STEP HEIGHT INFLUENCE ON BACKWARD STEP-UP EXERCISE: AN ELECTROMYOGRAPHIC STUDY IN HEALTHY INDIVIDUALS AND IN THOSE WITH PATELLOFEMORAL PAIN SYNDROME

FLÁVIO PULZATTO[1], KARINA GRAMANI-SAY[1], ANA CRISTINA BARROSO DE SIQUEIRA[2], GILMAR MORAES SANTOS[3], DÉBORA BEVILAQUA-GROSSI[4], ANAMARIA SIRIANI DE OLIVEIRA[4], VANESSA MONTEIRO-PEDRO[5].

SUMMARY

The aim of this study was to evaluate the influence of the step height in the electric activity of the vastus medialis obliquus (VMO), vastus lateralis longus (VLL) e vastus lateralis obliquus (VLO) on backward step-up exercise. Twenty-seven females, being 15 healthy (21.13 ± 2.17 years old) and 12 with Patellofemoral Pain Syndrome PPS (21.08 ± 2.31 years old), have participated in the study. The electric activity was recorded by surface electrodes. The volunteers performed the backward step-up exercise in two different heights: with the knee joint flexion at 45º and at 75º. The whole electric signal normalized by the average of repetitions was used to study the VMO:VLO and VMO:VLL activation ratio. The two-way ANOVA and Duncan post hoc ($p \leq 0.05$) showed that in the PPS group, the VMO: VLO and VMO: VLL ratio was greater at 45º than at 75º angle. In the Control group, the VMO: VLO ratio was greater at 45º than at 75º, while the VMO: VLL ratio was greater at 75º. The results of this study suggest that backward step-up exercise at 45º can be used for PPS treatment programs because it activated the VMO muscle in a more selective way.

Keywords: Knee; Pain; Electromyography; Muscle; Exercise.

INTRODUCTION

The Patellofemoral Pain Syndrome (PPS) is defined as a painful disorder in knee joint resulting from a poor patellar alignment[1]. Its main symptom is diffuse pain at the anterior or retropatellar region of the knee, the effects of which cause functional damages to affected individuals[1]. It has an insidious onset, and usually affects young females, adolescents and athletes of both genders[2] and the painful picture may be stronger after activities such as running, squatting, stepping up or down stairs and slopes, sitting for a long period or standing up from seated position[3].

PPS etiology is not well established, but unbalances of the patellar stabilizing muscles have been suggested as one of the major triggering factors of the PPS[3]. However, there still are controversies in literature about the muscular action on patellar stabilization, while some studies suggest the existence of unbalances in the electric activity range of vastus medialis obliquus (VMO) and vastus lateralis (VL)[4,5] muscles, and other studies do not note this fact[2,6]. The vastus lateralis obliquus (VLO) muscle, from anatomical(7) and electromyographhic[8] studies, was considered as important for patellar stabilization as a VMO antagonist, laterally imposing traction the patella[9].

In the conservative treatment of PPS, programs aim the strengthening of the quadriceps and, more selectively, of the VMO muscle, since it is considered as essential for the maintenance of patellar alignment[6]. Among recommended exercises, the step is indicated for intermediary and final phases of PSS rehabilitation, because they mimic functional activities and allow for muscular co-contraction, resulting in a better joint stability[3,10].

The step exercises can be performed in different heights allowing different knee flexion angles. Similarly, step exercises can be performed in a concentric (up) or eccentric (down) manner, and also in forward, lateral or backward direction. The backward step is indicated for PPS treatment[11], but there are just a few studies analyzing the effects of this kind of exercise on muscle electric activity.

In the reviewed literature, only the study by Cabral and Monteiro-Pedro[12] has controlled the step height with knee flexed at 75º, and the authors assessed the electric activity of the VMO, VLL and VLO muscles in up and down exercises, both forward and backward, in 18 individuals with PSS. Their results showed that the VMO muscle was more active than the VLO and the VLL in all exercises. However, no studies were found in literature comparing different step heights and their effects on electric activity.

Thus, the objective of this study was to investigate the effect of different step heights (45º and 75º of knee flexion) on VMO, VLO and VLL muscles electric activity in normal individuals and in those with PPS. For this, the activity ratios VMO:VLO and VMO: VLL were assessed during backward step-up exercises in an adjustable height step.

MATERIALS AND METHODS

Subjects

Twenty-seven female volunteers with ages ranging from 18 to 30 years old, non-athletes, have participated in the study, and were divided into two groups. The Control group was formed by 15 subjects (21.13 ± 2.17 years) without surgery, pain, trauma, or history of injury on the osteomyoarticular system of the lower limbs.

Study conducted by the Laboratory of Assessment and Intervention in Orthopaedics and Traumatology (LAIOT), Department of Physical Therapy, Federal University of São Carlos – UFSCar.

Correspondences to: Rua Santos Dumont, 1490 - CEP 16200-330 Centro - Birigui - SP - e-mail: flaviopul@yahoo.com.br.

1. *Master in Physical Therapy – UFSCar*
2. *Graduation student in Physical Therapy – UFSCar*
3. *PhD student at the Physical Therapy Post-Graduation Program– UFSCar*
4. *Professor, PhD, Department of Biomechanics, Medicine and Rehabilitation of the Locomotive Apparatus – FMRP-USP*
5. *Professor, PhD, Associate Doctor, Department of Physical Therapy – UFSCar*

Received in: 01/24/05; approved in: 07/01/05

The PPS group was formed by 12 subjects (21.08 ± 2.31 years) presenting with:[1] Pain during at least 3 of the following activities: long-time squatting, going up or downstairs, kneeling, running, long-time sitting, isometrical contraction of the quadriceps muscle and sports practice.[2] Pain intensity of at least 2 cm (0 – 10 cm) at the Analogical Visual Scale (AVS) in the past week during the performance of the activities above mentioned, and, complaints of pain of any intensity during the performance of the following functional tests: stepping down from a 25cm-high step, and bipodal squatting with knees flexed at 90°, both performed during 30 seconds.
All volunteers signed a Formal and Informed Consent Term for participating in the study, which was approved by the Committee on Ethics in Research of the Federal University of São Carlos.

Instruments
The electric activity of the VMO, VLL, and VLO muscles was captured by means of surface simple differential active electrodes (Ag/AgCl) connected to an electromyographer EMG-8 (EMG System do Brasil). The sampling rate was 2000 Hz and a band-passing filter of 20 to 500 Hz was used. For data acquisition, the software AqDados 7.02.06 was used.
The step used in this study consisted of a 49-cm high, 68-cm wide and 40-cm deep wooden step with a drawer-like mechanism, allowing the adjustment of height in 1.5-cm increments[12]. For obtaining knee flexion angles of 45° and 75°, the step was adjusted, in average, at 11 cm and 21 cm, respectively. A metronome (Witner) adjusted for 63 beats/ minute helped the volunteers on controlling backward step-up exercises time. An electrogoniometer connected to the electromyographer and fixed on the studied knee joint was used for monitoring the flexion range at the moment of exercise.

Procedures
Following trichotomy and skin cleaning with alcohol 70%, the electrodes were fixed on volunteer's skin with a double-face patch for electromyography at the venter of each muscle and with detection surfaces oriented perpendicularly to muscle fibers[10].
For electrodes fixing, a line was firstly drawn ranging from the anterosuperior iliac spine to the center of the patella. This line served as a reference for inclination angles measurement of all electrodes. For the VMO muscle, the electrode was fixed at 4 cm above the superomedial edge of the patella and with an inclination of 55°[3]. For the VLL muscle, the electrode was fixed at 15 cm above the superolateral edge of the patella with an inclination of 13.6°[9] and, for the VLO muscle, the electrode was fixed at the center of the muscle venter from lateral femoral epicondyle with lateral inclination of 50.4°[9]. Also, a reference claw-type electrode with 2.5 x 3.5 cm metallic surface, covered with conductor gel, fixed at the distal region of the volunteer's leg, near to the ankle joint contra-laterally to the studied one.
The volunteers, helped by the metronome, performed 3 repetitions of backward step-up in two different angles. For this, step height was adjusted for each volunteer so that, at the moment of stepping-up, the knee joint flexion angle was at 45° in the first series and at 75° in the second series of exercises.

Exercises and Sign Analysis
After stretching and warming-up the major muscle groups of the lower limbs, three repetitions of backward step-up at 45° and 75° were performed, totaling 6 repetitions.
The volunteer was positioned so that the step was at her back and after a voice command: "attention, prepare, climb", she stepped-up backwards, initiating the exercise with the limb to be studied followed by the contralateral one, as shown in Figure 1.
The electromyographic signs of the concentric contraction (up) were processed by a software Matlab 6.1 routine, which calculated the value of the area integral below electric sign wrapper after filtering and grinding by total wave. Data were normalized by the average value of the wrappers of the three repetitions by each volunteer.
From the values of the integral of each muscle sign, values for the relationship between muscles VMO:VLO and VMO:VLL were calculated.

***Figure 1** - Volunteer performing the backward step-up exercise in a height-adjustable step.*

Statistical Analysis
For comparing Control and PPS groups, as well as the different step heights, the variance analysis (two-way ANOVA) and Duncan post hoc were used, both considering $p \leq 0.05$.

RESULTS
The analysis of the electric activity ratios VMO:VLO and VMO:VLL showed the existence of significant differences between 45° and 75° angles (step height) both in Control group ($p = 0.00$) and in PPS group ($p = 0.00$) (Table 1).
The PPS group presented higher muscle ratio values with the step at 45° when compared to 75° step, both for VMO:VLO ratio and for VMO:VLL ratio (Table 1).
In Control group, the VMO:VLO ratio was higher at 45° angle while the VMO/VLL ratio was higher with the step at 75° (Table 1).
In the inter-muscle analysis, the VMO/VLL ratio was higher than the VMO/VLO ratio, both in Control group ($p = 0.00$) and in PSS group ($p = 0.00$) in both angles studied (Table 1).
The inter-group analysis showed no differences in muscle ratio values between Control and PPS groups ($p = 0.53$) in both step heights.

DISCUSSION
Our results showed that the exercise performed in the step at 45° more strongly recruited the VMO muscle in comparison to VLO and VLL muscles when compared to the 75° angle in both groups.
In clinical practice, the PPS treatment tries to selectively strengthen the VMO aiming to maintain medial and lateral forces balance acting on the patella, since this muscle is selectively atrophied in situations resulting in PPS[13]. In addition, exercises in closed kinetic chain (CKC) with the step cause less patellofemoral stress, being the most indicated for PPS treatment[9].
Thus, backward step-up exercises performed with knee joint at 45° are indicated for PPS treatment, because they provide a better advantage of the VMO muscle in comparison to its antagonists. Furthermore, at 45° of flexion, the patellofemoral joint is stable and there is great patellar congruence on trochlear groove[14], which corroborates the indication of this angle for performing step exercises.
Cabral and Monteiro-Pedro[12] also observed a stronger activity of the VMO muscle compared to VLO and VLL muscles in individuals with PPS during step-up and step-down exercises at 75° of knee flexion. The authors report that the backward step-up exercises recruited more intensively the VMO muscle and suggest the indication of this exercise on PPS rehabilitation.
The values of muscle ratios, ranging from 1 to 1.3 in this study, are in accordance to previous studies both in healthy individuals

and in PPS patients in CKC[5,4] at both angles. Those values demonstrate that the VMO muscle has always been more active than its antagonists. On the other hand, Tang et al.[15] found VMO:VLL ratio values lower than 1 during squatting exercise, both at 45º and 75º of knee flexion in healthy individuals and in those with PPS. Those values indicate a greater activation of the VL muscle when compared to the VMO, thus not in accordance to our results at both knee angles.

KNEE FLEXION ANGLE	CONTROL GROUP		PPS GROUP	
	VMO/VLO	VMO/VLL**	VMO/VLO	VMO/VLL**
45º	1.21 (± 0.16)*	1.24 (± 0.17)*	1.25 (± 0.26)*	1.34 (± 0.19)*
75º	1.06 (± 0.08)	1.25 (± 0.16)	1.06 (± 0.17)	1.20 (± 0.14)

* significant difference (p = 0.00) compared to 75º step

**significant difference (p = 0.00) compared to VMO/VLO within the same group.

Table 1 - *Average and standard deviation of values for VMO:VLO and VMO: VLL ratios in backward step-up exercise at 45º and 75º knee flexion of Control group (n=15) and PPS group (n=12).*

As previously reported, no studies were found in literature investigating the effects of the step height on the electric activity of patellar stabilizers. We believe that this methodology allows volunteers to be submitted to proportional values of patellar compression and stress regardless of each individual's height. Thus, knee flexion angle control with the step height adjustment, standardizes the comparison among groups and exercises. Regarding the VLO muscle, except for the study by Cabral and Monteiro-Pedro[12], no studies were found in literature investigating its electric activity in functional tasks (such as the step, for instance).

Our results show that in the step at 75º, the VLO muscle presented activity values close to those of the VMO muscle in both groups, but this pattern did not happen for the VLL muscle. This behavior suggests that the VLO muscle can be more strongly recruited the greater the knee joint flexion angle is, participating more actively on patellar lateralization than the VLL muscle.

An important data from our study is the fact that the control group presenting a higher value of VMO:VLL ratio at 75º cannot be explained only by means of electromyography, but other factors may be involved. However, as mentioned, the other muscle ratio values were significantly higher with the step at 45º, especially in PPS group, thus confirming the indication of this angle for treating this population.

Our results, similarly to previous studies[2,6], did not evidence differences in the electric activity ratios among studied groups. This may suggest that other factors, anatomical or biomechanical, may be related to the presence of PPS and not only the unbalance of muscular action[3].

CONCLUSIONS

Our results showed that the VMO:VLO and VMO:VLL ratios were significantly higher in the step-up exercise with knee flexed at 45º. Thus, in the conservative treatment of PPS, this exercise should be preferentially used, because it selectively recruits the VMO muscle compared to its antagonists, favoring patellar stability in individuals with PPS. Furthermore, the step-up exercise at 75º potentialized the VLO muscle activation in both groups, favoring patellar lateral dislocation, being contraindicated to PPS patients.

REFERENCES

1. Thomeé R, Augustsson J, Karlsson J. Patellofemoral pain syndrome. A review of current issues. Sports Med 1999; 28:245-62.
2. Cerny K. Vastus medialis oblique/vastus lateralis muscle activity ratios for selected exercises in persons with and without patellofemoral pain syndrome. Phys Ther 1995; 75:672-83.
3. Cowan SM, Bennell KL, Hodges PW, Corssley KM, 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.
4. Souza DR, Gross MT. Comparison of vastus medialis obliquus: vastus lateralis muscle integrated electromyographic ratios between healthy subjects and patients with patellofemoral pain. Phys Ther 1991; 71:310-20.
5. Taskiran E, Dinedurga Z, Yagiz A, Uludag B, Ertekin C, LökV. Effect of the vastus medialis obliquus on the patellofemoral joint. Knee Surg Sports Traumatol Arthrosc 1998; 6:173-80.
6. Sheehy P, Burdett RG, Irrgang JJ, Vanswearingen J. An electromyographic study of vastus medialis oblique and vastus lateralis activity while ascending and descending steps. J Orthop Sports Phys Ther 1998; 27:423-9.
7. Hallisey MJ, Doherty N, Bennett WF, Fulkerson JP. Anatomy of the junction of the vastus lateralis tendon and the patella. J Bone Joint Surg Am 1987; 69:545-9.
8. Morrish GM, Woledge RC. A comparison of the activation of muscles moving the patella in normal subjects and in patients with chronic patellofemoral problems. Scand J Rehabil Med 1997; 29:43-8.
9. Bevilaqua-Grossi D, Monteiro-Pedro V, Bérzin F. Análise funcional dos estabilizadores patelares. Acta Ortop Bras 2004; 12: 99-104.
10. Monteiro-Pedro V, Viiti M, Bérzin F, Bevilaqua-Grosso D. Electromyographic activity of vastus medialis oblique muscle in step-up and step-down exercises. Brazilian J Morphol Sci 1997; 14:19-23.
11. McConnel J. The management of chondromalacia patellae: a long-term solution. Aust J Physioth 1986; 32:215-23.
12. Cabral CMN, Monteiro-Pedro V. Efeito dos exercícios em cadeia cinética fechada realizados no step na atividade elétrica dos componentes medial e lateral do músculo quadríceps femoral. Dissertação. São Carlos: Universidade Federal de São Carlos; 2001.
13. Grabiner MD, Koh TJ, Draganich LF. Neuromechanics of the patellofemoral joint. Med Sci Sports Exerc 1994; 26:10-21.
14. Manske RC, Davies GJ. A nonsurgical approach to examination and treatment of the patellofemoral joint. Part 1: examination of the patellofemoral joint. Crit Rev Phys Rehabil Med. 2003; 15:141-66.
15. Tang SF, Chen CK, Hsu R, Chou SW, Hong WH, Lew HL. Vastus medialis obliquus and vastus lateralis activity in open and closed kinetic chain exercises in patients with patellofemoral pain syndrome: an electromyographic study. Arch Phys Med Rehabil 2001; 82:1441-5.