TITLE:

The effect of hip rotation on shear elastic modulus of the medial and lateral hamstrings during stretching.

AUTHOR(S):

Umegaki, Hiroki; Ikezoe, Tome; Nakamura, Masatoshi; Nishishita, Satoru; Kobayashi, Takuya; Fujita, Kosuke; Tanaka, Hiroki; Ichihashi, Noriaki

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ABSTRACT

Regarding hamstring stretching methods, many studies have investigated the effect of stretching duration or frequency on muscle stiffness. However, the most effective stretching positions for hamstrings are unclear because it is impossible to quantify muscle elongation directly and noninvasively in vivo. Recently, a new ultrasound technology, ultrasonic shear wave elastography, has permitted noninvasive and reliable measurement of muscle shear elastic modulus, which has a strong linear relationship to the amount of muscle elongation. This study aimed to investigate the effect of hip internal and external rotation on shear elastic modulus of the lateral and medial hamstrings, respectively, during stretching in vivo using ultrasonic shear wave elastography. Twenty-three healthy men (age, 23.0 ± 2.1 years) for this study. To investigate the effect of hip rotation on the elongation of the medial and lateral hamstrings, shear elastic modulus of the biceps femoris (BF) and semitendinosus (ST) was measured at rest (a supine position with 90° knee flexion, 90° hip flexion, and hip neutral rotation) and in seven stretching positions (with 45° knee flexion and hip internal, external, and neutral rotation) using ultrasonic shear wave elastography. In both BF and ST, the shear elastic modulus in the rest position was significantly lower than that in all stretching positions. However, no significant differences were seen among stretching positions. Our results suggest that adding hip

rotation at a stretching position for the hamstrings may not have a significant effect on muscle elongation of the medial and lateral hamstrings.

Key Words: hamstrings, ultrasonic shear wave elastography, stretching, hip rotation

1   **Introduction**

2   Hamstring muscle strain is one of the most common sports injuries (Bishop and Fallon,
3   1999, Brooks et al. , 2006, Ekstrand et al. , 2011, Gabbe et al. , 2006) and causes
4   considerable lost time from training and competition (Brooks, Fuller, 2006, Ekstrand,
5   Hagglund, 2011). Therefore, many studies have been performed to investigate an
6   effective method to prevent hamstring muscle strain (Gabbe, Bennell, 2006, McHugh
7   and Cosgrave, 2010, Witvrouw et al. , 2003). Stretching has been used as one of the
8   main methods for preventing hamstring muscle strain, supported by the finding that less
9   flexibility of the hamstrings increases the risk of hamstring muscle strain (Witvrouw,
10   Danneels, 2003). However, a recent systematic review on prevention of hamstring
11   muscle strain found inadequate evidence for the preventive effect of stretching
12   (Goldman and Jones, 2010). Nevertheless, limited evidence suggests that time for
13   recovery to full function may be reduced by increased frequency of stretching (Mason et
14   al. , 2007). To clarify the value of stretching, many studies have investigated the impact
15   of stretching on muscle flexibility with attention to stretching duration and frequency
16   (Ben and Harvey, 2010, Magnusson et al. , 2000, Ylinen et al. , 2009). However, no
17   studies have investigated effective stretching positions for improving flexibility of the
18   hamstrings in vivo or vitro.

For hamstrings, which have knee flexion and hip extension moment arms, a stretching position with knee extended and hip flexed is generally selected. Medial hamstrings, which consist of the semitendinosus (ST) and semimembranosus, have hip internal rotation moment arms, and lateral hamstrings, which consist of the biceps femoris (BF), have hip external rotation moment arms (Dostal et al. , 1986). Therefore, we hypothesized that the medial hamstrings could be stretched more by adding external rotation, and the lateral hamstrings could be stretched more by adding internal rotation.

No studies have investigated effective stretching positions in vivo because it is impossible to quantify muscle elongation directly and noninvasively in vivo. Recently, a new ultrasound technology, ultrasonic shear wave elastography, has permitted noninvasive and reliable measurement of muscle shear elastic modulus. Previous studies have reported a strong linear relationship between the shear elastic modulus measured by ultrasonic shear wave elastography and the amount of muscle elongation (Eby et al. , 2013, Koo et al. , 2014, Maisetti et al. , 2012). Therefore, ultrasonic shear wave elastography is a very useful tool to estimate changes in muscle elongation in vivo. Nevertheless, no studies have investigated the most effective stretching positions using this apparatus.

This study aimed to investigate the effect of hip internal and external rotation

37 on shear elastic modulus of the lateral and medial hamstrings, respectively, during
38 stretching in vivo using ultrasonic shear wave elastography.

39

40 **Methods**

41 **Subjects**

42 Twenty-three healthy men (age, 23.0 ± 2.1 years; height, 172.0 ± 4.7 cm; weight, $66.1 \pm$
43 7.1 kg) volunteered for this study. Subjects were non-athletes and had not been involved
44 in any regular stretching or resistance training. Subjects with a history of neuromuscular
45 disease or musculoskeletal injury involving the lower limbs were excluded. All subjects
46 were fully informed of the procedures and purpose of the study. Written informed
47 consent was obtained from all subjects. This study was approved by the ethics
48 committee of Kyoto University Graduate School and the Faculty of Medicine (E-1162).

49

50 **Experimental protocol**

51 The subjects were placed in a supine position, and their pelvises were secured by a belt.
52 The rest position (Rest) was defined as the position with 90° knee flexion, 90° hip
53 flexion, and hip-neutral rotation. Stretching was performed in the following seven
54 positions: 1) R0 (45° knee flexion and 90° hip flexion at hip-neutral rotation); 2) IR10
55 (adding 10° hip internal rotation to R0); 3) IR20 (adding 20° hip internal rotation to

R0); 4) IR30 (adding 30° hip internal rotation to R0); 5) ER10 (adding 10° hip external rotation to R0); 6) ER20 (adding 20° hip external rotation to R0); 7) ER30 (adding 30° hip external rotation to R0). These positions were determined by measuring the joint angles using a goniometer and were manually maintained. Rest and R0 are shown in Fig. 1. Our study (Nakamura et al. , 2013) reported that >2 min of stretching decreased muscle stiffness. Therefore, in this study, each position was maintained for <10 s to avoid the effects of changes in muscle stiffness. The order in which positions were measured was randomized to remove the effect of measurement time.

Measurement of shear elastic modulus

Shear elastic modulus of the BF and ST muscle bellies of the dominant leg was measured at the midpoint of the thigh from the greater trochanter to the lateral and medial epicondyles of the thighbone. These points were confirmed by palpation and marked prior to measurement. Shear elastic modulus of the BF and ST was measured using ultrasonic shear wave elastography (Axiplorer; SuperSonic Imagine, Axi-en-Provence, France). This apparatus uses acoustic radiation force created by ultrasound beams to perturb muscle tissues by inducing shear waves that propagate within the muscle. As the shear waves propagate, they are captured by the ultrasound

transducer at an ultrafast frame rate. Shear wave propagation speed is estimated at each pixel using a cross-correlation algorithm. Shear elastic modulus (G) can be calculated using the shear wave speed (v) by the following equation:

$$G = \rho v^2$$

where ρ is the muscle mass density, which is assumed to be 1000 kg/m³. An ultrasound transducer (50 mm long SL-15-4 linear ultrasound transducer) was positioned on the marking points along the sagittal plane of the muscle fibers for BF and ST, which were confirmed by tracing several fascicles without interruption across the B-mode image. Shear wave elastography generated color-coded images with a scale from blue (low) to red (high) depending on the shear wave propagation speed (Fig. 2). The region of interest (ROI) was set near the center part of the muscle belly in the image. The mean shear wave propagation speed (m/s) of an 11-mm-diameter circle set near the center of the ROI was automatically calculated. The measurements of shear elastic modulus for ST and BF were performed once in each position. Measurement of shear elastic modulus was performed by an experienced measurer. The reliability of the shear elastic modulus measured by this apparatus has been confirmed in previous studies (Koo, Guo, 2014, Maisetti, Hug, 2012).

92 Measurement reliability

93 Measurements of shear elastic modulus were repeated twice, in different sessions, to
94 assess reliability (8 healthy men; age 22.8 ± 1.8 years; height 172.8 ± 3.6 cm; body
95 mass 67.0 ± 7.5 kg).

96

97 Priori sample size calculation

98 We calculated the sample size needed for one-way repeated measures analysis of
99 variance (ANOVA) (alpha error = 0.05, power = 0.95, effect size = 0.25 [middle]), and
100 the requisite number of subjects for this study was 23.

101

102 Statistical analysis

103 Statistical analysis was performed using SPSS (version 18.0, SPSS Japan INC., Tokyo,
104 Japan). Measurement reliability was assessed using the intraclass correlation coefficient
105 (ICC [1, 1]) with 95% confidence interval (CI), and the coefficients of variation were
106 calculated. An ICC value of 0.40 is generally considered as poor reliability, 0.40–0.75 as
107 moderate to good, and 0.75 as excellent reliability (Leong et al. , 2013). For the shear
108 elastic modulus of the BF and ST, one-way repeated measures analysis of variance
109 (ANOVA) was used to determine the differences in positions. When a significant main
110 effect was observed, the differences between positions were determined using
111 Bonferroni's post hoc test. Differences were considered statistically significant at an

alpha level of $P < 0.05$. In addition, after Bonferroni's adjustment, differences were considered statistically significant at an alpha level of $P < 0.00625$.

Results

Reliability of shear elastic modulus is shown in Table 1. The ICC (1, 1) was 0.966–0.998 for shear elastic modulus of BF and 0.959–0.995 for shear elastic modulus of the semitendinosus ST at all positions. The results of shear elastic modulus of the BF and ST are shown in Table 2, presented as mean $\pm$ SD (standard deviation). For both BF and ST, one-way ANOVA indicated significant main effects (BF: $F = 9.69$, $P < 0.05$, ST: $F = 9.37$, $P < 0.05$) of positions. The post hoc test indicated that the shear elastic modulus in Rest was significantly lower than that in all stretching positions. However, no significant differences were seen among the stretching positions in both BF and ST.

Discussion

The ICC (1, 1) was 0.966–0.998 for shear elastic modulus of BF and 0.959–0.995 for shear elastic modulus of ST at all positions, and the ICC for both BF and ST was greater than 0.75. Therefore, we consider the data in this study to be reliable. We investigated the effect of hip internal and external rotation on shear elastic modulus of the medial and lateral hamstrings during stretching using ultrasonic shear wave elastography. To

131 the best of our knowledge, this is the first report examining effective stretching
132 positions of the hamstrings in vivo.

133 In this study, the shear elastic modulus of the BF and ST in Rest was
134 significantly lower than that in all stretching positions. This result suggested that the
135 medial and lateral hamstrings could be stretched at 45° knee flexion and 90° hip flexion
136 regardless of hip rotation angle. However, no significant differences among stretching
137 positions were found for BF or ST. Therefore, adding hip rotation at a stretching
138 position may have less effect on muscle elongation in the medial and lateral hamstrings.
139 We hypothesized that the medial hamstrings could be stretched more by adding external
140 rotation and the lateral hamstrings could be stretched more by adding internal rotation.
141 However, the results of this study did not support the hypothesis. The moment arm can
142 be calculated by dividing the amount of elongation of muscle tendon unit (MTU) by the
143 changes in joint angle (tendon excursion methods) (Maganaris et al. , 2000). Therefore,
144 MTU would be more elongated as moment arm and changes in joint angle become
145 greater. In both BF and ST, the moment arm of hip internal and external rotation was
146 considerably smaller than that of knee flexion (Buford et al. , 1997, Dostal, Soderberg,
147 1986). Moreover, in this study, change in hip rotation angle (maximally 30°) was
148 smaller than the change in knee extension angle (from 90° to 45°). Therefore, the effect

149 of hip rotation may be lesser than that of knee extension.

150   Some limitations of this study must be noted. First, the amount of elongation of
151 the medial and lateral hamstrings could not be directly measured using shear elastic
152 modulus. Although previous studies have reported a strong linear relationship between
153 the shear elastic modulus measured by ultrasonic shear wave elastography and the
154 amount of muscle elongation(Eby, Song, 2013, Koo, Guo, 2014, Maisetti, Hug, 2012), it
155 may not be adequately evaluated by a slight change in muscle elongation. Second, in
156 this study, only the effect of hip rotation on the shear elastic modulus of BF and ST was
157 investigated. It is very important to develop an effective stretching position for
158 improving flexibility of the hamstring muscles to prevent hamstring muscle strain.
159 Further research is required to investigate the most effective stretching position besides
160 hip rotation for the hamstrings.

161

162 **Conclusion**

163 We investigated the effect of hip internal and external rotation on the shear elastic
164 modulus of the BF and ST using ultrasonic shear wave elastography. Our results suggest
165 that adding hip rotation at a stretching position for the hamstrings may not have a
166 significant effect on muscle elongation of the medial and lateral hamstrings.

167   **References**

- 168   Ben M, Harvey LA. Regular stretch does not increase muscle extensibility: a randomized
169   controlled trial. *Scandinavian journal of medicine & science in sports*. 2010;20:136-44.
- 170   Bishop GW, Fallon KE. Musculoskeletal injuries in a six-day track race: Ultramarathoner's
171   ankle. *Clinical Journal of Sport Medicine*. 1999;9:216-20.
- 172   Brooks JH, Fuller CW, Kemp SP, Reddin DB. Incidence, risk, and prevention of hamstring
173   muscle injuries in professional rugby union. *The American journal of sports medicine*.
174   2006;34:1297-306.
- 175   Buford WL, Jr., Ivey FM, Jr., Malone JD, Patterson RM, Peare GL, Nguyen DK, et al.
176   Muscle balance at the knee--moment arms for the normal knee and the ACL-minus knee.
177   *IEEE transactions on rehabilitation engineering : a publication of the IEEE Engineering in*
178   *Medicine and Biology Society*. 1997;5:367-79.
- 179   Dostal WF, Soderberg GL, Andrews JG. Actions of hip muscles. *Physical therapy*.
180   1986;66:351-61.
- 181   Eby SF, Song P, Chen S, Chen Q, Greenleaf JF, An KN. Validation of shear wave
182   elastography in skeletal muscle{Eby, 2013 #441}. *Journal of biomechanics*. 2013;46:2381-7.
- 183   Ekstrand J, Hagglund M, Walden M. Injury incidence and injury patterns in professional
184   football: the UEFA injury study. *Br J Sports Med*. 2011;45:553-8.

- 185 Feeley BT, Kennelly S, Barnes RP, Muller MS, Kelly BT, Rodeo SA, et al. Epidemiology of
186 National Football League training camp injuries from 1998 to 2007. The American journal of
187 sports medicine. 2008;36:1597-603.
- 188 Gabbe BJ, Bennell KL, Finch CF, Wajswelner H, Orchard JW. Predictors of hamstring injury
189 at the elite level of Australian football. Scandinavian journal of medicine & science in sports.
190 2006;16:7-13.
- 191 Goldman EF, Jones DE. Interventions for preventing hamstring injuries. The Cochrane
192 database of systematic reviews. 2010:CD006782.
- 193 Koo TK, Guo JY, Cohen JH, Parker KJ. Quantifying the passive stretching response of
194 human tibialis anterior muscle using shear wave elastography. Clinical biomechanics.
195 2014;29:33-9.
- 196 Leong HT, Ng GY, Leung VY, Fu SN. Quantitative estimation of muscle shear elastic
197 modulus of the upper trapezius with supersonic shear imaging during arm positioning. Plos
198 One. 2013;8:e67199.
- 199 Maganaris CN, Baltzopoulos V, Sargeant AJ. In vivo measurement-based estimations of the
200 human Achilles tendon moment arm. European journal of applied physiology. 2000;83:363-9.
- 201 Magnusson SP, Aagaard P, Nielson JJ. Passive energy return after repeated stretches of the
202 hamstring muscle-tendon unit. Medicine and science in sports and exercise. 2000;32:1160-4.

203 Maisetti O, Hug F, Bouillard K, Nordez A. Characterization of passive elastic properties of
204 the human medial gastrocnemius muscle belly using supersonic shear imaging. *Journal of*
205 *biomechanics*. 2012;45:978-84.

206 Mason DL, Dickens V, Vail A. Rehabilitation for hamstring injuries. *The Cochrane database*
207 *of systematic reviews*. 2007:CD004575.

208 McHugh MP, Cosgrave CH. To stretch or not to stretch: the role of stretching in injury
209 prevention and performance. *Scandinavian journal of medicine & science in sports*.
210 2010;20:169-81.

211 Nakamura M, Ikezoe T, Takeno Y, Ichihashi N. Time course of changes in passive properties
212 of the gastrocnemius muscle-tendon unit during 5 min of static stretching. *Manual therapy*.
213 2013;18:211-5.

214 Witvrouw E, Danneels L, Asselman P, D'Have T, Cambier D. Muscle flexibility as a risk
215 factor for developing muscle injuries in male professional soccer players - A prospective
216 study. *Am J Sport Med*. 2003;31:41-6.

217 Ylinen J, Kankainen T, Kautiainen H, Rezasoltani A, Kuukkanen T, Hakkinen A. Effect of
218 stretching on hamstring muscle compliance. *Journal of rehabilitation medicine : official*
219 *journal of the UEMS European Board of Physical and Rehabilitation Medicine*.
220 2009;41:80-4.

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239 Table 1

240 Reliability of shear elastic modulus

Position	BF			ST		
	ICC	95% CI	CV (%)	ICC	95% CI	CV (%)
Rest	0.993	0.967–0.999	3.5	0.959	0.783–0.990	4.6
R0	0.982	0.897–0.996	4.3	0.991	0.956–0.998	2.8
IR10	0.993	0.964–0.999	2.6	0.984	0.918–0.997	2.6
IR20	0.990	0.950–0.998	3.0	0.993	0.946–0.998	2.2
IR30	0.995	0.961–0.998	2.2	0.995	0.967–0.999	1.9
ER10	0.966	0.840–0.993	3.3	0.985	0.921–0.997	4.4
ER20	0.996	0.948–0.998	2.6	0.985	0.898–0.996	3.9
ER30	0.998	0.940–0.998	2.8	0.995	0.959–0.998	2.6

241 ICC: intraclass correlation coefficient (1, 1)

242 95% CI: 95% confidence interval

243 CV: coefficients of variation

244

245

246

247 Table 2

248 Shear elastic modulus of the biceps femoris and semitendinosus in each position.

Position	BF (kPa)	ST (kPa)
Rest	20.1 ± 7.9	13.9 ± 4.4
R0	67.8 ± 21.5**	49.7 ± 15.5**
IR10	74.6 ± 24.1**	50.3 ± 17.5**
IR20	71.9 ± 22.6**	46.6 ± 12.7**
IR30	74.9 ± 22.6**	46.7 ± 14.5**
ER10	64.2 ± 24.3**	50.4 ± 17.9**
ER20	67.7 ± 26.2**	55.5 ± 16.9**
ER30	65.0 ± 23.8**	56.3 ± 22.2**

249 Values are expressed as mean ± SD (standard deviation).

250 **p < 0.01. Significant difference from Rest

251 BF: biceps femoris, ST: semitendinosus

252 95% CI: 95% confidence interval

253 Rest: position with 90° knee flexion, 90° hip flexion, and hip-neutral rotation

254 R0: position with 45° knee flexion and 90° hip flexion at hip-neutral rotation

255 IR10: position with 45° knee flexion and 90° hip flexion at 10° hip internal rotation

256 IR20: position with 45° knee flexion and 90° hip flexion at 20° hip internal rotation

257 IR30: position with 45° knee flexion and 90° hip flexion at 30° hip internal rotation

258 ER10: position with 45° knee flexion and 90° hip flexion at 10° hip external rotation

259 ER20: position with 45° knee flexion and 90° hip flexion at 20° hip external rotation

260 ER30: position with 45° knee flexion and 90° hip flexion at 30° hip external rotation

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Fig. 1

Rest

Rest: the position with 90° knee flexion, 90° hip flexion, and hip-neutral rotation

R0

R0: the position with 45° knee flexion and 90° hip flexion at hip-neutral rotation

282 Fig. 2

283 Representative image of the biceps femoris measured by shear wave elastography

284 A. Rest

285 Rest: position with 90° knee flexion, 90° hip flexion, and hip-neutral rotation

286

287 B. R0

289 R0: position with 45° knee flexion and 90° hip flexion at hip-neutral rotation

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