Electromyographic activity evaluation of the patella muscles during squat isometric exercise in individuals with patellofemoral pain syndrome

Débora Bevilaqua-Grossi[1], Lílian Ramiro Felicio[2], Rebeca Simões[3], Kelly Rafael Ribeiro Coqueiro[4] and Vanessa Monteiro-Pedro[5]

ABSTRACT

The objective of this study was to compare the electromyographic (EMG) activity of *vastus medialis obliquus* (VMO), *vastus lateralis longus* (VLL) and *vastus lateralis oblíquus* (VLO) during wall slide squat isometric exercises at 45° (WS 45°) and at 60° (WS 60°) of knee flexion. Fifteen healthy control women and fifteen women with patellofemoral pain syndrome (PPS) participated in this study. The EMG activity was registered during WS 45° and WS 60° performed at maximal isometric voluntary contraction (MIVC) using surface differential electrodes connected to an EMG system. The EMG signals were analyzed using the root mean square (RMS) values and were normalized by MIVC obtained at 75° of knee flexion. To compare data between groups and exercises, the ANOVA-two-way and Duncan post hoc tests were applied ($p \leq 0.05$). The results demonstrated higher EMG activity for all muscles studied at WS 60° when compared to WS 45° in both control and PPS groups. There were not significant differences between muscles during WS 60° in the control group, although a higher activity of VLL in relation to VMO and VLO was observed during WS 45° in control group. For the PPS group, no statistical difference was observed between muscles during both exercises. Thus, strengthening programs using WS 60° could be more effective for healthy women; however, both exercises could be indicated for rehabilitation programs aimed at women with PPS. In addition, the absence of significant differences between muscles in PPS group verified in this study suggests that muscle unbalance could not be a predisposing factor for PPS in women.

Key words: Patellofemoral pain syndrome (PPS). Exercise. Electromyography. Physiotherapy.

INTRODUCTION

One of the most frequent knee musculoskeletal disorders is the patellofemoral pain syndrome (PPS)[1-3], including approximately 25% of the orthopedic diagnosis[2], being defined as an anterior and/or retropatellar knee pain as result of structural and biomechanical alterations of the joint[4-6]. This dysfunction frequently affects athletes and female sedentary population, where young adult individuals are the most afflicted[5,7-9].

Although the etiological factors for PPS are still unknown, some authors point the biomechanical alterations of the lower limb as the main cause[5,7,8,10]. Among the most frequent biomechanical factors related to the PPS development, the static and dynamic unbalance stands out[5].

Among the alterations on the static unbalance, some authors assure that abnormalities such as excessive subtalar pronation, increase on the Q angle, external tibia torsion, retraction of the lateral retinaculum and improper patellar behavior can cause anterior knee pain[11,12]. However, other authors relate PPS with the unbalance on the dynamic stabilizer muscles, especially among the *medialis* and *lateralis* components[5,11-14] and, more recently, the oblique portion of the *vastus lateralis*, the *vastus lateralis obliquus* (VLO)[15].

The conservative treatment is always the first choice for individuals with PPS[3,16]. These rehabilitation programs are based on closed kinetic chain (CKC) and open kinetic chain (OKC) exercises[5,8,11,14,17]. However, many authors report that CKC exercises in the first 60° of knee flexion are more tolerated by individuals with PPS[11,17,18].

Among the CKC exercises, the squat exercise is considered as safe and effective due to the stabilizing effect of the quadriceps and ischiotibial muscle co-contraction[16,17]. The squat exercise is frequently used in conditioning programs of many sports that require high power and strength levels[19].

Rehabilitation protocols for individuals with PPS are aimed at the selective strengthening of the VMO muscle in order to reestablish the normal function of the patellofemoral joint[3,16,20,21].

Anderson *et al.*[22] evaluated the EMG activity of VMO and VL muscles in healthy individuals during squat exercises at 0° to 30°, 0° to 60° and 0° to 90°, and verified that the VMO:VL relation tended to increase with the increase on the knee flexion, therefore suggesting that this increase on the knee flexion leads to an increase on the VMO activity in relation to VL.

Earl *et al.*[17] also analyzed the EMG activity of VMO and VL (*vastus lateralis*) muscles in female and male normal athletes during squat exercises at 0°-30° knee flexion with and without hip adduction. The authors found no significant differences between VMO and VL muscles during exercises. However, those authors evaluated athlete individuals without PPS only. Besides, the physical activity, not specified by the authors, could lead to alterations on the EMG activity of the muscles evaluated.

Similarly, Tang *et al.*[5] found no significant difference between the EMG activity of VMO and VL muscles during squat eccentric and concentric phases between 15°-75° knee flexion in normal individuals with symptoms of PPS.

However, works aimed at the evaluation of the EMG activity of VMO, VLO and VLL muscles during squat exercises in female untrained individuals with symptoms of PPS were not found in literature.

1. PhD in Physiotherapy. Professor of the Department of Biomechanics, Medicine and Rehabilitation of the Locomotor Apparatus and Coordinator of the Physiotherapy Course – Ribeirão Preto School of Medicine – São Paulo University – USP.
2. Physiotherapist. MS underway in Orthopedics, Traumatology and Rehabilitation of the Locomotive Organs – FMRP-USP.
3. Physiotherapy graduation course underway – UFSCar.
4. Physiotherapist. MS in Physiotherapy – UFSCar.
5. Physiotherapist. Assistant Professor of the Department of Physiotherapy – UFSCar.

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Correspondence to: Débora Bevilaqua-Grossi, Faculdade de Medicina de Ribeirão Preto-USP, Campus Universitário – 14049-900 – Ribeirão Preto, SP, Brasil. Tel./fax: (16) 602-4413/633-0336. E-mail: deborabg@fmrp.usp.br

Thus, the objective of this work was to evaluate and to compare the EMG activity of VMO, VLO and VLL muscles during wall slide squat exercise at 45º and 60º knee flexion in clinically healthy individuals and in individuals with PPS.

METHODS

Volunteers

Thirty female untrained volunteers were analyzed, being divided into two groups: control group (n = 15) with average age of 20.93 ± 3.15 years, average weight of 58.38 ± 5.88 kg and average stature of 165 ± 4.3 cm and group with PPS (n = 15) average age of 21.8 ± 3.12 years, average weight of 50.53 ± 5.83 kg and average stature of 158 ± 5.6 cm. The inclusion and exclusion criteria for PPS group are presented in table 1. All individuals from the control group did not present any history of pain, surgery, trauma or lower limb osteomyoarticular lesion[12,23]. This study is in agreement with resolution 196/96 of the National Health Council.

TABLE 1
Inclusion and exclusion criteria for group with PPS

Inclusion criteria
The individuals must not present surgeries, traumas or lower limb osteomyoarticular lesions.
The individuals must report previous episodes of knee pain during activities such as climbing up or going down stairs, squatting and remaining sitting for long periods of time.
The presence of three clinical signs or symptoms in the functional evaluation (among them: bayonet sign, increase on the Q angle, external tibia torsion, excessive subtalar pronation, medialized patella and sensitiveness to palpation of the patella facets).
Exclusion criteria
Use of medications and physiotherapy sessions during the period of 6 months previous to the study.
Neurological diseases.

Equipment

The EMG recordings of VMO, VLL and VLO muscles were obtained by means of simple active Ag/AgCl electrodes (10 x 1 mm) (Lynx Tecnologia Eletrônica Ltda.) with 100 times gain and a reference electrode with 3 cm of diameter connected to a EMG system *Myosystem*® with magnification of 10 times, summing up a gain of 1000 times. The common mode rejection ratio (CMRR) was of 80 dB and the sampling frequency was of 2000 Hz. A low-pass filter of 10-500 Hz was used and the inlet impedance was higher than 100 MΩ.

Procedures

The skin was previously trichotomized and cleaned with alcohol 70% and the electrodes were fixed to the skin with the aid of micropore surgical tape. For the electrodes fixation on the VMO, VLO and VLL muscles, a line from the anterior-superior iliac spine to the center of the patella was drawn and used as reference for the measurement of the inclination angles of each portion of the quadriceps muscle evaluated[24]. For the VMO muscle, the electrode was positioned on the muscular core at approximately 2 cm from the femur lateral epicondyle with inclination of 50.4º, and for muscle VLL, the electrodes were positioned at 10 cm above the patella upper-lateral border with approximate inclination of 17º[15] (figure 1). The reference electrode greased with electro-conductive gel remained fixed to the tibia anterior tuberosity.

The EMG activity of these muscles was quantified using the root mean square (RMS) of the three repetitions of each squat exercise.

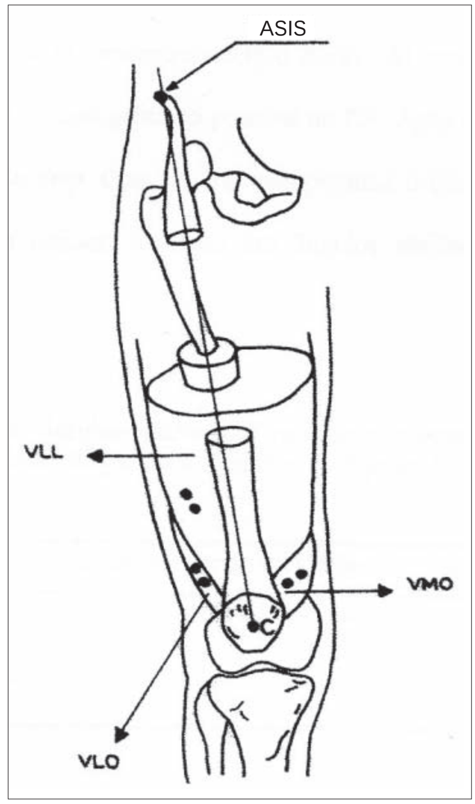

Fig. 1 *– Positioning of electrodes in the* vastus medialis obliquus *(VMO),* vastus lateralis longus *(VLL) and* vastus lateralis oblíquus *(VLO) according to the inclination of each portion in relation to the line from the anterior-superior iliac spine (ASIS) to the center of the patella (C)[15].*

Exercises

Each volunteer performed wall slide squat exercises with back against the wall and knees positioned at 45º (WS 45º) and 60º (WS 60º) of flexion (figures 2A and B); the exercises order was randomly performed. Each squat exercises was repeated three times with interval of two minutes between each exercise and of four minutes for the new positioning. Each exercise repetition was maintained for approximately seven seconds and the EMG recording collection initiated two seconds after the beginning of the exercise in the affected limbs for individuals from PPS group and in the dominant limb for individuals from the control group. The volunteers were familiarized with exercises during the period previous to collection.

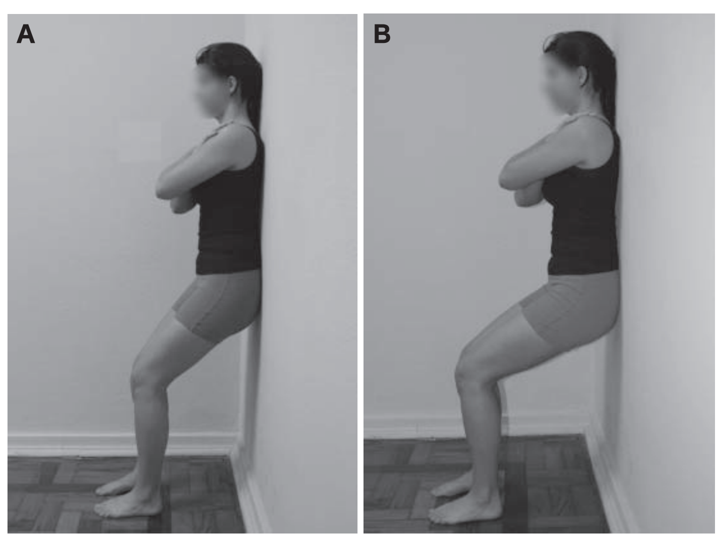

Fig. 2 *– Wall slide squat exercise at 45º of knee flexion* ***(A)*** *and wall slide squat exercise at 60º of knee flexion* ***(B)****.*

The EMG data normalization was obtained through the average of three repetitions of each wall slide squat isometric exercise (WS 45º and WS 60º) expressed as percentage of the average RMS of three wall slide squat repetitions at 75º and are presented as arbitrary units (A.U.).

$$\frac{\text{RMS average value of the wall slide squat exercise at } 45^{\circ} \text{ or } 60^{\circ}}{\text{Average value of the wall slide squat exercise at } 75^{\circ}}$$

Statistical analysis

The two-way ANOVA and Duncan *post hoc* tests were applied ($p < 0.05$) for the analysis of data.

RESULTS

The results for the control group showed higher EMG activity in the VLL muscle when compared to the VMO ($p = 0.022$) and VLO ($p = 0.009$) muscles during WS 45º; however, during WS 60º, no significant difference was observed between these muscles (table 2).

With regard to the PPS group, no significant difference between VMO, VLO and VLL muscles was observed during WS 45º and WS 60º exercises (table 2).

In the intragroup comparison of VMO, VLL and VLO muscles, one could observe for both normal and PPS groups that the WS 60º exercises presented higher EMG activity for all muscles when compared to the WS 45º exercise (table 2).

The intergroup comparison for each exercise analyzed presented no statistically significant difference between muscles.

TABLE 2
Averages (± SD) of the normalized EMG recordings (RMS) (A.U.) of VMO, VLL and VLO muscles in the wall slide squat exercises (WS) 45º and 60º for control and PPS groups

	Control		PPS	
	WS 45º	**WS 60º***	**WS 45º**	**WS 60º***
VMO	44.86 (± 14.24)	75.38 (± 13.65)	49.03 (± 11.84)	76.41 (± 14.23)
VLL	56.57 (± 11.26)#	77.02 (± 14.75)	54.94 (± 10.08)	75.78 (± 11.71)
VLO	44.05 (± 13.43)	75.55 (± 17.05)	49.54 (± 13.31)	69.76 (± 12.45)

* Significant difference in relation to WS 45º ($p = 0.0001$).
\# Significant difference in relation to VMO ($p = 0.022$) and VLO ($p = 0.009$) muscles.

DISCUSSION

One knows that the patellofemoral dysfunction presents the conservative treatment as main intervention, in which wall slide squat exercises at 45º and 60º of knee flexion are frequently performed in sportive trainings and in knee rehabilitation programs.

Our data showed higher EMG activity of VLL muscle during WS 45º for the control group; however, during the performance of WS 60º, no difference between VMO, VLO and VLL muscles was observed. Therefore, for individuals without PPS, the squat exercise WS 45º does not seem to be the best alternative for a muscular strengthening program, once, in this work, the VLL muscle is favored at this angle, what could result in unbalance on the dynamic stabilizer muscles, unlike the WS 60º that presented no difference between the portions of the quadriceps muscle, indicating a balance between the patella *medialis* and *lateralis* dynamic stabilizer muscles.

Despite the methodological differences, these data corroborate those found by Anderson *et al.*[22], who verified increase on the EMG activity of VMO and VL muscles with the increase on the knee flexion during squat exercise. According to those authors, this occurs due to the increase on the knee flexion in CKC, the rectus femoralis is more active and hence the VMO should also increase its EMG activity in order to maintain the patella in its adequate alignment.

One observes for group with PPS that during WS 45º and WS 60º, no significant differences were found between VMO, VLO and VLL muscles. Thus, one believes that WS 45º and WS 60º exercises provide a balance between the medial and lateral portions of the patella dynamic stabilizer muscles, and should be indicated during rehabilitation program for individuals with PPS. However, the comparison between exercises revealed that the WS 60º squat exercise presented higher EMG activity of the quadriceps muscle portions.

Similarly, Tang *et al.*[5] also observed significant differences in the VMO:VL relation during concentric and eccentric phases of squat exercise between 0-90º knee flexion; however, they observed a better VMO:VL relation during phases evaluated of the squat exercise at 60º knee flexion, suggesting higher activation of the VMO muscle both for the control group and for the group with PPS.

Despite the methodological differences, our data corroborate those found by Tang *et al.*[5] and Anderson *et al.*[22]. The results of this work revealed that the quadriceps muscle generally presented higher EMG activity as the knee flexion angle increases. The VMO muscle, in turn, presented no higher activation in any of the exercises proposed.

Many authors report that the muscular unbalance may be a preponderant factor of PPS[5,8,11,13,14]; however, despite not being the objective of this work, one observes that the EMG activity of the medial quadriceps muscles components – VMO and lateral components – VLL and VLO presented no significant differences between control and PPS groups, suggesting that the muscular unbalance may not predispose to PPS.

The data found by Cerny[26] also reinforce that hypothesis, once analyzing the EMG activity of VMO and VL muscles in the wall slide exercise at 45º in normal individuals and in individuals with PPS, no difference was observed between groups, corroborating results found in this work.

According to those data, one may conclude that the wall slide squat exercise performed at 60º presented higher activation of the patella stabilizer muscles of normal individuals and individuals with symptoms of PPS when compared to the wall slide squat exercise performed at 45º, being able to be indicated during rehabilitation programs in which the objective is the increase on the activation of these muscles.

Different works analyzed the squat exercise in different situations associated to adduction[17,26] and to the lateral and medial hip rotation[27]. However, no studies on the comparison of VMO, VLL and VLO muscles between squat exercises in different positions and knee angles were found in the literature researched.

Thus, studies comparing the EMG activity of VMO, VLL and VLO muscles during different squat exercise modalities are required for a better understanding of the role these muscles play in squat exercises in order to favour the elaboration of exercise protocols aimed at a more effective physiotherapeutic investigation in individuals with PPS.

All the authors declared there is not any potential conflict of interests regarding this article.

REFERENCES

1. Biedert RM, Warnke K. Correlation between the Q angle and the patella position: a clinical and axial computed tomography evaluation. Arch Orthop Trauma Surg 2001;121:346-9.
2. Powers CM, Maffucci R, Hampton S. Rearfoot posture in subjects with patellofemoral pain. J Orthop Sports Phys Ther 1995;22:155-60.
3. Wilk KE, Reinold MM. Principles of patellofemoral rehabilitation. Sports Medicine and Arthroscopy Review 2001;9:325-36.

4. Baker MM, Juhn MS. Patellofemoral pain syndrome in the female athlete. Clin Sports Med 2000;19:315-29.
5. Tang SFT, Chen CK, Hsu R, Shih-Wei Chou, Wei-Hsein Hong, Lew HL. Vastus medialis obliquus and vastus lateralis activity in open and closed kinetic chain exercise in patients with patellofemoral pain syndrome: an electromyographic study. Arch Phys Med Rehabil 2001;82:1441-5.
6. Cowan SM, Bennell KL, Hodges PW, Crossley KA, McConnell J. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Arch Phys Med Rehabil 2001; 82:183-9.
7. Baker V, Bennell K, Stillman B, Cowan S, Crossley K. Abnormal knee joint position sense in individuals with patellofemoral pain syndrome. J Orthop Res 2002; 20:208-14.
8. Cowan SM, Bennell KL, Crossley KM, Hodges PW, McConnell J. Physical therapy alters recruitment of the vasti in patellofemoral pain syndrome. Arch Phys Med Rehabil 2002;34:1879-85.
9. Swenson EJ, Hough DO, McKeag DB. Patellofemoral dysfunction. How to treat, when to refer patients with problematic knees. Postgrad Med 1987;82:125-9.
10. Wilk KE, Davies GJ, Mangine RE, Malone TR. Patellofemoral disorders: a classification system and clinical guidelines for nonoperative rehabilitation. J Orthop Sports Phys Ther 1998;28:307-22.
11. McGinty G, Irrgang JJ, Pezzullo D. Biomechanical considerations for rehabilitation of the knee. Clin Biomech (Bristol, Avon) 2000;15:160-6.
12. Wityrouw E, Sneyers C, Lysens R, Victor J, Bellemans J. Reflex response times of vastus medialis oblique and vastus lateralis in normal subjects and in subjects with patellofemoral pain syndrome. J Orthop Sports Phys Ther 1996;24:160-5.
13. Callaghan MJ, McCarthy CJ, Oldham JA. Electromyographic fatigue characteristics of the quadriceps in patellofemoral pain syndrome. Man Ther 2001;6:27-33.
14. Cowan SM, Bennell KL, Hodges PW, Crossley KM, McConnell J. Simultaneous feedforward recruitment of the vasti in untrained postural tasks can be restored by physical therapy. J Orthop Res 2003;21:553-8.
15. Bevilaqua-Grossi D, Monteiro-Pedro V, Bérzin F. Análise funcional dos estabilizadores da patela. Acta Ortop Bras 2004;12:99-104.
16. Stiene HA, Brosky T, Reinking MF, Nyland J, Mason MB. A comparison of closed kinetic chain and isokinetic joint isolation exercise in patients with patellofemoral dysfunction. J Orthop Sports Phys Ther 1996;24:136-41.
17. Earl JE, Schmitz RJ, Arnold BL. Activation of VMO and VL during dynamic mini-squat exercises with and without isometric hip adduction. J Electromyogr Kinesiol 2001;11:381-6.
18. Wityrouw E, Lysens R, Bellemans J, Peers K, Vanderstraeten G. Open versus closed kinetic chain exercises for patellofemoral pain. A prospective, randomized study. Am J Sports Med 2000;28:687-94.
19. Escamilla RF. Knee biomechanics of the dynamic squat exercise. Med Sci Sports Exerc 2001;33:127-41.
20. Cabral CMN, Monteiro-Pedro V. Recuperação funcional de indivíduos com disfunção femoropatelar por meio de exercícios em cadeia cinética fechada: revisão da literatura. Rev Bras Fisioter 2003;7:1-8.
21. Doucette SA, Child DD. The effect of open and closed exercise and knee joint position on patellar tracking in lateral patellar compression syndrome. J Orthop Sports Phys Ther 1996;23:104-10.
22. Anderson R, Courtney C, Carmeli E. EMG analysis of the vastus medialis/vastus lateralis muscles utilizing the unloaded narrow and wide stance squats. J Sports Rehabil 1998;7:236-47.
23. Powers CM. Patellar kinematics, part I: The influence of vastus muscle activity in subjects with and without patellofemoral pain. Phys Ther 2000;80:956-64.
24. Bevilaqua-Grossi D, Monteiro-Pedro V, Sousa GC, Silva Z, Bérzin F. Contribution to the anatomical study of the obliqúe portion of the *vastus lateralis* muscle. Braz J Morphol Sci 2004;21:47-52.
25. Lieb FJ, Perry J. Quadriceps function. An anatomical and mechanical study using amputed limbs. J Bone Joint Surg 1968;50:1535-48.
26. Cerny K. Vastus medialis oblique/vastus lateralis muscle activity ratios for selected exercises in person with and without patellofemoral pain syndrome. Phys Ther 1995;75:672-83.
27. Lam PL, Ng GYF. Activation of the quadriceps muscle during semisquatting with different hip and knee positions in patients with anterior knee pain. Am J Phys Med Rehabil 2001;80:804-8.