ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

EFFECTS OF MECHANICAL PROPERTIES OF MUSCLE AND TENDON ON PERFORMANCE IN JUNIOR LONG DISTANCE RUNNERS

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INTRODUCTION

It is well known that performance of distance running is significantly correlated to physiological and mechanical variables such as maximum oxygen uptake, lactate threshold and running economy. Previous work demonstrated that the superior running economy would be a key factor of the great successful of the African runners [1], suggesting the importance of running economy for distance running.

Running economy is influenced by many factors (e.g. running form, morphology of body segments and mechanical properties of muscle-tendon tissues). During running, ankle joint generates and transfers remarkable mechanical power. In fact, it has been reported significant effects of mechanical properties of muscle and tendinous tissues (deep aponeurosis and the distal tendon) among plantar flexors related to ankle joint on running economy and performance. However, for tendinous tissues, there exist both reports with positive and negative correlations between stiffness and running economy as well as performance [2,3]. In addition, information on relation between stiffness of muscle and performance is limited so far.

Not only senior but also junior athletes are participating distance running, and the results are of particular interest as information for discovering talents. In the present study, we determined the indices of stiffness and Young modulus on both muscle and tendinous tissues of plantar flexors in junior distance runners using B-mode ultrasonic imaging and then examined the effect of the variables on running performance.

METHODS

Twenty male Japanese junior long distance runners participated in this study. Ten subjects whose best official record of 5000m is from 14:04 to 14:56 (mean: 14:33±0:21) were selected as a high performance group (HPG). Also, ten subjects from 15:39 to 16:53 (mean: 16:08±0:26) as a normal performance group (NPG). Both group had similar age, body height, and weight.

Morphological parameters of lower limb such as lower leg length, length of Achilles tendon defined as length from junction between medial gastrocnemius muscle belly and tendinous tissues up to insertion of tendon at calcaneus, and cross sectional area of Achilles tendon at junction between soleus muscle belly and tendinous tissue, and maximal cross sectional area of calf were measured.

Passive torque and voluntary isometric plantar flexion torque of ankle joint were evaluated by means of specially designed dynamometers. Elongations of muscle and tendinous tissues in plantar flexors were assessed by an ultrasonic apparatus with an 7.5-MHz electronic linear array probe during passive plantar flexion and isometric plantar flexion, respectively. On the longitudinal ultrasonic images of medial gastrocnemius muscle from 70% distal portion of lower leg, the point at which one fascicle was attached to the aponeurosis was visualized. The elongations of both tissues were measured by the positional change of this point (see [3,4]).

In order to determine mechanical properties of muscle tissues, ankle joint angle was passively changed and fixed at 20deg and 10deg plantar flexed positions, 0deg (neuronal position), and 10deg dorsi flexed position with a knee joint fully extended. The relation between increment of passive torque and lengthening of muscle tissues was determined at each condition. Then, to examine mechanical properties of tendinous tissues, the relation between voluntary joint torque and lengthening of tendinous tissues was measured during isometric contraction. At ankle joint 0deg, subject was instructed to develop a gradually increasing force from relaxed state to maximal voluntary contraction within 5 s.

Stiffness Index defined as the slope of relation between torque and lengthening of tissues, and Young Modulus Index correcting the effect of individual variation of length and cross sectional area of Stiffness Index was calculated as the index of material property. The correction was applied with muscle belly length (lower leg length – Achilles tendon length) and maximal cross sectional area of calf for muscle tissue, and with length and cross sectional area of Achilles tendon for tendinous tissues.

RESULTS AND DISCUSSION

In addition to height and weight, other morphological variables related to length and cross sectional area have no significant difference between HPG and NPG (shown in Table 1).

The mechanical properties related to only tendinous tissues showed significant differences between HPG and NPG. Typical examples of relation between joint torque and lengthening of tendinous tissues are represented in Figure 1. The Stiffness Index and Young Modulus Index of tendinous tissues of HPG were more compliant by 40% ($p<0.01$) and by 41% ($p<0.01$) than those of NPG, respectively. However, no significant difference was observed in Induces of muscle tissue. All variables measured in this study are summarized in Table 1.

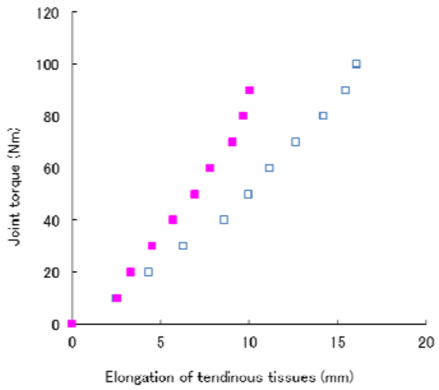

Figure 1: Typical examples of relation between joint torque and lengthening in tendinous tissues. (Open square: data from a subject in HPG, Filled square: data from a subject in NPG)

The results that HPG has compliant tendinous tissues is corresponded to the report by Kubo et al. [3] while not the report by Arampatzis et al. [2]. The difference of not only Stiffness Index but also Young Modulus Index imply the difference in material properties between HPG and NPG, which is affected by biomaterial composition like collagen. On the other hand, the mechanical properties of muscle tissue does not differ between HPG and NPG. Dumke et al. [5] used free oscillation method to determine the mechanical properties of muscle tissues and found the significant positive correlation between stiffness of muscle tissues and running economy. Although we could not conclude the reason of the different results between reports, the variation in subjects such as performance level, age, race would conflict the results.

During stance phase of running, muscle-tendon systems of calf muscles could recoil elastic energy, generate joint torque passively. Also, muscle-tendon interaction by visco-elasticity of tendinous tissues could influence muscle behavior for economical energy consumption [6]. Thus, optimal mechanical properties for each distance runner would exist dependent on their running speed and style. The present result that HPG had a compliant tendinous tissues to be related to the optimal usage of muscle-tendon systems during distance running.

CONCLUSIONS

We examined relations between mechanical properties of both muscle and tendon and running performance in junior runners. The Stiffness Index and Young Modulus Index of tendinous tissues of HPG were more compliant by 40% ($p<0.01$) and by 41% ($p<0.01$) than those of NPG, respectively. However, no significant difference was not observed. These results suggest the importance of compliant mechanical properties in tendinous tissues for achievement of high performance in junior distance running.

ACKNOWLEDGEMENTS

This study was supported by the Grant-in-Aid for Scientific Research(C) (23500729 to T. Oda) from Japan Society for Promotion of Science.

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Table 1: measured variables of HPG and NPG

	HPG		NPG
Best official record (minits : seconds)	14:33 (0:21)	*	16:08 (0:26)
Height (cm)	170.7 (7.4)		169.4 (6.7)
Weight (kg)	55.6 (4.3)		55.1 (5.2)
Lower leg length (cm)	35.5 (2.5)		34.6 (2.2)
Length of Achilles tendon (mm)	221.0 (13.6)		221.9 (15.7)
Cross sectional area of calf (cm^2)	105.4 (8.71)		106.36 (5.74)
Cross sectional area of Achilles tendon (mm^2)	57.7 (9.9)		55.2 (6.7)
Stiffness Index of muscle tissue from 0deg to -10deg (Nm/mm)	1.87 (1.2)		1.33 (0.52)
Stiffness Index of tendinous tissues (Nm/mm)	7.36 (1.44)	*	12.24 (4.50)
Young Modulus Index of muscle tissue from 0deg to -10deg (Nm/cm^2)	0.0042 (0.0032)		0.0031 (0.0013)
Young Modulus Index of tendinous tissues (Nm/mm^2)	0.29 (0.10)	*	0.50 (0.21)

Date shown as mean (SD), HPG high performace group, NPG normal performance group, * significantly diffirent