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TITLE

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Effective stretching positions of the piriformis muscle evaluated using shear wave elastography

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ABSTRACT

(230 /300words)

Context

Piriformis syndrome is often associated with muscle spasms and shortening of the piriformis muscle (PM). Physical therapy, including static stretching of the PM, is one of the treatments for this syndrome. However, the effective stretching position of the PM is unclear in vivo. This study aimed to determine the effective stretching positions of the PM using ultrasonic shear wave elastography (SWE).

Design

Observational study

Methods

Twenty-one healthy young men (22.7 ± 2.4 years) were participated in this study. The shear elastic modulus (G) of the PM was measured at 12 stretching positions using shear wave elastography. Three out of the 12 positions were tested with maximum internal rotation at 0° , 20° , or 40° hip adduction in 90° hip flexion. Nine out of the 12 positions were tested with maximum external rotation at positions combined with three hip flexion angles (70° , 90° , and 110°) and three hip adduction angles (0° , 20° , and 40°).

Results

25 The G of the PM was significantly higher in the order of 40°, 20°, and 0° of adduction and higher in external
26 rotation than in internal rotation. The G of the PM was significantly greater in combined 110° hip flexion and 40°
27 adduction with maximum external rotation than in all other positions.

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29 Conclusion

30 This study revealed that the position in which the PM was most stretched was maximum external rotation with
31 110° hip flexion and 40° hip adduction.

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34 **Keywords**

35 muscle elongation, shear elastic modulus, piriformis muscle, physical therapy

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1. INTRODUCTION

The main symptom of piriformis syndrome is pain in the buttocks and lower extremities, which worsens with prolonged sitting¹. Piriformis syndrome has been reported in athletes²⁻⁴ and is often associated with spasms and shortening of the piriformis muscle (PM), leading to compression of the sciatic nerve¹. PM spasms cause compression of the sciatic nerve. The main treatment for piriformis syndrome is physical therapy, which includes static stretching⁵. Stretching can reduce tension in the PM and surrounding organization, especially the sciatic nerve, thereby easing pain. Generally, stretching that applies more traction to the tissues is known to reduce their stiffness after stretching⁶. To effectively reduce PM tension, it is important to identify the most effective stretching maneuvers.

In previous studies on stretching in patients with piriformis syndrome, a combination of hip flexion, adduction, and internal or external rotation has been used^{5,7,8}. However, it is unclear whether internal or external rotation of the hip is better for PM stretching. The length of a muscle increases when the muscle origin and insertion moves apart. In addition, the amount of muscle elongation is associated with the moment arm of the muscle and the magnitude of the change in the joint angle in the opposite direction when considered in terms of tendon excursion methods⁹. The moment arm of the PM changes from external hip rotation to internal rotation with an increase in hip flexion angle, and the magnitude of the moment arm for hip extension and abduction also changes with hip joint angle¹⁰. Thus, the conventional stretching method may not be an effective stretching position for the PM. A study that simulated the amount of PM elongation reported that the PM was most stretched in a position that combined 117° hip flexion, 27° adduction, and 40° external rotation¹¹. However, the amount of elongation of

the PM during stretching in vivo has not been studied; therefore, it is necessary to clarify the effective stretching positions for the PM in vivo.

Ultrasonic shear wave elastography (SWE) enables noninvasive measurement of the elongation of individual muscles in vivo^{12,13}. In this method, the shear elastic modulus (G) of the tissue is qualitatively calculated from the propagation velocity of shear waves generated by the acoustic radiation force when ultrasound pulses are converged and irradiated into the tissue¹⁴. Previous studies have shown that the G is related to the stiffness during muscle stretching in passive motion and tensile tests^{15,16} meaning that the G is an indirect indicator of the amount of the muscle elongation. Muscle stiffness increases with increased muscle length. Therefore, the higher the G is, the greater the muscle elongation. Many previous studies have determined effective stretching positions of individual muscles by examining the position with the highest G ¹⁷⁻²⁰. Therefore, the G of the PM can be used to identify the effective stretching position of the PM by measuring the change in G with the change in hip angle.

This study aimed to examine effective stretching positions of the PM for healthy young men using SWE. The PM has a moment arm of hip abduction and extension in almost all hip positions and a moment arm of internal rotation in hip flexion above 65°¹⁰. Therefore, we hypothesized that the hip flexion adducted and external rotated position would produce the highest G : the PM is most stretched in the maximum hip flexion and adduction positions with hip external rotation.

2. METHODS

2.1. Study Design

This was an observation study. Our main outcome was the shear elastic modulus. The independent variable in this study was the stretching position and the dependent variable was G .

2.2. Participants

The participants were 21 healthy young men (age 22.7 ± 2.4 years, height 171.2 ± 5.1 cm, mass 60.4 ± 7.4 kg) with no orthopedic or neurological diseases of the lumbar region or buttock. The sample size was calculated using G*power 3.1 (Heinrich Hein University, Duesseldorf, Germany). As a previous study examining the changes in G due to stretching using a paired t-test reported large effect sizes¹⁸, the required sample size was 15 subjects (effect size=0.8, α error=0.05, power=0.8). In the preliminary experiment, the G of the PM was measured in eight out of the ten subjects (success probability: 80%). Therefore, 21 participants were recruited to meet the required sample size to avoid underpowering due to missing data. The participants were informed about the study in advance, and written informed consent was obtained for participation in this study. The study protocol was approved by the ethics committee of the author's institution (registration number: R0233).

2.3 Procedure

The G in the left PM was measured using shear wave elastography with an SL 10-2 linear probe (Aixplorer, Supersonic Imagine, Aix-en-Provence, France). The probe was placed slightly medial to the midpoint of the line connecting the posterior superior iliac spine and greater trochanter on the left side, which was defined as a reference site. Using the transverse ultrasound B-mode, we identified the PM that passed through the greater

94 sciatic foramen slightly medial to the reference site and between the superior and inferior gluteal arteries. The
95 probe was then rotated so that it was parallel to the muscle fibers, and a mark was depicted on the skin at the
96 location. A color map of the *G* was captured at this position during stretching (Figure 1).

97 The *G* of the PM was measured at 12 positions using SWE (Figure 2). Three out of the 12 positions
98 were tested with maximum internal rotation at 0°, 20°, and 40° hip adductions in 90° hip flexion. Nine out of the
99 12 positions were tested with maximal external rotation at positions combined with three hip flexion angles (70°,
100 90°, and 110°) and three hip adduction angles (0°, 20°, and 40°). After defining the hip flexion and adduction angles
101 using a goniometer, one examiner rotated the hip joint as much as the participants could tolerate without pain, and
102 another examiner measured the *G* of the PM at that position. We fixed the hip joint position while taking US
103 images in each position.

104 In a preliminary experiment that measured the maximal flexion and adduction angles of the hip in six
105 subjects at maximum hip flexion position, all subjects could achieve at least 110° hip flexion and 40° adduction.
106 Based on this result, we set 110° hip flexion and 40° adduction (F110 AD40) as the maximum angles in this
107 experiment.

108 The participants were instructed to relax in each position so that the muscles would not contract.
109 Three examiners performed the pelvic immobilization, stretching, and ultrasound measurements. To prevent
110 compensatory movement of the pelvis, another examiner fixed the pelvis to the bed with a belt. The same examiner
111 performed all the procedures throughout the experiment (Figure 3). The *G* was measured by one physical therapist
112 with 6 years of US experience.

The stretching positions were measured in a random order to eliminate order effects according to the randomization sequence generated using the random function in Excel (Microsoft, Redmond, USA). A 5-minute interval was allowed between each stretching position.

The G at each position was measured seven times, and the average value was used for the analysis.

On the color map of the elastography image, a 1 cm square region of interest (ROI) was set at the center of the muscle belly. A Q-Box with a diameter of 10 mm was set within the ROI, and the average G within this circle was calculated.

The shear elastic modulus (G) was calculated as follows:

$$G = \rho v^2$$

Further, ρ is the material density and v is the shear wave velocity. The material measured in this study is muscle, and the density ρ of the muscle can be assumed to be 1 g/cm^3 ²¹. Although, in practice, the ρ is slightly greater than 1 g/cm^3 because the muscle is not isotropic²², many previous studies have used ρ as 1 g/cm^3 ^{18,23,24}.

In previous studies, it has been reported that in muscles, the Young's modulus during muscle elongation was correlated with the G measured by Aixplorer^{15,16}. Although many assumptions have been made about the G , G has been used in many studies to evaluate the amount of muscle elongation^{12,13,18,20}, so the G was calculated in this study as well. A patient was excluded if measurements were not collected in any positions.

2.4. Statistical Analysis

Statistical analyses were performed using SPSS Statistics 22 (IBM SPSS, Armonk, NY). The intraclass

correlation coefficient (ICC) (1,7) was calculated from seven measurements at each position to examine the measurement reliability. The Shapiro–Wilk test was used to confirm the normality of G . Since the rotation action of the PM is internal rotation at hip flexion, stretching was mainly performed in hip external rotation in this study. First, to confirm whether the PM is actually elongated more in hip external rotation than in hip internal rotation regardless of the change in the angle of adduction, a two-way analysis of variance with repeated measures (ANOVA) was conducted using hip adduction angle and rotation angle as factors. For the factors that showed a main effect, a paired t-test with Bonferroni correction was performed between the levels as a post hoc test. Next, a one-way repeated-measures ANOVA was performed for the nine positions in the hip external rotation positions. In the case of the main effect, a paired t-test with Bonferroni correction was performed to compare the values for F110 AD40 with the other eight positions because we hypothesized that the PM would be most stretched in F110 AD40, the largest hip flexion and adduction position, with additional hip external rotation. Statistical significance was set at 5%.

3. RESULTS

Six out of the 21 subjects (age 22.2 ± 1.6 years, height 172.1 ± 4.7 cm, mass 66.5 ± 8.7 kg) were excluded because it was impossible to measure their PM with the ultrasound in any position. There were significant differences in body mass and body mass index (BMI) between the measurable and nonmeasurable groups ($p = 0.05$). Thus, the data of 15 participants (age 22.9 ± 2.6 years, height 170.9 ± 5.3 cm, mass 58.4 ± 6.0 kg) were used for analysis.

3.1. Reliability

ICCs (1,7) were 0.865 to 0.978 in all positions; thus, the measurement reliability was “almost perfect”²⁵ (Table 1).

3.2. Comparison of G

The Shapiro–Wilk test showed that the data were normally distributed for all positions.

First, using a two-way repeated-measures ANOVA for hip adduction and rotation angles, we found significant main effects for hip adduction and rotation angles ($p < 0.01$), without any interaction effects (Figure 4A). Post-hoc results showed that G was higher in the order of 40°, 20°, and 0° of adduction and was higher in external rotation than in internal rotation ($p = 0.001$, < 0.001 , < 0.001 , respectively) (Figure 4A). The G was larger in ER than in IR in all participants, except for 1 participant in AD0 and 2 participants in AD40 (Figure 4B).

There was a significant main effect between each level of hip adduction and rotation angle, without any interaction effect.

Next, a one-way repeated-measures ANOVA was performed for the nine positions in the hip external rotation positions (Figure 5), and a significant main effect was observed ($p < 0.05$). Based on the hypothesis, a t -test was performed using Bonferroni correction. The results showed that the G was significantly greater in F110 AD40 than in any other positions (Figure 5).

4. DISCUSSION

In this study, the effective stretching position of the PM was investigated using SWE. This study showed that the G was significantly higher in external rotation than in internal rotation at any adduction angle of 90° hip flexion. In addition, the G of F110 AD40 was the highest among the nine positions with hip external rotation. These results indicate that the most effective stretching position for the PM is F110 AD40 with hip external rotation, supporting our hypothesis that the PM is most stretched in the largest hip flexion and adduction positions with external hip rotation. To the best of our knowledge, this is the first study to examine the effective stretching position of the PM in vivo using SWE.

The PM was stretched more during hip external rotation than during internal rotation. The moment arm of the PM is external rotation from 0-65° hip flexion but switches to internal rotation above 65° hip flexion¹⁰. Additionally, the amount of muscle elongation is associated with the moment arm, which changes with joint angle²⁶. Based on our findings, the G of the PM in hip external rotation was significantly higher than that in internal rotation at 90° hip flexion. In other words, the PM was significantly stretched during external rotation.

Comparing the stretching positions in hip external rotation, the highest G was found in F110 AD40. In other words, the PM was stretched in positions where both hip flexion and adduction angles were the greatest. A previous study reported that the PM always has a moment arm of hip extension and abduction, regardless of the angle of hip flexion-extension and adduction-abduction¹⁰. The length of a muscle changes as the muscle origin and insertion move apart. In addition, in the tendon excursion methods, the moment arm can be determined by dividing the elongation of the muscle-tendon unit (MTU) by alterations in the joint angle²⁶. When the moment

arm and joint angle changes are greater, the MTU becomes more elongated ²⁷. In other words, the amount of muscle elongation is associated with the moment arm of the muscle and the magnitude of the change in the joint angle in the opposite direction. Therefore, we assumed that the PM was stretched significantly in the position where both hip flexion and abduction angles were the greatest.

In a previous study that simulated PM length, the most stretched position was 117° hip flexion, 27° adduction, and 40° external rotation ¹¹. This study indicated that the PM was stretched at the maximum hip flexion and adduction angles with external rotation in the representative example. Therefore, the results of the present study, which showed the greatest stretching position with maximum external rotation at F110 AD40, support the findings of the previous study.

In this study, the maximum external rotation at F110 AD40 was the most stretched position in healthy young men. However, in clinical practice, this stretching position may not be applicable to some patients due to hip joint restriction or dislocation after THA. Additional analysis was performed to propose better PM stretching position for such patients. In the additional analysis, a two-way ANOVA with flexion and adduction angle as factors showed main effects for each angle, respectively (Supplemental 1). The effect size was larger for flexion (partial $\eta^2 = 0.650$) than for adduction (partial $\eta^2 = 0.813$). For patients with pain or contraindications, these findings suggest that: 1. hip adduction after maximal hip flexion is important, even if the position does not reach F110 AD40; 2. prioritizing hip flexion is critical for patients whose hip can only be mobilized in either flexion or adduction.

Our study had several limitations. First, it was conducted only with healthy young men. A previous

study has reported that bone morphology may affect the amount of elongation of the PM¹¹. Piriformis syndrome is more common in women than in men and occurs most commonly in their 40–50s²⁸. Sex differences exist in pelvic and femoral bone morphology, hip flexion and extension, and internal and external rotation ranges of motion²⁹. It is necessary to further investigate whether similar results can be obtained in a variety of subjects, including women and patients with piriformis syndrome. Second, this study did not examine the effects of stretching intervention. Further studies must examine whether an intervention with an effective stretching position could improve symptoms in patients with piriformis syndrome. Finally, PM measurements using the SWE could not be performed on 6 of the 21 individuals. This limitation was likely due to their significantly higher BMI compared to the measurable group. Previous studies have reported that muscle depth affects SWE measurements^{30,31}. High BMI is generally associated with an increased amount of body fat, which made the depth of measurement incompatible with the SWE measurements. However, the only subject characteristics available to determine why the PM could not be measured were mass and BMI. Further research is needed to identify unmeasured factors that may have affected the stretching positions.

5. CONCLUSION

In this study, the effective stretching position of the PM in healthy young men was investigated using SWE. This study found that the PM was more stretched during external rotation of the hip than during internal rotation and that the stretching position in which the PM was most stretched was maximum external rotation with

227 110° hip flexion and 40° hip adduction.

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231 **Declarations of interest:** none.

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321 **Table 1.** ICCs (1,7) in each position

F90	F90	F90	F70	F70	F70	F90	F90	F90	F110	F110	F110
AD0	AD20	AD40	AD0	AD20	AD40	AD0	AD20	AD40	AD0	AD20	AD40
IR	IR	IR	ER	ER	ER	ER	ER	ER	ER	ER	ER
0.865	0.920	0.964	0.923	0.972	0.961	0.978	0.974	0.966	0.937	0.972	0.931

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323 F70: 70° hip flexion, F90: 90° hip flexion, F110: 110° hip flexion,

324 AD0: 0° hip adduction, AD20: 20° hip adduction, AD40: 40° hip adduction,

325 IR: hip internal rotation, ER: hip external rotation

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Figure Captions

Figure 1. An example of the shear elastic modulus colormap image

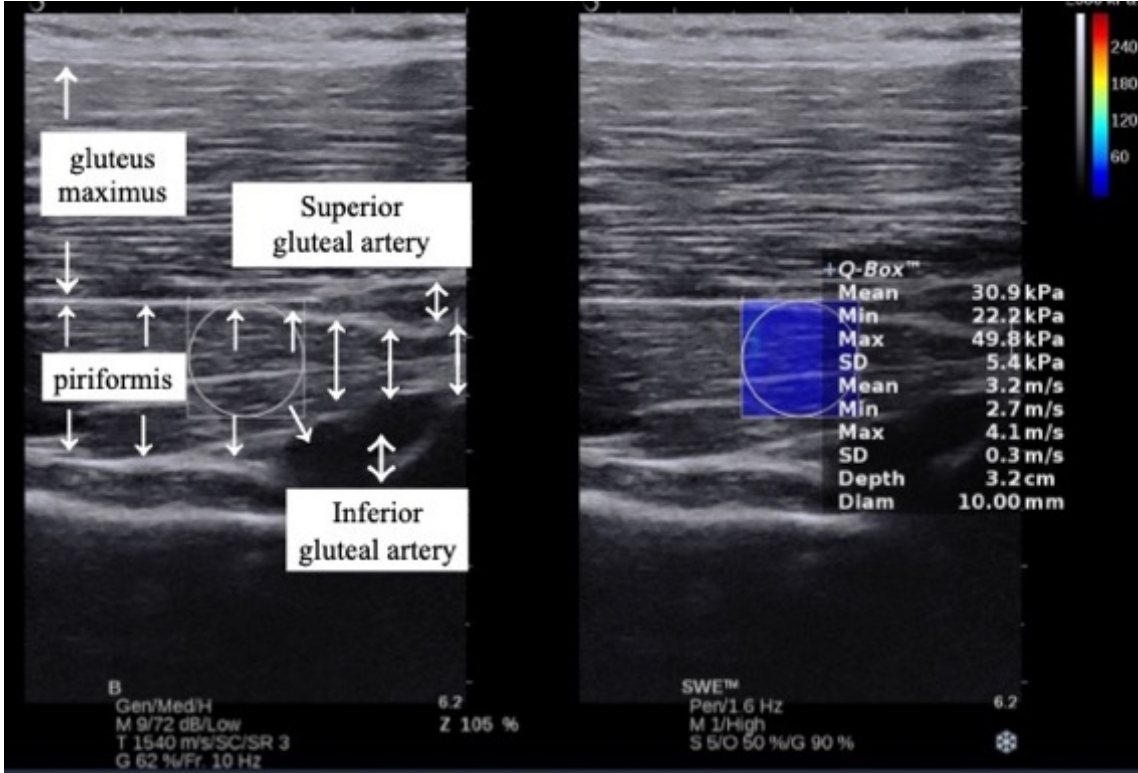
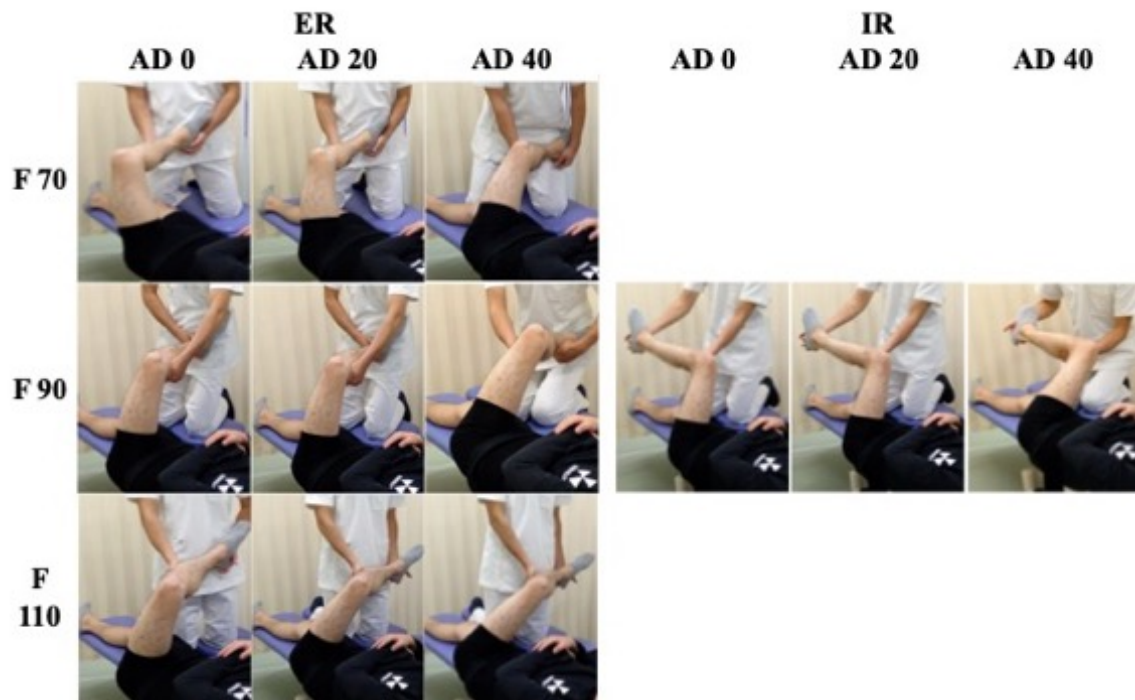
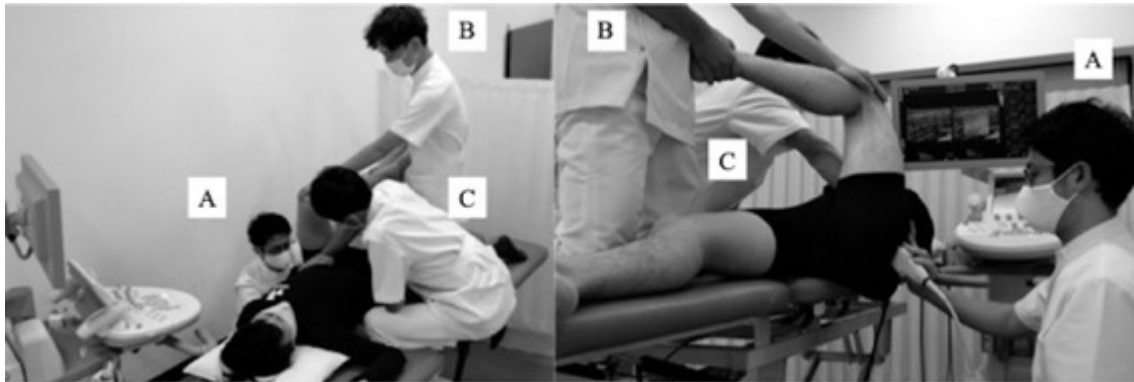


Figure 2. Stretching positions



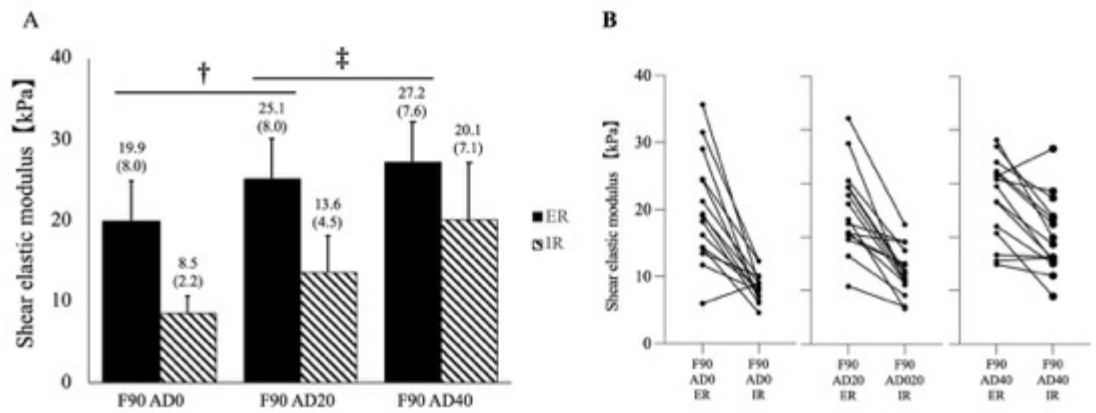
F70: 70° hip flexion, F90:90° hip flexion, F110: 110° hip flexion, AD0: 0° hip adduction, AD20: 20° hip adduction, AD40: 40° hip adduction, ER: hip external rotation, IR: hip internal rotation

Figure 3. Experimental setup



To prevent compensatory movement, the pelvis was fixed to the bed with a belt. Same examiners performed all procedures: the first examiner (A) measured the elastic modulus of the piriformis muscle using the SWE, the second examiner (B) performed stretching, and the third examiner (C) fixed the pelvis by hand in addition to fixing it with a belt.

Figure 4. Changes in the shear elastic modulus during hip adduction and internal/external rotation (in 90° hip flexion)



A. Comparison of the shear elastic modulus (kPa) using the post-hoc test for internal/external rotation. **B.** Individual changes in shear elastic modulus during hip adduction and internal/external rotation (in 90° hip flexion).

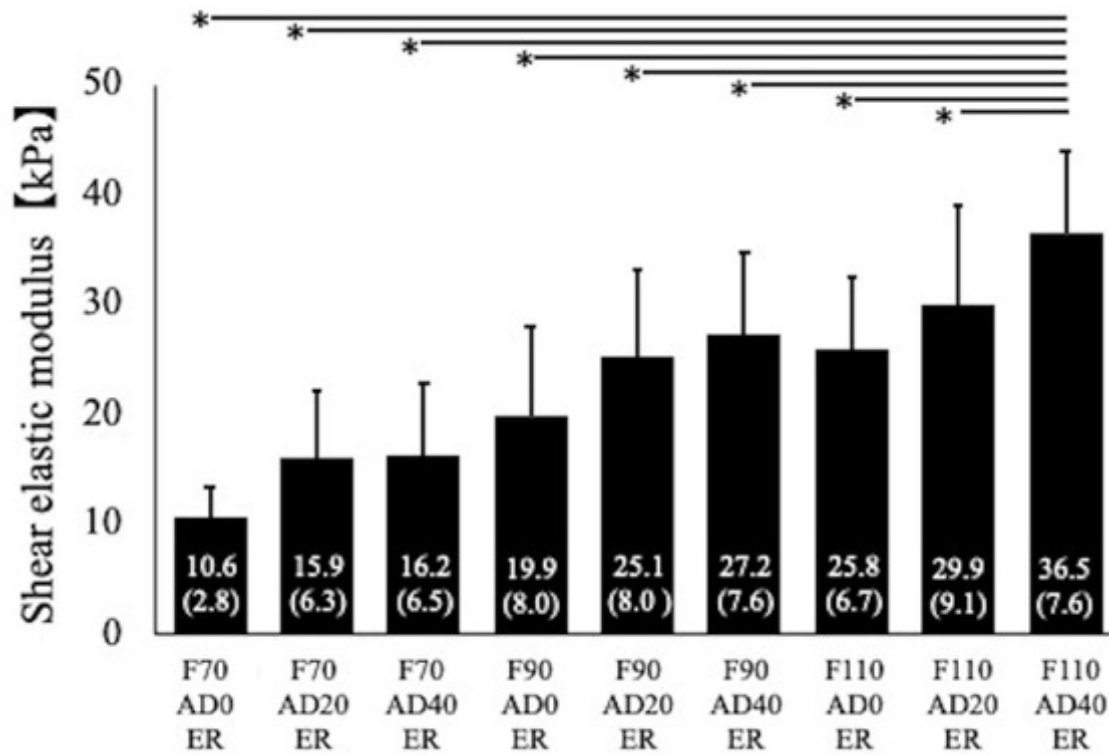
F90: 90° hip flexion, AD0: 0° hip adduction, AD20: 20° hip adduction, AD40: 40° hip adduction, ER: external rotation, IR: internal rotation

† Significant difference between AD0 and AD20 ($p < 0.01$).

‡ Significant difference between AD20 and AD40 ($p < 0.05$)

There was a significant main effect between each level of hip adduction and rotation angle without any interaction effect.

Figure 5. Shear elastic modulus of the piriformis in each position (except for in hip internal rotation)



F70: 70° hip flexion, F90: 90° hip flexion, F110: 110° hip flexion

AD0: 0° hip adduction, AD20: 20° hip adduction, AD40: 40° hip adduction, ER: hip external rotation

* A significant difference between the results of the t-test with Bonferroni correction for F110 AD40 and other positions is shown ($p < 0.01$).