Original research

Effect of tibia rotation on the electromyographical activity of the vastus medialis oblique and vastus lateralis longus muscles during isometric leg press

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Abstract

Objectives: To evaluate the electrical activity of the vastus medialis obliquus (VMO) and vastus lateralis longus (VLL) with the tibia in neutral, medial and lateral rotation on the horizontal leg press.

Design: Repeated measures analysis of the effects of tibia rotation on VMO and VLL activity.

Setting: Evaluation and intervention in orthopaedics and traumatology laboratory.

Participants: Fifteen healthy participants, no previous musculoskeletal damage of the lower limb.

Main outcome measures: Electrical activity (Root Mean Square) of the VMO and VLL was measured during submaximal isometric contractions (SIC) with the knee at 90° of flexion. The effect of tibia rotation in electrical activity of the VMO and VLL was measured.

Results: VLL activity was significantly higher than VMO activity with the tibia in medial rotation (p = 0.03). Tibia rotation did not influence the activity of the VMO muscle (p = 0.26). VLL activity was significantly higher with medial than neutral tibia rotation (p = 0.005).

Conclusions: The results suggest that tibia rotation does not strengthen selectively the VMO muscle during isometric leg press at 90° knee flexion.

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Keywords: Leg press; Femoral quadriceps; Rehabilitation

1. Introduction

The patellofemoral pain syndrome (PFPS) is among the complaints most commonly observed in sports medicine, usually manifesting as pain localized in the retropatellar or peripatellar region (Doucette & Goble, 1992). This syndrome is more common among women aged 16–26 years but with a high incidence among athletes (Pumiello, 1993). According to Grabiner, Koh, and Miller (1991) the PFPS occurs in 17% of male and 33% of female knee pathology. The pain is usually aggravated by activities involving patellofemoral compressive forces such as remaining in the sitting position with the knees flexed for long periods of time (movie theater sign), climbing up and downstairs, remaining in the kneeling position, and squatting.

Although the exact aetiology of PFPS is unknown (Eng & Perrynowski, 1993), investigators propose that this disorder may be related to non-traumatic factors such as bone abnormalities, muscle imbalance, laxity or tightness of the ligaments or joint capsule, or to a direct traumatic injury to the joint (Sheehy, Burdett, Irrgang, & VanSwearingen 1998).

Among non-traumatic factors, the patellar malalignment has been pointed out as one of the major causes of patellofemoral pain (Paulos, Rusche, Johnson, & Noyes, 1980; Fulkerson, 1983). Adequate patellar alignment depends on the balance between static and dynamic medial and lateral stabilizers. The static stabilizers of the patella are the bone structures, retinaculum and ligaments (Merchant, Mercer, Jacobsen, & Cool, 1974; Woodall & Welsh, 1990; Ruffin & Kiningham, 1993; Sheehy et al. 1998).

Dynamically, the major stabilizers are the four components of the femoral quadriceps muscle—vastus medialis (VM), vastus lateralis (VL), vastus intermedius, and rectus
femoris (Blackburn & Craig, 1980). Lieb and Perry (1968) observed that the fibers of the VM muscle present different orientations. Besides, in one of the cadavers studied, it was observed the presence of an areolar fascial plane. Thus, a portion of long fibers was recognized and denoted vastus medialis longus (VML), and an oblique portion was denoted vastus medialis obliquus (VMO), the latter being the only dynamic medial stabilizer of the patella. The fibers of the VMO muscle originate from the femur and from the tendon of the adductor longus and adductor magnus muscles, with an inclination angle of 50–55° in relation to the longitudinal axis of the femur, described by Lieb and Perry (1968). This inclination angle favours an advantageous line of action for medial patella traction (Bose, Kanagasuntherum, & Osman, 1980).

Similarly, other studies (Scharf, Weinstabl, & Firbas, 1986; Hallisey, Doherty, Bennet, & Fulkerson, 1987; Weinstabl, Scharf, & Firbas 1989; Javadpour, Finegan, & OBrien, 1991; Bevilaqua-Grosso, Monteiro-Pedro, & Berzin, 1997) have shown that the VL muscle is also divided into two portions. In an anatomical study, Bevilaqua-Grosso et al. (1997) reported that the VL muscle has a long and proximal portion denoted vastus lateralis longus (VLL), and an oblique and distal portion denoted vastus lateralis obliquus (VLO), separated by a fascia in the distal portion. The fibers of the VLL muscle originate from the femur and are inserted into the middle of the quadriceps tendon (Javadpour et al., 1991), while the fibers of the VLO originate from the rough line of the femur and from the lateral intermuscular septum and are inserted through their own tendon that runs inferiorly and laterally to the VLL tendon, joining the latter in a common tendon in the superolateral margin of the patella (Bevilaqua-Grosso et al., 1997). Bevilaqua-Grosso et al. (1997) also reported that the long fibers of the VL have an inclination of approximately 13.6° and the oblique fibers have an inclination of 50.4° in relation to the longitudinal axis of the femur.

Some investigators (Hanten and Schulthies, 1990; McConnell, 1986) have reported that adequate patellar alignment is obtained by balance between the VMO and VL muscles and that muscular imbalance caused by weakness of the VMO muscle may result in lateral subluxation and pain in the patellofemoral joint.

It is thought that isolated insufficiency of the VMO muscle or in combination with other factors such as bone abnormalities and malalignment of the lower limb, may result in improper tracking of the patella in the femoral groove and an abnormal distribution of loads in the patellofemoral joint.

On this basis, selective strengthening of the VMO muscle has been indicated by several authors (Insall, 1982; Szczepanski, Gross, Duncan, & Chandler, 1991; Doucette & Goble, 1992) to be of fundamental importance for the treatment of PFPS. Hanten and Schulthies (1990) stated that, for an effective patellar realignment, emphasis should be placed not only on increased VMO activity, but also on decreased VL activity.

The pattern of VMO and VL muscle recruitment has been studied during various exercises in the open kinetic chain (OKC) and closed kinetic chain (CKC) used for knee rehabilitation. However, there are contradictions in the definition of kinetic chain terminology (Ellenbecker & Davies, 2001). Thus, recognizing the contradictions in the definition of kinetic chain terminology, we opted not to use it in the present study. The term leg press will be used throughout the manuscript, but without defining exercise as OKC or CKC.

A topic that has attracted great interest and that requires further study is the influence of tibia or hip rotation on the pattern of recruitment of the VMO and VL muscles. Some studies (Slocum & Larson, 1968; Engle, 1987; Gough & Ladley, 1971) showed that the tibia or hip rotation changed the recruitment pattern of the VMO and VL muscles. On the other hand, other studies (Hanten & Schulthies, 1990; Cerny, 1995) didn’t find any difference in the electrical activity of the VMO and VLL muscles with lower limb rotation.

However, the literature has no data about the demonstration of the effect of tibia rotation during isometric leg press on the pattern of the femoral quadriceps muscle. On this basis, the purpose of this study was to evaluate the electrical activity of the VMO and VLL muscles during submaximal isometric contraction (SIC) of the femoral quadriceps muscle with the knee joint in 90° flexion and the tibia in a neutral, medial or lateral position, on the horizontal leg press.

2. Methods

2.1. Subjects

The study was conducted on 15 healthy participants (10 women and 5 men) aged 18–25 years (X = 21.9, SD = 1.57) who undertook physical activity at a frequency of twice a week or more. The participants reported no previous musculoskeletal damage to the hip, knee or ankle joints. To verify this statement, the participants were submitted to physical evaluation consisting of specific tests for these joints. Before the beginning of the experimental procedure, the participants signed a formal term of agreement, and the study was conducted according to the guidelines of the National Health Council, Resolution 196/96. This research was carried out with approval from the Human Ethics Committee of the Federal University of Sao Carlos, Brazil.

2.2. Instruments

The electrical activity of the VMO and VLL muscles was determined using simple active differential surface electrodes (Delsys Inc.) and a 16-channel signal conditioning
module (MCS 1000-V2-Lynx Electronics Technologies). The simple active differential surface electrode (Delsys Inc.) housing is constructed with a waterproof polycarbonate plastic case, which is internally shielded to reject ambient electrical noise. The electrode contacts are made from 99.9% pure silver bars measuring 10 mm in length, 1 mm in diameter and spaced 10 mm apart. The electrode has a Common Mode Rejection Ratio (CMRR) higher than 80 dB, an internal gain (V/V) of 10 times, an input impedance higher than 100 MΩ and a noise of 1.2 μV.

The signal conditioning module (MCS 1000-V2) was interfaced with a computer and has a digital analogue A/D converter (CAD 12/32-60K- LYNX Electronics Technologies) with a resolution of 12 bits, an acquisition frequency of 1000 Hz per channel and a data acquisition program Aqdados version 4.6 (Lynx Electronics Technologies). Besides, this equipment has a filter Butterworth type with bandpass of 10.6–509 Hz and a gain of 100 times. The electromyographic signals were sampled in a synchronous manner and stored for later processing.

SIC was performed on a horizontal leg press, Top Line model (Vitally-Industry of Gymnastics Equipment). A universal goniometer was used to measure the flexion angle of the knee joint and the inclination angle of the VMO and VLL muscles.

2.3. Procedures

Before the recording of the electrical potential of the muscles studied, the skin was shaved and cleaned with 70% alcohol and the electrodes were fixed to the skin with micropore adhesive tape. A line joining the anterosuperior iliac spine to the center of the patella was traced with a demographic pen to guide electrode placement at the different angles of insertion of the portions of the femoral quadriceps muscle. For the recording of the electrical activity of the VMO muscle, the electrode was positioned 4 cm from the superomedial border of the patella (Hanten & Schulthies, 1990; Laprade, Culham, & Brouwer, 1998), at an inclination angle of 50–55° in relation to the reference line (Lieb & Perry, 1968). For the VLL muscle the electrode was fixed 15 cm from the superolateral border of the patella, with an inclination angle of approximately 13.6°, according to the anatomical study of Bevilaqua-Grosso et al. (1997). A universal goniometer was used to position the electrodes on the muscle belly. To achieve this, the goniometer axis was aligned to the centre of the patella, the fixed arm was aligned to the reference line (line joining the anterosuperior iliac spine to the centre of the patella) and the mobile arm moved up to the inclination angle desired. In addition, palpation of the muscle belly with the subject in the testing position was also used to confirm electrode placement. The electrodes were fixed to the midline of the muscle belly with the detection surface perpendicular to the muscle fibers, as suggested by DeLuca (1997). A reference electrode was fixed to left wrist of the participant with Velcro tape in order to eliminate possible external interferences.

Before testing, the participants were submitted to a period of training for familiarization with all the test procedures.

During the week before the recording of the electromyographic signal the participants were submitted to a test for the determination of maximal repetition (MR) based on the load addition method of De Lorme and Walkins (1948). The proposed protocol was as follows: with the thoracic and lumbar regions in contact with the seat of the equipment and the left foot sole in contact with a vertical support platform of the leg press, the participant was instructed to extend the knee joint from 120° of flexion to complete extension and then to return to the initial 120° position with an initial load of 15 kg. The participant repeated this procedure ten times and 10 kg was then added to the load. The 10 MR was considered to be that observed before the participant started to present symptoms of fatigue and/or pain or was unable to achieve the full amplitude of movement. In the actual study, the contractions performed against this load were called SIC.

Initially, the electrical activity of the VMO and VLL muscles was recorded during maximal isometric contraction (MIC), which was used only for the normalization of the electromyographic recordings obtained during SIC. The MIC was performed with the hip and knee joints at 90° flexion and with the tibia in neutral rotation. Three 4-s MIC were performed, with a 30-s resting interval between contractions. During MIC, the investigator encouraged the participant with the following verbal commands: Prepare! Go! Pull! Pull! Relax!

For SIC, the load was first adjusted according to the previously established 10 MR. The participant was then positioned with the knee joint in 90° flexion and the tibia randomly positioned in neutral, lateral or medial rotation (Figs. 1 and 2). Three SIC were performed for each tibia rotation and maintained for a period of 4 s. A 30-s resting interval was established between contractions and a 2-min interval was established between the various tibia rotations to prevent possible fatigue. During SIC the participant was verbally encouraged as follows: Hold it! Hold it! Relax! The electrical activity of the muscles under study started to be recorded 2 s after the beginning of muscle contraction according to the protocol of Hanten and Schulthies (1990).

The Root Mean Square (RMS) of the electromyographic signal was used to evaluate the pattern of muscle electrical activity during each contraction. The RMS is representative of the number of active motor units during contraction and is commonly used as a measurement of muscle activity (Basmajian & De Luca, 1985). The data obtained during SIC at the different tibia rotations were normalized as a function of the recordings obtained during MIC. Mean RMS values (in μV) obtained during MIC were first calculated for the VMO and VLL muscles, followed by the calculation of mean RMS values for the same muscles during SIC. On this basis, the mean RMS values obtained during SIC were...
expressed as percentage of the mean RMS values obtained during MIC considering the muscle studied (mean RMS during SIC/mean RMS during MIC £ 100).

2.4. Statistical analysis

The differences between the two muscles and between the three tibia rotations were analyzed statistically by 2 £ 3 (muscles by tibia rotations) two-way repeated measures analysis of variance. When the effects were found to be significant, the data were submitted to contrast analysis and one-way repeated measures analysis of variance considering separately tibia rotations for each muscle and, conversely, considering separately the muscles for each tibia rotation. The level of significance was set at p < 0.05 in all analyses. Prior to statistical analysis, tests for normality of descriptive analysis were performed. All calculations were performed with the S-PLUS statistical software (S-PLUS 2000, Lucent Technologies, Inc.).

3. Results

The effects of muscle and tibia rotations were both close to significance (p = 0.04 and 0.06, respectively) with greater electrical activity for the VLL muscle. However, two-way repeated measure analysis of variance revealed a no significant interaction between muscles and tibia rotation (p = 0.28). Analysis of variance of contrast variables for tibia rotation showed significantly higher electrical activity for medial rotation of the tibia compared with neutral rotation (p = 0.03), whereas no significant difference was observed between medial and lateral rotation (p = 0.15) or between neutral and lateral rotation (p = 0.37; Table 1).

One-way repeated measures analysis of variance considering separately muscles for each tibia rotation showed significantly greater electrical activity for medial rotation of the tibia compared with neutral rotation (p = 0.58), or between medial and lateral rotation (p = 0.080). The electrical activity of the VMO muscle was not significantly changed by tibia rotation (p = 0.260; Table 2 and Fig. 3). When tibia rotation was analyzed separately for each muscle, the electrical activity of VLL was found to be significantly higher than that of VMO in medial tibia rotation (p = 0.007), however, did not differ in neutral (p = 0.100) or lateral (p = 0.150) tibia rotation (Table 3 and Fig. 4).

4. Discussion

The present study was an initial one carried out to determine the pattern of VMO and VLL muscle recruitment during isometric leg press with variation of tibia rotation.
Fig. 2. Tibia in neutral (A), maximal lateral (B) and maximal medial (C) rotation.
In order to obtain a more homogeneous sample for our protocol, we studied healthy individuals. However, caution should be exercised when extrapolating these results to individuals with patellofemoral dysfunction. Thus, the same protocol will be applied to subjects with this dysfunction in future studies.

It is important to point out that many of the electromyographic studies of the VMO and VL muscles did not describe the placement of the electrodes in a precise manner. In the present study, the placement of the electrode on the belly of the VMO muscle was based on the anatomical study of Lieb and Perry (1968) and on the electromyographic study of Hanten and Schulthies (1990), and the placement of the electrode on the VLL muscle was based on the anatomical study of Bevilaqua-Grosso (1997).

Observation of the force vector of the oblique portion of the VL muscle suggests that it may play a more important role in patellar alignment than the long fibers. This was previously observed by Morrish and Woledge (1997), who reported that the oblique fibers of the VL muscle can control the position of the patella by acting in opposition to the VMO. However, when the different portions of the VL are considered, the long portion is found to be much greater than the oblique one (Hallisey et al., 1987). Thus, although the orientation of the oblique fibers of VL represents an advantageous line of action for lateral patellar traction, it is questionable whether it is the major factor responsible for this action, since the long portion has a greater dimension.

One of the limitations of the present study was the fact that VLO and VML activity was not evaluated. Thus, in order to elucidate the efficiency of VLO and VML on patellar alignment and to determine whether rotation of the lower limb affects its activity, future studies evaluating this portion are needed.

With respect to the knee flexion angle used in the present study, it is known that during the support phase of the gait cycle, 90° knee flexion is not used, a fact that leads us to believe that the position studied here is not functional. However, 90° flexion is used in other activities such as sitting on a chair, and in this case the angle is functional. In addition, this angle was chosen for this study because it is frequently used for knee rehabilitation, and previous studies (Wilk et al., 1996; Escamilla et al., 1998) have demonstrated a greatest mean amplitude of the electric signal of the femoral quadriceps muscle during exercise on the leg press at this angle.

Selective strengthening of the VMO muscle has been extensively studied in investigations about knee rehabilitation. Several exercises are used in clinical practice in order

### Table 1
Two-way repeated measure analysis of variance

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Internal comparison</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscles</td>
<td>Medial–neutral</td>
<td>0.04*</td>
</tr>
<tr>
<td>Rotations</td>
<td>Medial–lateral</td>
<td>0.06</td>
</tr>
<tr>
<td>Muscles × rotations</td>
<td>Neutral–lateral</td>
<td>0.28</td>
</tr>
</tbody>
</table>

*Significant difference.

### Table 2
One-way repeated measure analysis of variance for each tibia rotation

<table>
<thead>
<tr>
<th>Source of variation (VLL)</th>
<th>Source of variation (VMO)</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotations</td>
<td>Rotations</td>
<td>0.260</td>
</tr>
<tr>
<td>Medial–neutral</td>
<td>Medial–neutral</td>
<td>0.020</td>
</tr>
<tr>
<td>Medial–lateral</td>
<td>Medial–lateral</td>
<td>0.005*</td>
</tr>
<tr>
<td>Neutral–lateral</td>
<td>Neutral–lateral</td>
<td>0.080</td>
</tr>
</tbody>
</table>
| VMO, Vastus Medialis Obliquus; VLL, Vastus Lateralis Longus. *Medial rotation significantly higher than neutral rotation for VLL muscle.

![Fig. 3. Mean and standard deviation (SD) of normalized electrical activity readings (as percentage of maximal isometric contraction) of the vastus medialis obliquus (VMO) and vastus lateralis longus (VLL) considering muscles for each tibia rotation.](image-url)
to selectively strengthen this muscle. However, electromyographic studies have not confirmed this theory, with several controversies still persisting. For example, for many years there was a belief that the VM muscle was active only at the last degrees of knee extension (Mariane & Caruso 1979). Thus, this exercise has been extensively used in clinical practice to selectively strengthen the VM muscle. However, more recent studies (Boucher, King, Lefebvre, & Pepin, 1992; Worrell, Connelly, & Hilvert, 1995; Isear, Erickson, & Worrell, 1996) have demonstrated that this muscle is activated throughout the amplitude of knee extension, including 90° flexion.

Similarly, tibia rotation was proposed as another form of selective VMO strengthening, since Slocum and Larson (1968) stated that the VMO is inserted into the anteromedial aspect of the tibia through a medial extensor aponeurosis and can resist lateral tibia rotation during the first 60° of knee flexion. On this basis, it was suggested that medial tibia rotation exercise may selectively strengthen the VMO. However, Hanten and Schulthies (1990) did not detect a significant difference between the activity of the VMO and VL muscle during resisted medial tibia rotation at 30° knee flexion in healthy individuals. On the other hand, the results obtained by Laprade et al. (1998) support the statement made by Slocum and Larson (1968). These investigators detected a greater VMO/VL ratio during resisted medial tibia rotation combined with knee joint extension at 70° of flexion compared to other exercises, both for healthy individuals and for patients with patellofemoral pain. Based on their results, Laprade et al. (1998) suggested that exercises involving knee extension in combination with resisted medial tibia rotation could be used for selective strengthening of the VMO muscle. We observed some contradictions in the findings related to the effect of tibia rotation on VMO recruitment. Powers (1998) reported that these studies applied different methods and procedures to evaluate the electromyographic recordings, thus preventing direct comparisons between them. Perhaps these differences are the major reason why no definitive conclusions have been reached thus far with respect to the effect of tibia rotation on VMO activity.

The present results demonstrate a significantly higher activity of the VLL muscle than of the VMO muscle on medial rotation, whereas no significant difference was observed in lateral or neutral rotation. Thus, on the basis of these results, we may suggest that medial rotation should not be used to strengthen selectively the VMO muscle, as pointed out by Laprade et al. (1998). However, the present study was carried out under an axial load which was not present in the study by Laprade et al. (1998). Another difference is that Laprade et al. (1998) performed medial tibia rotation under resistance, whereas in our study the tibia was only positioned in medial rotation. Some literature reports evaluated the effect of lower limb rotation during exercises under an axial load. Ninos et al. (1997) concluded that rotation of the lower extremity does not affect the pattern of activity of the VM and VL muscles during the descent and ascent phases of the Olympic squat. Similarly, Willett et al. (1998) reported that there was no significant difference in the VMO/VL ratio between neutral, medial and lateral rotation of the lower extremity during knee extension with support of body weight against elastic
resistance in the popliteal region (also referred to as the ‘stove-pipe’ or ‘walk-stance’ exercise). However, these studies detected the influence of rotation of the lower limb on quadriceps activity, whereas in the present study we only investigated the influence of tibia rotation. The results of the present study suggest that medial tibia rotation with the knee in 90° flexion causes preferential activation of the VLL, and could therefore be used to strengthen this muscle.

One-way repeated measures analysis of variance considering the muscles separately for each rotation demonstrated that tibia rotation does not influence the pattern of VMO recruitment. Thus, it is not possible to strengthen selectively the VMO muscle with a variation of tibia rotation during isometric leg press with the knee in 90° flexion. These results differ from those reported by Signorile et al. (1995a, b), who stated that the VMO muscle produced a significantly higher activity in neutral rotation than in medial rotation at 90° knee flexion.

On the other hand, the electrical activity of the VLL was significantly higher with the tibia in medial rotation than in neutral rotation. However, there was no significant difference between medial and lateral rotation or between neutral and lateral rotation. These results also disagree with those reported by Signorile et al. (1995a, b), who detected a significantly higher activity of the VL muscle in neutral rotation than in medial rotation. These results also might have been divergent results may be related to the methodological differences between the two studies. The results obtained here for the VLL (higher activity in medial than in neutral rotation) support those reported previously in the analysis of tibia rotation with respect to the muscles, with medial rotation resulting in higher activity in the VLL than in the VMO.

When evaluating other knee flexion angles (5 and 30° flexion), Signorile et al. (1995a, b) noted that the pattern of VM and VL recruitment was different from that observed at 90°. Thus, another limitation of the present study was the fact that other knee angles were not analyzed, since results differing from those obtained at 90° might have been observed. Thus, other angles will be explored on future studies on the leg press, which may lead to conclusions differing from those reached in the present study about the selective strengthening of the VMO.

5. Conclusions

The results of the present study obtained under the experimental conditions used permit us to reach the following conclusions:

1. The electrical activity of the VLL muscle was significantly higher in medial rotation than in neutral rotation, with no significant difference between medial and lateral rotation or between lateral and neutral rotation.

2. Tibia rotation does not affect the pattern of VMO muscle recruitment. Thus, it is not possible to strengthen selectively the VMO muscle during isometric leg press at 90° knee flexion by varying tibia rotation.

3. The electrical activity of the VLL muscle was significantly higher than that of the VMO muscle with the tibia in medial rotation, but the difference was not significant when neutral or lateral rotation was used.

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References


