

Original Research

Effects of the ankle angle on the electromyographic activity of the trunk and lower extremities during isometric squat exercises

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Abstract

Background: Life in modern society has become convenient, but the lack of exercise due to a sedentary lifestyle has led to muscle weakness. The quadriceps femoris is essential for walking, standing, and using stairs in daily life. Muscle weakness can lead directly to impaired function. Squatting is the most representative exercise for effective muscle development and increasing the knee extensor strength. This study examined the effects of ankle angle during wall squats on the muscle activity of the vastus medialis oblique (VMO), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), rectus abdominis (RA), and erector spinae (ES) to determine which ankle angle can better strengthen the vastus medialis oblique as a method of rehabilitation training after a knee joint injury. **Methods:** All subjects ($n = 20$) performed the following three types of wall squats randomly: (1) GWS (General Wall Squat), (2) WSD 10° (Wall Squat with dorsiflexion 10°), and (3) WSP 10° (Wall Squat with plantarflexion 10°). Each subject completed all three kinds of wall squatting exercises three different times, and the muscle activity data of the VMO, VL, RF, BL, RA, and ES were recorded. **Results:** Compared to GWS exercise, the VMO and RF muscle activity increased significantly under WSP 10° exercise ($p < 0.05$), whereas the VL, BF, RA, and ES activity did not increase significantly ($p > 0.05$). No significant change between WSD 10° and WSP 10° was observed ($p > 0.05$). **Conclusions:** WSP 10° can help increase the quadriceps muscle activity. Wall squat exercise with different ankle angles can be used for quadriceps muscle strengthening training for normal people and for recovery training for patellofemoral pain syndrome (PFPS) patients in the rehabilitation stage.

Keywords: Electromyography; Wall squat; Vastus medialis oblique

1. Introduction

With the advances of science and technology, life in modern society has become convenient, but a lack of exercise due to increasing sedentary lifestyles has led to obesity [1]. Weight training is one of the easiest ways to strengthen the body [2]. Many types of lower body exercises in weight training can be performed, such as calf lifts, adduction, leg presses, and squats. Among these, the squat is the most fundamental exercise for the following: (1) lower body training; (2) strengthening the tendons, bone density, and ligaments; (3) training the important muscles for jumping, lifting, and running [3].

Squatting is the most representative exercise for effective muscle development because it uses the upper and lower body muscles [4–7]. Squat exercises are commonly used in sports for strength and regulation. The squat is an exercise that indirectly improves the quality of life of sports and non-sports people by increasing the hip and knee extensor strength [8]. Squats can recruit multiple muscle groups in a single movement and is related to many daily activities, such as lifting heavy objects [9]. Exercise is also included as a core in many sports to improve athletic performance [10]. The squat exercise mainly strengthens the lower body and core muscles, including the quadriceps femoris, BF, RA, and ES [5].

The quadriceps femoris is essential for walking, standing, and using stairs in daily life. Muscle weakness can lead directly to impaired function, and people with weak muscles are much more likely to be disabled [11,12]. Strengthening exercises for the quadriceps femoris can reduce the pain and dysfunction of patients with knee osteoarthritis [13]. The strength and endurance of the quadriceps femoris are essential to the normal function of the knee joint. Hence, strengthening the quadriceps function after knee joint injury is an integral part of rehabilitation, such as the rehabilitation of patellofemoral pain syndrome (PFPS) and recovery from anterior cruciate ligament (ACL) reconstruction surgery. Intensive training of the quadriceps femoris plays a vital role [14–16].

Common ways for varying squat exercises include changing the standing width, foot position, hip depth, and extra load. In addition, the gender and ground environment when squatting may also be factors [17–19]. On the other hand, many people have examined the effects of these conditions on quadriceps femoris muscles. Wall squatting is a common exercise used to train the thigh muscles and buttocks [20]. Wall squat exercises are an improved version of squatting exercises designed to overcome these potential risks. Potential knee or lower back damage can be prevented by supporting the body weight against the wall while



squatting. Squat wall exercises are easy for beginners to perform. Modified squats stabilize the lumbar spine and strengthen the muscles of the lower body [21]. Previous studies reported the effects of three different wall squatting exercises on the activity of the quadriceps femoris. The results showed that wall squatting could produce greater quadriceps muscle activity, which is more suitable for people with a knee injury [12]. Wall squatting is more effective in strengthening the VMO and VL muscle activity than regular squatting [22]. Previous studies examined the effects of different wall squatting methods on the activity of the quadriceps femoris [23].

Wall squats improve the strength and endurance of the muscles of the lower extremities, particularly the quadriceps femoris. This exercise is suitable for patients with knee injuries as the best way to help restore the quadriceps muscle strength [22]. Marchetti *et al.* [24] reported that the quadriceps muscle activity is highest when the knee angle is 90° during squatting. On the other hand, excessive knee flexion during squat exercise can cause pain in people with knee disease or knee surgery. Purdam *et al.* [25] reported that when the knee flexion is more than 70° during squat exercise, the patellofemoral will be over-compressed, causing knee pain. Therefore, it is difficult to flex the knee at 90° for people with knee pain during squatting. Decreasing sagittal plane motion at the ankle leads to decreased knee flexion [26]. The wedge board is related to the decrease in knee flexion angle, and squatting on a wedge board can improve an individual's ability to participate in sports and reduce pain [26–29]. In addition, several authors suggested that squatting on a wedge board can increase the knee extensor muscle activities more than natural squats and is more helpful for rehabilitating the knee joint in the training of athletes [3,30]. Therefore, squatting on a wedge board for those with knee pain is an excellent way to strengthen the quadriceps muscle without increasing the knee flexion angle.

The above research suggests that a change in ankle angle during wall squat exercise will affect the muscle activity of the quadriceps. On the other hand, most research only examined the lower limb muscles at different ankle angles; there is little data on the upper limbs muscles. Therefore, this study evaluated the effects of wall squats performed at different ankle angles on the activity of the vastus medialis oblique (VMO), vastus lateralis (VL), rectus femoris (RF), biceps femoris (BF), rectus abdominis (RA), and erector spinae (ES). In addition, this study examined which ankle angle can increase the activity of the quadriceps femoris better during wall squatting for rehabilitation training after a knee joint injury.

2. Methods

2.1 Experimental subjects

Twenty healthy college students were enrolled as research subjects. The sample size was ob-

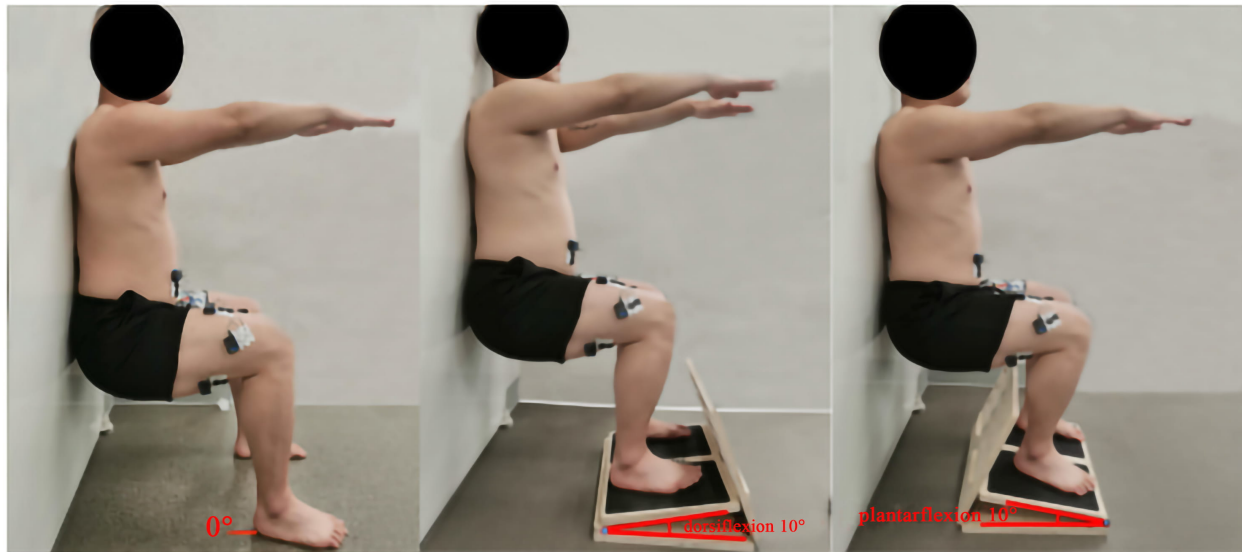
tained using G-Power software (Heinrich Heine University, Dusseldorf, Germany, available at <https://www.psychologie.hhu.de/arbeitsgruppen/allgemeine-psychologie-und-arbeitspsychologie/gpower>).

The three wall squat exercises were carried out in random order. The three wall squat exercises were written on notes, and the subjects chose the exercises by drawing lots. Before starting the experiment, the subjects were explained the content of the study and signed an informed consent form. The Research Ethics Committee of Daegu University approved this study (IRB No.1040621-202101-HR-008). The inclusion criteria were as follows: those who did not perform extreme exercise one week before the experiment and had no history of musculoskeletal or neurological diseases or disorders that affected the normal function of the hip, knee, or ankle in the past six months. The exclusion criteria were previous knee musculoskeletal injury or surgery, knee and thigh pain, and open wounds making it difficult to paste the electrode.

2.2 Experimental procedure

The changes in the VMO, VL, RF, BF, ES, and RA muscles before and after the different wall squat exercises at various angles were examined. Squat exercises with three different squat ankle angles were developed. The first wall squat was a general wall squat (GWS) position with the feet flat. The feet were spread out shoulder-width apart and in the erect posture. The body was leaned against the wall, and the knees and hips were then flexed to 90° with an angle ruler. In the second wall squat exercise (WSD 10°), the feet were spread out shoulder width while standing on an incline board with an incline wedge of 10°. In the erect posture, the body was leaned against the wall, and the knees and hips were then flexed to 90° using an angle ruler. In the third wall squat exercise (WSP 10°), the feet were spread out shoulder width while standing on a wedge decline of 10°. In the erect posture, the body was leaned against the wall, and the knees and hips were flexed to 90° with an angle ruler (Fig. 1).

Before the experiment, surface electrodes were placed on the subject's dominant side of the VMO, VL, RF, BF, ES, and RA muscles. The researchers thoroughly explained the movement of squatting on the wall to the subjects. When each subject was squatting on the wedge board at different angles, they first ensured that their legs were as wide as their shoulders, and stood with their backs directly against the wall, so that the hips and knees were bent at 90° to the thighs along the wall and the calves parallel to the wall. The subjects showed that they understood the method by practicing each posture at least three times in advance. Finally, the muscle activity of the subjects was measured when they performed the wall squats at three different angles. The wall squat postures were as follows. Each movement was repeated three times at random. The exercise order was randomized by drawing lots to avoid order bias due



A. GWS

B. WSD 10°

C. WSP 10°

Fig. 1. Different wall squat exercises.

to fatigue [31]. All subjects were instructed to keep the knee and hip flexed at 90° for five seconds. Each condition was repeated three times. The subjects were allowed to rest for one minute between the different conditions. The experiments were carried out in random order (Fig. 2).

2.3 Interventions

In this study, all subjects wore uniform shorts or loose clothing that fully exposed their thighs. Approximately 10 minutes of warm-up exercise was performed before the experiment to prevent unnecessary injury during the formal experiment. The three different wall squat exercises were carried out randomly. The subjects were given sufficient rest after each action. After the subjects were familiar with the movements of the experiment, the surface electrode was used to record the EMG data of the VMO, VL, RF, BF, ES, and RA muscles (Fig. 3).

2.4 EMG measurement

2.4.1 Signal collection and analysis

A 16-channel radio-surface electrocardiogram (TeleMyoDTS, NoraxonIns, AZ, USA) was performed to collect the myocardiogram data and process signals to understand the changes in muscle activity during wall squats with different ankle angles. The muscle activities of the VMO, VL, RF, BF, ES, and RA were measured during the squat exercises. The collected electrodynamic analog signals were sent to the Telemyo system DTS, converted to digital signals, and the other signals were then filtered and processed using Myoresearch XP 1.08 software (NoraxonIns, AZ, USA).

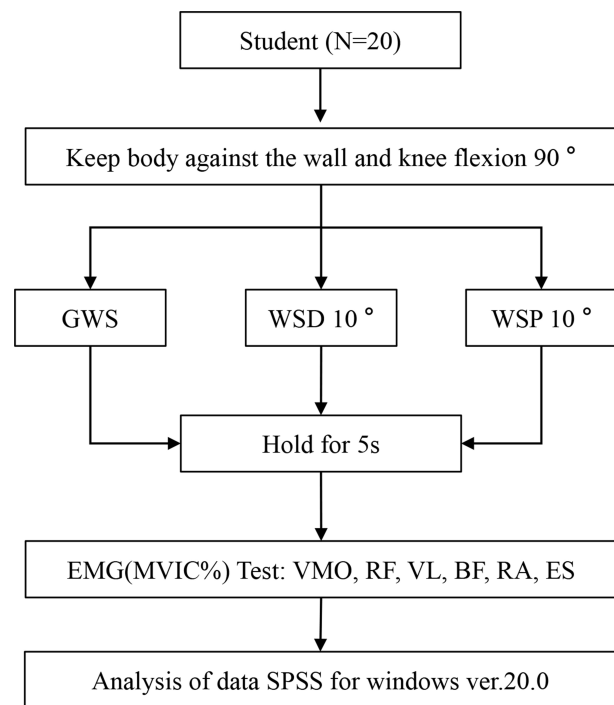


Fig. 2. Study flow chart. VMO, vastus medialis obliques; VL, vastus lateralis; RF, rectus femoris; BF, biceps femoris; RA, rectus abdominis; ES, erector spinae; GWS, general wall squat; WSD 10°, wall squat with dorsiflexion 10°; WSP 10°, wall squat with plantarflexion 10°.

The surface electrocardiogram signals were filtered, and a personal computer processed the other signals. The

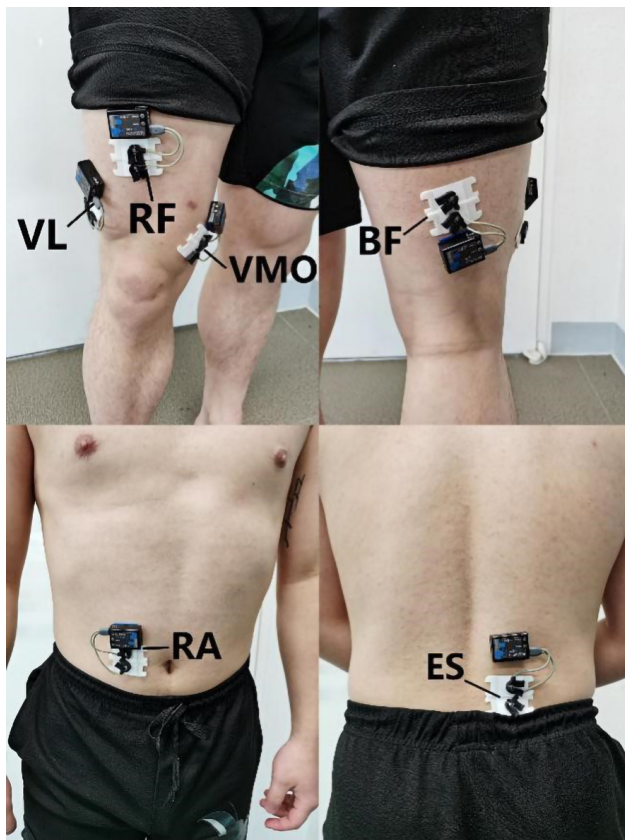


Fig. 3. The placement of surface electrode. VMO, vastus medialis obliques; VL, vastus lateralis; RF, rectus femoris; BF, biceps femoris; RA, rectus abdominis; ES, erector spinae.

sampling rate was set to 1500 Hz to measure the activity. The frequency bandwidth was filtered using a bandpass filter of 40 to 450 Hz and a notch filter of 60 Hz to quantify all the myocardial conduction signals collected [32]. The signals collected for each muscle were treated as an effective mean (RMS). The collected signals were treated as a percentage (%) of the maximum numerical normal length contraction.

2.4.2 Normalization

The measurements were performed using the method reported by Choi and Kang [33]. The EMG signal of each action was collected for five seconds; the data of the first and last second were deleted; only three seconds were analyzed. The EMG was measured three times, and the average value was taken. A one-minute rest was allowed between each measurement. All EMG data were averaged in three replicates. The experimental data are expressed as a percentage of the calculated RMS of the MVIC (% MVIC).

The maximal voluntary isometric contraction (MVIC) activity was measured for the tested muscles to normalize the EMG activity. Each subject was asked to voluntarily and maximally contract each muscle for five seconds each. The quadriceps femoris (VMO, VL, and RF) MVIC of the subjects was collected. The subjects sat on a chair with their

knee joint and hip joint flexed 90°. They were instructed to extend the knee forcefully into an immovable strap, and the researcher placed their hands on the tibia and gave the resistance against it for five seconds. The BF MVIC was collected with the subject sitting on a chair with their knee joint and hip joint flexed 90°. They were instructed to flex the knee, and the researcher placed their hands on the ankle joint and provided the resistance against it for five seconds. The RA MVIC was collected with the subjects flexing the trunk to the maximum, and the activation was held at the highest point for five seconds. The principal investigator provided manual resistance at the shoulders by pushing in the trunk extension direction. The ES MVIC was collected with the subject executing an upper torso lift from the prone position with their arms out to the side while the resistance was applied to the shoulders bilaterally by the researcher [34].

2.4.3 The placement of the surface electrode

The subjects wore shorts or loose clothes. Surface electrodes were placed on the subject's dominant leg. The dominant leg was determined by which leg the participants would preferentially use to kick a ball [35]. The skin where the electrodes were attached was shaved and wiped with a disposable medical alcohol test paper to ensure that the skin was clean and smooth. The surface electrode pairs were placed at an interelectrode distance of 2 cm. For the VMO, the electrodes were placed at an oblique angle (55°), 2 cm medially from the superior rim of the patella. The palpate for the muscle during the knee was extended. The electrodes were placed on the distal third of the vastus medialis oblique. For the VL, the electrodes were placed approximately 3 to 5 cm above the patella; the oblique angle was just lateral to the midline. For the RF, the electrodes were placed in the center of the anterior surface of the thigh, approximately half the distance between the iliac spine and the knee. For the BF, the two active electrodes were 2 cm apart, parallel to the muscle fibers on the lateral aspect of the thigh, two-thirds of the distance between the back of the knee and the trochanter. The muscle was palpated and tested manually with the knee at 90° and the thigh in slight lateral rotation. For the ES, the two active electrodes were placed parallel to the spine, 2 cm apart, and approximately 2 cm from the spine over the muscle mass. The iliac crest can be used to determine the L-3 vertebra. The electrodes were best placed while the patient was in the slightly forward flexion, with their hands resting on the knees and supporting the torso. For the RA, the abdominal wall in the area close to the umbilicus was palpated. The muscle mass was located. The electrodes were placed 3 cm apart, parallel to the rectus muscle fibers, so they were located approximately 2 cm lateral to and across from the umbilicus over the muscle belly [36].

2.5 Statistical analysis

The data were analyzed using SPSS (statistical package for the social sciences) version 20.0 for Windows software (version 20.0, SPSS Inc., Chicago, IL, USA). One-way repeated ANOVA was conducted to compare the statistical significance of the changes in the muscle activity of the VMO, VL, RA, BF, ES, and RA on the different wall squat exercises (GWS, WSD 10°, and WSP 10°). Post-hoc analysis was performed using an LSD test, and the level of significance was $p < 0.05$.

3. Results

Table 1 lists the general physical characteristics of the study subjects ($n = 20$). Significant differences in the VMO and RF were observed according to ankle angle during wall squat postures ($p < 0.05$). With WSP 10°, the VMO and RF muscle activities were significantly higher than that after the GWS ($p < 0.05$). On the other hand, there was no significant difference in VMO and RF muscle activity between the GWS and WSD 10° ($p > 0.05$). In addition, there was no significant difference between WSP 10° and WSD 10° ($p > 0.05$). There was no significant difference in the VL, BF, RA, ES according to ankle angle during the wall squat postures ($p > 0.05$) (Table 2) (Fig. 4).

Table 1. General characteristics of participants (N = 20).

	Participants
Age (year)	25.69 (3.59) ^α
Height (cm)	171.15 (8.68)
Weight (kg)	64.87 (10.80)
BMI (score)	21.97 (1.85)

^αMean (Standard deviation). BMI, Body Mass Index.

Table 2. Muscle activation of VMO, VL, RF, BF, RA, ES according to ankle angle during wall squatting postures (N = 20) (Units: MVIC %).

	GWS	WSD 10°	WSP 10°	F	p
VMO	89.31 (27.48) ^α	99.73 (26.22)	123.43 (23.31)	4.31	0.02*
VL	74.43 (39.37)	77.74 (36.65)	87.06 (45.23)	0.39	0.68
RF	25.61 (22.37)	38.35 (24.19)	55.12 (36.69)	4.05	0.03*
BF	40.16 (34.87)	44.11 (37.71)	47.13 (42.51)	0.10	0.91
RA	17.45 (28.85)	19.05 (28.64)	22.24 (37.78)	0.07	0.93
ES	36.60 (17.98)	36.50 (16.96)	39.43 (20.90)	0.29	0.75

^αMean (standard deviation). VMO, vastus medialis obliques; VL, vastus lateralis; RF, rectus femoris; BF, biceps femoris; RA, rectus abdominis; ES, erector spinae; GWS, general wall squat; WSD 10°, wall squat with dorsiflexion 10°; WSP 10°, wall squat with plantarflexion 10°; * $p < 0.05$.

4. Discussion

Excessive knee flexion during squat exercise can cause pain in people with knee disease or knee surgery. Therefore, the quadriceps muscle activity can be increased by adjusting the ankle joint angle without increasing the knee joint angle. Unfortunately, most studies only analyzed the lower limb muscles at different ankle angles, and there is insufficient data to analyze the upper limb muscles. Therefore, this study examined the effects of wall squats performed at different ankle angles on the activity of the VMO, VL, RF, BF, RA, and ES.

In this study, the muscle activity data of the VMO, VL, RF, BF, RA, and ES were measured using a % MVIC method to understand the changes in the lower limb muscles and trunk muscles in three different wall squatting postures (GWS, WSD 10°, and WSP 10°). The EMG activity of the VMO and RF muscles was significantly different in the GWS and WSP 10°. Compared to the GWS posture, the VMO muscle activity was increased by approximately 10.42% in the WSP 10° posture. The RF muscle activity increased by approximately 29.51% in the WSP 10° posture compared to the GWS posture. In addition, the VL, BF, RA, and ES were similar in all three wall squats. The activities of the VL, BF, RA, and ES muscles were similar when the WSD 10° and WSP 10° postures were used.

The squat movement caused the simultaneous movement of the hip joint, knee joint, and ankle joint [34,37], and the muscle activity varied according to the flexion angle of the knee joint [3]. The passive and active calf tensions were reduced while squatting on a decline board by forcing the ankle in plantar flexion. Therefore, the muscle work done was reduced, and the joint moments about the ankle reduced the loads and muscle activity at the ankle. In contrast, a more focused exercise to target the knee extensors increased the muscle activity and knee moments [38]. The muscle work done and joint moments at the ankle can be controlled by altering the direction of the foot on the squat platform by changing the declination angle [38,39]. The smaller flexed hip and ankle joints observed during the decline squat compared to the standard squat shifted the center of gravity (COG) of the body further behind the axis of the knee joint, which would increase the knee extensor moment, muscle activity, and the load on the patellar tendon [30]. When the COG was moved backward, the distal and proximal ends became relatively closer along the axis of the sagittal plane of the body as foot declination was increased, reducing the moment arm about the ankle [38]. Therefore, the knee extensor muscles can be strengthened by varying the decline angle to increase the loads around the knee, which at the same time minimizes the loads at the ankle.

In addition, squatting on an unstable support surface improved the core muscle balance, enhanced the joint function, and increased the muscle activity in the lower limbs [3]. During wall squats on a declining board, the subjects

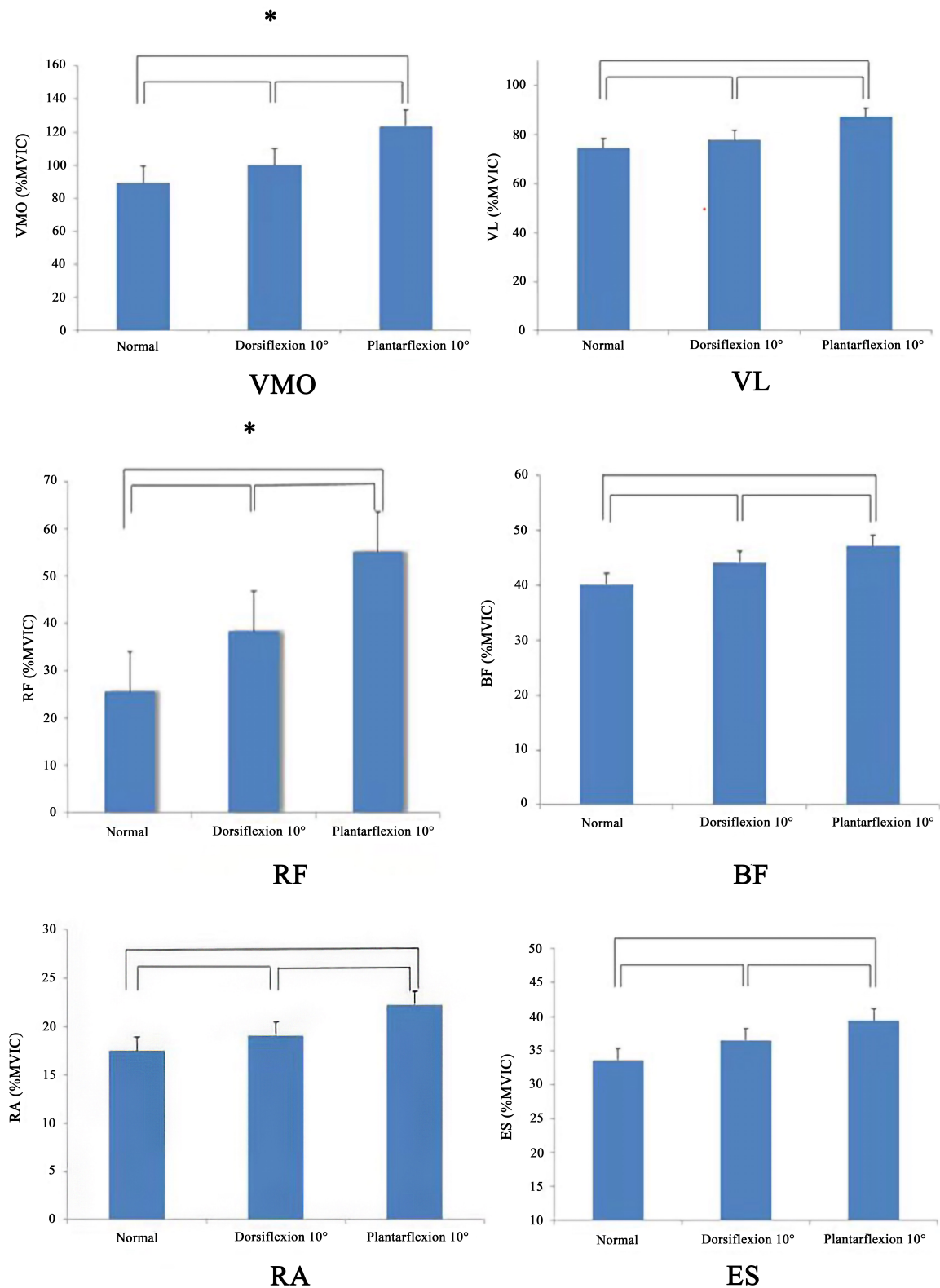


Fig. 4. Comparison of changes in muscle activation according the ankle angle during wall squatting postures. VMO, vastus medialis obliques; VL, vastus lateralis; RF, rectus femoris; BF, biceps femoris; RA, rectus abdominis; ES, erector spinae; * $p < 0.05$.

attempted to compensate for the feeling of falling forward by moving their truncus backward. As a result, the head, trunk, knees, and ankles all moved behind the COG line, increasing the external movement that unfolds the knee joint [40]. This minimized the effects of the calf muscle, relaxed the back of the thigh muscle, and erected the trunk. Hence, the effects of the hip muscle were also minimized so that intense resistance could be given to the quadriceps femoris muscle [41]. As a result, the COG line was transferred backward, which would increase knee extensor activity, and the quadriceps femoris, as the main knee extensor, would show increased activity. These findings are consistent with Kitamura *et al.* [42], who reported that the backwards movement of the COG during squatting exercise would increase the quadriceps activity. Therefore, the WSP 10° exercise was more advantageous for priority strengthening of the VMO and RF muscle. This also proved indirectly that activation of the lower limb muscles, VMO muscle, and RF muscle, particularly the VMO muscle, would increase significantly under the wall squatting with the ankle angle. Lee *et al.* [43] reported that squats on a declining board produce more external movement than squats on flat ground, increasing the RF muscle activity significantly. Therefore, the WSP 10° can exercise the quadriceps femoris more effectively and meet the training needs of PFPS patients in the later stages of rehabilitation. These results are consistent with Kongsgaard *et al.* [30], who reported that the knee extensor muscle activity increased when the ankle angle was increased compared to performing a squat with the ankle joint at a neutral angle. A change in the ankle joint angle helps rehabilitate the knee joint in training athletes.

The current study had several limitations. First, the smaller sample size may have affected some variables and the results. Therefore, these results cannot be generalized to all subjects with patellofemoral pain syndrome and other hip, knee, and ankle dysfunctions. Second, the current experiment was a crossover design, making it difficult to observe the long-term effects of the wall squats. Third, functional measurements were not performed. Therefore, more studies, including a long-term follow-up assessment, will be needed to evaluate the long-term benefits of wall squats. Fourth, the results are difficult to generalize because this study was on healthy adults. Hence, it cannot be used in the treatment of PFPS patients or other knee injury patients. Fifth, the effects of muscle fatigue were ignored in the experiment. Accordingly, future studies should consider muscle fatigue, and adequate rest time should be given.

5. Conclusions

In this study, the VMO, VL, RF, BF, RA, and ES muscle activities of 20 subjects were measured during wall squats at different ankle flexion positions to determine which posture would better increase the vastus medialis oblique activity or be suitable for rehabilitation training after knee injuries. The EMG activity of the VMO and RF

muscles was significantly different after the GWS and WSP 10°. Compared to the GWS posture, the VMO and RF muscle activity showed an increasing trend when measured in WSP 10°. Overall, wall squats with ankle plantarflexion of 10° on a declining board will increase the quadriceps femoris muscle activity.

Author contributions

Conceptualization—ZC, YYT; Data curation—MKK; Formal analysis—ZC, YYT; Investigation—ZC, YYT; Methodology—MKK; Project administration—MKK; Software—MKK; Writing – original draft—ZC, YYT; Writing – review & editing—ZC, YYT.

Ethics approval and consent to participate

All procedures were performed in accordance with the guidelines of our Institutional. The Research Ethics Committee of Daegu University approved this study (IRB No.1040621-202101-HR-008) and adhered to the tenets of the Declaration of Helsinki. All patients' information was anonymous.

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Conflict of interest

The authors declare no conflict of interest.

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