

Original Article

Analysis of muscle activations in lower extremities muscles at various angles of ankle flexion using wedges during static squat exercise

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Abstract. [Purpose] This study aimed to investigate changes in activation of the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius muscles during one-legged squats performed at various angles of ankle flexion. With the use of wedges, the muscles were activated at different angles of ankle flexion angles to establish the appropriate posture necessary for muscle strengthening and rehabilitation. [Subjects and Methods] Healthy adults aged 20–40 years were recruited from Good Morning Hospital in Ulsan City. Of the 22 participants, two dropped out during the tests, leaving a final sample of 20 participants. The wedges were 100 mm wide and 200 mm long and had inclinations of 10°, 30°, and 50°. EMG Analyzer software was used to measure muscle activation. [Results] A significant difference in the activation of the rectus femoris muscle at various angles of ankle flexion was seen. The gastrocnemius muscle exhibited significant differences in activation among the 0°–30°, 0°–50°, and 10°–50° inclinations. [Conclusion] Wedge-assisted muscle activation under different ankle flexion angles can be introduced as an effective exercise option under clinical conditions.

Key words: Strengthening, Rehabilitation, One-leg squats

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INTRODUCTION

Although modern science has made life in contemporary society convenient, individuals have become susceptible to many adult diseases caused by lack of activity. Such susceptibility has become a social problem prompting increased efforts to treat associated health complications—measures that translate to increased costs and time spent remedying such problems¹⁾.

Fitness exercise regimes for health should be supported by weight training programs that focus on cardiopulmonary endurance, physical strength and endurance and improvements in muscle strength and endurance²⁾. Current weight training programs are implemented not only to enhance the performance of athletes, but also to rehabilitate an individual's physical abilities and perform out muscle manipulation therapy. Weight training prevents fractures, joint injuries, and low back pain by improving muscle strength and endurance; it also increases bone mass and muscle power by stimulating each muscle in the human body³⁾. Basic training

exercises, such as squats, dead lifts, overhead presses, and bench presses, can be performed. These exercises enhance the agonistic and synergistic movement of joints because they actively work different muscles simultaneously⁴⁾.

In modern society, individuals have become accustomed to prolonged sitting and therefore suffer from weakened muscles and joints in the lower extremities and secondary injuries caused by diminished muscle and joint function. Lower extremities not only support body weight, but also absorb impact stress from walking or running. The weight and impact borne by the lower extremities exert heavy loads on joints, and reducing such loads necessitates muscle strengthening exercises⁵⁾.

Although many studies have been conducted on muscle activation after squat exercises, few have been devoted to changes in the activation of lower extremity muscles during high-intensity exercises and the variables presented by other joints. Most previous studies compared the activation of gluteal muscles and femoral muscles, but overlooked the effects of squat exercises on the agonistic movement of femoral and lower leg muscles. To fill this gap, the current work investigated the activation of the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius muscles under different ankle flexion angles. Activation was induced by the use of wedges during static squat exercises. The wedges were used to ensure correct posture for muscle strengthening and rehabilitation.

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SUBJECTS AND METHODS

Subjects

Healthy adults aged 20–40 years were recruited from G hospital in Ulsan City. Pilot experiments were conducted on three participants to determine potential problems with the tests. The tests were then modified based on the findings. Of the 22 participants, two dropped out during the study, leaving a final sample of 20 participants. After sufficient explanation of the purpose and procedures of the study, voluntary consent was obtained from the subjects before experiments were initiated. The participants were provided a written informed consent form in accordance with the ethical standards of the Declaration of Helsinki. All the subjects stated that they understood the purpose of the research.

Methods

Before the experiments, the participants were instructed on how to assume a one-legged standing position. In the beginning position, legs were spread shoulder width apart with the dominant leg oriented forward and the other leg oriented backward. Uniform weight bearings were attached to each leg. The wedges (none, 10° wedge, 30° wedge, and 50° wedge) were used for the dominant leg and were applied in random order. The participants were instructed to look straight ahead to avoid postural effects. Measurements were taken with the participants in a uniform position, regardless of wedge inclination, thereby maintaining 30° trunk flexion, 50° hip flexion, and 45° knee flexion. The participants were verbally instructed to perform isometric exercises with full weight bearing applied to the dominant leg. To minimize muscle fatigue that might be caused by repetitive measurements, the participants were allowed a 2-minute break between measurements.

EMG Analyzer software (BTS, Italy) was used to measure the activation of the rectus femoris, biceps femoris, anterior tibialis, and gastrocnemius muscles. Before electrodes were attached to the participant's head, their hair was shaved off and the points of attachment were cleaned with alcohol to minimize skin resistance. Ag/AgCl electrodes were used. The EMG sampling rate was 1,000 Hz, and muscle activation was calculated using a 20-Hz high-pass filter and a 500-Hz low-pass filter at 50 m/s to eliminate noise effects.

One-way ANOVA was used to analyze the activation of the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius muscles under various ankle flexion angles during the one-legged squat exercises. Post-hoc analysis was conducted using LSD. A value of 0.05 was considered significant, and the obtained data was analyzed using SPSS 20.0 for Windows.

RESULTS

A significant difference was found in the activation of the rectus femoris muscle (Table 1), whereas no significant difference was found in the activation of the biceps femoris muscle. The tibialis anterior muscle exhibited no significant difference in activation among the ankle flexion angles, but a statistically significant difference was seen in the gastrocnemius muscle at different angles of flexion.

Table 1. The activation of each muscle according to the ankle flexion angle (N=20)

Muscle	Angle	Mean±SD
Rectus femoris*	0°	22.24±14.26
	10°	24.86±15.69
	30°	32.62±20.15
	50°	45.24±26.39
Biceps femoris	0°	16.88±10.10
	10°	18.25±10.12
	30°	21.77±11.13
	50°	26.05±13.04
Tibialis anterior	0°	28.94±17.98
	10°	29.48±21.00
	30°	30.28±17.30
	50°	35.34±16.52
Gastrocnemius medialis*	0°	21.42±10.26
	10°	23.73±12.33
	30°	31.67±19.09
	50°	40.68±19.94

*p<0.05, Mean±SD: mean±standard deviation

The results of the post-hoc analysis were as follows. The rectus femoris muscle showed no significant difference in activation among the 0°–50°, 10°–50°, and 30°–50° inclinations. Similarly, the biceps femoris muscle exhibited no statistically significant difference, as indicated by one-way ANOVA. In the post-hoc analysis, however, this muscle registered a significant difference between the 0°–50° and 10°–50° ankle flexion angles. No significant difference in the activation of the tibialis anterior muscle was found, whereas significant differences in the activation of the gastrocnemius muscle was found among the 0°–30°, 0°–50°, and 10°–50° ankle flexion angles.

DISCUSSION

Two types of muscle strengthening exercises for the lower extremities can be performed: open-kinetic chain and closed-kinetic chain. Open-kinetic exercises are performed with the legs flat on the floor and spread apart, whereas closed-kinetic exercises are executed with the feet firmly on the floor. Squat exercises are closed-kinetic exercises and are effective for muscle strengthening⁶. Squat movements generate the co-activation of the ankle, knee, and hip joint. They are functionally effective exercises for the lower extremities because of the co-contraction of muscles, compression, and eccentric and concentric contractions, which are accompanied by multi-joint muscle movements; such movements improve proprioceptive input and motor learning⁷.

When performing squat movements, which are good exercises for improving muscle strength and function, individuals should look straight ahead with their heads slightly inclined upward to correctly perform the exercises and maximize the effects of the workout^{8, 9}. Correct positioning is also necessary because such exercises affect the various joints of the spine and lower extremities. The lower extremi-

ties are spread shoulder-width apart, after which a sitting position is slowly assumed until the thighs are parallel to the floor. Maintaining the upper and lower back in a straight position is essential¹⁰. The most important aspect of squat exercises is knee position. Bending the knees so they extend slightly beyond the toes is an effective position. To execute this stance, an individual should ensure that his/her hips are pulled back to the maximum extent¹¹.

Previous studies have shown that squat exercises serve as good measures for motor learning/control and strengthening the lower extremities. Despite the progress made in research, however, most studies focus on knee joints and muscle pain. To expand the current literature, the present work investigated and introduced the activation of the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius muscles. Activation was carried out using wedges to vary ankle flexion angles. The study was designed to elucidate the correct body position for strengthening and rehabilitation by demonstrating the activation of the aforementioned muscles. The EMG technique, which is the most commonly applied method of measuring muscle activation, was adopted in this work. Although muscle activation cannot present the motor unit and firing rate of muscles, it is extensively carried out in studies on muscle tension because the electrical activity of muscles can be revealed by EMG analysis. In addition, quantification, which helps control physiological signals from muscles, is necessary when attaching various electrodes to a single muscle or when comparing multiple muscles¹².

The results of this study can serve as reference for establishing appropriate methods and amounts of exercise for patients with orthopedic and neurological disorders or other movement problems because the findings elucidate changes in the activation of lower extremity muscles. As indicated by the results, one-legged squats are highly effective exercises for rehabilitating lower extremities when surfaces of various inclinations are used. Such workouts are also useful for evaluating muscle strengthening and rehabilitation under clinical conditions¹³.

Squat movements, which combine the functional movements induced by different components of a weight training program, are critical to the performance of activities of daily living such as lifting, sitting, running, and jumping because they can improve the strength of the ankle, knee, and hip

joints and the back muscles. Symmetric and functional movement and stability are used in protocols to assess the influence exerted by ankle joints¹⁴.

Certain limitations of the study are worth noting. The sample was relatively small, and long-term effects were not investigated. Finally, diverse measurements were not adopted. These limitations should be addressed in future research by exploring other effective methods for activating the tibialis anterior muscle.

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