Analysis on the activation of the VMO and VLL muscles during semisquat exercises with and without hip adduction in individuals with patellofemoral pain syndrome

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Abstract

Objective: The purpose of this study was to investigate the effect of hip adduction on the activity of the Vastus Medialis Obliquus (VMO) and Vastus Lateralis Longus (VLL) muscles during semisquat exercises.

Methods: Twenty female subjects, divided into two groups comprising healthy and patellofemoral pain syndrome (PFPS) subjects (ten volunteers for each group), performed three double-leg semisquat exercise trials with maximum hip adduction isometric contraction (DLSS-HA) and three double-leg semisquat exercise trials without hip adduction (DLSS). The normalized electromyographic muscle data were analysed using Repeated Measure ANOVA (p ≤ 0.05).

Results: The electrical activity of both VMO and VLL muscles was significantly greater during DLSS-HA exercise than during DLSS (p = 0.0002) for both groups. Additionally, an independent Repeated Measure ANOVA revealed that the electric activity of the VLL muscle was significantly greater (p = 0.0149) than that of the VMO muscle during DLSS exercises only for the PFPS group. However, no differences were found during DLSS-HA exercises.

Conclusions: Although there was no preferential VMO muscle activation, the association of hip adduction with squat exercise promoted a greater balance between the medial and lateral portions of the quadriceps femoris muscle and could be indicated for the conservatory treatment of PFPS patients. The association of isometric hip adduction with isometric semisquat exercises produced a more overall quadriceps activity and could be indicated for clinical rehabilitation or muscle strengthening programs.

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Keywords: Surface electromyography; Knee rehabilitation; Squat exercise; Quadriceps femoris muscle

1. Introduction

Patellofemoral pain syndrome (PFPS), a disorder related to peripatellar or retropatellar pain, most frequently occurs in athletes and women [6]. It is aggravated by a number of factors such as sports activities, stairs climbing, kneeling or squatting and prolonged sitting with the knee flexed [7,21]. Although its aetiology has not yet been clearly defined [26], it is possible to relate it to various components that can result in patellar malalignment, such as an increase in the Q angle, patella alta, excessive subtalar pronation and external tibial rotation [24,31,36]. Also, the imbalance caused by the atrophy and dysplasia [12] of the oblique portion of the Vastus Medialis Obliquus muscle (VMO) plays an important role in patellar malalignment. Such
imbalance occurs because the VMO muscle cannot oppose to the countering force produced by both the vastus lateralis (VL) muscle and the iliotibial band [9]. The result is that the combination of all those elements contributing to patellar malalignment can seriously impair the recruitment pattern of the quadriceps muscle in PFPS subjects.

Therefore, treatment protocols for PFPS must aim primarily at the functional recovery of the VMO muscle [5]. However, it is important to find out what the correct protocol is and, even more important, to find out if the chosen exercises are really contributing to prompt and quick muscle recovery. In order to do so, one of the main techniques used by researchers worldwide is to measure the electric activity of muscles ( electromyography) during specific exercises [17,27]. But what would the best exercises for PFPS treatment be? Unfortunately, no agreement has been reached on that matter. Knee extension exercises in both open kinetic chain (OKC) and closed kinetic chain (CKC), for instance, have been suggested to be used in association with tibial rotation [1,21], hip rotation [20] and hip adduction [14,15,27]. However, it is noteworthy that hip adduction exercises can be used to selectively strengthen the VMO muscle [14,23,27,30] since part of it originates in the adductor magnus muscle and part of it originates in the adductor longus muscle [4,22]. But what kind of chain (OKC or CKC), for hip adduction exercises or for hip adduction exercises associated with knee extension, should be performed to produce the best selective strengthening of the VMO muscle?

A number of studies can be found in the literature concerning the activation of the VMO and VL muscles during different exercises. Nevertheless, most of them cannot be applied to answer that question since they are not directly related to it, are not conclusive and do not agree as to many aspects. Some authors have reported an increase in the VMO muscle activity as compared to VL activity when OKC isometric hip adduction exercises are performed by healthy subjects [14]. Others, however [37], have not found such effect. Also, when isometric adduction is associated with OKC knee extension exercises, no increase in the VMO muscle activity as compared to VL activity has been reported for healthy [6,19,21] or PFPS subjects [6,21].

CKC exercises such as squat have been widely indicated for knee rehabilitation [11,28] since the functional nature of those exercises, including co-contraction of the quadriceps femoris and hamstrings, decreases tibiofemoral translation and compression forces on the tibiofemoral joint [36], thus promoting strengthening and normal proprioceptive input [26,33]. Gresalmer and Klein [13] and Escamilla [10] reported that such exercises should be performed in PFPS subjects with the knee flexed at 0–45° or 0–50°.

The electric activity of the VMO and VL muscles during hip adduction exercises with knee extension have been studied for healthy [6,9] and PFPS [6] subjects. The results show that those exercises increase the electric activity of both muscles. Furthermore, it has been shown that exercises also lead to a higher electric activity of the VMO muscle as compared to the electric activity of the lateral portions of the quadriceps muscle for healthy [15] and PFPS subjects [29].

It is noteworthy that, although a number of works have described the activity of VMO and, considering anatomic descriptions and the long portion of the VL muscle, i.e., the Vastus Lateralis Longus muscle – VLL [17,28,30] during different exercises, very little has been reported about the association of double-leg semi-squat exercises with hip adduction. To this date, the authors of this study have found only one report of hip adduction associated with mini-squat exercises in healthy subjects [9]. Nothing has been found concerning the electric activity of the VMO and the VLL muscles during double-leg semisquat exercises associated with hip adduction in PFPS subjects.

In order to fill that gap and to shed new light on feasible treatment protocols for PFPS, the authors in this study decided to investigate the effects of hip adduction on the electric activity of the VMO and VLL muscles during double-leg semisquat exercises at 45° knee flexion in healthy and PFPS subjects.

2. Methods

2.1. Subjects

The population for this study consisted of twenty female volunteers divided into two groups:

- Ten healthy subjects (age: 21.8 ± 2.52 years old, height: 165 ± 0.043 cm, weight: 58.38 ± 5.88 kg): subjects who did not report pain in the knee area and had never had any significant knee or lower limb pathology or surgery.
- Ten sedentary PFPS subjects (age: 23.2 ± 2.65 years old, height: 158 ± 0.056 cm, weight: 50.53 ± 5.83 kg): subjects who did not report any previous muscle-skeletal damage to the hip, knee or ankle joints and were submitted to physical evaluation consisting of specific tests for those joints.

The following aspects defined the inclusion criteria for PFPS volunteers in this work:

- Asymptomatic for at least three months prior to the physical evaluation [7].
- Reports of episodes of anterior or retropatellar knee pain when performing at least two of the following activities: prolonged sitting, squatting, ascending or descending stairs, running, kneeling and jumping [7].
Three or more of the following signs and symptoms had to be detected: excessive pronation of the subtalar joint, patella alta, hyper or hypomobile patella, tightening of the iliotibial band (Ober’s Test), increase of the Q angle, external tibial rotation, squeezing patellae and pain on patella palpation [7,24].

The exclusion criteria were based on:

- History of knee or lower limb surgery [7].
- History of patellar dislocation or subluxation [7].
- Clinical evidence of meniscal or ligamentous lesions and patellar tendon pathology [7].

Table 1 shows the percentage of incidence of the signs and symptoms used in the inclusion criteria of PFPS volunteers.

This study was approved of by the Ethics Committee for Human Experimentation Research of the Federal University of São Carlos and all the subjects were asked to sign a consent form.

2.2. Instrumentation

The electrical activity of the VMO and VLL muscles was detected by active differential surface EMG electrodes, supplied by Lynx Electronics Technologies (Brazil). The main features of those electrodes are:

- Detection surfaces: two Ag parallel bars – 10×2 mm of contact area.
- Distance between electrodes: 10 mm.
- Gain: 100×.
- Input impedance: higher than 100 MΩ.
- Common mode rejection ratio (CMRR): higher than 80 dB @ 60 Hz.

Signal conditioning included a further gain of 10× and a band pass filter tuned at 20 and 500 Hz. A 12-bit A/D card (CAD 12/26–60 K by Lynx Electronics Technologies) was used to sample the data at 2000 Hz. The electromyographic (EMG) signals were synchronously sampled (simultaneous sample and hold) and stored for later processing.

Table 1

<table>
<thead>
<tr>
<th>Signs and symptoms</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>External tibial rotation</td>
<td>30</td>
</tr>
<tr>
<td>Excessive pronation of the subtalar joint</td>
<td>30</td>
</tr>
<tr>
<td>Increase of the Q angle</td>
<td>100</td>
</tr>
<tr>
<td>Hyper or hypomobile patella</td>
<td>10</td>
</tr>
<tr>
<td>Squeezing patellae</td>
<td>60</td>
</tr>
<tr>
<td>Patella alta</td>
<td>20</td>
</tr>
<tr>
<td>Pain on patella palpation</td>
<td>40</td>
</tr>
<tr>
<td>Tight iliotibial band (Ober’s Test)</td>
<td>20</td>
</tr>
</tbody>
</table>

A knee extension table was used for the maximum isometric voluntary contraction (MIVC) exercises and the angular position of the knee was measured by a universal goniometer. Hip adduction exercises were performed against a mechanical resistance device, as shown in Fig. 1 [29].

2.3. Procedures

A reference line, joining the anterosuperior iliac spine to the centre of the patella, was drawn with a pen to help define the correct position of the surface EMG electrodes. The “VMO electrode” was fixed approximately 4 cm superior and medial to the superomedial border of the patella [14] at a 50–55° angle to the reference line [22]. The “VLL electrode” was fixed 15 cm superior to the superolateral border of the patella at approximately 13.6° to the reference line [3]. The electrodes were positioned, with the subjects standing, on the midline of the belly muscle with the detection surface (two parallel bars) perpendicular to the direction of the muscle fibres, as suggested by De Luca [8]. The reference electrode was positioned on the volunteer’s left wrist and held in place by Velcro tape. Adhesive tape was used to hold the active electrodes in place. To minimise the contact impedance, the skin was shaved, swabbed with alcohol 70% and abraded with sandpaper. The electrodes were placed on only one of the volunteers’ legs. For the PFPS group, a leg was randomly chosen; for the healthy group, the leg with one or no PFPS signals was selected (in the case where both legs presented the same number of signals, a random choice was also made).

Prior to the experiments, the volunteers were submitted to a short training in order to become used to testing procedures. This included a warm-up session and the stretching of the adductor, quadriceps, hamstrings and calf muscles for one minute.

The volunteer was then stabilised on the knee extension table with the ankles, knees and hips flexed at 90°.
A thoracic belt encircling the back of the table was fastened under the axillae and a pelvic belt, also fixed to the table, was fastened around the subject’s pelvis, just under the anterior superior iliac spines. A resistance pad was positioned 2.5 cm above the medial malleolus, with the knee flexed at 90°, in order to provide maximum resistance to the extension of knee.

The average of the RMS (root mean square) values of three MIVC knee extension exercises performed on the knee extension table was used as benchmark to normalise the EMG recordings obtained during the double-leg semisquat exercises. To do so, the volunteers were asked to extend their knee as hard as possible and encouraged by continuous verbal commands (Attention! Prepare! Go! Push! Push! Relax!). The three MIVCs, lasting 6 s each, were performed following two-minute intervals (resting period).

In this study, double-leg semisquat (DLSS) exercise refers to semisquat exercise on two legs performed with the knees flexed at 45°. Double-leg semisquat exercise associated with hip adduction (DLSS-HA) refers to semisquat exercise on two legs performed with the knees flexed at 45° associated with hip adduction at MIVC against a mechanical resistance (Fig. 1).

As described earlier, the angular position of the knee was measured by a universal goniometer. The device’s rotation centre was positioned directly over the joint’s rotation centre. The proximal arm was fixed over the thigh’s lateral line and aligned with the lateral midline of the femur, using the greater trochanter as reference. The distal arm was fixed on the lateral aspect of the lower leg and aligned with the lateral midline of the fibula, using the lateral malleolus as reference [18].

DLSS-HA exercises were performed with the mechanical device, which was created to provide resistance to hip adduction, on the knee joint interline throughout the whole exercise. This provided a 30° angle of abduction during the exercises. On the other hand, DLSS exercises used that device only to establish the initial position of the knee and then removed, just before the beginning of the exercise. This ensured that both exercises began with the knees in the same position.

The volunteers were also instructed to maintain the trunk in the upright position, the feet in the neutral position and the shoulders flexed at 90° (Fig. 2) for both exercises. This arrangement aimed to ensure that the movement was as stable as possible.

DLSS exercises were executed according to the following sequence:

1. descend to 45° knee flexion (Fig. 2),
2. hold for 6 s and
3. ascend to the initial position.

Three sequences were executed following two-minute intervals. During the exercise the volunteer was verbally encouraged with commands such as Hold it! Hold it! Relax!

DLSS-HA exercises were executed as follows:

1. descend to 45° knee flexion (Fig. 2),
2. hold and perform a hip adduction MIVC against the mechanical resistance for 6 s and
3. ascend to the initial position.

Three sequences were executed following two-minute intervals. During the exercise the volunteer was verbally encouraged with commands such as Squeeze it! Squeeze it! Relax!

The volunteers executed the exercise sequences (DLSS and DLSS-HA) at 4-minute resting intervals. The order in which the sequences were executed was randomly defined.

EMG data acquisition began 2 s after the volunteer got into the “hold” phase for DLSS exercises, and 2 s encouraged with commands such as Hold it! Hold it! Relax!
after he began hip adduction at MIVC for DLSS-HA exercises. These data were analysed in terms of their RMS values, normalised by the mean RMS value of the three knee extension MIVC executed on the resistance knee extension table [14]

\[
\text{DLSS or DLSS – HA} \times 100. \\
\text{knee Extension MIVC}
\]

2.4. Statistical analysis

Tests of Repeated Measure Analysis of Variance were used to evaluate the differences between groups, muscles and exercises. The analyses were performed between subjects to evaluate groups and among subjects to evaluate muscles and exercises. Significance levels were set at \( p \leq 0.05 \).

Independent repeated measure analyses of variance were also performed for each group. Those were defined by tests of hypotheses among subjects for the effects of muscles and exercises.

Prior to statistical analysis, statistical normality tests were performed and descriptive analysis was carried out. Calculations were performed using the R statistical free software [16].

3. Results

The global analyses involving comparisons between and among subjects showed that there were no significant differences for groups (0.0935) and a small significance level for muscles (\( p = 0.6122 \)). On the other hand, the analyses of exercise effects showed a high level of significance (\( p = 0.0002 \)). In other words, for both groups, the electric activity of the VMO and VLL muscles were significantly greater during DLSS-HA exercises than during DLSS exercises.

A separate analysis was also performed for the healthy and PFPS groups. It showed a significant difference in muscle effect with greater electric activity of the VLL muscle (\( p = 0.0049 \)) than that of the VMO muscle during DLSS exercise only for the PFPS group.

The normalised RMS mean values for the electric activity of the VMO and VLL muscles during the exercises performed by both groups are shown in Table 2.

4. Discussion

The experiments presented here show that there was a significant increase in the activity of the VMO and the VLL muscles when double-leg semisquat exercise was associated with hip adduction (DLSS-HA) for both healthy and PFPS groups. Those findings are in agreement with previous studies that report an increase in the electrical activity of the VMO and VL muscles when isometric hip adduction was combined with dynamic mini-squat at 30° knee flexion [9], wall-sit up to 60° knee flexion [15] or wall-slide up to 45° knee flexion [6] in healthy [6,9,15] and PFPS subjects [6]. Therefore, it seems that, whatever the type of squat exercise, i.e., mini-squat, semi-squat, wall-sit or wall-slide exercises, there is a tendency to an overall increase in the activity of the quadriceps femoris muscle when such exercise is associated with hip adduction for both healthy and PFPS subjects.

However, the authors of this study did not find any evidence of preferential activation of the VMO muscle as reported by Hodges and Richardson [15] and Miller et al. [25], who studied the effect of hip adduction associated with dynamic wall-sit at 60° knee flexion and wall-slide at 75° knee flexion. It is possible that dynamic exercises and higher knee flexion angles could produce such differences. However, some of those studies used EMG data collected during dynamic contractions, which is very controversial, since the EMG signal can be altered by the relative movement of the electrode with respect to the contracting muscle fibres. The fact is that the authors of this study as well as many others, such as De Luca, 1997 [8], normally recommend avoiding collecting EMG data during anisometric contractions (as it was the case for the experiments shown in this work). But, even if there was no error in the technique used for EMG data acquisition, other questions could still arise for our experiments, such as “why did we choose 45°
knee flexion? Why did we choose to normalise the data using MIVC?...”.

Steinkamp et al. [34] suggested that CKC knee extension exercises in the functional range of motion should be emphasised to strengthen the knee joint muscles because of its lower stress on the patellofemoral joint. Therefore, it seems that those exercises are good for the PFPS treatment. However, what would optimum knee flexion during squat exercises be? The answer could be pointed by Escamilla [10], who stated ‘...because the peak compressive forces generally occur near maximum knee flexion, individuals with patellofemoral disorders should avoid performing the squat at high knee flexion angles’. But what would those “high knee flexion angles” be? It certainly depends on each patient. In view of such situation, the authors in this study elected 45° as a good compromise for all the participant volunteers.

The normalisation of the raw data is an important requirement if one intends to study and compare data collected from different muscles and different individuals in different situations. MIVC was elected as the normalisation unit based on the experience of many researchers worldwide and its use in similar studies concerning PFPS and the muscles of the thigh [1,6,9,14,18,25,29]. However, we used data collected during MIVC extension of the knee at OKC to normalise CKC contractions. According to Schaub and Worrel [32], this is not a problem either, since they have shown that muscle recruitment patterns are very similar for OKC and CKC exercises.

Nevertheless, considering that there are differences between the evaluated groups, especially regarding muscle imbalance in PFPS subjects, widely reported in the literature [1,7,9,20,21,23,24,29,33,35,36], we felt that a separated statistical analysis comparing, for each group, electric activity between the VMO and the VLL muscles during DLSS and DLSS-HA exercises would be clinically important for knee rehabilitation programs. This independent analysis revealed that, the electrical activity of the VLL muscle was significantly greater than that of the VMO muscle during DLSS exercise for the PFPS group and no differences were found during DLSS-HA exercise. The greater electrical activity of the VLL muscle when compared with that of the VMO muscle during DLSQ exercise confirms the reports of imbalance between the medial and lateral compartments of the quadriceps femoris muscle in PFPS subjects [1,7,9,12,20,21,23,24,29,33,35,36]. However, this theory should be carefully dealt with, since this work investigated only EMG data and other tools, such as magnetic resonance imaging (MRI) and computed tomography (CT), should be added to explore the investigation of muscle imbalance.

However, although there was no selective recruitment of the VMO muscle during DLSS-HA exercise, considering that during DLSS exercise there was a significant difference between the VLL and the VMO muscles and that such difference had not been found during DLSS-HA, we believe that DLSS-HA exercises could promote a greater muscle balance between the electric activity of the VMO and VLL muscles and could benefit the treatment of PFPS patients. This greater balance caused by the effect of hip adduction on the activity of the VMO muscle could be explained by the strong anatomical relation between the adductor muscles and the VMO muscle. The action of adductor muscles is essential to selectively strengthen the VMO muscle. According to Hanten and Schulties [14], “…a strong VMO originating from weak adductors would serve only to draw the adductor tendons toward the patella...” and, on the other hand, “…strong hip adductors give the VMO a stable origin from which to contract...”. Besides, another favourable factor for the selective contraction of the VMO muscle during DLSS-HA exercise refers to the length tension properties, as proposed by Beck and Wildermuth [2] who reported that with the addition of hip adduction there is a stretch to the VMO muscle, which would alter length tension properties, thus contributing to an enhanced contraction force.

This study was designed with the primary goal of providing information regarding the effects of hip adduction on the electric activity of the VMO and VLL muscles in healthy and PFPS subjects. It has demonstrated that the association of isometric hip adduction with isometric semi-squat exercise produces a balanced activity of the quadriceps muscle group. Therefore, this exercise can be indicated when overall quadriceps activity is desired for clinical rehabilitation or muscle strengthening programs. Furthermore, because of the greater balance between the medial and lateral portions of the quadriceps femoris muscle promoted by the association of semi-squat exercise at 45° knee flexion and hip, it could also be indicated for the conservatory treatment of PFPS. However, to confirm this statement, further EMG investigation would be necessary in order to compare the effects of muscle training programs based on DLSS-HA exercises for both groups.

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