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

Jun Umehara, MS, PT\textsuperscript{a,b,*}, Masatoshi Nakamura, PhD, PT\textsuperscript{a}, Kosuke Fujita, MS, PT\textsuperscript{a}, Ken Kusano, BS, PT\textsuperscript{a}, Satoru Nishishita, MS, PT\textsuperscript{a}, Kojiro Araki, MS, PT\textsuperscript{a}, Hiroki Tanaka, MS, PT\textsuperscript{a}, Ko Yanase, MS, PT\textsuperscript{a}, Noriaki Ichihashi, PhD, PT\textsuperscript{a}

\textsuperscript{a}Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto, Japan
\textsuperscript{b}Rehabilitation Unit, Kyoto University Hospital, Kyoto, Japan
\textsuperscript{*}Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare, Niigata, Japan
\textsuperscript{d}Rehabilitation Group, Department of Medical Technique, Nagoya University, Nagoya, Japan
\textsuperscript{e}Department of Rehabilitation, Sapporo Tokushukai Hospital, Sapporo, Japan

Background: Stretching maneuvers for the pectoralis minor muscle, which involve shoulder horizontal abduction or scapular retraction, are performed in clinical and sports settings because the tightness of this muscle may contribute to scapular dyskinesis. The effectiveness of stretching maneuvers for the pectoralis minor muscle is unclear in vivo. The purpose of this study was to verify the effectiveness of stretching maneuvers for the 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 3 stretching maneuvers (shoulder flexion, shoulder horizontal abduction, and scapular retraction) at 3 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 9 aforementioned stretching maneuver-angle combinations.

Results: The shear elastic modulus was highest in horizontal abduction at 150°, followed by horizontal abduction at 90°, horizontal abduction at 30°, scapular retraction at 30°, scapular retraction at 90°, scapular retraction at 150°, flexion at 150°, flexion at 90°, and flexion at 30°. The shear elastic moduli of horizontal abduction at 90° and horizontal abduction at 150° were significantly higher than those of other stretching maneuvers. There was no significant difference between horizontal abduction at 90° and horizontal abduction at 150°.

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

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The study design was approved by the ethics committee of Kyoto University Graduate School and Faculty of Medicine (R0314).

*Reprint requests: Jun Umehara, MS, PT, Human Health Sciences, Graduate School of Medicine, Kyoto University, 53 Shogoin-Kawahawa-cho, Kyoto 606-8507, Japan.
E-mail address: umehara.jun.777r@st.kyoto-u.ac.jp (J. Umehara).

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In shoulder rehabilitation, clinical evaluation and intervention for scapular dyskinesis are important because of its relation to various shoulder injuries, such as subacromial impingement, rotator cuff tear, and frozen shoulder. The literature suggests that scapular dyskinesis may be caused by multiple factors such as bone, joint, neurologic, or soft-tissue mechanisms. 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. Previous studies have reported that the tightness of the PMi is related to posture, including scapular internal rotation in the resting position, and decreases in scapular external rotation and posterior tilt during arm elevation. These changes, which comprise scapular internal rotation and anterior tilt, are similar to the change in scapular motion found in many shoulder injuries, 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. Therefore, some studies have investigated stretching maneuvers for the PMi. Borstad and Ludewig compared the length of the PMi during stretching maneuvers using an electromagnetic motion-capture system with skin surface markers in healthy adults. Their study concluded that the most effective PMi stretching maneuver was a unilateral corner self-stretch similar to a horizontal abduction of the shoulder joint. On the other hand, Muraki et al directly measured the length of the PMi during 3 passive shoulder motions and 3 stretching techniques using displacement sensors in fresh cadavers. They advocated that scapular retraction resulted in the greatest change in PMi length. The contradictory findings of these 2 studies most likely resulted from differences between the subjects (living persons vs cadavers) or measurement methods. In addition, it is unknown whether the results of these previous studies apply to living persons with regard to effective stretching positions of the PMi because Borstad and Ludewig did not measure the tension of the PMi during stretching but instead measured the distance between the clavicular process and the fourth rib–sternum junction; moreover, Muraki et al used cadavers in their study. Therefore, an investigation of the effectiveness of in vivo stretching maneuvers for the PMi determined by measuring muscle tension during stretching is needed.

A new ultrasound-based technology called ultrasonic shear wave elastography (SWE) has been developed, allowing reliable and noninvasive measurement of soft-tissue viscoelastic properties. 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. Because of the strong linear relationship, identified by prior studies, between passive muscle tension calculated by traditional methods and the shear elastic modulus measured by SWE in vitro, SWE has been used in many studies of skeletal muscle stretching. In addition, our previous studies indicated an increase in the shear elastic modulus with muscle elongation during stretching. Therefore, SWE has proved to be a valid technology for noninvasively investigating muscle elongation in vivo.

Regarding stretching maneuvers for the PMi, a unilateral corner self-stretch and scapular retraction at a 30° shoulder flexion angle have been recommended by Borstad and Ludewig and Muraki et al, respectively. Muraki et al also reported that the PMi can be stretched by 150° of passive shoulder flexion and scapular-plane elevation, as well as scapular retraction or shoulder horizontal abduction. Thus, we hypothesized that shoulder horizontal abduction or scapular retraction with the shoulder in an elevated position is an effective maneuver for stretching the PMi. The objective of this study was to quantitatively verify the effectiveness of stretching maneuvers for 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 orthopedic or nervous system abnormalities in the upper limbs participated in this study. The participants were recruited from the students at our institution. The participants orally confirmed that they complied with the following exclusion criteria: women, athletes or persons who perform any extensive exercise, and persons having a history of orthopedic disease or neuropathy in the upper limbs. The sample size was calculated by use of G*Power software (version 3.1; Heinrich Heine University, Düsseldorf, Germany) for a 1-way analysis of variance (ANOVA) with repeated measures (effect size, 0.25; α error, 0.05; power, 0.8), which showed that 17 participants were required. The study protocol conformed with the principles of the Declaration of Helsinki.

Experimental procedures

This study was an experimental study, with randomized allocation of the stretching intervention for each participant using a random number table. Healthy male participants were randomly recruited. After the aim and procedures were explained to all participants, the participants underwent 9 stretching maneuvers performed by 1 researcher. The outcome was measured and analyzed by another researcher.
All procedures were performed by the same 2 investigators, who both had physical therapist licenses: One investigator measured the shear elastic modulus using SWE, whereas the other performed the stretching maneuver. The nondominant upper limb was chosen for intervention. Each participant lay on his side on a bed with the non-intervention arm under his head, the trunk parallel to the long axis of the bed, and both the hip and knee flexed 45°. The relaxed (resting) position was defined as follows: The shoulder was in 0° of flexion and 0° of abduction, the elbow was fully extended, and the palm of the hand was parallel to the bed. In this study, 3 stretching maneuvers (flexion, horizontal abduction, and scapular retraction) were investigated at 3 shoulder elevation angles (30°, 90°, and 150°), for a total of 9 stretching positions, on the basis of previous studies. For passive shoulder motion, the interventional shoulder of the participant was passively flexed at 30° (Flex30), 90° (Flex90), and 150° (Flex150) by the investigator (Fig. 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 (Fig. 2). For scapular retraction, the interventional fully flexed elbow was maximally pressed along the longitudinal axis of the humerus, and the interventional scapula was passively maximally retracted at the shoulder for flexion angles of 30° (Retraction30), 90° (Retraction90), and 150° (Retraction150) by the investigator (Fig. 3). The participants underwent stretching until reaching a point of discomfort (but not pain), as verbally acknowledged by the participants. During all stretching maneuvers and measurement acquisitions, participants 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 (4- to 15-MHz linear probe) was defined as the indicator of muscle elongation of the PM. The shear elastic modulus (G) was calculated from the shear wave propagation speed (V) generated by the transducer by use of the following formula:

\[ G = \rho \frac{V^2}{2} \]

in which \( \rho \) is the muscle density, assumed to be 1000 kg/m³. A previous study showed that there was a significant correlation between the shear elastic modulus, which was measured by SWE, and muscle elongation, which was measured by a traditional tension test.

![Figure 1 - Passive shoulder flexion at 30° (A), 90° (B), and 150° (C).](image)

![Figure 2 - Shoulder horizontal abduction stretching at 30° (A), 90° (B), and 150° (C).](image)

![Figure 3 - Scapular retraction stretching at 30° (A), 90° (B), and 150° (C).](image)
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 on the ultrasonic image. The probe was placed parallel with the muscle fascicle of the PMI. The region of interest was established near the center point of the muscle belly on the ultrasound image. The shear elastic modulus was measured 3 times at each measurement site, and the mean value was used for analysis. All analyses were performed by a researcher who was blinded to the stretching positions by anonymizing all ultrasonic images. The participants 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.

The data from 5 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 measurements. The measurements were acquired for 3 passive shoulder motions and 3 stretching maneuvers. The reliability of the shear elastic modulus measurements was confirmed using the intraclass correlation coefficient (ICC) with a 95% confidence interval. ICC values, which represent intraobserver reliability in a day, were calculated from the shear elastic modulus. ICC values fell within a range of 0.90 to 0.99 for all measurements (Table I). A previous study that investigated the reliability coefficient suggested that a range of 0.81 to 1.0 indicated "almost perfect." Therefore, the measured values of the shear elastic modulus in our study were considered reproducible because the ICC observed was almost perfect, according to this previous study.

**Data analysis**

Statistical analysis was performed with IBM SPSS Statistics software (version 22; IBM, Armonk, NY, USA). To find whether the PMI was elongated in the 9 stretching positions, differences in the shear elastic modulus between the resting position and each stretching position were assessed with the paired Student t test with Bonferroni revision. In addition, when the shear elastic modulus was found to be significantly different from that at rest, a 1-way ANOVA with repeated measures was used to determine the effect of passive motion or stretching maneuvers on the shear elastic moduli among them. If a significant main effect was found, then a Bonferroni multiple-comparison procedure for the post hoc test was performed. A confidence level of .05 was used in all statistical tests.

**Results**

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 all 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 in which the shear elastic modulus were significantly higher than those at rest, a 1-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 procedure 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 the moduli of Flex150 (P < .001) and Retraction150 (P < .001), there were no significant differences among the other positions (Fig. 4).

**Discussion**

This is the first study to determine the effectiveness of stretching maneuvers for 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 elevation angles 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 (ie, Hab150 or Retraction150). Our results showed that the shear elastic modulus at all measurement positions, except Flex30 and Flex90, was higher than that at rest. Furthermore, the shear elastic moduli of Hab90 and Hab150 were significantly greater than those of all measurement positions whose shear elastic moduli were greater than that at rest. These results suggest that the most effective stretching maneuvers for the PMI are Hab90 and Hab150, which is partly consistent with our hypothesis.

Borstad and Ludewig compared the mean length change from the coracoid process of the scapula to the fourth rib/sternum junction for 3 pectoralis minor stretches: unilateral corner self-stretch, sitting manual stretch, and spine manual stretch. They concluded that the unilateral corner self-stretch, in which a subject abducts the humerus to 90° with the palm on a wall and then rotates the trunk away from the elevated arm to increase shoulder horizontal abduction, lengthened the PMI most effectively. Our results, showing 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 aforementioned study by Borstad and Ludewig. On the other hand, Muraki et al. directly measured PMI shortening during 3 passive shoulder motions and 3 stretching techniques using fresh cadaveric transthoracic specimens. Their study concluded that scapular retraction at an angle of 30° of flexion, in which the examiner exerted posterosuperior pressure on the elbow along the longitudinal axis of the humerus, resulted in the greatest change in PMI length measured by displacement sensors; this finding is inconsistent with our results. These contradictory findings probably originate from methodologic differences. Horizontal abduction of the shoulder might stretch the pectoralis major muscle and the clavipectoral fascia, which may directly affect the elongation of the PMI. Removing these tissues overlaying the PMI to expose the muscle, as stated in the report of Muraki et al., could be the reason for the contradictory findings. In addition, there was a glaring difference in the nature of the study medium (ie, live tissue vs cadaveric tissue), which likely contributed to this inconsistency. It is possible that the differences in the viscoelasticity and other material properties of the shoulder joint between a living person and a cadaver affect the elongation of the PMI. Contrary to these previous studies, our study examined the applicability of various stretching maneuvers for the PMI in living persons 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 anatomic perspective, the external rotation and posterior tilt of the scapula stretch the PMI 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 rotates, and tilts posteriorly and that, during shoulder horizontal abduction, the scapula externally rotates and tilts posteriorly. Comparison of scapular motion of shoulder flexion and that of shoulder horizontal abduction in these previous studies shows that the scapular external rotation during shoulder horizontal abduction was greater than that during shoulder flexion. Thus, the results of our study indicating that the shear elastic moduli of Hab30, Hab90, and Hab150 were significantly higher than the elastic modulus of Flex150 suggest that scapular external rotation contributes more to stretching the PMI than scapular posterior tilt. Furthermore, 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 with 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 have shoulder instability. Therefore, Hab30 or Retraction30 might be better suited for these patients. Further research is required to investigate the effects of stretching interventions for the PMI in patients with shoulder instability and limited range of motion.

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, when interpreting the findings of this study, one should note the following: First, the participants 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 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. reported that there was no difference in lengthening of the PMI. Thus, the shear elastic modulus of the PMI measured in our study might represent that of the whole PMI muscle.

Conclusions

We quantitatively investigated the effectiveness of stretching maneuvers for the PMI using shear elastic modulus values obtained by SWE. Our results showed that shoulder horizontal abduction at shoulder elevation angles of 90° and 150° effectively elongated the PMI. The stretching maneuvers for the PMI proposed in this study may be useful for clinical application.

Disclaimer

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