Original Article

Electromyographic analysis of lower extremity muscle activities during modified squat exercise: Preliminary study

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ABSTRACT

The squat is a movement that keeps the knee angle at 90° while keeping the weight of the one's shoulder to the shoulder width and maintaining equal weight load on the left and right legs. However, sufficient muscle activation of the lower limb is necessary to maintain a knee angle of 90 degrees. Thus, this study has been conducted to confirm the possibility that a modified squat exercise compared to traditional squat exercise can be recommended for elderly or patients. Two healthy adult males participated in this study. They performed a traditional squat exercise and a modified squat exercise. The modified squat exercise was performed in a general squat exercise posture while keeping the knee at 90 degrees and extending the hip joint with leaning the ball behind the back (supine position). The muscle activity of rectus femoris, vastus medialis, vastus lateralis, and gastrocnemius during exercises was measured by surface electromyography. As a result of this study, it was found that muscle activities were less in the right and left rectus femoris, vastus lateralis, vastus medialis during the modified squat exercise compared to the traditional squat exercise. The results showed that the muscle strength of the lower limb was activated to less than 50% compared with the traditional squat exercise during the modified squat exercise. These results may be used as an effective rehabilitation method for patients with weak muscles in the lower limb. **Keywords:** Squat exercise; Muscle activity; Electromyographic analysis.

Cite this article as:
Song, S., Lee, S., Lee, D., Hong, S., & Lee, G. (2019). Electromyographic analysis of lower extremity muscle activities during modified squat exercise: Preliminary study. *Journal of Human Sport and Exercise*, *in press*. doi:https://doi.org/10.14198/jhse.2020.154.01

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Submitted for publication June 2019
Accepted for publication July 2019
Published *in press* October 2019
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

doi:10.14198/jhse.2020.154.01

INTRODUCTION

Squat is a multiple-joint exercise of the lower extremity considering the biomechanical mechanism (Dionisio et al., 2008; Flanagan et al., 2003; Liu et al., 2010). In the squat exercise, the subjects spread their feet shoulder width apart and bend their knees into a 90° angle while maintaining equal weight bearing on their left and right lower limb (Miyaji et al., 2012). Engaging in such squat exercise incurs large force in the lower extremity within a short time and contracts the related muscles of the lower extremity (Choi et al., 2015; Escamilla, 2001; Franco-Márquez et al., 2015; Rønnestad et al., 2015; Salem et al., 2003). Also, during the squat exercise, eccentric contraction occurs when ankle, knee, and hip joints are in flexion state and concentric contraction occurs when the joints are in extension state (Dionisio et al., 2008; Nagura et al., 2002), while at the same time, rectus femoris, vastus medialis, and vastus lateralis are activated (Cheron et al., 1997; Dan et al., 1999; Escamilla et al., 1998; Flanagan et al., 2003; Hase et al., 2004). Muscle activity through the squat exercise not only enhances muscle strengthening but also should significantly improve endurance (Escamilla, 2001; Marques et al., 2015). Therefore, the squat exercise can be used as an important exercise method to strengthen muscles necessary for daily life (Escamilla, 2001; Saeterbakken & Fimland, 2013).

Study where squat exercise was performed by subjects who were healthy adults or athletes focused on increase in range of motion and strengthening of muscles (Demers et al., 2018; Galvin et al., 2018), while studies where squat exercise was performed by subjects who were patients with mild knee injuries also focused on pain decrease, increase in range of motion, and strengthening of muscles (Bynum et al., 1995; Shelbourne et al., 1992). Furthermore, other previous studies mainly reported muscle activity by angle of the squat position performed in the standing position where subjects were healthy adults (Tang et al., 2001; Park et al., 2015). Thus, previous studies mainly had subjects who were healthy adults or patients with mild knee injuries (Bynum et al., 1995; Demers et al., 2018; Galvin et al., 2018; Shelbourne et al., 1992). However, there is question whether the squat exercise can be generally applied to the elderly with weak muscle strength and patients with knee injuries at a light to moderate level or a serious level. During squat exercise, certain level of activity is required by the lower extremity muscles so an exercise method that is relatively easier than the existing squat exercise may be required for the weaker elderly or patients with injuries to the lower extremity which are greater than light to moderate level. Generally, the squat exercise is performed in the standing position. But in this position, the muscle contraction has to oppose gravity so if the squat exercise was performed in the supine position where gravity is removed or reduced, the exercise can be relatively effective compared to the exercise performed in the standing position. But there is no study comparing the traditional squat exercise in the standing position with the modified squat exercise in the supine position.

Therefore, this study conducted to compare the activity of the rectus femoris, vastus medialis, vastus lateralis, and gastrocnemius while performing the traditional squat exercise and the modified squat exercise where the subjects were healthy adults.

METHODS

Participants

Two healthy adult males participated in this study. The subjects were recruited by announcing on an offline bulletin board within a University. Subjects were screened according to the following criteria. Selection criteria consisted of 1) healthy adult male in his twenties, 2) person who has no past history of back and lower extremity surgery, and 3) person who does not have osteoarthritis in the lower extremity. A total of 2 volunteers were recruited and satisfied the criteria. The characteristics of the participants are following; age of 23 (0), height of 172 (0) cm, and weight of 73.5 (1.5) kg. This study was conducted after approval by the Ethics Review Committee of Kyungnam University.

Procedure

The general characteristics of the subjects including age, height, and weight were collected through brief interview, and then, using surface electromyography, the maximum voluntary isomeric contraction of the subjects' rectus femoris, vastus medialis, vastus lateralis, and gastrocnemius were measured. And the subjects performed the traditional squat exercise and the modified squat exercise for 30 seconds. During they performed the exercises, the activities of the rectus femoris, vastus medialis, vastus lateralis, and gastrocnemius were measured using surface electromyography. Prior to the experiment, the researcher demonstrated the traditional squat exercise and the modified squat exercise to the subjects for accurate execution. All experiments were conducted in a quiet, wide space to minimize the effect of the external environment.

Squat exercise

Traditional squat exercise

Method of the traditional squat exercise is as follows. The subject spreads his feet shoulder width apart and bends his knees into a 90° angle while maintaining equal weight bearing on their left and right lower extremities (Miyaji et al., 2012). With the sole of the feet staying planted on the floor, while in the standing position, the head of the femur moves to a point which is horizontal with the height of the knee then returns to the original position. To ensure that the upper body does not lean forward at this time, swiss ball is squeezed between the wall and the subject's back when the above exercise is performed (Figure 1).

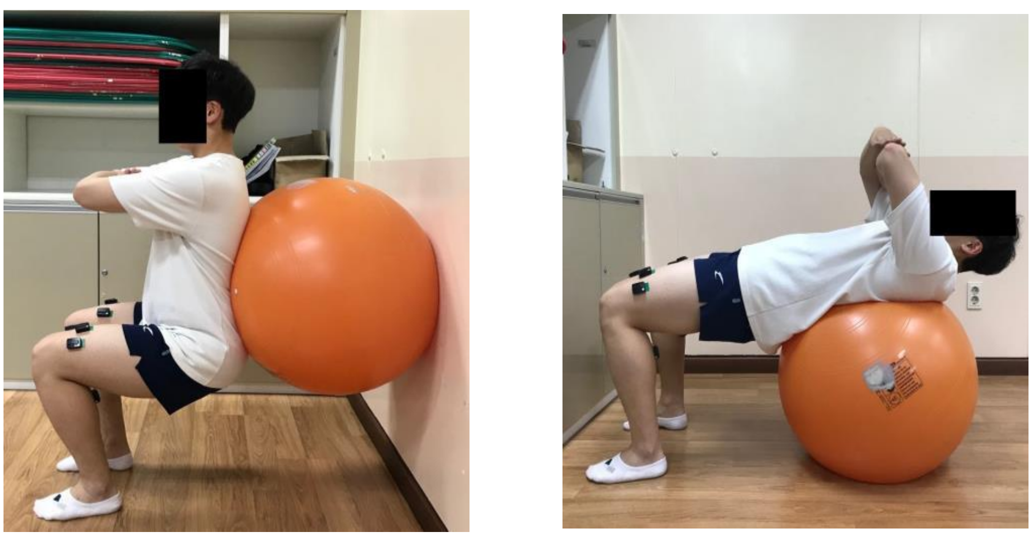

Figure 1. Traditional squat exercise (Lt.) and modified squat exercise (Rt.).

Modified squat exercise

Method of the modified squat exercise is as follows. In the supine position, a swiss ball is squeezed between the subject's back and the floor and the subject spreads his feet shoulder width apart to apply equal weight bearing on their left and right lower extremities. Angle of the knees is set to 90° and the position of the hip is maintained at the same height as the knees. While the subject maintains the modified squat exercise posture, the subject is cautioned not to lean his upper body to the side when performing the exercise (Figure 1).

Electromyographic analysis

A surface electromyography (TrignoTM Wireless EMG, Delsys Inc., Boston, MA, USA) was used to measure and analyse the muscle activity. Electromyography electrode placement locations were selected according to the SENIAM guideline. Quadriceps electrodes were placed 1/3 distal from the subject's vastus medialis and vastus lateralis and 1/3 proximal from the rectus femoris. For the lateral and medial gastrocnemius, electrodes were placed 1/5 proximal of the distance from knee joint of the shin to the lateral malleolus (Padua et al., 2012). Also, the skin of the placement location was cleanly prepared with abrasive and alcohol (Hermens et al., 2000).

EMG signals were filtered between 10 and 50 Hz by using fourth-order Butterworth filters. The root mean square (RMS) was calculated for raw EMG data. The EMG data from each muscle was normalized by calculating the RMS of a 5-second MVIC for the muscles. The EMG data collected during the ground walking and the Pedalo Reha-Bar riding were expressed as %MVIC.

Statistical analysis

All data were analysed by using the IBM SPSS Statistics program (Ver. 24.0). To compare muscle activities during the traditional squat exercise and the modified squat exercise, descriptive statistic was used.

RESULTS

Table 1. Comparison of electromyographic muscle activities between traditional squat and modified squat exercises.

Variable		Traditional squat	Modified squat	Difference %
RF	R	19.74 (3.83)	6.27 (2.68)	13.47
	L	55.64 (29.03)	19.10 (1.10)	36.54
VM	R	39.36 (15.53)	11.64 (4.72)	27.72
	L	44.48 (11.09)	12.73 (0.74)	31.75
VL	R	35.11 (5.19)	13.55 (6.82)	21.56
	L	59.99 (6.02)	20.19 (0.48)	39.80
GCM	R	27.94 (24.76)	20.79 (22.02)	7.15
	L	26.59 (9.54)	25.53 (9.16)	1.06

Abbreviation: RF; Rectus Femoris, VM; Vastus Medialis, VL; Vastus Lateralis, GCM; Gastrocnemius.

Results comparing muscle activities of the lower extremity during the traditional squat exercise and the modified squat exercise are shown in Table 1. During the modified squat exercise, compared to the traditional squat exercise, muscle activities in the right and left rectus femoris, right and left vastus medialis, right and left vastus lateralis, etc. are shown to be less activated by a minimum of 13% to a maximum of 39%. However, muscle activities in the right and left gastrocnemius are shown to be a difference level of minimum of 1% to a maximum of 7%.

DISCUSSION

This study analysed and compared muscle activities of the lower extremity during the traditional squat exercise and the modified squat exercise with subjects as healthy males, and through the results of this study, we can confirm that the possibility of the modified squat exercise to replace the traditional squat exercise to be recommended as a rehabilitation intervention. As a result, the modified squat exercise showed less muscle activity in the rectus femoris, vastus medialis, and vastus lateralis compared to the traditional squat exercise.

Squat exercise has the close kinetic chain mechanism. Lee et al. (2016) stated that the knee extension from the open kinetic chain exercise creates anterior shearing force to induce stress onto the patella-femoral joint. Close kinetic chain exercise such as the squat exercise causes co-contraction for agonist and antagonist of the lower extremity and through direct weight bearing to the lower extremity, stability of the ankle, knee, and hip joints for maintaining posture can be promoted (Kang et al., 2014; Lee et al., 2015; Tang et al., 2001). And previous studies stated that the squat exercise increases muscle activities of the rectus femoris, vastus medialis, vastus lateralis, etc. (Cheron et al., 1997; Dan et al., 1999; Escamilla et al., 1998; Flanagan et al., 2003; Hase et al., 2004). Earl et al. (2001) made 20 healthy adults perform the traditional squat exercise and the squeeze squat exercise (squat exercise squeezing the hip joint). As a result, it was reported that, during the squeeze squat exercise, there were significantly increase the activity of the vastus medialis and vastus lateralis. Also, when Koh et al. (2011) made 21 healthy adults perform 3 types of modified squat exercises (traditional squat exercise, isometric adduction exercise using a ball, and isometric abduction exercise using a belt), isometric adduction exercise using a ball compared to other exercise postures significantly increased the activity ratio of the vastus medialis and vastus lateralis. Perchthaler et al. (2013) stated that as the knee angle increases (30°, 45°, 60°), muscle activity increased for the rectus femoris and biceps femoris which are agonist of the lower extremity. The result of this study also showed that the activity was higher in the rectus femoris, vastus medialis, and vastus lateralis during the traditional squat exercise compared to the modified squat exercise. Rectus femoris is attached from the anterior inferior iliac spinet to the patella and is a muscle the passes two joints which activates during hip flexion and knee extension. Vastus medialis is attached from the intertrochanteric line and linea aspera of the femur to the medial boundary of the patella which activates during knee extension. Vastus lateralis is attached from the gluteal tuberosity to the lateral boundary of the patella which activates during knee extension. During the traditional squat exercise, biggest moment arm occurs in the knee joint due to gravity and in particular, greater force is applied to the knee extensor (quadriceps, rectus femoris) than the ankle muscles and hip extensor (Souza et al., 2017). However, because force is reduced on the gravity applied to the hip joint due to the swiss ball (Dionisio et al., 2008; Nagura et al., 2002) during the modified squat exercise, activity is shown to be lower on the rectus femoris, vastus medialis, and vastus lateralis during the modified squat exercise compared to the traditional squat exercise. Although the modified squat exercise is similar to the traditional squat exercise in that it is an exercise that uses right and left rectus femoris, right and left vastus medialis, and right and left vastus lateralis equally, the results show that it has less muscle activity than the traditional squat exercise by a minimum of 13% to a maximum of 39% and show a possibility to be recommended to people with weak muscle strength in the lower extremity or patients with paralysis.

But, as the results of this study, during the modified squat exercise performed, no difference was shown in the activity of the gastrocnemius compared to the traditional squat exercise. During the modified squat exercise, swiss ball was used to support the body to reduce the burden of gravity on the hip and knee joint but gravity applies to the ankle joint similarly to the traditional squat exercise so there was no difference in the activity of the gastrocnemius. According to the previous studies, angle of the knee and muscle activity of the gastrocnemius are also proportional during the squat exercise and in particular, high muscle activity was shown in the gastrocnemius when the knee angle was between 60°~ 90° (Escamillia et al., 1998; Isear et al., 1997). Gastrocnemius is a multiple-joint muscle attached to the femur as well as the medial epicondyle and lateral epicondyle of the femur and connected to the calcaneus. During the traditional squat exercise, as the knee angle decreases, plantarflexion of the ankle occurs and, in other words, shows concentric contraction of the gastrocnemius. As the knee angle increases, ankle dorsiflexion occurs and, in other words, shows eccentric contraction of the gastrocnemius (Dahlkvist et al., 1982; Escamilla et al., 1998, 2001). During the modified squat exercise, gastrocnemius showed greater muscle activity compared to the quadriceps because there seemed to be more muscle activity in the ankle joint compared to the hip and knee joint due to the body being supported from the supine position on top of the swiss ball. Also, torque in the flexor of the knee joint is activated before the torque in the extensor of the hip joint so there seemed to be more activity in the gastrocnemius which is a knee extensor.

According to this result, excluding the gastrocnemius, the modified squat exercise compared to the traditional squat exercise uses other muscles of the lower extremity less to reduce the burden and instead of immediately applying the traditional squat exercise on elderly with weak lower extremity muscle strength and patients with knee injuries greater than light to moderate level, we can recommend to perform the modified squat exercise first.

However this study has a few limitations. First, this study only had 2 healthy adult males as subjects and it is difficult to generalize the results of this study because the number of subjects was too small. Also, the study was unable to confirm whether the modified squat exercise was possible or effective for the weak elderly or patients with lower extremity injuries. Therefore, future studies will be required to remedy the many limitations of this study.

CONCLUSION

This study conducted to investigate the possibility of the modified squat exercise as a rehabilitation exercise method to be applied to people with weak muscle strength of the lower extremity. Traditional squat exercise and the modified squat exercise were performed to compare the muscle activity of the lower extremity. Compared to the traditional squat exercise, the modified squat exercise resulted in less activities in the right and left rectus femoris, right and left vastus medialis, and right and left vastus lateralis. Therefore, the modified squat exercise may be recommended ahead of the traditional squat exercise for the elderly with weak lower extremity muscle strength and patients with knee injuries. However, high quality research will be necessary in the future.

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