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The Influence of Ankle Inversion Angle on Trunk Muscle Activity during Squat Exercise

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Abstract

Objectives: To see the trunk muscle activation during squat exercise in accordance with the inversion angle. **Methods/Statistical Analysis:** After previous research, we recruited healthy adult of 12 males and 12 females (The mean age 20.7±1.66, a total of 24 adults) who agreed to participate in this study. This study measured External Oblique abdominis (EO), Transverse Abdominis (TrA), Eractor Spinae (ES), Multifidus (MF) muscle activation during the squat exercise according to four inversion angles (0°, 10°, 15°, 20°). In order to calculate the subject characteristics, the mean value and the standard deviation of all the variables of the subjects, descriptive statistics were employed. One-way repeated ANOVA was used to compare muscle activities of EO, TrA, ES and MF depending on the four inversion angles. Bonferroni's correction was used as post-hoc comparison and statistical significance level was set at $\alpha = .05$. **Findings:** In EO, there was significant difference on four inversion angles ($p<.001$). Post-hoc test result showed significant difference ($p<.001$) on four inversion angles between 0°-10°, 0°-15°, 0°-20°, 10°-15° and 15°-20°. In TrA, there was significant difference on four inversion angles ($p<.001$) as well. Post-hoc test result indicated significant difference($p<.001$) on four inversion angles between 0°-15°, 0°-20°, 10°-15° and 10°-20°. In ES and MF, they did not show significant difference in every inversion angle. Also, post-hoc test result did not reveal significant difference between every intervention. This study has been conducted to see the change of trunk muscle activation in accordance with inversion angle during squat exercise. In order to investigate the changes, we compared global and local muscles of trunk by applying the four inversion angles (0°, 10°, 15°, 20°). Since lower extremity or trunk global muscle activation has been studied a lot already, we put difference by measuring local muscle additionally during squat exercise. There were lots of studies about lower extremity and trunk muscle activation using squat exercise. In this research, however, the back muscle did not show a significant difference during squat exercise. These results mean that back muscle is not that significant in the squat exercise with altering inversion angles. Also, we experimented with the traditional squat exercise and added an intervention of changing the inversion angle. However, we presume that if we provide a variety of intervention on the trunk position, or require a trunk flexion or extension, there would be another result on the back muscle. Thus, more research, related with trunk position as well as ankle position, needs to be carried out continuously. **Application/Improvements:** In conclusion, squat exercise with inversion angle is an effective exercise method in that it can cause the activation of both global and local muscle of the abdomen. Also, the inversion angle of 15° is the most ideal one to activate the trunk muscle with effectiveness without ankle inversion injury. Therefore, the squat exercise with the varying inversion angles will be helpful to maintain trunk stability for the position through time effectiveness.

Keywords: Inversion Angle, Muscle Activation, Squat Exercise, Trunk Muscle

1. Introduction

The dynamic exercise provides a greater stimulus to the neuromuscular system than existing static exercise or exercise in a stable surface. Dynamic exercise leads to the rapid response of the muscle and the advantage of it is based on the importance of neuromuscular adaptation with the increases in strength. As muscle strength

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increases we can expect an increase in cross-sectional area of muscle and the improvement of coordination ability of the neuromuscular system. Therefore, dynamic exercise can reduce the incidence of injuries at joints of lower extremity[1].

Squat exercise, which is closed kinetic chain exercise, occurs the knee joint flexion, the ankle joint flexion and the hip joint flexion at the same time. It minimizes the stress to anterior cruciate ligament by decreasing shearing force to tibiofemoral joint through the joint compression force and cooperation contracture[2].

During weight bearing exercises such as squat exercise, there should be shown a lot of muscle strength and joint motion. Also, it can be considered a functional exercise because there was promotion of functional pattern, which stimulates the proprioceptor during the muscle contraction[3]. However, with squat exercise, more dominant leg is used habitually, which causes muscle imbalance[4]. In addition, the exercise can give a load, so the probability of an injury will increase when knees are over toes in saggittal plane. In order to prevent this kind of injury, it is needed to maintain the correct operation while doing the squat exercise[5].

The main areas of the squat exercise are biceps femoris, gluteus maximus, gluteus medius, rectus femoris, vastus lateralis and vastus medialis, but squat exercise, which is typical dynamic exercise, is a full body workout and a complex exercise that involves different parts of muscles. Also, it is a squat exercise workout using the weight of the heaviest weight training.

According to previous studies, squat exercise related to the hip joint adduction increases the activation of the vastus medialis oblique and gluteus medius[6]. Moreover, as squat depth is deeper, the muscle activity of the gluteus maximus becomes bigger[7]. In[8] reported that squat exercise on a unstable surface leads to use not only the muscles around vertebra, but also a variety of lower extremity and trunk muscle for maintaining posture. Especially, it is said that soleus, vastus lateralis, upper-lumbar erector spinae and lumbo-sacral eractor spinae affect most[8]. In a similar study, squat exercise increased the activation of core muscle[9], and it showed a higher activation in the trunk muscle. Therefore, it presented the result that there is no need to add any other dynamic exercise except for the squat exercise for a stabilization train[1]. On the other hand, Author in[10] showed contradictory views when the wall squat exercise is conducted, TrA and internal oblique increased, while the thickness of the MF did not.

There is another previous study for the ankle joint. In[11] have examined the squat exercise in the non-wedge state and 12° plantar flexion wedge state of ankle joint. As a result, the valgus stress of the knee joint was bigger in the latter state of ankle joint and the activation of the quadriceps has decreased. So, the incidence of injuries such as patellofemoral pain syndrome would increase[11].

Existing studies had drawn a variety of results related to the incidence of joint injury caused by the ankle joint movement and effects of the lower extremity and trunk muscle through a variety of interventions with the squat exercise. Although squat exercise is a complex exercise that involves the muscles of the different parts, researches on the local muscle activation measurement are insufficient, compared to the studies on global muscle. Also, ankle joint can make multi-directional movements, not unidirectional movement because it consists of subtalar joint and talocrural joint[12]. However, previous studies have only revealed researches on the unidirectional movement such as toe-in and plantar and dorsiflexion. Also, muscle can be classified functionally into two types of it; global and local muscle. Squat exercise is a good exercise that properly activates both two types of muscle. Though, there is only little research conducted by adding the inversion and eversion, and both global and local muscle activation in the squat exercise.

Thus, the purpose of the this study is to find out that changes of global and local trunk muscle activation in accordance with the inversion angle of the ankle joint while the squat exercise.

2. Methods

2.1 Subjects

Subjects were healthy males and females and we had recruited only subjects who gave written consent and were willing to volunteer, after full explanation, the purpose and method of study. Subjects were selected with 12 males and 12 females, so total 24 adults. Characteristics of the subjects are shown in Table 1. Exclusion criteria were the students without orthopedic, neurological surgical problems. There were no excluded subjects due to such factors. This study was conducted with the approval of SunMoon University Institutional Review Board (SM-201506-015-1).

Table 1. Subject characteristics (N = 24)

Characteristic		Value
Gender	Male	n=12
	Female	n=12
Age (year)		20.7 ± 1.66
Height (cm)		167.53 ± 7.48
Weight (kg)		61.65 ± 9.85
All values are mean ± standard deviation		

2.2 Maintaining the Integrity of the Specifications

The design of this experiment was cross sectional study and one group repeated test. Subjects took off their shoes and socks and put on comfortable outfit for more exact experiment. Weight and height were measured before the experiment, and electrodes of Surface Electromyography (sEMG) were attached to EO, TrA, ES and MF after a squat exercise training. In this study, a squat exercise was performed at four different angles (0°, 10°, 15°, 20°), and the subjects performed to align the feet on the inside edges of wooden wedges. Then, they widened their feet as much as their shoulder width (Figure 1). Squat exercise performed in 10 seconds, repeated 3 times. Resting period was taken 1 minutes between each task. No subjects left out in the experiment.

2.3 Position of Squat

Subjects aligned the feet on the inside edges of wooden wedge (0°, 10°, 15°, 20°) and stood with their feet at the shoulder width. During the squat exercise, we required them to keep 90° of the knee angle, and let the angle of the trunk and hip flexed naturally[13]. The knee was not over toe and we conducted verbal comment not to make the distance between two knees wider or closer.

Sights should be straight ahead and they performed to keep the shoulder with 90° flexion and 0° horizontal adduction (Figure 1). Squat exercise performed in 10 seconds, repeated 3 times.

2.4 Measurement of Muscle Activation

OQUS100 (Zero WIRE EMG, Italy) sEMG system was utilized to measure muscle activation, and sEMG software myoReserch 1.06.44 software was used for analyzing the collected data. Disposable bipolar Ag-AgCl disc surface electrodes with a diameter of 1.0 cm were attached

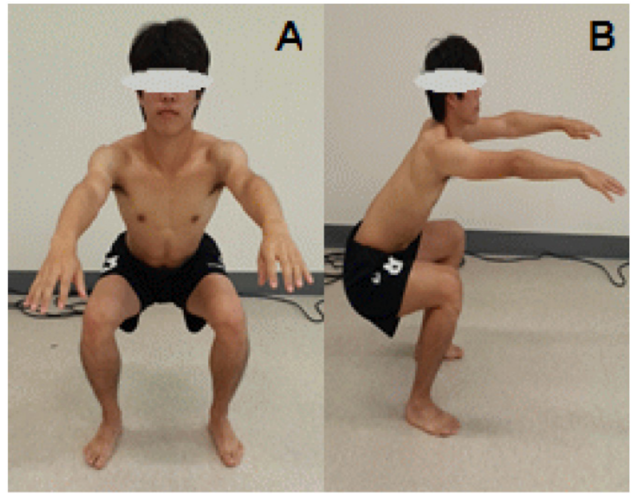

Figure 1. The position of squat exercise. **(a)** Anterior view. **(b)** Lateral view.

on both front and back side. So as to minimize errors during the measurement and decrease the resistance between the skin and the electrode, the dead skin and hair were removed using shavers.

After that, the skin is cleaned with an alcohol swab, and attached the electrode of surface electromyography (sEMG) on muscle belly. To prevent errors caused by movement of the electrode during the exercise, we fixed the electrode with tape. The distance of the EO

Electrodes were 2 cm apart, and they were placed parallel to the muscle fibers and located with the lateral 15 cm distance from the umbilical area, which is slightly oblique angle at 5° below 12th rib. TrA electrodes were placed 2cm apart and placed parallel to the muscle fibers and located in the medial-inferior 2cm from the Anterior Superior Iliac Spine (ASIS). ES electrodes were placed 2 cm apart and placed parallel to the muscle fibers and located in the lateral 3 cm from 3rd lumbar spinous process. MF electrodes were placed 2cm apart and placed parallel to the process. sEMGs were full-wave rectified and then band-pass filtered at 20-500 Hz with sampling frequency of 1000 Hz. Root Means Square (RMS) values were computed for each collection period.

Percentage of Maximum Voluntary Isometric Contraction (MVIC) was calculated by using the following formula to determine muscle activation of EO, TrA, ES and MF. MVIC was measured by traditional Manual Muscle Test (MMT) method. To get MVIC of EO, the subjects performed isometric 45° trunk lateral-flexion against manual resistance in supine position. The measurement of TrA has been done with isometric abdominal draw-in maneuver (ADIM) in supine position. For MVIC of ES and MF, the subjects performed isometric trunk extension against manual resistance in prone position. When measuring the MVIC, we required them to give maximum power for 5 seconds and repeat the set 3 times.

2.5 Data Analysis

In this study, SPSS version 22.0 statistical software (SPSS Inc, Chicago, IL, USA) was used for all statistical analysis. In order to calculate the subject characteristics, the mean value and the standard deviation of all the variables of the subjects, descriptive statistics were employed. One-way repeated ANOVA was used to compare muscle activities of EO, TrA, ES and MF depending on the four inversion angles. Bonferroni's correction was used as post-hoc comparison and statistical significance level was set at α=.05.

3. Result

Result of trunk muscle activation on the four inversion angles are shown in Figure 2. In EO, there was significant difference on four inversion angles (p<.001). Post-hoc test result showed significant difference (p<.001) on four inversion angles between 0°-10°, 0°-15°, 0°-20°, 10°-15° and 15°-20°. In TrA, there was significant difference on four inversion angles (p<.001) as well. Post-hoc test result indicated significant difference (p<.001) on four inversion angles between 0°-15°, 0°-20°, 10°-15° and 10°-20°. In ES and MF, they did not show significant difference in every inversion angle. Also, post-hoc test result did not reveal significant difference between every intervention.

%MVIC: Percent of maximum isometric contraction°: Inversion angle *p<.001.

4. Discussion

This study has been conducted to see the change of trunk muscle activation in accordance with inversion angle during squat exercise. In order to investigate the changes, we compared global and local muscles of trunk by applying the four inversion angles(0°, 10°, 15°, 20°). Since lower extremity or trunk global muscle activation have been studied a lot already, we put difference by measuring local muscle additionally during squat exercise. There were lots of studies about lower extremity and trunk muscle activation using squat exercise.

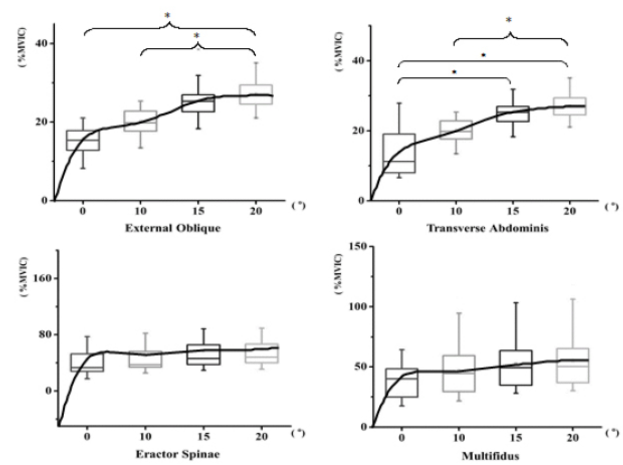

Figure 2. Mean activity and significant difference between muscles according to post-hoc test result.

In[14] was targeting 20 healthy male adults and conducted free weight squat with four interventions to measure the rectus abdominis, EO, TrA, internal oblique and ES muscle activation. The result had statistically significant different in the EO and ES during the squat exercise on a stable surface. Meanwhile, there was a statistically significant different only in EO while the squat exercise on a unstable surface[14]. There were some differences in the intervention with the previous reports similar in that there was a significant difference only in the EO, which is an abdominal muscle. Also, in this study, there were not a statistically significant differences in ES and MF, which are back muscles, on the wedge. This is because the low-extremity muscle acts more on the wedge in order to maintain the balance. Moreover, as a compensation of the balance for moving the center of gravity forward, the squat exercise led to trunk flexion. It also reported in a previous study that squat exercise leads to a compression force of spinal instability and lumbar spine[15]. So, we were able to draw a conclusion that back muscle did not make enough activation for the spine during the squat exercise in change of the surfaces[16].

As a study on ankle inversion angles, In[17] measured latissimus dorsi, pectoralis major and rectus abdominis depending on the dominant side and non-dominant side during the relaxed standing position on the ankle inversion 5° and 10°. As a result of this study, there was no statistically significant difference of muscle activation between dominant side and non-dominant as ankle inversion angle[17]. In addition, In[18] conducted isokinetic exercise on the ankle inversion 10° and 20° for six weeks with healthy adults and adults with ankle injury. As a result, there was no significant difference in the ankle invertor and evertor activation of the functional movement between the both groups[18]. However, a result of this study has revealed statistically significant difference from 0° to 15° as the ankle inversion angle increases. In particular, the result has shown that the muscle activation is applied nearly twice only to TrA. Also, the previous study suggested the contrary result in that there was not a significant difference for the trunk muscle activation for the angle over 20°.

The result of altering the inversion angle for the trunk muscle activation is still debatable. According to another previous study, author in[6] studied the risk factor of injury associated with the inversion while the subjects' running with wearing 15° and 25° inverted orthosis. As a result, there was a reduction in the inversion moment with the inverted orthosis (15° and 25°), while there was not without it (0°). Specifically, during squat exercise, the angle of 15° would show more effective performance than that of 25°.[6] Besides, author in[12] researched the stress on the metatarsal bone during the standing position on the inversion angle 10° and 20°. In this study, as the stress increases on the lateral metatarsal bone, the inversion angle becomes higher. Therefore, it suggests that ankle inversion injury can occur more easily[11]. There was a difference in that this study is including the various inversion angle intervention from 0° to 20° with the increment of 5° and the measurement of the activation of the trunk muscle. However, the result has a thread of a connection in that the inversion angle of 15° has more effective value and that the stress for the ankle will increase as the ankle inversion angle increases.

This study has shown the abdominal muscle activation which was statistically significant during the squat exercise with the inversion angles from 0° to 15°. However, the inversion angles between 15° and 20° gave more stress on the ankles as it increased the ankle inversion angle, so the trunk muscle did not function effectively. A previous study reported that it reduced the effect of rearfoot inverter more with the inversion angle of 20° than in that of 0°, and the trunk muscle activation reduced to maintain the posture, which provides a sufficient external stability in frontal plane[19].

In this study, between 15° and 20°, as the inversion angle is bigger, the muscle activation increases, but there was no statistically significant difference. This means that the trunk muscle function analogously between the two angles, because it only provides a external stability, not the whole foot during the squat exercise with the angle of more than 20°. Also, the weight that is distributed to three parts in the feet is given to the 5th metatarsal head intensively as the inversion angle increases, and higher stretching force was applied to the anterior talofibular ligament, which leads to instability in the ankle joint.

Therefore, it suggests that the risk for ankle inversion injury can increase with higher inversion angle. Seeing this result, when the inversion angle is 20° or more, only the stress on the ankle joint increases. We cannot say, however, that the squat exercise is effective. That is, the kinetic effect of squat exercise cannot be more higher.

We have shown that between 0° and 15° only in abdominis, the muscle activates most. In particular, TrA activates nearly two times more. However, the angles of more than 20° showed the least effect on the abdominal and back muscle. Consequently, if the squat exercise is carried out with the angle of 0° and 15° within same time, time effectiveness can increase more at 15° angle since more muscle is used. So, our study obtained a result that 15° inversion angle is the most ideal angle to carry out as the time effectiveness becomes higher without ankle inversion injury. In addition, muscle can be classified functionally into two types of muscle; global muscle is the muscle that can give great force in a moment for movements, and local muscle gives stability to the trunk to maintain the posture[20]. An exercise that activates both two types of muscle properly is better, and we can say that squat exercise is the very exercise. In some previous researches by[21,22] they investigated the activation of global muscle during squat exercise[21, 22]. However, in this study, we figured out that local muscle also activated during the squat exercise. Therefore, we suggests that both global and local muscle of the abdominal can be used when the squat exercise is carried out in the inversion angle 15°.

In this research, however, the back muscle did not show a significant difference during squat exercise. These results mean that back muscle is not that significant in the squat exercise with altering inversion angles. Also, we experimented with the traditional squat exercise and added a intervention of changing the inversion angle. However, we presume that if we provide a variety of intervention on the trunk position, or require a trunk flexion or extension, there would be another result on the back muscle. Thus, more research, related with trunk position as well as ankle position, needs to be carried out continuously.

5. Conclusions

In conclusion, squat exercise with inversion angle is an effective exercise method in that it can cause the activation of both global and local muscle of the abdomen. Also, the inversion angle of 15° is the most ideal one to activate the trunk muscle with effectiveness without ankle inversion injury. Therefore, the squat exercise with the varying inversion angles will be helpful to maintain trunk stability for the position through time effectiveness.

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