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Hip Adduction Does not Affect VMO EMG Amplitude or VMO:VL Ratios During a Dynamic Squat Exercise

Michelle Boling, Darin Padua, J. Troy Blackburn,
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Context: Clinicians commonly attempt to facilitate vastus medialis oblique (VMO) activity by instructing patients to squeeze a ball between their knees during squatting exercises. **Objective:** To determine whether VMO activation amplitude and the VMO to vastus lateralis (VL) activation ratio (VMO:VL) were altered when performing active hip adduction during a dynamic squat exercise. **Design:** Single test session. **Participants:** Fifteen healthy subjects, with no history of knee pain, volunteered for this study. **Intervention:** Surface EMG of the VMO, VL, and hip adductor (ADD) muscles were recorded while subjects performed 10 consecutive squats against their body weight through a range of 0° to 90° of knee flexion. Subjects performed the squat exercises during two different conditions: (1) active hip adduction and (2) no hip adduction. **Main Outcome Measures:** Average VMO EMG amplitude and VMO:VL ratio were determined during the knee flexion (0° to 90°) and knee extension (90° to 0°) phases of the squat exercise. **Results:** Active hip adduction did not significantly change VMO amplitude or VMO:VL ratio during the knee flexion or knee extension phases of the dynamic squat exercise. **Conclusions:** Based on these results, we conclude that VMO amplitude and the VMO:VL ratio are not influenced by performing active hip adduction during a dynamic squat exercise in healthy subjects. **Key words:** knee, electromyography, squat

The origin of the vastus medialis oblique (VMO) from the adductor longus and magnus tendons has led clinicians to believe that an isometric contraction of the hip adductors may facilitate VMO activity when strengthening the quadriceps.^{1,2} Quadriceps strengthening is especially important for rehabilitation programs following anterior cruciate ligament (ACL) reconstruction as well as in patients with patellofemoral pain syndrome (PFPS). When performing quadriceps strengthening exercises, it is crucial to have proper patella alignment to prevent anterior knee pain development. The VMO and vastus lateralis (VL) align the patella within the trochlear groove as the knee moves through flexion and extension.^{1,3} Therefore, imbalances in activation of these muscles can cause patellar malalignment and

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lead to anterior knee pain. Imbalances in activation of the VMO and VL can be assessed with the VMO:VL ratio. Previous research has reported that healthy subjects have significantly larger VMO:VL ratios than subjects with PFPS.⁴ Therefore, determining exercises that increase the VMO:VL ratio is important for treatment of individuals who may have an imbalance in VMO and VL activation.

Tibial rotation and hip adduction have been suggested as mechanisms which may selectively increase VMO activity when performing quadriceps strengthening exercises.⁵⁻⁹ Signorile et al⁵ investigated the use of tibial internal rotation when performing a knee extension exercise and revealed that VMO activity was not selectively increased but overall quadriceps activity was increased. Willis et al⁹ reports that an open stance cycling position (tibial external rotation) significantly increased the VMO/VL ratio as compared to the traditional cycling position (neutral tibial rotation). Other studies^{2,6-8} were performed to investigate the effects of hip adductor contraction on VMO activity during open kinetic chain (OKC) exercises. Laprade et al⁶ demonstrated that adding an isometric hip adductor contraction while performing knee extensions did not preferentially activate the VMO. Similarly, Zakaria et al⁸ concluded that when performing quadriceps sets combined with hip adduction, VMO activity does not significantly increase as compared to quadriceps sets without hip adduction and quadriceps sets with active dorsiflexion. In contrast, Hanten and Schulthies² and Monteiro-Pedro et al⁷ observed that VMO activity significantly increased when subjects performed isometric contraction of the hip adductors during OKC quadriceps exercises. Additional studies¹⁰⁻¹³ have been conducted to investigate the effect of hip adduction on quadriceps activity during closed kinetic chain (CKC) activities. The results of three of the investigations indicated an increase in quadriceps activity when hip adduction is incorporated with a closed kinetic chain exercise.¹⁰⁻¹²

Few investigations have used quadriceps exercises that are common in a clinical setting. Based on our observations, many clinicians have patients perform a “ball squeeze” during a squat exercise. Performing a squat while isometrically contracting the hip adductors in order to squeeze a ball between the knees, is believed to facilitate VMO activity because of the VMO’s attachment to the adductor longus and magnus tendons.^{1,2} The isometric adductor contraction may provide a more stable origin for the VMO as it contracts during the squat motion.² However, no research has been performed to determine whether performing a “ball squeeze” during a squat exercise facilitates VMO activity. Therefore, the purpose of this study was to determine if active hip adduction performed during a dynamic squat exercise affects average VMO electromyography (EMG) amplitude and VMO:VL ratio.

Methods

Subjects

Fifteen healthy volunteers (8 females, 7 males, age = 22.27 ± 2.69 years, height = 172.21 ± 6.99 cm, mass = 70.42 ± 16.07 kg) with no history of knee abnormalities or injury to the lower extremities within the past six months participated in this study. Additionally, subjects were not to have participated in a lower extremity rehabilitation program within the six months prior to testing. All subjects read and

signed a written consent form that was approved by the university's Institutional Review Board. The dominant lower extremity was defined as the limb which the subject would use to kick a ball for maximum distance and was used for EMG data collection.

Instrumentation

Surface Electromyography. An eight-channel EMG system (Konigsberg Instruments, Inc., Pasadena, CA) was used to record muscle activity. Unit specifications included an amplifier gain of 10,000 over a frequency bandwidth of 2000 Hz, CMRR 114 dB, and input resistance from 20 MOhm to 1 GOhm. Bi-polar Ag-AgCl surface electrodes (Medicotest, Rolling Meadows, IL) measuring 10 mm in diameter with a center to center distance of approximately 20 mm were placed in parallel arrangement over the muscle bellies¹⁴ of the vastus medialis oblique (VMO), vastus lateralis (VL), and adductor longus muscles (ADD). The VMO electrode was oriented at approximately a 55° angle, and the VL electrode was oriented at approximately a 12° angle.¹⁵ A ground electrode was placed over the tibial tuberosity. Muscle activity was collected from surface electrodes via a battery-operated FM transmitter/amplifier worn by the subject. All data were collected and reduced using custom LabVIEW 6i software (National Instruments, Austin, TX).

Procedures

Subject Preparation—Surface Electromyography. Electrode sites were shaved and cleaned with isopropyl alcohol prior to application of surface electrodes. All electrode placements were confirmed with manual muscle testing and checked for minimal cross talk. Surface electrodes were further secured using an elastic bandage to prevent cable tensioning and limit movement artifact during the squatting motion.

Squatting Exercise. The EMG activity of the VMO, VL, and ADD musculature was recorded while subjects performed 10 consecutive squats. Subjects performed the repeated squatting motions against gravity from full extension to 90° of knee flexion. The squatting exercises were performed by having the subject place his/her back against a physioball (diameter = 55 cm diameter) on the wall in an attempt to eliminate friction between the subject and the wall and to control upper body positioning. The feet were placed hip-width apart (distance measured from ASIS to ASIS) in neutral tibial rotation (tibial tuberosity facing anteriorly) to standardize subjects foot positioning. Subjects were instructed to keep the arms in 90° of shoulder flexion, elbows extended, and maintain the torso in an upright position while performing the squat exercises (Figure 1). Knee range of motion during the squat exercise protocol was controlled as subjects were instructed to come to a fully extended knee position when ascending (concentric phase) and lightly touch a tripod set at 90° of knee flexion with the gluteal region when descending (eccentric phase). Rate of movement during the squat exercise protocol was controlled using a digital metronome set at a frequency of 25 squat cycles/min (approximately 1 squat cycle every 1.5 seconds). One squat cycle was defined as the period of time when



Figure 1—Illustration of dynamic squat exercise with active hip adduction.

the subject moved from an upright standing position to 90° of knee flexion and then back to the upright standing position. The phase of the squats was determined by a trigger pushed by the researcher that was recorded simultaneously through a separate analog channel. Subjects were instructed to maintain a constant rate of movement for both the concentric and eccentric phases of the motion.

Subjects performed the squat exercises under two different conditions: (1) maximal active hip adduction by squeezing a ball (diameter = 21.6 cm, mass = 0.4 kg) between their knees (ball squeeze) and (2) no hip adduction (no ball squeeze). The order in which subjects performed the squat exercises was randomized. Each subject was read a set of instructions before performing the squat exercise (Table 1), and then given as many warm-up repetitions as needed to perform the proper squatting motion. One minute of rest was given between the two different squat exercise conditions.

Table 1 Instructions Given to Subjects for Each Squat Exercise

Squat exercise with ball	Squat exercise without the ball
<ol style="list-style-type: none"> 1. Place the ball between your legs at your knees. 2. Maximally contract against the ball to hold it in place throughout the squatting motion. Try to apply the same amount of force against the ball during the squats. 3. Hold your arms out in front of you, eyes looking forward, and keep your back upright and flat against the ball. 4. Perform the squats to the beat of the metronome. Each beat signifies a different phase of the squat. Beat (start or descend). Beat (ascend or move back to the upright position). 5. Bend at your knees squeezing the ball between your knees until your bottom lightly touches the stool. 6. Do not stop when you touch the stool; ascend in a continuous motion still squeezing the ball between your knees. 7. Once you reach the position from which you started, you will bend at the knees again and repeat the squatting cycle for a total of 10 trials. I will keep count of the squats and tell you when to stop. 8. Hold the same contraction against the ball for all 10 squats. 	<ol style="list-style-type: none"> 1. Hold your arms out in front of you, eyes looking forward, and keep your back upright and flat against the ball. 2. Perform the squats to the beat of the metronome. Each beat signifies a different phase of the squat. Beat (start or descend). Beat (ascend or move back to the upright position). 3. Bend at your knees until your bottom touches the stool. 4. Do not stop when you touch the stool; ascend in a continuous motion. 5. Once you reach the position from which you started, you will bend at the knees again and repeat the squatting cycle for a total of 10 trials. I will keep count of the squats and tell you when to stop.

Data Processing and Analysis

Data Collection. All EMG data were sampled at a frequency of 1000 Hz. Post-acquisition, EMG data were band-pass filtered (10-350 Hz), notch filtered (59.5–60.5), and smoothed using a root mean square (RMS) sliding window function with a 20 ms time constant. EMG data was not normalized to maximal voluntary isometric contraction (MVIC) as this study was a within subjects design (fully repeated measures), thus allowing for comparison of non-normalized EMG amplitude between the two squat tasks.¹⁶

Mean EMG amplitude during the squat exercise conditions was calculated for the concentric and eccentric phases of the squat exercise separately. The concentric phase was defined as the period when the subject moved from 90° of knee flexion to full extension during the squat exercise. The eccentric phase was defined as the period when the subject moved from full extension to 90° of knee flexion. Each phase was identified in the EMG data by the trigger signal. The VMO:VL (VMO divided by VL) mean amplitude ratio was also determined during the concentric and eccentric phases of the squat. The average values for the middle 6 trials were used for statistical analysis.

Statistical Analysis

Separate repeated measures analysis of variance (ANOVA) were performed for the mean EMG amplitude of the VMO, as well as the VMO:VL ratio. Each analysis involved squat condition (2 levels: ball squeeze, no ball squeeze) and squat phase (2 levels: concentric, eccentric) as within subject variables. Statistical significance was set a priori at $\alpha < .05$. SPSS version 11.0 was used for all statistical analyses (SPSS Inc, Chicago, IL).

Results

VMO Activity

Statistical analyses revealed no significant main effect for the ball condition, $F_{1,14} = .001$, $P = .991$, and no significant ball condition by squat phase interaction, $F_{1,14} = .186$, $P = .673$ (Figure 2). Thus, performing active hip adduction using the “ball squeeze” technique in this investigation did not increase VMO activation. There was a significant main effect for squat phase, $F_{1,14} = 44.274$, $P = .001$. It was demonstrated that VMO activity during the concentric phase was 33% greater than that of the eccentric phase of the squat exercise.

VMO:VL Ratio

Statistical analyses revealed no significant main effect for the ball condition, $F_{1,14} = .441$, $P = .518$, nor a significant ball condition by squat phase interaction, $F_{1,14} = .654$, $P = .432$ (Figure 3). Based on these findings, the performance of a “ball squeeze” to achieve active hip adduction did not change the VMO:VL ratio. However, there was a significant main effect found for squat phase, $F_{1,14} = 5.682$, $P = .032$ as the VMO:VL ratio during the concentric phase was 20% greater as compared to that of the eccentric phase of the squat exercise.

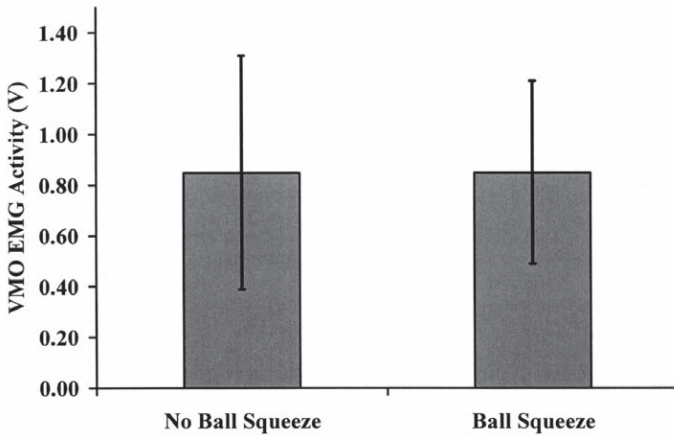


Figure 2—Average VMO EMG amplitude during both ball conditions.

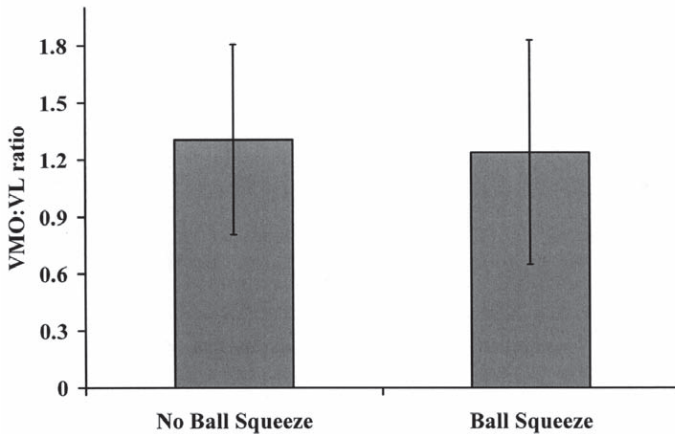


Figure 3—VMO:VL ratio during both ball conditions.

Adductor Activity

Statistical analyses revealed a significant main effect for ball condition, $F_{1,14} = 8.332$, $P = .012$ (Figure 4) and a significant main effect for squat phase, $F_{1,14} = 12.960$, $P = .003$. These findings indicate that the adductor activity was significantly greater during the ball squeeze condition as compared to the no ball squeeze condition. Also, adductor activity was 17% greater during the concentric phase of the squat exercise. No significant ball condition by squat phase interaction, $F_{1,14} = 1.036$, $P = 0.069$, was revealed.

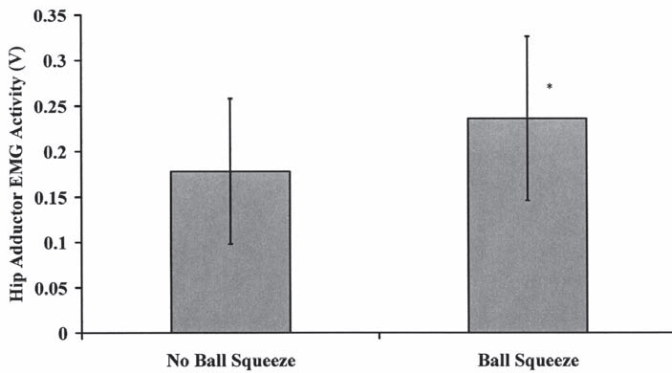


Figure 4—Hip adduction activity during both ball conditions.

Note: * $P < .05$.

Comments

The primary findings of this study indicate that neither VMO activity nor the VMO:VL ratio are significantly altered as a result of performing isometric hip adduction (ball squeeze) during a squat exercise. Direct comparison with previous research is difficult due to differences in methodology. Hertel et al¹³ used a single leg stance knee extension exercise and reported no increase in quadriceps activity when the exercise was combined with isometric hip adduction. However, these findings appear to disagree with previous research reporting an overall increase in quadriceps activity when isometric hip adduction was combined with a knee extension task.^{10-12,17} Some of these investigations incorporated a static wall slide exercise, which differs from the dynamic ball squat exercise incorporated in the current study.^{10,11,17} These studies revealed a 25-89% increase in quadriceps activity when performing a static wall slide exercise with active hip adduction in comparison to exercise conditions without active hip adduction.^{10,11,17} Earl et al¹² used a dynamic wall squat exercise and revealed approximately a 20% increase in quadriceps activity. While demonstrating an increase in overall quadriceps activity, none of the previous studies demonstrated a change in VMO activity or the VMO:VL ratio.

The lack of agreement between the current study and those of previous investigations may best be explained by differences in methodology. Previous investigations incorporated a static exercise while the current study used a dynamic squatting motion.^{10,17} Coqueiro et al¹¹ used a dynamic exercise but collected EMG activity during the static phase of the exercise. Differences in exercise execution between studies may greatly affect the demands placed upon the quadriceps, as well as the range of motion over which muscle activation was assessed. Both factors may influence the level of quadriceps activity and perhaps account for the discrepancies.

Earl et al¹² and Cerny¹⁰ used a dynamic squat exercise similar to the current study. However, the subjects in the previous investigations performed the squat exercise with their backs maintained flat against the wall and only through a 30°¹²

or 45° ¹⁰ range of motion. In the current study, subjects performed the squat exercise with their backs maintained against a physioball that rolled along the wall and squatted through a range of 0 - 90° of knee flexion. The physioball was used in an attempt to have subjects perform the squatting motion similar to the way in which they would perform the exercise in a “clinical” setting. In addition, the physioball helped to reduce the friction between the individual and the wall during the squat exercise. Greater friction during the wall slide squat exercise used by Earl et al¹² and Cerny¹⁰ may have increased the difficulty of this exercise in comparison to utilizing the physioball. The use of the physioball also allowed the subjects to maintain a more “natural” posture when moving into knee flexion by allowing flexion at the trunk as well as the ability to shift the hips posteriorly relative to the trunk. While allowing for a more “natural” positioning during the exercise, this change in positioning may have reduced the external flexion moment at the knee joint.¹⁸ The wall slide squat exercise used by previous investigations forced subjects to maintain their center of mass (COM) over the hips, and may have created a large external flexion moment that had to be counterbalanced by greater quadriceps activity.^{10,12} The external flexion moment was increased by moving the line of action of the center of mass posteriorly, increasing the moment arm relative to the knee joint. The combination of overcoming potentially larger friction forces and a greater external knee flexion moment may have made the squat exercise used by Earl et al¹² and Cerny¹⁰ more demanding than the ball squat exercise used in the current study. This may partially account for disagreement between the current study and previous investigations.

Another factor that may have contributed to the lack of agreement within the literature is the range of motion over which the squat exercises were performed. Previous studies that reported a significant increase in quadriceps activity have collected EMG data at 45° ¹¹ and 60° ¹⁷ of knee flexion or through an arc of 30° ¹² or 45° ¹⁰ of knee flexion. In this study, we chose to collect data through a 90° arc of motion based on previous research that has reported increased VMO activation at 60° of knee flexion during CKC knee extension¹⁹ and 65 - 85° during OKC knee extension.²⁰ Also, if a portion of the VMO originates from the adductor magnus and longus tendons,¹ when performing isometric hip adduction throughout a 90° arc of motion, we may expect to see increased activation throughout the range of motion. If we were to examine the VMO and VMO:VL ratio over arcs of motion such as 30° or during an isometric phase of the squat exercise, we may have observed findings similar to previous investigations.^{10-12,17}

The method of inducing isometric active hip adduction also differs between this study and previous studies. Investigators used a range of devices such as a pad, bolster, or a dynamometer that was placed between subjects' knees to perform isometric hip adduction during a quadriceps exercises.^{2,10-12} The current study had subjects maximally squeeze a rubber ball between their knees during the squat exercise. Problems such as subject discomfort, object stability, and maximal hip adduction effort by subjects may have caused the differing results in quadriceps activity. We do not feel that in our study the lack of significant findings was a result of subjects not actively contracting their hip adductors. Adductor muscle activity was monitored throughout the ball squat exercise in this study and increased significantly during the ball squeeze conditions in comparison to the no-ball squeeze squat exercises (Figure 4).

Perhaps the most important distinction between our study and previous investigations is the method of EMG processing. The current study and Hertel et al¹³ did not normalize the EMG data. The investigations that normalized EMG data were also the studies that reported significant increases in quadriceps activity.^{2,10-12} Due to the within subjects design of the current study and the variability associated with MVIC normalization, it was felt that normalizing to MVIC may increase the amount of variability of the data, thereby affecting the results. Also, previous investigations collected EMG data from a small arc of motion or during an isometric phase of the quadriceps exercise. The current study investigated a larger range of motion and divided this into the concentric and eccentric phases of the squat exercise. Thus, while this study and previous studies investigated similar variables, the methods were very different making direct comparison of results difficult.

The results from this study agree with previous studies that demonstrate no change in the VMO:VL ratio when performing active hip adduction during knee extension type exercises.^{10,12,21} Therefore, it does not appear that the VMO:VL ratio during a squat type of exercise is affected by performing active hip adduction; however, it was demonstrated that VMO activity and the VMO:VL ratio significantly increased during the concentric phase of the ball squat exercise compared to the eccentric phase. This finding is in agreement with previous research that has shown increased VMO and VL activity during the concentric phase of the squat exercise, particularly within the 90° to 60° arc of motion.²²⁻²⁴

Limitations

The major limitation to this research is that we studied normal, healthy individuals and not those who have VMO inhibition. Perhaps VMO activity and the VMO:VL ratio are affected by performing active hip adduction in those individuals with VMO inhibition, such as individuals suffering from PFPS or recovering from previous knee surgery. Future research should investigate the influence of isometric hip adduction during the squatting motion in subjects with demonstrated inhibition of the VMO.

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