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Original Article

Comparison of toe grip strength and muscle activities during maximal toe grip strength exertion according to the presence/absence of an ankle immobilization belt

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Abstract. [Purpose] The aim of this study was to compare toe grip strength and muscle activity during toe grip strength exertion according to the presence/absence of an ankle immobilization belt and to examine the relationship between the differences in muscle activity and toe grip strength. [Subjects] The Subjects were 13 healthy young women. [Methods] We measured toe grip strength and muscle activity during toe grip strength exertion in the presence and absence of an ankle immobilization belt using electromyography. Activity in the following leg muscles was recorded: rectus femoris, biceps femoris, medial head of the gastrocnemius, and tibialis anterior. We then calculated the percent integrated electromyography during toe gripping. [Results] Toe grip strength and percent integrated electromyography of the medial head of the gastrocnemius muscle were significantly higher with ankle belt immobilization compared with without ankle belt immobilization. In addition, in the presence of ankle belt immobilization, the percent integrated electromyography of the tibialis anterior muscle and medial head of the gastrocnemius muscle demonstrated a positive correlation with toe grip strength ($r = 0.75$ and $r = 0.65$, respectively). [Conclusion] These findings suggest that greater toe grip strength could be exerted in the presence of ankle belt immobilization. The measured values reflect the percent integrated electromyography of the crural muscles. Therefore, it was shown that toe grip strength should be measured in the presence of an immobilization belt.
Key words: Toe gripping strength, Muscle activity, Immobilization belt

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INTRODUCTION

Muscle strength in the lower extremities is an essential element of physical therapy evaluation and can have a significant impact on activities of daily living (ADL) functions and walking ability[1–3)]. The strength of the quadriceps muscle is of particular relevance in terms of walking ability[1)], maximum walking speed[2)], and mobility in activities of daily living[3)]; therefore, strength in the quadriceps femoris may be used as a representative value of muscle strength in the lower extremities.

Many studies have reported on the use of toe grip strength as a measure of muscular strength in the elderly[4–11)]; low toe grip strength is a risk factor for falls in this population[4–6)]. Toe grip strength can be increased by training[7, 8)], and foot grip strength training can decrease the risk of falls[4, 5)]. While it has been established that interventions targeting toe grip strength are effective, the method by which toe grip strength should be measured has not been sufficiently investigated.

The position in which toe grip strength is measured has been standardized; the subject is required to sit with the trunk in the vertical position, the hip and knee joints at 90°, and the ankle joint in a neutral position[4–10)]. Devices are currently available for measuring toe grip strength[7, 9, 11)] and are easy to manufacture. Hence, in many studies, original devices are created for performing measurements[4, 6, 8, 10)]. Therefore, it is unclear whether the measurement method involves fixation of the ankle area with a belt.

The purposes of this study were (1) to compare toe grip strength and muscle activity during toe grip strength exertion according to the presence/absence of an ankle immobilization belt and (2) to examine the relationship between the difference in muscle activity and toe grip strength.

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SUBJECTS AND METHODS

The subjects were 13 healthy females with no known orthopedic impairments. Their age, height, and body weight (mean ± standard deviation) were 20.3 ± 0.6 years, 159.2 ± 4.0 cm, and 51.3 ± 4.6 kg, respectively. The present study was approved by the Ethics Committee for Human Research of Tohoku Fukushi University (RS150402), and the subjects provided informed consent to participate.

We synchronously recorded the toe grip strength of the dominant toe and the toe grip strength according to the presence/absence of an ankle immobilization belt, as measured by a toe grip dynamometer. In order to assess the activity of the rectus femoris, biceps femoris, medial head of the gastrocnemius, and tibialis anterior muscles, the electromyographic (EMG) activity of the ipsilateral thigh was also synchronously recorded.

Toe grip strength was measured using a toe grip dynamometer (T.K.K. 3360; Takei Co., Ltd., Niigata, Japan). Regarding the reproducibility of this instrument, the intraclass correlation coefficient (1, 1) was reported to be as high as 0.823[11]. As described by Uritani[9], the subjects were instructed to sit with their trunk in a vertical position, place their hip and knee joints at 90°, and keep their ankle joints in a neutral position. To eliminate the effect of artifacts on EMG data, the measurements were performed with the subjects in an upright sitting position in which the midpoint between the head of the fibula (the electrode attachment site at the long head of the biceps femoris muscle) and the ischial tuberosity did not touch the seating surface. In a normal upright sitting position, weight is mainly supported by the ischial tuberosity, posterior surface of the thigh, and sole of the foot. However, in the present study, weight was mainly supported by the ischial tuberosity and sole of the foot. The handle of the force meter was set on the first metatarsophalangeal joint. After a sufficient number of training trials and adequate rest, the toe grip strength was measured twice. The maximum force was used in the analysis. The measurements of toe grip strength in the presence and absence of an ankle immobilization belt were performed in random order. In all subjects, the right toe was dominant; the dominant toe was defined as the toe used to kick a ball.

To measure the angle of the ankle, an electrogoniometer (EM-551; Noraxon USA Inc., Scottsdale, AZ, USA) attached to inside of the lower leg over the center line and the plantar surface of the toe was used. When achieving the maximum voluntary isometric contraction of the rectus femoris, biceps femoris muscle, tibialis anterior muscle, and medial head of the gastrocnemius muscle, the level of exertion of muscular activity may vary depending on the joint angle examined. Therefore, the maximum muscular strength was measured with specific joint angle at the time of measurement of toe grip strength. Thus, to measure the maximum voluntary contraction (MVC) activities of the tibialis anterior 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 the maximal force of plantar flexion and dorsiflexion in isometric contraction to resist the force applied by the examiner in the direction of dorsiflexion and plantar flexion. To measure the MVC activity of the rectus femoris and biceps femoris muscles, each subject was instructed to sit in a chair with the hip and knee joints at 90°, and to exert maximal isometric force of knee extension and flexion in isometric contraction to resist the force applied by the examiner in the direction of flexion and extension. The EMG activity was recorded for 3 s while each subject exerted maximal force.

Muscular activity was measured using a surface EMG apparatus (TeleMyo G2; Noraxon USA Inc., Scottsdale, AZ, USA). After confirming adequate skin preparation (skin resistance of <5 kΩ), electrodes (Bluesensor; Ambu Inc., Ballerup, Denmark) were attached to the tibialis anterior, medial head of the gastrocnemius, rectus femoris, and biceps femoris muscles, as described by Peroto[12].

For the tibialis anterior muscle, electrodes were attached four finger breadths from the tibial tuberosity and one finger breadth outside the tibial crest. For the medial head of the gastrocnemius muscle, electrodes were attached five finger breadths from the popliteal fossa crease and in the medial belly. To measure the rectus femoris muscle, an electrode was attached to the midpoint between the superior edge of the patella and the anterior superior iliac spine. To measure the long head of the biceps femoris, an electrode was attached to the midpoint between the head of the fibula and ischial tuberosity.

The EMG signals were collected and transferred to a personal computer using analysis software (MyoResearch XP; Noraxon USA Inc., Scottsdale, AZ, USA), which was transferred to a personal computer. The bandwidth was 20–500 Hz. The EMG signal segment selected and integrated (IEMG) for analysis was the middle 1 s of the entire 3-s duration of continuous maximal toe grip strength exertion. The IEMG was normalized to the IEMG of the MVC of each muscle. The muscular activity used for analysis was based on the data for the maximum toe grip strength.

The SPSS software (version 12.0 for Windows; SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Comparison of toe grip strength and muscle activity during toe grip strength exertion according to the presence/absence of an ankle immobilization belt was undertaken using the paired t-test. The relationship between the toe grip strength, presence/absence of an ankle immobilization belt, and percent IEMG (%IEMG) of each muscle was statistically analyzed using Spearman's correlation. The level of significance was set at 5%.

RESULTS

Toe grip strength measured in the presence of ankle belt immobilization was significantly higher compared with that measured in the absence of ankle belt immobilization (Table 1) (Fig. 1). In terms of the comparison of %IEMG in each muscle during the toe gripping with and without ankle belt immobilization, the %IEMG of the medial head of the gastrocnemius muscle was significantly higher in the presence of ankle belt immobilization (Table 1).

According to Spearman's correlation coefficient, there was a significant positive correlation between the toe grip strength with ankle belt immobilization and the %IEMG values of both the tibialis anterior ($r = 0.75$, $p < 0.05$) and the

Table 1. Comparison of outcome variables according to the presence/absence of ankle belt immobilization

Variable	Ankle belt immobilization (n = 13)	No ankle belt immobilization (n = 13)
Toe grip strength (kg)	15.0±4.5*	9.9±2.6
Rectus femoris muscle (%IEMG)	3.0±1.6	2.5±1.1
Long head of the biceps femoris muscle (%IEMG)	31.2±19.8	26.2±18.1
Tibialis anterior muscle (%IEMG)	33.4±19.1	36.4±17.7
Medial head of the gastrocnemius muscle (%IEMG)	49.8±20.5*	42.3±24.1

%IEMG: percent integrated electromyography
*p<0.05

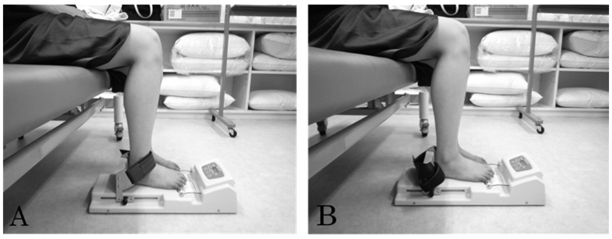

Fig. 1. Measurement of toe grip strength (A) with ankle belt immobilization and (B) without ankle belt immobilization

Table 2. Correlation between toe grip strength in the presence of ankle belt immobilization and percent integrated electromyography (%IEMG) during toe grip strength exertion

	Correlation (r)
Rectus femoris muscle (%IEMG)	0.20
Long head of the biceps femoris muscle (%IEMG)	−0.31
Tibialis anterior muscle (%IEMG)	0.75*
Medial head of the gastrocnemius muscle (%IEMG)	0.63*

*p<0.05

Table 3. Correlation between toe grip strength in the absence of ankle belt immobilization and percent integrated electromyography (%EMG) during toe grip strength exertion

	Correlation (r)
Rectus femoris muscle (%IEMG)	0.07
Long head of the biceps femoris muscle (%IEMG)	−0.91
Tibialis anterior muscle (%IEMG)	0.36
Medial head of the gastrocnemius muscle (%IEMG)	0.41

medial head of the gastrocnemius muscle ($r = 0.63$, $p < 0.05$) (Table 2). This correlation was not present in the assessment of toe grip strength without ankle belt immobilization (Table 3).

DISCUSSION

The present study compared toe grip strength and muscle activity during toe grip strength exertion according to the presence/absence of an ankle immobilization belt, and the relationship between the differences in muscle activity and toe grip strength was assessed. In our analysis, both toe grip strength and %IEMG of the medial head of the gastrocnemius muscle were significantly greater when measured in the presence of ankle belt immobilization compared with the results recorded in the absence of immobilization. Moreover, in the presence of ankle belt immobilization, there was a positive correlation between toe grip strength and the %IEMG of the tibialis anterior muscle and between toe grip strength and the %IEMG of the medial head of the gastrocnemius muscle. These findings suggest that greater toe grip strength could be exerted in the presence of ankle belt immobilization, and these measured values reflect the %IEMG values of the crural muscles. Therefore, it was shown that toe grip strength should be measured in the presence of an immobilization belt.

The present results show that toe grip strength is stronger and that the %IEMG of the medial head of the gastrocnemius muscle is significantly higher with ankle belt immobilization than without it. This is inferred to be caused by the anatomical limitations of the interphalangeal and metatarsophalangeal joints during the exertion of toe grip strength without belt immobilization and the accompanying attenuation of active tension. Toe grip strength is measured by using the forefoot, including the toes, to bend a grip bar fixed to a toe grip strength measuring instrument, while the heel serves as a supporting point. Therefore, in the absence of an ankle immobilization belt, force for immobilizing the heel is also required when toe grip strength is being exerted. However, if there is inadequate force for immobilizing the heel, then the exertion of toe grip strength is inferred to be accompanied by anterior movement of the foot pivoting about the grip bar. Therefore, in the absence of ankle belt immobilization, anatomical limitations and the resulting attenuation of active tension from the tension-length curve are believed to reduce the toe grip strength that can be exerted. With ankle belt immobilization, however, the ankle belt provides the needed auxiliary force for immobilizing the heel. Therefore, the concentric contraction associated with flexing of the interphalangeal and metatarsophalangeal joints and isometric contraction of the end feel are believed to enable the exertion of toe grip strength. In addition, the flexor hallucis longus and flexor digitorum longus, considered agonist muscles for toe grip strength, are common muscles of the ankle plantar flexion action similar to the medial head of the gastrocnemius muscle. Thus, exertion of toe grip strength with ankle belt immobilization resulted in high %IEMG values for the medial head of the gastrocnemius muscle.

In the present study, measurements taken with belt immobilization during the exertion of toe grip strength showed a significant positive correlation between the %IEMG values of the tibialis anterior and medial head of the gastrocnemius muscle and toe grip strength. This shows that that when the tibialis anterior and medial head of the gastrocnemius muscle have a greater %IEMG values, as obtained by belt immobilization of the ankle during the exertion of toe grip strength, toe grip strength is correspondingly greater. Toe grip strength is a form of muscle strength exerted by the actions of the flexor pollicis brevis, flexor pollicis longus, lumbrical muscle, flexor digitorum brevis, and flexor digitorum longus, all of which are deep muscles. Therefore, muscle activity during the exertion of toe grip strength cannot be directly ascertained, but the toe grip strength obtained with ankle immobilization was reflective of crural muscle activity. During the exertion of toe grip strength as measured with ankle belt immobilization, simultaneous contraction of the crural muscles and the tibialis anterior plays an important role[13]; this was affirmed by our results. However, the findings of the present study also demonstrated a significant positive correlation between the %IEMG of the medial head of the gastrocnemius and toe grip strength, which has not been demonstrated in previous studies. The toe flexor muscles, which output toe grip strength, also act as accessory muscles in plantar flexion of the ankle. Thus, as toe grip strength is exerted, the plantar flexion of the ankle, i.e., the %IEMG of the medial head of the gastrocnemius, increases. Therefore, the ankle is thought to be stabilized by contraction of the antagonist tibialis receptor muscle and simultaneous contraction of the crural muscles. Although we cannot demonstrate the reason for the observed correlation between the %IEMG of the medial head of the gastrocnemius and toe grip strength based on the present study, we inferred the following. The difference between previous studies and the present study is the position in which the toe grip strength was measured. In the present study, to eliminate artifacts during EMG measurement, the measurements were performed with the subjects in an upright sitting position in which the midpoint connecting the head of the fibula (the electrode attachment site in the long head of the biceps femoris muscle) and the ischial tuberosity did not touch the seating surface. In a normal upright sitting position, weight is mainly supported by the ischial tuberosity, posterior surface of the thigh, and sole of the foot. In the present study, however, weight was mainly supported by the ischial tuberosity and sole of the foot. Therefore, the load on the heel was inferred to be greater in this study than in previous studies. In addition, fixation of the heel by its own weight was considered to result in easier activity of the medial head of the gastrocnemius.

However, the subjects were unable to exert increased muscle strength when measuring toe grip strength in the absence of ankle belt immobilization, and the measured values did not reflect the %IEMG of the crural muscles. For toe grip strength, this suggests the possibility that without ankle immobilization, the muscles that are active during the foot gripping action are not always constant, nor are their activity levels. During the foot gripping action, the use of an immobilization belt to compensate for heel immobilization caused by the exertion of muscles surrounding the ankle is thought to cause the muscles involved in toe gripping to be exerted in a reproducible manner. This shows that an immobilization belt should be used for measuring toe grip strength. Therefore, it may be necessary to reassess previous studies suggesting relationships between foot grip muscle strength values and physical ability or falling if the studies did not use an immobilization belt.

Our study has some limitations. First, we were unable to avoid various common problems that negatively affect surface EMG, such as resistance of the skin, artifacts, and the effects of proximal muscles. Second, we were unable to clearly differentiate the activities of the crural muscles between this study and previous studies. Third, only healthy young females participated; thus, it is difficult to extrapolate our findings to the general population. Future studies should include healthy young men and other age groups.

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