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Original Article

The effect of different hip rotation angles on electromyography activity of the quadriceps muscle during closed kinetic chain tasks in healthy females

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Abstract. [Purpose] The purpose of this study was to investigate electromyographic activity of the quadriceps muscle in different positions of hip rotation (while standing on the toes) in healthy females. [Participants and Methods] The study was conducted on 35 healthy females. Electromyographic activity of the rectus femoris, vastus medialis oblique, and vastus lateralis muscles were recorded with the hip in a neutral position as well as different angles of internal and external rotation (15, 30, and 45 degrees (°)) while the participants were standing on their toes. [Results] There was a significant difference of 15° in external rotation, a neutral position, 15° of internal rotation, and at the end of an internal rotation position. Paired comparison between muscle activity using Bonferroni showed that vastus lateralis activity in 15° of external rotation, a neutral position, 15° of internal rotation, and at the end of a position of internal rotation was more than that of rectus femoris muscle. [Conclusion] The present study showed that average vastus lateralis activity was the highest in all positions. However, the positions studied in the current study did not lead to an increase in muscle activity of the vastus medialis oblique as a medial dynamic stabilizer compared to vastus lateralis.

Key words: Hip rotation, Quadriceps electromyography, Closed kinetic chain

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INTRODUCTION

Muscle imbalance changes the normal biomechanics of the patellofemoral joint and can lead to patellofemoral syndrome. This condition is a prevalent problem in the knee joint among young and active adults, affecting 25% of the population1). Patellofemoral syndrome is characterized by retro-patellar and anterior knee pain2). The symptoms are aggravated by full flexion of the knee, sitting for long periods of time, as well as repeated and forceful flexion and extension of the knee3). The syndrome has several potential causes many of which are related to impaired biomechanics of the knee joint4). Researchers believe that a lack of balance in the dynamic stabilizer muscles shifts the patella laterally. The dynamic stabilizers of the patella are the oblique part of the vastus medialis (VMO) and vastus lateralis (VL) muscles5). Anatomically, the VMO is the medial part of the quadriceps muscles and attaches to the patella at an angle of 55° to the femoral shaft. It is functionally

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*Corresponding author. Mohammad Mohsen Roostayi (E-mail: roosta@sbmu.ac.ir) significant as it acts as the dynamic stabilizer of the patella and prevents excessive rotation and lateralization of the patella[6]. Most of the conventional methods developed to strengthen the quadriceps have not reported a dominance of VL strength over VMO strength. In cases of imbalance, strengthening the quadriceps muscle using these methods increases the disparity between VL and VMO[7]. Therefore, designing therapeutic exercises to increase the functional strength of the muscle, adjust biomechanical imbalances, and reduce the recurrence of symptoms should be the focus of any physiotherapy program[4].

Rehabilitation programs for patellofemoral syndrome use both open kinetic chain (OKC) and closed kinetic chain (CKC) exercises to balance muscle strength of the knee stabilizers[8]. Researchers have not reported significant differences between the outcome of CKC and OKC exercises. However, CKC exercises are generally preferred as they can stimulate proprioception, engage co-contraction, facilitate functional movement patterns and engage multiple joints[4, 9]. Several studies have shown that there is greater synchrony between recruitment of motor units of the VL and VMO in isometric and CKC contractions[10]. One of the proposed methods for strengthening the knee muscles is performing CKC and OKC exercises in various positions of tibial and hip rotation, as well as hip adduction. These exercises can selectively strengthen VMO as one part of the muscle originates from adductor longus[11]. The effect of hip adduction on activating VMO remains a controversial topic. Several studies report an increase in VMO activity compared to VL activation while increasing hip adductor activity, however further studies have not confirmed these results. This controversy could arise from the exercise parameters used in the studies; such as type of contraction, angle of the joint, and range of motion[12]. Various studies have attempted to increase VMO activity by changing parameters such as the nature of contraction (CKC vs. OKC), type of contraction (concentric, eccentric, and isometric), degree of tibal and femoral rotation, or differing hip adduction or abduction. Certain factors are thought to predominately influence VMO function: 1. Co-contraction of VMO and VL in relation to ankle movement; 2. Quadricep muscle activation at the same time as the ankle muscles or 100 ms earlier; 3. During activities such as standing on the heel or toes, where knee stabilization is important and the quadriceps and ankle muscles are co-activated[13]. It has been reported that activity in the soleus produces a discharge in not only to its motor neurones but also to the quadriceps motor neurons[14]. Regarding the benefits of CKC exercise and the effect of the limb/ankle position on the quadriceps muscle, this study aimed to investigate the effect of various positions of hip rotation (while standing on the toes) on the electrical activity of the quadriceps muscle.

PARTICIPANTS AND METHODS

This quasi-experimental study was performed on 35 non-athlete female participants between the ages of 18 and 36 years. Their body mass index's (BMI) were less than 30[15]. The goal of the treatment and procedures were explained to the participants, and written consent was obtained before proceeding with the study. This study was approved by the Ethical Committee of Shahid Beheshti University of Medical Sciences (approval number: 12933). The inclusion criteria were: 1) No previous history of pain when participating in more than two of the following activities; running, kneeling, sitting for prolonged periods of time, or going up and down stairs, during the three months prior to the study; 2) no previous history of lower limb surgery or musculoskeletal injury of the hip, knee, or ankle[14, 16]. Participants were excluded from the study if they lost interest in continuing or experienced a musculoskeletal injury during the study period.

The electrical activity of the rectus femoris (RF), VMO, and VL was recorded using a DataLog EMG system (Biometrics Ltd., UK). All signals were within a 20 to 500 Hz bandwidth and the sampling rate was 1,000 Hz. Signals were recorded from the dominant limb. To determine the dominant limb, the participants were asked to kick a ball three times. The prevailing limb was determined as the one used more frequently[7]. All experiments were scheduled to be performed at the same place and at the same specific time of day. The skin of the signal recording area was prepared by cleaning with 70% alcohol[16]. The silver/silver chloride electrodes (2 cm diameter) were attached to the RF, VMO and VL according to the recommendations of SENIAM (Surface EMG for Non-Invasive Assessment of Muscles)[17]. In addition, muscle bulk was palpated in the testing position to ensure accurate electrode placement. Before the main recording procedure, a signal was recorded in a state of maximal voluntary isometric contraction (MVIC) to provide a standard value for normalizing signal properties. The electrical activity in the testing position was expressed as a percentage of the MVIC to compare participants. This normalization of data increases reliability.

At the beginning of the study, the participants were trained for MVIC tests in a seated position with EMG electrodes placed on the RF, VMO, and VL. After five minutes of rest, a physiotherapist applied resistance against knee extensor muscles at maximum effort, with the knee flexed at 45° (like manual muscle test technique). This technique was implemented on the dominant side and the knee angle was checked using a goniometer. All participants received vocal cues to maximize their force of contraction. The contraction was sustained for five seconds and repeated 3 times with 3-minute intervals. The maximum signal amplitude was recorded as their MVIC[18]. As a warm-up, the participants were then asked to perform 3 sets of 30-second stretches of the quadriceps, hamstrings, calf muscles and hip adductors[19]. EMG activity was then recorded in the following positions; standing on the toes with a neutral hip position, 15° of external hip rotation, 30° of external hip rotation, full range of motion of the hip in internal rotation so that the left and right toes touched each other, 15° of internal hip rotation, 30° of internal hip rotation and 45° of internal hip rotation. To set the position of hip rotation, a plate was designed with two parallel lines 30 cm apart. Additional lines were printed at angles of 15, 30, and 45° to the parallel lines (Fig. 1). The participants were asked to stand on the plate in a position so that the middle line passed posteriorly through the central

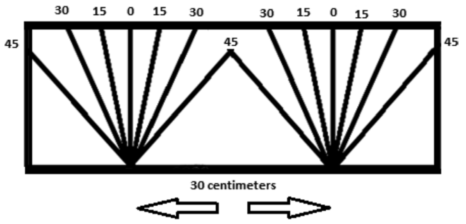

Fig. 1. Designed plate to set the angle of hip rotation.

Table 1. Demographic information of the participants (n=35)

Variables	Mean ± SD	Range	
		Minimum	Maximum
Age (years)	25.62 ± 4.82	18	36
Height (cm)	162.85 ± 7.07	151	179
Weight (kg)	60.84 ± 8.53	34.80	79
BMI (kg/m^2)	22.84 ± 2.61	18.02	27.43

Table 2. Normalized values (% of MVC) for the 3 muscles in 7 angles

	Rectus femoris		Vastus medialis oblique		Vastus lateralis	
Different angles	Mean ± SE	Range (Min–Max)	Mean ± SE	Range (Min–Max)	Mean ± SE	Range (Min–Max)
15° Int.Rot	22.05 ± 3.22	1.43–70.22	28.40 ± 3.78	1.47–88.91	35.28 ± 4.99	3.53–150
30° Int.Rot	30.14 ± 4.34	1.06–88.27	32.58 ± 4.00	2.1–78.54	39.40 ± 5.03	3.85–118.13
45° Int.Rot	27.78 ± 4.03	0.3–94.11	43.96 ± 7.56	3.38–201.07	46.70 ± 6.94	2.04–203.79
Neu.Pos	22.51 ± 3.58	1.89–87.88	26.84 ± 4.56	1.14–88.68	34.26 ± 5.74	0.81–122.47
15° Ext.Rot	24.71 ± 3.72	0.29–95.58	28.06 ± 4.66	1.16–106.73	34.84 ± 5.28	0.13–125.16
30° Ext.Rot	27.90 ± 5.62	0.91–161.24	36.26 ± 9.85	0.97–297.88	39.99 ± 7.18	2.25–149.46
45° Ext.Rot	20.28 ± 3.21	0.31–68.31	25.69 ± 4.27	1.06–84.81	27.25 ± 4.08	0.72–86.63

MVC: Maximum Voluntary Contraction; Neu.Pos: Neutral Position; Int.Rot: Internal Rotation; Ext.Rot: External Rotation. Range (Min–Max): Range (Minimum–Maximum). All data were reported as means ± standard error (Mean ± SE).

calcaneus and anteriorly through the second toe. For hip rotation, the participant's feet were placed on the angled lines as described above. The starting position was standing with feet 35 cm apart and arms hanging neutrally[14)]. To start recording, participants stood on their toes whilst lifting their heels. They were verbally instructed to adopt this position, hold for five seconds and then return to the resting position. This movement was repeated 3 times with 30-second intervals to eliminate the effect of fatigue on recordings. After four minutes of sitting in a chair at rest, the participants then stood on the plate and switched to another randomly selected foot angle. Root mean square (RMS) and MVIC were calculated from EMG recordings of RF, VMO, and VL, and were normalized using Equation 1.

Equation 1: Normalized EMG = [EMG activity − EMG Rest/EMG MVIC − EMG Rest] ×100

Raw data was analyzed using SPSS ver. 18. Kolmogrov-Smirnov (K-S) test was used to determine the normal distribution. An ANOVA with repeated measures and a Bonferroni method for paired comparisons was used to assess the differences. The significant level was set at $p<0.05$.

RESULTS

Demographic information of the participants is presented in Table 1. Normal distribution for normalized data values were assessed by K-S test (p=0.11). Table 2 demonstrates a summary of normalized values for the three muscles at seven angles. ANOVA repeated measures showed no significant difference among EMG activity for 30° of internal rotation, 30° of external rotation, and 45° of external rotation ($p>0.05$). However, there was a significant difference in EMG activity of muscles in 15° of internal rotation (p=0.003), 15° of external rotation (p=0.039), and 45° of internal rotation (p=0.015), and neutral position (p=0.003).

Bonferroni's test for pairwise comparisons showed that the activity of VL in 15° of internal rotation was significantly more than that of RF (p=0.002). The difference between VMO and VL activities (p=0.327) as well as that between VL and RF activities (p=0.26), was not significantly different. VL activity was significantly more than RF activity in the neutral angle position (p=0.004). The difference between VMO and VL activities (p=0.72) and between VMO and RF activities (p=0.643) were not significantly different in the neutral angle position. In 15° of internal rotation, the activity of VL was significantly more than that of RF (p=0.002), but there was no significant difference between VMO and VL activities (p=0.237) or between VMO and RF activities (p=0.261). In 45° of internal rotation, VL activity was significantly more than RF activity (p=0.016), but the difference between VMO and VL activities (p=1.000) and between VMO and RF activities (p=0.105) were not significant.

DISCUSSION

The results of this study show that the relative activities of RF, VL, and VMO are different depending on hip rotation angle in CKC while standing on the toes. The hypothesis that VMO activity is higher than VL activity was not proven. However, during 15° and 30° of internal rotation, a neutral angle and 15° of external rotation, VL was more active than the other two muscles. At these angles VL activity was significantly higher than RF activity, but not higher than VMO activity. There was no significant difference among VL, VMO, and RF activities in 30° of internal rotation and 30° and 45° of external rotation.

There are similar studies investigating VMO and VL activity at different hip angles with controversial results. Laprade et al. found that in external knee rotation and internal hip rotation, electrical activity was higher in VMO compared to VL20). Sykes and Wong compared the straight leg raise (SLR) in internal rotation, external rotation, and neutral position of the hip, and reported higher activity of VMO compared to VL in SLR with hip external rotation21). In a study by Kushion et al. on the SLR with the hip in external rotation and in a neutral position, the SLR was performed in OKC and once in a short arc whereby the knee was flexed at 60° with the ankle supported on a table. It was reported that the short arc SLR did not selectively increase VMO activity but increased the level of activity of VMO and VL compared to the OKC SLR22). In all of these studies, the tests were performed in OKC activation. In the current research, the effect of hip rotation in CKC was studied on RF, VL, and VMO activity. CKC tests are more functional and used to facilitate normal muscle function, and are therefore preferable exercises for improving muscle function. CKC exercises have greater proprioceptive feedback and balance, which essential for improving daily activation4). Serrão et al. studied the effect of tibial rotation in CKC exercise on EMG activity of VMO and VL in an isometric leg press position, with the knee flexed at 90° with submaximal muscle contraction. Results showed that with medial tibial rotation, VL activity was more than VMO activity and that tibial rotation had no effect on the priority of VMO activity16). This study was similar to the present study in using CKC exercises, however differed in the knee position. Similarly, the results of the present study did not show a significant increase in VMO activity compared to VL and RF activities. Elton studied the effect of ankle position on VMO and VL in a CKC position. He demonstrated that when participants stood on their toes and anterior posterior perturbation was applied to the back of the knee, then VMO activity differed. In other words, simultaneous activity of the ankle and knee muscles was identified14). Elton's findings formed the basis of this present study design. In this study, tip-toe standing was added to hip rotation, and as previously mentioned, did not facilitate VMO. In this study there was no perturbation in the testing design. In summary, CKC exercises are generally accepted and were used because of their effectiveness in facilitating co-contraction and increasing stability and balance. In the positions tested, VMO activity as a dynamic stabilizer of patella did not increase in comparison to VL.

Despite the significant differences found between VL and RF activities in a neutral position, 15° and 45° of internal rotation and 15° of external rotation, and the insignificant difference in activity level between VL and VMO in all testing positions, tip-toe standing exercises cannot be recommended for strengthening the VMO muscle because of the higher VL activity recorded in all testing positions. The present study showed that the average VL activity was the highest in all the exercises. According to the results of this study it is suggested that in some cases, such as hyperlaxity and vastus lateralis weakness which can play a role in the development of medial patella subluxation, the VL may be selectively strengthened by performing hip rotations while standing on the toes. Further research is needed to distinguish the effects of these functional exercises in symptomatic participants.

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Conflict of interest

None of the authors declare competing financial interests.

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