Effect of scapular stabilization during cross-body stretch on the hardness of infraspinatus, teres minor, and deltoid muscles: an ultrasonic shear wave elastography study

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Background:

Posterior shoulder tightness is a contributing factor to shoulder injuries. Cross-body stretch is a method frequently prescribed to stretch the posterior shoulder structures. This stretching is performed horizontally adducting the shoulder with or without manual stabilization of the scapula by the therapist. However, no studies have investigated the effect of scapular stabilization during cross-body stretch using shear elastic modulus as an index of muscle hardness in vivo.

Objectives:

The aim of this study was to quantitatively examine, using ultrasonic shear wave elastography, whether scapular stabilization during cross-body stretch effectively decreased the hardness of the infraspinatus, the teres minor, or the posterior portion of the deltoid muscles.

Design:

A randomized, repeated-measures, cross-over design

Method:

Twenty healthy men participated in this study. The shear elastic modulus of the teres minor, the superior and inferior portions of the infraspinatus, and the posterior portion of the deltoid were measured before, and immediately after cross-body stretch with and without scapular stabilization.

Results:

The shear elastic modulus of the superior and inferior portions of the infraspinatus decreased significantly after cross-body stretch with scapular stabilization, but there was no significant change in the shear modulus of the measured muscles after cross-body stretch without scapular stabilization.

Conclusions:

Our results suggest that manual scapular stabilization during cross-body stretch effectively decreases the hardness of the infraspinatus muscle.

Keywords:

Shear wave elastography

Cross-body stretch

Scapular stabilization

1. Introduction

Posterior shoulder tightness relates to the state of the posterior capsular tightness at the glenohumeral joint (Tyler et al. 2010; Burkhart et al. 2003), and musculotendinous tightness of the posterior shoulder structures, which is composed of the infraspinatus, the teres minor (TM), and the posterior portion of the deltoid (PD) (Dashottar et al. 2014; Reinold et al. 2008). The posterior shoulder tightness also contributes to shoulder injuries such as shoulder impingement syndrome (Tyler et al. 2000; Ludewig, P.M., Cook 2002) and labral lesions (Grossman et al. 2005; Wilk et al. 2005) Generally, a stretching program is recommended as an intervention for posterior shoulder tightness. Horizontal adduction stretching (i.e., cross-body stretch) is a typical method prescribed for overhead athletes with posterior shoulder tightness and loss of internal rotation of the shoulder (Tyler et al. 2010). Due to the mobile scapula, the stretch is distributed in unknown proportions between the glenohumeral and the scapulothoracic muscles, and the stabilization of the scapula has thus been recommended (Wilk et al. 2013). McClure et al. (2007) reported a significantly greater increase in the internal rotation range of motion (ROM) of the shoulder after a four-week intervention of cross-body stretch without scapular stabilization in comparison with the sleeper stretch where the shoulder at 90° elevation is passively and internally rotated when lying down the stretched side.

Recently, Wilk et al. (2013) reported that the optimal stretch of the posterior shoulder structures cannot be achieved without stabilizing the scapula during the cross-body stretch, because accessory abduction of the scapula occurs during the horizontal adduction of the shoulder. Salamh et al. (2015) evaluated the effect of scapular stabilization during the cross-body stretch on horizontal adduction and internal rotation

ROM of the shoulder. Their study reported that cross-body stretch with scapular stabilization achieved significantly greater improvement in horizontal adduction and internal rotation of the shoulder than the cross-body stretch without scapular stabilization. Therefore, stabilizing the scapula during cross-body stretch is effective in increasing ROM.

The studies discussed thus far used ROM as the index of stretching. However, it has been reported that using only ROM measurements for evaluating muscle flexibility is insufficient, since the stretching does not necessarily improve the muscle properties, but might only alter the stretch tolerance of the skeletal muscle (Weppler and Magnusson 2010; Magnusson et al. 1996). Furthermore, the shoulder joint is composed of multiple joints (glenohumeral, scapulothoracic, sternoclavicular, and acromioclavicular). Hence, it is difficult to conclude which joint contributed the most to the change in the shoulder's ROM. This problem can be resolved by ultrasonic shear wave elastography (SWE), an ultrasound–based technique that allows noninvasive and reliable measurements of the viscoelastic properties of soft tissue (Bercoff et al. 2004). SWE has been used to quantify the stretching effects on the tibialis anterior (Koo et al. 2014) and the gastrocnemius muscle (Maïsetti et al. 2012). Some studies observed decreases in shear elastic modulus of the gastrocnemius muscle (Akagi and Takahashi 2013, 2014; Nakamura et al. 2014) and the hamstring muscle (Umegaki et al. 2015) after static stretching. Among these studies, Nakamura et al. (2014) showed that a positive correlation exists between rate of change in the shear elastic modulus, as measured by SWE, and rate of change in the muscle stiffness, as calculated from the passive torque-angle curve. Nakamura et al. also suggested that the decrease in the shear elastic modulus reflects the decrease in the muscle hardness after stretching.

There is one study observing the effect of scapular stabilization during cross-body stretch using ROM of the shoulder as the index. Nevertheless, no prior studies quantitatively examined the importance of manual scapular stabilization on individual muscle hardness of the glenohumeral joint during cross-body stretch. SWE allows quantitative comparison of the effects of scapular stabilization with that of non-stabilization (i.e., when scapular stabilization is not applied) on the hardness of muscles composing posterior shoulder structures during cross-body stretch. Therefore, the objective of this study was to quantitatively examine using SWE, whether scapular stabilization during cross-body stretch effectively decreased the muscle hardness of the infraspinatus, the teres minor, and the posterior portion of the deltoid. Since previous studies have shown the effectiveness of scapular stabilization for increasing ROM, we hypothesized that cross-body stretch with scapular stabilization would produce a greater decrease in the shear elastic modulus compared to cross-body stretch without scapular stabilization.

2. Methods

2.1. Subjects

Eighteen healthy men participated in this study (age, 23.4 ± 3.3 years; height, 172.6 ± 5.7 cm; weight, 66.5 ± 7.6 kg). The subjects were non-athletes, and did not perform any extensive exercise. No subjects with a history of orthopedic or nervous system disease in their upper limbs were included. The upper limb to be used in the intervention was chosen randomly. The aim and procedures were explained to all subjects, and written informed consent was obtained. The study protocol conformed to the Helsinki Declaration and was approved by the Ethics Review Board of the Graduate School of Medicine and Faculty of Medicine of Kyoto University (approval number E–1162).

We calculated the sample size needed for the two-way analysis of variance with repeated measures (effect size = 0.25 [medium], α error = 0.05, power = 0.8) using the G*power software (Version 3.1., Heinrich Heine University, Duesseldorf, Germany). The effect size used herein was in accordance with a previous study using SWE (Umegaki et al. 2014; Umehara et al. 2015). The results showed that 18 subjects were required.

2.2. Experimental procedures

The cross-body stretch techniques for the two conditions studied (stabilization, non-stabilization) are illustrated in Figure 1. All procedures were performed by the same investigator, who is a physical therapist. Specifically, the investigator performed both the stretching maneuvers and the measurements of shear elastic modulus.

Each subject lay in a side lying position on the bed, with their non-intervention arm under their head, their trunk parallel to the long axis of the bed, and both the hip and knee flexed at 45°. The cross-body stretch under stabilization condition is shown in Figure 1A. Standing behind the subject at shoulder level, the investigator used one hand to hold the subject's intervention elbow, and the other hand to stabilize the subject's scapula, and positioned it into a full adduction position. The investigator abducted the humerus to 90° while keeping the scapula in adduction. Then, while keeping the humerus in 0° rotation, the investigator moved the humerus into horizontal adduction within the transverse plane to the maximum extent that did not cause discomfort or pain to the subject. The cross-body stretch under non-stabilization condition is shown in Figure 1B. Standing behind the subject at shoulder level, the investigator used one hand to hold the subject's intervention elbow, and the other hand to hold the subject's iliac crest. The investigator abducted the humerus to 90° without scapular stabilization. Then, while keeping the humerus in 0° rotation, the investigator moved the humerus into horizontal adduction within the transverse plane to the maximum extent that did not cause discomfort or pain to the subject. The cross-body stretch procedure lasted 30 seconds was repeated five times with 30-second intervals. The duration and number of repetitions were taken from the study of McClure et al (2007). The investigator measured the shear elastic modulus before (Pre) and immediately after (Post) the cross-body stretch using SWE.

2.3. Assessment of the shear elastic modulus

In this study, the shear elastic modulus of the TM, the superior and inferior portions of the infraspinatus (ISPs and ISPi, respectively), and the PD were measured. The shear elastic modulus was measured using an ultrasonic shear wave elastography (Aixplorer; SuperSonic Imagine, Aix-en-Provence, France) with a linear ultrasound transducer with a 4.5cm footprint and a frequency operation range of 2-10 MHz. The shear elastic modulus was calculated from the shear wave propagation speed generated by the transducer (Bercoff et al. 2004), and reflected the tissue elasticity (i.e., tissue hardness). The shear elastic modulus (G) was converted from the shear wave propagation speed (V) using the following equation:

$$G = \rho V^2$$

where ρ is the muscle mass density, as assumed to be equal to 1000 kg/m^3 (Umegaki et al. 2014; Nordez et al. 2008; Gennisson et al. 2005).

The subject's posture during the measurement of the shear elastic modulus, and the measurement sites for all muscles are presented in Figure 2. During the measurement, the subject sat in a chair without a backrest, put their arm on the supporting pillow in front of them, and maintained their arm relaxed, resting on the supporting pillow at 90° shoulder and 90° elbow flexion. The ultrasound transducer was positioned at the measurement site, in an orientation parallel to the muscle fiber. The region of interest (ROI) was set up near the central point of the muscle belly in the ultrasound image. The shear elastic modulus was measured three times at each measurement site, and the mean value was used for analysis.

2.4. Reliability of measurement

Seven healthy men (age, 25.6 ± 3.8 years; height, 173.0 ± 4.8 cm; weight, 69.7 ± 7.4 kg) were evaluated in order to investigate the reliability of the ultrasound measurement. Each subject visited the laboratory twice, with consecutive visits separated by more than three days. During these visits, the shear elastic modulus was measured three times with five-minute rest period per session, at each site. The intra-day reliability, which represents the reproducibility within a single session, was calculated from the three times measurements of the shear elastic modulus obtained in the first session. The inter-day reliability, which represents the reproducibility between sessions, was calculated using the mean value of three measurements in each session.

2.5. Statistical analysis

Statistical analysis was performed using SPSS (version 18.0, SPSS Japan Inc., Tokyo, Japan). The reliability of the shear elastic modulus measurement was ascertained using the intra-class correlation coefficients (1,1) ($ICC_{1,1}$). $ICC_{1,1}$ was calculated from the shear elastic modulus, and was then evaluated based on Landis's criteria. Landis and Koch (1977) reported that ICC values indicate reliability in accordance to the following classification, namely, substantial (0.61–0.80), or almost perfect (0.81–1.00).

A randomized, repeated-measures, cross-over design [condition (stabilization, non-stabilization) × time (Pre, Post)] was used to examine the acute effect of cross-body stretch on the muscle hardness. To avoid the carry-over effect of the stretching, each subject attended two sessions more than three days apart.

A two-way analysis of variance with repeated measure based on two factors [scapular condition (stabilization, non-stabilization) × time (Pre, Post)] was used to determine the effect of scapular stabilization during cross-body stretch on the shear elastic modulus. If a significant interaction was found, a post-hoc test was performed for each factor using the paired t-test. Additionally, if a significant difference was identified in the paired t-test, the rates of change before and after the cross-body stretch were calculated and compared using the Student's t test. A confidence level of 0.05 was used in all statistical tests. Cohen's *d* values were also reported as the effect size, with the values of 0.2, 0.5, and 0.8, considered to elicit small, moderate, and large effects, respectively (Cohen 1988). G*power software (Version 3.1., Heinrich Hein University, Duesseldorf, Germany) was used to determine the effect size of scapular stabilization and non-stabilization.

3. Results

The shear elastic moduli for all measurement sites are shown in Table 1. With respect to the superior portion of the infraspinatus, two-way analysis of variance showed a significant main effect of the scapular condition ($F = 5.24$, $p < 0.05$) and time ($F = 17.2$, $p < 0.01$), and a significant interaction between scapular condition and time. The post hoc test for time indicated that the Post-values of the shear elastic modulus were lower than the Pre-values for scapular stabilization condition ($p < 0.01$), whereas no significant difference between Pre and Post-values was found for the non-stabilization condition of the scapula ($p = 0.23$). With respect to the inferior portion of the infraspinatus, two-way analysis of variance showed a significant main effect due to time ($F = 23.69$, $p < 0.01$), no significant effect of scapular condition ($F = 0.08$, $p = 0.78$), and a significant interaction between scapular condition and time. The post-hoc test for time indicated that the Post-values of the shear elastic modulus were lower than the Pre-values for scapular stabilization condition ($p < 0.01$), whereas no significant difference between Pre and Post-values was found for the non-stabilization condition of the scapula ($p = 0.14$). On the other hand, two-way analysis of variance in the teres minor or the posterior portion of the deltoid muscle showed no significant main effects in regard to the scapular condition ($F = 0.01$, $p = 0.93$; $F = 0.09$, $p = 0.77$, respectively), due to time ($F = 0.30$, $p = 0.59$; $F = 2.27$, $p = 0.15$, respectively), or interaction.

For the superior portion of the infraspinatus and the inferior portion of the infraspinatus for which significant differences were found during the post-hoc test, the rate of changes were 25.8 ± 5.8% and 24.9 ± 4.4%, respectively. The Student's t-test showed no significant difference between the modulus of the superior portion of the infraspinatus and the inferior portion of the infraspinatus ($p = 0.62$).

The reliability values of the shear elastic modulus measurements are shown in Table 2, and these are classified as substantial, or almost perfect, in accordance to the study by Landis and Koch (1977).

4. Discussion

This study quantitatively evaluated the effect of scapular stabilization during cross-body stretch on the hardness of the infraspinatus, TM, and deltoid muscles, using shear elastic modulus measured by SWE. The main finding of this study indicated that stabilizing the scapula during cross-body stretch decreased the hardness of the infraspinatus.

We hypothesized that the decrease in the shear elastic modulus after cross-body stretch with scapular stabilization would be greater than the decrease obtained after cross-body stretch without scapular stabilization. Based on the results, our hypothesis was partially validated. Specifically, the shear elastic moduli of ISPs and ISPi decreased after cross-body stretch with scapular stabilization, but the moduli of TM and PD did not.

Our study showed that cross-body stretch without scapular stabilization produced no decrease in the shear elastic modulus, whereas cross-body stretch with scapular stabilization did produce such an effect. Salamh et al. (2015) compared scapular stabilization and scapular non-stabilization during cross-body stretch with respect to shoulder ROM in asymptomatic female volleyball players with glenohumeral internal rotation deficit (GIRD), which is a condition resulting in the loss of internal rotation of the glenohumeral joint as compared to the contralateral side. This study suggested that the addition of scapular stabilization during cross-body stretch might better target the soft tissue responsible for GIRD, and that cross-body stretch performed with scapular stabilization achieved significantly greater improvements in internal rotation and posterior shoulder tightness than cross-body stretch without scapular stabilization. The results of our study resemble the those obtained by Salamh et al. (2015) in that scapular stabilization during cross-body stretch had a significant effect. Concerning the origin of this effect, Wilk et al. (2013) suggested that scapular stabilization during cross-body stretch might better isolate the targeted tissues of the posterior shoulder structures, whereas cross-body stretch without scapular stabilization allowed the accessory abduction of the scapula during horizontal adduction of the shoulder, preventing the posterior shoulder structures from achieving optimal stretch. We therefore believe that cross-body stretch performed with scapular stabilization decreased the hardness due to the integration of elongation force into the posterior shoulder structures, whereas cross-body stretch without scapular stabilization produced no change of the hardness due to the distribution of the elongation force.

Although stabilizing the scapula during cross-body stretch decreases the hardness of ISPs and ISPi, there was no change in the shear elastic modulus of each TM and PD after cross-body stretch with scapular stabilization and no difference between ISPs and ISPi with respect to the rate of change. For the infraspinatus muscle, relevant literature suggests that horizontal adduction of the shoulder, which is similar to cross-body stretch, is a position that elongates the infraspinatus (Wilk et al. 2002; Houglum. 2001), and the results of our study support that theory. For the teres minor muscle, relevant literature reported that effective stretching of the TM was achieved by adding internal rotation at maximal elevation of the shoulder (Evjenth. 1993), or by adding maximal internal rotation during shoulder abduction (Houglum. 2010). The reason for the lack of decrease in the shear elastic modulus of TM observed in our study may be that cross-body stretch is not an appropriate maneuver for stretching the TM. For the deltoid muscle, cross-body stretch that involves horizontal adduction of the shoulder produced no decrease in the shear elastic modulus of the PD. This finding is not in agreement with the findings of a cadaveric study by Muraki et al. (2006), who reported that horizontal adduction of the shoulder stretches the PD. This disagreement probably originates from the difference in the nature of the study medium (i.e., the living body versus the cadaver). Previous studies reported that the viscoelastic and other material properties of cadaver muscle differ from those of the muscle in vivo (Leitschuh et al. 1996; Gottsauner-Wolf et al. 1995). It is also possible that the extent of stretching differed between our study and Muraki's, since the end point in our study was given by the subjects' threshold of discomfort or pain. Therefore, future study is needed regarding individual stretching maneuvers targeting shoulder muscles such as the TM and the deltoid, based on the shear elastic modulus obtained by SWE.

Our findings that scapular stabilization during cross-body stretch is important for stretching the infraspinatus may be useful in the clinical and athletic setting. However, this study had some limitations. First, the subjects in the study were healthy young men without a history of orthopedic or nervous system disease. Therefore, similar effects cannot always be expected in athletes such as baseball or volleyball players, who rely heavily on overhead motion. Second, we could not evaluate the posterior capsule of the glenohumeral joint, which is also responsible for posterior shoulder tightness, because of excessive reflection of the ultrasonic wave during the measurement using SWE. Therefore, a method that could measure the thin tissue around the bone is needed. Third, this study did not measure the scapular motion during cross-body stretch. Therefore, it is unknown how stable the scapula really was during the cross-body stretch. Fourth, it is unknown on whether the stretching procedure reproduced from a previously conducted study (McClure et al. 2007), which was repeated five times, with each time interval spanning 30 s, and with 30 s intervals, is optimal for TM and PD, given the lack of significant differences. Considering the p-value and the effect size of TM, it is possible that TM is more stretched by cross-body stretch at longer stretching period. Fifth, the measurement order may have affected the shear elastic modulus. The shear elastic modulus was measured in a sequential order and in accordance to ISPs, ISPi, TM, and

PD measurements. Thus, muscles measured at later times may demonstrate a diminished effect. However, we believe that there are minor effects on the shear elastic modulus due to the measurement order because all the serial measurements were performed within five minutes. Finally, posture changes for the measurement—from lying down to sitting—possibly reduces the stretching effects by actively lifting the arm. Further research work is required to address these issues.

5. Conclusions

Manual scapular stabilization during cross-body stretch is an efficient maneuver that can be used to decrease the hardness of the infraspinatus muscle.

References

Akagi R, Takahashi H. Acute effect of static stretching on hardness of the gastrocnemius muscle. Med Sci Sports Exerc. 2013 Jul;45(7):1348–54.

Akagi R, Takahashi H. Effect of a 5-week static stretching program on hardness of the gastrocnemius muscle. Scand J Med Sci Sports. 2014 Dec;24(6):950–7.

Bercoff J, Tanter M, Fink M. Supersonic shear imaging: A new technique for soft tissue elasticity mapping. IEEE Trans Ultrason Ferroelectr Freq Control. 2004 Apr;51(4):396–409.

Burkhart SS, Morgan CD, Ben Kibler W. The disabled throwing shoulder: Spectrum of pathology Part I: Pathoanatomy and biomechanics. Arthrosc - J Arthrosc Relat Surg. 2003 Apr;19(4):404–20.

Cohen J. Statistical power analysis for the behavioral sciences. New Jersy: L. Erlbaum Associates; 1988.

Dashottar A, Costantini O, Borstad J. A comparison of range of motion change across four posterior shoulder tightness measurements after external rotator fatigue. Int J Sports Phys Ther. 2014;9(4):498–508.

Gennisson JL, Cornu C, Catheline S, Fink M, Portero P. Human muscle hardness assessment during incremental isometric contraction using transient elastography. J Biomech. 2005 Jul;38(7):1543–50.

Gottsauner-Wolf F, Grabowski JJ, Chao EYS, An KN. Effects of freeze/thaw conditioning on the tensile properties and failure mode of bone-muscle-bone units: A biomechanical and histological study in dogs. J Orthop Res. 1995;13(1):90–5.

Grossman MG, Tibone JE, McGarry MH, Schneider DJ, Veneziani S, Lee TQ. A cadaveric model of the throwing shoulder: a possible etiology of superior labrum anterior-to-posterior lesions. J Bone Joint Surg Am. 2005;87(4):824–31.

Koo TK, Guo J-Y, Cohen JH, Parker KJ. Quantifying the passive stretching response of human tibialis anterior muscle using shear wave elastography. Clin Biomech (Bristol, Avon). 2014 Jan;29(1):33–9.

Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977 Mar;33(1):159–74.

Leitschuh PH, Doherty TJ, Taylor DC, Brooks DE, Ryan JB. Effects of postmortem freezing on tensile failure properties of rabbit extensor digitorum longus muscle tendon complex. J Orthop Res. 1996;14(5):830–3.

Ludewig, P.M., Cook TM. Translations of the Humerus in Persons With Shoulder Impingement Symptoms. J Orthop Sports Phys Ther. 2002;32(6):248–59.

Magnusson SP, Simonsen EB, Aagaard P, Sørensen H, Kjaer M. A mechanism for altered flexibility in human skeletal muscle. J Physiol. 1996;497 (Pt 1(1996):291–8.

Maïsetti O, Hug F, Bouillard K, Nordez A. Characterization of passive elastic properties of the human medial gastrocnemius muscle belly using supersonic shear imaging. J Biomech. 2012 Apr 5;45(6):978–84.

McClure P, Balaicuis J, Heiland D, Broersma ME, Thorndike CK, Wood A. A randomized controlled comparison of stretching procedures for posterior shoulder tightness. J Orthop Sports Phys Ther. 2007 Mar;37(3):108–14.

Muraki T, Aoki M, Uchiyama E, Murakami G, Miyamoto S. The effect of arm position on stretching of the supraspinatus, infraspinatus, and posterior portion of deltoid muscles: a cadaveric study. Clin Biomech (Bristol, Avon). 2006 Jun;21(5):474–80.

Nakamura M, Ikezoe T, Kobayashi T, Umegaki H, Takeno Y, Nishishita S, et al. Acute effects of static stretching on muscle hardness of the medial gastrocnemius muscle belly in humans: An ultrasonic shear-wave elastography study. Ultrasound Med Biol. 2014 Jul 25;40(9):1991–7.

Nordez a, Gennisson JL, Casari P, Catheline S, Cornu C. Characterization of muscle belly elastic properties during passive stretching using transient elastography. J Biomech. 2008 Jul 19;41(10):2305–11.

Reinold MM, Wilk KE, Macrina LC, Sheheane C, Dun S, Fleisig GS, et al. Changes in shoulder and elbow passive range of motion after pitching in professional baseball players. Am J Sports Med. 2008;36(3):523–7.

Salamh P a., Kolber MJ, Hanney WJ. Effect of Scapular Stabilization During Horizontal Adduction Stretching on Passive Internal Rotation and Posterior Shoulder Tightness in Young Women Volleyball Athletes: A Randomized Controlled Trial. Arch Phys Med Rehabil. 2015;96(2):349–56.

Tyler TF, Nicholas SJ, Lee SJ, Mullaney M, McHugh MP. Correction of posterior shoulder tightness is associated with symptom resolution in patients with internal impingement. Am J Sports Med. 2010;38(1):114–9.

Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. Am J Sports Med. 2000;28(5):668–73.

Umegaki H, Ikezoe T, Nakamura M, Nishishita S, Kobayashi T, Fujita K, et al. The effect of hip rotation on shear elastic modulus of the medial and lateral hamstrings during stretching. Man Ther. 2014 Aug 13;7–10.

Umegaki H, Ikezoe T, Nakamura M, Nishishita S, Kobayashi T, Fujita K, et al. Acute effects of static stretching on the hamstrings using shear elastic modulus determined by ultrasound shear wave elastography: Differences in flexibility between hamstring muscle components. Man Ther. 2015;4–7.

Umehara J, Ikezoe T, Nishishita S, Nakamura M, Umegaki H, Kobayashi T, et al. Effect of hip and knee position on tensor fasciae latae elongation during stretching: An ultrasonic shear wave elastography study. Clin Biomech. 2015 Sep;30(10):1056–9.

Weppler CH, Magnusson SP. Increasing Muscle Extensibility: A Matter of Increasing Length or Modifying Sensation? Phys Ther. 2010 Mar 1;90(3):438–49.

Wilk K, Reinold M, Dugas J, Arrigo C, Moser M, Andrews J. Current concepts in the recognition and treatment of superior labral (SLAP) lesions. J Orthop Sport Phys Ther. 2005;35(5):273–91.

Wilk KE, Hooks TR, Macrina LC. The modified sleeper stretch and modified cross-body stretch to increase shoulder internal rotation range of motion in the overhead throwing athlete. J Orthop Sports Phys Ther. 2013 Dec;43(12):891–4.

Wilk KE, Meister K, Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. Am J Sports Med. 2002 Aug 10;30(1):136–51.

Table 1. Shear elastic modulus (kPa) of ISPs, ISPi, TM, and PS.

	Condition	Pre (kPa)	Post (kPa)	Effect size	Interaction
ISPs	Stabilization	6.7 ± 2.1	4.9 ± 2.1	0.9	$p < 0.05$
	Nonstabilization	7.1 ± 2.7	6.6 ± 2.2	0.2	$F = 4.91$
ISPi	Stabilization	6.8 ± 1.8	5.0 ± 1.5	1.0	$p < 0.01$
	Nonstabilization	6.0 ± 1.0	5.7 ± 1.2	0.3	$F = 8.92$
TM	Stabilization	6.5 ± 2.4	6.4 ± 3.0	0.6	$p = 0.43$
	Nonstabilization	6.2 ± 2.5	6.6 ± 2.3	0.2	$F = 0.96$
PD	Stabilization	17.1 ± 5.7	16.4 ± 6.5	0.1	$p = 0.74$
	Nonstabilization	17.8 ± 8.0	16.5 ± 4.8	0.2	$F = 0.11$

Values are expressed as mean value ± standard deviation. The effect size represents Cohen's *d* values. ISPs: superior infraspinatus, ISPi: inferior infraspinatus, TM: teres minor, PD: posterior portion of deltoid.

Table 2. Reliability of shear elastic modulus measurements.

	Intra-day reliability (95% CI)	Inter-day reliability (95% CI)
ISPs	0.89 (0.69–0.97)	0.98 (0.90–0.97)
ISPi	0.94 (0.81–0.98)	0.82 (0.34–0.96)
TM	0.97 (0.92–0.96)	0.90 (0.60–0.98)
PD	0.99 (0.98–0.99)	0.77 (0.20–0.95)

CI: confidence interval, ISPs: superior infraspinatus, ISPi: inferior infraspinatus, TM: teres minor, PD: posterior portion of deltoid.

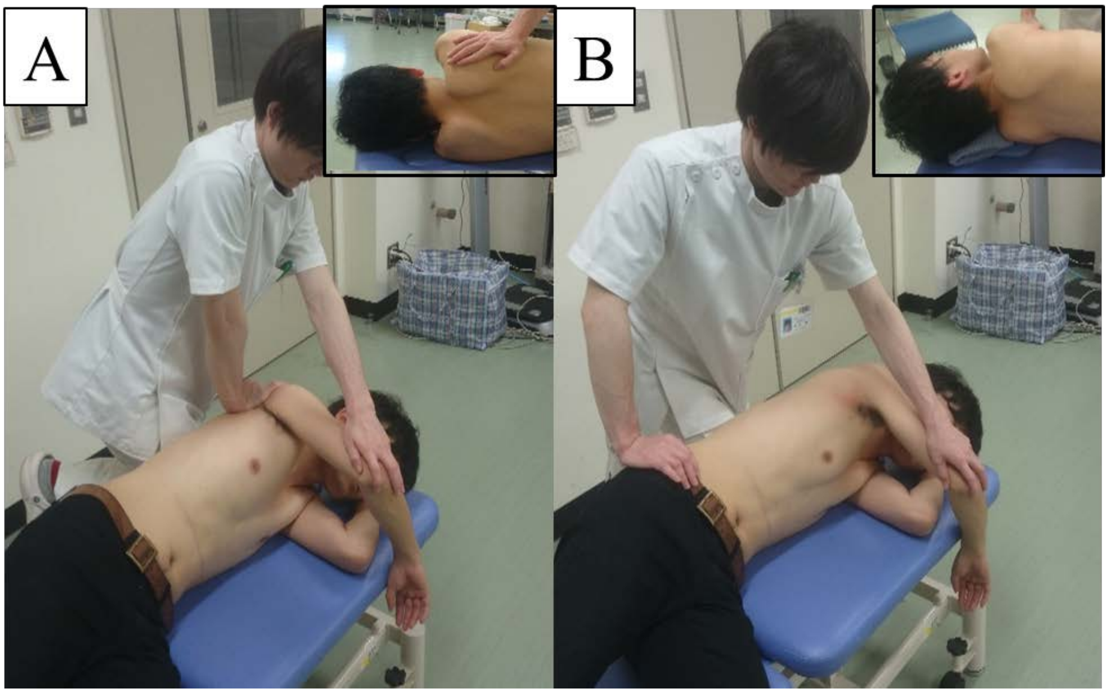

Figure 1. Cross-body stretch techniques.

Panel A illustrates the cross-body stretch with scapular stabilization. Panel B illustrates the cross-body stretch without scapular stabilization.

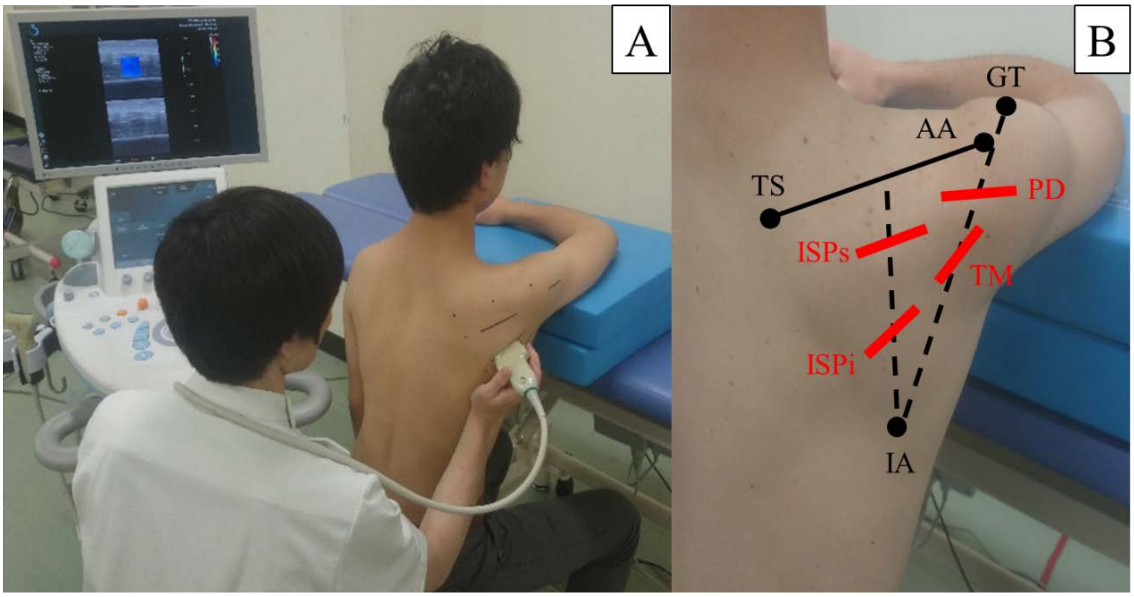

Figure 2. Measurement of shear elastic modulus for each muscle.

Panel A illustrates the posture for measuring the shear elastic modulus. The subject's shoulder is flexed forward at 90°, while the elbow is also flexed at 90°, but with the forearm and arm in the horizontal plane. Panel B indicates the location of each muscle, as considered for the ultrasound measurement of the shear elastic modulus. Each red line marks the measurement site and the orientation of the ultrasound transducer on the muscle. The measurement site for superior infraspinatus (ISPs) was defined as the intersection of the line that connects the greater tubercle (GT) to the quarter point between trigonum scapulae (TS) and the inferior angle (IA), and the line that connects IA to the half point between TS and the acromial angle (AA). The measurement site for ISPi (inferior infraspinatus) was defined as the intersection of the line that connects GT to the three-quarter point between TS and IA, and the line that connects IA to the half point between TS and AA. The measurement site for teres minor (TM) was defined as the half point between IA and GT, while the measurement site for posterior portion of deltoid (PD) was defined as the point that lies 4 cm below AA.