RELATIONSHIP BETWEEN MUSCLE FORCE AND SIZE OF HUMAN INTRINSIC FOOT MUSCLES

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INTRODUCTION

Human foot is the only body parts that contact the ground during locomotion, hence the function of foot muscle is considered for an important. Human foot has many bones and muscles to construct a unique arch structure. Foot flexor muscles are aggregation of the muscles across metatarsal phalangeal and ankle joints and are divided into two muscle groups: the plantar intrinsic foot muscles (PIFM) and the extrinsic foot muscles. PIFM is the major foot muscle group due to that their origins and insertions of muscles are within a foot.

It has been reported that the toe flexor muscle strength is important determinants of balance or dynamic postural control [2]. Therefore, foot function should be evaluated with not only architecture of foot, but also force generating capacity of foot muscles. Understanding the architectural and neuromuscular function of foot could be a great hint for how human is evolutionally advanced to bipedal locomotion and then to provide practical information to prevent modern increases in the number of musculoskeletal disorders of a foot.

Evaluation of muscle force generating capacity along with muscle size is important way to quantify the physiological condition and muscle functions in human movements [8]; however, there is no information available how maximum force generating capacity of foot is related to the muscle size of PIFM. The purpose of this study was to investigate the relationship between force generating capacity and muscle size of PIFM.

METHODS

Twenty-eight young healthy sedentary volunteers (20.6 ± 2.0 yrs, body height 166.6 ± 8.0cm, body mass 59.8 ± 9.1 kg, means ± SD) were participated. They had no history of diagnosed neuromuscular disorder or lower limb injury, and no visible symptoms of hallux valgus and toe deformities. This study were approved by the Research Ethical Committee in Ritsumeikan University. Written informed consent was obtained from them.

The maximum voluntary isometric strength of the foot grip was measured by a custom designed dynamometer (T.K.K. 3361, Takei Scientific Instrument Co Ltd, Niigata, Japan). The subjects sat on a chair with 90 degrees of their hip, knee, and ankle joints. They were instructed to place their test foot on the dynamometer and placed another non-test foot on parallel side, and optimally grabbed the grip-handle bar of the dynamometer by toe and fingers of foot. Subjects first performed a few sub-maximum efforts to familiarize themselves with the measurements, and then exerted maximum voluntary isometric force as explosively as possible and tried to keep the force plateau for 3 seconds. Measurements of foot grip force (FGF) were repeated three times with at least one-minute rest period between bouts, and the largest value among the trials was chosen for the analysis. Both left and right feet were measured in randomized order.

The whole foot images were acquired by 1.5T MR system (Signa HDxt, GE Healthcare Co., USA). The serial T1-weighted MR images were acquired perpendicular to the plantar aspect of the foot using a fast spin-echo sequence (TE = 500 ms, TR = 16 ms, slice thickness = 4 mm, no gap, FOV = 120 × 120 mm). To measure the cross sectional area of plantar intrinsic foot muscles (CSA_{PIFM}), image at
the metatarsophalangeal joint was selected due to that the anatomical cross-sectional area of the PIFM is the largest at this point [1]. Examining each images, wherever possible, non-contractile tissues such as bone, tendon, fat, connective tissue, nerve and blood vessels were excluded. All measurements and calculations were carried out by the same investigator using specially designed image analysis software (SliceOmatic 4.3, Tomovision Inc., Montreal, Canada).

RESULTS AND DISCUSSION

Significant correlations were found between FGF and CSA$_{PIFM}$ in all feet (n = 56, r = 0.748, p < 0.001), and its correlations in male and female were r = 0.682 (n = 28, p < 0.01) and r = 0.594 (n = 28, p < 0.01), respectively (Figure 1). All the y-intercepts of the regression lines between FGF and CSA$_{PIFM}$ were not significantly different from zero.

![Figure 1: Relationships between cross sectional area of plantar intrinsic foot muscle (CSA$_{PIFM}$) and foot grip forces (FGF).](image)

Gender differences were found in FGF (Male 173.1 ± 51.7 N, Female 119.8 ± 42.8 N) and CSA$_{PIFM}$ (Male 16.4 ± 2.9 cm$^2$, Female 12.3 ± 2.0 cm$^2$) All these values were significantly larger in male as compared to female. However, when FGF was normalized with CSA$_{PIFM}$, there was no significant difference between genders. The values of force per cross sectional area (FGF/CSA$_{PIFM}$) for male and female were 10.5 ± 2.4 N/cm$^2$ and 9.6 ± 2.8 N/cm$^2$, respectively.

It is well known that muscle force is related to the size of skeletal muscle. The muscle force generating capacity is generally determined with the maximum force normalized to cross sectional area, known as specific tension/force. The specific tension of human leg muscles was reported for ankle plantar flexor and dorsiflexor muscles [3,5,6] and quadriceps muscles [7]. Specific tension of plantar intrinsic foot muscles was first to show in this study. Our results of specific tension of PIFM were somewhat lower than its leg muscles shown in previous studies. This might be that, because measurement of FGF is a net force production of all conjunctive muscles, the force production of FGF is not able to isolate from the force production of only agonist intrinsic foot muscles. Also, the difficulty in determination of specific tension of PIFM was due to the fact that most of the major intrinsic foot muscles lay in oblique not directly the transverse or sagittal planes [4].

CONCLUSIONS

The relationships between FGF and CSA$_{PIFM}$ were significantly correlated in young subjects. FGF was higher in male than in female subjects; however, the force generating capacity (FGF/CSA$_{PIFM}$) was not significantly different between male and female.

REFERENCES


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