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Original Article

The effect of knee flexion angles and ground conditions on the muscle activation of the lower extremity in the squat position

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Abstract. [Purpose] The purpose of this study is to research the most effective knee flexion angle and ground condition in the squat position. [Subjects and Methods] The subjects of this study were 15 female college students who were able to perform squat movements and who had never previously experienced surgery, orthopedic disease, or musculoskeletal impairment. This study was conducted to examine changes of muscle activation of low-extremity muscles at different knee flexion angles of 70°, 90°, and 100°. Balance Pad (Aero Step, TOGU, Germany) was used as unstable ground. Surface electromyogram (4D-MT & EMD-11, Relive, Korea) was used for measuring muscle activation. Measured muscles were vastus medialis, biceps femoris, tibialis anterior, and gastrocnemius. Muscle activation was determined by the root mean square (RMS). [Results] There was a difference in muscle activation of the vastus medialis and tibialis anterior according to the change of the knee flexion angle with the stable ground. However, there was no difference in muscle activation of the lower extremity muscles according to the change of the knee flexion angle with the unstable ground. [Conclusion] These results suggest that changes in the angle of the knee flexion with the stable ground affect the muscle activation of the vastus medialis and tibialis anterior. It was found that as the joint angle increases, muscle activation also increases. However, ground condition does not affect muscle activation.

Key words: Squat, Knee flexion angle, Ground condition

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INTRODUCTION

Squat exercise is the most commonly used exercise among various weight training methods because it is easily accessible without using tools[1)]. Squat exercises strengthen the gluteal, quadriceps, and trunk muscles that are important for running, jumping, and lifting[2)]. It is a basic exercise that strengthens bone density, ligaments, and tendons, as well as training the lower body. Squat movement, a close kinetic exercise, causes ankle joint flexion, knee joint flexion together with hip joint flexion, and is conducive to joint compression force and co-contraction[3)].

Therefore, squat movements are more advantageous than non-weight bearing exercises by moving many joints, mobilizing more muscles, and stimulating proprioceptive more strongly[4)]. However, the correct posture is important because the effect of squat exercise is influenced by posture, such as the lower extremity joints. In this regard, Tang et al.[5)] experimented how muscle activation of the vastus medialis and vastus lateralis by squat-to-stand and stand-to-squat tasks was affected while changing the angle of the knee joint from 0 to 90 degrees in 15° increments. They reported the results of the study demonstrating that the highest muscle activation was observed at 60°. Park et al.[6)] showed that the muscle activation of the

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biceps femoris, vastus medialis, vastus lateralis, gastrocnemius, and tibialis anterior increased as the knee flexion angle increased by 45°, 60°, and 90° when squatting against the wall.

Since squat movement is also related to maintaining posture, ground conditions can also affect squat movement. In this regard, Lim[7] compared squat movement on air cushions of different air pressures, specifically 0 mbar, 1 mbar, 2 mbar, and on stable ground at a knee flexion angle of 60°. He reported muscle activation of vastus medialis, vastus lateralis, gluteus maximus, and biceps femoris was higher in squatting on the air cushions than on the stable ground. Thus, previous studies have already demonstrated that the angle of the knee flexion and ground conditions affect squat movement.

Nevertheless, no studies have yet been performed that consider different knee flexion angles with ground conditions during squat exercises. Therefore, this study researched the most effective knee flexion angle for strengthening low-extremity muscles. At the same time, this study researched the effects of stable ground and unstable ground regarding for improving lower extremity muscle strength in squat exercise.

SUBJECTS AND METHODS

The subjects of this study were 15 female college students who were enrolled in S university in Busan and were able to perform squat movements and did not have surgery experience, orthopedic disease, or musculoskeletal impairment. The purpose of this study and the experimental method were explained to all study subjects. This study complied with the ethical standards of the Declaration of Helsinki, and written informed consent was obtained from each participant. The general characteristics of the subjects were mean age 21.5 ± 0.7 years, mean weight 59.4 ± 11.0 kg and average height 160.6 ± 10.6 cm. To measure the knee flexion angle, a goniometer (Professional Goniometer Set, PATTERSON MEDICAL, China) was used. Squats were performed from various poses and postures. Escamilla[2] separated squat movements depending on the angle of the knee, as mini squat (30°), semi squat (40−60°), half squat (70−100°), and deep squat (100°). In addition, Park et al.[8] reported that when the knee flexion angle was above 90°, muscle activation of the rectus femoris, the vastus medialis, and the vastus lateralis decreased.

Therefore, this study was conducted to examine changes of muscle activation of low-extremity muscles at different joint angles of 70°, 90°, and 100°, 70° being the minimum of the knee flexion angle of the half squat; 90° showing decrease of muscle activation, and 100° is the starting range of the deep squat.

The knee flexion angle was measured as the relative angle of the femur to the fibular, as suggested by Lee et al.[9] Electromyography measurements were performed on stable ground and on unstable ground using the surface electromyography (4D-MT & EMD-11, Relive, Korea). The surface of the stable ground was flat with no obstacles and balance pad (Aero Step, TOGU, Germany) was used as unstable ground. Electromyography measurements were performed with the knee flexion angles of 70°, 90°, and 100°, which were maintained for 5 seconds. A total of three measurements were made and a 5 minute break between the measurements was given. The subjects were verbally instructed to keep their arms straight forward, legs at shoulder width, gaze toward the front, and the back straight with knees bent. Measurement was performed at the angle with a paused posture. The joint angle was measured by the goniometer attached to the lateral side of the knee. The sampling rate of the signal of surface electromyography used in this study was 1,000 Hz, and the signals were filtered using 60 Hz analog notch filter and a 20−500 Hz digital band pass filter. The attachment site of the surface electrode was the right leg, the dominant leg of each subject.

Measured muscles were vastus medialis, biceps femoris, tibialis anterior, and gastrocnemius. The muscle activation was determined by the root mean square (RMS) average value. The average value of the root mean square (RMS) values for three seconds was calculated by linear filtering the values of three measurement data for five seconds and excluding one second for each of the initial and late phases.

Data were analyzed by paired sample t-test to determine the difference of the value which was measured on both unstable ground and stable ground at each knee flexion angle. Then repeated measurement ANOVA test was performed to determine whether there was a difference in muscle activation according to the angle in each ground condition. Post analysis was performed using Bonferroni Correction. The statistical program used in this study was SPSSWIN (ver. 23.0), with a significance level $\alpha=0.05$.

RESULTS

There was a difference in muscle activation of the vastus medialis according to the change of the knee flexion angle with stable ground ($p<0.05$). Post analysis showed that muscle activation was greater at 90° and 100° than at 70° of the knee joint, but no difference was demonstrated between 90° and 100°.

On the other hand, on unstable ground, there was no apparent difference in muscle activation according to the angle change of the knee joint. In biceps femoris, there was no difference in muscle activation due to the angle change of the knee joint with both stable ground and unstable ground. In the tibialis anterior muscle, there was a difference in muscle activation according to the angle of the knee joint on stable ground ($p<0.05$). Post analysis showed that there was no difference between knee flexion angle 70° and 90°, 90° and 100°, but muscle activation was greater at 100° than at 70°.

However, there was no difference in muscle activation according to the angle change with the unstable ground. In the case

Table 1. The effect of knee flexion angle and ground condition on the muscle activation in the low-extremity muscle (Unit: mV)

Muscle	Condition	70°	90°	100°
		Mean ± SD	Mean ± SD	Mean ± SD
Vastus medialis	Stable ground*	39.7 ± 12.5[a]	48.5 ± 12.1	48.0 ± 13.6
	Unstable ground	42.9 ± 14.2	48.0 ± 13.0	47.3 ± 14.7
	t	−1.400	0.324	0.448
	p	0.183	0.751	0.661
Biceps femoris	Stable ground	34.9 ± 30.5	39.0 ± 37.9	41.7 ± 37.6
	Unstable ground	48.3 ± 34.7	45.7 ± 30.5	42.9 ± 22.7
	t	−1.243	−0.800	−0.281
	p	0.234	0.437	0.783
Tibialis anterior	Stable ground*	60.3 ± 22.7[b]	68.5 ± 25.2	74.0 ± 23.9
	Unstable ground	72.5 ± 23.3	72.3 ± 26.3	73.9 ± 22.4
	t	−2.071	−0.441	0.008
	p	0.057	0.666	0.994
Gastrocnemius	Stable ground	41.2 ± 29.7	43.7 ± 31.2	43.7 ± 27.6
	Unstable ground	51.6 ± 26.7	54.2 ± 28.5	49.5 ± 28.4
	t	−1.785	−1.496	−0.918
	p	0.096	0.157	0.374

*$p<0.05$ with Repeated ANOVA according to knee flexion angle
[a]70°<90°=100° by using Boneferroni Correction as post analysis
[b]70°<100°, 70°=90°, 90°=100° by using Boneferroni Correction as post analysis

of the gastrocnemius, there was no difference in muscle activation according to the angle change of the knee joint with both the stable ground and the unstable ground. In addition, differences in muscle activation measured with the stable ground and the unstable ground at the different knee flexion angles were checked. The data show that there is no difference in muscle activation in the case of the vastus medialis, the biceps femoris, the tibialis anterior and the gastrocnemius according to the ground condition (Table 1).

DISCUSSION

In this study, it was confirmed that muscle activation of the vastus medialis measured on stable ground was significantly increased at the knee flexion angles 90° and 100°, compared to 70°. Marchetti et al.[10] studied changes in muscle activation of the vastus medialis at the knee flexion angles 20°, 90°, and 140°. As a result, it reported that muscle activation was the highest at 90 °, which is the same as the result of this study. This result can be explained by the principle of the lever. In general, torque can be described as the amount of force multiplied by the distance from the line of action of the force to the axis of movement. When the knee flexion angle is 90°, the distance from the axis of movement to the line of action is the longest, resulting in maximum torque[11].

Therefore, this study and the study of Marchetti et al.[10] report that the knee flexion angle of 90° is a suitable joint angle for generating the maximum torque during squat movement.

In addition, muscle activation of the Tibialis anterior was increased at the knee flexion angles of 90° and 100° on stable ground. Park et al.[6] reported that muscle activation of the Tibialis anterior at the knee flexion angle 90° was higher than at 45° and 60°. These results show that as the angle of the knee joint increases, the center of gravity (COG) of the subject gradually moves away from the base of support (BOS) and the subject uses more force to maintain the center of gravity within the base of support for a stable pose[11]. At this time, the ankle attempts to maintain balance using the ankle joint strategy in response to postural sway[12], and the balance against the alternating sway caused by the ankle joint strategy is dependent on alternating activation of the tibialis anterior and the gastrocnemius medialis[13]. For this reason, it is clear from this study that the tibialis anterior is more activated when the center of gravity (COG) of the body moves backward, and this contributes to balance of the body.

In the case of biceps femoris, muscle activation increased as the angle increased, but there was no statistically significant difference. It appears that the quadriceps femoris was more active than biceps femoris because the muscle activation was measured while bending the knee joint for 5 seconds. And the muscle activation of gastrocnemius increased as the angle increased, but it did not show a statistically significant difference. This is because the region of the origin and of the insertion of the gastrocnemius is attached to the calcaneus starting from the back of the tibia and the fibular, so that the angle of the knee joint seems not to affect the gastrocnemius. Hence, in the case of squat movements on stable ground, the knee flexion angle from 90° to 100° is considered to be effective for the exercise of the vastus medialis and tibialis anterior because the knee flexion angle from 90° to 100° has the highest muscle activation in the vastus medialis, and the knee flexion angle of 90° has the highest muscle activation in the tibialis anterior. Checking the difference in muscle activation of the low-extremity muscles according to ground conditions, there was no difference in muscle activation of the vastus medialis, tibialis anterior, biceps femoris, and gastrocnemius.

These results suggest that changes in the angle of the knee joint affect the muscle activation of the vastus medialis and tibialis anterior. It was found that as the joint angle increases, the muscle activation increases, while ground conditions do not affect muscle activation.

Therefore, it can be said that a squat posture is helpful to increase the muscle power of the vastus medialis and tibialis anterior. On the other hand, if the subject can safely balance on the balance pad, it is suggested that the he or she can squat at an angle of 70° on unstable ground. However, if the subject is unable to balance on the balance pad due to the lack of balance ability, it is reasonable to suggest he or she perform squat movements at the knee flexion angle 100° on stable ground. But for confirmation these facts various study will be needed more in the future.

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