Title

Effective stretching position for the supraspinatus muscle evaluated by shear wave elastography in vivo

Authors and academic degrees

Satoru Nishishita, P.T., M.Sc. [1) 2) 3)], Satoshi Hasegawa, P.T., Ph.D. [1)], Masatoshi Nakamura, P.T., Ph.D. [1)], Hiroki Umegaki, P.T., M.Sc. [1)], Takuya Kobayashi, P.T., M.Sc. [1)], Noriaki Ichihashi, P.T., Ph.D. [1)]

Department and Institution

[1)] Human Health Sciences, Graduate School of Medicine, Kyoto University

[2)] Institute of Rehabilitation Science, Tokuyukai Medical Corporation

[3)] Kansai Rehabilitation Hospital, Tokuyukai Medical Corporation

*__Corresponding author__:

Satoru Nishishita

Human Health Sciences, Graduate School of Medicine, Kyoto University

53 Shogoinkawahara-cho, Sakyo-ku, Kyoto 606-8397, Japan

Telephone: +81-75-751-3935; Fax: +81-75-751-3909

E-mail: nishishitasatoru@gmail.com

Ethical Committee approval

This study has been approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine: No. R0314.

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Conflict of Interest

None.

Abstract

Background:

Stretching is useful for increasing flexibility in clinical and athletic situations. Although several authors have recommended various stretching techniques for the supraspinatus muscle, there is no consensus on the effective stretching position owing to a lack of quantitative analysis in vivo. This study used ultrasonic shear wave elastography in vivo to verify the effective stretching positions for the supraspinatus muscle.

Methods:

The study participants were 15 healthy male volunteers. The shear elastic modulus, used as the index of supraspinatus muscle elongation, was computed using ultrasonic shear wave elastography. The shear elastic modulus was measured at neutral position and maximum internal rotation in 9 positions: 0° elevation, 90° abduction, 90° flexion, maximum extension, maximum horizontal adduction at 45° and 90° elevation, and maximum horizontal abduction at 20°, 45°, and 90° elevation.

Results:

The shear elastic moduli were significantly greater in maximum internal rotation at maximum horizontal abduction with 45° and 90° elevation and maximum internal rotation at maximum extension than those in the other positions. There were no significant differences in the shear elastic moduli among these 3 positions.

Conclusions:

This study demonstrated that maximum internal rotation at maximum extension, maximum internal rotation at maximum horizontal abduction with 90° elevation, and maximum internal rotation at maximum horizontal abduction with 45° elevation are effective stretching positions for the supraspinatus muscle.

Keywords

ultrasonic shear wave elastography

shear elastic modulus

supraspinatus muscle

stretching

shoulder

rehabilitation

Level of evidence

Basic Science Study, Biomechanics, Imaging.

Introduction

Stretching is useful for increasing flexibility in clinical and athletic situations. Many previous studies have reported on the effects of stretching[7, 9, 11, 18, 26] but few studies have reported the method or position used to create an effective stretch[24, 30]. Because the shoulder joint has multiple degrees of freedom and a large range of motion, the method used to stretch shoulder muscles needs to be investigated.

Many studies have reported the relationship between the 3-dimensional shoulder position and the moment arm[16, 17, 32] and torque-vector directions[2, 37] of each shoulder muscle. Therefore, the 3-dimensional shoulder position must be considered when devising effective methods for stretching the shoulder muscles.

Several authors have recommended various stretching positions for each individual muscle[6, 10, 31, 36], but there is no consensus on the effective stretching positions owing to a lack of an in vivo quantitative analysis. The cross-body stretch and the sleeper stretch are well known and commonly used for posterior shoulder tightness[22], but the effect of stretching on individual muscles and other tissues is unclear.

In previous cadaveric studies, the effective stretching position for the shoulder muscles and joint capsule was simulated and quantitatively analyzed[13, 23-25]. Clinicians are in great need of an in vivo quantitative analysis of the effect of stretching on individual muscles, but conventionally, it has been difficult to measure the evaluation index of stretching on individual muscles. In human studies, passive torque-angle measurements are widely used to noninvasively examine muscle stretch and passive muscle force[27, 33, 34]. However, torque-angle measurements are affected by many structures crossing the joint, such as synergistic muscles, aponeuroses, tendons, joint capsules, and ligaments, and cannot be used to identify the effect of an individual muscle. Therefore, passive torque-angle measurements are not specific to the passive stretching response of individual muscles, especially for the muscles of the shoulder joint.

A new ultrasound-based technology, called ultrasonic shear wave elastography, has been developed that reliably and noninvasively measures soft tissue viscoelastic properties[1]. Many studies have quantitatively assessed the muscle shear elastic modulus in vivo and in vitro[4, 14, 15, 19, 21].

The occurrence of shoulder injuries are associated with the supraspinatus (SSP) muscle and infraspinatus muscle because these muscles contribute to the dynamic stability of the shoulder joint[35]. We targeted the SSP because there is more evidence of reliability and validity using elastography on measuring the SSP[8, 12, 28] rather than infraspinatus muscle. Specifically, researchers have reported the link between a tight SSP and abduction contracture [5].

Several authors have recommended effective stretching positions for the SSP based on their knowledge of anatomy and kinesiology[6, 10, 31, 36]. The positions recommended for stretching the SSP are fully adducting the arm behind the back[6], positioning the arm behind the back while maintaining medial rotation[10], extension, adduction, and internal rotation (IR)[36], and placing the hand behind the back and reaching up between the shoulder blades[31]. Despite these recommendations, there is no consensus on the effective stretching positions. One cadaveric study recommended positioning the arm at abduction with extension as the most effective stretching position for the SSP[24]. Subsequent research has not been performed in vivo; therefore, an in vivo quantitative analysis is needed to determine the effective SSP stretching positions. The purpose of the present study was to quantitatively verify the effective SSP stretching positions using ultrasonic shear wave elastography in vivo.

Materials and Methods

We conducted this experimental study in accordance with the Declaration of Helsinki.

2.1. Participants

An a priori power analysis was conducted using G*Power software version 3.1 (Heinrich Heine University, Dusseldorf, Germany). We estimated that a sample size of 14 participants was required based on a 0.25 effect size, 0.05 α level, and 0.8 desired power level. Therefore, 15 healthy men (mean ± standard deviation; age: 23.4 ± 3.0 years, height: 172.9 ± 3.0 cm, weight: 66.3 ± 6.0 kg) were included. Participants with a history of neuromuscular disease or musculoskeletal injury involving the upper extremities were excluded. All participants were informed of the purpose and methods of the study before providing written consent.

2.2. Data Collection

Shear wave speed was measured by an Aixplorer ultrasound system using an SL10-2 linear array transducer (Supersonic Imagine, Aix-en-Provence, France) to assess the shear elastic modulus of the SSP in the nondominant shoulder. We examined the nondominant side to determine the influence of the shoulder position on the shear elastic modulus of the SSP, because some volunteers had experience participating in overhead sports.

An ultrasound probe was placed 20 mm above the midpoint between the acromial angle and the root of the spine of scapula. The ultrasound images were used to align the probe parallel to the SSP muscle fiber orientation as much as possible (Figure 1). Participants were instructed to sit relaxed on a chair. To consistently position each participant, all procedures were performed by the same 3 testers. One tester measured the shear wave speed, the second fixed the participant's thorax, and the third changed the arm positions (Figure 2). To minimize the measurement error, the shear elastic modulus was measured twice in the same position.

As many measurement positions were selected as possible while preventing patient fatigue and confounding results from stretching. The shear elastic modulus of the SSP was measured in the 10 arm positions under the following conditions: neutral position to evaluate the effect of stretching (reference), arm positions, including horizontal adduction to compare the effect of horizontal abduction, which was recommended in a previous study, and different combinations of varying shoulder joint angles, including horizontal adduction to detect motions that emphasized SSP stretching in the 3 shoulder motions. Actual measurement positions are IR at 0° elevation (Ele0), IR at 90° abduction (Abd90), IR at 90° flexion (Fle90), IR at maximum extension (Ext), IR at maximum horizontal adduction with 90° elevation (Ele90HAd), IR at maximum horizontal adduction with 45° elevation (Ele45HAd), IR at maximum horizontal abduction with 20° elevation (Ele20HAb), IR at maximum horizontal abduction with 45° elevation (Ele45HAb), IR at maximum horizontal abduction with 90° elevation (Ele90HAb), and a neutral rotation at 0° elevation (Rest).

The arm positions were defined based on the globe system[3]. In this study, horizontal adduction and horizontal abduction were defined as forward and backward changes of the plane of elevation. Elevation of the humerus in the 90°, 0°, and –90° planes was defined as flexion, abduction, and extension, respectively. The arm positions were defined as a combination of 3 shoulder motions. The sequence in which the arm was moved into the measurement position was elevation, subsequently horizontal abduction/adduction, and lastly, rotation. For elevation, the shoulder joint was moved to 45° or 90° abduction, as measured by a goniometer, and this angle was fixed during the subsequent 2 motions using a mark on a vertical pole to indicate the height of the elbow. For Ele20HAb, the position was defined by moving the elbow into the horizontal abduction position (ie, toward the participant's back) with the elbow contacting the thorax as much as possible without necessarily maintaining the height of the elbow at 20° elevation. For horizontal and rotational motion, the shoulder joint was moved to the maximum range of motion the individual could tolerate without discomfort or pain. The arm positions were performed in random order to preclude any effect of the measurement sequence

2.3. Data Analysis

The mean shear wave propagation speed (*m/s)* within the region of interest was automatically calculated. The shear elastic modulus (*G*) can be calculated using the shear wave speed (*cs*) through the following equation[29]:

$$G = \rho c_s^2$$

where ρ is the muscle mass density and is assumed to be 1,000 kg/m^3.

Measurement reliability was assessed using the intraclass correlation coefficient ($ICC_{1,1}$) with a 95% confidence interval. Comparison of the shear elastic modulus among the measurement positions was assessed using the mean value ± standard deviation.

A 1-way repeated measures analysis of variance was used to determine the difference in the shear elastic modulus of the SSP among the stretching positions. When a significant main effect was observed, the difference among positions was determined using the Bonferroni post hoc test. Statistical significance was defined using an $\alpha = 0.05$ for all tests. Statistical analyses were performed using IBM SPSS Statistics 22.0 software (IBM, Armonk, NY, USA).

Results

Reliability of the shear elastic modulus was assessed using the ICC with a 95% confidence interval (Table I). The ICC ranged from 0.81 for Ele90HAd to 0.98 for Rest. The shear elastic modulus at Rest was 8.7 ± 3.5 kPa and moduli in other positions are provided in Table II. The mean shear elastic modulus was highest at Ext, followed by Ele90HAb, Ele45HAb, Ele45HAd, Abd90, Ele20HAb, Ele90HAd, Fle90, Rest, and Ele0 (Fig. 3).

Repeated measures analysis of variance revealed a significant effect on the shear elastic modulus. Bonferroni post hoc tests indicated that the shear elastic moduli in 3 positions (Ext, Ele90HAb, and Ele45HAb) were significantly greater than those in the other 7 positions (Fig. 3). Only these 3 positions had shear elastic moduli that were significantly greater than that at Rest (Table II), and there were no significant differences in shear elastic moduli among these 3 positions. Differences in shear elastic moduli among the other 7 positions were not significant.

Discussion

The results of this study show that the shear elastic moduli in Ext, Ele90HAb, and Ele45HAb were significantly greater than those in the other 7 positions. This suggests that these 3 positions are more effective stretching positions for the SSP than the other 7 positions. To the best of our knowledge, this is the first report to investigate the effective SSP stretching positions using quantitative analysis with ultrasonic shear wave elastography in vivo.

In this study, the ICC ranged from 0.81 to 0.98 for all positions. ICCs in this range rank as "almost perfect" reliability according to the criteria of Landis[20]. Therefore, we consider the data in this study reliable. The Rest position was the most reproducible position and, therefore, the shear elastic modulus in that position had the highest reliability. In contrast, the shear elastic modulus in Ele90HAd demonstrated the lowest reliability among the 10 positions.

The shear elastic moduli in Ext, Ele90HAb, and Ele45HAb were significantly greater than that in Rest, suggesting that these 3 positions are effective SSP stretching positions. In contrast, the shear elastic moduli in Ele0, Abd90, Fle90, Ele90HAd, Ele45HAd, and Ele20HAb did not differ significantly from that in Rest, suggesting that these positions are not effective SSP stretching positions. All effective stretching positions found in this study include elevation, horizontal abduction, and maximum IR.

In clinical rehabilitation and sports, the cross-body stretch and the sleeper stretch have been widely used to improve posterior shoulder tightness. These positions are similar to the Ele90HAd and Fle90 positions used in this study. However, the shear elastic moduli in Ele90HAd and Fle90 were not significantly different compared with that in Rest. Our results suggest that horizontal abduction is more important than horizontal adduction for stretching the SSP. In other words, the arm is positioned not in front but in the back of the body to stretch the SSP effectively. In previous studies, the SSP has been found to have an IR moment arm at 90° of humeral elevation in the sagittal plane[17]. In the position in which SSP has an IR moment arm, contraction of SSP leads to IR. In other words, to stretch the SSP at 90° humeral elevation in the sagittal plane, the humerus must be externally rotated, not internally rotated.

Because differences in the shear elastic moduli among Ext, Ele90HAb, and Ele45HAb were not significant, we could not identify the most effective stretching position. The shear elastic moduli in Ext, Ele90HAb, and Ele45HAb were significantly greater than that in Ele20HAb. It is likely that higher elevation of the humerus behind the body is important to stretch the SSP.

Some of the following SSP stretching positions have been recommended: fully adducting the arm behind the back[6], positioning the arm behind the back while maintaining medial rotation[10], and placing the hand behind the back and reaching up between the shoulder blades[31]. In terms of the distance between the elbow and the back, these 3 recommended positions are similar to the Ele20HAb position used in this study. Judging from the results of this study, these 3 positions need to emphasize elevation to effectively stretch the SSP. Previous studies evaluated other factors, such as muscle contraction, pressure to the muscle, traction on the bone, and posture of the whole body, in addition to shoulder position. These factors may influence the effect of stretching. In contrast, Ylinen[36] recommended extension, adduction, and IR. When compared with elevation, this position is an effective SSP stretch. In terms of the importance of elevation and horizontal abduction, our results are similar to those of the quantitative analysis using cadavers reported by Muraki et al.[24] All of our test positions, except for Rest, included maximum IR. Whether maximum IR is necessary or not will require further study.

This study had several limitations. First, all of the participants in this study were healthy young men. Sex, age, and differences in sport and disease experience may affect the shear elastic modulus of the shoulder muscles; therefore, we need to be careful when using these results for therapy and training in clinical or athletic settings.

Second, we allowed the free movement of the scapula when positioning the humerus. Measuring the movement of the scapula may produce more accurate results. In addition to the shoulder position, most of the previous authors examined muscle contraction, pressure to the muscle, traction on the bone, and posture of the whole body. However, the focus of the current study was to evaluate the influence of the shoulder position only. Examining the influence of these other factors will be necessary in future studies.

We only evaluated the SSP in this study. Further measurements targeting the infraspinatus and other muscles should be conducted. By clarifying effective positions in multiple muscles, we may be able to determine the position needed to stretch multiple muscles simultaneously or to selectively stretch 1 muscle.

Conclusions

This study used quantitative analysis to determine the effective stretching positions for the SSP muscle, using ultrasonic shear wave elastography in vivo. Our results suggest that maximum internal rotation at maximum extension, maximum internal rotation at maximum horizontal abduction with 90° elevation, and maximum internal rotation at maximum horizontal abduction with 45° elevation are effective stretching positions for the SSP muscle.

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Figure and Table Legends.

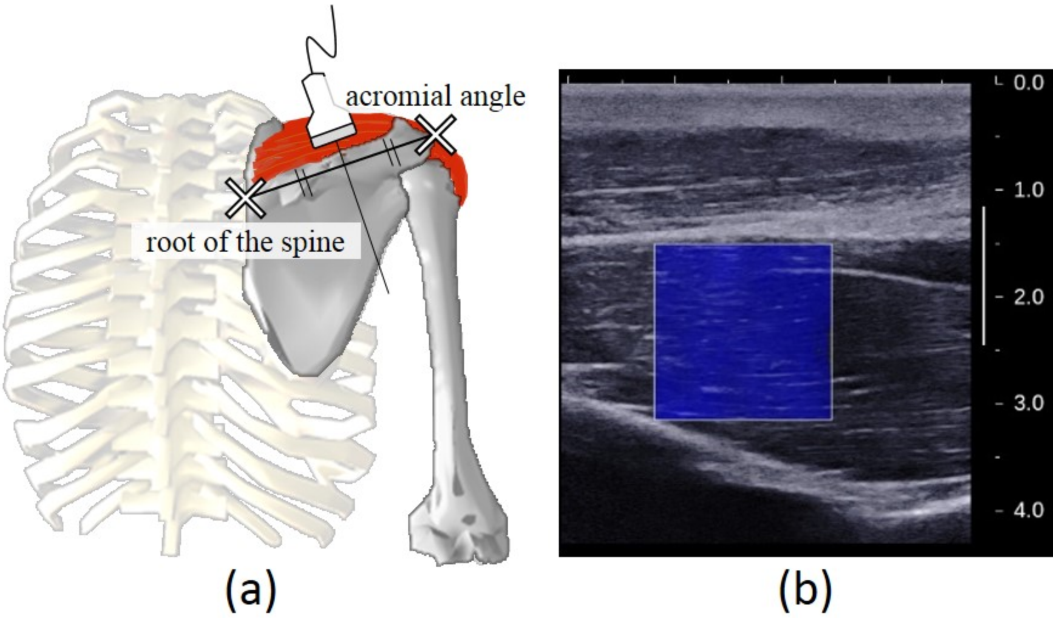

Figure 1 Position and angle of the probe during measurement. (a) An ultrasound probe was placed 20 mm above the midpoint between the acromial angle and the root of the spine of scapula. (b) The ultrasound images were used to align the probe parallel to the supraspinatus muscle fiber orientation as much as possible.

Figure 2 Experimental setup. Participants were instructed to sit relaxed on a chair. To consistently position each participant, all procedures were performed by the same 3 testers: the first tester measured the shear wave speed, the second fixed the participant's thorax, and the third changed the arm positions.

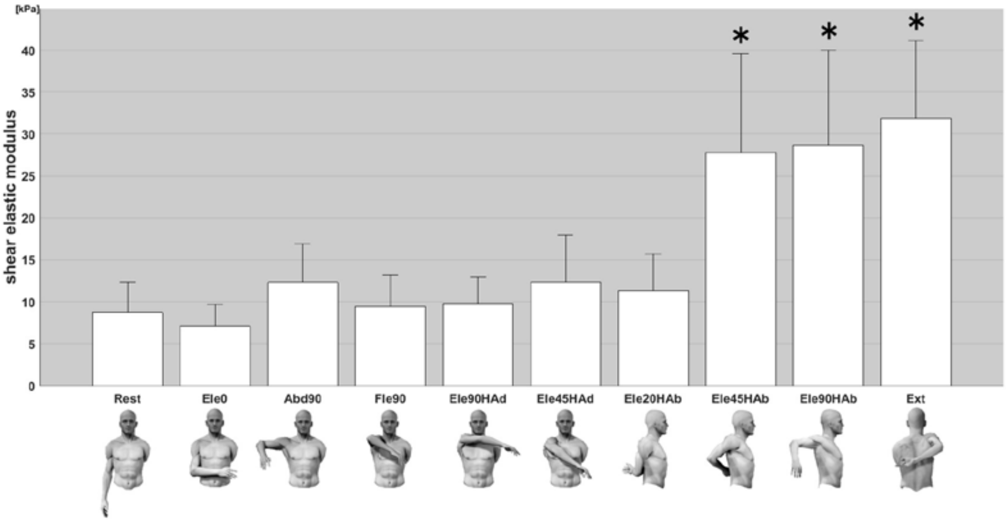

Figure 3 Shear elastic moduli of the supraspinatus muscle in each measurement position. The error bar shows the standard deviation. *Indicates that the shear elastic moduli in Ext, Ele90HAb, and Ele45HAb were significantly greater than those in the other 7 positions: Ele45HAb–Rest ($P = .002$), Ele45HAb–Abd90 ($P = .011$), Ele45HAb–Fle90 ($P = .005$), Ele45HAb–Ele90HAd ($P = .002$), Ele45HAb–Ele45HAd ($P = .047$), Ele45HAb–Ele20HAb ($P = .007$), Ele90HAb–Rest ($P = .001$), Ele90HAb–Abd90 ($P = .013$), Ele90HAb–Fle90 ($P = .001$), Ele90HAb–Ele90HAd ($P = .001$), Ele90HAb–Ele20HAd ($P = .002$), and the other positions ($P < .001$). Rest, neutral rotation at 0° elevation; Ele0, maximum internal rotation at 0° elevation; Abd90, maximum internal rotation at 90° abduction; Fle90, maximum internal rotation at 90° flexion; Ele90Had, maximum internal rotation at maximum horizontal adduction with 90° elevation; Ele45Had, maximum internal rotation at maximum horizontal adduction with 45° elevation; Ele20HAb, maximum internal rotation at maximum horizontal abduction with 20° elevation; Ele45HAb, maximum internal rotation at maximum horizontal abduction with 45° elevation, Ele90HAb, maximum internal rotation at maximum horizontal abduction with 90° elevation; Ext, maximum internal rotation at maximum extension.

Table I Intraclass correlation coefficient in each measurement position.

Position	ICC [95% CI]
Rest	0.98 [0.95, 0.99]
Ele0	0.85 [0.61, 0.94]
Abd90	0.93 [0.80, 0.97]
Fle90	0.84 [0.60, 0.94]
Ele90HAd	0.81 [0.53, 0.93]
Ele45HAd	0.93 [0.80, 0.97]
Ele20HAb	0.96 [0.90, 0.99]
Ele45HAb	0.97 [0.91, 0.99]
Ele90HAb	0.94 [0.83, 0.98]
Ext	0.93 [0.81, 0.98]

ICC, intraclass correlation coefficient; CI, confidence interval; Rest, neutral rotation at 0° elevation; Ele0, maximum internal rotation at 0° elevation; Abd90, maximum internal rotation at 90° abduction; Fle90, maximum internal rotation at 90° flexion; Ele90HAd, maximum internal rotation at maximum horizontal adduction with 90° elevation; Ele45HAd, maximum internal rotation at maximum horizontal adduction with 45° elevation; Ele20HAb, maximum internal rotation at maximum horizontal abduction with 20° elevation; Ele45HAb, maximum internal rotation at maximum horizontal abduction with 45° elevation; Ele90HAb, maximum internal rotation at maximum horizontal abduction with 90° elevation; Ext, maximum internal rotation at maximum extension.

Table II Shear elastic modulus of the supraspinatus muscle in each measurement position.

Position	Mean ± S.D. [kPa]	p value (Comparison with Rest)
Rest	8.7 ± 3.5	-
Ele0	7.1 ± 2.6	>0.999
Abd90	12.3 ± 4.4	0.725
Fle90	9.4 ± 3.6	>0.999
Ele90HAd	9.8 ± 3.0	>0.999
Ele45HAd	12.4 ± 5.4	>0.999
Ele20HAb	11.3 ± 4.2	>0.999
Ele45HAb	27.8 ± 11.4	0.002
Ele90HAb	28.7 ± 11.0	0.001
Ext	31.9 ± 8.9	< 0.001

SD, standard deviation; Rest, neutral rotation at 0° elevation; Ele0, maximum internal rotation at 0° elevation; Abd90, maximum internal rotation at 90° abduction; Fle90, maximum internal rotation at 90° flexion; Ele90HAd, maximum internal rotation at maximum horizontal adduction with 90° elevation; Ele45HAd, maximum internal rotation at maximum horizontal adduction with 45° elevation; Ele20HAb, maximum internal rotation at maximum horizontal abduction with 20° elevation; Ele45HAb, maximum internal rotation at maximum horizontal abduction with 45° elevation; Ele90HAb, maximum internal rotation at maximum horizontal abduction with 90° elevation; Ext, maximum internal rotation at maximum extension.