RELATIONSHIP BETWEEN MAXIMUM TOE FLEXOR MUSCLE STRENGTH AND ANTHROPOMETRIC VARIABLES OF THE LOWER LIMB AND THE FOOT IN CALLEGIATE ATHLETES

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The purpose of present study was to indicate reference values of toe flexor strength (TFS), and its relation with anthropometric variables of the lower limb and the foot in collegiate athletes. Subjects were 68 male and 26 female of collegiate athletes. Subjects were measured maximum TFS in standing position. In addition, it were carried out anthropometric measurements. And muscle thicknesses were measured with a B-mode ultrasonic apparatus in triceps surae, tibialis anterior, abductor halluces, flexor hallucis brevis, flexor digitorum brevis, and abductor digit minimi. TFS were in male and female collegiate athletes were 256.7±55.8N and 207.3±36.9, respectively. Stepwise multiple linear regression analysis revealed that important factors to determine TFS were the muscle thickness of flexor hallucis brevis muscle and body weight.

KEY WORDS: muscle thickness, determinant of TFS, flexor hallucis brevis muscle

INTRODUCTION: Foot is the only region of the body to contact with the ground during standing with lower limb. And it also has the important roles, for instance, attenuating shocks of ground contact, supporting the body weight, controlling the posture, and so on. In the recent studies, toe flexor muscle strength (TFS) is often measured as one of the indices of toe flexors function. TFS is suggested to play important roles for not only physical activity in daily life, but also improvement of sports performance. Goldman et al. (2013) had reported that improvement in TFS after short training period, and it contributed to enhancement of horizontal jump performance. Therefore, it may be possible that athletes have stronger TFS than general people as a result of event proper daily work out. However, it is not known the reference values of TFS in athletes though reference values in general people and children are reported, so far.

Kurihara et al. (2014) had revealed that cross-sectional area (CSA) of the plantar intrinsic and extrinsic muscles with Magnetic Resonance Imaging (MRI) technique is one of important factors of determining TFS. Furthermore, they reported that CSAs of foot muscles have been evaluated not individually but anatomical groups of muscles, because segmentation of individual foot muscle was not possible to identify the smaller muscles. Of course, MRI technique is very reliable to quantify CSAs though it is not easy measuring large numbers of subjects as a matter of costs and waste of time. On the other hand, some studies have been used ultrasound technique to evaluate morphological indices in toe flexor muscles. Ultrasound technique is easier, takes brief period, and inexpensive, compared with MRI technique. Therefore, the purpose of present study was to indicate reference values of TFS, and its relation with anthropometric variables of the lower limb and the foot in collegiate athletes.

METHODS: Subjects were 68 male and 26 female of collegiate athletes. Physical characteristics of subjects were shown in Table 1 and Table 2. The ethics committee of Graduate school of Juntendo University approved this study. All subjects were given an explanation of the objectives and content of the study before they provided written consent. Lower limb length and circumference were measured by tape measure. Foot length, distance from the heel to the toe, and foot arch height, and height from navicular to the upper surface of the platform were captured in sagittal plane by digital camera. The posture of subject to be taken photo were the posture putting one foot on a 40cm height box. Foot length and foot arch height were measured by computer software (ImageJ).

Muscle thicknesses were measured by a B-mode ultrasonic apparatus, and an electronic array probe used either 5.0MHz or 7.5MHz. Measurements of muscle thickness in the triceps surae muscle and tibialis anterior muscle were performed at the rest standing position, and scanned in a proximal 30% site of lower limb length. In addition, muscle thickness of toe flexor muscles (abductor halluces, flexor hallucis brevis, flexor digitorum brevis, and abductor digit minimi) were measured according to the method of Mickle et al. (2013).

TFS were measured using a specifically designed dynamometer (T.K.K.3364, Takei Scientific Instruments) in standing position. All subjects were gripped the bar with their toes in maximum effort for 3 seconds. Measurements were performed twice in each foot. Then, the higher value was accepted as the TFS values.

One hundred eighty eight feet were adopted as further analysis. All measurement values are presented as mean ± standard deviation values (mean ± SD). Pearson's product-moment correlation coefficients were calculated between TFS and other measurements. Stepwise multiple linear regression models were used to significant predictors of TFS, using as dependent variables of TFS that were significant correlated with TFS according to the Pearson's correlation coefficient. The level of significance was set at $p<0.05$.

RESULTS: The descriptive data in male and female were listed in Table 1 and 2, respectively. Significant positive correlations between TFS and all anthropometric variables were indicated. Stepwise multiple regression analysis revealed that the determinants of TFS were muscle thickness of the flexor hallucis brevis muscle and body weight (Table 3). Other measurements were not identified as determinants.

The stepwise multiple regression equation was obtained as follows:

$$\text{TFS (N)} = 13.77 \times \text{muscle thickness of the flexor hallucis brevis muscle (mm)} + 1.62 \times \text{Body weight (kg)} - 94.7$$

Table 1
Results of measurement in male

	Male	Kendo	Gymnastic	Swimmer
Number of subjects	68	31	23	14
Age (yer.)	20.2 ± 1.1	20.1 ± 1.2	20.3 ± 1.2	20.1 ± 0.8
Body height (m)	1.69 ± 0.07	1.71 ± 0.05	1.63 ± 0.05	1.76 ± 0.06
Body weight (kg)	66.1 ± 8.2	68.4 ± 7.1	59.4 ± 5.6	71.5 ± 7.0
Lower limb length (m)	0.38 ± 0.02	0.39 ± 0.01	0.37 ± 0.02	0.40 ± 0.02
Lower limb circumference (m)	0.37 ± 0.02	0.38 ± 0.02	0.35 ± 0.02	0.38 ± 0.02
Foot length (mm)	249.7 ± 13.0	254.5 ± 10.1	244.4 ± 9.4	259.1 ± 11.1
Foot arch height (mm)	47.1 ± 5.4	48.1 ± 5.2	46.3 ± 4.6	46.5 ± 6.7
Muscle thickness (mm)				
TS	68.7 ± 5.0	70.6 ± 4.3	65.3 ± 4.6	69.8 ± 3.8
TA	28.6 ± 2.8	29.7 ± 2.1	26.3 ± 2.4	29.7 ± 2.3
ABH	13.5 ± 2.3	13.3 ± 1.6	13.4 ± 2.7	14.1 ± 3.0
FHB	17.6 ± 1.5	17.2 ± 1.4	17.9 ± 1.5	17.7 ± 1.5
FDB	10.3 ±1.6	10.0 ± 1.2	10.8 ± 2.2	10.4 ± 0.9
ABDM	11.8 ± 1.4	11.8 ± 1.5	11.8 ± 1.5	12.0 ± 1.2
TFS (N)	256.7 ± 55.8	243.2 ± 59.6	261.4 ± 42.1	277.2 ± 62.1

TS= Triceps surae muscle, TA= Tibialis anterior muscle, ABH= Abductor halluces muscle, FHB= Flexor hallucis brevis muscle, FDB= Flexor digitorum brevis muscle, and ABDM= Abductor digit minimi muscle

Table 2
Results of measurement in female

	Female	Kendo	Gymnastic	Swimmer
Number of subjects	26	15	5	6
Age (yer.)	20.2 ± 1.3	20.6 ± 1.4	19.8 ± 1.3	19.4 ± 0.5
Body height (m)	1.60 ± 0.04	1.61 ± 0.03	1.57 ± 0.05	1.63 ± 0.02
Body weight (kg)	58.0 ± 5.2	57.7 ± 5.0	56.5 ± 5.7	60.7 ± 4.7
Lower limb length (m)	0.37 ± 0.01	0.37 ± 0.01	0.36 ± 0.02	0.37 ± 0.01
Lower limb circumference (m)	0.36 ± 0.02	0.36 ± 0.02	0.36 ± 0.02	0.36 ± 0.02
Foot length (mm)	240.4 ± 11.0	234.7 ± 7.1	229.2 ± 8.5	241.4 ± 4.2
Foot arch height (mm)	45.1 ± 4.9	46.8 ± 4.3	44.8 ± 4.6	40.3 ± 3.7
Muscle thickness (mm)				
TS	62.2 ± 4.5	61.8 ± 4.3	64.3 ± 5.3	60.9 ± 3.6
TA	26.4 ± 2.5	26.9 ± 3.0	26.0 ± 1.5	25.1 ± 0.9
ABH	12.0 ± 2.1	11.7 ± 2.0	12.7 ± 2.8	12.2 ± 1.7
FHB	15.7 ± 1.2	15.8 ± 1.2	15.9 ± 1.4	15.0 ± 0.7
FDB	8.0 ± 1.4	7.6 ± 1.1	9.5 ± 1.6	7.5 ± 0.7
ABDM	10.7 ± 1.5	10.7 ± 1.5	11.5 ± 1.6	9.7 ± 0.6
TFS (N)	207.3 ± 36.9	212.1 ± 29.9	203.7 ± 49.0	197.3 ± 40.9

TS= Triceps surae muscle, TA= Tibialis anterior muscle, ABH= Abductor halluces muscle, FHB= Flexor hallucis brevis muscle, FDB= Flexor digitorum brevis muscle, and ABDM= Abductor digit minimi muscle

Table 3
Stepwise Multiple Regression: Predict variables of TFS

	β	r
Muscle thickness of flexor hallucis brevis	.401**	.474**
Body weight	.239**	.372**
R^2	.283**	
Asj. R^2	.275**	

** *p<0.01*

DISCUSSION: Aims of this study were to indicate reference values of TFS, and its relation with anthropometric variables of the lower limb in collegiate athletes. The important findings of this study was that determinants of TFS were muscle thickness of the flexor hallucis brevis muscle and body weight from results of stepwise multiple linear regression analyses. This result was similar to the result with MRI technique. Kurihara et al. (2014) showed that the major determinant of maximum TFS was CSA_{MED} which was included flexor hallucis brevis, flexor digitorum brevis, quadratus plantae, lumbricals, and abductor halllucis. From these facts, it is suggested the importance of muscle thickness of flexor hallucis in particular among toe flexor muscles for TFS.

It is noteworthy that the body weight is included as a determinant of TFS in present study. It is considered that Agonist muscles of TFS are antigravity muscles. Additionally, toe flexor muscles are thought to be active at the push-off phase of walking to move the body forward. Therefore it is conceivable that body weight must affect TFS, since the exerting force in toe flexor muscles is also required improvement as increasing body weight. Therefore TFS should be necessary to be normalized by body weight in the case of evaluating TFS as a function of the toe.

This study surveyed collegiate athletes, though there were no study about it, so far. In comparison of the TFS value with previous studies, results of this study were 1.6 times and 2.0 times higher in men and female collegiate athletes, respectively compared with 20s Japanese. However, the difference in the posture during measurement, standing in present study, and the sitting in previous study, may cause the difference in TFS. Nakae et al. (2013) suggested that TFS was not affected on measurement posture, though there were significant

difference in %IEMG of the medial gastrocnemius muscle between the sitting and the standing.
Muscle thicknesses of toe flexor muscles were compared with those reported by Mickle et al. (2013). As a result, differences in the muscle thickness value were less than 1mm in abductor halluces muscle, flexor digitorum brevis muscle, and abductor digit minimi muscle. On the other hand, hallucis brevis muscle in this study was 4mm thicker than the previous study. Values of muscle thickness of toe flexor muscles in athletes have not been shown in previous study. Therefore, results of this study may be reference values in collegiate athletes. In this study, Foot structures as factors affecting TFS have also been studied, since toe flexor muscles and other intrinsic foot muscles support foot structures such as the medial longitudinal arch (MLA). Several previous studies have reported no association of TFS with MLA height. On the other hand, Hashimoto and Sakuraba (2014) suggested that arch maintenance function (longitudinal and horizontal foot arch) had improved along with increasing of TFS by the strength training. We measured navicular height as the evaluation of foot arch height, which is the index of MLA height. The result of this study indicated significant positive correlations between TFS and foot arch height ($r=0.157$, $p<0.05$). In the relationship between foot arch height and muscle thickness of the lower limb and foot, there were significant positive correlations with tibialis anterior muscle ($r=0.264$), triceps surae muscle ($r=0.214$), and flexor hallucis brevis muscle ($r=0.135$). However, their correlation coefficients were not so high.
Present study was examined focusing on the anthropometric variables of the lower limb and the foot for determinants of TFS in collegiate athletes. Results of this study indicated trends that collegiate athletes had higher TFS and muscle thickness of toe flexor muscles compared with general people in previous study. However, it has not been clarified these differences yet. In addition, it has not been apparent for effects of the sports events on TFS yet. Thus, we will examine the effect and the difference in sports events of TFS as the first future study.

CONCLUSION: This study indicated reference values of TFS in collegiate athletes, which is higher than values in general people reported in present studies. Furthermore, stepwise multiple linear regression analysis revealed that important factors to determine TFS were the muscle thickness of flexor hallucis brevis muscle and body weight. Results of this study suggested that the measurement of muscle thickness of toe flexor mucles by ultrasound was one of useful method for evaluation the relationship TFS and muscle mass of foot muscles.

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