Static stretching duration needed to decrease passive stiffness of hamstring muscle-tendon unit

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Abstract Static stretching (SS) is widely used to decrease and retain the passive stiffness of the muscle-tendon unit in clinical and athletic settings. It is important to consider the minimum SS duration required to decrease the passive stiffness of the hamstring, from the perspective of injury prevention of the hamstring muscle. The purpose of this study was to investigate the time course of the effect of static stretching (SS) on passive stiffness of the hamstring and to clarify the minimum SS duration required to decrease the passive stiffness. Fifteen healthy males participated in this study. SS of 60-s session was performed for five sessions with a 30-s rest between sessions. Passive stiffness was measured prior to SS (PRE) and immediately after each SS session to determine the minimum SS duration required to decrease the passive stiffness. Our results showed that SS for >180 s is recommended to decrease the passive stiffness of the hamstring muscle.

Keywords: static stretching, passive stiffness, hamstring, time course

Introduction Static stretching (SS) is widely used to improve and retain the range of motion (ROM) in clinical and athletic settings. Several studies have investigated the effect of SS on ROM1,2. However, it has been pointed out that various factors such as pain and stretch tolerance influence ROM measurements3,4. Therefore, the measurements of passive torque during passive movement and passive stiffness of muscle–tendon units calculated from the relationship between passive torque and joint angle are recommended as alternative approaches to ROM measurement5,6.

Several previous studies have investigated the acute effects of SS on passive stiffness5,7,8. It has been considered that there is a dose-response relationship between SS duration and the effect on passive stiffness. In fact, many studies have reported that longer duration SS resulted in a greater decrease in passive stiffness or greater sustained effect5,7,8. In this way, SS duration is recognized as an essential factor for the effect of SS on passive stiffness.

Our previous study demonstrated that the minimum duration of SS required to decrease passive stiffness of the gastrocnemius muscle–tendon unit was SS for >120 s13. Regarding the effect of SS on passive stiffness of the hamstring muscle, Magnusson et al. have reported no significant change in the passive stiffness of the hamstring muscle–tendon unit after SS for 90 s14. Matsuo et al. have reported that passive stiffness decreased after SS for 180 s and 300 s, but no significant changes were found after SS for 20 s or 60 s12. Considering the results of previous studies, a dose-response relationship is inferred between SS duration and a decrease in passive stiffness on the hamstring muscle; and it is speculated that more than 90 s or less than 180 s of SS duration may be needed to decrease passive stiffness on the hamstring muscle. However, since there are no studies investigating the time-course of changes in passive stiffness of the hamstring during SS intervention, the minimum SS duration required to decrease the passive stiffness of the hamstring remains unclear. Since higher passive stiffness of the hamstring may lead to risk of hamstring injury15, it is important to consider the minimum SS duration required to decrease the passive...
stiffness of the hamstring, from the perspective of injury prevention of hamstring muscle.

The purpose of this study was to investigate the time course of the effect of SS on passive stiffness of the hamstring and to clarify the minimum SS duration required to decrease the passive stiffness.

**Methods**

**Participants.** Fifteen healthy and non-athlete male volunteers participated in this study (age, 23.4 ± 2.2 years; height, 172.2 ± 2.6 cm; body mass, 67.2 ± 5.3 kg). Subjects with a history of neuromuscular disease or musculoskeletal injury in the lower extremity were excluded. All subjects were not involved in any regular resistance training or flexibility training. Written informed consent was obtained from all subjects. This study was approved by the Ethics Committee of Kyoto University Graduate School and the Faculty of Medicine (E-1268).

**Experimental protocol.** Five 60-s SS sessions were performed with a 30-s rest between each session. Passive stiffness was measured prior to SS (PRE) and immediately after each SS session to determine the minimum SS duration required to decrease passive stiffness. Subjects were familiarized with the procedure and instructed to remain relaxed throughout the measurement period.

**Measurement of passive stiffness.** With the participants in a supine position, the dominant lower leg was attached to a dynamometer (Biodex System 4.0, Biodex Medical Systems, Inc., USA) with the hip and knee angles set at 90° flexion. The pelvis was tilted anteriorly by placing a wedge between the pelvis and the bed. The knee joint was passively extended very slowly using the dynamometer manually by an examiner to prevent stretch reflex, starting from 90° flexion to the maximum angle that the participant could tolerate without pain or discomfort16,17. The change in the knee angle from 90° flexion was calculated, and the angle was defined as the final angle. After measuring the final angle, passive torque was measured during passive knee extension at a constant velocity of 5°/s, starting from 90° flexion to the final angle. The torque-angle curve was determined from the relationship between passive torque and knee joint angle; and passive stiffness was calculated as the slope of the torque-angle curve corresponding to 50% of the final angle (Nm/°)12,18.

**SS protocol.** SS was performed in a supine position with the pelvis anteriorly inclined, similar to the measurements of passive stiffness. The dominant lower leg was attached to a dynamometer (Biodex System 4.0, Biodex Medical Systems, Inc., USA) with the hip and knee angles set at 90° flexion. The knee joint was passively extended by an examiner manually, starting from 90° flexion to the final angle, and was held at the final angle for 60 s (constant-angle stretching)19,20. This SS protocol was repeated five times at the same angle for a total of 300 s12,18. The intervals between each SS session were set for 30 s at 90° knee flexion.

**Statistical analysis.** IBM SPSS (version 24.0; SPSS Japan Inc., Tokyo, Japan) was used for statistical analyses. To assess the minimum SS duration required to decrease passive stiffness, paired t-test with Bonferroni correction was applied to determine the differences between measurements at each time period and the initial evaluation. Differences were considered statistically significant at p < 0.05. Descriptive data are shown as mean ± standard deviation.

**Results**

The final angle was 55.6 ± 6.1°, and the passive torque at final angle was 40.6 ± 11.4 Nm at PRE. The final angle after five sessions (300 s) of SS was 70.5 ± 6.5°, which was significantly higher than that at PRE. Changes in passive stiffness are shown in Table 1. Passive stiffness after 180, 240, and 300 s of SS was significantly lower than at PRE.

**Discussion**

This study investigated the time course of the effect of SS on the passive stiffness of the hamstring muscle–tendon unit. Our results showed that passive stiffness was significantly lower after 180 s of SS than at PRE. To the best of our knowledge, this is the first report to investigate the minimum SS duration required to decrease the passive

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<th>Table 1. Changes in passive stiffness during static stretching</th>
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*: p < 0.01: significant difference between PRE
stiffness of the hamstring, although several studies have investigated the acute effect of SS on passive stiffness.

In this study, the final angle significantly increased after 300 s of SS, which is consistent with previous studies that investigated the acute effect of SS on ROM. In addition, our results showed that the minimum SS duration required to decrease the passive stiffness of the hamstring was >180 s. These results are consistent with previous studies that reported no significant changes in the passive stiffness of the hamstring after 20–90 s of SS[12,14], but showed a decrease in the passive stiffness after >180 s[12,21,22]. Our finding suggests that the minimum SS duration required to decrease the passive stiffness of the hamstring may be between 120 s and 180 s. Therefore, future study is needed to investigate in detail whether an SS duration between 120 s and 180 s could decrease the passive stiffness of the hamstring. High passive stiffness of the hamstring may lead to risk of hamstring injury[20]. Our results suggest that >180 s of SS may be necessary to prevent hamstring injury such as hamstring strain. Further studies are needed to investigate the effects of SS programs for preventing hamstring injuries.

The minimum SS duration required to decrease the passive stiffness of the gastrocnemius muscle–tendon unit was 120 s[13], which was comparatively shorter than that required to decrease the passive stiffness of the hamstring. The difference in the minimum SS duration between the gastrocnemius and hamstring might be because of the tension applied to muscle. The magnitude of the tension applied to the muscle is affected by muscle volume[22]. Because muscle volume of the hamstring muscle is larger than that of the gastrocnemius muscle[21], tension applied to the hamstring muscle as per muscle volume was lower than that applied to the gastrocnemius muscle. Therefore, the SS duration required to decrease passive stiffness of the hamstring might be comparatively longer than that of the gastrocnemius.

Our results showed that the minimum SS duration required to decrease passive stiffness of the hamstring was >180 s. Previous studies have reported that the SS duration required for increasing ROM was 30 s in young people23 and was 60 s in elderly people aged ≥65 years[24]. Based on the results of previous studies, our results suggest that the SS duration required to decrease the passive stiffness of the hamstring may be longer than that required to increase ROM. That is, it is likely that a longer SS duration is needed to decrease the passive stiffness than to increase ROM.

There were several limitations in this study. First, we did not monitor the muscle activity of the hamstring during SS and stiffness measurements. Second, we did not investigate chronic effects of the SS program on passive stiffness of the hamstring muscle. Further study is required including the chronic effects of an SS program on passive stiffness.

Conclusion

We investigated the minimum SS duration required to decrease the passive stiffness of the hamstring muscle–tendon unit in young men. Our results showed that SS for >180 s is recommended to decrease the passive stiffness of the hamstring muscle.

Conflict of Interests

None of the authors have any conflict of interests associated with this study.

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References


