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Evaluation of muscle stiffness in adhesive capsulitis with Myoton PRO

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Background: Adhesive capsulitis (AC) is characterized by pain and limited range of motion, caused by stiffness of the joint capsule and coracohumeral ligament. On the other hand, there have been few reports on muscle stiffness in AC. The purpose of this study was to assess muscle stiffness in patients of AC with a portable and noninvasive device, Myoton PRO. We hypothesized that muscle stiffness around shoulder joint increases in AC.

Methods: At first, we surveyed correlation between Myoton PRO and shear wave elastography with phantoms. Second, reproducibility and repeatability of healthy volunteers with Myoton PRO were evaluated. Finally, muscle stiffness was measured in 40 patients who were diagnosed with AC. Muscle stiffness was quantitatively measured with Myoton PRO. We compared the stiffness of the anterior deltoid (AD), pectoralis major, and latissimus dorsi (LD) in AC patients on both the affected and nonaffected sides.

Results: Correlation coefficient in shear wave elastography and Myoton PRO was 0.99($P = .001$). Reliability of intraoperator and interoperator with Myoton PRO was 0.9 or higher. Muscle stiffness values (N/m) of the AD, pectoralis major, and LD were 355 ± 61, 252 ± 54, 207 ± 51 in the affected sides and 328 ± 50, 252 ± 41, 186 ± 37 in the nonaffected sides, and the differences were significant in the AD and LD ($P = .005$, $P = .002$, respectively).

Conclusions: We used Myoton PRO to evaluate muscle stiffness in AC. The AD and LD muscles of AC patients were significantly stiffer on the affected side compared to the nonaffected side.

Adhesive capsulitis (AC) is described symptomatically as painful and limited range of motion (ROM) of the shoulder.[14] AC occurs in 2%-5% of the general population.[9] Limited ROM affects activities of daily living, such as combing hair and washing the body.[12] The joint capsule and the coracohumeral ligament (CHL) are major factors that contribute to the limited ROM of AC.[4,7] Moreover, some articles have shown stiffness of the supraspinatus and infraspinatus tendons in AC patients with ultrasound elastography.[18,20] Although the factors causing limited ROM are important for clinicians and physical therapists to manage the condition, the limited ROM in AC is related to various factors and identifying them can be challenging.

Recently, Hollmann et al have suggested muscle causes ROM restrictions in AC.[8] In their study, improvements in abduction and external rotation were found under anesthesia compared to preanesthesia in AC. Therefore, the muscle may be an additional mechanism related to the limited ROM in AC. To measure muscle status, shear wave elastography (SWE) has been used for noninvasive and objective measurement.[1,3] SWE can evaluate the targeted muscle stiffness as Young's modulus by analyzing shear wave velocity (SWV).[17] Although SWE is a valid and reliable tool to evaluate muscle stiffness, it is expensive and requires technical expertise to be widely used for research.[6] In contrast, Myoton PRO is a handheld device and very easy to operate. It can measure muscle stiffness quantitatively and noninvasively like SWE. It is a good device to assess superficial skeletal muscle.[11] To the best of our knowledge, no clinical studies have reported shoulder muscle measurements in AC with Myoton PRO.

This study aimed to evaluate the following: 1) correlation between SWE and Myoton PRO, 2) reproducibility and repeatability with Myoton PRO, and 3) muscle stiffness in AC with Myoton PRO.

This study was approved by the Tochigi Medical Center Shimotsuga Institutional Review Board approval (No.129).

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We hypothesized that Myoton PRO is a highly reproducible device that correlates with SWE and that the affected side is stiffer than the nonaffected side in AC.

Methods

This study was approved by the Tochigi Medical Center Shimotsuga Institutional Review Board (No.129).

Correlation Myoton PRO and SWE with phantoms

Before measuring muscle stiffness in AC, we evaluated the correlation between Myoton PRO and SWE using phantoms. There has been no study correlating stiffness in Myoton PRO and SWV in SWE, by using phantoms. We used 4 different stiffness phantoms (6.0 wt%, 6.5 wt%, 7.0 wt%, and 7.5 wt%) made in Kyoto Kagaku (Kyoto, Japan). The phantoms are water-soluble gel materials made from carboxymethyl cellulose (CMC). The "wt%" indicates the CMC content: the higher the CMC, the stiffer the phantom.

SWE measurement

SWE was measured using a Toshiba Aplio i800 ultrasound system equipped with a 5-18 MHz transducer (Canon Medical Systems, Tochigi, Japan). SWE was performed by the same examiner who had more than 5 years of ultrasound experience.

Myoton PRO measurement

Myoton PRO (Myoton AS, Tallinn, Estonia) is a handheld device that produces a mechanical impulse on the skin overlying a target structure.[15] The measurement method applied by Myoton PRO involves a mechanical impact that is released under a constant prepressure (0.18 N) on the subcutaneous panniculus above the muscle or tendon being measured. The oscillation of the tissue under the probe enables the calculation of the viscoelastic properties of the tissue. One parameter is dynamic stiffness, which has been used to identify muscle character.[16] The stiffness value can be calculated as the maximum acceleration of the oscillation and deformation of the tissue detected by the transducer (N/m).[2] We obtained measurements three times with Myoton PRO and SWE, assessed the average of the three times, and evaluated the correlation of SWV with SWE, and of stiffness with Myoton PRO.

Reproducibility and repeatability with Myoton PRO

To evaluate the intraobserver and interobserver repeatability with Myoton PRO, ten healthy volunteers (HV) were measured (8 men and 2 women with a mean age of 32.2 ± 9.7 years). Myoton PRO measures the stiffness of the superficial muscles. Therefore, we selected the anterior deltoid (AD), pectoralis major (PM), and latissimus dorsi (LD). The AD limits extension of the shoulder joint, the PM limits shoulder abduction, the LD limits shoulder flexion, and the AD, PM, and LD are important for movement of the shoulder joint.

Measurement locations were determined using bony landmarks, as shown in Figure 1. All measurements were performed in the supine position. The AD was measured at the midpoint between the clavicle and the rough surface of the deltoid muscle. The PM was measured at three-quarters of the line connecting the sternum and the ridge of the nodule. The LD was measured at a point 5 cm above the lower angle of the scapula with the shoulder flexed at 80°. Examiner 1 performed two sets of measurements spaced 15 min apart to determine the intrarater reliability. Examiner 2 performed the measurements during the first examiner's first and second sets.

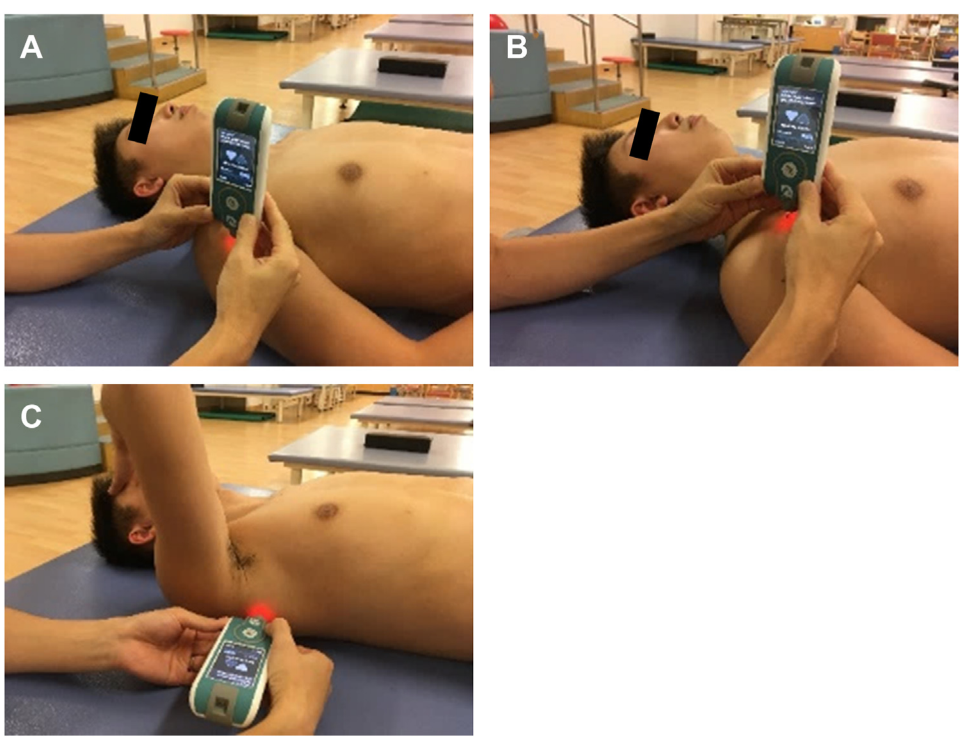

Figure 1 Measurement of each muscle. (**A**) The anterior deltoid was measured at the midpoint between the clavicle and the rough surface of the deltoid muscle. (**B**) The pec major was measured at three-quarters of the line connecting the sternum and the ridge of the nodule. (**C**) The latissimus dorsi was measured at a point 5 cm above the lower angle of the scapula with the shoulder flexed at 90°.

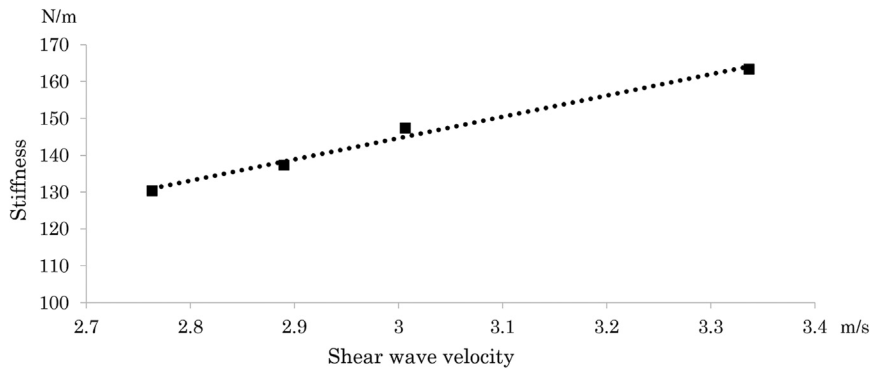

Figure 2 Results of correlation between SWV and stiffness. Correlation coefficient for SWV in SWE and stiffness in Myoton PRO was 0.99 ($P < .001$). *SWV*, shear wave velocity; *SWE*, shear wave elastography.

Evaluation of muscle stiffness in AC

This was a cross-sectional observational study. The subjects were 95 patients who were diagnosed with AC at our hospital between September 2019 and December 2020. According to previous studies, the limitations of ROM in AC were defined as those of <100° in forward flexion, <10° in external rotation, and <L5 level in internal rotation.[9] The inclusion criteria included those patients who were diagnosed with AC at the time of the study. The exclusion criteria were diabetes (25 patients), AC without contracture that defined the previous studies (24 patients), postbreast cancer surgery (3 patients), bilaterally symptomatic (2 patients), and calcific tendinitis (1 patient). After applying the exclusion criteria, 40 patients were finally selected. All patients underwent physical examination and imaging studies, including radiography and magnetic resonance imaging. We examined muscle stiffness in AC on the AD, PM, and LD of both the affected and nonaffected sides using Myoton PRO. It was measured twice for each muscle and analyzed using average values.

Statistical analysis

To investigate the relationship between the stiffness values determined using Myoton PRO and the SWV obtained by SWE, Pearson correlation coefficients were calculated for each phantom. Additionally, linear regression analysis was performed for the stiffness and SWV.

To evaluate the intraoperator and interoperator reliability of the HV, the intraclass correlation coefficient was used. The reliability evaluation standard was judged to be high when the intraclass correlation coefficient was 0.75 or higher.[5]

To evaluate muscle stiffness in AC patients, the detection power required for the paired t-test (effect size = 0.25 [medium], α error = .05) was calculated using G * Power 3.1 software (Heinrich Heine University, Düsseldorf, Germany). In this study, the detection power was 0.87 for 40 participants. For continuous variables, statistical analysis was performed using the t-test for all AC patients and the independent t-test for gender-separated cases. For categorical variables, we used the $\chi 2$ test or Fisher's exact test. The level of statistical significance was set at $P < .05$. Calculations were performed using SPSS 25 software (IBM, Armonk, NY, USA).

Results

Correlation of SWE and Myoton PRO with four phantoms

In the 6.0 wt% phantom, SWV was 2.76 ± 0.01 m/s and stiffness was 130.3 ± 0.5 N/m. In the 6.5 wt% phantom, SWV was 2.89 ± 0.03 m/s and stiffness was 137.3 ± 0.5 N/m. In the 7.0 wt% phantom, SWV was 3.01 ± 0.02 m/s and stiffness was 147.3 ± 0.9 N/m. In the 7.5 wt % phantom, SWV was 3.34 ± 0.03 m/s and stiffness was 163.3 ± 0.5 N/m. Correlation coefficient for SWV in SWE and stiffness in Myoton PRO was 0.99 ($P < .001$) (Fig. 2).

Reproducibility and repeatability in HV with Myoton PRO

The details are listed in Table I. In the AD, PM, and LD muscles on both the dominant and nondominant sides, the intraoperator and interoperator was 0.9 or higher. There was no significant difference in muscle stiffness between the dominant and nondominant sides in any muscle (Table II).

Table I
Intrarater and interrater reliability for Evaluator 1 and Evaluator 2 for parameters in healthy volunteers.

	Evaluator 1		Evaluator 2	Intra	95%CI	Inter	95%CI
	Trial 1	Trial 2	Trial 3	Operator		Operator	
Dominant side							
AD	291 ± 36	295 ± 37	299 ± 37	0.95	0.83-0.99	0.94	0.77-0.98
PM	212 ± 42	214 ± 46	218 ± 46	0.98	0.94-1.00	0.98	0.90-0.99
LD	204 ± 29	201 ± 30	204 ± 32	0.97	0.90-0.99	0.96	0.86-0.99
Non dominant side							
AD	294 ± 47	293 ± 49	284 ± 40	0.97	0.90-0.99	0.93	0.69-0.98
PM	219 ± 39	217 ± 37	218 ± 41	0.94	0.80-0.99	0.94	0.77-0.99
LD	184 ± 44	183 ± 48	185 ± 41	0.99	0.96-0.99	0.94	0.78-0.99

AD, anterior deltoid; *PM*, pec major; *LD*, latissimus dorsi; *CI*, confidence interval.
Data are presented as means ± standard deviation.

Table II
Comparison dominant side and nondominant side for muscle stiffness in healthy volunteers.

(n = 10)	Dominant	Nondominant	*P* Value
AD	293 ± 36	294 ± 48	.94
PM	213 ± 44	218 ± 37	.51
LD	202 ± 29	181 ± 42	.10

AD, anterior deltoid; *PM*, pec major; *LD*, latissimus dorsi.
Data are presented as means ± standard deviation.

Table IV
Stiffness values in AC patients.

Variables (n = 40)	Nonaffected side	Affected side	*P* Value
AD	328 ± 50	355 ± 61	< .01
PM	252 ± 41	252 ± 54	.98
LD	186 ± 37	207 ± 51	< .01

AC, adhesive capsulitis; *AD*, anterior deltoid; *PM*, pec major; *LD*, latissimus dorsi.
Data are presented as means ± standard deviation.

Comparison of stiffness between the affected side and nonaffected side using Myoton PRO

The demographic and clinical data are shown in Table III. We found significant differences in AD and LD muscle stiffness in AC (Table IV). The PM muscle showed no difference in AC.

Discussion

In this study, we found that Myoton PRO is a highly reproducible device that correlates with SWE. Additionally, it was shown that the AD and LD muscles on the affected side were stiffer than those in the nonaffected side in AC.

At first, we indicated Myoton PRO and SWE were significantly correlated on using phantoms. Feng et al reported the moderate correlation between the two devices in the gastrocnemius and Achilles tendons of healthy adults.[6] In addition, Kelly et al presented the low to moderate correlation between the two devices in three types of muscle contraction in the infraspinatus, erector spinae, and gastrocnemius muscles.[10] We investigated the correlation between the SWE and Myoton PRO using phantoms which is not anisotropic like muscles. Consequently, our result of correlation coefficient might be higher ($\geq$0.9) compared to those of other articles.

As a second study, we showed that intrarater and interrater reliabilities with Myoton PRO were very high. Yeo et al evaluated muscle stiffness of PM in patients with breast cancer by Myoton PRO.[19] They presented both intrarater and interrater reliability were high. There are no reports on AD and LD muscle stiffness measured by Myoton PRO. This is the first article surveying muscle stiffness of the AD and LD and the reproducibility when using Myoton PRO for them.

Although our result indicated that the AD and LD muscles on the affected side were stiffer than those on the nonaffected side in AC, there have been few studies on muscle stiffness in AC. Wada et al reported, using SWE, that the supraspinatus tendon, infraspinatus tendon, and CHL were stiff, however, they did not observe muscle stiffness around the shoulder.[18] Hollman et al reported that improvements of shoulder ROM under anesthesia in AC may be due to pain avoidance or pain-related cognition.[8] This behavior often results in motor adaptations such as muscle protection and reduced ROM.[13] In this research, the pain level of the subjects scored numerical rating scale was higher than in previous articles; therefore, pain might have influenced greater to muscle stiffness.[18] According to our outcomes, we presented that the AD and LD muscles were stiffer in the affected side than in the nonaffected side and the PM muscle was not significantly different in those. The reason for this was thought to be that the muscles of the AD and LD muscles were in the stretched position, while the PM muscles were in the resting position, so that the stretch stimulation might affect the muscle stiffness. In the future, it may be needed to measure the muscle stiffness at different limb position.

There were several limitations to our study. First, the muscles measured by Myoton PRO were specific. Considering the kinematics of the shoulder joint, it is important to evaluate the rotator cuff muscles. However, this study targeted only the surface muscles because Myoton PRO can measure only the surface layer. Second, the measurement was performed in the supine position in consideration of the effect not to increase pain. Therefore, only the parts that could be measured in that position could be observed. Third, Myoton PRO cannot evaluate muscles alone. Skin stiffness or subcutaneous fat thickness may also affect the measuring result. It is considered that the subjects who have skin disease or be severe obesity are not adapted to this device. Myoton PRO has some weak points. However, it may be a reproducible and useful device to measure muscle stiffness if you understand the properties. Lastly, this study suggested only phenomenon of muscle stiffness in AC. The correlation between clinical symptoms and Myoton PRO measurements is unclear. Our result did not explain clinical significance enough, so in the future we need to investigate the impact of therapeutic intervention to stiff muscle in AC.

Table III
Demographic and clinical data in AC patients.

Variables (n = 40)	Values
Age	56.9 ± 8.4
Gender (female/male)	30/10
Height(cm)/Weight(kg)	164 ± 19.3/59.4 ± 10.6
Affected side	
Dominant side/Nondominant side	15 /25
Duration of symptoms	6.2 ± 2.8
NRS score at motion	8.4 ± 2.6
Range of motion (degrees)	
Forward flexion	85 ± 12
Abduction	63 ± 15
External rotation at side	3 ± 8
Internal rotation	Buttock (Buttock-Sacrum)
Constant Score	25 ± 5
ASES score	27 ± 15

AC, adhesive capsulitis; *NRS*, numerical rating scale; *ASES*, American Shoulder and Elbow Surgeons.
Data are presented as means ± standard deviation.

Conclusions

Myoton PRO may be a helpful device to evaluate muscle stiffness in a specific part. In AC, there was significant stiffness in the AD and LD. In addition to the joint capsule and CHL, stiffness of the AD and LD could warrant further exploration in regard to their role in management of AC.

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