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Shoulder horizontal abduction stretching effectively increases shear elastic modulus of pectoralis minor muscle

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Ethics committee approval

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Abstract

Background

The stretching maneuver for pectoralis minor muscle, which is shoulder horizontal abduction or scapular retraction, is performed in a clinical and sport setting because the tightness of this muscle may contribute to scapular dyskinesis. The effective stretching maneuver for pectoralis minor muscle is unclear in vivo. The purpose of this study was to verify the effective stretching maneuver for pectoralis minor muscle in vivo using ultrasonic shear wave elastography.

Methods

Eighteen healthy men participated in this study. Elongation of the pectoralis minor muscle was measured for three stretching maneuvers (shoulder flexion, shoulder horizontal abduction, and scapular retraction) at three shoulder elevation angles (30°, 90°, and 150°). The shear elastic modulus used as the index of muscle elongation was computed using ultrasonic shear wave elastography for the above nine stretching maneuver-angle combinations.

Results

The shear elastic modulus was highest in horizontal abduction 150° followed by horizontal abduction 90°, horizontal abduction 30°, scapular retraction 30°, scapular retraction 90°, scapular retraction 150°, flex 150°, flex90° and flex30°. The shear elastic modulus of horizontal abduction 90° and horizontal abduction 150° were significantly higher than other stretching maneuvers. There was no significant difference between horizontal abduction 90° and horizontal abduction 150°.

Conclusions

This study determined that shoulder horizontal abduction at elevations of 90° and 150° were the most effective stretching maneuvers for pectoralis minor muscle in vivo.

Level of evidence: Basic Science Study.

Keyword

Stretching;
Pectoralis minor muscle;
Ultrasonic shear wave elastography;
Shear elastic modulus;
Shoulder horizontal abduction;
Rehabilitation

Introduction

In shoulder rehabilitation, clinical evaluation, and intervention for scapular dyskinesis are important because of its relation to various shoulder injuries, such as subacromial impingement[4,12,17,19,23], rotator cuff tear[14,24], unstable shoulder[20] and frozen shoulder[10]. The literature suggests that scapular dyskinesis may be caused by multiple factors such as bone, joint, neurological, or soft tissue mechanisms[13]. In soft tissue mechanisms, the tightness of the pectoralis minor muscle (PMi) is one of the factors inducing scapular dyskinesis, which can be examined and treated by a therapist[8]. Previous studies have reported that the tightness of the PMi is related to posture, including scapular internal rotation in the resting position[3] and decreases in scapular external rotation and posterior tilt during arm elevation[5]. These changes, which is the scapular internal rotation and anterior tilt, are similar to the change in scapular motion found in many shoulder injuries[19,20] and it is also possible that there might be a relationship between shoulder injury and the tightness of the PMi. Therefore, the flexibility of the PMi is important for preventing and improving scapular dyskinesis.

Stretching interventions are recommended to increase and improve muscle flexibility and stretching of the PMi is frequently used in rehabilitation programs[1,18,21]. Therefore, some studies have investigated stretching maneuver of the PMi. In a previous study, Borstad and Ludewig[6] compared the length of the PMi during three stretching maneuver using an electromagnetic motion capture system with skin surface markers in healthy adults. This study concluded that the most effective PMi stretching maneuver was a unilateral corner self-stretch similar to horizontal abduction of shoulder joint. On the other hand, Muraki et al.[25] directly measured the length of the PMi during three passive shoulder motions and three stretching techniques using displacement sensors in fresh cadavers. They advocated that scapular retraction made the greatest change in PMi length. The contradiction of these two studies most likely resulted from differences between the subjects (living body vs. cadaver) or measurement methods. In addition, it is unknown whether or not the results of these previous studies apply to live people for effective stretching positions of PMi, because Borstad and Ludewig[6] did not measure the tension of the PMi during stretching, but instead measured the distance between the coracoid process and the fourth rib/sternum junction, and Muraki et al.[25] used cadavers in their study. Therefore, an investigation of effective in vivo stretching maneuver of the PMi determined by measuring muscle tension during stretching is needed.

A new ultrasound-based technology called ultrasonic shear wave elastography (SWE) was developed, allowing reliable and non-invasive measurement of soft tissue viscoelastic properties[2]. SWE monitors the propagation of shear waves generated in tissue using acoustic radiation forces and is able to evaluate the shear elastic modulus of individual muscles[26]. Because of the strong liner relationship, identified by prior studies, between passive muscle tension calculated by traditional method and shear elastic modulus measured by SWE in vitro[9,15], SWE has been used in many stretching studies of skeletal muscle[9,15,27,28]. In addition, our previous studies indicate an increase in shear elastic modulus with muscle elongation during stretching[27,28]. Therefore, SWE has proven to be a valid technology for noninvasively investigating muscle elongation in vivo.

Regarding stretching maneuver of the PMi, a unilateral corner self-stretch or scapular retraction at a 30° shoulder flexion angle have been recommended by Borstad and Ludewig[6] or Muraki et al.[25], respectively. Muraki et al.[25] also described that the PMi can be stretched by 150° passive shoulder flexion and scaption as well as scapular retraction or shoulder horizontal abduction. Thus, we hypothesized that shoulder horizontal abduction or scapular retraction with the shoulder in elevated positions is an effective maneuver for stretching the PMi. The objective of this study was to quantitatively verify the effective stretching maneuver of the PMi using the shear elastic modulus measured by SWE in vivo.

Materials and Methods

Participants

Eighteen men (age, 26.2 ± 4.0 years; height, 171.1 ± 5.0 cm; weight, 67.4 ± 7.8 kg) with no orthopaedic or nervous system abnormalities in their upper limbs participated in this study. Participants were recruited from the students of our institution. The subject orally confirmed that they complied with the following exclusion criteria: females, athletes, or those who perform any extensive exercise, and subjects having a history of orthopaedic disease or neuropathy in their upper limbs. The sample size was calculated by the G*power software (Version 3.1., Heinrich Heine University, Dusseldorf, Germany) for a one-way analysis of variance (ANOVA) with repeated measures (effect size = 0.25, α error = 0.05, power = 0.8), which showed that 17 subjects were required. This study protocol conformed to the Helsinki Declaration and was approved by the Ethics Review Board of our institution.

Experimental procedures

This study was an experimental study, with randomized allocation of stretching intervention for each subject using a random number table. Healthy male subjects were randomly recruited. After the aim and procedures were explained to all subjects, the subjects underwent nine stretching maneuvers performed by one researcher. The outcome was measured and analyzed by another researcher.

All procedures were performed by the same two investigators who both had physical therapist licenses: one investigator measured the shear elastic modulus using SWE, while the other performed the stretching maneuver. The non-dominant upper limb was chosen for intervention. Each subject lay on their side on a 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 45°. The relax position (Rest) was defined as that the shoulder in 0° flexion, 0° abduction, the elbow fully extended, and the palm of the hand parallel the bed. In this study, three stretching maneuvers (flexion, horizontal abduction, and scapular retraction) were investigated at the three shoulder elevation angles (30°, 90°, and 150°) for a total of nine stretching positions, on the basis of previous studies[6,25]. For passive shoulder motion, the interventional shoulder of the subject was passively flexed at 30° (Flex30), 90° (Flex90), and 150° (Flex150) by the investigator (Figure 1). For shoulder horizontal abduction, the interventional shoulder was passively horizontally abducted as much as possible at shoulder elevation angles of 30° (Hab30), 90° (Hab90), and 150° (Hab150) while the shoulder was maximally externally rotated and the elbow was flexed 90° by the investigator (Figure 2). For scapular retraction, the interventional fully flexed elbow was maximally pressed along the longitudinal axis of the humerus, and the interventional scapular was passively maximally retracted at the shoulder for flexion angles of 30° (Retract30), 90° (Retract90), and 150° (Retraction150) by the investigator (Figure 3). The subjects were stretched until reaching a point of discomfort (but not pain), as verbally acknowledged by the subjects. During all stretching and measurement acquisition, subjects were instructed to relax as much as possible.

Instrumentation

In this study, the shear elastic modulus measured by SWE (Aixplorer, SuperSonic Imagine, Aix-en-Provence, France) with an ultrasound transducer (15-4 MHz linear probe) was defined as the indicator of muscle elongation of the PMi. The shear elastic modulus was calculated from the shear wave propagation speed generated by the transducer[2]. The shear elastic modulus (G) was calculated from the shear wave propagation speed (V) using the following formula:

$G = \rho V^2$

Where ρ is the muscle density, assumed to be 1,000 kg/m^3. A previous study showed that there is a significant correlation between the shear elastic modulus, which was measured by SWE, and the muscle elongation, which was measured by a traditional tension test[9,15].

The shear elastic modulus was measured in all measurement positions using SWE. The measurement place was defined as the midpoint between the coracoid process and the fourth rib/sternum junction, identified in the ultrasonic image. The probe was placed in parallel with muscle fascicle of the PMi. The region of interest (ROI) was established near the center 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. All analyses were performed by the researcher who was blinded to the stretching positions by anonymizing all ultrasonic images. The subjects were instructed to hold their breath during measurement of the shear elastic modulus to prevent PMi elongation due to the movement of the rib cage.

Five healthy men (age, 25.8 ± 3.7 years; height, 172.8 ± 5.0 cm; weight, 65.8 ± 4.6 kg) were used to evaluate the reliability of the ultrasound measurement. The measurement was acquired for three passive shoulder motions and three stretching maneuvers. The reliability of the shear elastic modulus measurement was confirmed using intraclass correlation coefficients (1,3) ($ICC_{1,3}$) with a 95% confidence interval (95% CI). $ICC_{1,3}$ values, which represent intra-observer reliability in the intra-day, were calculated from the shear elastic modulus. $ICC_{1,3}$ values fell within a range of 0.90 – 0.99 for all measurements (Table I). A previous study that investigated the reliability coefficient suggested that a range of 0.81 – 1.00 was almost perfect[16]. Therefore, the measured values of the shear elastic modulus in our study were considered reproducible since the $ICC_{1,3}$ observed was almost perfect, according to this previous study.

Data analysis

Statistical analysis was performed using IBM SPSS Statistics 22 (International Business Machines Corporation). To find whether the PMi was elongated in the nine stretching positions, differences in the shear elastic modulus between Rest and each stretching position were assessed using a paired Student's t-test with Bonferroni revision. Additionally, when the shear elastic modulus was found to be significantly different from that at Rest, a one-way ANOVA with repeated measures was used to determine the effect of passive motion or stretching maneuver on the shear elastic moduli amongst them. If a significant main effect was found, then a Bonferroni multiple comparison for the post hoc test was performed. A confidence level of 0.05 was used in all statistical tests.

Result

The shear elastic modulus for each measurement is shown in Table II. The shear elastic modulus was highest at Hab150, followed by Hab90, Hab30, Retraction30, Retraction90, Retraction150, Flex150, Flex90, and Flex30. The shear elastic moduli of these positions, except Flex30 and Flex90, were significantly higher than the elastic modulus at Rest ($P < .05$ or $P < .01$, Table II). For the measurement positions where the shear elastic modulus was significantly higher than that at Rest, a one-way ANOVA with repeated measures was used to indicate a significant main effect ($P < .001$, $F = 29.0$). For the positions showing significantly higher shear elastic moduli than the elastic modulus at Rest, a Bonferroni multiple comparison for the post-hoc test was performed, indicating that the shear elastic moduli of Hab90 and Hab150 were significantly higher than those of the other positions. However, there was no significant difference between Hab90 and Hab150. In addition, although the shear elastic modulus of Hab30 was significantly higher than those of Flex150 and Retraction150 ($P < .001$, respectively), there were no significant differences among the others (Figure 4).

Discussion

This is the first to determine effective stretching maneuver of the PMi using shear elastic modulus values measured by SWE, which quantitatively reflects the grade of muscle elongation during stretching in vivo. The main finding of this study was that maximal horizontal abduction of the shoulder at an elevation angle of 90° and 150° effectively elongates the PMi muscle.

We hypothesized that the PMi could be elongated effectively by shoulder horizontal abduction or scapular retraction at elevated shoulder positions i.e., Hab150 or Retraction150. In this study, our results showed that the shear elastic modulus at all measurement positions was higher than that at Rest, except for Flex30 and Flex90. Furthermore, the shear elastic moduli of Hab90 and Hab150 were significantly greater than those of all measurement positions whose shear elastic modulus was greater than at Rest. These results suggest that the most effective stretching maneuvers of the PMi are Hab90 and Hab150, which is partly consistent with our hypothesis.

Borstad and Ludewig[6] compared the mean length change from the coracoid process of the scapula to the fourth rib/sternum junction for three pectoralis minor stretches; unilateral corner self-stretch, sitting manual stretch, and spine manual stretch. They concluded that unilateral corner self-stretch, in which a subject abducts the humerus to 90° with the palm on a wall and then rotates their trunk away from the elevated arm to increase the shoulder horizontal abduction, lengthened the pectoralis minor muscle most effectively. Our results, that the shear elastic moduli of Hab90 and Hab150 were significantly higher than those of other measurement positions, were consistent with the findings of the previous study by Borstad and Ludewig[6]. On the other hand, Muraki et al. directly measured PMi lengthening during three passive shoulder motions and three stretching techniques using fresh cadaveric transthoracic specimens. Their study concluded that scapular retraction at an angle of 30° flexion, in which the examiner exerted a posterosuperior pressure to the elbow along the longitudinal axis of the humerus, resulted in the greatest change in PMi length measured by displacement sensor[25], this is inconsistent with our results. This contradiction probably originates from the difference in methodology. The horizontal abduction of the shoulder might stretch the pectoralis major muscle and the clavipectoral fascia, which may directly impact the ability of the pectoralis minor muscle to receive stretch influence. Removing these tissues overlying the PMi in order to expose this muscle, as stated in Murakis' study, could be the reason for the contradiction. In addition, there was a glaring difference in the nature of the study medium, i.e., live tissue versus cadaver tissue, which likely contributed to this inconsistency. It is possible that the difference in viscoelasticity and other material properties of the shoulder joint between a living body and a cadaver affected the elongation of the PMi[11]. Contrary to these previous studies, our study examined the applicability of various stretching maneuver of the PMi in live people using the shear elastic modulus values measured by SWE.

The shear elastic moduli of Hab30, Hab90, and Hab150 were significantly higher than the elastic modulus of Flex150. These results indicate that shoulder horizontal abduction is a more effective means of stretching the PMi than shoulder flexion, and that scapular motion is probably responsible for this difference. From an anatomical perspective, the external rotation and posterior tilt of the scapula stretches the PMi[6] because this muscle originates on the third, fourth, and fifth ribs and runs superolaterally, inserting at the coracoid process of the scapula. Previous studies measuring scapular motion reported that during shoulder flexion the scapula externally rotates, upwardly rotate, and tilts posteriorly[22], and that the scapula externally rotates and tilts posteriorly during shoulder horizontal abduction[7]. Comparing the scapular motion of shoulder flexion and that of shoulder horizontal abduction in these previous studies, the scapular external rotation during shoulder horizontal abduction was greater than that during shoulder flexion. Thus, the results of the current study indicating that the shear elastic moduli of Hab30, Hab90, and Hab150 were significantly higher than the elastic modulus of Flex150 suggests that scapular external rotation contributes more to stretching the PMi than scapular posterior tilt. Furthermore, the scapular motion also relates to the fact that the shear elastic moduli of Hab90 and Hab150 were found to be significantly higher than those of Retraction30, Retraction90, and Retraction150. The PMi could be more stretched by shoulder horizontal abduction than scapular retraction because the scapular external rotation of shoulder horizontal abduction is greater than that of scapular retraction. However, there was no study investigating scapular motion during scapular retraction. Further research is required to elucidate scapular motion during scapular retraction using electromagnetic sensors or optoelectronic markers.

When the shear elastic modulus at Rest was compared to the elastic moduli of other measurement positions, it was found to be significantly lower than all except the Flex30 and Flex90 positions. Considering these results, although Hab90 and Hab150 were the most effective for stretching the PMi, all measurement positions, except Flex30 and Flex90, effectively stretch the PMi. In the clinical setting, patients requiring stretching of the PMi frequently have a limited range of shoulder motion, and a shoulder instability. Therefore, Hab30 or Retraction30 might be better suited for these patients. Further research is required to investigate the effects of stretching intervention of the PMi in the patients with a limited range of motion and a shoulder instability.

Our determination of horizontal abduction of the shoulder at elevation angles of 90° and 150° as effective means of stretching the PMi may be beneficial in clinical and athletic settings. However, this study should be interpreted with note of the following. First, the participants in this study were healthy young men as prescribed by the exclusion criteria. Therefore, it is unknown whether similar effects can always be expected in patients with impingement syndrome or frozen shoulder. Second, we could not measure the scapular motion during the stretching maneuvers. Further research investigating scapular motion during stretching is required to identify any potential relationship between scapular motion and elongation of the PMi. Third, the shear elastic modulus of the lateral fiber groups of the PMi was measured in this study; thus, similar behavior cannot always be expected in the medial fiber groups of the PMi. However, we presume that there are few differences between the shear elastic moduli of the lateral and medial fiber groups of the PMi because Muraki et al.[25] reported that there was no difference of lengthening of the PMi. Thus, the shear elastic modulus of the PMi measured in the current study might represent that of the whole PMi muscle.

Conclusions

We quantitatively investigated effective stretching maneuver of the pectoralis minor muscle using shear elastic modulus values obtained by ultrasonic shear wave elastography. Our results showed that shoulder horizontal abduction at shoulder elevation angles of 90° and 150° effectively elongated the pectoralis minor muscle. The stretching maneuver of the pectoralis minor muscle proposed in this study may be useful for clinical application.

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[redacted] [redacted] [redacted]

Figure 1. Passive shoulder flexion; left figure is Flex30, centre figure is Flex90, and right figure is Flex150.

Figure 2. Shoulder horizontal abduction stretching; A is Hab30, B is Hab90, and C is Hab150.


[redacted] [redacted]

Figure 3. Scapular retraction stretching; A is Retraction30, B is Retraction90, and C is Retraction150.

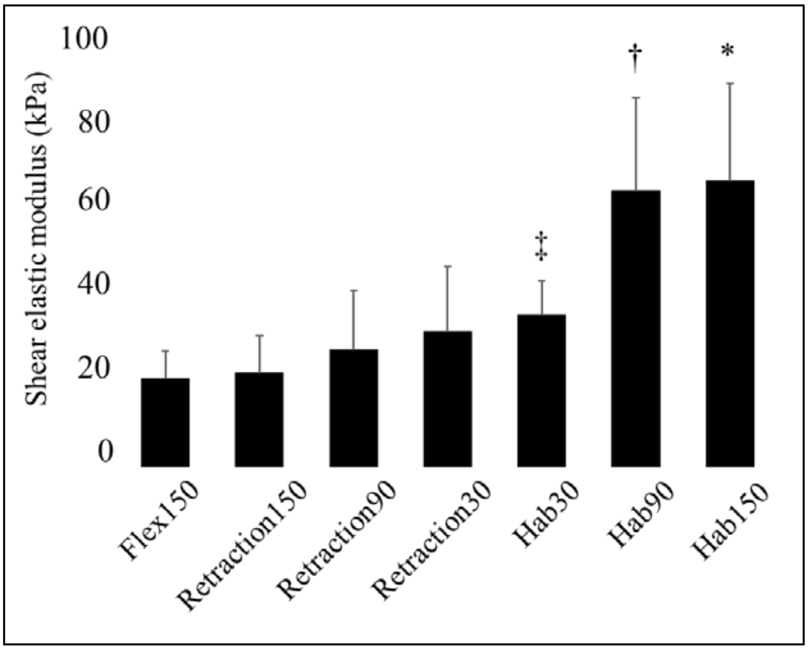

Figure 4. Multiple comparisons of shear elastic modulus; *: p<.01 Hab150 is significantly higher than others except for Hab90, †: p<.01 Hab90 is significantly higher than others except for Hab150, ‡: p<.001 Hab30 is significantly higher than Flex150 and Retraction150.

Table I Reliability of shear elastic modulus.

Measurement position	$ICC_{1,3}$	95% CI
Rest	0.99	0.94–1.00
Flex30	0.95	0.79–1.00
Flex90	0.94	0.74–0.99
Flex150	0.97	0.86–1.00
Hab30	0.90	0.55–0.99
Hab90	0.95	0.77–0.99
Hab150	0.99	0.94–1.00
Retraction30	0.95	0.78–0.99
Retraction90	0.95	0.76–0.99
Retraction150	0.93	0.69–0.99

ICC: intraclass correlation coefficient, 95% CI: 95% confidence interval

Table II Shear elastic modulus of pectoralis minor muscle in measurement positions.

Measurement position	shear elastic modulus mean value ±SD (kPa)	95% CI	Comparison with Rest (P value)
Rest	12.5 ± 2.6	11.3–13.7	
Flex30	12.8 ± 4.3	10.8–14.8	.99
Flex90	10.3 ± 3.0	9.0–11.7	.54
Flex150	18.0 ± 5.8	15.3–20.7	.02
Hab30	31.1 ± 7.0	27.9–34.4	<.001
Hab90	56.7 ± 19.1	47.9–65.6	<.001
Hab150	58.7 ± 20.0	49.5–68.0	<.001
Retraction30	27.8 ±13.4	21.6–34.0	.003
Retraction90	24.0 ± 12.2	18.4–29.7	.007
Retraction150	19.3 ± 7.7	15.7–22.8	.02

SD: standard deviation, 95% CI: 95% confidence interval