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The Activities of the Muscles around the Ankle Joint during Foot-gripping are Affected by the Angle of the Ankle

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Abstract. [Purpose] The purpose of this study was to determine the activities of the muscles around the ankle joint during foot gripping. [Subjects] The subjects of this study were 17 healthy females. [Methods] We measured the maximum voluntary contraction (MVC) activities of the soleus muscle, the medial head of the gastrocnemius muscle, and the tibialis anterior muscle, and calculated %IEMG during foot gripping in 3 different ankle joint positions: 10° of plantar flexion, 0°, and 10° of dorsiflexion. [Results] The maximal force of foot gripping achived by the crural muscles in any ankle position was 30–50% IMEG of the MVC. Repeated analysis of variance showed that the %IEMG was significantly lower in 10°of dorsiflexion than in the other 2 positions for all muscles. [Conclusion] These results suggested that the crural muscles help the ankle joint by co-contracting during foot gripping.
Key words: Foot-gripping strength, Angle of the ankle joint, Muscle activity

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INTRODUCTION

The toe-plantar surface of the foot is the only part of the body that directly contacts the ground in the standing position and during walking, making toe-plantar function very important[1, 2)]. Many studies have reported that foot-gripping strength is related to toe-plantar function[3–6)]. Foot-gripping, like hand-gripping, is a complex motion involving several muscles. In the foot, these are the flexor pollicis brevis, flexor pollicis longus, lumbrical, flexor brevis and flexor longus[3)]. Foot gripping strength has been found to be lower in subjects with history of falls than in those with no history of falls[3, 4)]. Foot gripping strength can be increased by training[3–6)], and foot-gripping strength training can decrease the risk of falls[3)]. Therefore interventions targeting foot-gripping strength are effective; however, the mechanism by which foot-gripping strength is produce remains unclear.

To explain any motor mechanism, it is necessary to investigate the activities of the muscles involved in the movement. One important tool for examining muscle activity is electromyography (EMG). The integral of an EMG wave can be used for quantitative evaluation of muscle force. EMG has been used not only for quantitative assessment of hand gripping, but also for qualitative assessment of the timing of the contraction of each muscle and the modulation of the muscle activity[7–12)].

Previous studies have used EMG to determine the activities of the relevant muscles during finger gripping; however, we are not aware of any report of the muscle activities in the lower legs during foot-gripping. In order to elucidate the relationship between the activities of the crural muscles and foot-gripping force, we analyzed the changes in muscle activity during foot gripping with the ankle joint in 3 different positions. The purpose of this study was to determine the effect of the angle of the ankle joint on the maximal muscle activities of the tibialis anterior, medial head of the gastrocnemius, and soleus muscles.

SUBJECTS AND METHODS

The subjects of this study were 17 healthy females with no known orthopedic impairments. Their average respectively (mean ± standard deviation) age, height, and body weight were 21.5 ± 1.0 years, 158.7 ± 4.4 cm, 52.2 ± 5.2 kg, This study was approved by the ethics committee for human research of Tohoku Fukushi University (RS1208283). The subjects provided their informed consent prior to participation.

We synchronously recorded the foot-gripping strength of the dominant foot and the EMG activity of the ipsilateral lower leg to assess the muscle activities of the anterior tibialis, medial head of the gastrocnemius, and soleus muscles.

As described by Murata[3)], the subjects were instructed to sit with the trunk vertical and the hip and knee joints at

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Table 1. Foot-gripping strength the three ankle joint positions

	Dorsiflexion	Neutral Position	Plantar flexion
Foot-gripping strength (kg)	19.0±4.1*	18.9±3.4*	16.8±4.9

Mean ± SD ; *: p < 0.05 versus plantar flexion

Table 2. %IEMG values of the tibialis anterior muscle, medial head of the gastrocnemius muscle, and soleus muscle in the three ankle joint positions

Activities of the muscle	Dorsiflexion	Neutral position	Plantar flexion
Tibialis anterior muscle (%iemg)	27.0 ± 18.7	33.1 ± 20.1*	33.2 ± 17.3*
Medial head of the gastrocnemius (%iemg)	29.3 ± 13.9	38.8 ± 21.1*	49.6 ± 20.5*
Soleus muscle (%iemg)	32.1 ± 19.1	39.9 ± 26.0*	37.3 ± 19.3*

Mean ± SD; *: p <0.05 versus dorsiflexion

90°. The foot-gripping strength was assessed in 3 different ankle joint positions: 10 ° of plantar flexion, 0 °, and 10° of dorsiflexion. The sequence of the ankle positions was chosen randomly for each subject.

The ankle joint position was set using an ankle joint correction plate (K2590M, SAKAI, Japan). The handle of the force meter was set on the first metatarsophalangeal joint. After a sufficient number of training trials and adequate rest, the foot-gripping strength was measured twice. The maximal force was used in the analysis. The right foot was dominant (defined as the foot used to kick a ball), in 90.5% of the subjects.

To measure the maximum voluntary contraction (MVC) activities of the soleus muscle and medial head of the gastrocnemius muscle, each subject was instructed to sit in a chair with the ankle joint in a neutral position and to exert maximal force of plantar flexion in isometric contraction to resist the force applied by the examiner in the direction of dorsiflexion. We recorded the EMG during the generation of each subject's maximal force of plantar flexion.

Finally, for measurement of the MVC of the tibialis anterior muscle, each subject was instructed to generate maximal force of dorsiflexion in isometric contraction to resist the force applied by the examiner in the direction of plantar flexion. We recorded the EMG during the generation of each subject's maximal force of dorsiflexion.

As described by Peroto[13)], 3 bipolar lead electrodes (DE-2.1, Delsys, Inc.) were attached to tibialis anterior muscle, the medial head of the gastrocnemius muscle, and the soleus muscle, after confirmation of adequate skin preparation (skin resistance of less than 5 kΩ). In addition, when the electrodes had been attached to the skin over the medial head of the gastrocnemius muscle and the soleus muscle, we checked that the EMG readings reflected the contraction of these muscles by having the subject perform plantar flexion and dorsiflexion of the ankle joint with the knee joint in flexion and in extension.

The electrode on the tibialis anterior muscle was attached 4 finger's breadth from the tibial tuberosity and 1 finger's breadth from the tibial spine. For the medial head of the gastrocnemius muscle, the electrode was attached 5 finger's breadth below the center horizon line of the popliteal fossa. For the soleus muscle, the electrode was attached to the end of the medial head, anterior to the Achilles tendon. The EMG signal was collected using a ML846 Power Lab 4/26 (sample: 1000 Hz; AD Instruments Co., Ltd.) and then transferred to a personal computer. The bandwidth was 20–500 Hz. We selected the segment of the EMG signal corresponding to the middle 1 second of the entire 3 seconds of continuous maximal foot-gripping strength and then integrated it (Integrated Electronmyogram: IEMG) for analysis.

The IEMG was analyzed using LabChart Pro v7.3.5 (AD Instruments Co., Ltd.) and normalized to the IEMG of the MVC of each muscle.

We used SPSS software (IBM Co., Ltd.) for statistical analysis. We performed repeated analysis of variance (ANOVA) and the Dunnett test for multiple comparisons to compare the IEMG of each muscle (tibialis anterior muscle, soleus muscle, and the medial head of the gastrocnemius muscle) among the different ankle joint angles. The level of significance was chosen as 5%.

RESULTS

The average (mean ± SD) foot-gripping strength was 19.0 ± 3.3 kg in 10° of dorsiflexion, 18.5 ± 3.3 kg in the neutral position (0°), and 16.4 ± 5.0 kg in 10° of plantar flexion; these values were significantly different. Multiple comparisons showed that the foot-gripping strength was significantly lower in plantar flexion than in the other 2 positions ($p < 0.05$) (Table 1).

Table 2 shows the %IEMG values recorded in the anterior tibialis muscle, the medial head of the gastrocnemius muscle, and the soleus muscle during foot-gripping. Repeated ANOVA showed that the %IEMGs of the muscles were significantly different, and multiple comparisons showed that the %IEMG was significantly lower in 10° of dorsiflexion than in the other 2 positions for all muscles ($p < 0.05$).

DISCUSSION

This study measured the %IEMG of the muscle activities of the soleus muscle, the medial head of the gastrocnemius muscle, and the tibialis anterior muscle during the generation of maximal foot-gripping strength, and compared it among 3 angles of the ankle joint. We found that the crural muscles achieved 30–50% IMEG of the MVC during exertion of maximal foot-gripping strength force in all positions. This result suggests that not only weakness of the toe flexor muscles but also decreased function of the crural muscles can decrease foot-gripping strength.

In this study, we found that the % IEMG was lower when the ankle joint was in dorsiflexion than when it was in the neutral position or plantar flexion. Effective production of foot-gripping strength requires stabilization of the ankle joint, which is related to the crural muscles. Because the ankle is the talocrural joint, and the crural articular surface has a concave shape, ankle joint stability can be attained in dorsiflexion but not in plantar flexion[14]. We attribute the lower % IEMG in ankle dorsiflexion to this phenomenon, and consider good co-contraction of the peripheral muscles of the ankle joint necessary for stability of the joint in the neutral position and in plantar flexion.

The results of this study indicate that, foot-gripping force could be exerted more effectively, and with less dependence on the activities of the crural muscles, when the ankle joint was in dorsiflexion. Another reason for the more effective exertion of foot-gripping force in ankle dorsiflexion, in addition to the anatomical stability of the talocrural joint, is that the lengths of the muscles involved in foot-gripping, such as the flexor pollicis longus and flexor longus are similar to the optimum lengths shown on the muscle length–force curve[15].

Our study had some limitations. First, we were unable to avoid various common problems that negatively affect surface EMG, such as the resistance of the skin, artifacts, and the effects of proximal muscles. Second, only healthy young women participated this study, so it is difficult to extend our findings to the general population. In future studies, we need to consider this aspect, and involve healthy young men as well as other age groups.

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