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Electromyography Activity of Vastus Medialis Obliquus and Vastus Lateralis Muscles During Lower Limb Proprioceptive Neuromuscular Facilitation Patterns in Individuals with and without Patellofemoral Pain Syndrome

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ABSTRACT. Objective: Exercise therapy to strengthen quadriceps muscle is recommended in rehabilitation program for people with patellofemoral pain syndrome (PFPS). This study aimed to investigate the electromyography (EMG) activity of vastus medialis obliquus (VMO), vastus lateralis (VL) and VMO/VL ratio during PNF in individuals with and without PFPS. Methods: 26 persons with PFPS and 26 healthy subjects participated to study. All subjects performed PNF patterns (Flexion-Adduction-External Rotation (D_1FL), Extension-Adduction-External Rotation (D_2EX), D_1FL+ load, D_2EX+ load) and straight leg raise (SLR). The normalized EMG activity of VMO, VL and VMO/VL ratio were measured and analyzed using repeated measure ANOVA. Results: There were significant main effects of group and exercises for the both VMO and VL ($p<0.05$). It was found that except SLR and D_2EX, in the other motions PFPS group had lower VMO activity compared to healthy group ($p<0.05$). For VL except SLR, in the other motions PFPS group had lower VL activity too ($p<0.05$). The PNF patterns activated VMO more than SLR, however it was not significant ($p>0.05$). Also; there weren't any significant difference between the two groups in VMO/VL activation ratios. Also, performing the PNF patterns with load increased VMO and VL muscles activity significantly ($p<0.05$). It also found that in PFPS group the VMO/VL ratio values in PNF patterns were significantly more than SLR and the highest VMO/VL ratio value (0.96) was found during D_2EX. Conclusion: The PNF patterns due to provide optimal VMO/VL ratio value than SLR and proper balance between these two muscles can be recommended in rehabilitation of individuals with PFPS.

Key words: Patellafemoral pain syndrome, Physical therapy, Exercise therapy, Electromyography, Vastus medialis obliquus

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Patellofemoral pain syndrome (PFPS) is a common problem which has been reported mostly in young females and included 25% to 40% of knee injuries in athletes[1-4]. People with PFPS experience dull pain around and behind the patella during movements such as climbing stairs, running, jumping, or keeping knees in positions such as kneeling or quad sitting for a long time[1]. Normal patellar tracking on trochlea groove depends on coordination and balance of various structures including soft tissues, muscles, tendons, ligaments and the shape of articular surfaces around the knee joint[4,5]. Impairment of any of these factors effect on the patella's normal biomechanics and resulted in the increased pressure on the articular surface and PFPS[1,6].

Weakness of the Vastus Medialis Obliquus muscle (VMO) or the imbalance between VMO and Vastus Lateralis muscle (VL) activity are one of the most important fac-

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tors in increasing lateral force which can lead to PFPS[1,7,8]. VMO plays a critical role in maintaining patella in the trochlea groove. Therefore, the weakness or delay in VMO muscle activation which cause disturbance in the stabilization and function of the patella would lead to PFPS[1,9]. Previous studies demonstrated that proprioceptive neuromuscular facilitation (PNF) techniques can play an important role in reducing pain, increasing the range of motion, joints stabilization and facilitating the initiation of movement[10-12]. People with quadriceps muscle weakness are more likely at risk of PFPS, because it can lead to increase pressure on patellofemoral joint[13]. Therefore, exercise therapy to strengthen muscles is a part of the program for people with PFPS and studies showed muscle strengthening exercises can improve pain and biomechanics of the patellofemoral joint and these exercises are important part of PFPS treatment[14-17]. One of the important training methods in physical therapy exercises is PNF. In PNF diagonal motions, based on facilitation principles such as proprioceptors stimulation and overflow, a weak muscle can be strengthened with the help of strong components in the pattern[10,18,19].

The VMO is the first muscle that is atrophic and inhibited in the knee injuries[20]. Therefore, the focus of the exercises is to strengthen and increase its activity level and improve balance between VMO and VL activity. Some studies showed when the hip is externally rotated, VMO muscle contraction is at the highest level[21,22]. Also, the VMO originated from adductor magnus with tendons medially, so with hip external rotation and adduction, adductor muscles can provide a stable origin for VMO and increase VMO activity[1,23]. Previous studies showed that straight leg raise (SLR) with external rotation, and dorsiflexion, as well as adding hip adduction to open and close kinematic chain exercises are proper exercises to enhance VMO activation[1,8,24-26]. However, there is no consensus on this[27-30]. The PNF patterns are in different plane and contain different motions together. So, these patterns with combining motions simultaneously are functional and can activate the VMO and VL muscles well. Also, better results have been seen in improving the function of weak muscles by performing motor patterns in a group as compared to training a single muscle[18,19].

There is no study in PFPS to demonstrate the impact of PNF's diagonal patterns on the facilitation of VMO or balance between VMO and VL. Therefore, the aim of this study was to investigate the effect of PNF patterns on the activation of VMO and VL muscle in individuals with and without PFPS.

Methods

Subjects

Fifty two individuals (n= 26 PFPS, n=26 healthy) through an analytical design participated in the study. The inclusion criteria were: 1) reporting an anterior knee pain in the at least past 3 months during activities such as squatting, climbing, stepping, running, jumping, kneeling and quad sitting; 2) Having at least one positive PFPS clinical tests including, patellofemoral compression, patellofemoral gliding or resistive quadriceps setting[1,31]. The subjects were excluded from the study if they had history of knee surgery or injury, patellar dislocation or subluxation, any neurological or rheumatic disorders and pain intensity more than 5 (based on visual analogue scale). Subjects in healthy group should not have had any history of knee pain or other pathologies of knee in the past[1,7,31-33]. All participants signed an informed consent form to participate in this study that approved by the ethics committee of University of Social Welfare and Rehabilitation Sciences (Ethical number: IR. USWR.REC.1396.128)

Electromyography (EMG) assessment

In this study the EMG data of VMO and VL muscles were recorded during PNF patterns (Flexion-Adduction-External Rotation (D_1FL) in hip joint with knee extended, Extension -Adduction-External Rotation (D_2EX) in hip joint with knee extended, D_1FL+ load and D_2EX+ load) and SLR. The EMG data of VMO and VL were collected using MT8 EMG device manufactured by MIE in the UK. The participants lay supine on a bed and put their hands crossly on the chest. The electrodes were Ag/ AgCl, the diameter of the surface electrode was 10 mm and the electrode spacing was 20 mm. The sampling frequency was 1000 and the band pass filter was between 20-450 Hz[1,20]. Before the electrodes placement first, the skin of the area was prepared by shaving the hair and cleaning it with alcohol. A hypothetical line which connected anterior superior iliac spine to the center of the patella was considered as the reference line for electrodes placement. The VMO electrode was placed with an angle of 55° relative to the reference line, 4 cm above the superior border of the patella and 3 cm medially to the reference line. The VL electrode was placed with the angle was 15° relative to the reference line, 10 cm above the superior border of the patella and 7 cm laterally to the reference line. The ground electrode was placed on the patella[2,6,20].

Subjects first were trained on how to perform the movements. By using the goniometer and a designed device, we determined thirty degrees as target for elevation of lower limb during PNF patterns and SLR. The sequence of movements was random. To determine the sequence of movements, the participants selected random order sheets. To perform PNF patterns, the limb was first placed in an antagonistic pattern with a straight knee. By giving the verbal command, the subjects were asked to reach the lower limb to determined target point within 5 second according to their familiarization training. Between each exercise, there was 4 minutes of rest. The PNF patterns were also performed with weights. We used an adjustable weight cuff

Table 1. Comparison of normalized electromyographic activity of VMO, VL and VMO/VL ratio during PNF patterns and SLR between the PFPS and healthy groups

muscles	groups	exercises (The mean ±SD) (%MVIC)				
		D_1FL	D_2EX	SLR	D_1FL + load	D_2EX + load
VMO	PFPS	44.92 ± 15.44	45.87 ± 12.25	41.55 ± 13.22	58.01 ± 18.50	60.09 ± 13.96
	Healthy	56.52 ± 17.57	52.31 ± 12.47	49.57 ± 19.70	75.25 ± 15.45	67.95 ± 11.67
	p-value	0.01	0.06	0.09	0.001	0.03
VL	PFPS	49.15 ± 16.53	48.91 ± 13.47	51.05 ± 10.92	63.21 ± 19.48	63.98 ± 13.78
	Healthy	60.00 ± 11.38	56.80 ± 9.75	56.78 ± 15.84	80.77 ± 11.01	71.67 ± 9.93
	p-value	0.01	0.02	0.13	< 0.001	0.02
VMO/VL	PFPS	0.92 ± 0.17	0.96 ± 0.20	0.81 ± 0.18	0.93 ± 0.16	0.94 ± 0.16
	Healthy	0.93 ± 0.17	0.93 ± 0.19	0.84 ± 0.17	0.93 ± 0.12	0.95 ± 0.14
	p-value	0.90	0.57	0.58	0.96	0.91

PFPS, patellofemoral pain syndrome, VMO, vastus medialis oblique, VL, vastus lateralis, VMO/VL, ratio of vastus medialis oblique/vastus lateralis, SLR, straight leg raise, D_1FL, flexion, adduction, external rotation with knee straight, D_2EX, extension, adduction, external rotation with knee straight

that its weight could be changed. It was be fixed on ankle of subjects. The load which we added to exercise was determined according to the subjects' body mass index (BMI) as follows: 1 kg for those BMI less than 20, 1.4 kg for BMI of 20-22, 1.7 kg for BMI of 22-24 and 2 kg for those BMI more than 24[23,34]. To achieve the mean activity of VMO and VL muscles, the Raw data processed with the root mean square (RMS). Normalization was necessary to minimize variables between PFPS and healthy subjects. To compute the normalized data for VMO and VL muscles we also measured maximal voluntary isometric contraction (MVIC), so the participants were seated at the end of a bed to perform MVIC of the quadriceps muscle against manual resistance. The highest root mean square (RMS) value of the three MVICs was used for normalization purposes[35]. EMG data were collected during the patterns and SLR were normalized and expressed as a RMS processed percentage of MVIC. For assessing test-retest reliability, 10 subjects (5 healthy and 5 PFPS) were studied twice as the same mentioned methods with an interval of one day.

Statistical analyses

All data were analyzed using SPSS statistical software version 18. The repeated measures ANOVA were used to compare the mean of VMO and VL muscles activity separately and VMO/ VL ratios across exercises for each group and between the two groups. The post hoc test was also performed for pairwise comparison between the exercises. Multivariate analysis of variance (MANOVA) was used to compare the muscles activation level in each exercise between the two groups. ($p < 0.05$, indicating a significant difference)

Results

Twenty six PFPS subjects (18 women, 8 men) and 26 healthy subjects (18 women, 8 men) participated in this study. The mean ± SD of the age and BMI of participants in PFPS group were 22.92 ± 1.78 years, 22.97 ± 2.21 kg/m^2 and in healthy group were 23 ± 1.91 years, 23.08 ± 2.72 kg/m^2. There was no statistically significant difference in subject's age ($p = 0.98$) and BMI ($p = 0.88$) between the two groups. The intra-class correlation coefficients (ICC) values for assessing test-retest reliability was calculated. The results showed the reliability of EMG data of mean activity was greater than 0.86 in all exercises.

The results of repeated measures ANOVA for VL muscle activity revealed a significant effect of group × exercises ($F=2.90$, $p=0.04$) and significant effects of the exercises ($F=43.70$, $p<0.001$) and the group ($F=11.97$, $p=0.001$). This analysis for VMO muscle activity showed no significant interaction effect ($F=1.90$, $p=0.15$). However, significant main effects of exercises ($F=36.12$, $p<0.001$) and group ($F=10.49$, $p=0.002$) were observed. For VMO/ VL ratio the interaction effect of group × exercises was not significant ($F=0.47$, $p=0.68$). Also, main effect of group was not significant ($F= 0.001$, $p= 0.97$) however, significant main effects of exercises ($F= 10.07$, $p<0.001$) was observed.

The mean of EMG activity of VMO, VL and VMO/ VL ratio (as a percentage of MVIC) during PNF patterns and SLR in PFPS and Healthy groups have shown in Table 1. The result of MANOVA analysis of VMO activation level in each motion between the two groups showed that except SLR and D_2EX ($p>0.05$), in the other motions PFPS group had lower VMO activity ($p<0.05$). For VL except SLR, in the other motions PFPS group had lower VL activity too ($p<0.05$) (Table 1). Also, there weren't any signifi-

Table 2. Pairwise Comparisons of normalized EMG activity of muscles between exercises in PFPS and healthy groups

group	Exercises		VMO		VL		VMO/VL	
Healthy	(I)	(J)	Mean difference (I-J)	P value	Mean difference (I-J)	P value	Mean difference (I-J)	P value
	Comparison of D_1FL with	D_2EX	4.21	0.05	3.20	0.14	-0.001	0.96
		SLR	6.95	0.12	3.22	0.38	0.09	0.01
		D_1FL+ load	-18.73	< 0.001	-20.77	< 0.001	0.003	0.90
		D_2EX+ load	-11.43	< 0.001	-11.67	< 0.001	-0.02	0.40
	Comparison of D_2EX with	D_1FL	-4.21	0.05	-3.20	0.14	0.001	0.96
		SLR	2.74	0.49	0.02	0.99	0.09	0.05
		D_1FL+ load	-22.94	< 0.001	-23.97	< 0.001	0.004	0.89
		D_2EX+ load	-15.64	< 0.001	-14.87	< 0.001	-0.02	0.38
PFPS								
	Comparison of D_1FL with	D_2EX	-0.95	0.65	0.24	0.91	-0.04	0.17
		SLR	3.37	0.44	-1.90	0.60	0.11	0.001
		D_1FL+ load	-13.09	< 0.001	-14.06	< 0.001	-0.01	0.83
		D_2EX+ load	-15.17	< 0.001	-14.83	< 0.001	-0.02	0.37
	Comparison of D_2EX with	D_1FL	0.95	0.65	-0.24	0.91	0.04	0.17
		SLR	4.32	0.28	-2.14	0.46	0.15	0.002
		D_1FL+ load	-12.14	< 0.001	-14.30	< 0.001	0.03	0.27
		D_2EX+ load	-14.22	< 0.001	-15.07	< 0.001	0.02	0.59

cant difference between the two groups in VMO/VL activation ratios (p>0.05) (Table 1).

Pairwise Comparisons of the motions have shown in Table 2. As shown in Table 1 however, the mean of EMG activity of VMO in PFPS group during PNF patterns was more than SLR; there weren't any significant differences in VMO muscle activity between D_1FL, D_2EX and SLR (Table 2). Also, as shown in Table 1 however, the mean of EMG activity of VL in PFPS group during SLR was more than PNF patterns; there weren't any significant differences in VL muscle activity between D_1FL, D_2EX and SLR (Table 2). Adding weight to D_1FL and D_2EX increased VMO and VL muscles activity significantly in both groups (Table 2). The pairwise Comparisons showed that the VMO/VL ratios of the PNF patterns were significantly more than SLR too (p<0.01) (Table 2).

As shown in Table 1, the activation levels of VMO during the motions from the highest to the lowest in PFPS group were: D_2EX+ load, D_1FL+ load, D_2EX, D_1FL, SLR while, in healthy group were : D_1FL+ load, D_2EX+ load, D_1FL, D_2EX, and SLR. Also, the activation levels of VL during the motions from the highest to the lowest in PFPS group were: D_2EX+ load, D_1FL+ load, SLR, D_2EX and D_1FL while, in healthy group were: D_1FL+ load, D_2EX+ load, D_1FL, D_2EX and SLR (Table 1).

In addition, the Table 1 showed that the VMO/VL ratio during PNF patterns were significantly more than SLR and were near the ideal 1:1 ratio in two groups.

Discussion

The results of this study on comparison of VMO activation level in each exercises between the two groups showed that except SLR and D_2EX, in the other exercises PFPS group had lower VMO activity. In the other words SLR and D_2EX in PFPS group activated the VMO the same as healthy group. Also, pairwise comparisons of PNF patterns (without load) with SLR showed that the mean of EMG activity of VMO in PFPS and healthy groups during PNF patterns were more than SLR, however, these differences weren't significant. In PFPS group, the balance of internal and external forces on patellofemoral joint is disturbed and causing pressure on the joint and pain[1]. Due to pain the person with PFPS, reduces the motion of joint and it causes weakness of muscles and this weakness intensifies imbalance of forces on patellofemoral joint[7,8,13]. Therefore, this defective cycle is repeated. As our results, Hwang et al[36] showed that the EMG activity of muscle in PFPS group was less than healthy group. Also Giles et al[37] showed that atrophy of the quadriceps muscle was seen in person with PFPS. The quadriceps muscle strengthening program is one of the most important part of PFPS treatment and studies showed the effectiveness of these exercises on reduce pain and improvement of PFPS treatment[14,16,17].

SLR is one of the exercises that are often recommended for strengthening quadriceps muscle in patients with knee problems[24]. According to the results of this study, PNF patterns without load activated VMO muscle similar to the SLR. Mikaili et al[24] and Choi et al[1] showed that by adding external rotation and dorsiflexion to the SLR, the contraction force of VMO and VL muscles increases. Previous studies showed that, adding adduction to open and close kinematic chain exercises could increase VMO activity too[8,25,26,32,38]. Due to the origin of the VMO from adductor Magnus, contraction of adductor muscles can provide a stable origin for VMO and increase its activity[8,32]. The mentioned motions are similar to the D_1FL that used in this study, which simultaneously included flexion, adduction, external rotation and dorsiflexion. In fact, the PNF patterns by combining different components of motion together simultaneously and being functional can activate the VMO and VL muscles well. Based on the principle of Overflow (Irradiation) proposed in PNF, a muscle contraction in an area can affect the contraction of another muscle in the distant area and thus facilitates the activation of the weakened or inhibited muscle[10,18,19]. Also, according to another PNF facilitation principle (stretch reflex) starting the lower PNF patterns from the antagonist pattern, as it was used in this study, can improve weak muscle function[18]. Shimura et al[10] showed that facilitation position compared to normal position lead to increased muscle discharge and motor evoked potential, decreased muscles reaction time and latency, and improvement of joint functional movements.

The other results of the study were PNF patterns with load could significantly increase the VMO and VL activity. In agreement with our results, Sykes and Wong[21] found that adding external rotation to SLR was suitable for patients with PFPS, especially if this movement is done with a weight. In another study Wong[39] suggested that it is better to do exercises with weight to improve the neuromotor control in the vasti muscles. Also, Rhyu et al[19] showed the positive effect of PNF patterns using the Theraband resistance on the activation of the abductor muscles. In our study performing the PNF patterns with a low weight, increased VMO and VL activities significantly compared to weightless patterns. The basis of resistance used in PNF patterns is reinforcement of weak muscles by strong contractions of the other muscles[18]. Unfortunately because SLR with weight wasn't assessed in this study, the comparison of PNF patterns with weight and SLR with weight weren't included in this study.

Also, our results showed that the most activity of the muscles in PFPS group and healthy group were during D_2EX+ load and D_1FL+ load respectively. The comparison of PNF patterns showed that in PFPS group D_2EX activated the muscles more than D_1FL, while in the healthy group, D_1FL activated the muscles more than D_2EX.

In D_2EX quadriceps contracts eccentrically in the direction of gravity, while in D_1FL quadriceps contraction is concentric and against the gravity. In agreement with our results, Douglas et al[40], and Chen et al[41], showed that eccentric exercises are better than concentric for improving muscle performance, especially if they are accompanied by resistance. Also, one of the strategies used in PNF therapeutic methods is the use of eccentric motion to facilitate the agonist muscle[10].

The other result of this study was that the VMO/VL ratio values in PNF patterns were significantly more than SLR. Also, in the PFPS group VL showed more activity during SLR compared to PNF patterns while, the VMO had the least activation during SLR. The lower VMO/VL ratio value during SLR compared to PNF patterns ratios can be attributed to lower VMO activity and/or the higher VL activity which found in our study. In PFPS group the VMO/VL ratio values in PNF patterns (with and without load) were near to the ideal 1:1 ratio and the highest VMO/VL ratio value (0.96) was found during D_2EX[7].

It is possible that during SLR hip flexion would activate the rectus femoris more than VMO and VL muscles[23]. Also the selective activation of VL compared to VMO during SLR can be increased, because VL is a mobilizer muscle and has more fibers in perpendicular orientation[6]. In contrast, PNF patterns are functional and have different motion components in different planes, so they can activate both VMO and VL muscles.

Conclusion

In PFPS group the activity of VMO during PNF patterns (without load) were more than SLR, however, these differences weren't significant. The VMO had the least activation during SLR and the most in D_2EX, but the VL had the most activity during SLR. The VMO/VL ratio values in PNF patterns were significantly more than SLR and the highest VMO/VL ratio value (0.96) was found during D_2EX. Also, adding weight to D_1FL and D_2EX increased VMO and VL muscles activity significantly. The imbalance between VMO and VL activity is one of the most important factors in person with PFPS which PNF patterns can provide appropriate VMO/VL ratio value than SLR. Thus, these patterns (especially D_2EX) due to higher activity of VMO and lower activity of VL and proper balance between VMO and VL muscles can be recommended in rehabilitation of individuals with PFPS. Also, adding a weight even a low weight, to these patterns can increased VMO and VL activities.

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