Effects of shoulder position during static stretching on shear elastic modulus of biceps brachii muscle

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Abstract

Biceps brachii muscle consists of a long head (BBL) and a short head (BBS). Shortening the BBL and BBS causes tendinopathy of the intertubercular groove and coracoid process. Therefore, it is necessary to stretch the BBL and BBS separately. This study aimed to determine the positions where the BBL and BBS were most stretched, using shear wave elastography (SWE). Fifteen healthy young males participated in the study. The shear elastic moduli of the BBL and BBS of the non-dominant arm were measured using SWE. The measurement positions were the resting position (shoulder flexion and abduction 0°) and four stretching positions. The elbow was extended, and the forearm was pronated in all positions. Statistical analysis was performed using Wilcoxon's signed-rank test to compare the shear elastic moduli between the resting and stretched limb positions. In addition, Wilcoxon's signed-rank test was used to compare shear elastic moduli between the stretching positions that were significantly different compared to the resting position. Results show that for BBL and BBS, shear elastic moduli were significantly higher in the shoulder extension + external rotation and shoulder horizontal abduction + internal rotation positions than in the resting position. Moreover, the shear elastic modulus of the BBL was significantly higher in shoulder extension + external rotation than in shoulder horizontal abduction + internal rotation. In contrast, the shear elastic modulus of the BBS was significantly higher in shoulder horizontal abduction + internal rotation than in shoulder extension +

external rotation. The BBL and BBS were effectively stretched by shoulder extension + external rotation and horizontal abduction + internal rotation.

Keywords: Shear elastic modulus, Stretching, Biceps brachii, Rehabilitation, Shear wave elastography

1. Introduction

The biceps brachii (BB) consists of a long head (BBL) and a short head (BBS). The BBL and BBS, which run differently, tend to have different clinical conditions. Tendinitis of BBL is often observed in the intertubercular groove (Berlemann et al,. 1995), while inflammation of the BBS often occurs at the coracoid process (Karim et al., 2005). Thus, individual stretching positions for BBL and BBS should be considered because of differences in anatomy and clinical symptoms.

Several studies have reported stretching positions for BBL and BBS (Houglum et al ,. 2001, Evjenth et al,. 1993) . Specifically, elbow and shoulder extension and forearm pronation in the sitting or supine position has been reported as stretching positions for BBL and BBS (Houglum et al ,. 2001) . The individual stretching position of the BBL has been presented as a position combining shoulder extension, adduction, external rotation, forearm pronation, and elbow extension in the side-lying position (Evjenth et al,. 1993) . The individual stretching position of the BBS has been presented as a position combining shoulder abduction, external rotation, forearm pronation, and elbow extension (Evjenth et al,. 1993) . However, these are expert opinions, and no experimental studies have quantitatively examined the most effective stretching positions for BBL and BBS in vivo.

Ultrasonic shear wave elastography (SWE) has been used to measure the viscoelastic properties of soft tissues. With this method, it is possible to quantitatively calculate the shear elastic modulus of a tissue using the propagation shear wave velocity when the tissue is vibrated using a radiation force (Brandenburg et al., 2014) . The shear elastic modulus, which is highly correlated with the passive properties of the muscle (Eby et al., 2013; Koo et al., 2013) , has been used as an indicator of muscle elongation to examine the effective stretching positions of individual muscles (Asayama et al., 2021; Ogawa et al., 2020; Umehara et al., 2017; Yanase et al., 2021) . Therefore, SWE can be used to quantitatively examine the most effective stretching positions for the BBL and BBS.

BBL and BBS with moment arms for elbow flexion and forearm supination (Hale et al., 2011) are more stretched by elbow extension and forearm pronation. Furthermore, they are affected by the positions of the elbow and shoulder joints because they are bi-articular muscles. Anatomically, a BB with moment arms for shoulder flexion and horizontal adduction is considered to be stretched by shoulder extension or horizontal abduction. In addition, the BBL, which is anatomically located laterally, can be considered more stretched with shoulder extension. Conversely, the BBS, which is anatomically located medially, could be considered more stretched by shoulder horizontal abduction. However, no reports have quantitatively examined stretching methods for BBL and BBS that consider the position of the shoulder joint in addition to the elbow and forearm. Furthermore, studies have not quantitatively examined whether BBL and BBS are stretched by the external or internal rotation of the shoulder, and its effect remains unclear.

This study aimed to clarify the stretching position in which the BBL and BBS are most stretched using SWE, focusing on the shoulder joint position. The hypothesis was that the BBL is effectively stretched by elbow extension, forearm pronation, and shoulder extension. In contrast, the BBS is effectively stretched by elbow extension, forearm pronation, and shoulder horizontal abduction.

2. Methods

2.1 Participants

Fifteen healthy young men (age 26.8 ± 5.6 years; height, 172.3 ± 6.4 cm; weight, 65.5 ± 9.8 kg) participated in the study. People with any history of orthopedic or neurological diseases of the upper limb, including BB, were excluded from this study. The sample size was calculated using G*Power software (version 3.1; Heinrich Heine University, Dusseldorf, Germany) for Wilcoxon's signed-rank test (effect size, 0.8; alpha error, 0.05; power, 0.8), which showed that 15 participants were required. The sample size was determined referring to previous studies (Umehara et al,. 2017). All participants were fully informed about the study aims and procedures, and informed consent was obtained before participation. The study was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine (R0233).

2.2 Stretching procedures

The same two investigators with physical therapist licenses performed all procedures. One investigator measured the shear elastic modulus using SWE, whereas the other performed the stretching maneuver for the participant's non-dominant arm. The dominant arm is the arm that rows the ball during sports. All stretching exercises were performed in the prone position, elbow extension, and forearm pronation under the following five conditions (Fig. 1): (A) Resting position: shoulder extension 0°, abduction 0°, internal/external rotation intermediate position, (B) shoulder maximal extension + external rotation, (C) shoulder maximal extension + internal rotation, (D) shoulder maximal horizontal abduction + external rotation, and (E) shoulder maximal horizontal abduction + internal rotation. The order of stretching was as follows: shoulder rotation first, followed by shoulder extension or horizontal abduction, and finally, elbow extension and forearm pronation. The mean and SD values of the range of motion during extension and horizontal abduction for participants were 29.0° ± 12.8 and 11.5° ± 8.0, respectively. Stretching was performed at the maximum angle at which the participants felt no discomfort or pain. The time from the start of the stretching to the measurement was within 1 min. The order of stretching was randomized using a random number table (Microsoft Excel, Microsoft Corp., Redmond, WA, USA) (Yanase et al., 2021) . The participants rested for at least two minutes after each stretching session to remove the effects of sustained stretching (Asayama et al., 2021). The participants were instructed to relax as much as possible to avoid muscle contractions during stretching.

2.3 Measurements of shear elastic modulus

The shear elastic moduli of the BBL and BBS were measured using an ultrasonic SWE (Aixplorer; SuperSonic Imagine, Aix-en-Provence, France) with a linear probe (4–15 MHz, SL15-4, Vermon, Tours, France). The presets were set to Penetration and Smoothing 5, and the scale was set to an upper limit of 800 kPa. The measurement site was the distal 70% of brachial length (from the acromion to the lateral epicondyle). The long and short heads were separated by palpation at the site, and the elastic modulus was measured. To ensure that the measurement sites were consistent, body markers were used. First, the cross-sectional images of the BBL and BBS were confirmed using the B-mode, and the probe was placed parallel to the muscle fascicle of the BBL and BBS (Fig. 2). A region of interest (ROI) of

1.0 cm length and 2.5 cm width was set at the center of the muscle belly. For quantitative analysis, the shear elastic modulus in the ROI was measured using the Q-box™ trace function. The shear elastic moduli were measured twice for BBL and BBS, and the average values were used for the statistical analysis. The shear elastic modulus (G) was calculated from the shear wave speed (V) using the following equation:

$$G(\text{kPa}) = \rho V^2$$

where ρ is the muscle mass density (1000 kg/m^3); high values of ρ indicate high muscle stiffness. In this study, we calculated the shear modulus by dividing the Young's modulus, which was provided by the device, by three.

2.4 Measurements of electromyography

Surface electromyography (TeleMyo 2400, Noraxon USA, Scottsdale, AZ, USA) was used to measure muscle activity in the BBL and BBS to confirm no muscle contraction during stretching. Bipolar surface electrodes (Blue Sensor; Medicotest, Olsykke, Denmark) were attached to the muscle belly of the BB within 2 cm of the shear elastic modulus measurement site with a distance of 2 cm between the electrodes. The surface electromyogram (EMG) sampling rate was 1500 Hz, and bandpass filtering was set between 10 and 500 Hz. The root-mean-square (RMS) value was calculated after rectification. To normalize the measured data, the maximum voluntary isometric contraction (MVC) of elbow flexion was measured for 3 seconds in the sitting position at the shoulder joint neutral position and elbow joint flexion at 90°. MVC was measured at the end of the experiment.

2.5 Statistical analysis

Statistical analysis was performed using the IBM SPSS Statistics software (version 22.0, IBM Corp, Armonk, NY, USA). The reliability of the shear elastic modulus measurements for each position was evaluated using the variation and intraclass correlation coefficients (1,2) ($ICC_{1,2}$). Normality was confirmed using the Shapiro–Wilk test. The shear elastic moduli of BBL and BBS were analyzed using Wilcoxon’s signed-rank test and Bonferroni correction to compare resting and all stretching positions.

In addition, Wilcoxon's signed-rank test was used to compare stretching positions significantly different from the resting position. The significance level was set at $p < 0.05$.

3. Results

Regarding the reliability of the shear elastic moduli measurements for each position, the coefficient of variation was less than 10%, and the ICC (1,2) was greater than 0.8 for both BBL and BBS, indicating high reliability (Table 1). In addition, the muscle activity during each stretching motion was less than 5% MVC in both muscles, confirming that no contraction occurred during the stretching.

Tables 2 and 3 show the shear elastic moduli of BBL and BBS, respectively. The shear elastic modulus of the BBL was significantly higher for maximal extension + external rotation and maximal horizontal abduction + internal rotation than for the resting position (p = 0.002 and p = 0.003, respectively). Similarly, the shear elastic moduli of the BBS in maximum extension + external rotation and maximum horizontal abduction + internal rotation were significantly higher than those in the resting position (p = 0.003 and p = 0.002, respectively).

Next, Wilcoxon's signed-rank tests were performed between the stretching positions that showed significant differences compared to the resting position, that is, maximal extension + external rotation and maximal horizontal abduction + internal rotation, for both BBL and BBS. The results showed that maximum extension + external rotation was significantly higher than maximum horizontal abduction + internal rotation in BBL ($p = 0.012$) (Fig. 3). In the BBS, maximal horizontal abduction + internal rotation were significantly higher than maximal extension + external rotation ($p = 0.010$) (Fig. 4).

4. Discussion

In this study, we investigated the stretching position in which the BBL and BBS were the most stretched using SWE, focusing on the shoulder joint position. For both BBL and BBS, the shear elastic moduli were significantly higher in shoulder extension + external rotation and horizontal abduction + internal rotation than in the resting position (extension 0° and abduction 0°). Furthermore, the shear elastic modulus of BBL was significantly higher in shoulder extension + external rotation than in horizontal abduction + internal rotation, whereas BBS was significantly higher in horizontal abduction + internal rotation than in extension + external rotation. These results suggest that the elbow and shoulder joint position affect the amount of biceps brachii elongation and that the most stretched position differs between BBL and BBS. This is the first study to quantitatively examine the individual stretching positions for BBL and BBS using SWE.

The amount of muscle elongation was affected by the moment arm. In tendon excursion methods (Maganaris C N et al., 2000) , the muscle is stretched by joint motion opposite to the moment arm possessed by the muscle. Considering the muscle attachment sites, the BBL and BBS have moment arms for shoulder joint flexion and horizontal adduction. Thus, the muscles are stretched by shoulder extension and horizontal abduction. The results of this study support our hypothesis.

Furthermore, the results of this study suggest that shoulder extension, horizontal abduction, and shoulder rotation affect the extent of BB muscle elongation. Regarding the effect of shoulder rotation, it is possible that the shoulder extension range of motion was greater during external rotation than during internal rotation, which might have resulted in a higher shear elastic modulus with the combination of shoulder extension and external rotation. In contrast, it is possible that the shoulder horizontal abduction range of motion was greater during internal rotation than during external rotation, which might have resulted in a higher shear elastic modulus in the combination of horizontal abduction and internal rotation.

The results of this study showed that the shear elastic moduli were highest in shoulder extension + external rotation for BBL and horizontal abduction + internal rotation for BBS. Considering the difference in the most stretched position between BBL and BBS, BBS may have a larger shoulder horizontal adduction moment arm than BBL, and BBL may have a larger shoulder extension moment arm than BBS. This suggests that horizontal shoulder abduction and shoulder extension may have been effective in elongating the BBS and BBL, respectively.

Regarding clinical implications, effective stretching positions for muscle lengthening need to be identified separately for BBL and BBS because muscle attachment sites differ between them (van den Bekerom et al., 2016). Based on the results of this study, the recommended stretching position for BBL is elbow extension and forearm pronation combined with shoulder extension and external rotation, and the recommended stretching position for BBS is elbow extension and forearm pronation combined with shoulder horizontal abduction and internal rotation.

A limitation of this study is that the participants were healthy people; therefore, it is unclear whether the same effects can be expected for patients with musculoskeletal disorders. Second, the chronic effect of stretching on BB flexibility remains unknown. Further research is required to determine the effects of long-term stretching interventions on BB flexibility using effective stretching positions.

5. Conclusion

The current study measured the shear elastic moduli obtained by SWE to identify the stretching positions in which BBL and BBS were the most stretched. Our results revealed that the BBL was stretched in elbow extension and forearm pronation combined with shoulder extension and external rotation, whereas the BBS was stretched in elbow extension and forearm pronation combined with shoulder horizontal abduction and internal rotation. Shoulder joint position, including rotation, should be considered during BBL and BBS stretching, in addition to the elbow joint position.

Declaration of Competing Interest

The authors declare no conflicts of interest related to the manuscript.

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Author's contributions

K.I., K.Y., T.I., and N.I. conceived and designed the research. K.I. and K.Y. performed the experiment and analyzed the data. K.I., K.Y., T.I., and N.I. interpreted the results. K.I. and K.Y. wrote the manuscript. K.I. and K.Y. edited and revised the manuscript. All authors have approved the final version of the manuscript.

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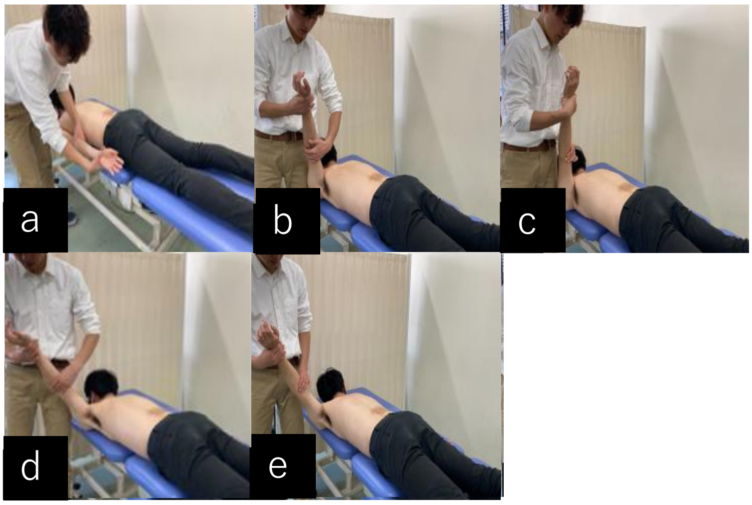

Figure 1 Positions for measuring the shear elastic modulus of the biceps brachii. All stretching was performed in the prone position, elbow extension, and forearm pronation. (a) Resting position; shoulder extension and abduction 0°. (b) Maximum shoulder extension + external rotation. (c)

Maximum shoulder extension + internal rotation. (d) Maximum shoulder horizontal abduction + external rotation. (e) Maximum shoulder horizontal abduction + internal rotation.

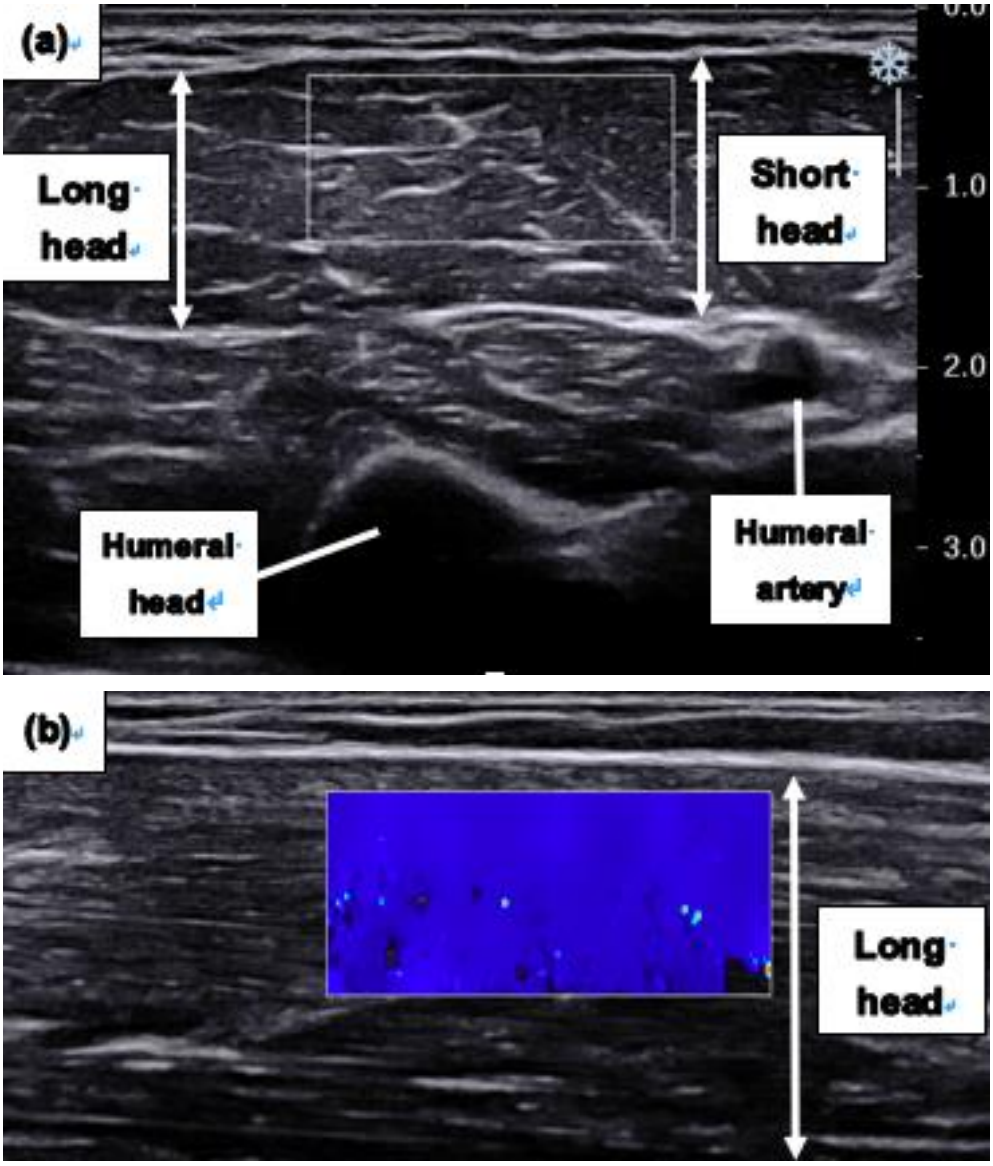

Figure 2 Ultrasound B-mode and shear wave elastographic images of biceps brachii long head and short head (a) B-mode cross-sectional image of the biceps brachii long and short heads. The distinction between adjacent long and short heads was performed by palpation. (b) Color mapping in

the region of interest indicates the muscle shear elastic modulus using shear wave elastography (longitudinal image of the biceps brachii long head).

Table 1 Reliability of shear elastic modulus measurements

Measurement position	CV (%)		ICC (1,2)			
	BBL	BBS	BBL	95% CI	BBS	95% CI
Rest (Extension 0° and abduction 0°)	4.7	7.5	0.96	0.90–0.98	0.82	0.48–0.94
Extension + external rotation	3.9	4.4	0.98	0.95–0.99	0.98	0.96–0.99
Extension + internal rotation	4.2	2.8	0.98	0.95–0.99	0.98	0.96–0.99
Horizontal abduction + external rotation	3.0	4.4	0.99	0.98–0.99	0.97	0.93–0.99
Horizontal abduction + internal rotation	3.6	5.0	0.98	0.98–0.99	0.96	0.90–0.98

CV, coefficient of variation; ICC, intraclass correlation coefficient; BBL, biceps brachii long head; BBS, biceps brachii short head; CI, confidence interval

Table 2 Shear elastic modulus of biceps brachii long head

Measurement position	Shear elastic modulus (Means ± SD, kPa)	Comparison with rest (*p* value)
Rest (extension 0° and abduction 0°)	22.9 ± 7.0	
Extension + external rotation	56.4 ± 25.1	**0.002**
Extension + internal rotation	22.8 ± 8.1	3.64
Horizontal abduction + external rotation	34.4 ± 14.4	0.124
Horizontal abduction + internal rotation	38.5 ± 13.7	**0.003**

In bold: statistically significant difference compared with rest

Table 3 Shear elastic modulus of biceps brachii short head

Measurement position	Shear elastic modulus (Means ± SD, kPa)	Comparison with rest (*p* value)
Rest (extension 0° and abduction 0°)	20.5 ± 6.0	
Extension + external rotation	36.0 ± 9.2	**0.003**

Extension + internal rotation	26.9 ± 19.6	1.22
Horizontal abduction + external rotation	41.2 ± 23.5	0.063
Horizontal abduction + internal rotation	48.3 ± 17.9	**0.002**

In bold: statistically significant difference compared with rest

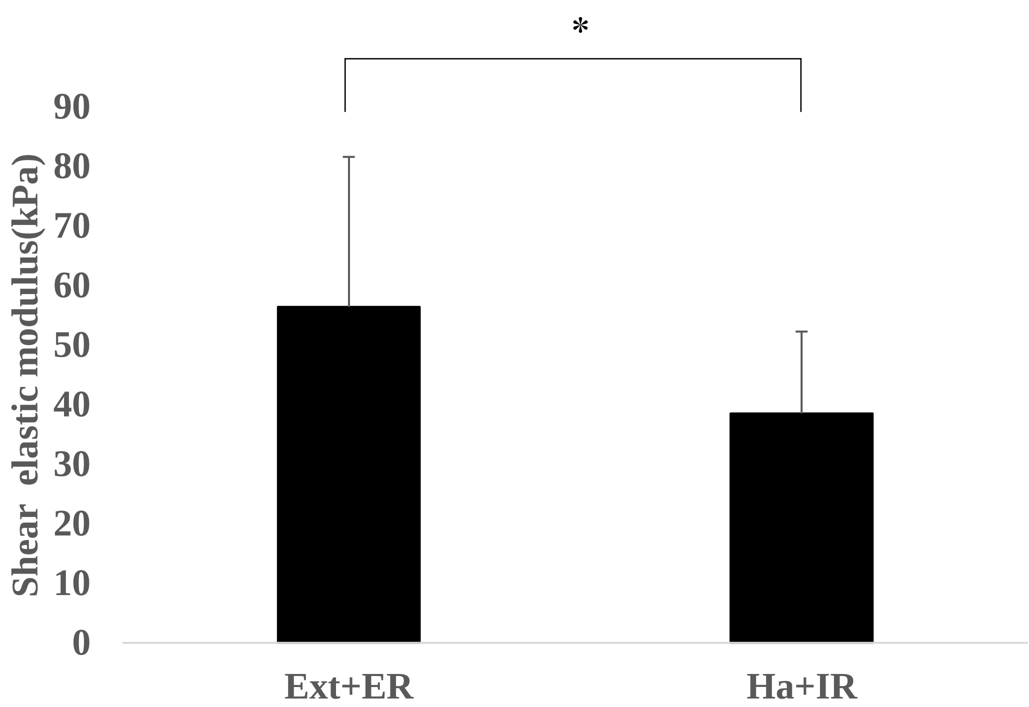

Figure 3 Comparison of shear elastic modulus of BBL between stretching positions with significantly higher elastic moduli compared to those of the rest. Ext+ER, shoulder extension + external rotation; Ha+IR, shoulder horizontal abduction + internal rotation * Ext+ER was significantly greater than Ha+IR ($p < 0.05$).

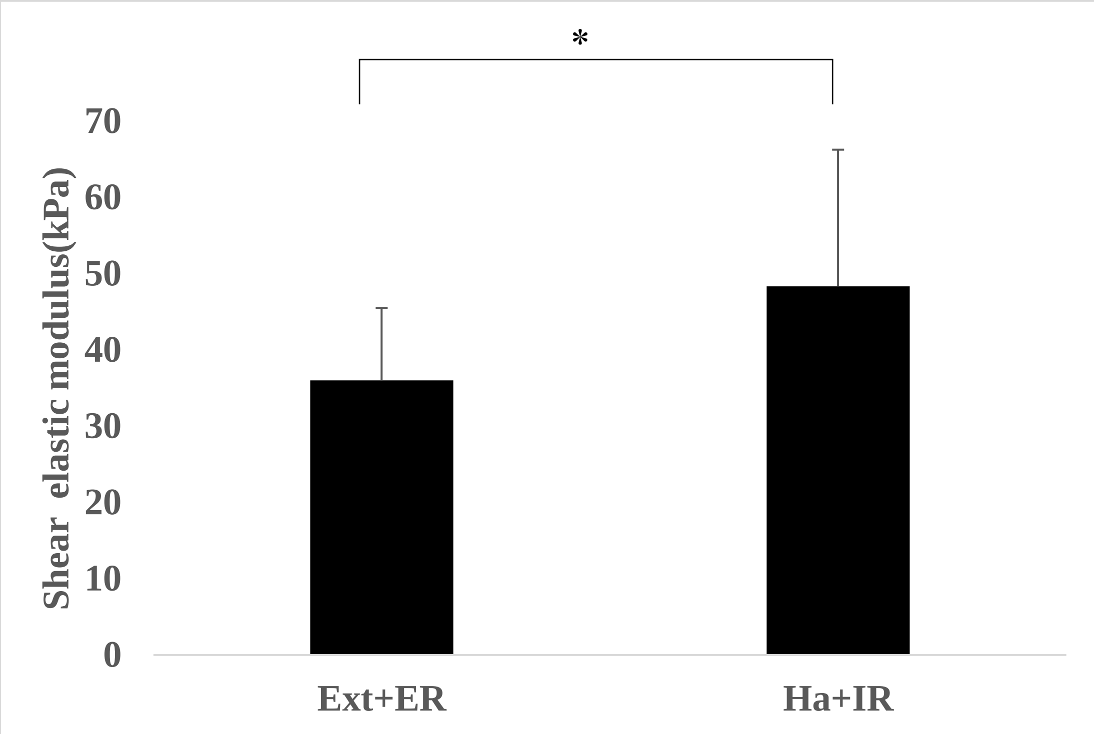

Figure 4 Comparison of shear elastic modulus of BBS between stretching positions with significantly higher elastic moduli compared to those of the rest. Ext+ER, shoulder extension + external rotation; Ha+IR, shoulder horizontal abduction + internal rotation * Ha+IR was significantly greater than Ext+ER ($P < 0.05$).