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Static stretching time required to reduce iliacus muscle stiffness

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ABSTRACT

Static stretching (SS) is an effective intervention to reduce muscle stiffness and is also performed for the iliopsoas muscle. The iliopsoas muscle consists of the iliacus and psoas major muscles, among which the former has a greater physiological cross-sectional area and hip flexion moment arm. Static stretching time required to reduce muscle stiffness can differ among muscles, and the required time for the iliacus muscle remains unclear. The purpose of this study was to investigate the time required to reduce iliacus muscle stiffness. Twenty-six healthy men participated in this study. A 1-min hip extension SS was performed five times. Shear elastic modulus, an index of muscle stiffness, of the iliacus muscle was measured using ultrasonic shear wave elastography before SS and immediately after each SS. One-way repeated analysis of variance showed a statistical effect of time on the shear elastic modulus. A paired *t*-test with Holm adjustment revealed that the shear elastic moduli after 1-5 SS were statistically lower than that before SS. In addition, the shear elastic modulus after 5 SS was statistically lower than that after 1 SS. The results suggested that the stiffness of the iliacus muscle decreased with 1-min SS and further decreased with 5-min SS.

19 (200 words)

20

21 KEYWORDS

22 Iliacus muscle

23 Static stretching

24 Ultrasonic shear wave elastography

25

26 **Introduction**

27 Limited hip extension range of motion (ROM) owing to increased stiffness or shortening of the
28 iliopsoas muscle is one of the functional impairments observed in athletes and patients (Ferber,
29 Kendall, & McElroy, 2010; Harvey, 1998; Roach et al., 2015). Limited hip extension ROM can
30 be a risk factor for various musculoskeletal disorders (Delp, Hess, Hungerford, & Jones, 1999;
31 Krivickas & Feinberg, 1996). Limited hip extension ROM reduces peak hip extension angle
32 during gait (Tsukagoshi et al., 2015), which leads to changes in gait such as shortened step length,
33 decreased gait velocity, and increased pelvic motion (Kerrigan, Lee, Collins, Riley, & Lipsitz,
34 2001; Miki et al., 2004; Perron, Malouin, Moffet, & McFadyen, 2000).

35 The iliopsoas muscle consists of the iliacus and psoas major muscles. The iliacus muscle
36 has greater physiological cross-sectional area (PCSA) and hip flexion moment arm than the psoas
37 major muscle (Blemker & Delp, 2005; Klein Horsman, Koopman, van der Helm, Prosé, & Veeger,
38 2007). Therefore, increased stiffness or shortening of the iliacus muscle affects hip extension
39 ROM more strongly than similar changes in the psoas major muscle.

40 Static stretching (SS) is an effective intervention to reduce muscle stiffness. Many
41 previous studies have used ROM (Boyce & Brosky, 2008; Ryan et al., 2008), passive torque, and
42 passive stiffness (Fowles, Sale, & MacDougall, 2000; S. Peter Magnusson, Simonsen, Aagaard,
43 & Kjaer, 1996) as indices of SS effects. However, ROM is inadequate as an index of muscle

stiffness because it is influenced by not only muscle stiffness but also pain and stretch tolerance (Weppeler & Magnusson, 2010). Passive torque and passive stiffness reflect the stiffness of many tissues other than the muscle (e.g., ligaments and joint capsule).

Recently, shear elastic modulus, assessed using ultrasonic shear wave elastography (SWE), has been used as an index of muscle stiffness (Kusano et al., 2017; Umegaki et al., 2015; Umehara et al., 2017). SWE estimates muscle stiffness by calculating shear elastic modulus from shear wave speed (Bercoff, Tanter, & Fink, 2004). Several studies reported a high correlation between the shear elastic modulus and passive muscle force (Eby et al., 2013; Koo, Guo, Cohen, & Parker, 2013). Therefore, the stiffness of an individual muscle can be evaluated using SWE.

Investigating the time required to decrease muscle stiffness is important to perform effective stretching, and is useful in time-limited situations such as clinical and athletic situations. A few studies have investigated the time required to reduce muscle stiffness and reported different results (Kusano et al., 2017; Nakamura, Ikezoe, Takeno, & Ichihashi, 2013). One of the potential reasons for the different results could be the innate differences in the targeted muscles, especially muscle size. With regard to muscle size, the iliacus muscle has a much smaller volume compared to the hamstring muscles or the gastrocnemius (Klein Horsman et al., 2007). Therefore, if the time required to reduce muscle stiffness is related to muscle size, the time required to reduce the stiffness of the iliacus muscle would be shorter than that required for the hamstring muscles or

the gastrocnemius. In addition, it was reported that passive torque decreased gradually even after a statistically significant reduction in passive torque occurred compared with before SS (Nakamura et al., 2013). Therefore, it is also important to investigate the time course of muscle stiffness after the first statistical difference is observed to perform effective SS.

Thus far, no study has investigated the effect of SS on the iliacus muscle. While several studies have performed a long-term intervention by using hip extension SS (Kerrigan, Xenopoulos-Oddsson, Sullivan, Lelas, & Riley, 2003; Watt et al., 2011), its effect on muscle stiffness or the time course remains unclear.

The purpose of the present study was to investigate the time required for hip extension SS to reduce the stiffness of the iliacus muscle. We hypothesised that the time required to reduce muscle stiffness of the iliacus muscle would be shorter than that of the hamstring muscles or the gastrocnemius reported in previous studies.

Methods

Participants

The sample size required for multiple comparisons after a one-way repeated analysis of variance (ANOVA) (effect size = 0.58, α error = 0.05, and power = 0.80) was calculated using G* power software (Heinrich Heine University, Düsseldorf, Germany). The effect size was determined

based on a previous study that investigated the acute effect of SS using SWE (Kusano et al., 2017).

The calculated sample size was 26. Twenty-six men (age: 23.2 ± 2.9 years; height: 170.5 ± 5.9 cm; mass: 63.7 ± 6.3 kg) were recruited for this study. None of the participants had musculoskeletal injury or neuromuscular disease in the hip or lumbar region. The exclusion criteria were (1) difficulty in taking the position at which the shear elastic modulus was measured owing to limited hip extension ROM, (2) no stretch sensation in their upper leg at maximal hip extension, and (3) pain or numbness in the right leg during SS.

This study was approved by the ethics committee of the Kyoto University Graduate School and the Faculty of Medicine (R0233-3). Each participant provided written informed consent for participation in the study.

Experimental protocol

Hip extension SS was performed for 1 min; this was repeated five times with 1-min rest intervals, corresponding to the time for measurement of shear elastic modulus. We used 1 min of SS to test the hypothesis that the time required to reduce the iliacus muscle stiffness would be shorter than 2 min. Also, we performed a total of 5 min of SS based on a previous study (Nakamura et al., 2013). The shear elastic modulus of the iliacus muscle was measured before SS (bSS) and immediately after each round of SS (SS1–SS5), corresponding to a total of six

98 measurements.

99 The participants were instructed to relax and not to activate their lower limb muscles
100 throughout the experiment. Each participant lay supine with the hip joint positioned at the edge
101 of the bed. The left hip was passively flexed as much as possible to tilt the pelvis backward
102 maximally by an investigator (YM), and thereafter, the pelvis was fixed to the bed with a non-
103 elastic belt. The right hip was held at 5° extension by another investigator (SN) and the shear
104 elastic modulus was measured (Figure 1). All six measurements of the shear elastic modulus
105 were performed at this position. We confirmed via a preliminary experiment that the shear
106 elastic modulus of the iliacus muscle did not decrease by maintaining this position for 1 min. In
107 hip extension SS, the left hip was maintained at maximal flexion by an investigator (YM), and
108 the right hip was extended by another investigator (SN) to the maximal angle that could be
109 achieved without the participants feeling any discomfort or pain (Figure 2). The right knee was
110 maintained in full extension to avoid elongation of the rectus femoris. The maximal hip
111 extension angle was measured during each round of SS and after all rounds of SS, using a 1°-
112 scale goniometer. The hip extension angle was defined as the angle between the trunk and the
113 femur. All measurements were obtained by the same three examiners, one of whom (MY)
114 performed the measurement of the shear elastic modulus and the hip extension angle, and two of
115 whom (YM and SN) fixed the limb position.

116

117 *Measurement of shear elastic modulus*

118 Shear elastic modulus was measured to assess the muscle stiffness. Ultrasonic SWE (Aixplorer;
119 SuperSonicImagine, Aix-en-Provence, France) with a SuperLinear SL 10-2 probe was used to
120 measure the shear elastic modulus. The shear elastic modulus of the iliacus muscle was measured
121 in the right limb. The measurement site was defined as a level 4 cm distal from anterior superior
122 iliac spines, because it was reported that the iliopsoas muscle was located most superficially at
123 this level (Jiroumaru, Kurihara, & Isaka, 2014). The iliacus muscle belly was identified at this
124 level using a B-mode ultrasonic image. Subsequently, the measurement site was determined and
125 marked on the skin. The probe was placed parallel to the muscle fiber on the mark, and it was
126 confirmed that the muscle fiber was uninterrupted on the ultrasonic image. Subsequently, the
127 shear elastic modulus was measured in ultrasonic SWE mode. The shear elastic modulus was
128 measured twice at each time point, and the mean value was used for statistical analysis. The total
129 time required for the two measurements in each round was < 1 min.

130 A region of interest (ROI), a square of side 1.5 cm, was set at the center of the iliacus
131 muscle belly. A circle was drawn in full size within the ROI. The mean shear wave speed in the
132 circle was calculated automatically (Figure 3). The shear elastic modulus (G) was calculated from
133 the shear wave speed (V) using the following equation:

134 $G \text{ (kPa)} = \rho V^2,$

135 where ρ is the muscle mass density, which is assumed to be 1000 kg/m³ (Gennisson, Cornu,
136 Catheline, Fink, & Portero, 2005). The calculation of shear elastic modulus values was performed
137 by an investigator (SN), who was different from the investigator who measured the shear elastic
138 modulus.

139 The intraclass correlation coefficient (ICC) was calculated in accordance with Shrout &
140 Fleiss (1979) for the two measurements at bSS as an index of the reliability of shear elastic
141 modulus values. ICC_{1,1} was 0.85 (95% confidence interval [CI]: 0.69–0.93), and ICC_{1,2} was
142 0.92 (95% CI: 0.82–0.96), and therefore good reliability was observed (Portney & Watkins, 2000;
143 Shrout & Fleiss, 1979).

144

145 *Statistical analysis*

146 Statistical analysis was performed using SPSS Statistics (version 22; IBM, Armonk, NY, USA).

147 A one-way repeated measures ANOVA was performed to assess the effect of time on the shear
148 elastic modulus. When a statistical effect was observed, a post hoc test was performed. A paired
149 *t*-test was performed between the shear elastic modulus at bSS and that at SS1–SS5.

150 Furthermore, the shear elastic moduli were compared between the time when the first statistical
151 difference compared with bSS was observed and afterward, by using a paired *t*-test. The level of

statistical rareness was set at $P < 0.05$. In post hoc tests, P values were corrected with Holm adjustment in each t -test. We estimated the effect size using partial η^2 and r for the one-way repeated measures ANOVA and post hoc test, respectively. The partial η^2 value is considered moderate and large when it is ≥ 0.07 and ≥ 0.14 , respectively (Cohen, 1988).

Results

The shear elastic modulus at each time point is shown in Table 1 as a mean $\pm$ standard deviation. The maximal hip extension angle during each round of SS is shown in Table 2 as a mean $\pm$ standard deviation.

The one-way repeated measures ANOVA showed a statistical effect of time (effect size partial $\eta^2 = 0.31$). The post hoc test revealed that the shear elastic moduli at SS1–SS5 were statistically lower than at bSS. Moreover, from a comparison of the shear elastic moduli using a paired t -test between SS1 and SS2–SS5, the shear elastic modulus at SS5 was observed to be statistically lower than at SS1.

Discussion and implications

In this study, we investigated the effect of hip extension SS on the stiffness of the iliacus muscle using SWE. The shear elastic moduli at measurements SS1–SS5 were statistically lower than that

at bSS. This result suggests that the stiffness of the iliacus muscle decreased with 1 min of SS, and is consistent with our hypothesis. Furthermore, the shear elastic modulus at SS5 was statistically lower than that at SS1. This result suggests that the stiffness of the iliacus muscle further decreased with 5 min of SS compared with 1 min of SS. To the best of our knowledge, this is the first study to demonstrate the time required for hip extension SS to reduce the stiffness of the iliacus muscle.

Previous studies reported that passive torque or passive stiffness decreased after 2–2.5 min of SS (Nakamura et al., 2013; Nordez, Cornu, & McNair, 2006) and did not decrease after 1–1.5 min of SS (S. P. Magnusson, Aagard, Simonsen, & Bojsen-Møller, 1998; McNair, Dombroski, Hewson, & Stanley, 2001). Therefore, more than 2 min of SS has been considered necessary to reduce muscle stiffness (Akagi & Takahashi, 2013; Nakamura et al., 2014, 2013). However, the shear elastic modulus of the iliacus muscle decreased after 1 min of SS in this study. The reasons for the shorter time in this study could be explained by the difference in the muscle size and the index of muscle flexibility.

Previous studies investigated the time to reduce muscle stiffness in hamstring muscles (S. P. Magnusson et al., 1998; Nordez et al., 2006) or the gastrocnemius (McNair et al., 2001; Nakamura et al., 2013). Kusano et al. (2017) reported that the stiffness of the infraspinatus muscle decreased after 20 s of SS. They explained that the smaller muscle size could be the reason for

the shorter time required. With regards to muscle size, the volume of the iliacus muscle is smaller than that of the hamstring muscles or the gastrocnemius (Klein Horsman et al., 2007). Therefore, the shorter time in this study could be explained by the smaller size of the iliacus muscle compared with that of hamstring or the gastrocnemius muscles.

The difference in the index of muscle stiffness could also be the reason for the shorter time required in the current study. The referred studies used passive torque or passive stiffness as an index of muscle stiffness (S. P. Magnusson et al., 1998; McNair et al., 2001; Nakamura et al., 2013; Nordez et al., 2006). While those indices reflect the stiffness of not only the muscle but also the entire joint complex, we evaluated the stiffness of the iliacus muscle solely by using SWE. By using shear elastic modulus as an index of muscle stiffness, Kusano et al. (2017) reported much shorter time than the referred studies that used passive torque and passive stiffness as an index of muscle stiffness (S. P. Magnusson et al., 1998; McNair et al., 2001; Nakamura et al., 2013; Nordez et al., 2006). In other words, it is indicated that the stiffness of muscle decreases earlier than that of the entire joint complex.

Furthermore, the shear elastic modulus of the iliacus muscle decreased gradually over every SS and a statistically significant difference was observed with SS5 compared with SS1. This result suggests that the stiffness of the iliacus muscle decreased further with 5 min of SS than 1 min of SS. Nakamura et al. (2013) reported a gradual decrease in passive torque over every

minute during 5 min of SS, which was similar to the result of this study. They showed that passive torque decreased statistically after 2 min of SS compared with before SS and decreased statistically after 5 min of SS compared with 2 min of SS. The mechanism of gradual decrease of passive torque was reported to be viscoelastic stress relaxation, which is a decline in the stress or force of the tissues when held at an extended position (Taylor, Dalton, Seaber, & Garrett, 1990). It has been reported that the force declines rapidly in the first few tens of seconds and thereafter declines gradually until 5 min (McNair et al., 2001; Toft, Sinkjaer, Kålund, & Espersen, 1989). In this study, five repetitions of SS could cause viscoelastic stress relaxation as well as 5 consecutive min of SS in the previous study (Nakamura et al., 2013).

In this study, a gradual decrease in muscle stiffness similar to that in consecutive SS was observed in repeated SS. This result could be clinically beneficial. This is because repeating 1 min of SS five times may be much easier for therapists than performing 5 consecutive min of SS.

There are a few limitations to this study. First, 1 min of SS might not necessarily be required to reduce the shear elastic modulus of the iliacus muscle because the effect of SS shorter than 1 min is unclear. However, we confirmed that the shear elastic modulus of the iliacus muscle hardly decreased in a preliminary experiment in which 30 s of SS was repeated. Therefore, we chose to repeat 1 min of SS. Second, we investigated only the acute effect of SS, and the duration of the effect and the long-term effect are unclear. Therefore, the acute effect of SS for shorter time

intervals (i.e., 30–60 s), the effect of long-term intervention, and the effect on performance will be further investigated. Third, the effects of SS on the psoas major remain unclear, although we chose the iliacus muscle rather than the psoas major, based on the greater PCSA and hip flexion moment arm.

Conclusion

In this study it was suggested that the stiffness of the iliacus muscle decreased with 1 min of hip extension SS and further decreased with 5 min of SS.

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236

237 **Disclosure statement**

238 The authors declare no conflicts of interest.

239

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242

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Table 1 Shear elastic modulus of the iliacus muscle at each time point

	Shear elastic modulus (kPa)	Vs. bSS		Vs. SS1	
		<i>P</i> value	effect size (r)	<i>P</i> value	effect size (r)
bSS	22.1 ± 3.5	-	-	-	-
SS1	20.5 ± 4.2	0.008	0.50	-	-
SS2	20.1 ± 4.4	0.008	0.54	0.49	0.14
SS3	19.8 ± 3.7	<0.001	0.71	0.28	0.29
SS4	19.4 ± 3.5	<0.001	0.69	0.19	0.36
SS5	18.2 ± 2.4	<0.001	0.85	0.006	0.58

The shear elastic modulus is expressed as a mean ± standard deviation.

SS: static stretching

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Table 2 Maximal hip extension angle during each round of SS and after SS

Maximal hip extension angle (°)	
1st SS	19 ± 4
2nd SS	21 ± 5
3rd SS	23 ± 5
4th SS	25 ± 5
5th SS	26 ± 5
After SS	26 ± 6

Results are expressed as a mean ± standard deviation.

The angle was measured during each round of SS and after all rounds of SS. The angle during 2nd SS was indicated as the maximal angle, which was a result of 1st SS, for example.

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Figure captions

Figure 1 Position at which the shear elastic modulus was measured

The left hip was maintained at maximal flexion and the right hip was maintained at 5° extension.

Figure 2 Position of static stretching

The left hip was maintained at maximal flexion and the right hip was extended to the maximal angle at which there was no pain or discomfort.

Figure 3 Typical example of measuring the shear wave speed

An ROI, a square of side 1.5 cm, was set at the center of the iliacus muscle belly. A circle was drawn in full size within the ROI. The mean shear wave speed in the circle was calculated automatically.