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Comparison of Triceps Surae EMG in Plantar Flexion Test of MMT at Different Knee Angles

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Abstract

This study was conducted to examine changes in the muscle activity of the triceps surae, specifically the gastrocnemius and the soleus, depending on the angle of the knee joint during the manual muscle test (MMT) of the plantar flexion of the ankle. The muscle activity of the medial and lateral heads of the gastrocnemius was statistically significantly reduced when the angle of the knee joint was 15°, 30°, and 45° compared to when the angle was 0°. However, there was no statistically significant difference in muscle activity at the angles of 15° and 30° or 45°. There was no statistically significant difference in the muscle activity of the soleus depending on the angle of the knee joint. The ratio of the muscle activity of the soleus to that of the triceps surae showed a statistically significant increase when the angle was 15°, 30° and 45° compared to when the angle was 0°. However, there was no statistically significant difference in muscle activity at the angles of 15° and 30° or 45°. When the angle of the knee joint was 15° or higher during the test of the isolated soleus, the muscle activity of the gastrocnemius was reduced. These results indicate that the angle is suitable for the test of the isolated soleus, but there was no statistically significant difference in the muscle activity of the gastrocnemius when the angle was higher than 15°. Therefore, it can be concluded that the most suitable angle of the knee joint for the isolated MMT test of the soleus is 15°.

***Keywords** : manual muscle test (MMT), gastrocnemius, soleus, surface electromyography, knee joint, isolated contraction*

1. Introduction

The triceps surae is composed of the gastrocnemius and the soleus, providing 80% of the total plantar flexion torque. In addition, it generates a sufficient muscle strength to maintain stability during exercises of the lower extremities, [1] and also maintains a balance to prevent the body from falling forward due to muscular contraction using the ankle lever in a standing position. [2]

The soleus originates from the posterior surfaces of the tibia and fibula, and inserts to the heel through the Achilles tendon. The soleus is deeper than the gastrocnemius, and it is involved in the plantar flexion of the ankle joint. [3] The soleus has many slow contractile fibers and thus maintains the posture, while the gastrocnemius has many fast contractile fibers, and performs strong exercises. [2] While walking, the gastrocnemius maintains the center of mass of the basal surface through continuous muscular contraction, [4] and supports balance on an unstable ground surface. [5]

The gastrocnemius originates from the inner and lateral condyles of the femur and inserts to the heel through the Achilles tendon. The muscle that originates from the inner surface of the femur is called the medial head, and the muscle that originates from the lateral condyle of the femur is called the lateral head.

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The gastrocnemius is a biarticular muscle that is involved in the flexion of the knee joint, and the plantar flexion of the ankle joint. [3]

The manual muscle test (MMT) has been used as a basic muscular strength assessment tool that checks the conditions and prognosis of patients in terms of muscular strength over time. During the MMT of the plantar flexion of the ankle, the heel is lifted as high as possible in a standing position. During the MMT of the isolated soleus, the knee is slightly bent, which is assessed as normal, good or fair. [6] The heel raising exercise is an exercise that lifts the heels and the body through the plantar flexion of the ankles in a standing position. This exercise is an effective aid in enhancing the function and muscular strength of the triceps surae, and it is also suitable for testing muscle activity. [7]

As discussed above, when testing the isolated soleus, the knees are bent. When the plantar flexion of the ankle joints is performed with the two legs stretched, the thickness and muscular strength of the gastrocnemius can be developed to the maximum level. However, when the plantar flexion of the ankle joint is performed with the knee bent, the involvement of the gastrocnemius is reduced, and the load is concentrated on the soleus. [8] It was reported that the gastrocnemius is involved in both the knee joint and the ankle joint, but that it is impossible to display the maximum strength of the joints simultaneously. [9] [10] This can be attributed to active insufficiency caused by the multi-joint muscles that are shortened as short as possible.[11] For this reason, when testing the isolated soleus during the dorsiflexion of the ankles, the heel is lifted in a standing position with the knee bent.

However, there is no uniform standard of the flexion angle of the knee joint available, and no sufficient scientific basis for testing the isolated soleus in a standing position. There are few studies available to identify the precise angle of the knee joint for the isolated contraction of the soleus.

In this regard, this study aimed to test the isolated soleus during the MMT of the plantar flexion of the ankle by setting the angle of the knee joint as 0°, 15°, 30°, and 45°, to compare the muscle activity of the soleus and the gastrocnemius, and thus to suggest the most efficient angle of the knee joint by reducing the activity of the gastrocnemius in a standing position and isolating the soleus. By doing this, a suitable angle of the knee joints for assessing the isolated soleus during the MMT of the plantar flexion of the ankle was suggested.

2. Methods

1. Subjects

Subjects were selected from individuals who were in their 20s and had not experienced any musculoskeletal or neurological damage over the previous year, and who were able to perform the exercise of standing on one leg for over 10 seconds. The subjects were informed of the purpose and process of this study, and consented to participate in this study. Individuals whose dominant leg could not be identified or who had a grade of poor or lower in the MMT of the plantar flexion of the ankle were excluded from the subject pool.

2. Test posture and process

Each subject was instructed to stand on the ground, and while looking straight ahead, to hold their non-dominant leg in the air with the knee bent. The dominant leg was bent by 0°, 15°, 30° and 45° and the angle was measured using a goniometer. Subjects were instructed to lift the heel as high as possible, and to maintain the position for 5 seconds. Subjects had a break for 1 minute after each test, and the test was repeated three times for each angle. During the test, the muscle activity of the subjects was measured. During the exercise, only the minimum support was allowed to ensure the subjects maintained balance by themselves.

Figure 1. The test posture of the isolated soleus during the MMT of the plantar flexion of the ankles

3. Methods for measuring muscle activity

The surface electromyography of the medial and lateral heads of the gastrocnemius and the soleus was recorded. The skin and the locations of electrodes were prepared for surface electromyography, the hair of subjects on the skin to which the electrodes were to be attached was removed, and the area was cleaned with cotton balls with alcohol before attaching them. [12] Electrodes were attached 2cm inward and outward from the center of the calf below the knee, to measure the medial and lateral heads of the gastrocnemius, respectively. To measure the soleus, an electrode was attached to the lower exterior surface of the muscle belly of the gastrocnemius.

The electromyography of each area was measured for 5 seconds. The first and last second of each record was excluded, and the record taken was the root mean square (RMS) of the remaining 3 seconds. The muscle activity of each area was calculated as its ratio to the maximum voluntary isometric contraction (%MVIC), and the ratio of the muscle activity of the soleus to that of the gastrocnemius was calculated by dividing the mean %MVIC value of the soleus by the total mean %MVIC of the medial and lateral heads of the gastrocnemius and the soleus.

The angle with the highest ratio was recognized as the most suitable angle of the knee for the contraction of the isolated soleus. The angle of the knee joint was measured using a goniometer. The MVIC values were measured by manually applying resistance to the muscles while subjects lay face down. The hair on the skin was removed, and the skin was cleaned with cotton balls with alcohol before attaching electrodes. Measurement was performed under the supervision of a tester, and the subjects were not allowed to use any external support for balance. Electromyography was repeated 3 times at each angle, and the average value was used as the final muscle activity.

Figure 2. Areas of electrodes attached on the medial and lateral heads of the gastrocnemius, and the soleus

4. Data processing and analysis

The data measured in this study were statistically processed using the IBM SPSS Statistics 24 software package. Muscle activity of the gastrocnemius and the soleus depending on the angle of the knee joint was compared using One-way ANOVA, and a post-hoc test was conducted using Dunnett T3. The significant level was set at .05.

3. Results

1. General characteristics of subjects

The general characteristics of the subjects were as shown in Table 1.

Table 1. General characteristics of subjects

	Male(n=10)	Female(n=10)	Total(n=20)
Height (cm)	173.9±5.76	159.3±20.23	166.6±9.02
Weight (kg)	72.3±8.34	54.5±2.41	63.4±10.91
Age (years)	22.4±1.07	20.2±0.63	21.3±2.01

2. Comparison of muscle activity of the triceps surae depending on the angle of the knee joint

The higher the angle of the knee joint, the lower the muscle activity of the medial and lateral heads of the gastrocnemius during a heel-raising exercise (Table 2). When the knee angle was 15°, 30° and 45°, the muscle activity was statistically significantly reduced compared to when the angle was 0°, but there was no statistically significant difference between muscle activity at 15°, 30° and 45° (Fig 3). The muscle activity of the soleus did not show any statistically significant difference depending on the angle of the knee joint (Table 2).

Table 2. Muscle activity of the triceps surae during a heel-raising exercise depending on the angle of the knee joint (%MVIC)

	0°	15°	30°	45°	F	P
MG	82.07±7.85	75.64±8.3	68.74±11.68	61.7±16.21	11.65	.000*
LG	76.93±8.48	66.92±14.48	60.93±18.35	55.73±20.89	6.28	.001*
Soleus	77.04±11.25	81.56±13.04	78.26±12.5	77.34±12.95	.55	.648

MG : medial gastrocnemius, LG : lateral gastrocnemius

3. Ratio of the muscle activity of the soleus to that of the triceps surae

The higher the angle of the knee joint, the higher the ratio of the muscle activity of the soleus to that of the triceps surae. When the knee angle was 15°,30° and 45°, the muscle activity was statistically significantly higher than when the angle was 0°, but there was no statistically significant difference between 15°, 30° and 45° (Table 3).

Table 3. The ratio of the muscle activity of the soleus to that of the triceps surae (%)

	0°	15°	30°	45°	F	P
Ratio	32.58±3.93	36.29±4.2	37.94±5.14	40.7±6.99	8.5	.000*

4. Discussion

This study aimed to measure the most optimal angle of the knee joint for the isolated manual muscle test (MMT) of the soleus.

The triceps surae is composed of the gastrocnemius and the soleus. The gastrocnemius is the main muscle of the calf that exists in the most shallow area under the skin of the calf, and the soleus is a wide and flat muscle that exists in the deeper area near the gastrocnemius. [13] The triceps surae is involved in the plantar flexion of the ankle during one-leg support and heel-raising exercises, and gives momentum to walking. [12] The triceps surae contributes to the stability of the ankle and the subtalar joint, and plays an important role in walking. [3]

The gastrocnemius is divided into the medial head and the lateral head, and originates from the inner and lateral condyles of the femur and inserts to the heel through the Achilles tendon. [8] Since the Achilles tendon in general circles down in a spiral by 1/4 (90°), the fibers of the gastrocnemius are attached to the lateral area and the fibers of the soleus are attached to the medial area. This structure is important to use some energy as momentum, and to maintain the elasticity of the tendon that is required to absorb impact energy and rewind. [9]

The gastrocnemius is a biarticular muscle and acts as a large lever during the plantar flexion of the knee. When it is ruptured, the function of walking or maintenance of posture is damaged, and thus it is important to treat the ruptured muscle early. [14] In addition, the gastrocnemius exerts a large force to begin the swing phase by moving the leg, and the strong movement of the gastrocnemius is particularly important for sports activities requiring explosive movements, like sprinting or jumping. [15]

Type Ⅰ muscles are slowly contracted with a long endurance and are involved in small motor units, while type Ⅱ muscles are quickly contracted with strong muscular strength and are involved in big motor units. [16] The soleus has the superiority of type Ⅰ muscular fibers, while over 50% of the gastrocnemius is composed of type Ⅱ muscular fibers. [17] As the soleus is continuously activated when standing and walking, which requires a high level of endurance, and it is mainly composed of type Ⅰ muscular fibers, it is categorized as a postural muscle. [18] The soleus is involved in the forward propulsion and acceleration of the body. [15] [16]As shown above, the gastrocnemius and the soleus that compose the triceps surae are involved in the plantar flexion of the ankle, and fulfill an important function. [19] [20] However, since the number of joints that the muscles insert into is different and they have different structural characteristics, it is necessary to develop methods to isolate and test each muscle and to provide precise guidelines. For this reason, in this study, the isolated soleus was tested using the manual muscle test (MMT) of the plantar flexion of the ankle.

The MMT of the plantar flexion of the ankle can be performed in two different positions: completely straightening the knee or slightly bending the knee. The MMT of the plantar flexion of the ankle that is performed with the knee straightened activates all the triceps surae muscles. However, the MMT that is performed with the knee slightly bent does not activate the gastrocnemius, and thus in this study, the MMT was performed by isolating the soleus. [6] In order to identify the most suitable angle of the knee for the isolated test of the soleus, the angle of the knee joint was set as 0°, 15°, 30°, and 45°, and the muscle activity of the triceps surae was compared. Since it is difficult to maintain balance during a heel-raising exercise in a standing position with the angle of the knee higher than 45°, and the posture increases the mobilization of the proximal muscles of the lower extremities, angles higher than 45° were excluded from this study. [20][21][22]

Changes in muscle activity depending on the angle of the knee were measured during the heel-raising exercise. When the knee angle was 15°, 30° and 45°, the muscle activity of the medial and inner heads of the gastrocnemius was statistically significantly higher than when the angle was 0°, but there was no statistically significant difference between muscle activity at 15°, 30° and 45°. The muscle activity of the soleus did not show any statistically significant difference depending on the angle of the knee joint. When the knee angle was 15°,30° and 45°, the ratio of the muscle activity of the soleus to that of the triceps surae was statistically significantly higher than when the angle was 0°. However, there was no statistically significant difference between muscle activity at 15°, 30° and 45°.

The results of this study showed that the muscle activity of the gastrocnemius when the angle of the knee was 15° or higher was statistically significantly lower than the muscle activity when the angle was 0°. However, there was no statistically significant decrease depending on the angle of the knee. In addition, the ratio of the muscle activity of the soleus to that of the triceps surae when the knee angle was 15°, 30° and 45° was statistically significantly higher than when the angle was 0°. However, there was no statistically significant difference between muscle activity at the angles of 15°, 30° and 45°. These results indicate that sufficient contraction of the isolated soleus can be achieved simply by bending the knee joint by 15°. Therefore, it can be concluded that bending the knee joint by 15° is sufficient to obtain the isolated contraction of the soleus during the MMT in a standing position. This is because the muscle activity of the gastrocnemius was not statistically significantly reduced when the angle of the knee joint is higher than 15°, and the ratio of the muscle activity of the soleus to that of the triceps surae was not statistically significantly increased.

It should be noted that this study has some limitations. Since this study was conducted on healthy adults in their 20s, it is difficult to generalize the results to other age groups. As other muscles of the lower extremities were excluded from this study, further research in this area should include various age groups and other muscles of the lower extremities.

5. Conclusions

This study was conducted on 20 healthy adults in their 20s to examine changes in the muscle activity of the triceps surae during a heel-raising exercise depending on the angle of the knee joint. The muscle activity of the gastrocnemius when the angle of the knee joint was 15° showed a statistically significant decrease, while there was no statistically significant decrease when the angle was higher than 15°. There was also no statistically significant difference in the muscle activity of the soleus depending on the angle of the knee joint. The ratio of the muscle activity of the soleus to that of the triceps surae showed a statistically significant increase when the angle of the knee joint was 15°, but there was no statistically significant increase when the angle was higher than 15°.

Based on the results, it can be concluded that the most optimal angle of the knee joint to isolate and test the soleus in a standing position in clinical settings is 15°, and that positioning at an angle higher than 15° does not have a big impact on the isolated contraction of the soleus.

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