



Original Article

Activation of back and lower limb muscles during squat exercises with different trunk flexion

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Abstract. [Purpose] The purpose of this study was to investigate the activation of back and lower limb muscles in subjects who were performing a squat exercise at different angles of trunk flexion. [Subjects and Methods] Twenty healthy subjects (age 21.1 ± 1.8 years, height 168.7 ± 8.2 cm, weight 66.1 ± 12.3 kg) volunteered. The activation of the erector spinae muscle, rectus femoris muscle, gluteus maximus muscle and biceps femoris muscle was observed while the subjects performed squat exercises with a trunk flexion of 0° , 15° , and 30° . [Results] The erector spinae muscle, gluteus maximus muscle, and biceps femoris muscle were activated more during the squat exercise with the trunk flexion at 30° than the exercise with the trunk flexion at 0° . The rectus femoris muscle showed a tendency to decrease as the truck flexion increased. [Conclusion] Squat exercise be executed while maintaining an erect trunk posture if one wishes to strengthen the quadriceps muscle while reducing the load on the lower back.

Key words: Squat exercise, Trunk flexion, Muscle activity

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INTRODUCTION

Squat exercise is a good example of a closed chain exercise. It is an exercise that can strengthen the lower limbs while minimizing the stress on the anterior cruciate ligament by reducing the shearing force on the knee joint through reduction in compression force on the joint and simultaneous contraction. In addition, this exercise induces flexion of the ankle joint, knee joint and hip joint¹⁾. Moreover, squat exercise has the advantage of allowing the intensity of training by using an additional load, or cable machine, a Smith machine and vibration platform, though it can be performed with no additional load²⁾.

Since squat exercise is being utilized for a diverse range of purposes and methods, discerning the advantages and disadvantages of each exercise method is important. Improper posture or indiscriminate execution of the exercise can induce secondary side effects. In particular, posture during a squat exercise, which involves repeated bending and straightening of the upper body, can become a major risk factor for a lumbar disorder and can be associated with the occurrence of lower back pain and other disorders related to the exercise³⁻⁵⁾.

The majority of the existing studies focusing on squat exercises have either examined the extent of the activation of the lower limb muscles by diversely applying the basal plane^{2, 6)} or have examined the changes in the ratio of the extent of activation of the anterior and lateral muscles of the lower limb muscles in relation to the location of the knee joint or ankle joint⁷⁾. In addition, these studies have presented a squat exercise method for the effective training of the lower limb muscles by studying both the extent of the activation of the lower limb muscles and the resistance against during adduction of the hip joint or flexion of the shoulder joint when a squat exercise is executed^{8, 9)}. Accordingly, the majority of the existing research has focused on the extent of the activation of the leg muscles and the exercise dynamics in relation to the structure of the supporting plane or the posture of the legs when the squat exercise is executed. However, in spite of the fact that the location of the trunk of the body imparts an effect on the extent of the activation of the muscles in the lower back and lower limbs during squat exercise, there is inadequate research on this aspect of this exercise. The research related to the trunk curvature

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is mostly study of the kinematics of the trunk during restricted and unrestricted squat^{10, 11}).

Therefore, this study aims to present a safe and effective squat exercise method that can reduce injuries arising from the exercise by examining the effects of the posture of the trunk of the body on the extent of the activation of the lower back and leg muscles in normal people during squat exercise.

SUBJECTS AND METHODS

The purpose and methods of the study were explained to all potential subjects, and each subject voluntarily agreed to participate. Specifically, written informed consent was obtained from each subject. This study was approved by the Institutional Review Board of the Catholic University of Pusan (CUPIRB-2016-009) and was conducted in accordance with the ethical principles of the Declaration of Helsinki, good clinical practices, and applicable laws and regulations. This study was conducted on ten healthy males and ten healthy females (age: 21.10 ± 1.83 years [mean \pm standard deviation], height: 168.70 ± 8.26 cm, weight: 66.10 ± 12.31 kg). Those with leg or spine injuries, those with limited range of the movement of the trunk or leg joints, and those with an angle of the patellofemoral (the Q angle) that did not belong to $13.5^\circ (\pm 5^\circ)$ were excluded from this study.

A surface electromyography (EMG) system (Noraxon TeleMyo DTS Telemetry) was used to record the activity of the rectus femoris muscle, gluteus maximus muscle, erector spinae muscle and biceps femoris muscle. The recorded EMGs were processed using a personal computer and MyoResearch XP 1.06 Master Edition software. The activities of the muscles were recorded by surface electrodes, following the recommendations of SENIAM¹²⁾ and ISEK^{13, 14)} for skin preparation and electrode position. To minimize the impedance of the skin, the subjects' hair was shaved and the electrode sites were cleaned with alcohol on a cotton swab.

Prior to the participation and collection of the data in the experiment, all subjects were provided with detailed explanations of the proper posture of squat movements, and these postures were demonstrated for the subjects and practiced by them. For the squat posture, each subject was instructed to spread both legs as far as the width of their shoulders, with both arms interlocked in front of the chest. Lumbar spine was hold neutral position and pelvic controlled excessive posterior rotation during each squat. Then, each subject was told to slowly lower their upper body until the knee joint was bent to an angle of 90° and to hold the posture for five seconds before slowly returning to the standing posture. The angle of the trunk of the body was measured three times at each of the angles of the bending of the trunk by bending to 0° , 15° , and 30° . The measurements were taken using a goniometer at the center of the lateral part of each subject's trunk, with 30 seconds of rest between each of the measurements. The subjects were given three minutes of rest after each change in the angle of the bending of the trunk in order to avoid muscle fatigue.

Data were processed using SPSS 19 for Windows. To compare muscle activity during the squat exercises with 0° , 15° and 30° of truck flexion, a repeated measures analysis of variance was used. To identify differences for each muscle, Bonferroni's post hoc test was performed. Statistical significance was accepted for values of $p < 0.05$.

RESULTS

Although there were no statistically significant differences in the extent of activation of the erector muscles of the spine, there was a trend of an increase in the extent of muscle activation of the erector muscles of the spine with an increase in the angle of the bending of the trunk of the body ($p > 0.05$). The muscle activation of the gluteus maximus and biceps femoris significantly increased as the angle of the bending of the trunk increased ($p < 0.05$). The muscle activation of the rectus femoris displayed a tendency of reduction with an increase in the angle of the bending of the trunk, but this tendency was not statistically significant ($p > 0.05$) (Table 1).

DISCUSSION

The purpose of this study was to examine the changes in the extent of muscle activation of the erector muscle of the spine, the gluteus maximus, the biceps femoris, and the rectus femoris in relation to the angle of the bending of the trunk of the

Table 1. Differences in muscles activation for each experimental condition (N=20, units: %MVIC)

| Muscles | 0° | 15° | 30° |
|---------------------|-----------------|-----------------|-----------------|
| Erector spinae (m) | 21.5 ± 9.7 | 22.6 ± 7.2 | 24.8 ± 7.5 |
| Gluteus maximus (m) | 6.1 ± 4.0 | 6.27 ± 4.0 | $8.0 \pm 4.9^*$ |
| Biceps femoris (m) | 4.4 ± 3.5 | 5.7 ± 5.2 | $5.8 \pm 5.2^*$ |
| Rectus femoris (m) | 21.4 ± 18.8 | 18.8 ± 14.8 | 17.3 ± 13.3 |

Each value represents the mean \pm SD.

*Statistically significant, $p < 0.05$

body during a squat exercise.

The human trunk is associated with the transfer of energy and the connection of movements between the lower and upper body^{15, 16}). Therefore, the ability to execute exercises such as jumping or squatting can differ depending on the location of the trunk, vertical stiffness, and muscle activity^{17, 18}).

In this study, the muscle activation of the gluteus maximus and biceps femoris increased with an increase in the angle of the bending of the trunk during squat exercise. In particular, there was a significant increase when the trunk was bent at a 30° angle. Therefore, as the trunk is bent more toward the direction of gravity, the gluteus maximus and biceps femoris, which are the extensors of the hip joint, control the bending of the hip joint through eccentric contraction.

Although the gluteus maximus and biceps femoris act as the main movement muscles for the extension of the hip joint, the action of the biceps femoris, a muscle involved with two joints, on the flexion of the knee joint in the case of a closed-chain exercise, such as a squat exercise, must be considered. In other words, the biceps femoris acts not only on the extension of the hip joint during a squat exercise but also at the moment of flexion of the knee joint, thereby playing the antagonistic role against the moment of extension of the knee joint¹⁹). The moment of the flexion of the knee joint will become even larger with the increase in the moment of the extension of the knee joint. However, based on the observation that there is greater transfer of the center of gravity toward the front of the basal plane with an increase in the bending of the trunk, which reduces the muscle activation of the rectus femoris, the moment of extension decreases. Therefore, the more the trunk is bent, the more the action of the biceps femoris on the extension of the hip joint would have increased compared with the moment of the flexion of the knee joint. Therefore, squat exercise with fortified bending of the trunk will result in a reduction in the muscle activation of the knee joint extensor along with greater action of the hip joint extensor.

When the upper body is bent forward, the load on the trunk increases significantly. Bending of the upper body while in a standing posture will increase the compression on the intervertebral disc by almost 216% in comparison to an erect posture²⁰). A bent posture induces greater action of the muscles used to maintain the balance of the upper body²¹). This can be one of the main causes of problems in the lower back.

According to Albayrak et al.²²), the activation of the erector muscles of the spine and hamstring increased significantly when the upper body was bent forward without the support of the trunk. In this study, the extent of the activation of the erector muscles of the spine and hamstring increased as the lower back was tilted forward during the squat exercise. The erector muscles of the spine underwent eccentric contraction in order to adjust the tilting of the trunk forward during squat exercise. Accordingly, although the actions of the quadriceps muscle of the thigh increase, the activities of the erector muscles of the spine and hamstring are relatively reduced when a squat exercise is executed while the trunk is kept erect without bending forward. On the other hand, the actions of the erector muscles of the spine and hip joint extensor increase relatively while the actions of the quadriceps muscle of the thigh decrease when the trunk is bent by 30°. Therefore, a repetitive squat exercise while the trunk is bent forward can increase the load on the lower back and induce excessive fatigue of the erector muscles of the spine. Moreover, if additional load is exerted, this load and fatigue will increase even further.

In conclusion, squat exercise should be executed while maintaining an erect trunk posture in order to strengthen the quadriceps muscle while reducing the load on the lower back. Moreover, although the execution of squat exercise while the trunk is in a bent posture can actually fortify the strength of the biceps femoris and gluteus maximus, the load on the lower back will be increased substantially with this posture.

The limitations of this study include the failure to uniformly adjust the distribution of the weight of the left and right lower limbs during squat exercise and the failure to observe the changes in the extent of the activation of the abdominal muscles in relation to the extent of the bending of the trunk. In order to supplement these limitations, examining the extent of activation of the abdominal muscles together while controlling to ensure the weight on the left and right are the same would be necessary in future research.

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