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Effects of the trunk position on muscle stiffness that reflects elongation of the lumbar erector spinae and multifidus muscles: an ultrasonic shear wave elastography study.

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1 Effects of the trunk position on muscle stiffness that reflects elongation of the lumbar erector spinae  
2 and multifidus muscles: an ultrasonic shear wave elastography study

3

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1    **Abstract**

2    **Purpose**   The present study aimed to clarify the effects of the trunk position on muscle stiffness that  
3    reflects elongation of the lumbar erector spinae and lumbar multifidus muscles using ultrasonic shear  
4    wave elastography (SWE).

5    **Methods**   The study included ten healthy men. The shear elastic modulus of the left lumbar erector  
6    spinae and lumbar multifidus muscles were evaluated using ultrasonic SWE. Measurement postures  
7    for the left lumbar erector spinae muscle were (1) prone position (Rest), (2) sitting position with the  
8    trunk flexed (Flexion), (3) the Flexion position adding right trunk lateral flexion (Flexion-Lateral  
9    Flexion), and (4) the Flexion position adding right trunk rotation (Flexion-Rotation 1). The left lumbar  
10   multifidus muscle were measured in positions (1)-(3), and (5) the Flexion position adding left trunk  
11   rotation (Flexion-Rotation 2).

12   **Results**   The shear elastic modulus of the lumbar erector spinae muscle in the Flexion-Lateral  
13   Flexion position was significantly higher than that in the Rest, Flexion, or Flexion-Rotation 1 positions.  
14   Shear elastic modulus of the lumbar multifidus muscle was similar in the Flexion, Flexion-Lateral  
15   Flexion, and Flexion-Rotation 2 positions, but significantly lower in the Rest position.

16   **Conclusions**   The results of the present study suggest that the lumbar erector spinae muscle is  
17   stretched effectively in the position adding trunk contralateral lateral flexion to flexion. The results  
18   also indicate that the lumbar multifidus muscle, which does not appear to be affected by adding trunk

1 contralateral lateral flexion or ipsilateral rotation to flexion, is stretched effectively in the trunk flexion

2 position.

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4 **Keywords** Paraspinal muscles • Muscle elongation • Muscle stiffness • Ultrasonography

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19 **Introduction**

1 Low back pain (LBP) can be attributed to several factors, such as intervertebral disks, intervertebral  
2 joints, ligaments, nerves, vertebral body, and lumbar back muscles, while there is a substantial  
3 incidence of non-specific LBP with unknown pathologies (Oliveira et al. 2018). Our previous study  
4 (Masaki et al. 2017) using ultrasonic shear wave elastography (SWE) demonstrated that muscle  
5 stiffness of the lumbar multifidus muscle in the prone position is high while that of the lumbar erector  
6 spinae muscle is unchanged in LBP patients compared to healthy subjects. The results of that study  
7 suggested that LBP is associated with increased muscle stiffness of the lumbar multifidus muscle  
8 rather than muscle stiffness of the lumbar erector spinae muscle. Furthermore, because muscle  
9 shortening of the lumbar erector spinae muscle, caused by inactivity, leads to a decreased range of  
10 trunk motion, stretching of that muscle is performed to promote muscle lengthening (Moore et al.  
11 2015; Sherman et al. 2010). Thus, clarification of the effective stretching position of the lumbar erector  
12 spinae and multifidus muscles is significant in rehabilitation.

13 The lumbar erector spinae muscle, a member of the superficial muscles of the trunk, has a long  
14 moment arm (MA), which is the distance between the joint center and the muscle, for the trunk  
15 (Chaffin et al. 1990; Dumas et al. 1991; Jorgensen et al. 2001; Lin et al. 2001; Moga et al. 1993). The  
16 lumbar erector spinae muscle has the action of trunk extension, ipsilateral lateral flexion, and  
17 ipsilateral rotation. In general, the muscle is effectively stretched in positions opposite to the direction  
18 of the muscle action. In rehabilitation, the lumbar erector spinae muscle is frequently stretched in the

1 trunk flexion position (Moore et al. 2015; Sherman et al. 2010). However, considering its muscle  
2 action, the lumbar erector spinae muscle may be stretched effectively in the position adding  
3 contralateral lateral flexion or contralateral rotation to flexion. On the other hand, the lumbar  
4 multifidus muscle, a member of the deep muscles of the trunk, has a short MA for the trunk (McGill  
5 et al. 1993). The lumbar multifidus muscle has the action of trunk extension, ipsilateral lateral flexion,  
6 and contralateral rotation. Thus, the lumbar multifidus muscle may be stretched effectively in the  
7 position adding contralateral lateral flexion or ipsilateral rotation to flexion. However, it has been  
8 difficult to assess muscle elongation of the individual lumbar back muscle isolating subcutaneous fat  
9 and fibrous tissue quantitatively. Thus, the effective stretching position of the lumbar erector spinae  
10 and multifidus muscles remains unclear.

11 The quantitative assessment of muscle stiffness that reflects elongation of the individual muscle has  
12 become possible by the shear elastic modulus measured using SWE. The shear elastic modulus  
13 measured by SWE reflects muscle elongation such as the length of muscle-tendon units or passive  
14 muscle force in lower extremity muscles (Koo et al. 2013; Maïsetti et al. 2012), and is associated with  
15 upper extremity muscle strength (Ateş et al. 2015). The shear elastic modulus is a measure of muscle  
16 stiffness, which can be used as an indirect measure of muscle length or force generation in upper and  
17 lower extremity muscles. Previous studies (Moreau et al. 2016; Creze et al. 2017; Kelly et al. 2018),  
18 which targeted the lumbar back muscles, also demonstrated that the shear elastic modulus measured

1 using SWE is a feasible method for quantifying muscle stiffness of the lumbar erector spinae and  
2 multifidus muscles.

3 Furthermore, a previous study using SWE examined the effective stretching position by assessing  
4 muscle stiffness that reflects elongation of the upper extremity muscles such as the infraspinatus, teres  
5 minor, and deltoid muscles (Umehara et al. 2017a). Previous studies also demonstrated the effects of  
6 the upper or lower extremity position on muscle stiffness that reflects elongation of the upper extremity  
7 muscles such as pectoralis minor muscle (Umehara et al. 2017b), and the lower extremity muscles,  
8 such as the semitendinosus, biceps femoris (Umegaki et al. 2015) and tensor fasciae latae (Umehara  
9 et al. 2015) muscles. However, no previous study examined the effects of the trunk position on muscle  
10 elongation of the lumbar erector spinae or the multifidus muscles using SWE.

11 Therefore, the present study aimed to assess muscle stiffness that reflects elongation of the stretched  
12 lumbar erector spinae and multifidus muscles using SWE in healthy young men, and to identify the  
13 effects of the trunk position on muscle elongation of the lumbar back muscles. We hypothesized that  
14 the lumbar erector spinae muscle is effectively stretched in the position adding trunk contralateral  
15 lateral flexion or contralateral rotation to flexion, and the lumbar multifidus muscle is effectively  
16 stretched in the position adding contralateral lateral flexion or ipsilateral rotation to flexion.

17

18 **Methods**



1 Participants

2 Ten healthy young men (age,  $22.9 \pm 2.3$  years; body height,  $171.0 \pm 4.9$  cm; body weight,  $65.3 \pm 6.2$   
3 kg [mean  $\pm$  standard deviation]) in Kyoto University, Japan, were included in the present study. The  
4 subjects with LBP at the time of evaluation, severe orthopedic disorder other than LBP, neurological,  
5 respiratory or circulatory disorders in the present, or previous spinal surgery were excluded.

6 The protocol was approved by the Ethics Committee of the Kyoto University Graduate School and  
7 the Faculty of Medicine. Written informed consent was provided by all participants.

8

9 Priori sample size estimation

10 The sample size was calculated using G\*Power software, version 3.1.9.2 (Franz Faul, University of  
11 Kiel, Kiel, Germany). Power analysis demonstrated that the sample size needed for the present study  
12 was 10 subjects, with an effect size of 0.40, an  $\alpha$  error probability of 0.05, and a statistical power of  
13 0.80.

14

15 Ultrasound measurement

16 An ultrasound imaging device with SWE (Aixplorer, Supersonic Imagine, Aix-en-Provence, France)  
17 was utilized for muscle stiffness measurement that reflects elongation of the lumbar back muscles.

18 Longitudinal ultrasound images of the left lumbar erector spinae (iliocostalis lumborum) and

1 multifidus muscles were taken once using the B-mode of the ultrasound imaging device with a linear  
2 array probe (SuperLinear 10-2), which was laid parallel to the muscle fibers to assess muscle  
3 elongation accurately, as previously described (Masaki et al. 2017). The measurement site of the  
4 lumbar back muscles was 7 cm lateral from the L3 spinous process for the lumbar erector spinae  
5 muscle, and 2 cm lateral to the L4 spinous process for the lumbar multifidus muscle (Masaki et al.  
6 2017).

7 Measurement postures for muscle elongation of the left lumbar erector spinae muscle were as  
8 follows: (1) the prone position (Rest), (2) the sitting position with the hip and knee joints in full flexion  
9 beneath them and with the trunk position of 40-45° flexion to stretch for the lumbar back muscles  
10 (Flexion), (3) the Flexion position adding 30° right trunk lateral flexion (Flexion-Lateral Flexion), and  
11 (4) the Flexion position adding 30° right trunk rotation (Flexion-Rotation 1). Measurement postures  
12 for muscle elongation of the left lumbar multifidus muscle were as follows: (1) the Rest position, (2)  
13 the Flexion position, (3) the Flexion-Lateral Flexion position, and (5) the Flexion position adding 30°  
14 left trunk rotation (Flexion-Rotation 2). These positions were chosen on the assumption that the lumbar  
15 erector spinae and multifidus muscles would be stretched sufficiently in the positions opposite to the  
16 direction of muscle action.

17 The subjects maintained a relaxed state as much as possible while leaning against a stretch pole  
18 with towels placed under their stomach and against the assistance of a tester to maintain

1 measurement postures in the Flexion, Flexion-Lateral Flexion, and Flexion-Rotation positions.  
2 Another tester operated a linear array probe of an ultrasound imaging device (Fig.1). Trunk angle in  
3 measurement postures was set using a goniometer. Measurement postures were assigned in a random  
4 order to each subject.

5 The shear elastic modulus of the lumbar erector spinae and multifidus muscles was evaluated by  
6 measuring the shear wave propagation speed in the tissues generated using SWE in each  
7 measurement posture (Fig. 2). In analyses for muscle elongation, the circular regions of interest  
8 (ROIs) were set manually in the color-coded box presentation (approximately 3 cm × 3 cm) on a B-  
9 mode ultrasound imaging. Three ROIs with a diameter of 10 mm were set in the color-coded box,  
10 with one located at the center of the box and the other two inferior to the initial ROI. The mean shear  
11 elastic modulus values in each ROI and the mean values of the three ROIs were calculated.

12 Furthermore, the shear elastic modulus from the muscle mass density and the shear wave  
13 propagation speed is computed (Aubry et al. 2013). The enhanced shear elastic modulus indicates  
14 high muscle elongation. Intraclass correlation coefficients (ICC 1.1) for the lumbar erector spinae  
15 muscle and lumbar multifidus muscle in one measurement of the shear elastic modulus using SWE  
16 were 0.784 and 0.913, respectively, which are high values (Masaki et al. 2017). The ROIs were  
17 determined by the same examiner. The shear elastic modulus was automatically calculated from an  
18 ultrasound imaging device.

1

2    Statistical analyses

3    Statistical analysis was performed using SPSS version 20.0 (IBM Japan; Tokyo, Japan). The  
4    differences in the shear elastic modulus of the lumbar erector spinae and lumbar multifidus muscles  
5    in each measurement posture were analyzed by repeated-measures analysis of variance or Friedman  
6    tests after normality of the variable was examined by Shapiro-Wilk tests. If a significant primary  
7    effect was found, pairwise comparisons were performed by post hoc Bonferroni or Bonferroni  
8    correction using Wilcoxon signed-rank test. *P* values of <0.05 were considered statistically  
9    significant. *P* values from Wilcoxon signed-rank test were multiplied by 6 in Bonferroni correction.

10

11    **Results**

12    Repeated-measures analysis of variance and Friedman test showed that there was a significant primary  
13    effect on measurement posture in the lumbar erector spinae and lumbar multifidus muscles. Following  
14    post hoc multiple comparisons, the shear elastic modulus of the lumbar erector spinae muscle (Fig. 3)  
15    in the Flexion (mean  $\pm$  standard deviation,  $13.7 \pm 4.2$  kPa; standard error, 1.3) and Flexion-Lateral  
16    Flexion (mean  $\pm$  standard deviation,  $20.3 \pm 8.4$  kPa; standard error, 2.6) positions was shown to be  
17    significantly higher than that in the Rest position (mean  $\pm$  standard deviation,  $5.0 \pm 1.1$  kPa; standard  
18    error, 0.3) (Rest  $\times$  Flexion;  $p < 0.01$ , Rest  $\times$  Flexion-Lateral Flexion;  $p < 0.01$ ). Furthermore, the shear

1 elastic modulus of the lumbar erector spinae muscle in the Flexion-Lateral Flexion position was  
2 significantly higher than that in the Flexion and Flexion-Rotation 1 positions (mean  $\pm$  standard  
3 deviation,  $9.2 \pm 2.7$  kPa; standard error, 0.8) (Flexion  $\times$  Flexion-Lateral Flexion;  $p = 0.03$ , Flexion-  
4 Lateral Flexion  $\times$  Flexion-Rotation 1;  $p < 0.01$ ). No significant difference was seen in the other  
5 comparisons (Rest  $\times$  Flexion-Rotation 1;  $p = 0.36$ , Flexion  $\times$  Flexion-Rotation 1;  $p = 0.30$ ).

6 The shear elastic modulus of the lumbar multifidus muscle (Fig. 4) in the Flexion (mean  $\pm$  standard  
7 deviation,  $30.5 \pm 9.5$  kPa; standard error, 3.0), Flexion-Lateral Flexion (mean  $\pm$  standard deviation,  
8  $26.0 \pm 6.4$  kPa; standard error, 2.0), and Flexion-Rotation 2 (mean  $\pm$  standard deviation,  $27.5 \pm 12.8$   
9 kPa; standard error, 4.0) positions was significantly higher than that in the Rest position (mean  $\pm$   
10 standard deviation,  $5.8 \pm 1.6$  kPa; standard error, 0.5) (Rest  $\times$  Flexion;  $p = 0.03$ , Rest  $\times$  Flexion-Lateral  
11 Flexion;  $p = 0.03$ , Rest  $\times$  Flexion-Rotation 2;  $p = 0.03$ ). No significant difference was seen in the other  
12 comparisons, and there was no significant difference in the shear elastic modulus of the lumbar  
13 multifidus muscle between the Flexion, Flexion-Lateral Flexion, and Flexion-Rotation 2 positions  
14 (Flexion  $\times$  Flexion-Lateral Flexion;  $p = 0.99$ , Flexion  $\times$  Flexion-Rotation 2;  $p = 0.99$ , Flexion-Lateral  
15 Flexion  $\times$  Flexion-Rotation 2;  $p = 0.99$ ).

16

## 17 Discussion

18 We assessed muscle stiffness that reflects elongation of the lumbar erector spinae and multifidus

1 muscles in a variety of the trunk position in healthy young men. In the present study, the lumbar erector  
2 spinae muscle was stretched effectively in the position adding contralateral lateral flexion to flexion,  
3 which was consistent with our hypothesis. On the other hand, the shear elastic modulus of the lumbar  
4 multifidus muscle was not affected by adding trunk contralateral lateral flexion or ipsilateral rotation  
5 to flexion, but was stretched effectively in the trunk flexion position. These results are not consistent  
6 with our hypothesis. To the best of our knowledge, the present study is the first to assess muscle  
7 stiffness that reflects elongation of the stretched lumbar erector spinae and multifidus muscles  
8 individually and quantitatively, by using SWE in healthy young men, and to clarify the effects of the  
9 trunk position on muscle elongation of the lumbar back muscles.

10 The lumbar erector spinae muscle, a member of the superficial muscles of the trunk, is capable of  
11 generating the extension moment due to the long distance between the joint center and the muscle, and  
12 has a long extension moment arm (MA) for the trunk (Chaffin et al. 1990; Dumas et al. 1991;  
13 Jorgensen et al. 2001; Lin et al. 2001; Moga et al. 1993). A previous study (McGill et al. 1993)  
14 demonstrated that extension MA and ipsilateral lateral flexion MA for the trunk of the lumbar erector  
15 spinae muscle measured in the lumbar spine were  $6.1 \pm 0.6$  cm and  $2.2 \pm 0.4$  cm, respectively. These  
16 findings suggest that although ipsilateral lateral flexion MA of the lumbar erector spinae muscle is  
17 shorter than extension MA, the muscle acts as trunk ipsilateral lateral flexor. This observation is  
18 consistent with our results that the lumbar erector spinae muscle is more stretched in the position

1 adding trunk contralateral lateral flexion to flexion, which is opposite to the muscle action.

2 On the other hand, we initially hypothesized that muscle elongation of lumbar erector spinae muscle

3 might also be higher in the Flexion-Rotation 1 position, which is the position of trunk contralateral

4 rotation, because this muscle has ipsilateral rotation MA (i.e. acts as ipsilateral rotator) of the trunk.

5 However, muscle elongation of the lumbar erector muscle in the Flexion-Lateral Flexion position was

6 significantly higher than that in the Flexion-Rotation 1 position. This observation suggests that the

7 lumbar erector spinae muscle was stretched effectively in the position adding trunk contralateral lateral

8 flexion rather than contralateral rotation to flexion. A previous study (Maganaris et al. 2000)

9 demonstrated that the MA of the muscle is calculated by dividing the stretched amount of muscle-

10 tendon unit by the change of joint angle using the tendon-excursion methods. Based on that study, it

11 is assumed that the muscle-tendon unit is more stretched when the MA of the muscle is longer or the

12 change in joint angle is higher. Although no study has examined the ipsilateral rotation MA for the

13 trunk of the lumbar erector spinae muscle, we postulate that it may be shorter than the ipsilateral lateral

14 flexion MA. Thus, it is assumed that the lumbar erector spinae muscle was stretched effectively in the

15 position adding trunk contralateral lateral flexion rather than the contralateral rotation to flexion. In

16 rehabilitation, the stretching method for the lumbar erector spinae muscle is generally performed using

17 the trunk flexion position (Moore et al. 2015; Sherman et al. 2010). However, the results of the present

18 study show that the lumbar erector spinae muscle is stretched effectively in the position adding trunk

1 contralateral lateral flexion to flexion rather than the trunk flexion position or the position adding trunk  
2 contralateral rotation to flexion. The results of the present study also show that this is only a unilateral  
3 effect, and the lumbar erector spinae muscle during trunk contralateral rotation likely do not  
4 experience any added benefits.

5 Trunk extension and ipsilateral lateral flexion MA for the trunk of the lumbar multifidus muscle, a  
6 member of the deep muscle of the trunk, are shorter than those of the superficial muscles of the trunk,  
7 such as the lumbar erector spinae muscle (McGill et al. 1993). Although the lumbar multifidus muscle  
8 is advantageous in stabilizing the lumbar spine by increasing the compressive force (Bergmark. 1989;  
9 MacDonald et al. 2006), it is disadvantageous for generating the joint movement. A previous study  
10 (McGill et al. 1993) demonstrated that the extension MA ( $5.5 \pm 0.7$  cm) for the trunk of the lumbar  
11 multifidus muscle measured in the lumbar spine is shorter than the extension MA ( $6.1 \pm 0.6$  cm) for  
12 the trunk of the lumbar erector spinae muscle, although the extension MA for the former muscle is  
13 comparatively long. The lumbar multifidus muscle has the action of ipsilateral lateral flexion and  
14 contralateral rotation of the trunk. However, the ipsilateral lateral flexion MA ( $1.1 \pm 0.1$  cm) for the  
15 trunk of the lumbar multifidus muscle measured in the lumbar spine is shorter than the extension MA  
16 ( $5.5 \pm 0.7$  cm) for the trunk, and the ipsilateral lateral flexion MA for the trunk is short (McGill et al.  
17 1993). Furthermore, although no previous study has described the trunk rotation MA of the lumbar  
18 multifidus muscle, the contralateral rotation MA may be shorter than the extension MA. Thus, it is



1 assumed that the lumbar multifidus muscle was not stretched effectively in the position adding  
2 contralateral lateral flexion or ipsilateral rotation to flexion. The results of the present study clarified  
3 that the lumbar multifidus muscle is stretched effectively in the trunk flexion position without adding  
4 trunk contralateral lateral flexion or ipsilateral rotation.

5 There are several limitations in the present study. First, the shear elastic modulus measured by SWE  
6 assessed muscle stiffness that reflects elongation but not directly muscle elongation. Second, as the  
7 present study included only young men, it is unclear if the results can be applied to other age and sex  
8 groups. Third, we did not assess muscle elongation of the lumbar back muscles in the trunk flexion  
9 position adding trunk lateral flexion and rotation to flexion simultaneously. Fourth, although we  
10 examined the effects of the trunk position on muscle elongation of the lower back muscle in healthy  
11 subjects, performing stretching of the lumbar back muscle, proposed in the present study, requires  
12 attention in athletes (Hangai et al. 2009; Kaneoka et al. 2007) and elderly individuals (Hangai et al.  
13 2008) with degenerative intervertebral discs.

14

## 15 **Conclusions**

16 The results of the present study suggest that the lumbar erector spinae muscle is stretched effectively  
17 in the position adding trunk contralateral lateral flexion to flexion. The results also indicate that the  
18 lumbar multifidus muscle is stretched effectively in the trunk flexion position and is not affected by

1 adding trunk contralateral lateral flexion or ipsilateral rotation to flexion.

2

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6 **Compliance with ethical standards**

7 **Conflicts of interest** On behalf of all authors, the corresponding author states that there is no conflict

8 of interest. No funding sources were used for the present study.

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4

## 5 **Abbreviations**

6 ICC Intraclass correlation coefficient

7 LBP Low back pain

8 MA Moment arm

9 ROI Region of interest

10 SWE Shear wave elastography

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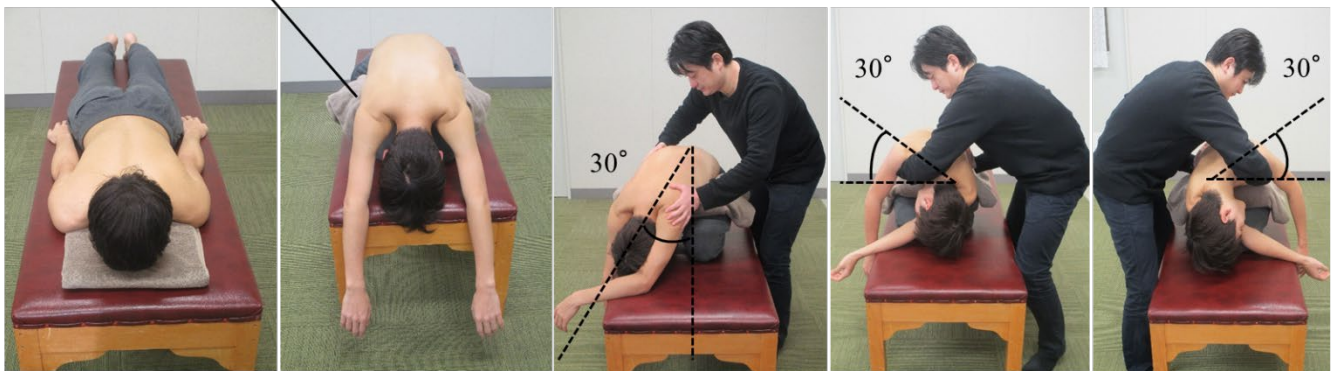
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Stretch pole  
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Bath towels



Rest Flexion Flexion-Lateral Flexion Flexion-Rotation 1 Flexion-Rotation 2

Fig. 1 Muscle stiffness measurement that reflects elongation of the lumbar back muscles in the Flexion, Flexion-Lateral Flexion, and Flexion-Rotation positions.



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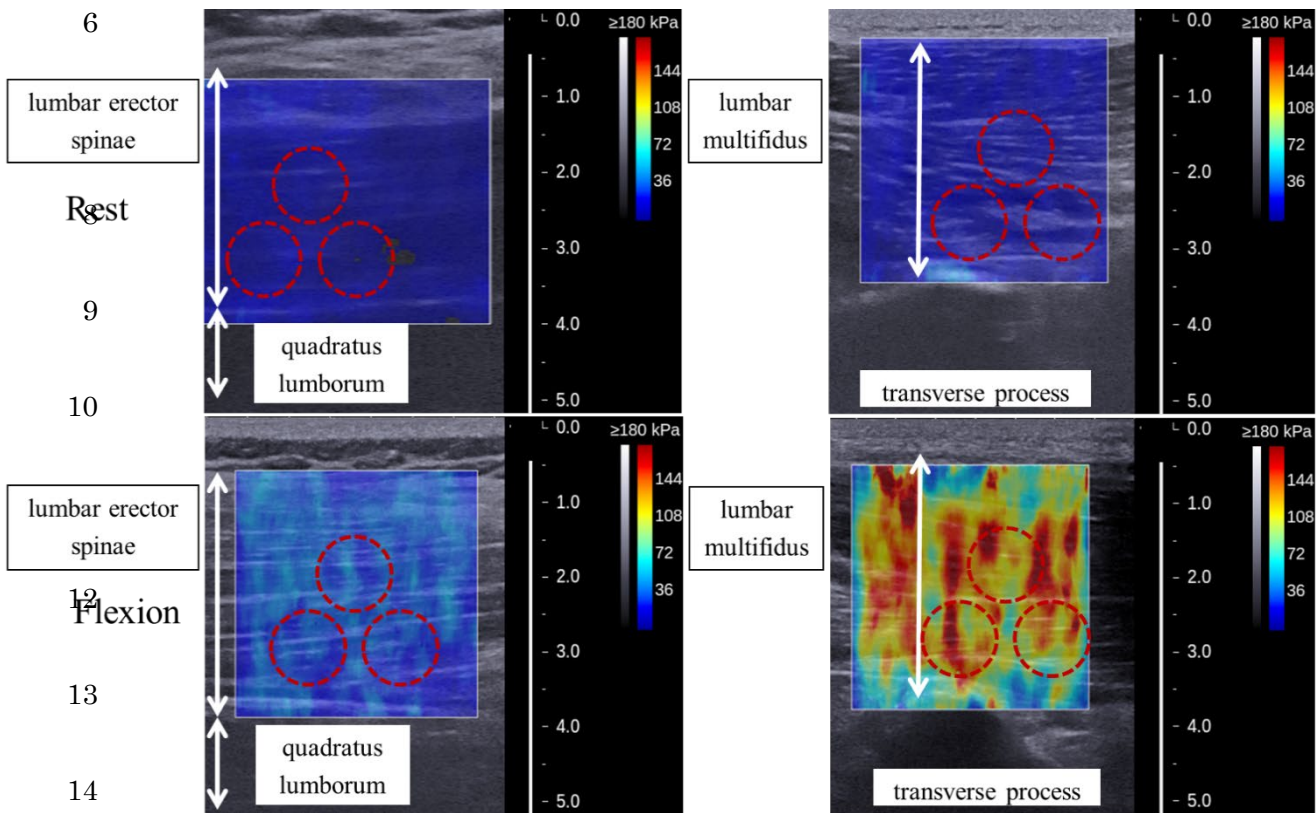
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15 Fig. 2 Muscle stiffness measurement that reflects elongation of the lumbar back muscles in the Rest

16 and Flexion positions.

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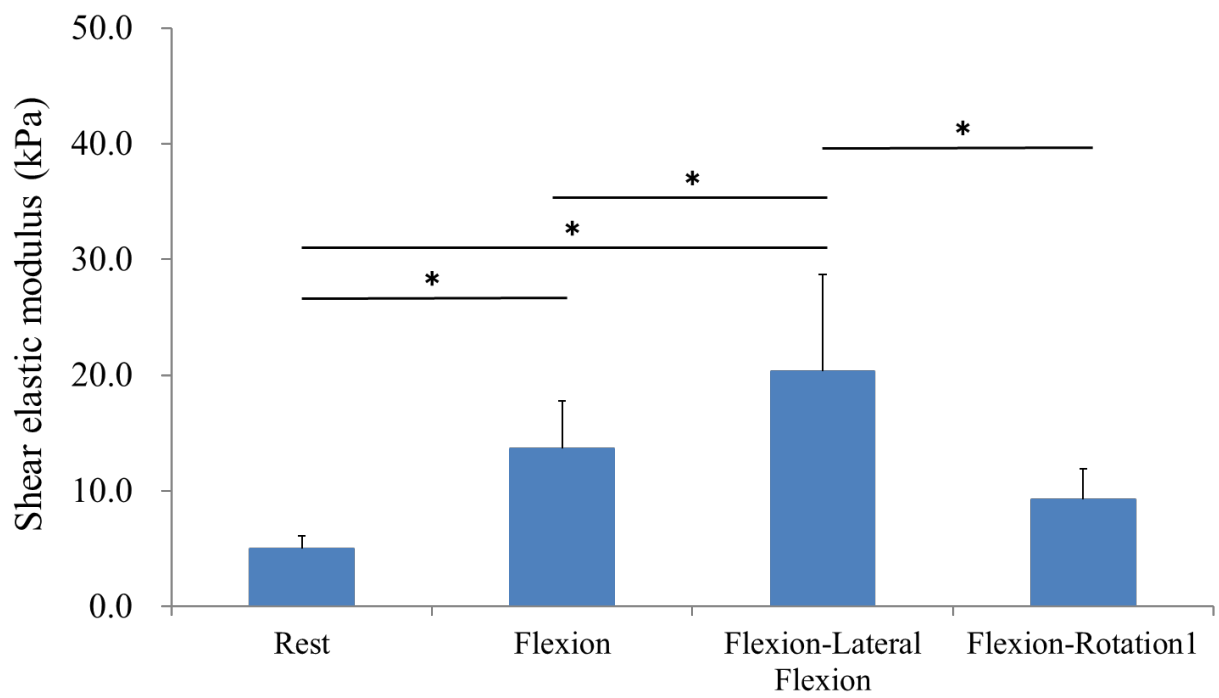
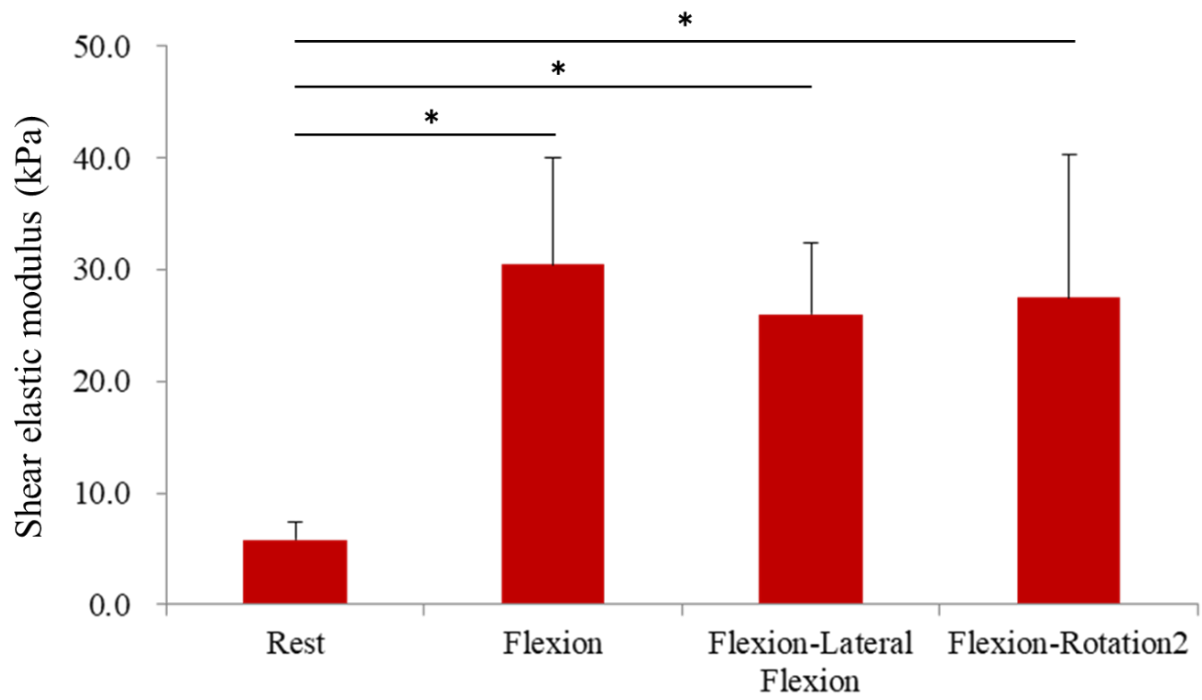


Fig. 3 The shear elastic modulus of the lumbar erector spinae muscle in each measurement posture.

Error bar: standard deviation.

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13 Fig. 4 The shear elastic modulus of the lumbar multifidus muscle in each measurement posture.

14 Error bar: standard deviation.