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CITATION:

Kobayashi, Kotono ...[et al]. Effective stretching position of the coracobrachialis muscle. Journal of Biomechanics 2021, 120: 110390.

ISSUE DATE:

2021-05

URL:

http://hdl.handle.net/2433/268029

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Type of Article: Original Article

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Keywords: elastography; shear modulus; stretching; coracobrachialis muscle; shoulder

Word count: 2077

ABSTRACT (250 words)

An increase in the stiffness of the coracobrachialis muscle can restrain proper movement of the glenohumeral joint and scapula during arm elevation. Therefore, muscle stiffness should be reduced through stretching. The aim of this study was to determine the effective stretching position of the coracobrachialis muscle using ultrasound shear wave elastography imaging to evaluate the stiffness of individual muscles. Eighteen healthy young men participated in this study. The shear modulus of the coracobrachialis muscle was measured at the following eight shoulder positions: i) 20° abduction (Rest), ii) maximal external rotation at 90° abduction (ER2), iii) maximal internal rotation at 90° abduction (IR2), iv) maximal flexion (Flex), v) maximal extension (Ext), vi) maximal horizontal abduction at 90° abduction (Hab), vii) maximal horizontal abduction and maximal external rotation at 90° abduction (HabER), and viii) maximal horizontal abduction and maximal internal rotation at 90° abduction (HabIR). The shear modulus in each position was compared with that of Rest using the Wilcoxon signed-rank test, and a multiple comparison test was performed among the positions that exhibited significant difference. The shear modulus of all stretching positions was significantly higher than that of Rest, except for Flex. Moreover, the shear moduli of IR2, Ext, Hab, HabER, and HabIR were significantly higher than that of ER2. The shear modulus of Ext was significantly higher than that of HabIR. The coracobrachialis muscle could be stretched effectively at IR2, Ext, Hab, HabER, and HabIR. Among these positions, Ext, Hab, and HabER are recommended for clinical settings.

INTRODUCTION

The shoulder is the joint in the body with the largest freedom of movement, and it consists of true joints and functional articulations. The true joint consists of the sternoclavicular, acromioclavicular, and glenohumeral joints. The functional articulation consists of the scapulothoracic joint and subacromial space. In the elevation of the upper extremity, it is well known that the glenohumeral joint and scapula, which consist of the compound motion of the sternoclavicular, acromioclavicular, and scapulothoracic joints, move cooperatively (Lee et al., 2020; Ludewig et al., 2009; Matsuki et al., 2011).

The coracobrachialis muscle can affect the movements of the glenohumeral joint and scapula and can be a limiting factor in several situations: i) for shoulder extension, as it has a moment arm of shoulder flexion (Schenkman and Rugo de Cartaya, 1987), ii) for horizontal abduction because it has a moment arm of horizontal abduction when the shoulder is at 90° abduction and 90° external rotation (Bassett et al., 1990), iii) for internal rotation because it has a moment arm of external rotation in the shoulder at 90° abduction and 90° external rotation (Bassett et al., 1990). From the morphological features, the coracoid process is pulled inward and downward when the coracobrachialis muscle contracts. Thus, shortening of the coracobrachialis muscle could cause anterior tilt and internal rotation of the scapula. Because upward rotation, posterior tilt, and external rotation of the scapula are necessary for upper limb elevation (Tsai et al., 2003), shortening of the coracobrachialis muscle could be an inhibiting factor for the movement of the scapula. Therefore, reducing the stiffness of the coracobrachialis muscle is important for inducing proper movement of the shoulder.

Static stretching has often been used to decrease muscle stiffness; however, no previous reports have mentioned the effective stretching of the coracobrachialis muscle. Range of motion, passive torque, and passive joint stiffness have been conventionally used to assess the effect of stretching (Bandy and Irion, 1994; Boyce and Brosky, 2008; Ryan et al., 2008). Nonetheless, it has been reported that such indicators are not able to evaluate the stiffness of individual muscles because they are multiplex indicators that may be affected by the contralateral synergists, ligaments, and articular capsules that exist across the joint (Maisetti et al., 2012). Besides, the shoulder has a complex anatomical structure. Therefore, conventional stretching indicators cannot determine which position is more effective in stretching the coracobrachialis muscle.

Using ultrasound shear wave elastography (SWE), which is one of the features of sonography, we can noninvasively and indirectly evaluate the lengthening of an individual muscle (Koo et al., 2014; Kusano et al., 2017). The SWE measures the propagation velocity of the shear wave generated by the acoustic radiation force from a push pulse and calculates the shear modulus within the region of interest (ROI) (Brandenburg et al., 2014). Previous studies have indicated a high correlation between the shear modulus and the degree of muscle extension (Koo et al., 2013), suggesting that a higher shear modulus indicates that the muscle is more extended. Thus, the shear modulus is considered a useful index for the objective evaluation of the degree of muscle extension by stretching (Umehara et al., 2015).

The aim of this study was to determine the effective stretching position of the coracobrachialis muscle using ultrasound SWE imaging. We hypothesized that stretching in extension and horizontal abduction would effectively extend this muscle because of its functions of flexion and horizontal adduction of the shoulder (Bassett et al., 1990; Schenkman and Rugo de Cartaya, 1987).

MATERIALS AND METHODS

Participants

Eighteen men (age = 24.8 ± 4.4 years; height = 171.4 ± 8.2 cm; mass = 66.7 ± 10.4 kg) participated in this study. Participants did not have any orthopedic or nervous system abnormalities in the upper limbs. All participants did not perform specific training and/or stretching exercise, which could influence to the muscle properties. The sample size was calculated using G*Power software (version 3.1; Heinrich Heine University, Dusseldorf, Germany) for a *t*-test model (effect size = 0.83; α error = 0.05; power = 0.8), which revealed that 14 participants were required. It should be noted that the effect size was calculated from a previous study with a similar empirical procedure (Umehara et al., 2017). Therefore, we recruited 18 participants, considering the absence of data. All participants were fully informed about the procedures and purpose and signed the participation agreement prior to the experiment. This study was approved by the Ethics Committee of Kyoto University Graduate School and Faculty of Medicine (approval number: R0233-7).

Measurement positions

The shear modulus was measured at rest and in seven possible stretching positions as follows: i) 20º shoulder abduction (Rest), ii) shoulder maximal external rotation at 90º abduction (ER2), iii) shoulder maximal internal rotation at 90º abduction (IR2), iv) shoulder maximal flexion (Flex), v) shoulder maximal extension (Ext), vi) shoulder maximal horizontal abduction at 90º abduction (Hab), vii) maximal shoulder abduction and maximal external rotation at 90º abduction (HabER), and viii) shoulder maximal horizontal abduction and maximal internal rotation at 90º abduction (HabIR). All the positions are shown in Figure 1. The elbow joint was fully extended in the measurement of Rest, Flex, and Ext, and at 90º flexion in the other positions. Before each measurement, we determined the elbow angle using a goniometer, and the investigator hold the position. Participants lay in a supine position on a plinth during the measurements. The shoulder was passively moved to the angle just before the participants felt pain, and then the position was maintained by the investigator during the measurements. Two investigators performed ultrasound measurements and the position setting, respectively. During all measurements, participants were instructed to relax as much as possible, and their shoulder was supported to avoid muscle contraction. Measurements for Rest were conducted first, followed by the other positions in a random order to avoid the carry-over effect. The computerized random number function in Microsoft Excel (Microsoft Japan Co., Ltd, Japan) was used for randomization.

Shear wave elastography

The shear modulus of the coracobrachialis muscle was measured using ultrasound SWE imaging (Aixplorer version 12.2.0; SuperSonic Imagine, Aix-en Provence, France) with a linear probe (2–10 MHz, SuperLiner SL10-2). The measurement modes were custom musculoskeletal preset penetration modes with high persistence, a frequency of 2.0 Hz, a smoothing level of 5, opacity of 100%, and gain of 90%. The coracobrachialis of the non-dominant upper limb was captured to assess the shear modulus. The dominant limb was determined as the limb that is preferred for throwing a ball, which was the right limb in 15 participants and the left limb in 3. As the positional relation between the belly of the coracobrachialis muscle and the probe changed at each position, we identified the muscle belly based on the proximal 20% point of the line connecting the acromion of the scapula and the lateral epicondyle of the humerus before capturing longitudinal images. The measurement location was marked on the skin in the resting position for capturing the images at same the location across the different stretching positions. In addition, on the B-mode image the intramuscular tendon in the coracobrachialis muscle was also confirmed as the maker. The shear modulus measurement was repeated three times at each position, and the average value was used for further analysis.

Image analysis

For image analysis, the ROI was set to 1 × 1 cm at the center of the muscle belly. Then, a circle with a diameter of 8 mm was set in the ROI, and the average shear wave propagation velocity in this circle was calculated. A circle with a diameter of 5 mm was used when the measurable muscle belly was thinner than 8 mm or when there was an obvious artifact owing to an intramuscular tendon or fascia. The shear modulus (G) was calculated from the shear wave propagation speed (V) and muscle density (ρ) as follows:

$$G = \rho V^2$$

The muscle density is assumed to be 1 g/cm^3 (Nakamura et al., 2014). The ultrasound images of all positions are shown in Figure 2.

Statistical analyses

Statistical analyses were performed using SPSS software (version 22; IBM Japan, Tokyo, Japan). The reproducibility of the measurements was assessed using the intraclass correlation coefficient (ICC) (1, 3), as calculated from the data measured three times at each position.

The Shapiro–Wilk test was performed to confirm the normality of the data. The results revealed that the normality of the data was not confirmed in Flex, Ext, Hab, and HabIR. Thus, the shear modulus at each stretching position was compared with that at Rest by the Wilcoxon signed-rank test with Bonferroni correction. Furthermore, in stretching positions that exhibited a significant difference compared to Rest, the Friedman test was performed, followed by the Wilcoxon signed-rank test with Bonferroni correction as a multiple comparison test. In addition, for the cases in which the multiple comparison test did not reveal a significant difference between positions, the effect size (*r*) was calculated. An alpha level of 0.05 was used in all statistical tests. The effect sizes (*r*) of 0.1, 0.3, and 0.5 were considered small, medium, and large effect sizes, respectively (Cohen, 1988).

RESULTS

The shear modulus measurements were reproducible, as shown in Table 1, because the ICCs (1,3) were over 0.8 in all positions.

The shear moduli at each position are shown in Figure 3. The Wilcoxon signed-rank test with Bonferroni correction demonstrated that the shear modulus at all positions was significantly higher than that of Rest ($P < .01$), except for Flex ($P = .306$). In the Friedman test, a significant main effect ($P < .001$) was observed, and the multiple comparison tests revealed that the shear modulus was significantly higher at IR2, Ext, Hab, HabER, and HabIR compared with ER2 ($P < .001$). The shear modulus was significantly higher in Ext than in HabIR ($P = .033$). There were no significant differences between the other positions.

In addition, we calculated the effect sizes (*r*) of the five stretching positions in which multiple comparisons revealed no significant differences (Table 2). The effect sizes were relatively large for the differences between Ext and HabIR (0.457), Ext and IR2 (0.621), HabER and IR2 (0.559), Hab and IR2 (0.549), and Hab and HabIR (0.498).

DISCUSSION

In this study, we investigated the effective stretching position of the coracobrachialis muscle using ultrasound SWE imaging. The results revealed that the shear moduli at ER2, IR2, Ext, Hab, HabER, and HabIR were significantly higher than those at Rest, except for Flex; moreover, the shear moduli were significantly higher at IR2, Ext, Hab, HabER, and HabIR compared with ER2. Furthermore, the shear modulus was significantly higher at Ext than at HabIR. The way to determine the effective stretching positions followed previous studies (Umehara et al., 2017; Nishishita et al., 2018; Ogawa et al., 2020; Umegaki et al., 2015). These results partially support our hypothesis that the effective stretching position of the coracobrachialis muscle could be extended or horizontal abduction. To the best of our knowledge, this is the first study to investigate the effective stretching position of the coracobrachialis muscle using SWE.

The stretching of a muscle is considerably affected by its moment arm. Considering tendon excursion methods (Maganaris et al., 2000), a muscle could be stretched with a joint movement in the direction opposite to its moment arm. The coracobrachialis muscle has a moment arm of shoulder flexion. Additionally, it also has a moment arm of horizontal adduction and external rotation in shoulder abduction at 90° and external rotation at 90°. Therefore, we supposed that the muscle would not be stretched at the position of Flex and ER2 because the joint was moved in the direction defined by the moment arm. By contrast, it could be stretched at Hab, HabER, or HabIR because of its joint movement in the direction opposite to the moment arm.

It is important to identify the recommended stretching position for the coracobrachialis muscle for clinical applications. Compared with HabIR, there was no significant difference in the shear modulus of Hab and HabER, but the shear modulus of Ext was significantly higher. The effect sizes were relatively high for the difference between Ext, Hab, HabER, and IR2 or HabIR. These results suggest that the coracobrachialis muscle can be effectively stretched at Ext, Hab, or HabER; therefore, these stretching positions are particularly recommended.

Considering the anatomy, the coracobrachialis muscle is attached to the coracoid process. Thus, shortening of the coracobrachialis muscle could cause anterior tilt of the scapula. This is serious problem in clinical settings because the scapular anterior tilt cause subacromial impingement and also limits upper limb elevation. Therefore, we believe that our findings can be applied to patients who have limitation in upper limb elevation. Moreover, the musculocutaneous nerve passes though the coracobrachialis muscle. Stiffness of the coracobrachialis muscle can cause strangulation of the musculocutaneous nerve and limit elbow flexion (Pecina and Bojanic, 1993). The present findings may be useful for these patients as well. This study has some limitations. First, the influence of muscle activity could not be completely eliminated because muscle activity was not measured. However, the influence of muscle activity on the shear modulus may be negligible as participants were instructed to relax, and the investigator sufficiently supported their limb. Second, we did not stabilize the scapula to which the coracobrachialis muscle attaches. However, it is considered that the scapula could be partly secured by the plinth because the stretching was performed in the supine position. Third, the shear modulus could be changed in stretching and rest time. However, we kept the stretching time as short as possible, and we put participants' arm the initial position for avoiding changes in muscle elasticity when it took long time for the ultrasound measurement. Additionally, we had sufficient resting time between the stretching procedures, randomized the order of stretching, and compared changes in elastic modulus within subjects. Therefore, the stretching and resting time effects on the muscle elasticity might be negligible. Forth, we investigated only the acute effects of stretching position. Therefore, it is unclear whether the intervention program affects the coracobrachialis muscle elongation. Further studies need to examine the effects of stretching interventions in patients or elderly people.

In conclusion, we investigated the effective stretching positions of the coracobrachialis muscle using ultrasound SWE imaging. The results indicated that the coracobrachialis muscle was stretched in the following five positions: internal rotation at 90º abduction, extension, horizontal abduction, horizontal abduction with external rotation, and horizontal abduction with internal rotation. Among them, the extension, horizontal abduction, and horizontal abduction with external rotation stretched the coracobrachialis muscle to a maximum extent based on their higher effect sizes. These findings are clinically useful in patients with a limited range of motion owing to increased coracobrachialis muscle stiffness.

ACKNOWLEDGEMENTS

We would like to thank Ms. Ibuki and Editage (www.editage.jp) for assisting in English language editing.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

AUTHORS' CONTRIBUTIONS

K.K., J.U., S.N., and N.I. conceived and designed the research. K.K., J.U., and S.N. performed the experiment and analyzed the data. K.K., J.U., S.N., and N.I. interpreted the results. K.K., J.U., and

S.N. wrote the manuscript. J.U., S.N., and N.I. edited and revised the manuscript. All authors have approved the final version of the manuscript.

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Table 1. Intra-observer reliability for the shear wave measurement in each position

Rest	ER2	IR2	Flex	Ext	Hab	HabER	HabIR
0.990	0.877	0.928	0.841	0.990	0.990	0.906	0.927

Rest: shoulder 20° abduction, ER2: shoulder maximal external rotation at 90° abduction, IR2: shoulder maximal internal rotation at 90° abduction, Flex: shoulder maximal flexion, Ext: shoulder maximal extension, Hab: shoulder maximal horizontal abduction at 90° abduction, HabER: shoulder maximal horizontal abduction and maximal external rotation at 90° abduction, HabIR: shoulder maximal horizontal abduction and maximal internal rotation at 90° abduction. The values represent intraclass correlation coefficients (1,3).

Table 2. Effect size between the stretching positions

	Ext-IR2	Ext-HabIR	Ext-HabER	Ext-Hab	Hab-IR2	Hab-HabIR	Hab-HabER	HabER-IR2	HabER-HabIR	HabIR-IR2
Effect size (*r*)	0.621	0.693	0.457	0.169	0.549	0.498	0.221	0.559	0.231	0.046

Rest: shoulder 20° abduction, ER2: shoulder maximal external rotation at 90° abduction, IR2: shoulder maximal internal rotation at 90° abduction, Flex: shoulder maximal flexion, Ext: shoulder maximal extension, Hab: shoulder maximal horizontal abduction at 90° abduction, HabER: shoulder maximal horizontal abduction and maximal external rotation at 90° abduction, HabIR: shoulder maximal horizontal abduction and maximal internal rotation at 90° abduction. The values represent the effect sizes of *r*.

Figure 1. Measurement positions

Rest: shoulder 20° abduction, ER2: shoulder maximal external rotation at 90° abduction, IR2: shoulder maximal internal rotation at 90° abduction, Flex: shoulder maximal flexion, Ext: shoulder maximal extension, Hab: shoulder maximal horizontal abduction at 90° abduction, HabER: shoulder maximal horizontal abduction and maximal external rotation at 90° abduction, HabIR: shoulder maximal horizontal abduction and maximal internal rotation at 90° abduction.

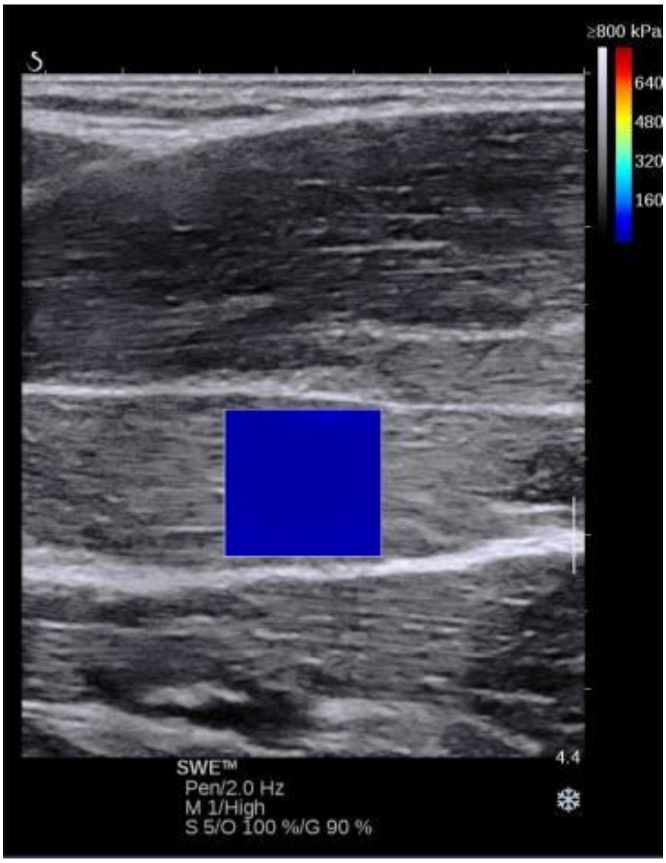

Fig. 2. The ultrasound image of the coracobrachialis muscle at Rest.

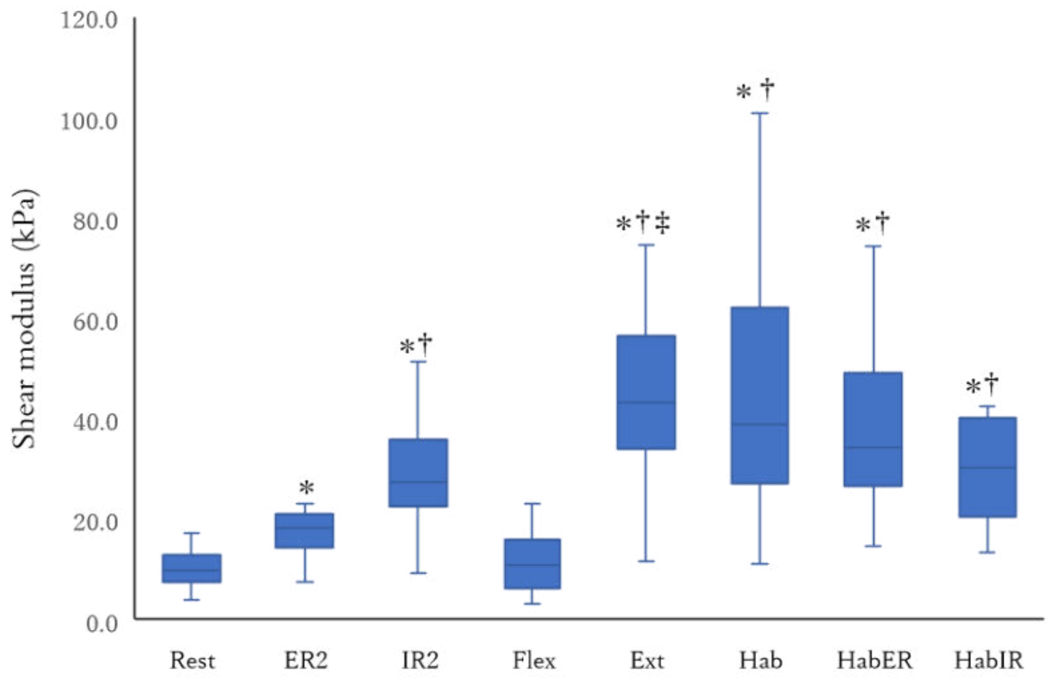

Figure 3. The shear modulus of the coracobrachialis muscle in the positions assessed. Rest: shoulder 20° abduction, ER2: shoulder maximal external rotation at 90° abduction, IR2: shoulder maximal internal rotation at 90° abduction, Flex: shoulder maximal flexion, Ext: shoulder maximal extension, Hab: shoulder maximal horizontal abduction at 90° abduction, HabER: shoulder maximal horizontal abduction and maximal external rotation at 90° abduction, HabIR: shoulder maximal horizontal abduction and maximal internal rotation at 90° abduction.

* Positions that showed a significant difference compared to Rest

† Positions that showed a significant difference compared to ER2

‡ Positions that showed a significant difference compared to HabIR

Whiskers indicate the range of data, and the line and box represent the median and quartile, respectively.