J. Phys. Ther. Sci. 28: 3131–3135, 2016

The Journal of Physical Therapy Science

Original Article

Examinations of factors influencing toe grip strength

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Abstract. [Purpose] This study examined the relationship between toe grip strength and its associated factors by focusing on factors that were suggested to have a relationship with toe grip strength in previous studies, aiming to clarify the factors influencing the toe grip strength of healthy women. [Subjects and Methods] Twelve healthy young women were selected for this study. Their toe grip strength, angular changes in their ankle joint during toe grip, maximum voluntary contraction activities of the rectus femoris, biceps femoris, and tibialis anterior muscles, and the medial head of the gastrocnemius muscles were measured using electromyography. Their toe curl ability, foot-arch height ratio, and weight were also measured. [Results] Multiple regression analysis demonstrated that the predictors of toe grip strength in the resulting model were foot-arch height ratio and the percentage of integrated electromyography (%IEMG) of the tibialis anterior muscle, as the dependent variables. This reveals that women whose tibialis anterior muscle %IEMG values and foot-arch height ratio are high have greater %IEMG values have greater toe grip strength. [Conclusion] These findings suggest a significant relationship between foot-arch height ratio and toe grip strength, with a reciprocal interaction. These findings further indicate that the risk of falls by the elderly could be decreased if toe grip strength were enhanced, by increasing the height of a low foot-arch with the help of an inserted insole.

Key words: Toe grip strength, Impact factor, Healthy females

(This article was submitted Jun. 1, 2016, and was accepted Jul. 21, 2016)

INTRODUCTION

Toe grip is a complex motion that involves several muscles, similar to hand grip. The muscles involved in toe grip include the flexor pollicis brevis, flexor pollicis longus, the lumbricals, flexor brevis, and flexor longus[1)]. Toe grip strength can be increased by training[2, 3)], which can decrease the risk of falls[1, 4, 5)]. Therefore, interventions targeting toe grip strength are effective; however, the mechanisms behind toe grip strength have not been sufficiently investigated.

Murata et al.[6)] reported that toe grip strength is affected by three factors: body weight, foot flexibility, and foot- arch height. Moreover, Uritani et al.[7)] reported that toe grip strength is affected by four factor: age, gender, height, and weight. Recently, Souma et al.[8, 9)] measured toe grip strength using surface electromyography (EMG) . They reported that the crural muscles help the ankle joint by co-contracting during toe grip, and that the activity of the tibialis anterior muscle plays a specific and important role. Souma et al.[10)] performed a kinematic analysis of angular changes in the ankle joint and compared the results with the percentage of integrated electromyography (%IEMG) of the leg muscle activities during toe grip. They reported

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that the mean change in the ankle angle in dorsiflexion from a neutral position was 3°, and a positive correlation was found between this angle and toe grip strength. Moreover, the activities of the tibialis anterior muscle and the medial head of the gastrocnemius muscle demonstrated positive correlations with toe grip strength. Some studies have reported that a change in the angle of ankle dorsiflexion during toe-grip actions, and the activities of the tibialis anterior muscle and the medial head of the gastrocnemius muscle are related to toe grip strength. Accordingly, this study aimed to determine the main factor influencing toe grip strength among these factors.

The purposes of this study were to examine the relationship between toe grip strength and the factors suggested to have a relationship with toe grip strength in previous studies, aiming to clarify the factors influencing toe grip strength in healthy women.

SUBJECTS AND METHODS

The subjects were 12 healthy women with no known orthopedic impairments. Their age, height, and body weight (mean ± standard deviation) were 21.2 ± 0.4 years, 159.6 ± 3.7 cm, and 51.5 ± 4.8 kg, respectively. The present study was approved by the Ethics Committee for Human Research of Tohoku Fukushi University (RS160103), and all subjects provided their informed consent prior to participation.

As described by Murata[6)], Uritani[7)] and Souma[8–11)], the toe grip strength of the dominant foot, angular changes in the ankle joint during toe grip, maximum voluntary contraction (MVC) activities of the rectus femoris, biceps femoris, tibialis anterior, and medial head of the gastrocnemius muscles, toe curl ability, foot-arch height ratio, and weight were measured. Electrogoniometer and EMG activities were synchronously recorded during toe grip.

Toe grip strength was measured using a toe-grip dynamometer (T.K.K.3360; Takei Co., Ltd., Niigata, Japan). The subjects were instructed to sit with their trunk in a vertical position, to place their hip and knee joints at 90°, and to keep their ankle joints in the neutral position[7–10)]. 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, and the maximum force was used in the analysis. In all subjects, the right toe, which was defined as the toe used to kick a ball, was dominant.

An electrogoniometer (EM-551; Noraxon Inc., Scottsdale, AZ, USA) was attached to the inside of the lower leg over the center line, and the plantar surface of the toe was used[10)]. When achieving maximum voluntary isometric contraction of the rectus femoris, biceps femoris, tibialis anterior, and medial head of the gastrocnemius muscles, the level of exertion of muscular activity may vary depending on each joint angle. Therefore, the maximum muscular strength at a specific angle was measured at each joint angle at the time of the toe grip strength measurement. To measure the MVC activities of the tibialis anterior and medial head of the gastrocnemius muscles, each subject was instructed to sit on a chair with the ankle joint in the neutral position, and to exert maximal force of plantar flexion and dorsiflexion in isometric contraction in order 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 on a chair with the hip and knee joints at 90° and to exert maximal isometric force of knee extension and flexion in isometric contraction in order to resist the force applied by the examiner in the direction of flexion and extension. EMG was recorded for 3 s while each subject exerted maximal force.

Muscular activity was measured using a surface EMG apparatus (TeleMyoG2; Noraxon Inc., Scottsdale, AZ, USA). After adequate skin preparation (skin resistance of <5 kΩ), electrodes (Blue sensor; 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[11)]. To measure the tibialis anterior muscle, electrodes were attached at four fingerbreadths from the tibial tuberosity and one fingerbreadth from the tibial crest. For the medial head of the gastrocnemius muscle, electrodes were attached five fingerbreadths from the popliteal fossa crease in the medial belly. For the rectus femoris muscle, an electrode was attached to the midpoint between the superior edge of the patella and the anterior superior iliac spine. For the long head of the biceps femoris muscle, an electrode was attached to the skin at the midpoint between the head of the fibula and ischial tuberosity[10)].

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

To measure the toe curl ability, the foot length, which was defined as the length between the tip of the big toe and heel, and the flexed foot length, which was defined as the length between the tip of the big toe and heel while placing the fulcrum in the calcaneal region and bending the toe, were measured. The toe curl ability was calculated as the flexed foot length minus the foot length, divided by the foot length[6, 7)]. The toe curl ability is used as an indicator of flexibility, and greater toe curl ability values indicate greater toe and foot flexibility and mobility[6, 7)].

To measure the foot-arch height ratio, the navicular height, which was defined as the height between the navicular tuberosity and floor, was measured. The foot-arch height ratio was calculated as the navicular height divided by the foot length. The foot-arch height ratio is used as an indicator of the degree of the medial longitudinal arch of the foot, and greater foot-arch height ratio values indicate a higher medial longitudinal arch of the foot[6, 7, 12, 13)].

SPSS software (version 12.0 for Windows; SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. The relationship between toe grip strength and each measured value was analyzed using Spearman correlation coefficients. Thereafter, stepwise multiple regression analyses (step-down procedure) were performed, with toe grip strength as the dependent variable, and weight, foot flexibility, foot-arch height percentage, angular changes in the ankle joint during toe grip, and %IEMG of the rectus femoris, biceps femoris, tibialis anterior, and medial head of the gastrocnemius muscles as the independent variables, in order to find factors that influenced toe grip strength. The level of significance was chosen as 5%.

RESULTS

Table 1 shows the average and standard deviations of the measured values of the 12 subjects. Based on Spearman's correlation coefficient, in higher order of correlation, toe grip strength was significantly positively correlated with foot-arch height ratio (r=0.69, p<0.05), %IEMG of the tibialis anterior muscle (r=0.67, p<0.05), toe curl ability (r=0.66, p<0.05), %IEMG of the medial head of the gastrocnemius muscle (r=0.61, p<0.05), and angular changes in the ankle joint (r=0.60, p<0.05) (Table 2). However, toe grip strength was not correlated with weight, %IEMG of the rectus femoris muscle, and biceps femoris muscle.

Variables with significant differences were subjected to multiple regression analysis with toe grip strength as the dependent variable. The predictors in the resulting model were the foot-arch height ratio (β=0.54, p<0.01) and %IEMG of tibialis anterior muscle (β=0.51, p=0.01). The adjusted R^2 was 0.72.

DISCUSSION

The present study examined the relationship between toe grip strength and each factor by measuring weight, toe curl ability, foot-arch height ratio, angular changes in the ankle joint during toe grip, and %IEMG of the rectus femoris muscle, biceps femoris muscle, tibialis anterior muscle, and the medial head of the gastrocnemius muscle. These factors were suggested to

Table 1. Mean and standard deviations of the measured values (n=12)

	Mean	Standard deviation
Toe grip strength (kg)	15.9	4.3
Toe curl ability (cm)	2.9	0.8
Foot-arch height ratio (cm)	19.9	2.3
Weight (kg)	51.5	4.8
Angular changes in the ankle joint (°)	3.2	2.0
Rectus femoris muscle (%IEMG)	3.1	1.6
Long head of the biceps femoris muscle (%IEMG)	31.9	20.8
Tibialis anterior muscle (%IEMG)	35.3	19.3
Medial head of the gastrocnemius muscle (%IEMG)	20.9	19.2

%IEMG: percentage of integrated electromyography

Table 2. Correlation between toe grip strength and each measured value during toe grip strength exertion (n=12)

	Toe grip strength	Weight	Toe curl ability	Foot-arch height ratio	Angular changes in the ankle joint	Rectus femoris muscle (%IEMG)	Long head of the biceps femoris muscle (%IEMG)	Tibialis anterior muscle (%IEMG)
Weight	0.30							
Toe curl ability	0.66*	0.05						
Foot-arch height ratio	0.69*	−0.01	0.83**					
Angular changes in the ankle joint	0.60*	3.95	0.46	0.25				
Rectus femoris muscle (%IEMG)	0.01	−0.12	0.12	0.19	0.40			
Long head of the biceps femoris muscle (%IEMG)	−0.4	−2.4	−0.37	−0.29	−0.02	0.58*		
Tibialis anterior muscle (%IEMG)	0.67*	0.44	0.31	0.28	0.53	0.25	−0.05	
Medial head of the gastrocnemius muscle (%IEMG)	0.61*	0.03	0.34	0.67*	0.31	0.54	0.06	0.63*

Pearson's correlation coefficient. *p<0.05; **p<0.01

have relationships with toe grip strength in previous studies, and the aim of this study was to clarify the factors influencing toe grip strength in healthy women.

In the present study, single correlation analysis found toe grip strength had significant positive correlations with five factors: toe curl ability, foot-arch height ratio, angular changes in the ankle joint, and the %IEMG of the tibialis anterior muscle and the medial head of the gastrocnemius muscle. These five factors were also reported as having significant positive correlations with toe grip strength in previous studies[6, 10)]. Thus, the present study confirmed these correlations. The correlation coefficient of toe grip strength and the foot-arch height ratio was the highest among the measured items. The foot-arch height ratio is often used as an indicator of the medial longitudinal arch of the foot[12, 13)]. The structure of the medial longitudinal arch of foot includes the flexor pollicis longus and flexor longus, which exert toe grip strength. Therefore, these results are considered to be correlated. Furthermore, the present study demonstrated that when the tibialis anterior and medial head of the gastrocnemius muscle have greater %IEMG values, the toe curl ability and ankle angle increase, and toe grip strength are correspondingly greater. It is our opinion, that % IEMG of the tibialis anterior muscle reflects muscle activity stabilizing the ankle joint. Because the ankle is a talocrural joint[14)], and the crural articular surface has a concave shape, ankle joint stability can be attained in dorsiflexion or in the neutral position, but not in plantar flexion. The medial head of the gastrocnemius muscle, flexor hallucis longus and flexor digitorum longus are considered to be agonist muscles of toe grip strength. They are commonly involved in ankle plantar flexion action, similar to the medial head of the gastrocnemius muscle. Thus, it is our opinion that the %IEMG of the medial head of the gastrocnemius muscle reflects mutual interaction with the tibialis anterior while working to stabilize the ankle joint. Toe grip strength is measured by placing the fulcrum in the calcaneal region, grasping a bar with the toe, and bending the toe. Thus, as the angle of flexion in the toe joint increase through bending of the toe while the heel makes contact with the ground, the angle of dorsiflexion in the ankle joint also increases. Murata et al.[6)] showed that greater toe grip strength can be exerted by more flexible feet; thus, the findings of the present study, greater toe grip strength can be exerted with greater dorsiflexion of the ankle, is consistent with the results of Murata et al. These findings suggest that the greater toe grip strength of healthy young people arise not only from the strength of the toe flexor muscles, but also from the flexibility of the feet, particularly the muscle activity of the crural muscles, and that the strength of the tibialis anterior muscles is important.

The predictors in the resulting model derived from multiple regression with toe grip strength as the dependent variable were foot-arch height ratio and %IEMG of the tibialis anterior muscle. This indicates that when the %IEMG of the tibialis anterior muscle and foot-arch height ratio values are high, toe grip strength is correspondingly greater. The medial part the of the longitudinal arch of the foot house complex connections among many bones and ligaments of the tibialis anterior muscle, tibialis posterior muscle, flexor pollicis longus, flexor digitorum longus, and abductor pollicis muscles[15)]. The flexor pollicis longus and flexor digitorum longus are agonist muscles of toe grip strength, and the tibialis anterior muscles, which is important for toe grip strength exertion. These findings suggest significant relationships between foot-arch height ratio and toe grip strength, with reciprocal interaction, indicating that the risk of falls by the elderly could be decreased by enhancing toe grip strength by inserting an insole to raise a low foot-arch as shown by Hayashi et al[16)].

This study had 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, only healthy young women 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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