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Effective stretching positions for the posterior shoulder capsule as determined by shear wave elastography

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Background: Stretching is often used to prevent and treat posterior shoulder capsule tightness; however, the most effective stretching positions are not clearly defined. The purpose of this study was to identify the stretching positions that specifically applied the greatest passive tension on the posterior shoulder capsule by evaluating the elastic characteristics of posterior capsules and muscles in various stretching positions using ultrasound shear wave elastography (SWE).

Methods: We evaluated 9 fresh-frozen shoulders (mean age 86.6 ± 7.7 years) without osteoarthritis or rotator cuff tears. All posterior shoulder tissues were preserved intact. Shear moduli of the middle and inferior posterior shoulder capsules and the posterior shoulder muscles were evaluated using SWE. We obtained shear modulus measurements in 9 stretching positions using a combination of glenohumeral elevation planes and angles (frontal, sagittal, scapular; –30°, 0°, 30°, 60°, respectively). A 4-Nm torque for shoulder internal rotation or horizontal adduction was applied in each position. We also measured shear moduli in the resting position (0° elevation with neutral shoulder internal/external rotation). We compared the shear moduli of all stretching and resting positions using 1-way repeated measures analysis of variance ($P < .05$). In addition, we compared the shear modulus in 2 positions (ie, resting and each stretching) among tissues (ie, capsules and muscles) with repeated measures using 2-way analysis of variance ($P < .05$).

Results: Shear modulus values for the middle posterior capsules in "internal rotation at 30° in scapular plane elevation" (28.7 ± 14.3 kPa, $P = .01$) and in "horizontal adduction at 60° of elevation" (31.1 ± 13.1 kPa, $P < .001$) were significantly higher than that of the resting position (11.0 ± 7.3 kPa). The shear modulus value for the inferior posterior capsule in "internal rotation at 30° of flexion" was significantly higher than that of the resting position (39.0 ± 17.3 vs. 15.4 ± 13.9 kPa, respectively; $P = .004$). Additionally, the shear modulus values for the posterior capsules in "internal rotation at 30° in scapular plane elevation and flexion" were significantly higher than that of the posterior shoulder muscles.

Conclusion: Effective middle posterior shoulder capsule stretching positions were shoulder "internal rotation at 30° of scapular plane elevation" and "horizontal adduction at 60° of elevation." Shoulder "internal rotation at 30° of flexion" was the most effective position for the inferior posterior shoulder capsule. Stretching in these positions could relieve posterior shoulder capsule tightness and contribute to the prevention and treatment of throwing injuries of the shoulder.

This study has been approved by the Ethics Committee of the Sapporo Medical University: No 29-2-30.

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Level of Evidence: Basic Science Study; Biomechanics

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Tightness of the posterior shoulder capsule is common in overhead athletes such as baseball players.[1,5,30,31] Previous biomechanical studies using fresh-frozen cadavers showed that posterior shoulder capsule tightness induces abnormal translation of the humeral head during shoulder flexion and external rotation at shoulder abduction.[9-11,21,27] Thus, posterior shoulder capsule tightness is a factor for subacromial and internal impingement, which can lead to rotator cuff tears and labrum lesions.

Stretching is often used to prevent and treat tightness of soft tissues in rehabilitation. Although it may be difficult to elongate the thick and shortened capsule, a previous study showed that stretching contributes to the elongation of the posterior shoulder capsule.[26] Stretching is possibly effective for tightness of the capsule that is not severely thick and shortened yet. Previous studies investigated the most effective stretching position for the posterior shoulder capsule.[3,13] These studies used fresh-frozen cadavers and quantified the degree of elongation of the capsules via a strain gauge and indicated the stretching positions in which strain increased the most. However, these studies showed that all soft tissues, such as the muscle and skin located over the capsules, were removed to allow direct attachment of the strain gauge to the capsule. Thus, the influence of soft tissues, except for the capsule, on the stretching maneuver is unclear. Furthermore, the strain has a nonlinear relationship with passive tension.[8,18] The passive tension directly represents the intensity of stretching and is a proper variable for finding the effective stretching position.

Shear wave elastography (SWE) is an ultrasound-based imaging modality that provides a noninvasive estimate of tissue mechanical properties; it measures the speed of shear wave propagation through soft tissues. Recent studies using SWE have reported that the elastic modulus is strongly correlated with the passive tension in muscle tissues.[14,18] Based on these results, SWE was recognized as a useful tool for noninvasively estimating passive muscle tension and was used in several muscles to identify effective stretching positions wherein passive tension was strongly applied to the muscles.[28,33,34,36] In addition, a recent study indicated that the elastic modulus measured by SWE is highly correlated with the passive tension in posterior shoulder capsules.[12] Therefore, SWE can be used for estimating passive tension in the posterior shoulder capsule.

Here, we aimed to identify the stretching positions that specifically applied the greatest passive tension on the posterior shoulder capsule by evaluating the elastic characteristics of posterior capsules and muscles in various stretching positions using SWE.

Materials and methods

Preparation of specimens

This was a controlled laboratory study that investigated the effective stretching positions for the posterior shoulder capsule. We conducted a priori power analysis using G*Power 3.1 software (Heinrich Heine University, Dusseldorf, Germany). We estimated that a sample size of 8 specimens was required based on a 0.25 effect size, 0.05 α-level, and a 0.8 desired power level. Therefore, we investigated 9 fresh-frozen shoulders (6 males and 3 females) without osteoarthritis or rotator cuff tears. The age of the specimens at death ranged from 74-97 years (mean: 86.6 years). We obtained specimens within 24 hours of death. The individual and their families consented to the body donations. The appropriate ethics committee reviewed and approved the study protocol.

We disarticulated the shoulder specimens from the thorax, clavicle, radius, and ulna and maintained them at –20°C. We initiated thawing of the specimens at room temperature (22°C) 12 hours before preparation. We removed the serratus anterior, latissimus dorsi, rhomboid, and levator scapulae muscles. The skin covering the posterior aspect of the scapula was preserved intact, and we stripped the supraspinatus off the scapula. Next, we removed distal portions of the biceps brachii, brachialis, and triceps brachii to expose the distal third of the humerus. We inserted a Kirschner wire into the distal humerus so that the wire penetrated the medial and lateral epicondyles, indicating the direction of the forearm.

Testing apparatus

Based on a previous study,[13] we used a jig consisting of an acrylic board and a wooden post/column (height 700 mm, width 200 mm, and thickness 15 mm). We fixed the scapula of the specimen to the wooden post/column, so that the medial border of the scapula was perpendicular to the ground, simulating a resting scapula position (Fig. 1). A suture was connected to the muscle belly of the stripped supraspinatus. We applied a compression force of 500 g against the glenoid fossa along the long axis of the supraspinatus via a pulley, to keep the humeral head from dislocating inferiorly. During the experiment, specimens were kept moist using saline solution sprayed every 5-10 minutes. We maintained the room temperature and humidity at 22°C and 40%, respectively.

Elasticity measurement

We used SWE for elasticity measurement in this study, using an SL10-2 linear array transducer (AixPlorer Ver. 6; SuperSonic Imagine, Aix-en-Provence, France).

In the pilot study, we sought an appropriate measurement site for the posterior shoulder capsule over the skin. The opposite side of the shoulder specimens used for elasticity measurements was

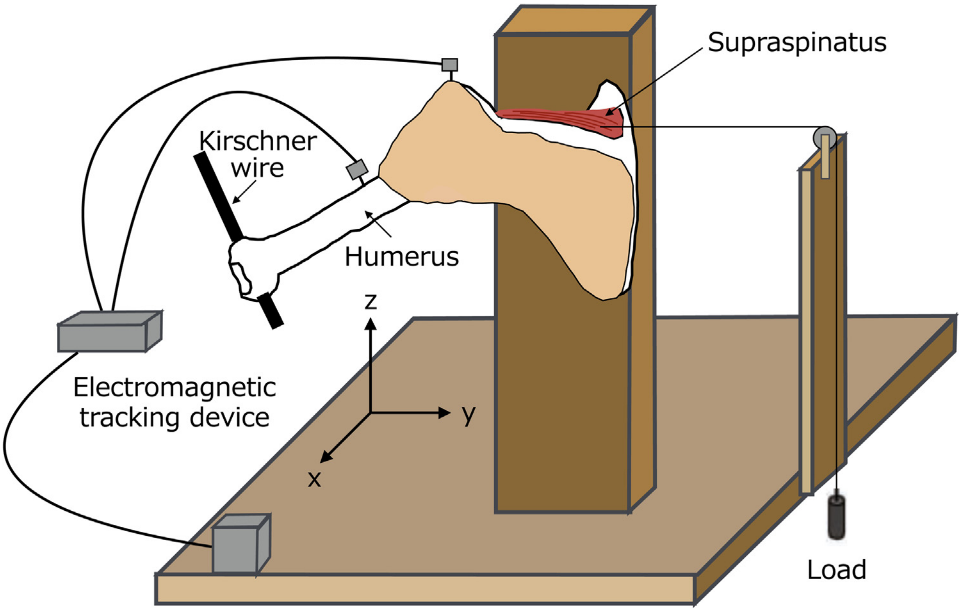

Figure 1 Experimental setup. The scapula of the specimen simulated a resting scapula position. An electromagnetic tracking device was used to monitor the glenohumeral angles during measurement.

used for this pilot study in same cadaver. First, we stripped distally all the soft tissues, including the muscles and skin, over the posterior capsules, exposing the posterior capsule. Next, we formed a foramen on the lateral edge of the glenoid wherein the middle and inferior posterior capsules were attached. For the right shoulder, the middle and inferior posterior capsules were defined as the areas corresponding to 9-o'clock and between 7- and 8-o'clock face position, respectively.[3,7,13] We repositioned posterior muscles and skin to their original location after forming the foramen. We confirmed the location of the probe, visualizing the foramen in the center using an ultrasonographic image on the skin. Using a tape measure, we measured the distance between the acromial angle and the center of the probe for each specimen. We used this for the elasticity measurement of the posterior capsule of the contralateral shoulder.

We measured the shear moduli of the middle and inferior posterior capsules (MPC and IPC, respectively), superior infraspinatus (SISP), inferior infraspinatus (IISP), teres minor (TM), and posterior deltoid (PD). The location of the probe for the posterior capsules was based on the pilot results, and that of the probe for the muscles was based on previous studies (Fig. 2)[35]. We defined the measurement site of the SISP as the intersection of the line connecting the greater tubercle to the quarter point between the trigonum scapulae and the inferior angle and the line connecting the inferior angle to the halfway point between the trigonum scapulae and the acromial angle. The measurement site of the IISP was defined as the intersection of the line connecting the greater tubercle to the three-quarter point between the trigonum scapulae and the inferior angle and the line connecting the inferior angle to the halfway point between the trigonum scapulae and the acromial angle. The measurement site of the TM was defined as the halfway point between the inferior angle and the greater tubercle. The measurement site of the PD was defined as the point 4 cm below the acromial angle. We positioned the probe at the measurement site, parallel to the muscle fiber. To minimize measurement error, we measured the shear moduli of capsules and muscles for each position 3 times.

Stretching maneuver

After the pilot study, we measured elasticity in a resting position (0° glenohumeral elevation and rotation). Next, elasticity was randomly measured in 9 stretching positions using a combination of glenohumeral elevation planes (frontal, sagittal, scapular) and elevation angles (–30°, 0°, 30°, and 60°). The direction of stretching was glenohumeral internal rotation or horizontal adduction in each stretching position (Table I). A 60° glenohumeral elevation in this cadaveric study corresponded to a 90° shoulder elevation in vivo[13,24,25] because the scapula is upward rotated at 30° when the arm is elevated at 90° in vivo.[29] In addition, a scapula is internally rotated by 30°, relative to a frontal plane in vivo.[6] Thus, elevation with an additional 60° of glenohumeral horizontal adduction, that is, relative to the scapular plane, corresponded to the elevation on the sagittal plane (flexion) in vivo. Elevation with an additional 30° of glenohumeral horizontal abduction, relative to a scapular plane, corresponded to the elevation on the frontal plane (abduction) in vivo.[13,24,25] All joint angles were represented in glenohumeral joint from this point.

We used a 6-degree-of-freedom electromagnetic tracking device (3 Space Fastrak; Polhemus, Colchester, VT, USA) to monitor glenohumeral angles during measurement. This device enabled measurement of the 3-dimensional position and orientation of the sensors relative to the absolute coordinates generated by the source. We placed one sensor on the acromion and the other on the middle portion of the humerus. In this system, the angle of arm elevation was defined as the angle between the perpendicular line relative to the scapular spine and the longitudinal axis of the humerus. The rotation angle was defined as the rotation of the humerus along the longitudinal axis. With a 750-mm range from

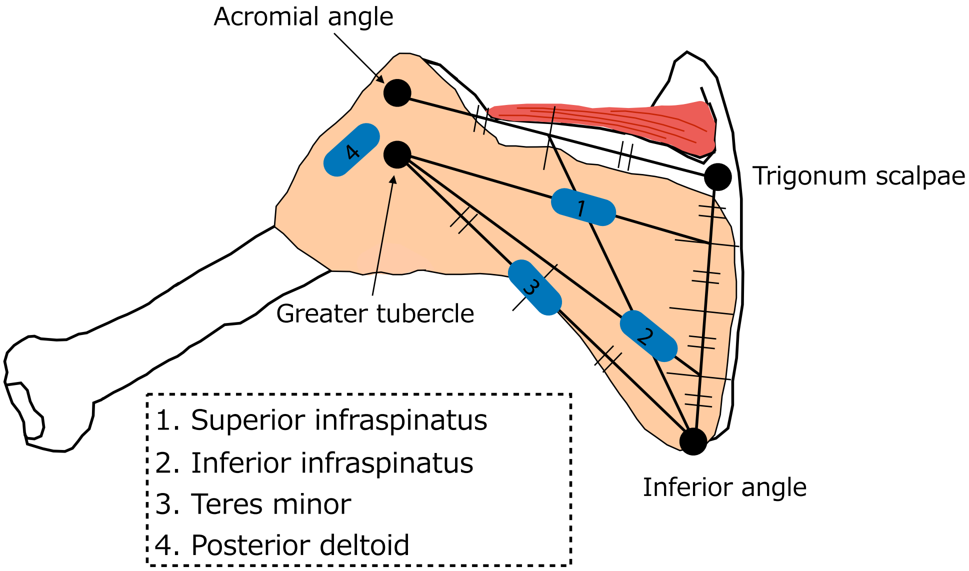

Figure 2 The location of the probes for the muscles. The measurement site of the superior infraspinatus, inferior infraspinatus, teres minor, and posterior deltoid are shown.

the source, the positional accuracy was 0.8 mm root mean square (RMS), and the angular accuracy was 0.5° RMS.

We applied 20 N of manual force using a digital push-pull gauge (RX-50; Aiko Engineering Co., Tokyo, Japan) to the Kirschner wire or to the humerus for glenohumeral internal rotation or horizontal adduction, respectively. The point of application of the force was 20 cm from the midpoint between the medial and lateral epicondyle or at the estimated center of the humeral head for glenohumeral internal rotation and horizontal adduction, respectively. Therefore, the stretching torque was standardized to 4 Nm for all the stretching positions.[3]

We obtained each elasticity measurement within 10 seconds[14] with 1-minute intervals in the resting position between each measurement to minimize creep or hysteresis effects due to repetitive load applications. After we obtained the elasticity measurements for all stretching positions, we remeasured resting position elasticity to evaluate the presence of elasticity changes due to creep or hysteresis effects.

Data analysis

The elasticity analysis software embedded in the SWE was not sufficient for the purposes of this study because it did not allow a circular region of interest (ROI) with a diameter of <1 mm, and capsules often have a thickness of <1 mm. Thus, we exported the elasticity images in JPEG format and analyzed the elasticity using custom analysis software (S-14133 Ver.1.2; Takei Scientific Instrument Co., Ltd., Niigata, Japan).[12] With this software, the ROI can be arbitrary in size and shape and can be located anywhere on the elasticity image, and the elastic modulus calculation is based on the color map scale.[12] In a pilot study, we investigated the relationships between the elasticity analyzed in the embedded and custom software. The difference of the elasticity analyzed using both software package was only <2%, demonstrating the validity of this custom software. In the current study, a rectangular ROI (width, 3 mm; height, 0.5 mm) was set 5 mm lateral to the edge of the labrum[30] (Fig. 3, *A*). The center height of the ROI was aligned

Table I Measurement position

Position	Rest	0	Fl30	Fl60	Scap30	Scap60	Abd30	Abd60	Ext30	HAdd
Elevation plane	—	—	Sagittal	Sagittal	Scapular	Scapular	Frontal	Frontal	Sagittal	—
Elevation angle	0	0	30	60	30	60	30	60	−30	60
Stretching direction	—	Internal rotation	Internal rotation	Internal rotation	Internal rotation	Internal rotation	Internal rotation	Internal rotation	Internal rotation	Horizontal adduction

Rest, 0° elevation with neutral shoulder internal/external rotation; *0*, internal rotation at 0° of elevation; *Fl30*, internal rotation at 30° of flexion; *Fl60*, internal rotation at 60° of flexion; *Scap30*, internal rotation at 30° of scapular plane elevation; *Scap60*, internal rotation at 60° of scapular plane elevation; *Abd30*, internal rotation at 30° of abduction; *Abd60*, internal rotation of 60° of abduction; *Ext30*, internal rotation at −30° of flexion; *HAdd*, horizontal adduction at 60° of elevation.

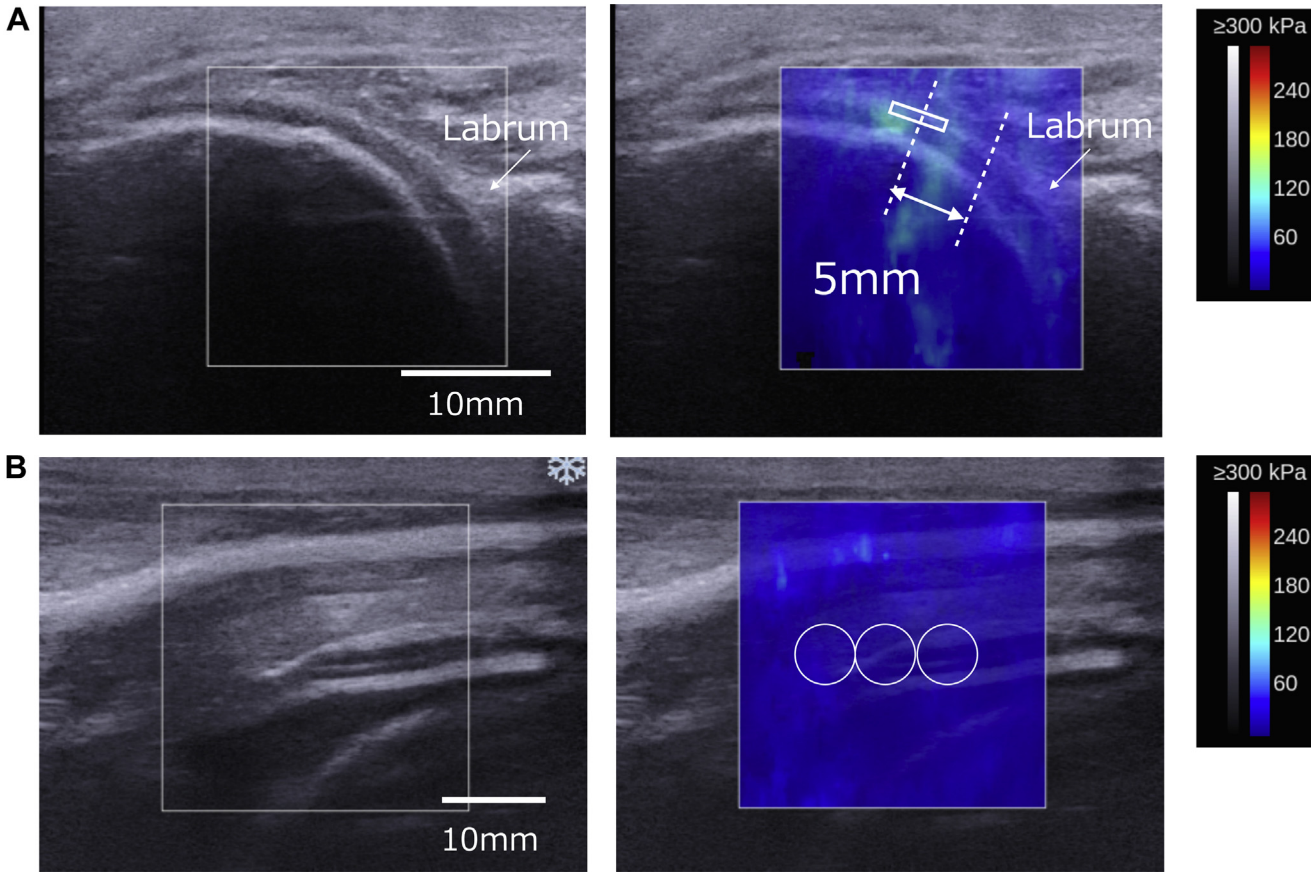

Figure 3 Location of the regions of interest (ROIs). (**A**) For capsules, a rectangular ROI (width, 3 mm; height, 0.5 mm) is set 5 mm lateral to the edge of the labrum. (**B**) For muscles, 3 adjacent circular ROIs were set at the midpoint of the muscle belly.

with the center thickness of the capsule. The mean value of Young's modulus in the ROI was the representing value of each image. For muscles, the software embedded in the SWE was used for the elasticity analysis. Three adjacent circular ROIs with a diameter of 5 mm were set at the midpoint of the muscle belly (Fig. 3, *B*). The mean value of Young's modulus in the 3 ROIs was the representing value of each image. In the SWE software, Young's modulus was quantified in kilopascals (kPa) based on the shear-wave propagation speed, c. For each ROI, Young's modulus, E, was deduced from $E = 3\rho c^2$, where ρ, density, is assumed to be constant (1000 kg/m^3) in human soft tissues. This SWE software calculated Young's modulus on the supposition that biological tissue is an isotropic material; however, muscles and capsules are not isotropic.[2,8,23] Therefore, we determined the shear modulus by dividing Young's modulus by 3. For each image, the ensemble mean across the 3 images was regarded as the shear modulus of the tested muscle and capsule at that position.

All data were analyzed using statistical software (SPSS Statistics Ver. 25.0, J for Windows; IBM, Armonk, NY, USA). The shear moduli in all stretching and resting positions were compared using 1-way repeated measures analysis of variance (ANOVA). If there was a main effect, Tukey test was used. Intraclass correlation coefficient (ICC) estimates were calculated based on a mean rating ($k = 3$), absolute agreement, and 2-way mixed effects model to evaluate the test-retest reliability of the SWE measurement.[15] Furthermore, the shear moduli of each muscle and capsule in the resting position before and after the stretching maneuver were compared using a paired *t* test. In addition, we compared the shear modulus in 2 positions (ie, resting and stretching) among 6 tissues (ie, MPC, IPC, SISP, IISP, Tm, and PD) with repeated measures using 2-way ANOVA. If there was an interaction between the positions and tissues, Tukey test was used. Only stretching positions, wherein the shear modulus of the capsules was significantly higher than those in the resting position, were subject to this statistical analysis. The level of significance was set at $P < .05$.

Results

The shear modulus for each measurement position is shown in Table II. The results of the 1-way ANOVA showed significant main effects in all tissues, except for the SISP. Tukey test indicated that the shear modulus values for the MPC in "internal rotation at 30° in scapular plane elevation" ($P = .01$) and "horizontal adduction at 60° of elevation" ($P < .001$) were significantly higher than the values in the resting position (Fig. 4, *A*). Additionally, the shear modulus value for the IPC in "internal rotation at 30° of flexion" was significantly higher than the value in the resting position ($P = .004$) (Fig. 4, *B*). Although there was

Table II Shear modulus for each measurement position (kPa)

Position	MPC	IPC	SISP	IISP	TM	PD
Rest	11.0 ± 7.3	15.4 ± 13.9	7.5 ± 4.0	6.7 ± 3.8	5.3 ± 2.0	7.1 ± 2.8
0	20.3 ± 13.5	18.4 ± 6.1	10.0 ± 7.3	9.1 ± 4.4	6.3 ± 3.2	9.1 ± 4.3
Fl30	15.0 ± 8.2	39.0 ± 17.3*	9.4 ± 3.0	8.8 ± 3.3	10.9 ± 6.8	22.5 ± 15.6*
Fl60	19.5 ± 6.0	33.4 ± 16.1	9.7 ± 5.6	8.1 ± 3.3	13.1 ± 8.7*	42.0 ± 18.1†
Scap30	28.7 ± 14.3*	25.7 ± 12.9	7.9 ± 4.4	10.0 ± 4.1	7.8 ± 3.1	12.1 ± 5.5
Scap60	16.6 ± 8.3	16.6 ± 8.4	7.6 ± 3.5	10.2 ± 4.0	12.3 ± 5.8	10.9 ± 5.5
Abd30	19.0 ± 9.4	32.2 ± 17.0	8.8 ± 6.4	9.8 ± 5.0	9.9 ± 6.1	10.2 ± 4.1
Abd60	22.7 ± 9.4	21.8 ± 11.8	7.9 ± 3.1	12.3 ± 7.1	8.8 ± 6.3	9.0 ± 3.5
Ext30	15.9 ± 10.1	19.3 ± 15.6	12.0 ± 7.5	13.8 ± 8.0*	8.0 ± 5.5	9.4 ± 3.8
HAdd	31.1 ± 13.1*	27.7 ± 11.8	7.5 ± 3.3	8.3 ± 3.2	11.7 ± 7.8	48.4 ± 20.3‡

Rest, 0° elevation with neutral shoulder internal/external rotation; *0*, internal rotation at 0° of elevation; *Fl30*, internal rotation at 30° of flexion; *Fl60*, internal rotation at 60° of flexion; *Scap30*, internal rotation at 30° of scapular plane elevation; *Scap60*, internal rotation at 60° of scapular plane elevation; *Abd30*, internal rotation at 30° of abduction; *Abd60*, internal rotation of 60° of abduction; *Ext30*, internal rotation at –30° of flexion; *HAdd*, horizontal adduction at 60° of elevation; *MPC*, middle posterior capsule; *IPC*, inferior posterior capsule; *SISP*, superior infraspinatus; *IISP*, inferior infraspinatus; *TM*, teres minor; *PD*, posterior deltoid.

The values are given as the mean ± standard deviation.

* Significantly larger than Rest ($P < .05$).

† Significantly larger than all positions except for HAdd ($P < .05$).

‡ Significantly larger than all positions except for FL60 ($P < .05$).

no main effect in the shear modulus of the SISP, the shear modulus value in "internal rotation at 30° of extension" was significantly higher than the value in the resting position in the IISP ($P = .017$). In the TM, the shear modulus value in "internal rotation at 60° of flexion" was significantly higher than the value in the resting position ($P = .025$). In the PD, the shear modulus value in "internal rotation at 60° of flexion" was significantly higher than the value in all positions, except for "horizontal adduction at 60° of elevation" ($P < .001$). Furthermore, the shear modulus value in "horizontal adduction at 60° of elevation" was significantly higher than the value in all positions, except for "internal rotation at 60° of flexion" ($P < .001$).

There was no difference in the shear modulus of the resting positions before and after the stretching position measurements of all tissues (MPC: $P = .173$; IPC: $P = .540$; SISP: $P = .808$; IISP: $P = .860$; TM: $P = .149$; PD: $P = .602$).

The test-retest reliability of SWE measurements was excellent at all stretching positions for all tissues (MPC: ICC = 0.967 ± 0.016; IPC: ICC = 0.952 ± 0.039; SISP: ICC = 0.991 ± 0.008; IISP: ICC = 0.986 ± 0.007; TM: ICC = 0.983 ± 0.022; PD: ICC = 0.991 ± 0.008).

In the stretching position of "internal rotation at 30° of scapular plane elevation," the shear modulus of the MPC was higher than the value in the resting position; the 2-way ANOVA results showed a significant interaction ($P = .002$). Tukey test revealed that the shear modulus value of the IPC was higher than that of the IISP ($P = .028$), TM ($P = .007$), and PD ($P = .040$) in the resting position. The shear modulus value of the MPC was higher than the values of the SISP ($P < .001$), IISP ($P < .001$), TM ($P < .001$), and PD ($P = .002$) in the stretching position. The shear modulus value of the IPC was higher than the values of the SISP ($P = .001$), IISP ($P = .004$), TM ($P = .001$), and PD ($P = .016$) in the resting position. The shear modulus values of the MPC ($P = .014$), IPC ($P = .030$), TM ($P = .048$), and PD ($P = .019$) in the stretching position were higher than the value in the resting position (Fig. 5, *A*).

In the stretching position of "horizontal adduction at 60° of elevation," the shear modulus value of the MPC was higher than the value in the resting position; the 2-way ANOVA results showed significant interaction ($P < .001$). The shear modulus value of the MPC was higher than the values of the SISP ($P = .001$), IISP ($P = .002$), and TM ($P = .012$) in the stretching position. The shear modulus value of the IPC was higher than the values of the SISP ($P = .008$) and IISP ($P = .012$) in the stretching position. The shear modulus value of the PD was higher than that of all other tissues (MPC: $P = .032$; IPC: $P = .006$; SISP: $P < .001$; IISP: $P < .001$; TM: $P < .001$) in the stretching position. The shear modulus values of the MPC ($P = .014$), IPC ($P = .030$), and PD ($P < .001$) in the stretching position were higher than the value in the resting position (Fig. 5, *B*).

In the stretching position of "internal rotation at 30° of flexion," the shear modulus value of the IPC was higher than the value in the resting position; the 2-way ANOVA results showed significant interaction ($P = .001$). The shear modulus value of the IPC was higher than the value of all other tissues (MPC: $P < .001$; SISP: $P < .001$; IISP: $P < .001$; TM: $P < .001$; PD: $P = .030$) in the stretching position. The shear modulus values of the IPC ($P = .013$), TM ($P = .032$), and PD ($P = .016$) in the stretching position were higher than the value in the resting position (Fig. 5, *C*).

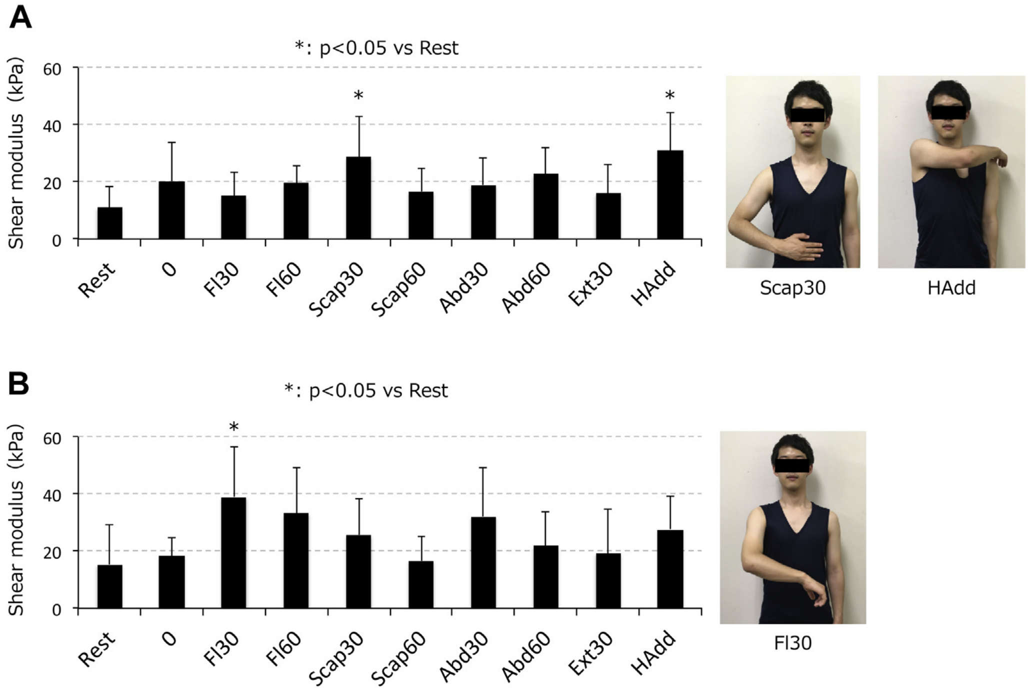

Figure 4 Shear moduli of the middle (MPC) and inferior posterior capsule (IPC) in each stretching position. (**A**) The shear moduli for the MPC in "internal rotation at 30° in scapular plane elevation" and "horizontal adduction at 60° of elevation" were significantly higher than the values in the resting position. (**B**) The shear modulus value for the IPC in "internal rotation at 30° of flexion" was significantly higher than the value in the resting position. The photos represent the stretching positions, in vivo, in which the shear modulus was significantly higher than the resting position. *Rest*, 0° elevation with neutral shoulder internal/external rotation; *0*, internal rotation at 0° of elevation; *Fl30*, internal rotation at 30° of flexion; *Fl60*, internal rotation at 60° of flexion; *Scap30*, internal rotation at 30° of scapular plane elevation; *Scap60*, internal rotation at 60° of scapular plane elevation; *Abd30*, internal rotation at 30° of abduction; *Abd60*, internal rotation of 60° of abduction; *Ext30*, internal rotation at –30° of flexion; *HAdd*, horizontal adduction at 60° of elevation.

Discussion

This study aimed to identify the stretching positions that specifically applied the greatest passive tension on the posterior shoulder capsule by evaluating the elastic characteristics of posterior capsules and muscles in various stretching positions via the SWE.

The results demonstrated that the stretching positions with shear modulus values higher than the resting position were "internal rotation at 30° in scapular plane elevation" and "horizontal adduction at 60° of elevation" for the MPC and "internal rotation at 30° of flexion" for the IPC. These stretching positions may be effective for each posterior shoulder capsule.

Although it may be difficult to elongate the thick and shortened capsule, a previous study showed that stretching contributes to the elongation of the posterior shoulder capsule.[26] Stretching is possibly effective for tightness of the capsule that is not yet severely thick and shortened. Effective posterior shoulder capsule stretching positions were previously investigated by measuring the strain of the capsule using a strain gauge.[3,13] Our results were consistent with those of the previous study[13] in terms of the effectiveness of "internal rotation at 30° in scapular plane elevation" for the MPC. However, the effective stretching position for the IPC differed between the current and previous studies.[3,13] This difference may be due to the condition of the specimens. All soft tissues, such as muscles and skin, over the capsule were removed in the previous studies[3,13]; by contrast, they were preserved in this study. Furthermore, the measurement location differed between the current and previous study.[13] The strain gauge was attached on the capsule on the side of the humeral head,[13] whereas the shear modulus was measured near the labrum in this study; the stiffness is higher in the dominant shoulder than in the nondominant shoulder at this location in baseball players.[30] In addition, previous studies evaluated the strain that indicated the mechanical characteristic of the tissue.[3,13] In contrast, this study used shear modulus, which strongly reflects the passive tension of the tissue.[12] Therefore, differing measurement variables may also explain the discrepancy in the results between the current and previous studies.

We hypothesized that the shear modulus of the posterior shoulder capsule was high in internal rotation at a much more horizontal adduction position (ie, internal rotation at

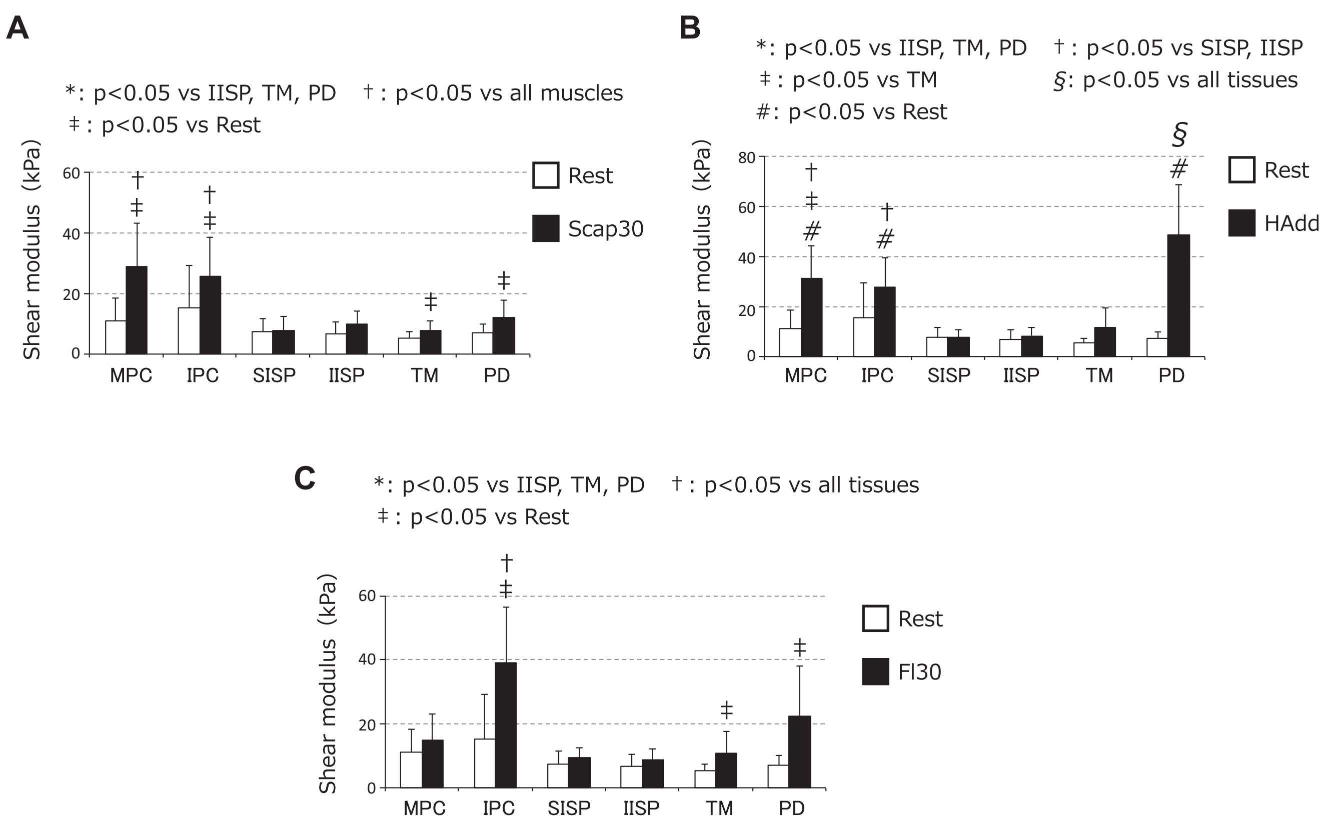

Figure 5 Shear moduli of all tissues in the resting position and stretching positions. (**A**) In the stretching position of "internal rotation at 30° of scapular plane elevation," the shear modulus values of the middle (MPC) and inferior posterior capsule (IPC) were higher than the value of all the muscles in this stretching position. (**B**) In the stretching position of "horizontal adduction at 60° of elevation," the shear modulus value of the MPC was higher than the values of the superior infraspinatus (SISP), inferior infraspinatus (IISP), and teres minor (TM); the shear modulus value of the IPC was higher than the value of the SISP and IISP, and the shear modulus value of the posterior deltoid (PD) was higher than that of all other tissues in this stretching position. (C) In the stretching position of "internal rotation at 30° of flexion," the shear modulus value of the IPC was higher than the value of all other tissues. *Rest*, 0° elevation with neutral shoulder internal/external rotation; *Scap30*, internal rotation at 30° of scapular plane elevation; *HAdd*, horizontal adduction at 60° of elevation; *Fl30*, internal rotation at 30° of flexion.

30° and 60° in flexion) because the posterior capsule laterally extends from the posterior region of the glenoid to the humeral head[2,7] and the fiber orientation of the posterior capsule is parallel to the longitudinal axis of the capsule.[2] However, the shear modulus of the MPC was high in internal rotation at 30° in scapular plane elevation, although the horizontal adduction angle was small in this position. Only the MPC had passive tension that increased in the stretching position because the shear moduli of all the muscles in this position did not increase. In addition, there was no difference between the shear moduli of the posterior capsules in the resting position and "internal rotation at 60° in flexion," wherein the horizontal adduction angle was large. We believe that the passive tension of the TM and PD increased in this stretching position before applying enough passive tension to the posterior capsules because the shear moduli of these muscles in this stretching position were higher than in the resting position.

In clinical situations, doctors and therapists need to selectively treat targeted tissues. Although many previous studies have indicated that sleeper stretching (ie, internal rotation at 60° in flexion) and cross-body stretching (ie, horizontal adduction at 60° in elevation) was effective for tightness of posterior shoulder tissues,[16,17,19,20,32] it was unclear how much of what tissues were extended. Direct measurement of the elongation of tissues using the strain gauge was reasonable in terms of the quantitative evaluation for the elongation of targeted tissue. However, it was impossible to simultaneously measure tissues located in different layers, such as muscles and capsules, because the strain gauge had to be directly attached to tissues. The present study enabled simultaneous measurement of the shear moduli of muscles and capsules by using SWE under the condition that all posterior shoulder tissues were preserved intact. Thus, we compared the shear modulus of tissues in the stretching position in which the shear moduli of the posterior shoulder capsules were higher than in the resting position. As a result, the shear moduli of the MPC and IPC were higher than those of all the muscle tissues in "internal rotation at 30° in scapular plane elevation."

Furthermore, the shear modulus of the IPC was higher than that of all other tissues in ‘‘internal rotation at 30° in flexion.’’ On the other hand, the shear moduli of the MPC and IPC were higher than those of the SISP, IISP, and TM; however, the shear moduli of the PD was even higher than that of the MPC and IPC in ‘‘horizontal adduction at 60° in elevation.’’ Therefore, sleeper stretching and cross-body stretching may not be appropriate as selective and effective stretching for posterior shoulder capsules. The present study indicated that ‘‘internal rotation at 30° in scapular plane elevation and flexion’’ were selective and effective stretching positions for posterior shoulder capsules. On the other hand, a recent meta-analysis indicated that cross-body stretching was effective for posterior shoulder tightness but not sleeper stretching.[22] The result of this meta-analysis may be related to our results to the effect that cross-body stretching was effective for both the capsule and muscle; however, sleeper stretching was effective for only muscles.

The present study has limitations. First, the location of the ROI (5 mm lateral to the edge of the labrum) set in this study was in an area known to be subject to tightness in baseball players,[30] however, it is unclear whether the small ROI reflects the elasticity of the entire capsule. The elasticity of capsule tissue may be heterogeneous. Second, there may be changes in the mechanical property of the tissues during the experiment because of repetitive load applications. Each elasticity measurement was obtained within 10 seconds to avoid changes in the mechanical properties of the tissues during the experiment.[14] As a result, there was no difference in the shear moduli of all the tissues before and after the stretching maneuvers. This indicates that there was no change in the mechanical property of the tissues that would influence the main results of the present study. Finally, we used cadavers to define an accurate glenohumeral joint angle and completely exclude muscle activation; this may have influenced the shear modulus.[4] However, the cadavers used in this study were older than common overhead athletes. Additionally, the mean age of the specimens used in this study was older than those of previous similar studies.[13,24,25] The composition of the collagen fiber in the capsules changes with growth and aging.[37] Furthermore, although there is a difference in the mechanical properties of the posterior shoulder soft tissues between the dominant and nondominant sides of overhead athletes,[30,38] we did not have information regarding the dominant side or the experience of overhead sports of the cadavers. Therefore, future studies are needed to investigate whether these results translate to overhead athletes.

Conclusion

Effective stretching positions for the MPC were shoulder ‘‘internal rotation at 30° of scapular plane elevation’’ and ‘‘horizontal adduction at 60° of elevation.’’ Shoulder ‘‘internal rotation at 30° of flexion’’ was the most effective position for the IPC. Stretching in these positions to relieve tightness of posterior shoulder capsules could contribute to prevention and treatment of shoulder throwing injuries.

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