that the exercise treatment improves the muscles strength.[18] Unlike these findings, we found an increase in the thigh circumference in all the participants who performed OKCE, and particularly in the affected side of PFPSG with NSOKCE. The clinician should, therefore, consider the quadriceps muscle atrophy in a PFPS patient[18] and the beginning exercises should be compatible with the daily activities restoring the patients functionality, first. The CKCE simulate most of the daily activities such as climbing stairs, walking uphill or downhill, and crouching. Although CKCE has been suggested to be a more functional exercise pattern than OKCE in the literature,[19] both improves the muscle strength and relieves the pain.[20] There is also no significant difference in the VAS scores of the patients treated with OKCE or CKCE.[20] Although several authors recommend CKCE in the treatment of PFPS suggesting that the CKCE generate lower stress than the open chains,[6,7,15] other studies have reported similar results obtained from both OKCE and CKCE, indicating that there is no particular advantage of one type of exercise to the other.[20] An EMG study has also advocated that both OKCE and CKCE improve the contraction strength of VMO muscle, however, OKCE provides more VMO activation.[21] Nonetheless, there is no consensus in the literature supporting the superiority of one exercise to the other.[22]

Several advantages of OKCE have been previously emphasized in the literature, such as that CKCE may not be well-tolerated by certain patients and that OKCE can be more effortlessly performed. The OKCE is preferred by a majority of the strengthening protocols[23] and it is easy to apply[9] with its advantage in selectively activating the VMO muscle, and it is the main reason we implemented the OKCE in our study, as well.

The initial activation of VL and VMO muscles is synchronous and well-coordinated, during the knee extension of an healthy individual. Conversely, in PFPS patients, a delayed onset of VMO muscle leads to a discordance between the VL and VMO muscles.[24] Moreover, the reflex inhibition of VMO muscle is more significant than VL muscle.[25] The weakness of the VMO muscle has been previously demonstrated in a SWE study.[12] The results of the present study also support the VMO muscle insufficiency in PFPS patients which was formerly described in the literature in such a manner that the exercise treatment improved the VMO resting tone in healthy participants, but no such enhancement was achieved in neither affected nor healthy sides of the PFPS patients.[18,26]

The discordance in the muscle activation onset between the VL and VMO muscles[9,10] is the leading cause of the VMO insufficiency and the biomechanical disorder of the joint due to lateral patellar translation. In the present study, we documented that VL resting tone in HCG was lower than PFPSG, and this phenomenon supports the dissociation where VL muscle overpowers VMO muscle. Furthermore, the fact that exercise treatment improved the resting VL muscle tone of PFPS patients to the same level with healthy controls, might indirectly indicate that VL muscle could be activated with the exercises even in a PFPS patient. Therefore, quadriceps exercises are recommended by several authors, in the early phases of the rehabilitation; precisely, selective strengthening of the VMO muscle is employed to restore dynamic stabilization of the patella.[14] The results of the present study demonstrated that both NSOKCE and SOKCE affected positively the resting tone of VMO and VL muscles in healthy participants; however, this improvement could not be achieved in the PFPSG for neither SOKCE nor NSOKCE. Also, when the contraction strengths were evaluated, both VL and VMO muscles were affected positively with the SOKCE

and NSOKCE. In the present study, we showed that PFPS patients were unable to increase their resting tone of VMO muscle, either in the affected or healthy sides, supporting the involvement of an actual VMO hypotonia in the pathophysiology of PFPS.

Since VMO originates partially from the adductor magnus fascia, it is activated in a better mechanical setting when the adductor magnus is contracted; adductor magnus coupling provides VMO a stronger resistance toward lateral shearing forces a stronger EMG activity is generated at VMO than VL muscle during isometric contraction of adductor magnus.[27] Even if there is no consensus in the literature on the benefit of the selective strengthening of VMO muscle, many authors recommend SOKCE and particularly including hip adduction. Inclusion of hip joint adduction to SOKCE has several reasons according to which, hip adduction was added to SOKCE in the present study. The participants in our study were instructed to dorsiflex their ankle joint to avoid the excessive external rotation of the tibia and to establish a better alignment, keeping the tibial tuberosity medial. Furthermore, the ankle dorsiflexion provides a 20% increase in the myoelectrical activity at VMO muscle, compared to the neutral position of the ankle.[28] In the supine position, the iliopsoas muscle tone tends to externally rotate the hip joint. Our patients were positioned in a semi-supine (beach chair) position to relax the iliopsoas muscle and, thus, to avoid hip external rotation.[29]

There are different methods utilized in the functional evaluation of the skeletal muscle such as surface EMG, dynamometer, mechanomyogram, and acceleromyography. However, there are several methodological limitations in the studies evaluating the selective strengthening of the VMO muscle. Therefore, there is an urge for an objective and quantitative method to analyze the VL and VMO muscle activities. Among these methods, SWE provides quantitative data and direct visualization of the mechanical alterations that occur during the muscle contraction. Moreover, it is useful for the indirect evaluation of the muscle stiffness.[12] The main advantage of SWE is the possibility of evaluating and providing quantitative data about a single muscle.[11-13] The muscles can be assessed with SWE in resting or in contraction phases.[30] The measurements obtained in the resting phase represents data on the resting tone of a muscle and measurements on the active muscle indirectly propounds information about the usefulness and the contraction effectiveness of the muscle.

Nonetheless, there are several limitations to our study. First, the mean age of the HCG was unable to be matched with the PFPSG, as it included younger healthy volunteers. However, in a review, Rothermich et al.[31] reported that the peak of prevalence of PFPS was observed in young active adolescents between the ages of 12 and 17. Therefore, our control group can be considered as a good match for a potential PFPS group. Another limitation is the lack of CKCE groups in our study, which has been also proven to be effective in the treatment of PFPS. We preferred OKCE in our study for the reasons that it is more simple to instruct and to perform, does not require special equipment, and it is easier to cooperate with patients with physical and mental comorbidities, high BMI values, having difficulty in ambulation, and in the early postoperative phase. Thus, the inclusion of a CKCE group in further studies evaluating the muscles with SWE is needed. In addition, we used the LKS in our study. However, the Turkish version of the scale is also simple, valid, and reliable and can be used for patients with knee disorders.[16]

In conclusion, both NSOKCE and SOKCE provide an increase in the thigh circumference with similar improvement in the functional scores. Based on our study results, the NSOKCE is more effective in relieving pain and increasing the muscle mass in PFPS patients. We believe that these results would provide reference values of resting and contraction phases to the researchers to appraise the effectiveness of the exercises.

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