

Original Article (short paper)

Effects of a 12-week hip abduction exercise program on the electromyographic activity of hip and knee muscles of women with patellofemoral pain: A pilot study

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Abstract - Aims: The purpose of our study was to compare the hip and knee muscle activity before and after a hip abduction exercise program in women with patellofemoral pain (PFP). **Methods:** Eleven women with PFP were included in our pre/post design study. Participants were assessed before and after 12-week hip abduction exercise program. All participants performed 6 stair climbing repetitions, 3 sets of rope jumps over 30 s and 5 sets of 8 squats to standardize the physical activity level before data collection. We recorded the electromyographic activity from gluteus medius, vastus medialis (VM) and vastus lateralis (VL) for double-legged squat with and without isometric hip abduction. Additionally, participants were asked to perform a step-down test to assess objective function (maximum number of repetitions over 30 s) and completed a clinical evaluation. **Results:** Longer duration of VM (Mean difference [95% CI]) = -0.97 [-1.48; -0.46], ES [effect size] = 0.66) and VL (-0.81 [-1.35; -0.27], ES = 0.54) were found after the hip abduction exercise program only for free squat. The participants also performed higher number of step-down repetitions (-3.54 [-5.84; -1.25], ES = 1.03) after the hip abduction exercise program and showed improvement in pain reports. **Conclusion:** A 12-week hip abduction exercise program changed the quadriceps muscle activation pattern and improved pain and objective function of women with PFP. The exercises promoted a longer VM and VL activation duration. Additionally, they promoted a clinical improvement in the patients with PFP.

Keywords: anterior knee pain, electromyography, biomechanics, knee

Introduction

Patellofemoral pain (PFP) is a chronic musculoskeletal condition characterized by peri or retropatellar pain during activities overloading the patellofemoral joint such as squatting, stair negotiation and running¹. PFP presents point-prevalence of 22.7% in the general population^{2,4} with women being 2 times more likely to present PFP than men³. In spite of PFP is multifactorial in nature, it is identified as risk factor the quadriceps weakness^{5,6} and biomechanical deficits at the trunk, hip, knee and foot^{7,8}.

It has been demonstrated that subjects with PFP have deficits of isometric / dynamic strength and power in the hip muscles (abductors and extensors)⁹. However, the hip muscle abductors weakness can not be considered a PFP risk factor^{10,11}, but a consequence of the pain complaint and inactivity¹¹. The most recent consensus from the International Patellofemoral Pain Research Retreatment suggests the use of specific knee and hip exercises (isolated or combined) as best management for PFP in the short-, medium- and long-term¹². However, the exact mechanism through which exercise is beneficial is still unknown.

A recent study reported that changes in hip kinematics failed to explain improvements in clinical symptoms of a cohort of people with PFP¹³. In this direction, there is no research exploring whether hip or knee muscle activity change or are associated with clinical improvement of people with PFP after a comprehensive exercise program. This assumption is supported by recent systematic reviews and original studies where altered electromyography (EMG) activity has been linked with PFP¹⁴⁻¹⁶. Additionally, it has demonstrated that strength training of the gluteus medius muscles generate significant improvement in symptoms¹⁷.

Most of the exercise trials in PFP focus their outcomes in patient-reported measures, not in objective measures^{18,19}. Subjective and objective outcomes have different constructs²⁰, therefore understanding the effect of a comprehensive exercise program in the objective function of women with PFP is a novel addition into PFP literature. Highlighting the importance of this question, a recent study reported that a progressive resistance training program targeting strength and power improved muscle capacity of people with PFP²¹. However, the effect of an exercise program in objective function of people with PFP is yet to be explored.

Although the exact cause of PFP remains unknown, in relation to muscle recruitment, a systematic review and meta-analysis indicated a trend for the delayed onset of vastus medialis oblique (VM) relative to vastus lateralis (VL) muscles in subjects with PFP in comparison to the asymptomatic population²². Furthermore, a systematic review showed that muscle activity of the gluteus medius (GMD) is delayed and of shorter duration during functional activities in individuals with PFP¹⁶.

In despite of the evidence that hip abduction strength is not a risk factor for future PFP was moderate, it is known that hip exercise is beneficial for patients with PFP¹¹; however, the literature does not show, to date, the exact mechanism on why hip exercise works. So, the main question of this study is: “does hip exercise change hip and knee muscle activity during dynamic squatting activity?”

The aim of our study was to investigate the effect of a 12-week hip abduction exercise program in the hip and knee electromyographic activity and objective function of women with PFP. Preliminary data of our pilot study is intended to inform a large randomized clinical trial.

Methods

This is a pilot with a pre/post intervention design. The sample consisted of 11 women (21.45 ± 2.88 years, 55.1 ± 5.2 kg) with clinical reports of PFP. Initially, the participants were informed about the research and signed the consent form. The study protocol was approved by the Research Ethics Committee of the Federal University of Santa Catarina (CAAE: 43111715.3.0000.0121).

Protocol of physical activity level standardization

The presence of the pain and different physical activity levels seems to change the recruitment patterns of the muscles and may be a potentially confounder parameter during the clinical assessments. In this way, a protocol for the physical activity level standardization may be an alternative to equalize pain in women with PFP^{15,23} and to enhance the methodological quality of our study.

All participants performed a protocol of exercises in order to standardize the physical activity level standardization previous the data collection. The protocol for the physical activity level standardization consisted of 6 stair climbing repetitions, 3 sets of rope jumps over 30 s and 5 series of 8 squats with 20% of body mass.

Clinical evaluation

The inclusion and exclusion criteria are summarized in Table 1¹⁴. For inclusion, a clinical questionnaire with five main questions was answered as yes (0 point) or no (1 point). After summation, scores above 4 were considered positive for PFP and below, negative. The questionnaire was applied to evaluate the patellofemoral pain under the following conditions: 1) in the last month, with a minimum score on the Visual numeric scale (VNS) equal to 2; 2) in at least 3 functional conditions (sitting for prolonged time, going upper stairs, squatting, running, kneel-

Table 1 - Inclusion and exclusion criteria¹⁴.

Inclusion criteria	<ol style="list-style-type: none"> 1. Retropatellar or anterior knee pain during at least two of the following activities: prolonged sitting, climbing stairs, squatting, running, and hopping and jumping; 2. Pain on patellar palpation; 3. Symptoms for at least month, insidious onset and unrelated to a traumatic event; 4. Pain level of at least 3 in a visual analog pain scale of 10cm in the last week; 5. Presence of at least 3 of the following clinical signs: positive Clarke signal, positive McConnell test, positive Waldron test, positive Zohler signal, Q angle greater than 18°, positive Noble compression test, lateral patella or medial; 6. Women with 18 - 30 years old; 7. Able to perform daily life activities; 8. Sign a free and informed consent form.
Exclusion criteria	<ol style="list-style-type: none"> 1. Other specific knee conditions, such as gonarthrosis, ligament injury, meniscus injury, patellar tendon injury, joint degeneration, osteoarthritis or referred pain from the spine; 2. Knee surgery; 3. History of patellar displacement or subluxation; 4. Knee treatments such as arthroscopy, use of anti-inflammatories, analgesics, anesthetics, acupuncture or physiotherapy during the last 6 months; 5. Presence of neurological diseases and inflammatory processes.

ing and jumping); 3) during bilateral squatting at 90° flexion, with a minimum score on the VNS equal to 2; 4) during step-down (25 cm), with a minimum score in the VNS equal to 2; 5) three positive clinical signs and symptoms of orthopedic tests on the same limb:

- Clarke's signal (positive in the presence of pain and symptom during quadriceps contraction with distal patellar compression)²⁴,

- McConnell's test (the patient performs isometric contractions of the quadriceps at 120, 90, 60, 30 and 0° during 10 s; if pain is produced, the examiner passively returns the leg to full extension, pushes the patella medially, returns the knee to the painful angle and request a new isometric contraction; if the pain is decreases, the test is positive to PFP)²⁵,

- Waldron's test (positive in the presence of crepitation and pain during passive knee flexion associated with patellar compression against the femur)²⁴,

- Zohler's signal (positive in the presence of pain during quadriceps contraction with distal patellar displacement)²⁴,

- Q angle greater than 18° (angle between the quadriceps muscles and the patellar tendon)²⁵,

- Noble's compression test (pain over the lateral femoral condyle at about 30° degrees of knee extension during the compression of the iliotibial band)²⁵,

- lateral or medial position of the patella²⁵.

Outcomes

Pain

For assessment of pain, the volunteers were asked about their pain in the last month using the VNS²⁶. This scale ranges from 0 to 10, which “0” means “no pain” and “10” is “pain as bad as it could be”²⁶.

Objective function: step-down test

The step-down test is a functional test which participants stood on a 20 cm high platform in a bipodal support keeping the trunk straight, hands on their waist, and to bend the knee on the tested side until the heel of the non-tested limb touched the floor. The functional step-down test was performed counting the number of times the volunteer’s foot approaches the ground and returns to the initial position for 30 s²⁷.

Electromyography acquisition

For the EMG acquisition, the following was used: a signal conditioner (model Miotol 400, Miotec®, Porto Alegre, Brazil) with bandpass filter (20 - 500 Hz), final gain of 1000 times, Common Mode Rejection Ratio (CMRR) greater than 80dB, impedance equal to 2012 Ω and acquisition frequency of 2000 Hz. The acquisition and storage of the signals were conducted through Miotol software (Miotec®, Porto Alegre, Brazil).

Immediately after the protocol of the physical activity level standardization, the participants received instruction and familiarization about EMG. Ag/AgCl surface electrodes were positioned on the GMD, VM and VL muscles on the symptomatic lower limb. For standardization, the electrodes positioning was performed according to SENIAM recommendations²⁸. Skin tricotomy, abrasion and cleaning were made prior to the EMG

acquisition. The reference electrode was positioned on the ulna styloid process homolateral to the evaluated lower limb.

The knee extensors maximal isometric voluntary contraction (MIVC) was performed with the volunteers in the seated position, 90° of hip flexion and 45° of knee flexion. They were oriented to perform a knee maximal isometric extension for 7 s while receiving verbal stimulus. To allow the accomplishment of the MIVC, an inextensible chain was attached to the ground and coupled to the chair stand (Figure 1). Subsequently, the volunteers were instructed to perform three free squats and three squats associated to the isometric hip abduction, both with 90° of knee and hip flexion (Figure 2). Free squats were asked to simulate the functional activities and the squats with hip abduction were realized in order to highlight the EMG activity of GMD for



Figure 1 - Data collection of MIVC.

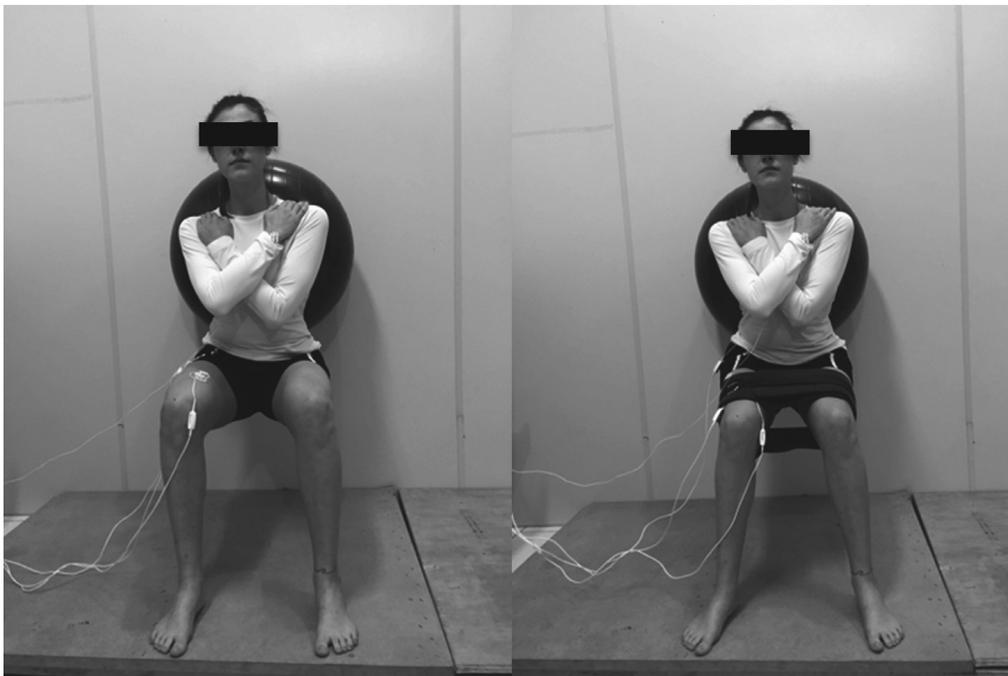


Figure 2 - Data collection of free squatting (left) and squatting with isometric hip abduction (right).

the analyses. A swiss ball (55cm diameter) was used as lumbar support. During the movement, the volunteers received verbal stimulation to perform the squatting in a slow and self-controlled manner, simulating the functional task, while the GMD, VM and VL electromyographic signals were collected.

Exercises protocol

According to Coppack, Etherington, Wills²⁹, exercises performed with a greater number of sets and repetitions as well as loads of 45 to 50% of maximal repetition (MR) have shown to increase dynamic muscle strength in previously untrained individuals. In this way, the protocol of the study consisted of a hip abduction exercise program in open chain (lateral decubitus) executed three times a week for a period of 90 days with loads proportional to a MR. Although MR was based on the symptomatic lower limb, the exercises were performed bilaterally with a similar load. For the exercise, the volunteer was lying on the side without resistance and, according to the progression, ankle weights were positioned around the ankle and they were asked to perform a 0-50° hip abduction and return to rest position, avoiding rotation of foot and leg. More details of the protocol are stated in Table 2, according to TIDIER checklist³⁰.

EMG signal processing

The signals were processed using algorithms developed in MatLab® software. First, a digital butterworth bandpass filter with cut-off frequencies of 20 and 500 Hz were applied to the signal. The parameters were determinate as follows: 1) VM and VL delay: 200 ms before the beginning of the activity, the signal more than three standard deviations from the baseline, for a minimum time of 25 ms (onset)³¹; 2) muscle activation duration: time elapsed between the activation onset and end (return the signal to the baseline); 3) muscular coactivation: cross correlation, which indicates the percentage of common signal between the two muscles (r^2)³²; 4) root mean square (RMS) normalized (free and abduction squat): for VM and VL, the two seconds of greater stability of the isometric signal obtained in the MIVC and, for GMD, the peak of contraction during each activity.

Statistical analysis

All analyses were performed using GraphPad Prism 5.0 (Graphpad Software Inc., USA) with an a priori level of significance of 0.05. All variables were assessed for normality and found to be normally distributed on the basis of obtainment of $p > 0.05$ in the Shapiro-Wilk test. Descriptive characteristics were presented in mean and standard deviation. Paired t-tests were used to compare electromyographic parameters (onset, duration, RMS, coactivation), pain and step-down outcomes between pre and post test. Effect sizes (ES) (and 95% confidence intervals ([95% CI]) for pre/post comparisons were calculated and interpreted as following: small (> 0.2), medium (> 0.5), large (> 0.8)³³. The correlations between electromyographic, step down test and VNS data were tested using the Pearson correlation and were considered as weak ($r = 0.0$ to 0.3), moderate ($r = 0.4$ to 0.6), or strong (0.7 to 1.0)³⁴.

Table 2 - TIDIER checklist for the hip abduction exercise protocol³⁰.

Brief name	Hip abduction exercise protocol
Why	It is known that exercises for hip abduction improve the pain in patients with PFP.
What (materials)	To implement the load, it was used ankle weight that can be achieved at sports shopping place.
What (procedures)	The exercises were done three times a week, supervised by a trained physiotherapist student, during 12 weeks. Between each set of exercise, an interval of two to three minutes was guaranteed for resting.
Who provided	Two physiotherapist students that were able to lead the exercise protocol and they were trained by an experienced (> 10 years) physiotherapist.
How	The intervention was done face-to-face and individually.
Where	Volunteers were recruited via advertisements placed at university, gyms and electronic media. The exercise protocol was conducted at a laboratory in the university in which there was an exercise mat.
When and how much	The protocol was applied 3 times a week, during 12 weeks. Each session had a maximal duration of 60 minutes.
Tailoring	Participants began the exercises without load and at 2 nd , 4 th , 6 th , 8 th and 11 th weeks the load were increased with 10, 20, 30, 40 and 50% of MR, respectively. Sets and repetitions were adjusted after 4 weeks (week 1-4: 5 x 8; week 5-8: 6 x 10, and week 9 to 12: 8 x 12).
Modifications	Not applicable.
How well (planned)	VNS was applied every session pre and post the exercise in order to show the volunteer the improvement in the pain.
How well (actual)	13 volunteers began the exercise protocol and 2 gave up, one because health problem and the second because incompatibility of the schedule.

Results

Muscular activation in free squatting

The results of electromyography parameters are summarized in the graphs of Figure 3; mean difference, 95% CI and effect size are shown in Table 3. In the free squatting, there was no change in the RMS values, but VM and VL presented longer duration ($p < 0.05$) with medium effect size when evaluated after the exercise protocol. No differences were observed for coactivation and delay between VM and VL.

Muscular activation in squatting with abduction

For squatting with abduction, VM RMS, coactivation between the VM and VL and delay between VM and VL were significantly higher ($p < 0.05$) at the post intervention. No differ-

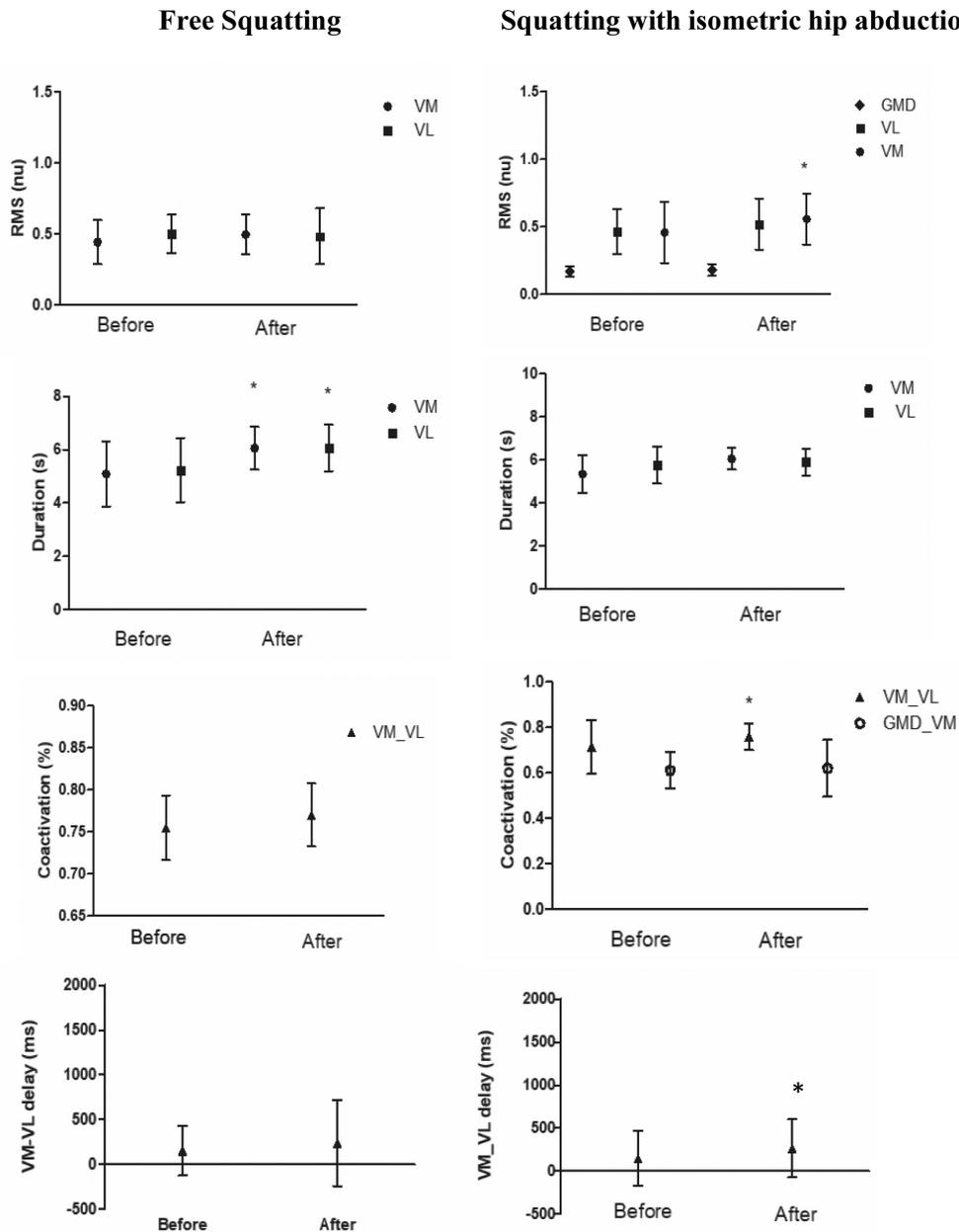


Figure 3 - Graphs representative of the RMS (nu - normalized unit), signal duration (s - seconds), muscular coactivation (%) and VM-VL delay (ms - milliseconds) of the vastus medialis (VM), vastus lateralis (VL) and gluteus medius (GMD), before and after the application of the intervention protocol. *indicates statistically significant difference ($p < 0.05$).

Table 3 - Data of mean difference, 95% coefficient interval and effect size of the EMG parameters in free squatting.

EMG parameters	Muscles	Mean difference	95% coefficient interval	Effect size (Cohen's d)
RMS (nu)	VM	-0.04	-0.12 to 0.04	0.23
	VL	0.04	-0.03 to 0.12	0.07
Duration (s)	VM	-0.97*	-1.48 to -0.46	0.66
	VL	-0.81*	-1.35 to -0.27	0.54
Coactivation (%)	VM-VL	-0.01	-0.04 to 0.00	0.24
Delay (ms)	VM-VL	-64.18	-270.40 to 100.20	0.15

Legend: vastus medialis (VM), vastus lateralis (VL), normalized unit (nu), seconds (s) and milliseconds (ms). *indicates statistically significant difference ($p < 0.05$).

ences were observed for the duration of activation (Figure 3). Table 4 shows the data of mean difference, 95% CI and ES of the EMG parameters.

Pain and function

Comparing the findings of the VNS (Figure 4) in the clinical evaluation before (6.64 ± 2.26) and after (2.63 ± 2.14) the protocol, the pain showed significantly reduction ($p < 0.05$).

The results established that after the application of the exercise protocol there was a significant increase in the number of repetitions in the step-down test (mean difference [95% CI] = $-0.545 [-5.841; -1.250]$; effect size [ES] = 1.03), as shown in Figure 4.

The correlation between the higher effect size EMG parameters (VM and VL duration) with step-down test or VNS are detailed in Table 5; VM and VL duration in free squatting showed strong correlation.

Discussion

This study used a protocol of physical activity level standardization prior to the GMD, VM and VL activation analysis in women with PFP. After 12 weeks of the hip abduction exercise program, our findings indicate higher values of VM RMS, VM-

VL coactivation and VM delay (in relation to VL) during squatting with abduction; and, longer VM and VL (moderate effect size) duration in free squatting. In addition, there was improvement of the pain and functional step-down test.

Gramani-Sa, et al.³⁵ indicated that during the free squatting exercise at different hip rotations, the electrical activity of the VM and VL muscles was significantly higher in the PFP group compared to the control group. Coqueiro *et al.*³⁶ did not observe a difference in VM and VL activity between the PFP and control groups during free and isometric hip adduction squatting exercises. The conflicting results can be explained by the presence of pain in subjects of the PFP group³⁶. Briani *et al.*²³ evaluated the capability of two-stair negotiation protocols, with and without an external load, to equalize pain in women with PFP and concluded that the patellofemoral joint loading protocol may be an alternative to equalize pain during clinical assessments. In this way, in our study, all participants performed a protocol of physical activity level standardization to be symptomatic at the evaluation time, which better controls the results.

Considering the abduction squatting after the exercises protocol, there was a significant VM RMS increase and a tendency for VL RMS increase, although not significant. Felicio *et al.*³⁷ compared the myoelectric activation of patellar and pelvis stabilizers between the free and isometric thigh adduction and

Table 4 - Data of mean difference, 95% coefficient interval and effect size of the EMG parameters in squatting in isometric hip abduction.

EMG parameters	Muscles	Mean difference	95% coefficient interval	Effect size (Cohen's d)
RMS (nu)	VM	-0.11*	-0.24 to 0.01	0.30
	VL	-0.05	-0.14 to 0.03	0.22
	GMD	-0.01	-0.03 to 0.01	0.16
Duration (s)	VM	-0.75	-1.15 to -0.35	0.68
	VL	-0.15	-0.61 to 0.31	0.11
Coactivation (%)	VM-VL	-0.02*	-0.05 to 0.00	0.38
	GMD-VM	-0.02	-0.08 to 0.02	0.06
Delay (ms)	VM-VL	-83.21*	-264.30 to 135.90	0.26

Legend: vastus medialis (VM), vastus lateralis (VL), gluteus medius (GMD), normalized unit (nu), seconds (s) and milliseconds (ms). *indicates statistically significant difference ($p < 0.05$).

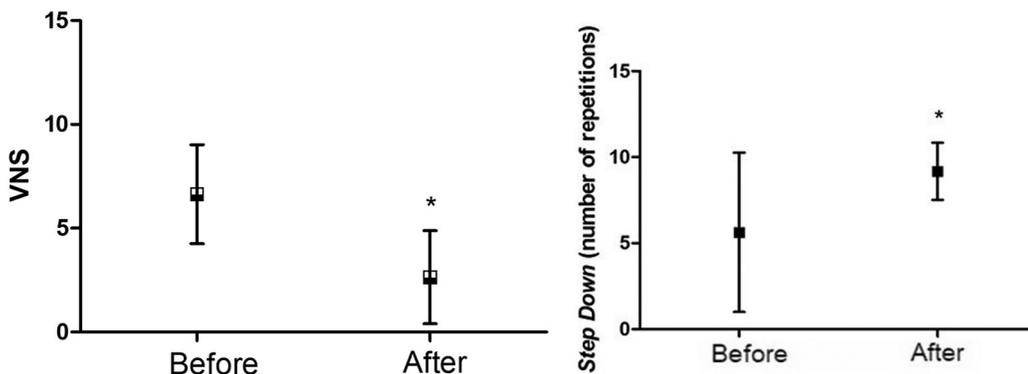


Figure 4 - Graphs of the visual numeric scale (VNS) and step-down test (number of repetitions) data before and after the application of the intervention protocol. *indicates statistically significant difference ($p < 0.05$).

Table 5 - Correlation and p values of the pre-post difference EMG and clinical parameters.

Pre-post difference parameters (p)	VNS	Step down
VM duration FS	0.120 (0.750)	0.860 (0.003)
VL duration FS	0.341 (0.360)	0.784 (0.012)
VM duration HA	0.436 (0.240)	-0.286 (0.439)
Step down	0.345 (0.320)	-

Legend: vastus medialis (VM), vastus lateralis (VL), free squatting (FS), hip abduction (HA) and visual numeric scale (VNS).

abduction squatting in healthy participants³⁷. The results proved that the squatting associated with thigh abduction produced moderate and greater activations than those achieved with free squatting for the vastus medialis oblique, vastus lateralis oblique, vastus lateralis longus and gluteus medius muscles³⁷.

Baffa *et al.*³⁸ illustrated a greater VM activation during the squatting exercise, while Cerny³⁹, Earl, Schmitz, Arnold⁴⁰ and Coqueiro *et al.*³⁶ reported that there was no significant difference in vastus activation. The divergent results can be explained by the different knee flexion angles adopted during the squatting: 60°, 45° and 30°^{36,38-40}. As discussed in the literature, the medial activation increase is directly proportional to the knee flexion angle during the squatting exercise⁴¹, which can be confirmed in the present study, since the knee flexion angle was 90°.

After the hip abduction exercise program, there was no significant change in the GMD activation during the squats. However, the increase in VM RMS and greater values of VM-VL coactivation in squatting with hip abduction after the exercises program may suggest that the exercises were effective to optimize the quadriceps strengthening and balance muscle action. The increase duration of contraction of the VM and the VL with moderate effect size during free squatting suggests a greater control of the muscular action after the hip abduction exercise program. Rabelo and Lucareli (2017)¹⁰ demonstrated that the evidences do not support the relationship between muscular strength and movement disturbance in individuals with PFP. They hypothesized that specific strengthening may improve the tolerance for the loads on the patellofemoral joint, that can be attributed to its impact on the central nervous system desensitization and not simply to its mechanical effects. In our study, the weak correlation between VM and VL duration with VNS indicates that significant improvement in pain after exercises was regardless of the changes in the muscle activation pattern during the squatting.

Studies have been observed an efficacy in pain reduction, as well as improvement in functional capacity after hip muscle strengthening in individuals with PFP^{21,42}. The results of the step-down test demonstrated that the volunteers were able to increase the number of steps ascended and descended maybe due hip abductors strength. We have found a weak correlation between number of steps and VNS which indicates that the functional capacity was not associated with pain. In this context, recently, Nunes *et al.*⁴³ observed that isometric and dynamic hip abduction strength were correlated (moderately and strongly, re-

spectively) with fewer step-down repetitions. They highlighted the possibility of including progressive resistance training to improve functional performance in people with PFP⁴³. These results are in accordance to our study in which we observed improve in step-down test after our 12-week hip abduction exercise program. Hott *et al.* (2019)⁴⁴ also demonstrated that hip-focused exercise, knee-focused exercise, or free physical activity performed during six weeks lead to increase in step down repetitions in people with PFP.

We highlight that our results showed a large effect size for the objective function estimated by the step-down test comparing pre and post intervention suggesting that this test should be used by clinicians in order to understand the evolution in the treatment of people with PFP. Moreover, the EMG parameters that showed moderate effect size in free squatting were highly correlated to the step down repetitions. The step-down is considered an important objective function test for patients with PFP, since it mimics the function of stair descent, that is a common aggravating factor; besides that, Loudon *et al.*⁴⁵ showed a high intrarater reliability for this measurement. De Oliveira Silva, *et al.*⁴⁶ related that people with PFP present deficits in the number of step-downs compared to asymptomatic people. So, we recommend that the step-down test should be incorporated to all clinical assessments of people with PFP.

Therefore, the application of the hip abduction exercise program in women with PFP is recommended. It is emphasized that the protocol of the exercises used in this study should be reproduced and investigated in other tasks to better understand the role of GMD, VL and VM in joint stabilization in women with PFP. As limitations of the study, we had a small number of volunteers, a female only sample, VNS subjectivity and the absence of a control group.

Conclusion

The findings indicated that the clinical protocol based on a series of the hip abduction exercise program for 12 weeks promoted a greater vastus medialis activation, greater vastus medialis and lateralis muscles coactivation during a squatting with abduction and a longer vastus medialis and vastus lateralis activation duration in the free squatting. Additionally, the pain questionnaires, functional conditions and clinical tests showed that the protocol promoted a clinical improvement in patients with patellofemoral pain.

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