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Comparison of the Electromyographic Changes in the Vastus Medialis Oblique and Vastus Lateralis Muscles According to the Knee Joint Angle During Squat Exercise Using a Gym Ball

Hee-won Jeong, MSc, PT, Seung-chul Chon, PhD, PT
Dept. of Physical Therapy, College of Medical Science, Konyang University

Abstract

Background: Squatting is one of the best functional exercises to strengthen the quadriceps muscle in independent gait and activities of daily living. Although the use of a gym ball during squat exercise is the most common way of strengthening the vastus medialis oblique (VMO) muscle, published data on this subject are limited.

Objects: The purpose of this study was to compare the sequential muscle activation of the VMO and vastus lateralis (VL) muscles during squat exercise using a gym ball at different knee flexion angles.

Methods: Forty healthy adults were randomly divided into experimental (squat exercise using a gym ball) and control (squat exercise alone) groups, in which squats were performed at 45° and 90° knee flexion. Electromyographic (EMG) activity data were collected over 10 seconds under the 2 angles of knee flexion (45° and 90°).

Results: There was significant group and time interaction effect for VMO and VL muscle activation at 45° knee flexion. This was similarly demonstrated at 90° knee flexion. No significant group main effect and time main effect for VMO and VL muscle activation were noted at 45° knee flexion, respectively. In contrast, there was significant group main effect and time main effect for VMO and VL muscle activation at 90° knee flexion. These significant differences were demonstrated through two-way analysis of variance over repeated measurements, suggesting that the EMG activity of the VMO muscle during squatting with a gym ball showed remarkable improvement compared to that of the VL muscle.

Conclusion: This research suggests that squat exercise using a gym ball may be more beneficial in improving the activity of VMO than of the VL muscle at both 45° and 90° of knee flexion, respectively. We highly recommend squat exercises with a gym ball for selective strengthening of the VMO muscle in knee rehabilitation.

Key Words : Electromyography; Gym ball; Squat exercise; Vastus lateralis; Vastus medialis oblique.

Introduction

Squatting is considered the best way to help restore the strength of the quadriceps muscle in overall activities of daily living. The squatting movement increases knee extensor muscle strength, which then indirectly improves the quality of life in the field of strength and conditioning (Schoenfeld, 2010). Muscle forces also vary depending on the angle of the knee joint assumed during a squat (Barton et al, 2014). The lower limb muscle activities also differ according to the movement of the arms and length-tension relationship in squat exercises (Dionisio et al, 2008).

Many muscle groups can be activated simultaneously when squatting is performed, as it is a multi-joint task. Several studies have shown that various squat exercises resulted in altered quadriceps muscle activity, depending on the foot position, surface stability, intensity of load, and range of motion (Aspe and Swinton, 2014; Paoli et al, 2009). As a multi-joint exercise, the knee extensors are considered to be the prime movers during a squat. In par-

Corresponding author: Seung-chul Chon keyjune@konyang.ac.kr

ticular, the use of a gym ball is already widely accepted as a common way to selectively strengthen the vastus medialis oblique (VMO) muscle in several clinical conditions (Oh, 2013). As the VMO and vastus lateralis (VL) muscles are antagonistic in terms of the knee joint position, the VMO and VL must be amplified in a coordinated manner to ensure efficient neuromuscular function of the quadriceps muscle. Knee joint problems such patellofemoral pain syndrome alters the biomechanical imbalance between the VMO and VL muscles.

Numerous studies have been reported about the electromyographic (EMG) activity of the VMO and VL muscles (Cowan et al, 2001; Sheehy et al, 1998). For instance, Boling et al (2006) reported that the VMO muscle activity increased during squat exercise with a gym ball because the activity of the hip adductor muscle is promoted. And also, it was reported that squatting performance required hip adduction as well as knee flexion (Boling et al, 2006). Irish et al (2010) referred that VMO/VL muscle activity ratio for selective strengthening VMO is recommended to 1.2:1 as the closed-kinetic chain exercise.

In contrast, Dionisio et al (2008) reported that the VMO muscle activity is higher than that of the VL, regardless of the angle of the knee joint during squat exercises, which indicates that the movement strength of the quadriceps muscle increases by lumbar stabilization irrespective of the angle of the knee joints. Park et al (2013) reported that below 100 degree of the knee joint only revealed increasing muscle activity of the quadriceps muscle through repeated squat exercises. Koh et al (2011) reported that the force of hip adduction could increase the VL muscle activation during squatting. Kim (2012) suggested that foot positioning and tibial torsion could affect the muscle activity of both the VMO and VL. Lastly, Barton et al (2014) reported that the activity of the gluteus maximus and gluteus medius muscles increased when squat exercise was performed using a gym ball.

Although evidence suggests that knee joint position drives the quadriceps muscle's performance during squatting (Oh, 2013; Park et al, 2013), little is known about the neuromuscular changes of the VMO and VL muscles that occur from a muscle activation standpoint. Elucidating how muscle activation patterns change in the knee extensors during squatting at different knee angles would enhance our understanding of how one could capitalize on maximizing muscle activation to specific evaluations and EMG normalization. The purpose of this study was to evaluate the muscle activity of the VMO and VL muscles during dynamic squatting using a gym ball compared with the existing static measures at two different knee joint angle positions.

Methods

Subjects

Forty healthy adults were recruited from a local community, and all of the subjects gave their informed consent. Randomization was done with sealed envelopes. The sealed letters for the experimental group (squat exercise using a gym ball) and the control group (squat exercise alone) were arranged by the experimenter. The experimenter prepared group allocation on a sheet of paper and blindly gave it to the subjects. Subjects were allocated before the initial measurement. All of them participated in the measurements. The experimenter undertaking the measurement was also blinded to the group allocation. The study subjects were free from any known medical problems. Subjects with any neuromuscular pathologies or history of spinal surgery were excluded from the study. The demographic characteristics of the study subjects are shown in Table 1.

Procedures

Surface EMG was used to record the amplitudes of the contractions of the VMO and VL muscles. These measurements were collected for the experimental and control groups to determine the sequential activation of these muscles during squatting. In order to reduce im-

Table 1. Demographic characteristics of the subjects (N=40)

Parameters	Experimental group (n_1=20)	Control group (n_2=20)	t	p
Sex (female/male)	10/10	10/10		
Age (year)	20±1.2[a]	20±1.1	-.271	.586
Height (㎝)	166.4±8.3	165.5±7.8	-.360	.574
Weight (㎏)	63.9±11.0	62.6±11.1	-.379	.953

[a]mean±standard deviation.

pedance, each subject's skin was shaved and an electrode gel was applied. A pair of active electrodes (inter-electrode distance of 2 ㎝) was placed in parallel over the muscle bellies to be tested. Tape and elastic straps were used to eliminate cable movement artifacts and to fix the electrode patches onto the skin.

The Myo-Research software (TeleMyo 2400T DTS, Noraxon Inc., Scottsdale, USA) was used to acquire the EMG signals at a sampling frequency of 1024 ㎐, and processed with a bandpass (20∼450 ㎐) and a 60 ㎐ notch filter. The root mean square (RMS) EMG amplitude for these muscles was calculated using the average time during the squat exercise, while the sequential activations of the VMO and VL muscle activities were displayed on a computer monitor. Electrode patches with a diameter of 1.1 ㎝ were placed on the VMO and VL muscles at standardized sites, as described by Gilleard et al (1998). To normalize the EMG signals recorded for each muscle, the RMS of 5 seconds maximal voluntary isometric contraction (MVIC) was calculated for each muscle at the manual muscle testing positions, as recommended by Kendall et al (2005); all of the EMG data were averaged over three repetitions of each measurement. The EMG signals collected were then expressed as a percentage of the calculated RMS of the MVIC (%MVIC).

During the squat exercise with a gym ball of diameter 180 ㎜, subjects were asked to adopt the standing position, and a 10 seconds set that ranges from standing to sitting was performed with the legs spread shoulder-length apart, and the heels planted firmly on the ground, while bending to the instructed knee flexion angles (Figure 1). Subjects were then asked to squat with a gym ball between their knees while adducting the hips in order to suspend the ball. An automatic auditory cue via a verbal instruction and visual feedback via a mirror was provided by the experimenter. The order of testing was randomly determined for each subject in order to avoid the learning effect. The squat exercise was performed for 10 seconds at 2 different angles of knee flexion (45° and 90°), and the RMS EMG amplitudes were collected as mean values.

The activation of the VMO and VL muscle was displayed on a computer monitor. Subjects were in-

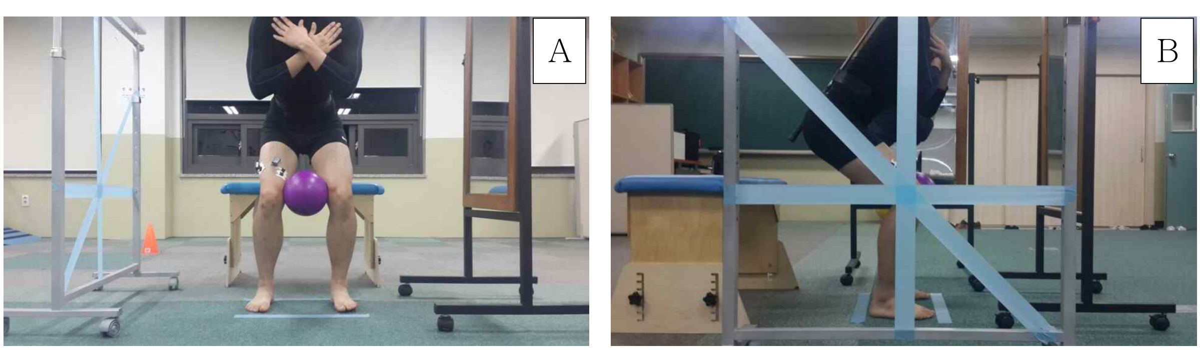

Figure 1. Squat positions (A: anterior view, B: lateral view).

structed to squat through contraction of the quadriceps muscles, including the VMO and VL muscles, followed by low abdominal contraction using a gym ball, and then rest before the next measurement. An automatic auditory cue was used to trigger each squatting event, which lasted for 10 seconds over a trial period. Based on this protocol, an immediate collection of the muscle activity data was displayed on the monitor and stored for further analysis. Data that were unacceptable due to movement artifact were discarded, and the collection was then repeated. The speed of the squat exercise was controlled to a comfortable 10 seconds to avoid fatigue of the lower limb muscles; a rest interval was given between each consecutive trial (Gefen et al, 2002).

Statistical analysis

The results are expressed as mean±standard deviation. The normal distribution of the sample was tested using the Kolmogorov-Smirnov test, which showed a normal distribution for all variables. Two-way analysis of variance with repeated measures was used to assess the main effects (group and time effects) and the interaction effects on each activation of the VMO and the VL muscles during squatting at 45° and 90° knee flexion, respectively. The collected data were analyzed using a SPSS ver. 18.0 (SPSS Inc., Chicago, IL, USA). The level of statistical significance was set at a p value of $<.05$.

Results

There was no significant group effect ($F=4.005$, $p=.530$) and time effect ($F=.307$, $p=0.058$) for VMO and VL muscle activation at 45° knee flexion. However, at this angle, there was significant group and time interaction effect ($F=9.316$, $p=.004$) for VMO and VL muscle activation (Table 2), indicating that the EMG activity of the VMO muscle showed remarkable improvement compared to that of the VL muscle, attributable to squatting using a gym ball.

Similarly, there was significant group effect ($F=26.025$, $p<.001$) and time effect ($F=44.715$, $p<.001$) for VMO and VL muscle activation at 90° knee flexion. Additionally, at this angle, there was also significant group and time interaction effect ($F=18.083$, $p<.001$) for VMO and VL muscle (Table 3), suggesting that squat exercises using a gym ball showed notable improvement, compared with the controls.

Discussion

Several studies have investigated the effects of squat exercises on the performance of a variety of activities on the muscles around the knee joint (Aspe and Swinton, 2014; Paoli et al, 2009; Schoenfeld, 2010). Different knee joint positions influence the quadriceps muscle forces during squat exercises; however, in spite of several results, little is known regarding the neuromuscular changes that occur from a quadriceps muscle activation standpoint. In this study, we evaluated the muscle activity of the VMO and VL muscles at two angles of knee joint flexion: at 45° and 90°, respectively. The major finding of this investigation was that during squat exercises with a gym ball, both knee joint flexion positions demonstrated high VMO muscle activation; in contrast, squat exercises performed on its own were as-

Table 2. Muscle activity of the vastus medialis oblique and the vastus lateralis at 45° knee flexion

Variable	Muscle	Experimental (n_1=20)	Control (n_2=20)	Group effect		Time effect		Interaction effect	
				F(1,38)	p	F(1,38)	p	F(1,38)	p
Knee flexion 45°	VMO[a]	22.26±6.54[b]	16.94±6.64	4.005	.530	.307	.058	9.316	.004
	VL[c]	20.86±6.46	18.96±3.68						

[a]vastus medialis oblique, [b]mean±standard deviation, [c]vastus lateralis.

Table 3. Muscle activity of the vastus medialis oblique and the vastus lateralis at 90° knee flexion

Variable	Muscle	Experimental (n_1=20)	Control (n_2=20)	Group effect		Time effect		Interaction effect	
				F(1,38)	p	F(1,38)	p	F(1,38)	p
Knee flexion 90°	VMO[a]	60.15±16.55[b]	37.31±8.85	26.025	<.001	44.715	<.001	18.083	<.001
	VL[c]	50.29±12.78	35.11±8.48						

[a]vastus medialis oblique, [b]mean±standard deviation, [c]vastus lateralis.

sociated with lower VMO muscle activation values. This result indicates that squat exercises using a gym ball was effective in strengthening the VMO muscle for quadriceps imbalance, considered one of the main contributing factors based on the neuromuscular changes observed in patients with knee joint problems (Park et al, 2013).

During the squat exercise, the collected EMG data for VMO and VL muscles were methodologically normalized as percentage values of %MVIC. The resulting data from direct comparisons obtained for different subjects showed less reliability as absolute amplitudes of EMG activity vary broadly among subjects (Cram et al, 1998). Therefore, the EMG activity for the subjects in this study was expressed as the percentage of the activity performed during maximum voluntary contraction; the %MVIC value obtained thus indicated the efficacy of the muscle contraction. In order to analyze the EMG change of both VMO and VL during squatting, we collected EMG data for 10 seconds. The activity of the VMO and VL muscles begins from the start to the end of a squat. The EMG data collected during this 10 seconds squatting exercise therefore mainly represent the muscular efforts associated with the whole process, which activates the VMO and VL to properly adapt the knee joints to gravitational force.

To quantify the mechanical movements of knee pathologies, most studies utilized the VMO:VL ratio to reflect the relative contributions of the VMO and VL muscles (Sheehy et al, 1998). However, apart from these two muscles, several other muscles and joints interact around the knee joints. In this study, we focused on the activation of the VMO and VL muscles according to the changing angle of the knee flexion in the sagittal plane. Additionally, variables such as knee joint height level, foot positions and body positions were well controlled during measurement process in this study.

The present EMG data are consistent with previous findings investigating the effects of the application of a gym ball on VMO muscle activation during squatting. At 45° and 90° knee joint flexion, the amplitude of the root mean square VMO muscle EMG data during the squat exercise in combination with a gym ball increased by approximately 38% and 62%, compared with that of the squat exercise alone, from 16.94 to 22.26 %MVIC and from 37.31 to 60.15 %MVIC, respectively. Our results confirm that squat exercises performed with a gym ball at two different knee joint flexion positions can increase hip adductor muscle activity associated with lumbar stabilization, resulting in increased activity of the VMO muscle. Additionally, although there were no statistically significant results between the 45° and 90° knee joint flexion, the VMO muscle activation tended to increase at the 90° flexion during squat exercises with a gym ball. These findings further indicate that low levels of knee flexion conditions may have produced recruitment of the hip adductor muscles, which efficiently stimulated the lumbar stabilization against the gym ball, leading to augmented squat exercise.

Certainly, these results have important clinical implications, as they demonstrated that squat exercise in combination with a gym ball is beneficial for selective recruitment of the VMO muscle and its closed-kinetic mechanism of action around the knee joint, and that the mechanism of stronger muscular-fascial chaining can be further augmented by hip adductor muscles. Previous evidence on the clinical management of knee joint problems suggests that support and protection of the VMO muscle is essential to stabilize the knee joints during selective strength training of the VMO muscle, thereby minimizing clinical complaints about patellofemoral pain syndrome, osteoarthritis, and knee joint instability.

Several shortcomings were identified in this research, which may be considered to enhance more robust and larger clinical studies in the future. First, this research represents a short-term period intended to investigate the immediate effects of squat exercises in combination with a gym ball among healthy subjects. Future studies examining the long-term effects of the intervention in pathological populations, such as those suffering from patellofemoral pain syndrome, osteoarthritis, and knee joint instability will be beneficial. Second, our sample size was admittedly small; a larger study will be required to corroborate our results. Third, muscle activity was evaluated exclusively with surface EMG, thereby opening the possibility of cross-talk or movement artifacts from the adjacent muscles during the squatting. Fourth, we did not consider more detailed kinematic or kinetic factors when measuring the effects of squatting. Kinematic data detected by measurements such as motion analysis could provide more detailed movement pattern data. However, the emphasis of this research was to identify the changes in VMO and VL muscle activation patterns that may be considered a primary cause of the majority of knee pathologies.

Conclusion

This study showed that squat exercises combined with a gym ball is useful in enhancing muscle activation in the VMO muscle. It offers clinical insights into the additive effects of a gym ball in selectively-stimulating the VMO muscle, and suggests that it may be used as an alternative squat exercise for the management of patients with patellofemoral pain syndrome, osteoarthritis, and knee joint instability.

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