MECHANICAL PROPERTIES OF ACHILLES TENDON IN RELATION TO VARIOUS SPORT ACTIVITIES OF COLLEGIATE ATHLETES

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The purpose of this study was to investigate whether mechanical properties of Achilles tendon adapt to the mechanics of diffrent sport activities. Subjects included thirty-five male collegiate track and field athletes (Sprinters, Long distance runners, Jumpers), swimmers, and non-athletes (Controls). The elongation of the Achilles tendon during isometric voluntary plantar flexion contraction was measured. Jumpers and swimmers displayed larger elongation, strain, tendon force and stress of the Achilles tendon when compared to long distance runners and controls. However, the stiffness and Young's modulus of the Achilles tendon were not significantly different between groups. These results suggested that mechanical properties of the Achilles tendon were unchanged with load characteristics of each sport activity.

KEY WORDS: Tendon adaptation; ultrasonography; MRI; Young's modulus; stiffness.

INTRODUCTION: It is commonly known that muscle can adapt to mechanical load. However, little knowledge exists regarding the tendon adaptation to mechanical load. The tendon transmits the force generated by muscle to bone, and the tendon may adapt by increasing its thickness and/or tone up elasticity to sustain if the tension would be augmented with increasing muscle strength.

In recent years, some researchers have revealed that tendon adaptation can occurr in various athletes; i.e.the domionant-side patellar tendon of badminton and fencing players was significantly thicker than the non-dominant side (Couppe et al., 2008) and the Achilles tendon in sprinter was higher stiffness than untrained subjects (Arampatzis, Karaminidis, Morey-Klapsing, De Monte, & Stafilidis, 2007). However, other reports contradicted the adaptation capacity of tendon in that the patellar tendon of sprinters was more compliant than untrained subjects (Kubo, Kanehisa, Kawakami, & Fukunaga, 2000) and significant tendon hypertrophy had not occurred after several weeks of training (Arampatzis, Peper, Bierbaum, & Albracht, 2010). On the other hand, some researchers have reported significant tendon hypertrophy by training (Kongsgaard et al., 2007). These discrepancies could be caused by the intensity and/or duration of load. Arampatzis et al. (2010) expected that there was a load threshold above which tendon would be hypertrophied, and even if the loading was high enough to gain the tendon effective magnitude to alter the tendon characteristics, a longer time duration of the loading was needed.

The purpose of the present study was to examine whether Achilles tendon have adapted to characteristics of training load. We hypothesized that after years of sport activities there would be changes in the mechanical characteristics of the Achilles tendon. In this manner, we compared athletes described hereinafter in terms of load intensity and load laterality. The sprinter would be subjected to a high load over a short time. While the long distance runner would probably be subjected to a lower load but it would be repeated on many occasions. There would be minimal laod imposed on the Achilles tendon during swimming. Otherwise, the jumper usually uses the unilateral leg for jumping, the bilateral different load would be distinct between the jumping and non-jumping leg.

METHODS: Thirty-five male collegiate subjects (Table 1) participated in this study and were categorized into five groups based on each participants sport; sprinters, long distance runners, jumpers in track and field athletics, swimmers, and non-athletic controls. No significant differences in physical characteristics were found among these groups. All the jumpers used the left-side as jumping leg. Written informed consent was obtained from each subject and the study was approved by the research ethics committee involving living human participants in Biwako Kusatsu campus, Ritsumeikan University.

Table 1: Physical characteristics of the subjects.

	Sprinters (N=8)	Runners (N=7)	Jumpers (N=6)	Swimmers (N=7)	Controls (N=7)
Height (cm)	175.9±7.4	172.6±6.3	179.4±5.9	173.0±5.3	172.8±5.6
Weight (kg)	65.6±5.0	59.1±4.7	67.1±4.1	64.9±4.1	62.4±8.4
Age (years)	20.6±1.4	20.4±1.3	20.8±1.3	19.0±1.0	21.6±1.8
Years of training(y)	8.8±1.8	8.5±1.8	8.7±1.4	18.0±0.6	---

Mechanical characteristics of Achilles tendon (AT) on both legs were measured from the displacement of the myotendinous junction during exertion of the maximum voluntary plantar flexion contraction (PF MVC) with the participant's knee extended at 180° and the ankle angle set at 90°. The upper body, hip, and knee were held on the seat using adjustable lap belts. The ankle joint was firmly fixed to the dynamometer (Biodex system 4, SAKAI med, Japan) with velcro straps. The center of rotation of dynamometer was visually aligned with the center of rotation of the ankle joint center. After warming up with several repetitions of submaximal plantar flexions (up to 50%MVC), PF MVC was performed to develop a gradually increasing force from a relaxed state to MVC within 5 s. At the same time, the myotendinous junction of the distal edge of medial gastrocnemius muscle was taken by an ultrasonic imaging device (SSD3500, Aloka, Japan; Figure 1). To estimate the precise mechanical properties of AT, the task was carefully checked during smooth incremental exertion during plantar flexion torque and the clearness of the ultrasound images. The tasks were repeated until acceptable data were obtained. Appropriate duration (at least 1 min) between tasks to avoid the influence of fatigue.

The ultrasonic imaging device was synchronized with the Biodex data. The data obtained by Biodex and the signal of the synchronizer were imported to the personal computer and analyzed using Chart software (Version 5, AD Instruments, Australia). The displacement of the myotendinous junction, defined as the elongation of AT, was analyzed by image analysis software Image J (Version 1.45, NIH, USA).

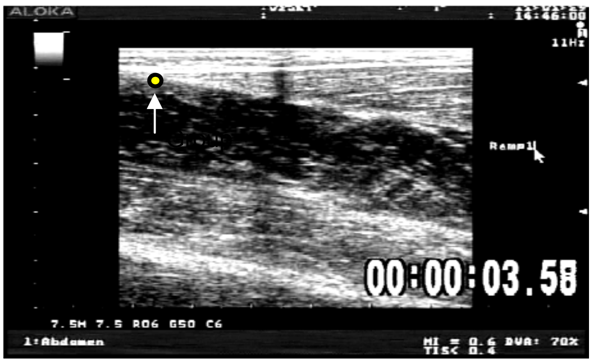

Figure 1: Analyzing point of Achilles tendon Elongation by ultrasonic image.

Serial cross-sectional images of the lower extremities were scanned by a magnetic resonance system (1.5T Signa HDxt, GE healthcare, Japan; Figure 2) with the participant in a supine position with the knee extended at 180° and ankle angle set at 90°. Conditions for the magnetic resonance (MR) images were; Fast Spin Echo, TR/TE 1500/15ms, ET 16, FOV 380mm, Matrix 512x512, NEX 4, scanning interval was set at 5mm between the distal part of the gastrocnemius muscle and the calcaneal bone. From magnetic resonance images, cross-sectional area (CSA) and the length of the AT were measured by image analysis software Osiris (Version 3.5, HUG, Switzerland).

Tendon force was calculated by dividing the PF MVC torque by the moment arm, with the AT moment arm applied from Rugg et al. (1990). The strain of the AT was calculated by dividing the elongation of AT by tendon length at rest (ΔL/mm). The stress of AT was calculated by dividing the calculated tendon force by minimum CSA of AT (N/mm^2). The Young's modulus of AT was calculated as the slope of the stress-strain relationship between 50 to 100% of the maximum tendon force by means of least square approximated linear regressions (GPa).

Descriptive data included mean ±standard deviation (S.D.). A two-way analysis of variance (ANOVA) (Groups × laterality, 5×2) was used to check the differences of parameters in each group, and then differences among means were analyzed using Tukey-Kramer multiple comparison tests. For all parameters, the level of significance was set 0.05.

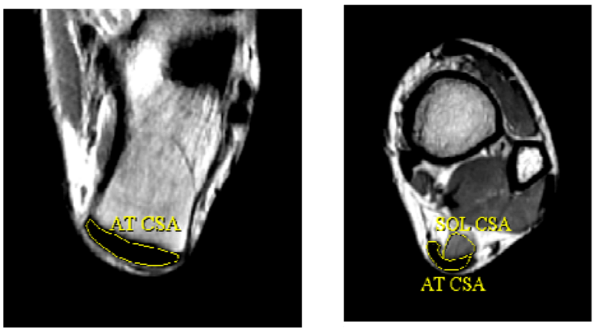

Figure 2: Typical examples of cross sectional magnetic resonance images.

RESULTS: The results of the morphological and mechanical characteristics of the AT are summarized in Table 2. The morphological characteristics of AT resting length and minimum CSA were not significantly different between groups.

Table 2: Morphological and mechanical characteristics of Achilles Tendon

		Sprinters	Runners	Jumpers	Swimmers	Controls
Resting tendon	R	203±29	212±16	204±16	193±21	194±14
length (mm)	L	211±22	223±16	208±13	206±24	203±12
Minimum CSA	R	53.0±8.7	45.9±10.3	49.6±6.3	51.3±6.6	47.1±6.6
(mm^2)	L	48.4±6.5	44.6±9.4	49.1±6.0	48.9±3.8	44.6±6.5
Elongation	R	19.9±3.6*	17.6±3.1	21.8±2.6*#	21.8±3.9*#	16.6±3.5
(mm)	L	21.4±5.3*	18.6±3.7	22.7±2.3*#	25.5±4.0*#	16.4±2.7
Strain	R	9.9±2.2	8.3±1.1	10.8±1.1*#	11.4±2.2*#	8.7±2.2
(%)	L	10.3±2.8	8.3±1.2	11.0±0.9*#	12.7±3.2*#	8.1±1.3
Tendon force	R	3146±573*	2718±285	3682±538*#$	3264±249*#	2352±439
(N)	L	3309±683*	2831±350	3864±547*#$	3337±426*#	2374±561
Stress (N/mm^2)	R	68.0±13.4*	66.0±7.2	80.3±7.2*#	69.9±10.9*#	57.5±14.4
	L	76.7±16.5*	68.5±9.9	87.2±13.4*#	73.2±8.5*#	61.0±12.0
Stiffness	R	248±76	233±47	221±56	211±44	221±111
(N/mm)	L	265±83	223±61	202±68	214±50	184±78
Young's	R	0.98±0.37	1.11±0.30	0.90±0.29	0.80±0.19	0.91±0.42
modulus(GPa)	L	1.16±0.35	1.17±0.44	0.84±0.33	0.91±0.27	0.84±0.32

*: Differences vs. Controls, #: vs. Runners, $: vs. Sprinters, P<0.05

Although there were no significant between-limb differences in any parameters of mechanical characteristics, between-group difference were observed. Elongation, strain, tendon force, and Stress of AT in jumpers and swimmers were larger than those in long distance runners and controls. Elongation of AT in sprinters was larger than that in controls. Tendon force in sprinters was larger than that in controls, and that in jumpers was larger than that in sprinters. Stress of AT in sprinters was larger than that in cotrols. However, stiffness and Young's modulus of AT were not significantly different between groups.

DISCUSSION: The elongation, strain, tendon force and stress of AT were significantly different between groups, while the stiffness and Young's modulus of AT were not significantly different between groups in different sporting activities. Therefore, our hypothesis has been partially supported. The previous studies reporting that the stiffness in athletes was higher than untrained subjects (Arampatzis, Karamanidis, Morey-Klapsing, et al., 2007) as well as the effects of resistance training on the mechanical characteristics of tendon (Arampatzis, Karaminidis, & Albracht, 2007). However, the mechanism of this adaptation is yet unknown. The present study suggested that, as for the subjects in the present study, there was no significant adaptation of stiffness and Young' modulus of tendon.

Actual training associated with dynamic and complex movements might differ from the restricted condition of training experiments. Since tendon loading during running, jumping or swimming in daily training has never been measured, its exact magnitude remains elusive.
In the present study, no bilateral differences were found in any morphological and mechanical characteristics of AT. This partially agreed with previous studies in that the stronger extremity had a greater cross-sectional area compared with the contralateral side, while the modulus did not differ significantly (Couppé et al., 2008). The discrepancies of morphological characteristics could be due to the examining region. We compared CSA at minimum region, where Achilles tendinopathy and ruptures frequently occur. If force is distributed homogenously throughout the tendon, the stress in the smallest side is somewhat greater than that of the other sides. However, the response to resistance training clarified that tendon hypertrophy was found in distal and proximal side, but not in middle-side (Kongsgaard et al., 2007). Future research should assess three dimensional structure and tendon volume, verifying if there is a difference between the subjects with various sport activities.

CONCLUSION:
The stiffness and Young's modulus of Achilles tendon were not significantly different among groups of the different sport activities. These results suggested that the mechanical characteristics of Achilles tendon were unchanged with load characteristics of each sport activity.

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