Effects of Running Exercises on Mechanical Properties in Vastus Lateralis Muscle Tendon Complex

YURI KIMURA*, TOSHIO YANAGIYA*

*Graduate school of Health and Sports Science, Juntendo University, Chiba, Japan

**Introduction:** Vastus lateralis muscle (VL) works to stabilize knee joint during foot contact\(^1\). Muscle tendon complex stiffness decreases with fatigue\(^2\). If the stiffness of VL tendon structure becomes lower during running, it may affect running performances. This study is aimed to clarify the effect of acute running on vastus lateralis muscle–tendon stiffness.

**Methods:** Four young male participants (22.8 ± 1.0 yrs, 1.73 ± 0.05 m, 62.8 ± 5.4 kg) performed maximal voluntary isometric knee extensions for three times before, immediately after and 30 min after the run. Subjects ran for 30 minutes on a treadmill with 5 min/km running pace. A real-time ultrasonic apparatus (SSD-4000, Aloka) was used to obtain longitudinal ultrasonic images of VL during torque measurements. From the ultrasonic images, we measured the lengthening of tendon structure. We calculated aponeurosis stiffness and hysteresis from the relations between force and lengthening\(^3\).

**Results:** Both maximal voluntary isometric knee extension strength and lengthening of VL aponeurosis were not significantly different between pre–run measurement and immediate measurements. Stiffness of VL tendon structure increased and VL tendon hysteresis decreased immediately after running. But they did not significantly change. And they returned to the same value as before the run after 30 minutes.

**Conclusion:** Stiffness of VL tendon structure tended to increase immediately after 5 minutes/km running for 30 minutes. But after 30 minutes it returned to the same value as before the run. We think that the pace and time of this study are not high intensity enough to change.

**Key words:** running, fatigue, stiffness, vastus lateralis muscle, aponeurosis

**Introduction**

The number of runner tends to be increasing because running is considered to be a highly effective exercise in maintaining and improving health\(^4\). Percentage of people jogging and running (once a year) peaked at 9.7% in 2012, and declined to 9.5% in 2014 and 8.6% in 2016. Though, it is still high level compared with the early 2000s\(^5\). When we run, our body receives huge force from the ground. Generally, it is said that the body receives about 2.4 times body weight in jogging, about 3 to 3.5 times in running\(^6\) contact time is too short (0.25 second), so the impact of the contact is very large. The personal record in a 5,000 m race was negatively correlated to the stiffness of the tendon structures in vastus lateralis muscle (VL)\(^7\). That is, the stiffness of VL in elite long distance runners is high. As a factor, a stiff tendon would be advantageous for performing brisk, accurate movements because it affects rapid tension changes\(^8\). On the contrary, instability of the lower limb may occur when the amount of extension of the tendon is high. Muscle tendon complex (MTC) stiffness decreases...
with repetition of contraction–relaxation. During running, lower limb muscles repeats contraction–relaxation. Likewise, it is considered that the stiffness of VL also decreases.

**Purpose**

This study is aimed to clarify the effect of 6 km running on vastus lateralis muscle tendon stiffness. If the stiffness of VL tendon structure becomes lower during running, it may affect running performances. We hypothesize that running reduces the stiffness of VL.

**Methods**

Four male college students with exercise habits were participated in this study. (age: 22.8 ± 1.0 yrs, height: 1.73 ± 0.05 m, body mass: 62.8 ± 5.4 kg). They had not been injured in lower extremities within six months.

After a warm-up, the subjects were asked to run 30 minutes on a treadmill running with 5 min/km pace. The subjects performed maximal voluntary isometric knee extension at before running (BEF), immediately after running (AFT) and 30 minutes after running (30M).

A dynamometer (VTK-001R, VINE, Japan) was used to determine torque output during isometric knee extension. the subjects were instructed to develop a gradually increasing force from relax to maximal voluntary contraction (MVC) within 5 s. The task was repeated three times with at least 1 minute rest between trials.

For the knee extension task the participant sat in an adjustable chair with support for the back and the hip joint flexed at the angle of 80° (full extension = 0°).

The ankle firmly attached to the lever arm of the dynamometer with a strap and fixed with their knee joint flexed at the angle of 80° (full extension = 0°).

A real-time ultrasonic apparatus (SSD-4000, Aloka, Japan) was used to obtain longitudinal ultrasonic images of VL in the right leg during torque measurements.

To evaluate the elongation of tendon structure, the movements of the following points of each task were recorded by ultrasonography (Figure-1). The cross-point of deep aponeurosis and a fascicle (P) in ultrasonic images of VL during knee extension move proximally with the increasing force production level. The displacement of cross-points (ΔLmm) was defined as the elongation of tendon structure during contraction. We calculated aponeurosis stiffness and hysteresis from the relationship between force and lengthening.

**Stiffness**

Muscle force and tendon elongation values above 50% of MVC were fitted to a linear regression equation, the slope which was adopted as stiffness.

The measured torque during isometric knee extension was converted to muscle force (F) by the following equation:

\[
F = k \times T \times M^{-1}
\]

where k is the relative contribution of the
physiological cross-sectional area in each of VL within quadriceps femoris muscles (22%, Narici et al. 1992\textsuperscript{8}), T is the measured torque and M is the moment arm length in each of the quadriceps femoris muscles at 80° (43 mm, Smidt 1973\textsuperscript{9}).

**Hysteresis**

The F–L curves during the ascending and descending phases of force development produced a loop. In the present study, the area of each of the curves under both the ascending and descending phases was calculated. Then the ratio of the area within the F–L loop (elastic energy dissipated) to the area beneath the curve during ascending phase (elastic energy input) was calculated as an index of hysteresis\textsuperscript{10–11}.

\[
\text{Hysteresis (\%) = } \frac{(\Sigma E_{Easc} - \Sigma E_{Edes})}{\Sigma E_{Easc}} \times 100
\]

**Statistics**

Descriptive data included means ± SD. One–way analysis of variance (ANOVA) was used to test differences in each parameter among three measurements timing. Bonferroni post hoc analysis was used to determine significant difference between mean values. The level of significance was set at \(p < 0.05\).

**Result**

Both maximal voluntary isometric knee extension strength and lengthening of VL aponeurosis were no significant changes between pre–running and immediately after running (Figure–2).

Stiffness of VL aponeurosis increased at immediately after running but no significant change (Figure–3). VL aponeurosis hysteresis decreased immediately after running (Figure–4,5). But it did not change significantly. Then it returned to the same value as before the run after 30 minutes.

**Figure–2**

Relationship ΔLmm and strength. Muscle strength and ΔLmm values above 50% of MVC were fitted to a linear regression equation, the slope which was adopted as stiffness.

**Figure–3**

Stiffness for BEF, AFT and 30M. Stiffness of VL aponeurosis increased at immediately after running but no significant change.

**Figure–4**

The ΔLmm-strength plots during loading and unloading phase. The area of each of the curves under both the ascending and descending phases was calculated for hysteresis.
As a result of this study, stiffness of VL aponeurosis did not change significantly after running. According to Proske and Morgan’s point of view, it is said that the elastic properties of tendon tissues are influenced not only by the force-velocity relationship of active muscles, but also by the speed of force exertion and the accuracy of movement.

In addition, in previous studies on the influence of bed rests or strength training, it has been reported that the elastic properties of human tendon tissues change in various ways depending on inactivity or training methods. VL do eccentric contraction at the landing to stabilize knee joint during running. As an eccentric muscle training, stiffness of the patellar tendon increased when downhill running for 5 weeks in rats. On the other hand, there was no change in running uphill running. Fast muscle contraction has significantly higher patellar tendon stiffness than slow muscle contraction.

The previous studies showed that maximal elongation of tendon structures in knee extensors was significantly lower in long distance runners than in untrained subjects. These previous findings implied that greater mechanical stresses imposed on knee extensors during long-term running training were responsible for the differences in the tendon properties in knee extensors between long distance runners and untrained subjects. Therefore, since the faster runners had performed large amounts of running training, their tendon structures in knee extensors may have been stiffer due to the greater mechanical stresses imposed by long-term running training. When MTC is stiffer, this makes it easier to transmit muscle tension to tendons. Therefore, long distance running record has been negatively correlated to the stiffness of tendon structures in VL.

The running muscle activities and running time may influence VL muscle tendon stiffness of the runners. As in the case of long distance runners, tendon stiffness may change in running as well. However, in the case of long distance runners who are trained at high strength, we think that the pace and time of this time are not high intensity and did not change.

VL tendon hysteresis decreased immediately after running. Though it did not change significantly. During the loading and unloading of the tendon, the force length relationship of the tendon displays a hysteresis, demonstrating the ability of the tendon to dissipate energy. The discrepancy in the dissipative properties of the Achilles tendon change, considering studies dealing with plyometric training effects may be due to training intensity and volume. It has already been shown in animal models that tendons submitted to high physiological loading levels exhibit lower mechanical hysteresis than tendons subjected to smaller loads. It has been reported that lowering hysteresis of tendon indicates that it is advantageous for moving including stretch–shortening cycle. This is due to the fact that the energy converted to heat decreases. A decrease in hysteresis after stretching indicates that the viscosity in the tendon tissue has decreased. Decreasing the viscosity in the tendon’s tissues is known to be advantageous in operations involving stretch–shortening cycles. The decrease in hysteresis improves muscular tension transmission and probably partially contributes to the increase in jump performance. In previous study, tendon structure changed by training in 6–8 weeks. While tendon hysteresis decreased after 14 weeks plyometric training. The previous studies required a long time. Our study experiment was only one time. It is thought that the period of
this study was not long enough to change. On the other hand, these previous studies used achilles tendon. Kyröläinen et al. indicated that the activation level of knee extensor muscles was lower than that of the plantar flexor muscles at the stance phase during running. In addition, the positive work done during stance phase of running was considerably lower at knee joint than at the ankle joint, although no difference in the negative work between knee and ankle joints. From these previous study, this study was not strong enough to change for VL aponeurosis hysteresis.

**Conclusion**

In conclusion, stiffness of VL aponeurosis did not change significantly after 5 min/km running for 30 minutes. Hysteresis of VL aponeurosis tended to decrease immediately after running. But it did not change significantly. However, it returned to the same value as before the run after 30 minutes. It is thought that the pace and time of this study are not high intensity enough to change.

**References**

1) Elliot BC, Roberts AD: A biomechanical evaluation of the role of fatigue in middle–distance running. Can J Appl Sport Sci, 1980; 5: 203–207.
2) Vigreux B, Cnockaert JC, Pertuzon E: Effects of fatigue on the series elastic component of human muscle. Eur J Appl Physiol Occup Physiol, 1980; 45: 11–17.
3) Kubo K, Tabata T, Ikebukuro T, Igarashi K, Yata H, Tsunoda N: Effects of mechanical properties of muscle and tendon on performance in long distance runners. Eur J Appl Physiol, 2010; 110: 507–514.
4) Sasakawa sports foundation. Sports life data. 2014.
5) Sasakawa sports foundation. Sports life data. 2016.
6) Milner CE, Ferber R, Pollard CD, Hamill J, Davis IS: Biomechanical factors associated with tibial stress fractures in female runners. Med Sci Sports Exerc, 2006; 38: 323–328.
7) Proske U, Morgan DL: Tendon stiffness: methods of measurement and significance for the control of movement. A review. J Biomech, 1987; 20: 75–82.
8) Narici MV, Landoni L, Minetti AE: Assessment of human knee extensor muscles stress from in vivo physiologiscal cross-sectional area and strength measurements. Eur J Appl Physiol, 1992; 65: 438–444.
9) Smith GL: Biomechanical analysis of knee flexion and extension. J Biomech, 1973; 6: 79–92.
10) Kubo K, Kanethisa H, Kawakami Y, Fukunaga T: Effects of repeated muscle contractions on the tendon structures in humans. Eur J Appl Physiol, 2001; 84: 162–166.
11) Maganaris CN, Baltzopoulos V, Sargeant AJ: Repeated contractions alter the geometry of human skeletal muscle. J Appl Physiol (1985), 2002; 93: 2089–2094.
12) Kubo K, Kanethisa H, Kawakami Y, Fukunaga T: Elasticity of tendon structures of the lower limbs in sprinters. Acta Physiol Scand, 2000; 168: 327–335.
13) Reeves ND, Narici MV, Maganaris CN: Strength training alters the viscoelastic properties of tendons in elderly humans. Muscle Nerve, 2003; 28: 74–81.
14) Kaux JF, Drion P, Libertaux V, et al: Eccentric training improves tendon biomechanical properties: a rat model. J Orthop Res, 2013; 31: 119–124.
15) Pearson SJ, Burgess K, Onambele GN: Creep and the in vivo assessment of human patellar tendon mechanical properties. Clin Biomech (Bristol, Avon), 2007; 22: 712–717.
16) Kubo K, Miyazaki D, Yamada K, Yata H, Shimizu S, Tsunoda N: Passive and active muscle stiffness in plantar flexors of long distance runners. J Biomech, 2015; 48: 1937–1943.
17) Cavagna G, Lafortune M: Ground reaction forces in distance running. J Biomech, 1980; 13: 397–406.
18) Maganaris CN, Paul JP: Hysteresis measurements in intact human tendon. J Biomech, 2000; 33: 1723–1727.
19) Wu YK, Lien YH, Lin KH, Shih TT, Wang TG, Wang HK: Relationships between three potentiation effects of plyometric training and performance. Scand J Med Sci Sports, 2010; 20: 80–86.
20) Shadwick RE: Elastic energy storage in tendons: mechanical differences related to function and age. J Appl Physiol (1985), 1990; 68: 1033–1040.
21) Wiesinger HP, Kösters A, Müller E, Seynnes OR: Effects of increased loading on in vivo tendon properties: a systematic review. Med Sci Sports Exerc, 2015; 47: 1885–1895.
22) Foure A, Nordez A, Corru C: Plyometric training effects on Achilles tendon stiffness and dissipative properties. J Appl Physiol (1985), 2010; 109: 849–854.
23) Kyröläinen H, Avela J, Komi PV: Changes in muscle activity with increasing running speed. J Sports Sci, 2005; 23: 1101–1109.
24) Schache AG, Blanch PD, Dorn TW, Brown NAT, Rosemond D, Pandy MG: Effect of running speed on lower limb joint kinetics. Med Sci Sports Exerc, 2011; 43: 1260–1271.