Original Article
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Reliability of Ultrasound Elastography According to Experience Level and Anatomic Location

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Background: Strain elastography (SE) and shear wave elastography (SWE) are emerging techniques for evaluating the elasticity of soft tissue. This study aimed to determine interobserver and intraobserver reliability for elasticity measurements of different tissues and anatomic locations using SE and SWE.

Methods: Ten healthy adult male individuals with 20 upper extremities participated in this study. The elasticities of the wrist extensor muscle, the common extensor tendon, and supraspinatus tendon were measured. Strain ratio and shear wave velocity were measured twice by 2 different examiners (examiner 1 with over 20 years of experience in musculoskeletal sonography and examiner 2 with 1 year of experience). Interobserver and intraobserver reliability was assessed using the intraclass correlation coefficient (ICC).

Results: The 10 individuals' age ranged from 28 to 35 years. In SE, interobserver reliabilities at the 3 anatomic locations (wrist extensor muscle, common extensor tendon, and supraspinatus tendon) showed fair to moderate agreement (ICC = 0.489, p = 0.076; ICC = 0.408, p = 0.131; and ICC = 0.296, p = 0.711, respectively). The intraobserver reliabilities of examiner 1 were moderate to substantial only at the wrist extensor muscle and the common extensor tendon (ICC = 0.563, p = 0.039 and ICC = 0.702, p = 0.006, respectively). In SWE, interobserver reliabilities for the wrist extensor muscle and the supraspinatus tendon were moderate to substantial (ICC = 0.756, p = 0.002 and ICC = 0.565, p = 0.039, respectively). The intraobserver reliabilities of examiner 1 at the 3 anatomic locations were almost perfect (ICC = 0.843, p = 0.001; ICC = 0.800, p = 0.001; and ICC = 0.825, p = 0.001, respectively). The results of examiner 2 showed almost perfect agreement at the wrist extensor muscle (ICC = 0.886, p = 0.001) and moderate to substantial agreement at the tendons of the common extensor and supraspinatus (ICC = 0.592, p = 0.029 and ICC = 0.682, p = 0.008, respectively).

Conclusions: SWE is a reliable method for assessing the flexibility of soft tissue, but it is affected by expertise and the specific anatomical site.

Keywords: *Elasticity imaging techniques, Ultrasonography, Elbow, Shoulder, Rotator cuff*

Ultrasound is commonly used in the field of musculoskeletal medicine to evaluate the structural properties of muscles and tendons. However, the evaluation of material properties, such as stiffness and elasticity, has been limited in conventional B-mode ultrasound. In 1998, Sarvarzyan developed elastography ultrasound (EUS) to evaluate tissue strain by measuring the degree of tissue distortion.[1,2] For 2 decades, several methods of stress application to tissues have been developed. In clinical practice, strain elastography (SE) and shear wave elastography (SWE) are the main techniques used.

SE is a technique based on manual application of low-frequency compression (stress) on the tissue using a

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handheld ultrasound transducer or via physiological body movement.[3] Then, the axial tissue displacement (strain) is calculated by comparing the echo sets before and after compression.[4] With the applied uniform stress, the elasticity is quantified using Young's modulus (E = stress/strain). There is an intrinsic loss of shear modulus when the target tissue has incompressible hard background materials, termed the eggshell effect.[5] Additionally, because of the manual application of stress, operator dependence is bound to exist. In contrast, SWE uses shear acoustic waves induced by the radiation force of a focused ultrasound beam. The elasticity is measured by the propagation speed, and the velocity is directly indicative of the stiffness (i.e., shear elastic modulus in kilopascal [kPa]).[6] Therefore, in SWE, limitations of SE can be avoided, but it is limited by the depth and shape of the region of interest (ROI).[5]

This imaging technique in the field of musculoskeletal medicine has focused on lower extremities, inflammatory diseases, and soft-tissue tumors.[7] Recently, there have been many studies on the application of EUS to the upper extremities, such as the shoulder and elbow, especially the rotator cuff muscles and tendons. Ishikawa et al.[8] demonstrated that the strain ratios of the middle deltoid, upper trapezius, supraspinatus, levator scapulae, and rhomboid major decreased with an increase from 10% to 30% maximal voluntary contraction force. Itoigawa et al.[9] and Hatta et al.[10] documented the feasibility and reliability of the SWE to rotator cuff by measuring 4 regions of the muscles. Since EUS was revealed as a reliable technique, various experimental studies have been conducted using this modality. Additionally, several studies have been conducted on the application of EUS to the elbow joint.[11-13] However, few studies have investigated the reliability of EUS in wrist extensor muscle and common extensor tendon.

To the best of our knowledge, no prior study has investigated tissue elasticity in different anatomic locations simultaneously using both SE and SWE. In this study, our goal was to assess the reliability of elasticity measurements for various tissues and locations using SE and SWE. We hypothesized that reliability may vary based on experience level, elastography type, and anatomic location.

METHODS

The Institutional Review Board of Korea University Anam Hospital approved this study, which is a diagnostic study on volunteers without a history of shoulder and elbow disease (IRB No. 2022AN0513). Written informed consent was obtained from all the participants.

Participants

Ten healthy male participants were recruited for this study. The exclusion criteria for participants included taking medication for any underlying disease, as well as having pathologic rotator cuff tendons, common extensor tendon, or wrist extensor muscle. Those with pathologic rotator cuff tendons were screened through physical examination, including tenderness over the greater tuberosity, positive impingement sign, and Jobe test. Participants with a pathological common extensor tendon or wrist extensor muscle were screened by identifying tenderness over the lateral epicondyle or a positive Cozen test. After physical examination, all participants underwent screening ultrasonography before elasticity measurements to detect any signs suggesting a tear or tendinopathy at the examined locations.

Equipment

B-mode gray-scale conventional ultrasound imaging, SE, and SWE were evaluated using an Aplio 500 Platinum Series (Canon Medical Systems Co.) coupled with a conventional linear probe (4–14 MHz, 14L5).

Scanning Protocol

Scanning was performed by 2 examiners in this study: examiner 1 (WKJ, an orthopedic surgeon with greater than 20 years of experience in musculoskeletal sonography) and examiner 2 (BP, a 1 year-experienced clinical fellow of orthopedic surgery). The examiners had brief instructions for standardization of the examination, such as participants' positioning, location of conventional B-mode imaging, and application of SE and SWE with minimal motion artifact. They followed the manufacturer's instructions to determine if the amount of compression applied for SE was appropriate. This involved identifying the strain graphs shown on the display. The compression mode was considered appropriate if the strain wave exhibited a regular sine wave with magnitude within the maximum range set by the manufacturer.

Three anatomical locations were investigated in a resting state: the wrist extensor muscle, common extensor tendon, and supraspinatus tendon of the rotator cuff. These 3 locations were selected because of proven assessability using EUS in previous studies.[7,11,14] For the wrist extensor muscle, the participants were positioned in the supine position with the elbow flexed at 90° on a support pillow and the supinated hand resting on the participants' belly (Fig. 1). Next, the wrist extensor muscle was identified in the longitudinal plane of the proximal forearm using conventional B-mode imaging with device A (Aplio

500 Platinum Series, Canon Medical Systems Co.). Assessment of SE and SWE was performed only if the alignment of the probe was parallel to muscle fiber orientation. The ultrasound probe was positioned in the largest part of the forearm extensor muscle, around one-fourth of the way down the length of the forearm. For the SE test, repeated manual compression was applied, and 2 circular ROIs were marked—one at the spot of highest strain in the muscle and the other in the subcutaneous fat layer directly above the ROI of muscles. These ROIs were used to calculate the strain ratio (strain of subcutaneous fat/strain of the wrist extensor muscle) for statistical analysis. In the case of the SWE test, a single circular ROI was placed at the middle depth of the muscle, without any boundary artifacts, at the same position as the ultrasound probe. The ROI in the quantitative analysis provided the average and standard deviation of stiffness in kilopascals (kPa) (Fig. 2).

The common extensor tendon was identified when the probe was placed more proximally. To standardize the probe placement, the lateral epicondyle of the humerus was used as the reference bony landmark. In SE, 2 circular ROIs were positioned on the tendon being studied: one inside the extensor carpi radialis brevis (ECRB) tendon, just above the deeper part of the lateral epicondyle, and the other on the subcutaneous fat layer, directly above the ROI of the ECRB tendon. In SWE, a circular ROI with a size of 0.07 m^2 was placed in the tendon at the same point, and an additional ROI was placed 0.5 cm distally for more accurate analysis. The measurements taken included the strain ratio, as well as the average and standard deviation of the stiffness in kilopascals (Fig. 3).

For the supraspinatus tendon of the rotator cuff, all images were obtained in the modified Crass position as follows: the participant placed the palm on the posterior aspect of the ipsilateral iliac wing and projected the flexed elbow joint posteriorly. The supraspinatus tendon was identified at the attachment site of the greater tuberosity of the humerus in the longitudinal plane. The examiners were asked to evaluate the supraspinatus tendon just posterior to the rotator interval. Two circular ROIs were placed in the supraspinatus tendon just above the middle of the supraspinatus footprint at the greater tuberosity of the humerus and the subcutaneous fat layer directly above the ROI of the supraspinatus tendon in SE. In SWE, a circular ROI with a size of 0.07 m^2 was placed in the tar-

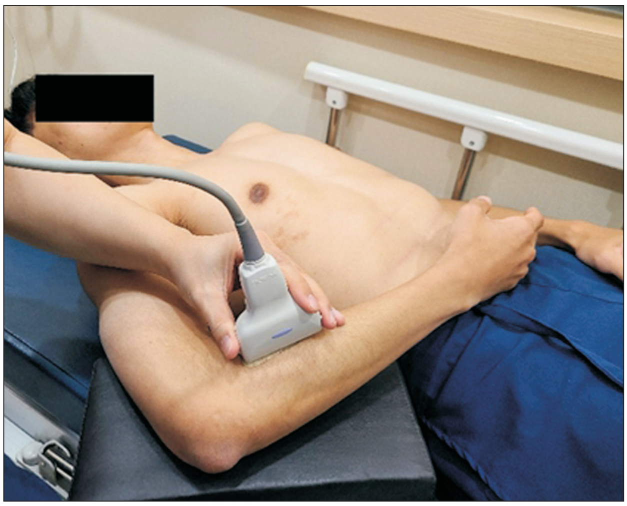

Fig. 1. During ultrasound evaluation of the wrist extensor muscle, the participants were positioned in the supine position with the elbow flexed at 90° on a support pillow and the supinated hand resting on the participants' belly.

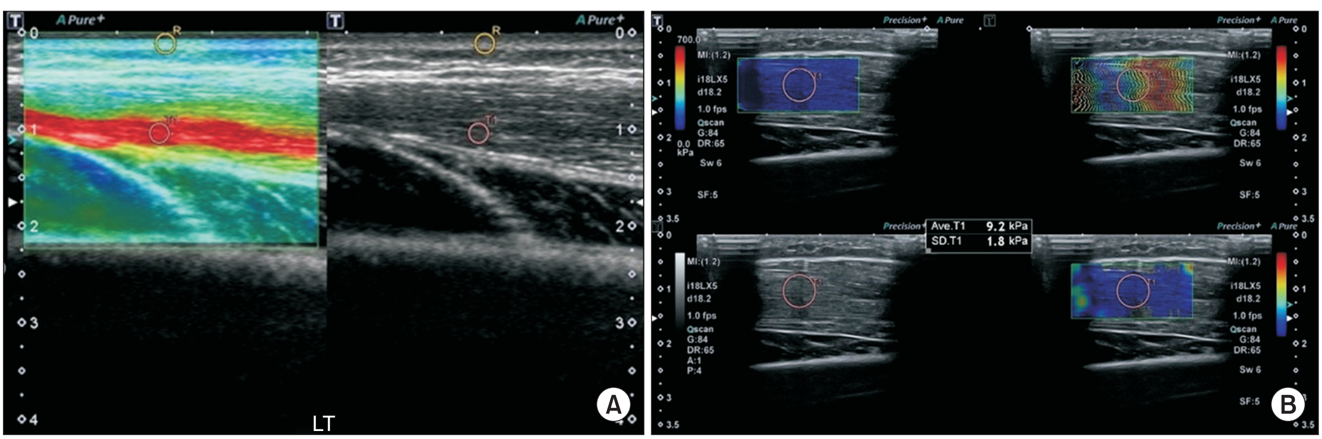

Fig. 2. Measurement of the elasticity of the wrist extensor muscle. (A) In strain elastography, 2 circular regions of interest (ROIs) were placed at the middle depth of the wrist extensor muscle and overlying subcutaneous fat layer. (B) In shear wave elastography, 1 circular ROI was placed at the same point at the middle depth of the wrist extensor muscle.

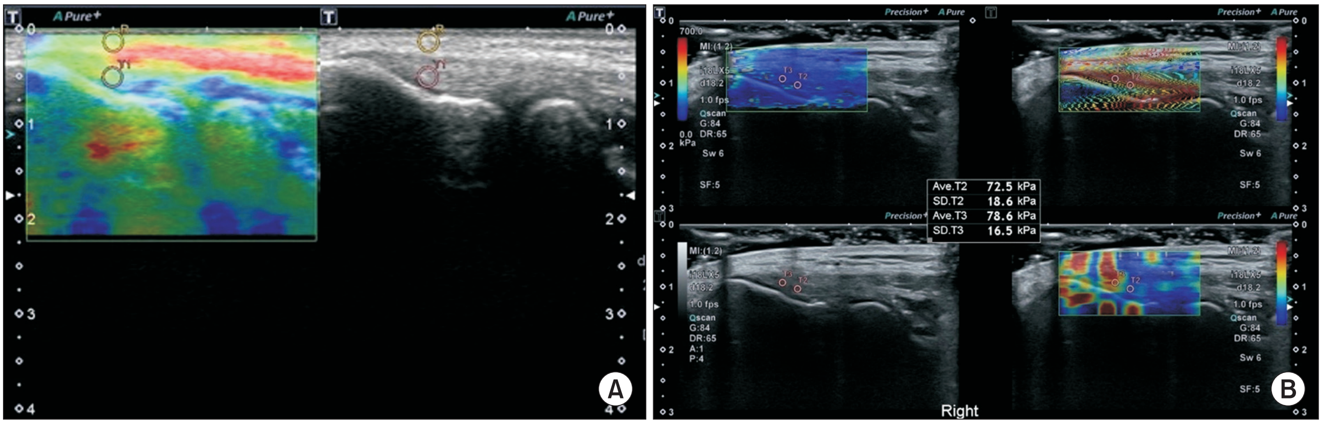

Fig. 3. Measurement of the elasticity of the common extensor tendon. (A) In strain elastography, 2 circular regions of interest (ROIs) were placed in the common extensor tendon, one distal to the lateral epicondyle of the humerus and the other on subcutaneous fat layer. (B) In shear wave elastography, a circular ROI of size 0.07 m^2 was placed in the tendon at the same point, and an additional ROI was placed 0.5 cm distally for more accurate analysis.

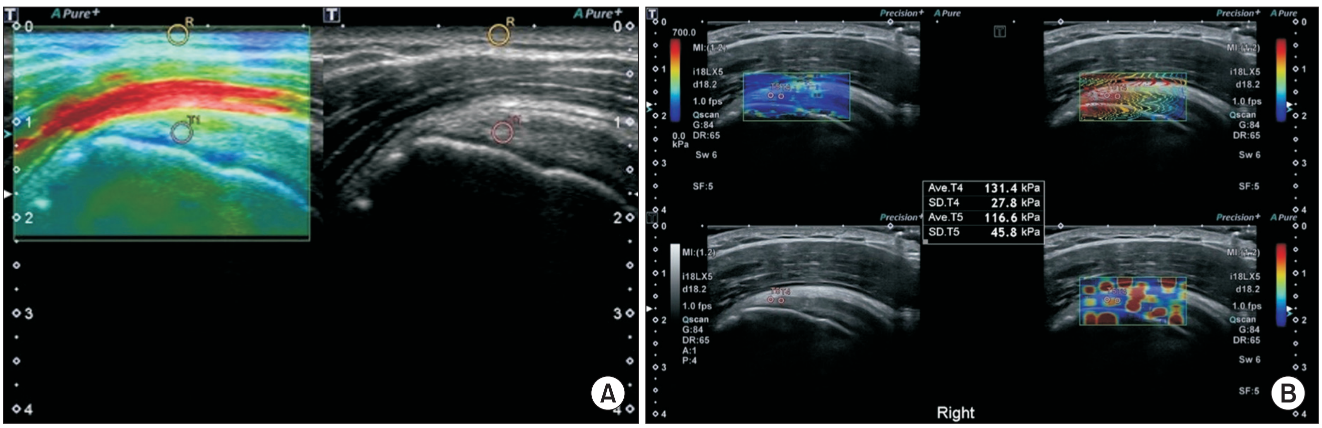

Fig. 4. Measurement of the elasticity of the supraspinatus tendon. (A) In strain elastography, 2 circular regions of interest (ROIs) were placed in the supraspinatus tendon just above the greater tuberosity of the humerus and overlying subcutaneous fat layer. (B) In shear wave elastography, 2 circular ROIs of size 0.07 m^2 were placed in the supraspinatus tendon in a row.

get tendon at the same point, and an additional ROI was placed 0.5 cm distally (Fig. 4). All measurements were performed by 2 examiners, and the scanning protocol was performed twice at 1-week intervals.

Statistical Analysis

To assess the interobserver and intraobserver reliabilities of SE and SWE, 2-way random effects intraclass correlation coefficients (ICCs) with 95% CIs were calculated using SPSS version 21.0 (IBM Corp.). Interpretation of kappa values and ICCs was based on Landis and Koch.

RESULTS

The 10 participants were all male and aged 28–35 years. The mean age was 30.7 years, and the mean body mass index was 30 kg/m^2. The mean strain ratio (± standard deviation [SD]) of the wrist extensor muscle and the common extensor tendon was 4.44 ± 1.32 and 0.37 ± 0.31, respectively, and that of the supraspinatus tendon was 0.67 ± 0.23. Mean elasticity (± SD) measured with SWE of the wrist extensor muscle and common extensor tendon was 20.82 ± 5.68 kPa and 112.20 ± 36.6 kPa, respectively, and that of supraspinatus tendon was 102.57 ± 26.99 kPa (Table 1).

For stiffness measurement of the wrist extensor muscle with SE, the interobserver reliability coefficient was 0.489 (p = 0.076), and the intraobserver reliability coefficient of examiner 2 was 0.155 (p = 0.622). For examiner 1, intraobserver reliability was moderate (ICC = 0.563, p = 0.039). On the other hand, in SWE, interobserver reliability was substantial (ICC = 0.756, p = 0.002), and in-

Table 1. Mean Strain Ratio and Mean Elasticity

	Strain elastography - strain ratio		Shear wave elastography - elasticity (kPa)	
	Examiner 1 senior	Examiner 2 fellow	Examiner 1 senior	Examiner 2 fellow
Wrist extensor muscle	4.44 ± 1.32	3.2 ± 0.77	20.82 ± 5.68	22.68 ± 6.83
Common extensor tendon	0.37 ± 0.31	0.70 ± 0.33	112.20 ± 36.6	90.69 ± 47.90
Supraspinatus tendon	0.67 ± 0.23	0.64 ± 0.36	102.57 ± 26.99	94.92 ± 31.08

Values are presented as mean ± standard deviation.

Table 2. Inter- and Intra-observer Reliability of Strain Elastography

	Interobserver reliability	Intraobserver reliability	
		Examiner 1 senior	Examiner 2 fellow
Wrist extensor muscle	0.489 (p = 0.076)	0.563 (p = 0.039)	0.155 (p = 0.622)
Common extensor tendon	0.408 (p = 0.131)	0.702 (p = 0.006)	0.360 (p = 0.745)
Supraspinatus tendon	0.296 (p = 0.711)	0.219 (p = 0.665)	0.197 (p = 0.989)

Table 3. Inter- and Intra-observer Reliability of Shear Wave Elastography

	Interobserver reliability	Intraobserver reliability	
		Examiner 1 senior	Examiner 2 fellow
Wrist extensor muscle	0.756 (p = 0.002)	0.843 (p = 0.001)	0.886 (p = 0.001)
Common extensor tendon	0.369 (p = 0.162)	0.800 (p = 0.001)	0.592 (p = 0.029)
Supraspinatus tendon	0.565 (p = 0.039)	0.825 (p = 0.001)	0.682 (p = 0.008)

traobserver reliability of examiners 1 and 2 was almost in perfect agreement (ICC = 0.843, p = 0.001 and ICC = 0.886, p = 0.001, respectively).

For the common extensor tendon in SE, the interobserver reliability coefficient was 0.408 (p = 0.131), and the intraobserver reliability coefficient of examiner 2 was 0.360 (p = 0.745). However, the intraobserver reliability of examiner 1 showed substantial agreement (ICC = 0.702, p = 0.006). In SWE, the results were as follows: interobserver reliability (ICC = 0.369, p = 0.162), substantial intraobserver reliability of examiner 1 (ICC = 0.800, p = 0.001), and moderate intraobserver reliability of examiner 2 (ICC = 0.592, p = 0.029).

In the case of the supraspinatus tendon in SE, the interobserver reliability coefficient was 0.296 (p = 0.711); intraobserver reliability coefficients were 0.219 (p = 0.665) and 0.197 (p = 0.989) for examiners 1 and 2, respectively. In SWE, the interobserver reliability was moderate (ICC = 0.565, p = 0.039), the intraobserver reliability of examiner 2 was substantial (ICC = 0.682, p = 0.008), and the intraobserver reliability of examiner 1 was almost perfect (ICC = 0.825, p = 0.001). The inter- and intraobserver reliabilities of SE and SWE according to anatomic location are listed in Tables 2 and 3, respectively.

DISCUSSION

This study showed that SWE is a more reliable technique to evaluate the elasticity of soft tissue than SE at all 3 anatomic locations. Both inter- and intraobserver reliabilities showed better agreement in SWE. This result supports findings of previous reports comparing SE and SWE. SE is a semi-quantitative method on Young's elastic modulus and uses the ratio of the relative strains between the ROI and a reference region. This method uses a stress-applying technique manually; it has operator dependence, such as different pressures, different tissue depths, probe alignment, and transducer movement.[3] Additionally, the selection process of the capture plane and drawing of the ROI are factors that reduce the reproducibility of SE.[15] In contrast, SWE does not require tissue compression; therefore, elasticity can be directly assessed, allowing for quantitative measurement.

In our study, all participants were healthy young males; thus, the diagnostic accuracy of SE and SWE was not evaluated. However, several studies have directly compared the diagnostic accuracies of the 2 techniques. There are no significant differences in the diagnostic ability between the 2 techniques in adhesive capsulitis, medial epicondylitis, and lateral epicondylitis.[16-18] However, the area under the curve values of shear wave velocity are relatively higher than those of the strain ratio in medial epicondylitis and lateral epicondylitis.[16,17] Therefore, SWE can be considered a more reliable and reproducible technique than that of SE in evaluating the elasticity of the upper extremities.

Comparing intraobserver reliabilities of the 2 examiners (well-experienced senior surgeon and 1 year-experienced clinical fellow), better reliability of the senior surgeon was identified in both SE and SWE. Before the scanning, despite the examiners having brief instructions for standardization of the examination, the intraobserver reliability of the clinical fellow was not in good agreement. It is understandable that there are differences in experience and competence levels. In a study that evaluated the reproducibility of SWE in assessing liver elasticity, a time longer than the 1-day training session and at least 50 supervised scans were recommended to novice examiners to obtain reproducible measurement.[19] However, unlike liver ultrasound, in the scanning of musculoskeletal ultrasound, more training and scans are needed because of challenges, such as the position of patients, personal anatomical differences, and many artifacts to obtain adequate conventional imaging.

Several studies have evaluated the reliability of EUS in each anatomical location: the common extensor and supraspinatus. In a cadaveric study with a histological examination by Klauser et al.,[12] EUS, in addition to B-mode ultrasound, improved histological results (ICC = 0.84) compared with examination using B-mode ultrasound alone (ICC = 0.57). Sendur et al.[13] concluded that the mean stiffness values of the common extensor tendon measured with SWE by the 2 observers were very similar, and there were no significant differences in the interobserver measurements ($p = 0.741$). Muraki et al.[20] reported high intraobserver reliability of EUS in the assessment of the supraspinatus muscle and tendon using SE with an acoustic coupler (ICC 1, 3 = 0.931–0.998). Rosskopf et al.[21] reported excellent interobserver reliability for the mean total shear wave velocity of the supraspinatus muscle (ICC = 0.89). Hackett et al.[7] also concluded that SWE had excellent intraobserver reliability in the supraspinatus tendon (ICC = 0.96). However, to the best of our knowledge, no study has reported the reliability of EUS in different anatomical locations simultaneously.

In our study, the reliability of measurement using SWE showed various results for each anatomic location. SWE was more reliable in the wrist extensor muscle than that in the common extensor tendon. The interobserver reliability of the wrist extensor muscle was moderate (ICC = 0.756), but the common extensor tendon showed fair agreement (ICC = 0.369). This finding can be explained by several factors. First, the muscle elasticity was relatively more uniform than that of the tendon. The mean elasticity of the wrist extensor muscle was 20.82 ± 5.68 kPa and that of the common extensor tendon was 112.20 ± 36.6 kPa. In the Shapiro-Wilk test with measured elasticity, the elasticity of the wrist extensor muscle was normally distributed ($p = 0.423$), but that of the common extensor tendon was not ($p < 0.001$). The elasticity of the tendon varies by person and can influence the results of elasticity by EUS without accurate measurement. Second, an adequate depth for the shear wave to propagate fluently was ensured in the wrist extensor muscle rather than in the common extensor tendon. SWE is known to be an unsuitable technique for superficial structures because a certain depth is required to generate a shear wave.[3] Despite the development of probes that generate shear-wave beams, there is still a concern. In this study, the depths of the placed ROIs were approximately or more than 1 cm in the wrist extensor muscle and supraspinatus, whereas they were 0.5–1 cm in the common extensor tendon. The elasticity measurement of the common extensor tendon was probably influenced by this issue. Third, the ROIs of the wrist extensor muscle had sufficient distance from the nearby bone. The "eggshell effect," i.e., the intrinsic loss of shear modulus when the target tissue has incompressible hard background materials, possibly influenced the measurement of elasticity at the common extensor tendon and supraspinatus.[5] Therefore, SWE is a useful technique for the measurement of soft-tissue elasticity; however, its application in the musculoskeletal area has an unexpected result, owing to differences in anatomical location.

Our study has several limitations. First, all participants were healthy young males. The elasticity of the muscles and tendons varies with age and sex. Further-more, in the presence of pathologies, such as myopathy or tendinopathy, elasticity will change.[7,11] Further studies are needed with extended recruitment of participants. Second, we performed this study using only one ultrasound machine. Many companies have developed EUS machines with their own specific technology. Therefore, interobserver and intraobserver reliability may be different with EUS machines of other manufacturers. However, the fundamental principle of measuring elasticity is similar, so the overall trend might not be much different.

In conclusion, SWE is a more reliable technique for evaluating elasticity of soft tissue in the upper extremity; however, it is influenced by experience level and anatomic location.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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