Title: Effects of two stretching methods on shoulder range of motion and muscle stiffness in baseball players with posterior shoulder tightness: a randomized controlled trial

Running title: Posterior shoulder stretching in baseball players

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Abstract

Background: The cross-body stretch and sleeper stretch are widely used for improving flexibility of the posterior shoulder. These stretching methods were modified by Wilk. However, few quantitative data are available on the new, modified stretching methods. A recent study reported the immediate effects of stretching and soft tissue mobilization on the shoulder range of motion (ROM) and muscle stiffness in subjects with posterior shoulder tightness. However, the long-term effect of stretching for muscle stiffness is unknown. The objective of this study is to examine the effects of two stretching methods, the modified cross-body stretch (MCS) and the modified sleeper stretch (MSS), on shoulder ROM and muscle stiffness in baseball players with posterior shoulder tightness.

Methods: Twenty-four college baseball players with ROM limitations in shoulder internal rotation were randomly assigned to the MCS or MSS group. We measured shoulder internal rotation and horizontal adduction ROM and assessed posterior shoulder muscle stiffness with ultrasonic shear wave elastography before and after a 4-week intervention. Subjects were asked to perform 3 repetitions of the stretching exercises every day, for 30 s, with their dominant shoulder.

Results: In both groups, shoulder internal rotation and horizontal adduction ROM were significantly increased after the 4-week intervention. Muscle stiffness of the teres minor decreased in the MCS group and that of infraspinatus decreased in the MSS group.

Conclusions: The MCS and MSS are effective for increasing shoulder internal rotation and horizontal adduction ROM and improving muscle stiffness of the infraspinatus or teres minor.

Level of evidence: Treatment study, randomized controlled study, level 2

Key words:

shear wave elastography; modified sleeper stretching; modified cross-over stretching; posterior shoulder tightness; baseball; infraspinatus; teres minor

Introduction

In the throwing motion in baseball, significant force is generated in the posterior shoulder, especially in the release to follow-through phases[10]. Due to this force generation, baseball players often exhibit glenohumeral internal rotation deficit (GIRD) and glenohumeral horizontal adduction deficit (GHAD) in their throwing arm[3, 4, 25, 34, 35]. Limitation in range of motion (ROM) may be caused by reduced soft tissue flexibility in the posterior shoulder region, referred to as posterior shoulder tightness[4, 25]. Baseball players with shoulder pathology have previously been reported to exhibit GIRD or GHAD[6, 24, 32, 33], and those with GIRD or GHAD have been reported to be at high risk for developing shoulder pathology[34, 38]; posterior shoulder tightness is therefore considered to be related to throwing injuries.

In regard to the relationship between posterior shoulder tightness and soft tissues in the posterior shoulder region, several studies have focused on the posterior glenohumeral joint capsule[11-13, 22, 23, 35]. On the other hand, several other studies have correlated certain muscles and posterior shoulder tightness, with some of them suggesting that baseball pitching and exercises involving shoulder external rotators are associated with immediate development of GIRD or GHAD along with exhaustion or mobility deficits of shoulder external rotators[8, 28, 31, 40]. In addition, some reports have shown increase in shoulder internal rotation (IR) or horizontal adduction (HA) ROM with physical therapy aimed at improving extensibility of the posterior shoulder muscles[2, 4, 21, 30, 41] or with dissection of the infraspinatus and teres minor muscles in cadaveric shoulders[5]. A recent study by Bailey et al. showed that the decrease of the infraspinatus stiffness leads to acute gain in shoulder ROM[2].

Therefore, not only the posterior glenohumeral joint capsule, but also the posterior shoulder muscles may be related to posterior shoulder tightness. However, few studies have examined the differences in muscle stiffness between the throwing and non-throwing sides[2].

Among the various stretching methods developed with the aim of reducing posterior shoulder tightness, the cross-body stretch, in which the shoulder is horizontally adducted, and the sleeper stretch, in which the shoulder is internally rotated, are used widely[17-20, 27]. Recently, a few authors proposed that scapular stabilization during the cross-body stretch enhanced the stretching effects on the posterior glenohumeral joint[27, 38]. Indeed, Salamh et al. demonstrated that manual scapular stabilization increases the effects of stretching, when the shoulder is horizontally adducted by a therapist[33]. On the other hand, these stretching methods can be painful in some cases[20]. For these reasons, Wilk et al. developed the modified cross-body stretch (MCS) and the modified sleeper stretch (MSS)[38]. However, little is known about the effects of these stretching methods for reducing GIRD and GHAD. In addition, the effects of these stretching exercises on muscle stiffness, which can be measured as shear elastic modulus using ultrasonic shear wave elastography (SWE) imaging[26], are not clear.

Therefore, this study aimed to compare baseline glenohumeral ROM and muscle stiffness between the throwing and non-throwing sides and to examine the effects of an intervention using the MCS and MSS in baseball players with posterior shoulder tightness of the throwing side. This information will help clinicians select the appropriate stretching method for preventing and improving posterior shoulder tightness in baseball players.

Materials and Methods

This is a randomized controlled study examining the effects of the MCS and MSS performed for 4 weeks in college baseball players with posterior shoulder tightness.

Subjects

Twenty-four college baseball players volunteered for this study. They were randomly assigned to the MCS (N = 12) or MSS groups (N = 12). The inclusion criterion for selection of players that they were participating in daily practice, had posterior shoulder tightness which was evaluated as the presence of GIRD > 10° on the throwing side compared with the non-throwing side[20, 29]. The exclusion criterion was inability to perform stretching exercises because of injury or pain, a history of surgery of the upper arm, or being rehabilitated for the disabled throwing shoulder. Using previously published changes in muscle shear elastic modulus after stretching intervention[26], a power of 0.80, an alpha level of 0.05, and large f of 0.4 were assumed for the two-way factorial analysis of variance, which determined the sample size of 13 per group. Those who were injured during the intervention and were unable to perform stretching exercises were excluded from the analysis. Written informed consent was obtained from each participant. This study was approved by the ethics committee of the Kyoto University Graduate School and Faculty of Medicine (approval number E2331).

Procedures

The testing was conducted in a laboratory at the Kyoto University. Twenty-four participants were randomized by the author using computer-generated permuted block randomization. The permutation lists were CCSS, CSCS, CSSC, SSCC, SCSC, and SCCS (C: MCS, S: MSS). A series randomization procedure was conducted after the recruitment. All measurements were performed by one tester with one or two assistants, who were not blinded to the group assignment. Bilateral pre- and post-intervention (4 weeks) glenohumeral ROM and muscle stiffness were assessed in each subject. To reduce deterioration of reproducibility, the pre- and post-intervention measurements were performed at the same time of the day.

Glenohumeral ROM Measurements

Prior to the ROM measurement, the subjects performed warm-up exercises consisting of 3 repetitions of shoulder flexion, held at the end range with hands clasped, for 10 s[20]. We used a digital angle meter (WR300, Wixey, USA) to measure passive glenohumeral IR, external rotation (ER), and horizontal adduction (HA) ROM. The ROM measurement method conformed to that used in previous studies[37, 39]. ROM measurements were performed with subjects in the supine position, the test shoulder in 90° abduction and elbow in 90° flexion, and the scapula stabilized. Each measurement was performed twice, and the average values were used for analysis. Total ROM was calculated by adding the IR and ER ROM.

Assessment of Shoulder Muscle Stiffness Using SWE

We used the ultrasonic SWE with a 2–10 MHz linear array probe (Aixplorer, Super-Sonic Imagine, Aix en Provence, France) to assess stiffness (shear elastic modulus) of the posterior shoulder muscles, i.e., infraspinatus, teres minor, and posterior deltoid. The previous study reported that the muscle shear modulus measured by using the ultrasonic SWE is highly correlated with Young's modulus from traditional material testing[9]. The ultrasonic SWE could measure the muscle shear modulus at a wide range, and it has high repeatability, with values of 0.978 and 0.948 between trials and between days, respectively[42]. In the assessment using SWE, a color-coded box showing the shear elastic modulus was superimposed on the B-mode ultrasound image, and the circular region of interest was set near the central part of the muscle[26] (Fig. 1). In this study, we used the average circular region of interest for analysis.

Assessment of muscle stiffness was performed in two positions: (1) the subject in the sitting position, with the test shoulder in 90° abduction and 40° IR, and the elbow in 90° flexion (2nd IR); (2) the subject in the sitting position, with the test shoulder in 110° HA and the elbow in 90° flexion (HA). Subjects were instructed to remain relaxed, and their shoulder was moved passively to the assessment position by an assistant. The shoulder and elbow angles were confirmed with a goniometer, and the assistant supported the arm during stiffness measurement. For the measurement at the 2nd IR position, the scapula was stabilized by another assistant who grasped the coracoid. However, the scapula was not stabilized during the measurement in the HA position because the probe placement was near the lateral border of the scapula, which could not be grasped for stabilization. The probe placement for each muscle was as follows (Fig.2): The infraspinatus was measured at the midpoint between the spine of the scapula and inferior angle of the scapula, and the probe was placed parallel to the infraspinatus. The teres minor was measured near the midpoint of the inferior angle of the scapula and the greater tubercle, where the teres minor was identified with the probe vertical to it; the probe was then placed parallel to the teres minor. The posterior deltoid was measured 4 cm below the posterior acromion. Each measurement was performed twice, and the average of the two values was used for analysis.

Two Stretching Methods — MCS and MSS

The modified conventional stretching methods, i.e., the MCS and MSS, are shown in Fig.3. The MCS was performed with the subjects in the side lying position on the throwing side to stabilize the scapula; the forearms were aligned, with the opposite forearm on top to restrict external rotation of the stretched shoulder; and the humerus of the throwing side was moved into HA using the opposite arm. The MSS was performed with the subjects in the side lying position on the throwing side; the trunk was rolled 30° posteriorly on the throwing side to decrease the pressure at the glenohumeral joint; a towel was placed under the subject's humerus to increase the amount of glenohumeral HA; and the humerus of the throwing side was moved into IR using the opposite arm. Subjects were instructed to perform 3 repetitions of the stretches on the throwing side only, once daily after practice or before going to bed, for 4 weeks, and to hold each stretch for 30 s.

Intra-rater Reliability

Because no intervention was applied to the non-throwing side, the intra-rater reliability of each measurement was established using the pre- and post- intervention values of the non-throwing side. The average value of two measurements was used for calculating the intraclass correlation coefficient [ICC (1, 2)]. The ICC (1, 2) values for each measurement are shown in Table 1. The standard error of mean (SEM) values of each item are also shown in the same table. In regard to the intra-rater reliability in this study, the ICC (1, 2) values for glenohumeral ROM and muscle stiffness were >0.8 and >0.7, respectively. Landis and Koch proposed that ICC values from 0.61 to 0.80 should be considered as “good” and those from 0.81 to 1.00 as “very good”[16].

Statistical Analysis

R 2.8.1 was used to provide the ICC (1, 2) and the SEM. SPSS ver. 17 (SPSS Japan, Tokyo, Japan) was used for statistical processing. To compare the baseline glenohumeral ROM and muscle stiffness between the throwing and non-throwing sides, we used the paired t-test or Wilcoxon signed-rank test depending on whether the data followed a normal distribution. To examine the effect of intervention with respect to all variables, a two-way factorial analysis of variance (group × time) was used, and post hoc comparison was made for the main effect using the paired t-test or Wilcoxon signed-rank test depending on whether the data followed a normal distribution. Effect sizes were calculated using Microsoft Excel. Between the throwing and non-throwing sides, the effect size was calculated as [throwing side mean − non-throwing side mean]/pooled SD, and within-group effect size was calculated as [post mean − pre mean]/pre SD. Differences were considered statistically significant at values of $P < 0.05$.

Results

Subjects were recruited from July 26 to November 15, 2014. In expectation of losses to follow up, we recruited 24 subjects overall. One of the subjects in the MSS group was excluded from the analysis due to an injury experienced during baseball practice involving the non-throwing shoulder, following which he was unable to continue with the stretching intervention. As a result, we analyzed 12 and 11 subjects in the MCS and MSS groups, respectively, who completed this study protocol (Fig. 4). We verbally confirmed that the subjects have performed the stretching more than 70% of days during the intervention period. No significant differences were found between the two groups at baseline (Table 2).

Comparison of Dominant and Non-dominant Shoulders

The baseline glenohumeral ROM and muscle stiffness for the throwing and non-throwing sides are shown in Table 3. The IR and HA ROM were smaller, and the ER ROM was larger on the throwing side compared with the non-throwing side ($P < 0.01$). In regard to muscle stiffness, the infraspinatus and teres minor at the 2nd IR position and the teres minor at the HA position had greater muscle stiffness on the throwing side than those on the non-throwing side ($P < 0.01$). The posterior deltoid showed no significant differences between the throwing and non-throwing sides.

Shoulder ROM

The glenohumeral ROM before and after 4 weeks of stretching and the amount of change are shown in Table 4. A significant main effect difference was found for time on the IR and HA ROM, but no interaction effects were found between groups. As a result of post hoc comparison in both groups, the IR ROM (both groups; $P < 0.01$) and HA ROM (MCS; $P < 0.01$, MSS; $P < 0.05$) were increased.

Shoulder Muscle Stiffness

The effects of 4 weeks of stretching on muscle stiffness are shown in Table 5. A significant main effect difference was found for time on the infraspinatus and teres minor at both positions, but no interaction effects were found between groups. As a result of post hoc comparison, muscle stiffness of the teres minor was decreased at both positions in the MCS group (both positions; $P < 0.05$). In the MSS group, muscle stiffness of the infraspinatus was decreased at both positions (2nd IR; $P < 0.01$, HA; $P < 0.05$). No significant main effect were found on the posterior deltoid.

Discussion

This study examined the effects of 4 weeks of the MCS and MSS in baseball players with posterior shoulder tightness of the glenohumeral joint and muscle stiffness.

First, we compared the baseline glenohumeral ROM and muscle stiffness between the throwing and non-throwing sides. In similar previous studies, IR ROM and HA ROM were smaller, and ER ROM was larger on the throwing side compared with the non-throwing side[2-4, 25, 35, 36]. In regard to muscle stiffness, the infraspinatus and teres minor showed significantly greater stiffness on the throwing side than the non-throwing side. In the previous study examining shoulder muscle stiffness using SWE, no difference was found between the throwing and the non-throwing sides in the stiffness of the infraspinatus[2]. This finding is not in accordance with our results. This discrepancy may be due to the difference in the subject's measurement position and the measured region. Some of the previous studies have reported that an immediate decrease in glenohumeral IR and HA ROM was induced with baseball pitching or exercises involving shoulder external rotators together with exhaustion or mobility deficits of these muscles[7, 28, 31, 39]. In prior research using SWE, muscle stiffness increased immediately after exercises, thereby causing muscle exhaustion and microdamage[1, 15]. It is possible that the fatigue, damage, and loss of flexibility in the infraspinatus and the teres minor secondary to repetitive throwing motions lead to posterior shoulder tightness. In a previous study that examined muscle activity of the upper extremities during baseball pitching using needle electromyography, the teres minor demonstrated the highest level of activity of all shoulder muscles during the deceleration phase[9]. Moreover, Kurokawa et al. clarified that the muscle activity ratio of the teres minor and infraspinatus during shoulder external rotation at 90° of abduction, which is necessary during the pitching motion, was significantly higher than that at 0° of abduction [14]. In other words, the throwing motion requires higher intensity eccentric contraction of the teres minor than the infraspinatus; the teres minor therefore tends to be more fatigued or injured, which could lead to GIRD or GHAD. We suggest that the teres minor is a key muscle to consider in cases of posterior shoulder tightness.

We will now discuss the effects of a 4-week stretching intervention. In both the MCS and MSS groups, glenohumeral IR and HA ROM were increased. Concerning the effects of a 4-week stretching intervention on ROM, glenohumeral IR and HA ROM were increased in both the MCS and MSS groups. Regarding the amount of the change in the glenohumeral ROM, no significant differences were found between groups. Compared with previous studies on performance of stretching intervention for posterior shoulder tightness, the amount of change was smaller in our study[19, 20]. This is probably because lesser repetition or shorter intervention period was performed in this study than the previous studies[19, 20]. Besides, performing other practices is not restricted in our study, such as amount of pitching and weight training for the upper body; thus, these daily practices could have affected the result of this study. In the MCS group, muscle stiffness of the teres minor was decreased. In the MSS group, muscle stiffness of the infraspinatus was decreased. In several previous studies examining the effects of a long-term stretching intervention for posterior shoulder tightness, both the cross-body and sleeper stretches were found to be effective for increasing glenohumeral IR and HA ROM[18-20]. We investigated the effects of the MCS and MSS, which are modifications of the cross-body and sleeper stretches, and determined that they are effective for increasing glenohumeral IR and HA ROM, similar to previous studies. Moreover, Akagi and Takahashi examined the effects of a 5-week stretching program for the gastrocnemius using SWE and reported that muscle stiffness was decreased and ankle dorsiflexion ROM was increased[1]. In our study, decreased muscle stiffness may be one of the reasons for the increase seen in the glenohumeral ROM.

Difference was found in muscles that respond to MCS and MSS for stiffness. The previous study, which used cadavers in examining the effective position for stretching, indicated that the infraspinatus could be stretched effectively by moving the shoulder into internal rotation, but not by moving into horizontal adduction. The result of this study supports the results of the previous study in that the stiffness of infraspinatus was decreased only in the MSS group, wherein the shoulder is internally rotated. No studies quantitatively examined the effective position with regard to the stretching of the teres minor. In this study, the stiffness of the teres minor was decreased only in the MCS group, wherein the shoulder is horizontally adducted. Another possibility is the difference in the side lying position. Although both stretching methods were performed in the side lying position on the throwing side, MSS was performed with the trunk rolled 30° posteriorly, whereas MCS was performed in the normal side lying position. Therefore, while the lateral margin of the scapula, which is the region of origin of the teres minor, was compressed and fixed on the floor in MCS, the infraspinatus fossa may have contacted the floor in MSS, resulting in effective stretching of the infraspinatus muscle.

So far, to the best of our knowledge, no previous studies examined the muscle tightness before and after a period of stretching intervention in baseball players having posterior shoulder tightness. This study showed that the MCS and MSS decreased the stiffness of the teres minor and infraspinatus, respectively, and both stretching methods resulted in improvement of the shoulder ROM. We think that the result of this study is useful for clarifying the mechanism of posterior shoulder tightness and developing methods of treatment or prevention.

Limitations

This study had several limitations. First, the number of pitches, the intensity of practice, and other stretching conditions were not controlled. Despite this, the fact that the intervention showed a significant effect proves that this study is meaningful and of practical value concerning the use of the MCS and MSS. Second, the glenohumeral joint capsule and ligaments affecting glenohumeral ROM were not examined in this study. Most previous studies have focused on the correlation between the joint capsule and posterior shoulder tightness[11-13, 22, 23, 35]. In these studies, plication of cadaveric posterior shoulder capsule led to decreased glenohumeral IR and change in humeral head movement during glenohumeral IR and HA. We did not examine these joint components; therefore, development of new methods for assessing these in vivo is desired. Third, humeral torsion was not examined in this study. Bailey commented that the humeral torsion did not affect shoulder stretching[2]; thus, we think that the humeral torsion has little relation to the result in this study. Fourth, we did not classify the subjects based on their symptoms such as pain; therefore, we could not determine the influence of stretching on pain. Further investigation accounting for pain in a larger sample size would be useful for assessing the effects of the MCS and MSS.

Conclusion

In this study, we compared glenohumeral ROM and muscle stiffness between the throwing and non-throwing sides in baseball players with posterior shoulder tightness, and examined the effects of a 4-week intervention using two stretching methods, the MCS and MSS, on glenohumeral ROM and muscle stiffness. Baseball players with posterior shoulder tightness exhibited smaller glenohumeral IR and HA ROM and greater muscle stiffness of the infraspinatus and teres minor on the throwing side. The MCS and MSS are effective for increasing shoulder IR and HA ROM and improving muscle stiffness of the infraspinatus and teres minor. These stretching techniques can be performed by baseball players without the help of a therapist, which enables them to treat or prevent posterior shoulder tightness independently.

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Table 1
Intra-class Correlation Coefficient [ICC(1, 2)] Values (intra-rater)

		ICC(1,2)	SEM
ROM	IR	0.88	2.37
	ER	0.93	3.18
	HA	0.92	4.49
Muscle Stiffness 2nd IR Position	Infraspinatus	0.73	1.39
	Teres Minor	0.88	1.50
	Posterior Deltoid	0.77	1.26
Muscle Stiffness HA Position	Infraspinatus	0.75	3.67
	Teres Minor	0.79	3.47
	Posterior Deltoid	0.84	2.86

Abbreviations: ROM; range of motion, IR; glenohumeral internal rotation, HA; glenohumeral horizontal adduction.

Table 2. Baseline Characteristics of Participants

		MCS (12)	MSS (11)
Age (year)		21.4±1.2	20.3±0.9
Height (cm)		173.0±4.0	171.7±6.9
Mass (kg)		70.4±3.0	68.6±6.0
ROM (°)	IR	49±6	53±6
	ER	118±9	116±8
	TOTAL	168±9	169±7
	HA	81±11	86±9
Muscle Stiffness 2nd IR Position (kPa)	Infraspinatus	9.8±2.4	10.0±2.8
	Teres Minor	15.5±4.5	13.5±2.9
	Posterior Deltoid	10.1±5.0	8.3±2.3
Muscle Stiffness HA Position (kPa)	Infraspinatus	12.6±4.5	11.3±5.7
	Teres Minor	19.6±5.3	17.5±5.1
	Posterior Deltoid	30.5±6.5	31.4±8.5

Abbreviations: MCS; modified cross-body stretch, MSS; modified sleeper stretch, ROM; range of motion, IR; glenohumeral internal rotation, ER;

glenohumeral external rotation, TOTAL; total glenohumeral rotation, HA; glenohumeral horizontal adduction,

Values are presented as mean ± SD.

At baseline, there was no significant difference between the two groups.

Table3

Comparison of Dominant and Non-Dominant Shoulders (baseline differences)

		Throwing Side	Non-Throwing Side	P value
ROM (°)	IR	51±7	66±7*	<.001
	ER	118±8	106±10	<.001
	TOTAL	169±8	173±12*	0.04
	HA	83±10	109±11*	<.001
Muscle Stiffness 2nd IR Position (kPa)	Infraspinatus	9.8±2.6*	8.1±2.3	<.001
	Teres Minor	14.3±4.0*	10.0±3.1	<.001
	Posterior Deltoid	9.2±3.9	8.4±2.6	0.16
Muscle Stiffness HA Position (kPa)	Infraspinatus	11.1±4.2	10.2±5.0	0.16
	Teres Minor	18.5±5.1*	14.3±4.5	<.001
	Posterior Deltoid	31.1±7.3	29.1±7.1	0.12

Abbreviations: ROM; range of motion, IR; glenohumeral internal rotation, ER; glenohumeral external rotation, TOTAL; total glenohumeral rotation, HA; glenohumeral horizontal adduction.

Values are presented as mean ± SD.

*Significant differences between the throwing and non-throwing sides

Table 4
Effects of a 4-Week Stretching Program on Glenohumeral ROM

	Group	Pre-Stretching (°)	Post-Stretching (°)	Amount of Change (°)	P value
IR	MCS	49±6	57±7**	8±5	<.001
	MSS	53±6	61±6**	8±4	<.001
ER	MCS	118±9	122±8	3±8	0.19
	MSS	116±8	119±8	3±8	0.22
TOTAL	MCS	168±9	179±9*	11±11	<.001
	MSS	169±7	180±10*	11±8	<.001
HA	MCS	81±11	86±9**	6±5	0.004
	MSS	86±9	90±12*	4±5	0.03

Abbreviations: MCS; modified cross-body stretch, MSS; modified sleeper stretch, ROM; range of motion, IR; glenohumeral internal rotation, ER; glenohumeral external rotation, TOTAL; total glenohumeral rotation, HA; glenohumeral horizontal adduction.

Values are presented as mean ± SD.

* Significant post-stretching changes in ROM compared to pre-stretching (P<.05)

** Significant post-stretching changes in ROM compared to pre-stretching

(P<.01)

Table 5

Effects of a 4-Week Stretching Program on Muscle Stiffness

		Group	Pre-Stretching (kPa)	Post-Stretching (kPa)	Amount of Change (kPa)	P value
2nd IR Position	Infraspinatus	MCS	9.8±2.4	9.1±2.8	−0.8±2.1	.23
		MSS	10.0±2.8	7.5±2.3**	−2.6±2.5	.006
	Teres Minor	MCS	15.5±4.5	12.1±3.6*	−3.4±4.3	.02
		MSS	13.5±2.9	12.5±1.7	−1.0±2.9	.29
	Posterior Deltoid	MCS	10.1±5.0	9.2±3.5	−0.8±2.4	.43
		MSS	8.3±2.3	8.5±2.5	0.2±0.9	
HA Position	Infraspinatus	MCS	12.6±4.5	11.3±5.7	−1.3±2.6	.13
		MSS	10.0±3.1	7.8±2.7*	−2.2±3.1	.04
	Teres Minor	MCS	19.6±5.3	15.8±5.7*	−3.8±5.0	.02
		MSS	17.5±5.1	17.2±4.0	-0.4±4.4	.77
	Posterior Deltoid	MCS	30.5±6.5	29.7±7.4	−0.7±5.2	.99
		MSS	31.4±8.5	32.2±6.4	0.7±6.5	

Abbreviations: MCS; modified cross-body stretch, MSS; modified sleeper stretch, IR; glenohumeral internal rotation, HA; glenohumeral horizontal adduction.

Values are presented as mean ± SD.

* Significant post-stretching changes in muscle stiffness compared to pre-stretching ($P<.05$)

** Significant post=stretching changes in muscle stiffness compared to pre-stretching ($P<.01$)

Fig.1. Assessment of Shoulder Muscle Stiffness Using SWE

A color-coded box showing the shear elastic modulus superimposed on the B-mode ultrasound image; the circular region of interest (ROI) was set near the central part of the muscle, and we used the average ROI for analysis.

Abbreviations: ISP; infraspinatus, TM; teres minor, PD; posterior deltoid

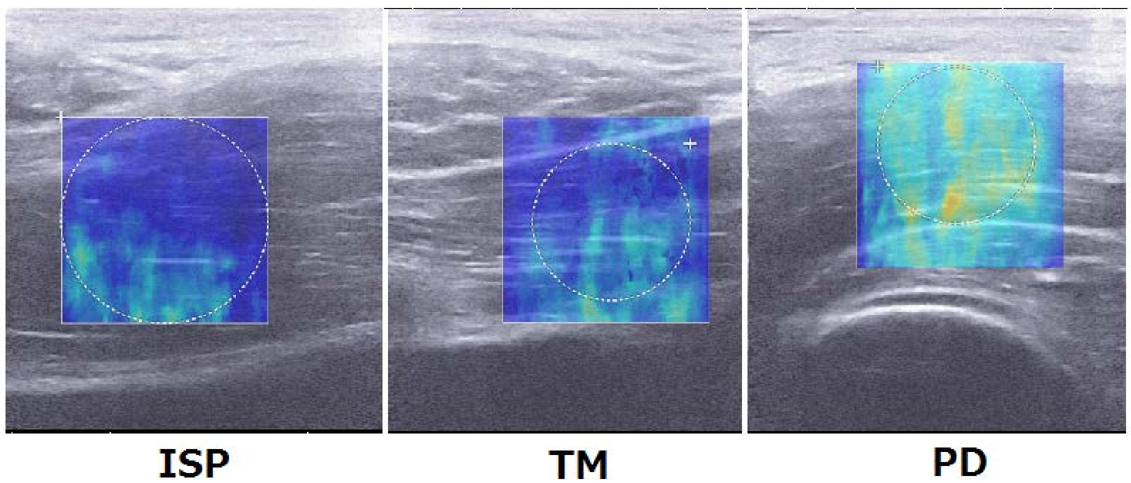

Fig.2. Probe Placement for Each Muscle

The probe placement is shown, with the subject seated and shoulder and elbow flexed to 90°. The ISP is measured at the midpoint of the spine of the scapula and its inferior angle, and the probe is placed parallel to the ISP. The TM is measured near the midpoint of the inferior angle of the scapula and greater tubercle, where the TM is identified with the probe vertical to the TM, and then the probe is placed parallel to the TM. The PD is measured at 4 cm below the posterior acromion, and the probe is placed parallel to the PD.

Abbreviations: ISP; infraspinatus, TM; teres minor, PD; posterior deltoid, SS; spine of the scapula, IA; inferior angle of scapula, GT; greater tubercle.

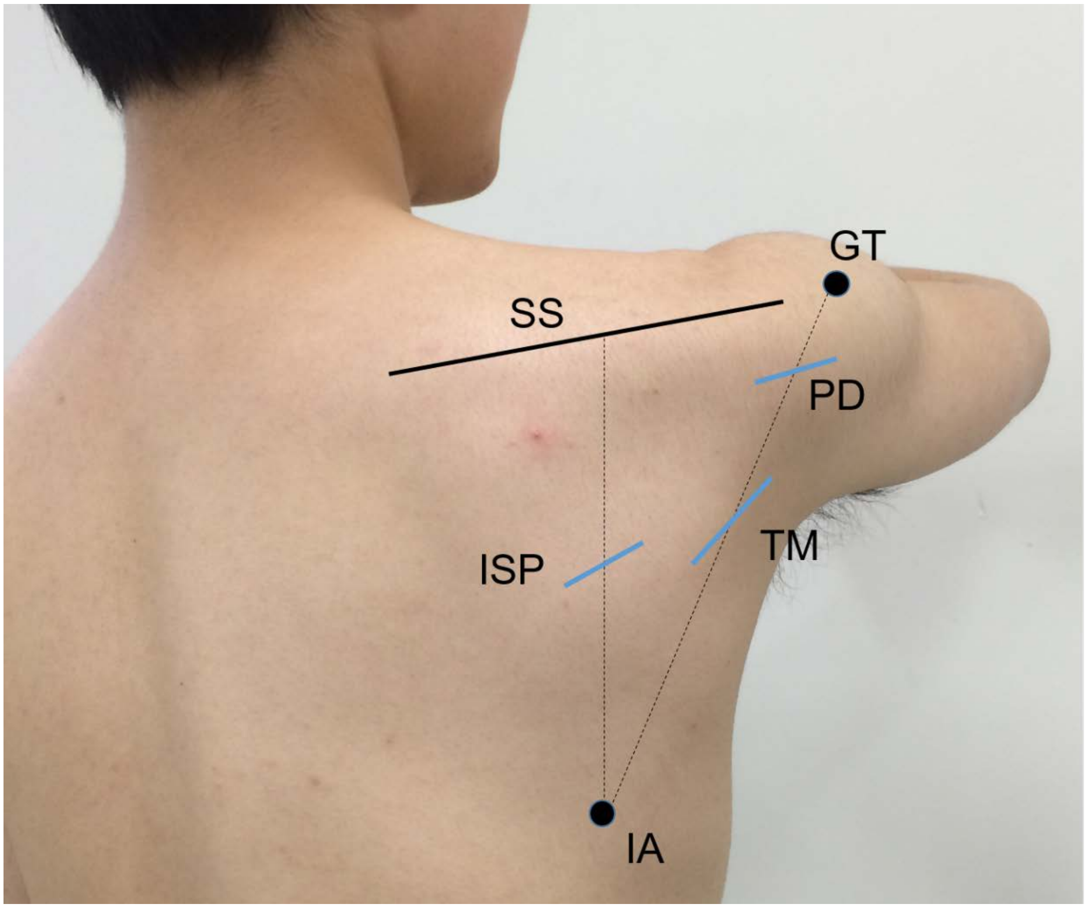
GT
SS
PD
TM
ISP
IA

Fig.3. Two Stretching Methods – MCS and MSS

In this study, we used the MCS and the MSS.

modified cross-body stretch (MCS)

modified sleeper stretch (MSS)

Fig.4. Flow Diagram Representing Enrollment, Allocation, Procedures, and Analysis.