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Original Article

Impact of decline-board squat exercises and knee joint angles on the muscle activity of the lower limbs

Daehee Lee, PhD, PT[1)], Sangyong Lee, PhD, PT[1)], Jungseo Park, PhD, PT[1)*]

[1)] *Department of Physical Therapy, Youngdong University: 310 Youngdong-eup, Youngdong-gun, Chungbuk 29131, Republic of Korea*

Abstract. [Purpose] This study aims to investigate how squat exercises on a decline board and how the knee joint angles affect the muscle activity of the lower limbs. [Subjects] The subjects were 26 normal adults. [Methods] A Tumble Forms wedge device was used as the decline board, and the knee joint angles were measured with a goniometer. To examine the muscle activity of the biceps femoris, rectus femoris, gastrocnemius lateralis, and tibialis anterior of the lower limbs, a comparison analysis with electromyography was conducted. [Results] The muscle activity of the biceps femoris, rectus femoris, gastrocnemius lateralis, and tibialis anterior increased with increased knee joint angles, both for squat exercises on the decline board and on a flat floor. When the knee joint angle was 45°, 60°, and 90°, the muscle activity of the rectus femoris was significantly higher and that of the tibialis anterior was significantly lower during squat exercises on the decline board than on the flat floor. When the knee joint angle was 90°, the muscle activity of the gastrocnemius lateralis was significantly lower. [Conclusion] Squat exercises on a decline board are an effective intervention to increase the muscle activity of the rectus femoris with increased knee joint angles.

Key words: Decline board, Squat exercise, Range of motion

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INTRODUCTION

The knee joint has a high risk of injury as it is involved in many movements and weight-loading activities at diverse angles. Moreover, as the knee joint is not protected by muscle or fat layers despite its role in supporting weight, diseases such as gonarthrocace and patellofemoral pain syndrome are frequently observed[1)].

Closed-chain exercises, which are currently implemented in clinics as a means of exercise therapy and rehabilitation for diseases related to the knee joint, are more efficient than open-chain exercises in stimulating the structures inside the joint and the mechanical receptors surrounding it. The exercises increase the joint's stability and consistency, creating a loading axis while supporting the weight[2)]. As most closed-chain exercises are performed in a weight-supporting posture, they promote co-contraction of the mover and antagonist muscles while increasing dynamic stability[2)]. The squat is one of the most representative types of closed kinetic exercises, and it constitutes an important element in training programs in physiotherapy and diverse sports environments[3)]. The squat exercise is performed by lowering the truncus until the thigh comes to a parallel height with the knee, and then standing up. It is one of the most fundamental lower-body exercises and brings functional training effects through co-contraction, compressive force, mobilization of multiple joints and muscle groups, action of accompanying eccentric and concentric muscles, input of proprioceptive sensibility, and attainment of proper exercise technique[4)].

In the case of squat exercises on a 25° forward-tilted board, subjects attempt to compensate for the sensation of falling forward by moving the truncus backward, and as a result, the ankles, knees, trunk, and head move behind the line of the center of gravity. This subsequently increases the external movement that unfolds the knee joint[5)]. Cannell et al.[6)] reported that squat exercises on a decline board showed a positive impact on pain reduction and argued that this can be easily applied at home, as it requires no separate training device because of the nonrequirement for external loading.

Coqueiro et al.[7)] reported that the entire quadriceps muscle was activated during semisquats and argued that this can be applied to training for muscle strength reinforcement or clinical therapies. Park et al.[8)] reported that the muscle activity of the vastus medialis and vastus lateralis was maintained at a high level up to a 90° knee joint angle during squat exercises, but decreased as the knee joint angle exceeded 90°. There is a previous study that separately dealt with squat exercises on decline boards and squat exercises according to knee joint angles[3, 4, 6)]. However, studies that compare the results between these squat exercises are rare.

*Corresponding author. Jungseo Park (E-mail: emotion526@nate.com)

Table 1. Comparison of activity in the BF, RF, GL, and TA according to the type of squat exercise and the knee joint angle (Unit: %)

Muscle	Board	45°	60°	90°
BF	FF**	12.1 ± 6.4	14.9 ± 9.4	24.8 ± 17.8†
	DB**	11.7 ± 8.4	15.7 ± 13.1	25.3 ± 19.8
RF	FF**	21.7 ± 10.2	28.0 ± 12.4	47.3 ± 16.8
	DB**	24.2 ± 10.0†	32.7 ± 13.3††	50.9 ± 16.4†
GL	FF**	10.0 ± 7.7	10.1 ± 6.6	15.8 ± 10.1
	DB**	8.2 ± 6.3	8.8 ± 6.1	11.9 ± 7.4††
TA	FF**	18.6 ± 15.9	24.7 ± 16.4	38.0 ± 19.0
	DB**	10.7 ± 7.8††	13.6 ± 9.6††	19.5 ± 10.2††

FF: flat floor, DB: decline board, BF: biceps femoris, RF: rectus femoris, GL: gastrocnemius lateralis, TA: tibialis anterior, *: repeated one-way ANOVA, †: paired t-test *,†: $p < 0.05$, **,††: $p < 0.01$

Hence, in this study, we attempted to investigate how squat exercises on a decline board and the changes of the knee joint angles can affect the lower limbs.

SUBJECTS AND METHODS

A total of 26 male and female adults in their 20s who were enrolled at University Y in Chungcheongbuk-do, Korea, were selected as the sample population of this study. The participants had no health abnormalities or lesions of the lower limbs during the previous 6 months. They volunteered to participate in this study and signed an informed consent form, following the ethical principles of the Declaration of Helsinki. The subjects' average age was 21.8 ± 1.8 years; their average height was 168.6 ± 7.9 cm; and their average weight was 62.3 ± 9.1 kg.

For the beginning posture, the subjects stood upright with feet shoulder-width apart and both arms crossed over the chest. After stretching before the exercise, they performed a 45° squat on a flat floor and maintained the posture for 6 s. After 10 s of rest, they performed a 60° squat for 6 s and rested for 10 s, followed by a 90° squat. The squat exercises were repeated on a decline board following an identical order. For the measurement of the knee joint angle with a goniometer, the tester asked the subjects to maintain a certain angle.

The decline board used in the experiment was a Tumble Forms wedge (Sammons Preston, USA) with a width of 60 cm, length of 71 cm, height of 30 cm, and slope of 25°. For the ground stability of the subject, plywood was fixated onto the board. To measure the changes in muscle activity, the MP150 surface electromyography (EMG) system (BIOPAC System Inc., Santa Barbara, CA, USA) was used. The surface electrodes were attached to the biceps femoris (BF), rectus femoris (RF), gastrocnemius lateralis (GL), and tibialis anterior (TA). The average EMG signal of each subject was expressed as a percentage of the maximum voluntary isometric contraction (%).

For the statistical analysis, repeated one-way ANOVA was used for comparing the squat exercises on the decline board and those on the flat floor according to the knee joint angle, whereas a paired t-test was used for the comparison between the squat exercises performed on the decline board and on the flat floor. For the verification of statistical significance, the significance level was set at 0.05. A commercial statistical program, Windows SPSS version 12.0, was used for statistical analysis of the data.

RESULTS

The muscle activity of the BF, RF, GL, and TA increased with the increases in the knee joint angle with squat exercises on the decline board and on the flat floor ($p < 0.05$). When the knee joint angle was 45°, 60°, and 90°, the muscle activity of the RF was significantly higher and that of the TA was significantly lower with squat exercises on the decline board than on the flat floor ($p < 0.05$). Moreover, when the knee joint angle was 90°, the muscle activity of the GL was significantly lower ($p < 0.05$) (Table 1).

DISCUSSION

In this study, we attempted to investigate the impact of decline-board squat exercises and of the knee joint angles on the muscle activity of the lower limbs.

Kim and Song[9] argued that the cooperation between the hamstring, the gastrocnemius muscle, and the cruciate ligament plays an important role in maintaining cnemis stability when the quadriceps either eccentrically contracts to control flexion of the knee joint or concentrically contracts to unfold the knee joint. Chae et al.[10] reported that the muscle activity of the quadriceps increased the most, as it becomes the mover muscle in squat exercises with an increased slope angle of the heel. Youdas et al.[11] conducted a comparison analysis of muscle activity of men's and women's quadriceps and hamstrings during squat exercises, and reported that the activity of the two muscles increased in both men and women. However, the female subjects showed a more prominent increase in muscle activity in the quadriceps, whereas the male subjects showed more increased muscle activity in the hamstring. Sin[12] conducted an experiment with a sample of female patients with gonarthrocace and measured the muscle activity of the RF and biceps of the thigh during squat exercises with knee joint angles of 45° and 90°. The authors reported that the muscle activity of the quadriceps increased after the experiment in both groups. Jang et al.[13] argued that 40–80% hip adduction loading is effective in strengthening the vastus medialis oblique muscle during squat exercises. Meanwhile, Hyong and Kang[14] argued that unstable surfaces are effective in activating and reinforcing the vastus medialis oblique muscle during squat exercises.

In this study, the activity of the BF, RF, GL, and TA increased according to increased knee joint angles in both squat exercises on a decline board and on a flat floor. Relevant to these results, Kismer and Colby[2] reported that in closed-chain exercises of the knee, external movement increases with larger knee flexion angles, which increases the activity of the muscles surrounding the knee. Moreover, the muscle activity of the RF increases as the external movement increases according to larger knee joint angles during squats. To secure the stability of cnemis and truncus posture, the muscle activity of the RF and GL, which act in association with the squat posture, increases when the knee joint angle increases, which stimulates the muscle activity of the BF. To compensate for the knee's protrusion during the squat, the TA muscle activity also increases. It is surmised that if the knee protrudes excessively to the front, the dorsiflexion angle of the ankle joint decreases, thus increasing the TA activity during the squat.

Squat exercises on the decline board showed significantly higher muscle activity of the RF and significantly lower muscle activity of the TA at knee joint angles of 45°, 60°, and 90°, compared with squat exercises on the flat floor. Moreover, with a knee joint angle of 90°, the muscle activity of the GL was significantly low. These results are similar to that of Opila et al[5]. That is, in squat exercises on a 25° forward-tilted board, subjects attempt to compensate for the sensation of falling forward by moving the truncus backward. As a result, the ankles, knees, trunk, and head all move behind the line of the center of gravity, increasing the external movement that unfolds the knee joint. Hence, when the knee joint angle is 45°, 60°, and 90°, squat exercises on a decline board result in more external movement than squat exercises on a flat floor, significantly increasing the muscle activity of the RF. Moreover, with squat exercises on a decline board, plantar flexion of the ankle joint occurs in order to maintain body posture and balance, unlike with squat exercises on a flat floor. This causes relatively small muscle activity in the TA and GL. In the future, it will be necessary to investigate how decline-board squat exercises and the knee joint angle affect the muscle activity of the upper limbs.

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