Title page

Effective stretching position for the posterior deltoid muscle evaluated by shear wave elastography

Running title: Stretching position for posterior deltoid muscle

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Stretching position for posterior deltoid muscle

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Abstract

Background: Deteriorated extensibility of the posterior deltoid muscle is one of the factors of posterior shoulder tightness, and improvement in its extensibility is needed. However, no study has investigated which shoulder positions effectively stretch the posterior deltoid muscle in vivo. The aim of this study was to verify the effective stretching position of the posterior deltoid muscle in vivo using shear wave elastography.

Methods: Fifteen healthy men participated in this study. The shear modulus of the posterior deltoid was measured at resting and 13 stretching positions: 60°, 90°, and 120° shoulder flexion; maximum shoulder flexion, horizontal adductions at 60°, 90°, and 120° shoulder flexion; internal rotations at 60°, 90°, and 120° shoulder flexion; and combinations of horizontal adduction with internal rotation at 60°, 90°, and 120° shoulder flexion. The shear moduli of each stretching position were compared to those of the rest. Then, among the stretching positions for which the shear modulus was significantly different from the rest, the shear moduli were compared using a three-way analysis of variance with repeated measures of the three factors—flexion, horizontal adduction, and internal rotation.

Results: The shear moduli in all stretching positions were significantly higher than those of the rest, except for maximum shoulder flexion. The three-way analysis of variance with repeated measures revealed significant main effects in flexion and horizontal adduction. Comparing the flexion angles, the shear modulus was significantly higher at 90° than that at

60° and 120°. The shear modulus with horizontal adduction was significantly higher than that without horizontal adduction. Moreover, a significant two-way interaction was found only at flexion and horizontal adduction. The shear modulus with horizontal adduction was significantly higher at all angles than that without horizontal adduction at each flexion angle. Comparing the flexion angles with horizontal adduction, the shear modulus was significantly higher at 90° than that at 60° and 120°. No significant three-way interactions were found.

Conclusion: Shoulder flexion and horizontal adduction affected the extensibility of the posterior deltoid muscle, whereas the effect of shoulder internal rotation was limited. More precisely, maximal horizontal adduction at 90° shoulder flexion was the most effective stretching position for the posterior deltoid muscle.

(356/400 words)

Level of evidence: Basic Science Study

Keywords: Posterior deltoid muscle; Posterior shoulder tightness; Rehabilitation; Stretching; Elastography; Overhead athletes

1 Introduction

Overhead athletes such as baseball and tennis players are susceptible to posterior shoulder tightness.[19] Posterior shoulder tightness causes deficits in shoulder internal rotation and horizontal adduction, which is related to shoulder internal impingement during shoulder external rotation at abduction position by deviating the humeral head on the glenoid fossa[15,17,23] and may consequently induce shoulder pain.[7] Among the factors of posterior shoulder tightness, deteriorated extensibility of the posterior shoulder muscle/tendon constituted by the infraspinatus, the teres minor, and the posterior deltoid (PD) muscle/tendon is fully addressed in rehabilitation.[7,9] More precisely, as the PD muscle is damaged by repetition of pitching,[8] conditioning and intervention are crucial for the improvement of PD muscle extensibility.

Static stretching is a common method to improve muscle extensibility. According to previous cadaveric studies, horizontal adduction at 60° glenohumeral (GH) joint flexion was more effective for the PD muscle than that in the GH neutral position and internal rotation at 0°, 30°, and 60° GH flexion and abduction.[10,18] However, these studies did not verify GH flexion beyond 60° or combined internal rotation with horizontal adduction for the PD muscle stretching procedures. Although cadaveric studies provided knowledge of the PD muscle stretching positions, the range of motion (ROM) of the shoulder joint and mechanical characteristics of muscles could differ from those in vivo. Additionally, the stretching position for the PD muscle in vivo was still unclear because, in the previous cadaveric studies, the scapula was fixed on the experimental pole during measurement of muscle lengthening, and the scapulothoracic joint movement was not considered. For in vivo studies, muscle elongation could not be evaluated individually using traditional measurements such as ROM,[4,22] passive torque, or extensibility,[6,16] because the traditional methods for estimating muscle elongation in vivo may be affected by factors such as other muscles, ligaments and the capsule crossing the joint, consequently making it difficult to evaluate the stretching position of the PD muscle.

Shear wave elastography (SWE) allows noninvasive and reliable measurement of individual muscle elasticity.[13] In this way, the shear modulus can be calculated based on the speed of the shear wave generated by an acoustic radiation force.[3] Previous studies investigated a strong exponential relationship between muscle strain measured by traditional methods and the shear modulus measured using ultrasonic SWE.[5] Therefore, ultrasonic SWE is an appropriate technology to investigate changes in individual muscle elongation in vivo.[25]

This study aimed to verify the effective stretching position of the PD muscle by determining whether shoulder flexion, horizontal adduction, and internal rotation and their combined motions change the shear modulus of the PD muscle using SWE. Considering the previous cadaveric studies[10,18] mentioned above and the scapulohumeral rhythm, the horizontal adduction at 90° shoulder flexion would be a more effective stretching position for the PD muscle. Considering that the PD muscle has the moment arm of shoulder external rotation[2] in terms of kinesiology and anatomy, we hypothesized that combining horizontal adduction and internal rotation with 90° shoulder flexion was the most effective stretching position for the PD muscle.

2 Material and Methods

2.1 Subjects

This was a controlled laboratory study where the effective stretching position of the PD muscle was investigated. Fifteen healthy men participated in this study (age, 22.4 ± 1.54 years; height, 171.4 ± 5.39 cm; weight, 60.4 ± 7.59 kg). None of the subjects had pain or limitations in their nondominant shoulders. We used G*Power 3.1 (Heinrich Heine University, Düsseldorf, Germany) to calculate the sample size for a t-test model with repeated measures (effect size = 0.8, α-error = 0.05, power = 0.8), considering a previous study with the same procedure.[25] It showed that 15 participants secured the statistical power. The PD muscle in their nondominant upper limb was used for the stretching and ultrasound measurements, in which the dominant limb was defined as the one they usually used in throwing a ball. The aim and procedures were explained to all participants and written informed consent was obtained from all participants. The study protocol conformed to the Helsinki Declaration and was approved by the Kyoto University Graduate School and Faculty of Medicine Ethics Committee (approval number R0233-9).

2.2 Experimental procedures

Two investigators conducted all the procedures throughout the experiment. One investigator measured the shear modulus using SWE, while the other performed stretching. The shear modulus of the PD muscle was measured during the resting and 13 stretching positions as shown in Figure 1: (a) rest (0° shoulder flexion/extension, abduction/adduction, and external/internal rotation), (b) 60° shoulder flexion (F60), (c) 90° shoulder flexion (F90), (d) 120° shoulder flexion (F120), (e) maximum flexion (Fmax), (f) horizontal adduction at 60° shoulder flexion (F60Had), (g) horizontal adduction at 90° shoulder flexion (F90Had), (h) horizontal adduction at 120° shoulder flexion (F120Had), (i) internal rotation at 60° shoulder flexion (F60IR), (j) internal rotation at 90° shoulder flexion (F90IR), (k) internal rotation at 120° shoulder flexion (F120IR), (l) horizontal adduction and internal rotation at 60° shoulder flexion (F60HadIR), (m) horizontal adduction and internal rotation at 90° shoulder flexion (F90HadIR), and (n) horizontal adduction and internal rotation at 120° shoulder flexion (F120HadIR). Each participant laid on the bed in a side-lying position, with the dominant upper limb under their trunk for the resting position, and in a supine position for the stretching positions. Horizontal adduction and internal rotation stretching were performed at the maximum angle that the participants could achieve without discomfort or pain. The maximal angles were measured using a manual goniometer. Measurements at positions of rest, F60, F90, F120, Fmax, F60Had, F90Had, and F120Had were performed with the elbow fully extended while at the positions of F60IR, F90IR, F120IR, F60HadIR, F90HadIR, and F120HadIR they were performed with elbow flexion at 90°.

Particular care was taken to keep the participants relaxed during the stretching procedures, with the investigator supporting the participants' arms. Except for the resting position, which was measured first, the stretching positions were performed randomly to avoid any effect of the measurement sequence. A computerized random number function in Microsoft Excel (Microsoft Japan Co., Ltd., Japan) was used for randomization.

2.3 Measurement of shear modulus

The shear modulus of the PD muscle was measured using an ultrasound system on SWE mode (Aixplorer v12.2, SuperSonic Imagine, Aix-en-Provence, France) with a linear probe (2–10 MHz, SuperLinear SL10-2). The musculoskeletal preset (muscle mode) was used with the following parameters: penetration mode, frequency, 1.7 Hz; smoothing level, five, persistence high; opacity, 100%; and gain, 90%. The shear modulus (G) was calculated from the shear wave speed (V) using the following equation:

$$G = \rho V^2$$

where ρ is the muscle mass density (1,000 kg/m^3).[20] We interpreted that the higher the shear modulus, the greater the PD muscle stretching in this study. As in a previous study,[24] the muscle belly was identified on the transverse B-mode image at 4 cm below the posterior acromial angle. Then, the probe was rotated parallel to the muscle fascicle, and longitudinal SWE images were taken after avoiding the humeral head region to avoid artifacts caused by ultrasound echoes (Fig. 2). A region of interest (ROI) of length 1 cm × width 2 cm was set at the center of the PD muscle belly, and a circle with a 1-cm diameter was set within the ROI. The average shear wave propagation velocity within this circle was calculated (Fig. 3). The SWE images were captured thrice at each stretching position, and the mean values were used for analysis. After the measurement in all positions, the shear modulus of the PD muscle was measured at the resting position to ensure that the shear modulus did not change before and after all stretching procedures.

2.4 Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics software (version 22; IBM, Armonk, NY, USA). For the reliability of the measurement, the interclass correlation coefficient was calculated from three measurements of each stretching position ($ICC_{1,3}$). The Shapiro–Wilk test was performed to confirm the normality of the data. The results revealed that normality of the data was not confirmed for F120Had, F60IR, and F120HadIR ($p <$ 0.001, $p < 0.001$, $p = 0.025$). The shear moduli of each stretching position were compared with those of the rest using the Wilcoxon test with Bonferroni correction to ensure that the PD muscle in each stretching position was lengthened beyond that of the rest. Further analysis was performed among the stretching positions in which the shear modulus was significantly different from the rest. The shear modulus was compared using a three-way analysis of variance (three-way ANOVA) with repeated measures to verify which factor influenced the extensibility of the PD muscle and which stretching position was the most effective for the PD muscle. The three factors were flexion (Flex), horizontal adduction

(Had), and internal rotation (IR). A significance level of 0.05 was used in all statistical tests.

In this study, normality was not confirmed in some of the data. Therefore, we used non-parametric statistics to compare the shear moduli of each stretching position with those of the rest. The shear modulus was then compared using a three-way ANOVA with repeated measures. Although ANOVA is generally used for parametric analysis, it is also a robust method for non-parametric analysis.[21]

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3 Result

3.1 The range of motion and electromyography

The ranges of motion for maximum shoulder flexion, horizontal adduction, and internal rotation are shown in Table I.

3.2 Reliability of measurement

The $ICC_{1,3}$ of the shear modulus for each stretching position is shown in Table II, representing a range from 0.773 to 0.995. A previous study suggested that the ranges of 0.61 to 0.80 and 0.81 to 1.00 indicated "substantial" and "almost perfect," respectively.[14] Therefore, the measured values of the shear modulus in this study were considered reliable.

3.3 The shear modulus

The shear modulus for each stretching position is shown in Figure 4, and the statistical values resulting from the three-way ANOVA with repeated measures are listed in Table III. The Wilcoxon test with Bonferroni correction demonstrated that the shear moduli were significantly higher than those at rest in F60 (p = 0.009), F90 (p = 0.010), F120 (p = 0.009), F60Had (p = 0.009), F90Had (p = 0.009), F120Had (p = 0.009), F60IR (p = 0.009), F90IR (p = 0.010), F120IR (p = 0.013), F60HadIR (p = 0.009), F90HadIR (p = 0.009), and F120HadIR (p = 0.009). However, there was no significant difference in shear modulus between the rest and Fmax (p =

0.843).

Next, a three-way ANOVA with repeated measures was performed for all stretching positions except Fmax. No significant three-way interactions were found (p = 0.233). A significant two-way interaction was found for Flex × Had (p < 0.001) but not for Flex × IR or Had × IR (p = 0.230, 0.372). Comparing with and without Had at each Flex angle, the shear modulus with Had was significantly higher than that without Had at all Flex angles (p < 0.001). Comparing the Flex angles under Had, the shear modulus was significantly higher at 90° than at 60° (p < 0.001) or 120° (p < 0.001).

Significant main effects were found for Flex (p = 0.001) and Had (p < 0.001) but not for IR (p = 0.206). Comparing the Flex angles, the shear modulus was significantly higher at 90° than at 60° (p = 0.001) and 120° (p < 0.001). Compared with and without Had, the shear modulus was significantly higher in those with Had (p < 0.001).

4 Discussion

This study investigated whether shoulder flexion, horizontal adduction, and internal rotation and their combined motions changed the shear modulus of the PD muscle and identified the effective stretching position of the PD muscle using SWE. The results revealed that the shear moduli of all stretching positions except for Fmax were significantly higher than those of the resting position. Moreover, a comparison was performed among the stretching positions for which the shear moduli were significantly higher than the rest. We found that shoulder flexion and horizontal adduction interactively influenced the shear modulus of the PD muscle, whereas shoulder internal rotation had less effect. These results partly supported our hypothesis that the combination of horizontal adduction and internal rotation at 90° shoulder flexion is the effective stretching position for the PD muscle. To the best of our knowledge, this is the first study to determine the effective stretching position of the PD muscle using SWE.

Identifying the recommended stretching position of the PD muscle is crucial for clinical applications. A two-way interaction was found only at flexion and horizontal adduction. The shear modulus with horizontal adduction was significantly higher than that without horizontal adduction at all flexion angles. By comparing the flexion angles during horizontal adduction, the shear modulus was significantly greater at 90° than that at 60° and 120°. These results suggest that shoulder horizontal adduction at 90° shoulder flexion is recommended as the effective stretching position of the PD muscle.

Muscle lengthening is related to the moment arm. Considering tendon excursion methods, by which the moment arm is defined as the partial deviation of muscle length with respect to the joint angle,[11] a muscle is theoretically lengthened by the joint movement opposite its moment arm. Although the PD muscle has the moment arm in shoulder extension, this moment arm decreases with the flexion angle.[1,12] Kuechle et al. reported that the PD muscle lost the moment arm of flexion/extension at around 70° GH flexion and then exhibited the moment arm of flexion with further flexion.[12] Conversely, Ackland et al. reported that the PD muscle still had the moment arm of extension at 120° shoulder flexion.[1] Our results reveal that the shear modulus of the PD muscle was higher at 90° shoulder flexion than that at 120°, which was in agreement with Kuechle's study. Additionally, the PD muscle has a moment arm of horizontal abduction at 90° shoulder flexion.[1] Although it also has an external rotation moment arm at shoulder neutral, flexion, and abduction positions, this moment arm is smaller than the shoulder extension or horizontal abduction moment arm.[1,2,12] Therefore, the PD muscle could be stretched effectively through horizontal adduction at 90° shoulder flexion, and shoulder internal rotation had less effect on the lengthening of the PD muscle. These results are reasonable because they are consistent with previous studies that indicated the effective stretching position of the PD muscle using a cadaveric shoulder.[10,18] While shoulder flexion beyond 90° and the combination of shoulder horizontal adduction with internal rotation have not been fully verified in previous studies, this study investigated their effects on the shear modulus of the PD muscle, thus ensuring novelty. Additionally, the stretching position of the cadaveric study did not include the scapulothoracic joint movement because the scapula was fixed on the experimental pole during the measurement of muscle lengthening. However, in this study, the experiment was performed in vivo without fixing the scapula. This method is more useful for application in clinical practice because it can take normal shoulder joint motion into account by performing stretching in vivo. Therefore, we believe that this study calls for a need to update previous findings and clinical practice.

The effective stretching position of the PD muscle can be useful in patients with posterior shoulder tightness due to shortening of the PD muscle. The stretching method of the PD muscle could also contribute to the clinical treatment of overhead athletes because stretching the PD muscle may contribute to decreasing and/or preventing posterior shoulder tightness.[9,19] From this perspective, we believe that our findings are clinically meaningful.

This study has some limitations. First, the scapula to which the PD muscle attaches was not stabilized during stretching. Therefore, we expect that the PD muscle can be stretched more effectively by manually stabilizing the scapula. Second, we investigated the effective stretching position, but not the acute/chronic intervention effects on PD muscle elasticity. Further studies that examine the acute and chronic intervention effects of PD muscle stretching in patients or overhead athletes are needed.

5 Conclusion

This study aimed to investigate the effective stretching position of the PD muscle using SWE. Consequently, shoulder flexion and horizontal adduction affected the extensibility of the PD muscle, whereas the effect of shoulder internal rotation was limited. More precisely, maximal horizontal adduction at 90° shoulder flexion was the most effective stretching position for the PD muscle.

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Figure legends

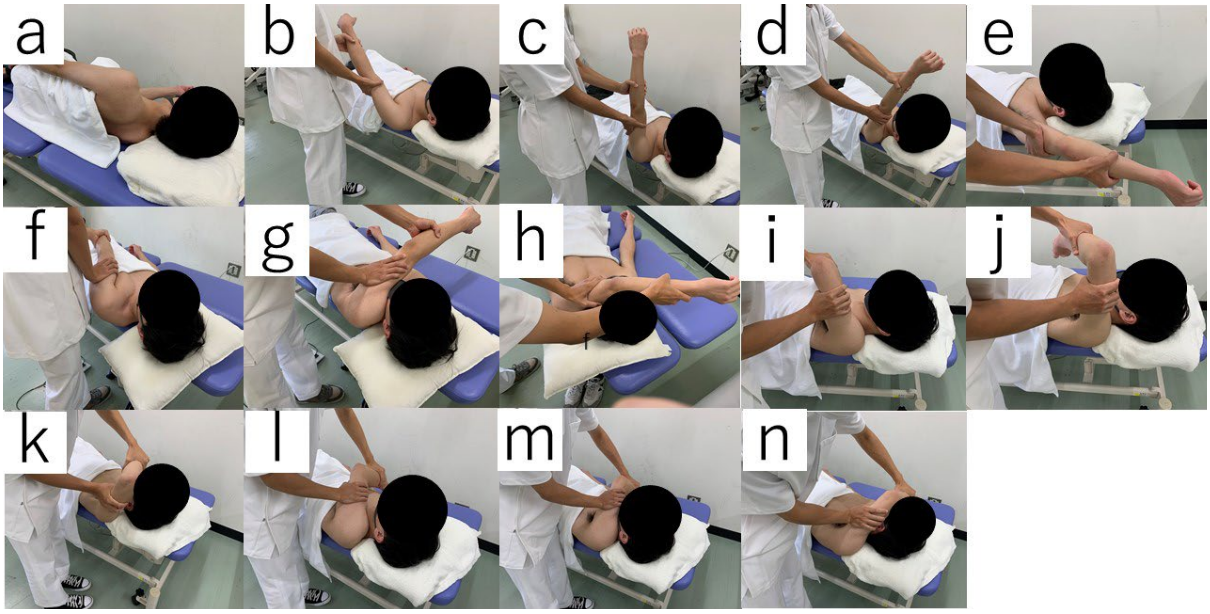

Figure 1. Arm positions

(a) rest (0° shoulder flexion/extension, abduction/adduction, external/internal rotation), (b) 60° shoulder flexion (F60), (c) 90° shoulder flexion (F90), (d) 120° shoulder flexion (F120), (e) maximum flexion (Fmax), (f) horizontal adduction at 60° shoulder flexion (F60Had), (g) horizontal adduction at 90° shoulder flexion (F90Had), (h) horizontal adduction at 120° shoulder flexion (F120Had), (i) internal rotation at 60° shoulder flexion (F60IR), (j) internal rotation at 90° shoulder flexion (F90IR), (k) internal rotation to 120° shoulder flexion (F120IR), (l) horizontal adduction and internal rotation at 60° shoulder flexion (F60HadIR), (m) horizontal adduction and internal rotation at 90° shoulder flexion (F90HadIR), and (n) horizontal adduction and internal rotation at 120° shoulder flexion (F120HadIR)

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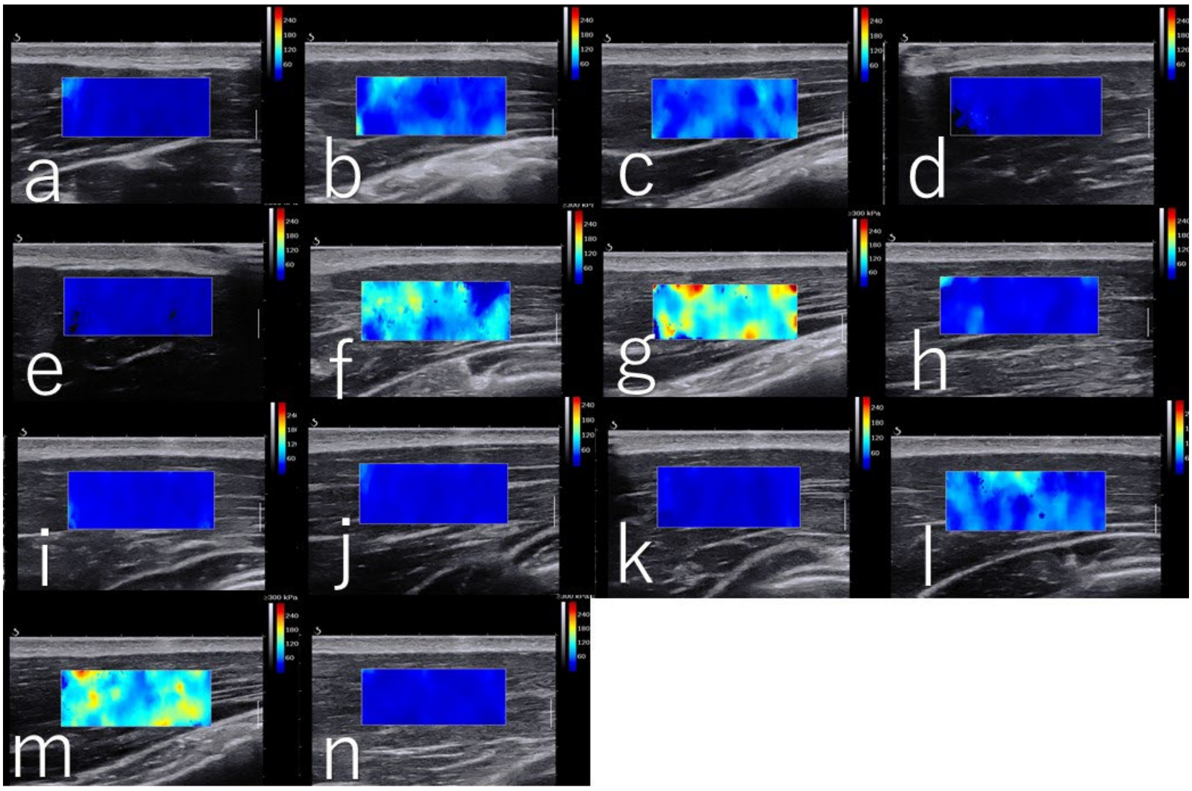

Figure 2. An image of the shear modulus

(a) rest (0° shoulder flexion/extension, abduction/adduction, external/internal rotation), (b) 60° shoulder flexion (F60), (c) 90° shoulder flexion (F90), (d) 120° shoulder flexion (F120), (e) maximum flexion (Fmax), (f) horizontal adduction at 60° shoulder flexion (F60Had), (g) horizontal adduction at 90° shoulder flexion (F90Had), (h) horizontal adduction at 120° shoulder flexion (F120Had), (i) internal rotation at 60° shoulder flexion (F60IR), (j) internal rotation at 90° shoulder flexion (F90IR), (k) internal rotation to 120° shoulder flexion (F120IR), (l) horizontal adduction and internal rotation at 60° shoulder flexion (F60HadIR), (m) horizontal adduction and internal rotation at 90° shoulder flexion (F90HadIR), and (n) horizontal adduction and internal rotation at 120° shoulder flexion (F120HadIR)

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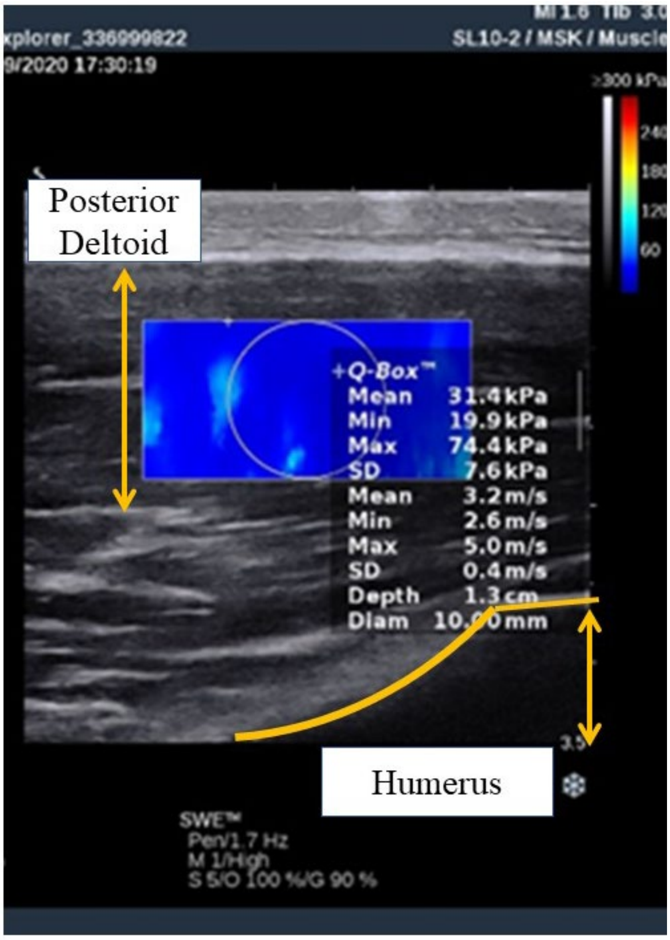

Figure 3. The image used for analysis

A region of interest (ROI) of 1 cm × 2 cm was set at the center of the PD muscle belly, and a circle with a 1-cm diameter was set within the ROI. The average shear wave propagation velocity within the circle was calculated

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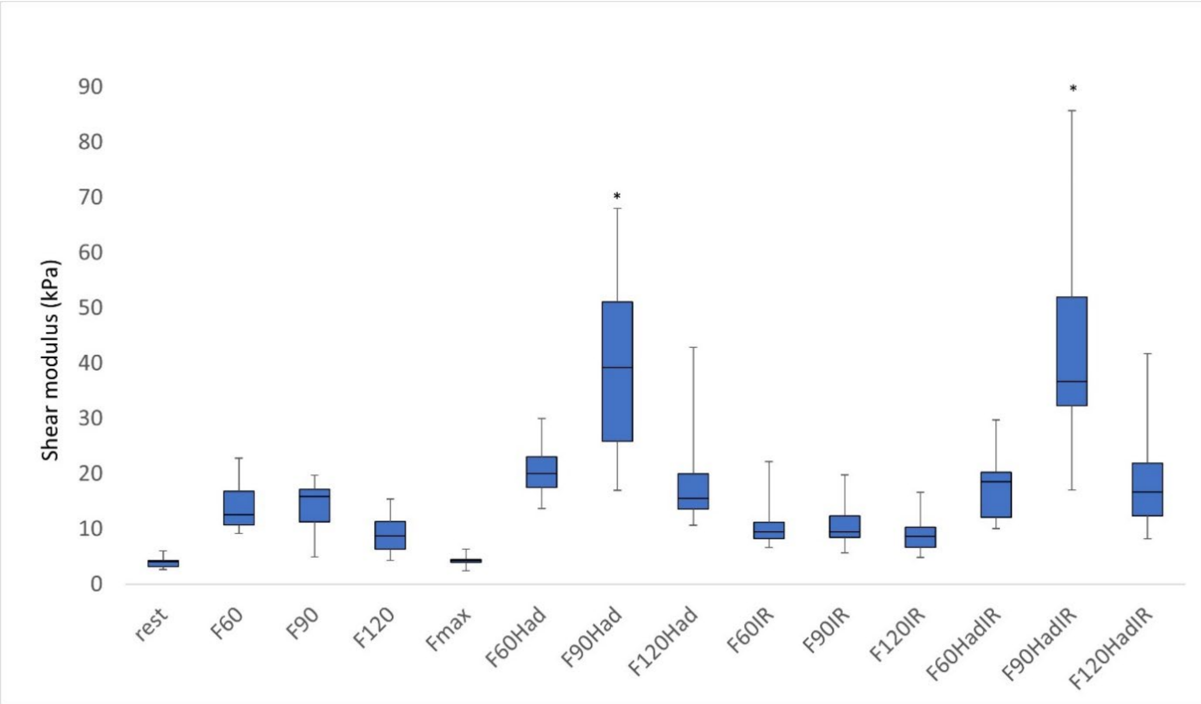

Figure 4. The shear modulus of the PD muscle for each position

*: the position recommended from the results of the three-way ANOVA and post-hoc analysis. rest, 0° shoulder flexion/extension, abduction/adduction, and external/internal rotation; F60, 60° shoulder flexion; F90, 90° shoulder flexion; F120, 120° shoulder flexion; Fmax, maximum flexion; F60Had, horizontal adduction at 60° shoulder flexion; F90Had, horizontal adduction at 90° shoulder flexion; F120Had, horizontal adduction at 120° shoulder flexion; F60IR, internal rotation at 60° shoulder flexion; F90IR, internal rotation at 90° shoulder flexion; F120IR, internal rotation to 120° shoulder flexion; F60HadIR, horizontal adduction and internal rotation at 60° shoulder flexion; F90HadIR, horizontal adduction and internal rotation at 90° shoulder flexion; F120HadIR, horizontal adduction and internal rotation at 120° shoulder flexion

Table captions

Table 1. The range of motion for all stretching positions

	Range of motion (°)		
Positions	Flexion	Horizontal adduction	Internal rotation
Fmax	177±10	-	-
F60Had	60±0	124±4	-
F90Had	90±0	163±7	-
F120Had	120±0	144±9	-
F60IR	60±0	-	63±13
F90IR	90±0	-	56±10
F120IR	120±0	-	46±7
F60HadIR	60±0	126±8	50±14
F90HadIR	90±0	151±14	31±11
F120HadIR	120±0	146±8	31±11

Fmax, maximum flexion; F60Had, horizontal adduction at 60° shoulder flexion; F90Had, horizontal adduction at 90° shoulder flexion; F120Had, horizontal adduction at 120° shoulder flexion; F60IR, internal rotation at 60° shoulder flexion; F90IR, internal rotation at 90° shoulder flexion; F120IR, internal rotation at 120° shoulder flexion; F60HadIR, horizontal adduction and internal rotation at 60° shoulder flexion; F90HadIR, horizontal adduction and internal rotation at 90° shoulder flexion; F120HadIR, horizontal adduction and internal rotation at 120° shoulder flexion

Table 2. ICC$_{1,3}$ for each arm position

Position	**rest**	**F60**	**F90**	**F120**	**Fmax**	**F60Had**	**F90Had**
ICC; $_{1,3}$	0.908	0.989	0.990	0.987	0.773	0.960	0.988
Position	**F120Had**	**F60IR**	**F90IR**	**F120IR**	**F60HadIR**	**F90HadIR**	**F120HadIR**
ICC; $_{1,3}$	0.995	0.960	0.994	0.980	0.955	0.983	0.993

Fmax, maximum flexion; F60Had, horizontal adduction at 60° shoulder flexion; F90Had, horizontal adduction at 90° shoulder flexion; F120Had, horizontal adduction at 120° shoulder flexion; F60IR, internal rotation at 60° shoulder flexion; F90IR, internal rotation at 90° shoulder flexion; F120IR, internal rotation at 120° shoulder flexion; F60HadIR, horizontal adduction and internal rotation at 60° shoulder flexion; F90HadIR, horizontal adduction and internal rotation at 90° shoulder flexion; F120HadIR, horizontal adduction and internal rotation at 120° shoulder flexion

Table 3. The result of the three-way ANOVA with repeated measures

Interactions and main effects							
Factor	Flex	Had	IR	Flex×Had	Flex×IR	Had×IR	Flex×Had×IR

Stretching position for posterior deltoid muscle

F	23.24	125.73	1.76	26.32	1.55	0.85	1.54
p	.001*	< .001*	.206	< .001*	.230	.372	.233

Post-hoc of main effect

Flex	Mean differences (kPa)	*p*	Had	Mean differences (kPa)	*p*
60° < 90°	−11.52	.001*	with > without	15.09	< .001*
60° > 120°	1.468	1.000			
90° > 120°	12.62	< .001*			

Post-hoc of two-way interaction

Flex with Had	Mean differences (kPa)	*p*	Had with Flex	Mean differences (kPa)	*p*
60° < 90°	−28.89	< .001*	with > without (60°)	6.81	< .001*
60° < 120°	−0.219	1.000	with > without (90°)	28.28	< .001*
90° > 120°	21.67	< .001*	with > without (120°)	10.19	< .001*

* Significant difference. The mean difference was calculated by subtracting the right variable with the left variable. For example, in the case of 60° < 90°, the mean difference was indicated as – because the mean value was higher than 90°, whereas in the case of 90° > 120°, the mean difference was indicated as + because the mean value was higher than 90°

Flex, flexion; Had, horizontal adduction; IR, internal rotation