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Original Article

Baseline muscle tendon unit stiffness does not affect static stretching of the ankle plantar flexor muscles

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Abstract. [Purpose] The aim of this study was to investigate the influence of baseline muscle tendon unit stiffness on static stretching. [Participants and Methods] Eighteen healthy males were divided into two groups according to their muscle tendon unit stiffness as follows: High (n=9) and Low (n=9). Flexibility assessment was performed before and after 10 minutes of static stretching. Alterations in range of motion, passive torque at the terminal range of motion, muscle tendon unit stiffness, muscle tendon junction displacement, and tendon length were examined. [Results] No significant interactions were found in all the measurements. After static stretching, the range of motion, passive torque, muscle tendon junction displacement, and tendon length increased, while muscle tendon unit stiffness decreased. There were significant differences in range of motion, muscle tendon unit stiffness, and muscle tendon junction displacement between the groups. [Conclusion] Ten minutes of static stretching increased the range of motion through a decrease in muscle tendon unit stiffness and an increase in tolerance in both groups. Differences in muscle tendon unit stiffness and muscle tendon junction displacement caused the differences in range of motion. Baseline muscle tendon unit stiffness had no effects on static stretching.

Key words: Static stretching, Muscle tendon unit stiffness, Ultrasonography

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INTRODUCTION

Static stretching (SS) is commonly applied before playing sports and during rehabilitation to improve flexibility and prevent sports-related injuries[1, 2)]. Previous studies have reported that SS can improve flexibility as measured using range of motion (ROM), muscle tendon unit (MTU) stiffness, and passive torque[3–6)]. Mizuno et al.[6)] examined the effects of 5 minutes of SS for the gastrocnemius muscle, and reported an increase of ankle dorsiflexion ROM. The authors attributed the increase of ROM to the decrease in MTU stiffness and increase in tolerance[6)]. Tolerance is measured by using passive torque at terminal ROM during passive ankle dorsiflexion[6)].

Ultrasonography has been used to investigate changes in muscle and tendon flexibility after SS[7, 8)]. However, previous findings regarding the influence of SS on muscle and tendon flexibility remain controversial[7, 8)]. Kato et al.[8)] reported that 20 minutes of SS at an intensity of 15% of maximal voluntary contraction increased ROM and decreased tendon stiffness, however, muscle stiffness did not change. Morse et al.[7)] showed that five repetitions of holding the ankle in a dorsiflexed position for 1 minute increased ROM of ankle dorsiflexion and muscle elongation, though tendon elongation did not change. Although the reasons for these discrepancies are unknown, it is possible that the baseline MTU stiffness of the participants influenced the effects of SS.

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Abellaneda et al.[9] divided participants into two groups based on their passive stiffness of ankle dorsiflexion (participants with high values indicated low flexibility), and examined the differences in muscle and tendon elongation during passive ankle dorsiflexion. The relative contribution of muscle elongation was greater in the group with low passive stiffness than in that with high passive stiffness. These results indicate that baseline MTU stiffness of the participants may influence the relative contributions of muscle and tendon elongation during passive ankle dorsiflexion. Freitas et al.[10] suggested that higher intensity SS is a crucial factor to increase maximum ROM. When the relative contributions of muscles and tendons during ankle dorsiflexion are different owing to the baseline MTU stiffness of the participants, it is possible that the effects of SS are different for each participant.

Therefore, the purpose of this research was to clarify the influence of the baseline MTU stiffness on the effect of SS.

PARTICIPANTS AND METHODS

Eighteen healthy males who did not participate in physical activity on a regular basis were recruited for the present study (24.3 ± 1.7 years; 173.0 ± 5.7 cm; 64.4 ± 6.1 kg). All participants were divided into two groups based on their MTU stiffness: LS (n=9) or HS (n=9). LS indicated lower values of MTU stiffness than HS. The exclusion criteria were a history of neuromuscular disease or surgery of their lower limbs. All risks and benefits were explained to the participants prior to the investigation. Informed consent was obtained from each participant. The study was approved by the ethical committee of the Graduate School of Comprehensive Human Sciences in the University of Tsukuba, Japan (25-82).

The participants were secured to a calibrated isokinetic dynamometer machine with the knee in full extension (BIODEX system 4, Sakai Medical Co., Japan) in a room with constant temperature (25 °C). Their dominant foot was placed on the foot plate of the machine and their ankle joint axis was adjusted on the dynamometer axis. A 90 degree angle between the footplate and floor was defined as 0 degrees of ankle dorsiflexion/plantarflexion.

The foot plate moved from 0° to maximum ankle dorsiflexion angle with a constant velocity of 5°/s, in which velocity caused no reflex[11]. After the ankle joint was moved until the maximum angle of the ankle dorsiflexion, passive SS was provided for 10 minutes at the terminal position. The maximum dorsiflexion angle was defined as the maximum tolerable angle without pain[12].

To assess contributing factors to the alteration of ankle flexibility, the following factors were examined pre- and post-SS: passive torque at terminal ROM, MTU stiffness, muscle tendon junction (MTJ) displacement, and tendon length.

Passive torque of ankle plantarflexion through the entire ROM was recorded. Increased passive torque at terminal ROM meant that participants were stretched with higher force. In other words, increased tolerance for stretching was obtained by passive SS when the passive torque at terminal ROM indicated higher values. A passive torque–ankle dorsiflexion angle curve was plotted and the slope of the curve from 15° to 25° was defined as MTU stiffness[12, 13].

B-mode ultrasonography (HI VISION Preirus, Hitachi Aloka Medical, Ltd., Japan) was used to determine the displacement of the MTJ for the gastrocnemius medialis during passive ankle dorsiflexion. The MTJ was identified according to Maganaris and Paul[14] and visualized on a sagittal plane ultrasound image using a 5 MHz linear array probe. The ultrasound probe was attached securely to the skin. Displacement of the MTJ was defined as the distance between a reflective marker attached to the skin and the MTJ. Displacement of the MTJ was calculated using open-access software (Image J 1.45s, National Institutes of Health, USA). Muscle elongation was defined as displacement of the MTJ, according to previous reports[12, 15].

Changes in total length of the MTU during passive ankle dorsiflexion were calculated using the following regression model[6, 16].

$$\text{MTU length change} = -22.185 + 0.30141(90 + \theta A) + 0.00061(90 + \theta A)^2$$

where θ is the ankle dorsiflexion angle (°), defined as a positive value to indicate ankle dorsiflexion. To estimate tendon length change, displacement of the MTJ was subtracted from displacement of the MTU.

All data were represented as means ± standard deviations. A two-way repeated-measures analysis of variance was used to examine the effects of group (HS vs. LS) and time (pre-value vs. post-value). To examine the difference of the characteristics between groups, an un-paired t-test was used. SPSS statistics version 20 (IBM, Japan) was used for all statistical analyses. Differences were considered statistically significant at an alpha level of $p<0.05$.

RESULTS

There was no significant difference in age (HS: 24.6 ± 1.6 years, LS: 24.1 ± 1.9 years, p=0.60), height (HS: 172.0 ± 6.1 cm, LS: 174.0 ± 5.5 cm, p=0.48), and weight (HS: 65.7 ± 7.3 kg, LS: 63.2 ± 4.9 kg, p=0.41) between groups.

Table 1 shows the results of ROM, passive torque at terminal ROM, and MTU stiffness. Two-way ANOVA showed no significant interaction in these variables (p=0.86, 0.60, 0.56, respectively). ROM and passive torque at terminal ROM were increased (both p<0.05), but MTU stiffness was decreased after 10 minutes of SS (p<0,05). There were significant differences in ROM and MTU stiffness between groups (both p<0.05).

Table 2 shows the results of MTJ displacement and tendon length. There was no significant interaction in these variables

Table 1. Changes of ROM, passive torque and MTU stiffness

	LS		HS	
	Pre	Post	Pre	Post
ROM (degree)	37.8 ± 5.4	43.2 ± 6.7*	31.6 ± 3.7#	37.2 ± 3.7*#
Passive torque at terminal ROM (Nm)	28.5 ± 10.8	34.7 ± 12.0*	29.1 ± 8.7	34.0 ± 11.1*
MTU stiffness (Nm/degree)	0.65 ± 0.12	0.53 ± 0.08*	0.97 ± 0.14#	0.79 ± 0.15*#

*Significant difference compared with pre ($p<0.05$). #Significant difference compared with LS ($p<0.05$).

Table 2. Changes of MTJ displacement and tendon length

	LS		HS	
	Pre	Post	Pre	Post
MTJ displacement (cm)	1.74 ± 0.22	1.84 ± 0.27*	1.26 ± 0.36#	1.38 ± 0.36*#
Tendon length change (cm)	0.86 ± 0.25	1.09 ± 0.37*	1.02 ± 0.35	1.22 ± 0.35*

MTJ: muscle tendon junction. *Significant difference compared with pre ($p<0.05$). #Significant difference compared with LS ($p<0.05$).

($p=0.34$ and 0.23, respectively). MTJ displacement and tendon length were increased after 10 minutes of SS (both $p<0.05$). There was a significant difference in MTJ displacement between groups ($p<0.05$).

DISCUSSION

There were significant differences in ROM, MTU stiffness, and MTJ displacement between groups, although there was no significant difference in the passive torque at terminal ROM and tendon length. Alteration of ROM is attributed to alteration of MTU stiffness or tolerance for stretching[17, 18]. Tolerance for stretching was measured by using passive torque at terminal ROM in this study. Therefore, the differences in MTU stiffness caused the differences in ROM between groups. Changes in MTU stiffness is related to changes in muscle flexibility[6, 19], which is measured by using MTJ displacement in this study. Kato et al.[19] reported that decreased passive torque during SS was negatively associated with increased fascicle length. Furthermore, Mizuno et al.[6] suggested that a decrease in muscle stiffness caused a decrease in MTU stiffness. Based on these results, it is possible that differences in muscle flexibility have an impact on the ROM of participants.

Ten minutes of SS increased ROM and passive torque at terminal ROM and decreased MTU stiffness in both groups. These results are consistent with those reported by previous studies[8, 20]. Kato et al.[8] reported that 10 minutes of SS increased ankle dorsiflexion ROM by 5°. Mizuno et al.[18] reported that SS for 5 minutes increased ankle dorsiflexion ROM through a decrease in MTU stiffness and an increase in tolerance. In the present study, 10 minutes of SS increased MTJ displacement and tendon length. Nakamura et al.[21] examined the time course of changes of MTJ displacement during SS using an ultrasonography, and showed that it is necessary to continue SS for more than 2 minutes to increase MTJ displacement. On the other hand, the time course of changes of tendon length during SS was not examined. However, other studies have reported that 5 minutes of SS does not increase tendon flexibility[6, 7, 22], although 10 minutes of SS increases it[8, 23]. These data may help explain why the 10 minutes of SS in the present study increased both muscle and tendon flexibility.

In the present study, 10 minutes of SS changed ROM, MTU stiffness, and passive torque at terminal ROM to the same degree in both groups. A previous study showed that ROM of the participants does not influence the effect of SS[24]. The intensity is one of the important factors for the effects of SS[25]. There was no significant difference in passive torque at terminal ROM between groups in this study, which indicated that both groups received SS at same intensity. This may be the reason for no significant difference of the effects of SS between groups. To our knowledge, this is the first study to examine the effects of baseline MTU stiffness on the effects of SS by using an isokinetic machine and ultrasonography. The results indicated that baseline MTU stiffness influenced the relative contributions of muscle and tendon elongation during passive ankle dorsiflexion as reported in the previous study[9]. However, baseline MTU stiffness had no influence on the effects of SS on muscle and tendon elongation.

The participants of present study were healthy males. Therefore, it is necessary to study whether the results of the present study apply to those with pathological flexibility changes.

In conclusion, 10 minutes of SS increased ROM through decrease in MTU stiffness and an increase in tolerance for stretching. Differences in MTU stiffness and MTJ displacement caused the difference in ROM of the participants. Baseline MTU stiffness had no influence on the effects of SS.

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Conflict of interest

None.

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