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ORIGINAL RESEARCH ARTICLE

Investigation of Biomechanical Characteristics of Intact Supraspinatus Tendons in Subacromial Impingement Syndrome

A Cross-sectional Study with Real-time Sonoelastography

ABSTRACT

Kocyigit F, Kuyucu E, Kocyigit A, Herek DT, Savkın R, Aslan UB: Investigation of biomechanical characteristics of intact supraspinatus tendons in subacromial impingement syndrome: a cross-sectional study with real-time sonoelastography. Am J Phys Med Rehabil 2016;95:588–596.

Objective: The aim of this work was to evaluate the real-time sonoelastography (RTSE) in the assessment of the supraspinatus tendon in patients with subacromial impingement syndrome (SIS).

Methods: Twenty-five patients with unilateral shoulder pain that was diagnosed as SIS according to magnetic resonance imaging findings were included in the study. Healthy shoulders of the patients comprised the control group. Bilateral shoulder RTSE examinations were performed by a radiologist who was blinded to the involved side of the participants. The RTSE images were recorded and assessed by 2 radiologists individually 1 month later. American Shoulder and Elbow Surgery shoulder index, Quick Disabilities of Arm Shoulder and Hand Questionnaire, and Constant scores were applied to evaluate the disability and functional status. The correlation between strain ratio and functional scores were investigated.

Results: Of the 25 participants, 9 (36%) were men and 16 (64%) were women. The RTSE findings were pathologic in tendons of 23 patients (92%) with SIS. The strain ratio was significantly higher in the affected shoulders ($P < 0.001$). The interobserver agreement was good for image analysis. There was no significant correlation between strain ratio and functional scores.

Conclusion: Structural changes in the supraspinatus tendon can be demonstrated with RTSE in patients with SIS.

Key Words: Tissue Elasticity Imaging, Rotatot Cuff, Musculoskeletal Disease, Diagnosis, Interobserver Variability

Subacromial impingement syndrome (SIS) is the most common cause of shoulder pain in adults.[1] It is a result of compression of the supraspinatus tendon, subacromial bursa, and other structures as they pass through the space between the acromion and humeral head.[2] Subacromial impingement syndrome is an umbrella term that comprises supraspinatus tendinopathy, rotator cuff ruptures, and subacromial bursitis. Tendinopathy is defined as any pathologic condition of a tendon. Both tendinitis and tendinosis are covered by the term *tendinopathy*. Tendon rupture is defined as tearing of a tendon that occurs when the forces placed upon the tendon exceed its tensile strength. Although tendon ruptures may be included by the term, tendinopathy mentioned intact tendons in this study.

Supraspinatus tendinopathy constitutes a significant portion of SIS.[1] Compression of the supraspinatus tendon causes inflammation and pain. If the inflammation is prolonged, chronic tendinopathy that involves vascular alterations and collagen breakdown is developed. The resulting structural changes might cause alterations in the mechanical properties of the tendon, which is an important parameter in detecting the tendon's tendency to tear as well as its healing and repair capacity after the injury. However, it is not possible to measure these changes with the help of routine diagnostic imaging studies like B-mode ultrasonography and magnetic resonance imaging (MRI).[3]

Real-time sonoelastography (RTSE) is a noninvasive, relatively new ultrasound-based imaging method that provides information on the mechanical properties of tissues (stiffness and elasticity), reflecting their quality.[4] It is based on the principle that tissues deform and move away from the ultrasound transducer when pressure is applied. Strain is defined as the amount of displacement from the probe. The strain differs between tissues and lesions according to their elastic properties. Specific software systems convert the computed strain to color codes that represent different degrees of elasticity during RTSE. Lesions affecting the elasticity of tissue can be distinguished in this way as altered areas of stiffness.[4]

Many recent researchers investigated the use of RTSE in musculoskeletal disorders.[3,5,6]

A recent study of De Zordo et al.[7] showed that injured tendons exhibited a softer tissue color on RTSE when compared to healthy tendons in the evaluation of Achilles tendinopathy. Tudisco et al.[3] reported that RTSE was a feasible method applicable in small supraspinatus tears, and there was a correlation between RTSE findings and clinical results of the patients.

Supraspinatus tendon elasticity is a challenging topic for research because of the high susceptibility of the tendon for injury. Detecting the histopathological structural changes will help to comment on healing capacity and tearing tendency of the injured tendon. A comprehensive combined conservative treatment will be recommended to the patients with histopathological changes to prevent tendon ruptures. These patients will be followed up more attentively than those without structural changes. To the best of our knowledge, there is no study investigating the tendon mechanical properties of the intact supraspinatus tendon in patients with SIS to date. The objective of this study was to use RTSE to assess the elasticity of the supraspinatus tendon in the intact supraspinatus of the tendon of the patients with SIS compared to their contralateral healthy shoulder.

MATERIALS AND METHODS

The procedures followed in this study were in accordance with the ethical standards of the Helsinki Declaration. The study was approved by the institutional ethics committee. Each patient gave written informed consent.

Patients

Patients presenting with unilateral shoulder pain diagnosed as shoulder impingement syndrome were prospectively scrutinized and enrolled in this study according to inclusion criteria listed in Table 1 between January 2015 and March 2015. Shoulder subacromial impingement syndrome was diagnosed on MRI because it is the criterion standard imaging technique for diagnosing shoulder pathologies. Seeger et al. developed a classification of shoulder impingement lesions according to MRI findings. Type I impingement is characterized by the presence of subacromial bursitis, and signal intensity in supraspinatus may remain normal. In Seeger's type II impingement, the supraspinatus tendon demonstrates increased signal intensity on type T1–weighted images. Increased tendon signal intensity on T2-weighted images is considered a type IIb change and may represent a partial tear. Type III tear is characterized by a complete tear of the rotator cuff with or without retraction. We included type I and IIa lesions in our study to exclude partial or complete rotator cuff tears.[8] Demographical parameters, symptom duration, involved shoulder, hand dominance, work status, and co-orbidities of the patients were recorded. Physical examination included a thorough neurological examination to exclude cervical radiculopathy, as well as an evaluation of subacromial and bicipital

TABLE 1 Inclusion and exclusion criteria for the study

Inclusion Criteria	Exclusion Criteria
Involved shoulder	Presence of calcific tendinitis and/or supraspinatus history of previous shoulder fracture/surgery
Unilateral shoulder pain diagnosed as SIS type I and IIa according to magnetic resonance imaging findings	Previous or concurrent diagnosis of frozen shoulder
Age between 18 and 65 years	Tendon rupture documented on magnetic resonance imaging
Approval of inclusion in the study	Glenohumeral osteoarthritis
Healthy shoulder	Inflammatory joint disease
Absence of shoulder pain	Peripheral vascular disorder
No limitation of range of motion	Steroid or estrogen medication
Positive results for <2 provocative tests for SIS	Presence of obstacle for RTSE imaging

tenderness. The range of motion of the affected and healthy shoulders was measured. Provocative tests for the shoulder impingement syndrome (Hawkins test, Neer impingement sign, Empty can test, painful arc test, Speed test, and Yergason test) were applied. American Shoulder and Elbow Surgery (ASES) shoulder index, Quick Disabilities of Arm Shoulder and Hand (DASH) Questionnaire, and Constant scores were applied to evaluate the pain, function, and disability. Healthy shoulders of the patients constituted the control group. After these preliminary clinical and functional evaluations, RTSE examinations were performed for both shoulders.

Ultrasonography Imaging

A high-resolution ultrasound device (Logiq E9, GE Healthcare, Milwaukee, WI) equipped with an elastography-compatible 9- to 15-MHz matrix linear probe was used to scan both supraspinatus tendons in the supraspinatus fossa. Conventional B-mode ultrasonography (US) and RTSE were performed while the patient was in the sitting position. The radiologic evaluations were made by the same radiologist (A.K.). The radiologist was blinded to the involved side of the patient.

Patients were positioned with 90-degree elbow flexion, their hand on their back and palm facing in the posterior direction. Perpendicular positioning of the probe was necessary to avoid anisotropy when performing conventional US and to prevent tissue shifting when performing RTSE. Manual light compression and decompression of the supraspinatus tendon by the probe was performed attentively to achieve an optimal and consistent color coding shown on the sonography screen. The force applied to the tendon was adjusted appropriately according to the visual indicator seen on the US screen. The visual indicator is a bar scale of 1 to 7 that showed optimal strain at the region of interest. The radiologist evaluated the images having adequate compression when the bar scale was 5 to 7. Each RTSE scan was repeated by compression and relaxation of the scan area several times (at least 3 compression-decompression cycles) until the findings were confirmed to be reproducible as defined by De Zordo et al.[6] Real-time sonoelastography and B-mode US images were simultaneously displayed as a 2-panel image. The elastographic box contained the supraspinatus tendon, the deltoid muscle, head of the humerus, and the surrounding tissue for all patients. Both the color scales and strain ratio were used for describing the elastography findings. All the RTSE images were recorded by the sonography device digitally and also sent to the local picture archiving and communication system for later evaluation and statistical analysis. Real-time sonoelastography images were evaluated 2 weeks later by 2 radiologists individually (A.K. and D.H.T.). Both of the radiologists were experienced in sonography for 10 years and experienced in RTSE for 1 year. The radiologists were blinded to the involved side of the patient during evaluation. Both researchers evaluated the color scale and calculated strain ratios on recorded images.

For the qualitative analysis, a visual grading system was adopted from the qualitative evaluation system by Cho et al.[9] The relative stiffness of the tissues ranged from red (soft) to blue (stiff). Blue represented stiff areas. Green or green-yellow and red or orange-red represented moderately and severely softened areas, respectively (Fig. 1A–C).[4]

Strain ratio was used for semiquantitative analysis. Strain ratio was calculated using the ratio of the strain in the reference small circular region of interest (ROI) in the deltoid muscle (E2) to that of the target ROI, the most affected region of the supraspinatus tendon (E1). Most affected region was defined according to the RTSE color scale, and the area with

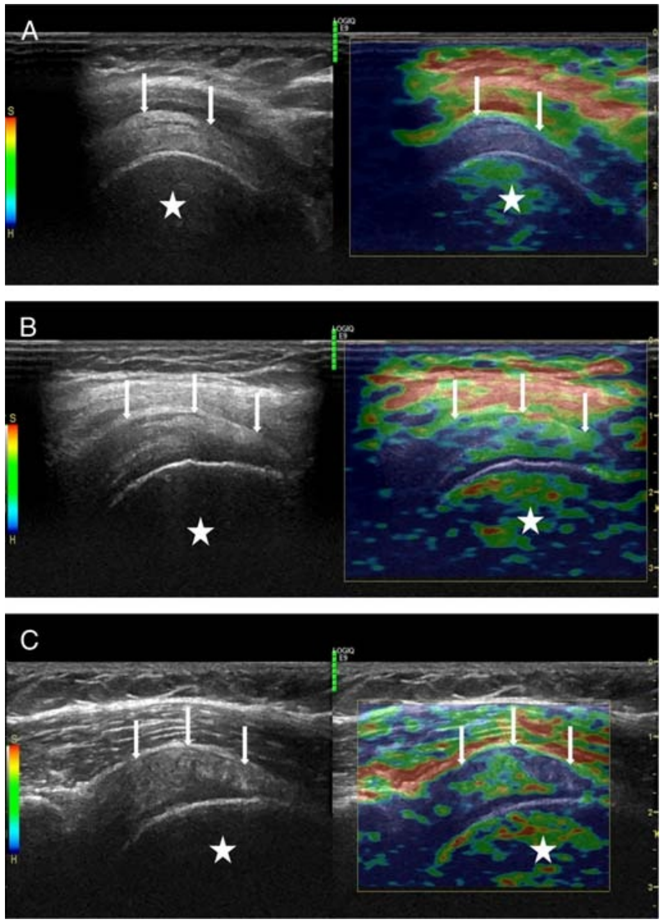

FIGURE 1 *A–C. Grayscale (left) and color (right) sonograms demonstrate type 1 elasticity pattern (A, blue), type 2 elasticity pattern (B, green), and type 3 elasticity pattern (C, orange-red) in supraspinatus tendon.*

the largest color scale was selected as ROI. The selection of the reference ROI is a factor that may have an impact on the strain ratio measurements. We selected the reference ROI at the deltoid muscle just above the target ROI for standardization of reference ROI location. The reference and target ROI sizes were similar on both the affected and healthy shoulders. A higher strain ratio indicates decreased stiffness in the affected supraspinatus tendon (Fig. 2A–D).

Statistical Analysis

Statistical analysis was performed with SPSS software, release 17.0 (SPSS Inc, an IBM Company, and Chicago, IL). The sample size was estimated to be 25 for 95% of the statistical power with an alpha level of 0.05. Standard descriptive statistics was used to summarize characteristics of the participants including mean and standard deviation (SD) of all continuous variables and counts and percentages for the categorical variables.

We calculated the area under the receiver operating characteristics (ROC) curve for RTSE, B-mode US, and color Doppler US findings. The area under the ROC curve was categorized as follows: <0.6, worthless; 0.6–0.7, poor; 0.71–0.80, fair; 0.81–0.9, good; and 0.91–1, excellent.[10]

The Kolmogorov-Smirnov test was used to verify data for normality. The study sample showed the normal distribution for the analyzed parameters. A paired sample t test was used to compare objective outcomes. Further analysis was conducted to investigate the feasibility of RTSE in the acute phase of SIS. Patients with symptom duration of 8 weeks or less were selected (n = 14), and strain ratio of the involved shoulder was compared to that of the healthy shoulder. Two-sided statistical significance was defined as $P < 0.05$. Pearson correlation coefficient (r) was used to compare strain ratio to age, sex, symptom duration, Quick DASH score, Constant score, and ASES score.

To evaluate interobserver agreement for color scaling of RTSE images, we used the Cohen kappa (κ) coefficient. To assess interobserver agreement for the strain ratio measurements, we used interclass correlation coefficient. The Cohen kappa can range from -1 to $+1$. A negative value for Cohen κ indicates that agreement between the 2 raters was less than the agreement expected by chance with -1, indicating

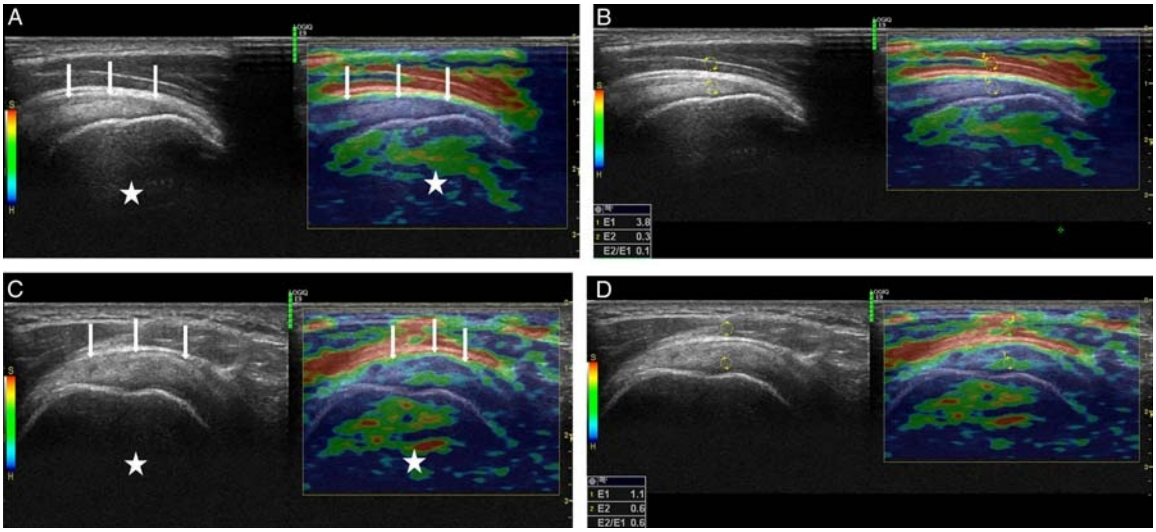

FIGURE 2 *A, Real-time sonoelastography image of right SIS in a 45-year-old man. Image shows normal left supraspinatus tendon (arrows), (asterisk depicts head of the humerus). B, Strain ratio (E2/E1:0.1) of normal left supraspinatus tendon (first ROI chamber (E1: 3.8) is in the supraspinatus tendon, and the second one (E2: 0.3) is on the deltoid muscle). C, Image demonstrates the right supraspinatus tendon with tendinosis (arrows). Asterisk depicts the head of the humerus. D, Image shows strain ratio (E2/E1: 0.6) of right supraspinatus tendon with tendinosis (first ROI chamber [E1: 1.1] is in the supraspinatus tendon, and the second one [E2: 0.6] is on the deltoid muscle).*

that there was no observed agreement, and zero, indicating that agreement was no better than chance. Interobserver agreement was categorized as follows: 0–0.20, poor; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; and 0.81–1.00, almost perfect.[11] $P < 0.05$ was considered statistically significant.

RESULTS

Thirty-three patients were scrutinized for participation in the study until the estimated participant number 25 was reached during the enrollment period. Three patients were on hormone replacement treatment, 2 patients had a diagnosis of rheumatoid arthritis and were also excluded. In 3 obese patients, US was not feasible.

Of the 25 participants, 9 (36%) were men and 16 (64%) were women. The mean ± SD age was 45 ± 15 years (range, 20–65 years). Other demographic parameters are shown in Table 2.

Shoulder impingement syndrome involved the right side in 15 patients (60%) and the left side in 10 patients (40%). The mean ± SD symptom duration was 23 ± 28 weeks (range, 1–100 weeks).

The range of motion of the affected shoulders was limited significantly in flexion ($P < 0.001$) and abduction ($P < 0.001$) when compared to healthy shoulders. Results of specific shoulder tests and other physical examination findings are presented in Table 3.

The mean ± SD visual analog scale (VAS) for pain was 58 ± 25 mm (range, 5–94 mm) and the mean ± SD Quick DASH score was 38.14 ± 20.61 points (range, 9.09–88.6 points). The mean ± SD ASES score was 51.23 ± 19.1 points (range, 7.5–91.25 points), and the mean ± SD Constant score was 64 ± 16 points (range, 42–91 points).

TABLE 2 Demographical parameters of the study group

Demographical Parameter	Number
Sex	
Female	16
Male	9
Educational status	
Primary school or less	16
Elementary school	4
High school and more	5
Employment Status	
Present employee	8
Unemployed	14
Retired	3
Presence of comorbidities	
None	14
Only one comorbidity	7
>1 comorbidities	4
Hand dominance	
Right	20
Left	5
Involvement	
Right	15
Left	10
Presence of night pain	
Yes	20
No	5
Total	25

TABLE 3 Physical examination findings of the involved and healthy shoulders

Parameter	Shoulders With SIS	Healthy Shoulder	*P*
Range of motion			
Flexion, mean ± SD, degree	156 ± 22.5	177 ± 3	0.000
Abduction, mean ± SD	154 ± 26.2	180 ± 0	0.000
Palpation findings[a]			0.000
Subacromial tenderness	14	0	0.000
Bicipital tenderness	15	2	0.000
Provocative tests[a]			
Hawkins test	23	1	0.000
Neer impingement sign	22	1	0.000
Jobe test	21	0	0.000
Painful arc test	23	0	0.000
Speed test	17	0	0.000
Yergason test	6	0	0.011
Color scale[b]	23	4	0.000
Strain index	0.71 ± 0.25	0.24 ± 0.10	0.000
Total	25	25	25

[a]Presented as number of patients with positive physical examination finding/test result.

[b]Presented as number of patients with affected color scale (green, yellow, and red).

The mean ± SD ROI diameter was 0.4 ± 0.08 mm on the affected side and 0.4 ± 0.06 mm on the healthy side. There was no significant difference between the ROI sizes of affected and healthy sides ($P = 0.253$). At RTSE, the mean ± SD strain ratio in the affected shoulder was 0.63 ± 0.22 (range, 0.1–0.9) and that of the healthy shoulder was 0.14 ± 0.07 (range, 0.1–0.4). The strain ratio was significantly higher in the affected shoulders ($P < 0.001$). Documentation of biomechanical changes in the supraspinatus tendon even in the early phase of compression is necessary for both prognosis and management. Strain ratio was also significantly higher in shoulders with SIS compared to healthy shoulders in the acute phase of the disease ($P < 0.001$).

When RTSE color scales of affected shoulders were analyzed, 2 patients demonstrated blue, 11 patients showed green, 12 patients demonstrated red or orange-red. When the healthy shoulders were evaluated according to a color scale, 21 patients showed blue and 4 patients demonstrated green. Red or orange-red were not present on the RTSE of healthy shoulders.

The area under an ROC curve quantifies the ability of a diagnostic test to discriminate between those individuals with the disease and those without the disease. The area under the ROC curve analysis for strain ratio measurement was 0.974, and that for color scaling was 0.918 ($P < 0.001$).

When correlation analysis for strain ratio and functional test scores were performed, no correlation between strain ratio and Constant score, ASES score, and Quick DASH score was found. Table 4 shows the full data of values of Pearson correlation coefficients between strain ratio and all the considered clinical variables.

Interobserver agreement for color scale evaluation was rated as substantial ($\kappa = 0.71$, $P = 0.001$). Interobserver agreement for strain ratio measurement was rated as perfect (interclass correlation coefficient, 0.92; $P = 0.001$).

DISCUSSION

This study investigated RTSE findings in patients with SIS and the correlation of these findings with age, sex, and functional scores. The results of the study documented that RTSE was a feasible imaging technique that could evaluate changes in tendon stiffness in SIS with substantial interobserver agreement. Real-time sonoelastography findings did not correlate with functional scores.

Two previous studies investigated the mechanical properties of healthy supraspinatus tendons in the literature. The first research, by Arda et al., aimed to measure the elasticity of various tissues in healthy subjects. The authors reported higher elasticity values in men than in women for supraspinatus muscle, without any positive or negative correlation between age and sex.[12] In the present study, we did not observe a correlation between strain ratio and neither sex (correlation coefficient, 0.193; $P =$ value 0.35) nor age (correlation coefficient, 0.93; $P = 0.66$) in a cohort of middle-aged patients with SIS. Other precipitating factors (dominant arm, activities of misuse/overuse, and repetitive smoking) may handle structural tendon changes in middle-aged patients.

TABLE 4 Pearson correlation analysis results between strain index and clinical and demographical parameters

	Strain Index	
	Correlation Coefficient (*r*)	*P*
Age	−0.09	0.66
Symptom duration	0.3	0.14
Gender	0.19	0.35
Presence of trauma	−0.14	0.51
Constant score	−0.22	0.28
ASES score	0.12	0.54
Quick DASH Score	−0.24	0.25

The second research on healthy supraspinatus tendon reported that RTSE has the potential to detect changes in the elasticity of the supraspinatus muscle noninvasively. The elasticity changes were obtained during voluntary contractions of the supraspinatus muscle in the study.[13]

Sonoelastography can aid the diagnosis and rehabilitation musculoskeletal injuries.[6] A recent research on RTSE findings of lateral epicondylitis reported that both color scaling and strain ratio measurements were superior to B-mode US according to area under the ROC curve analysis.[14] We also conducted area under the ROC curve analysis for RTSE parameters. We documented that both color scaling and strain ratios of the supraspinatus tendon were excellent in discriminating healthy from involved shoulders in patients with SIS.

Tendon quality may be an important parameter in the management of patients with SIS. Tendons with lower elasticity are thought to be prone to tears and delayed healing. Documentation of biomechanical changes in the supraspinatus tendon even in the early phase of compression is necessary for both prognosis and management. Patients would be under close follow-up to prevent disruption of tendon integrity if these patients could be detected. Both exercise and pharmacological treatment of these patients would be planned more cautiously.[15] For these reasons, it is important in clinical practice to detect elasticity changes in the compressed supraspinatus tendon. Tissue elasticity changes are expected to be closely related to the prognosis of SIS.[2] However, the literature is scarce on the histological evaluation results of patients with SIS and intact supraspinatus tendons. There remains a need for high-quality studies of the pathological condition investigating structural tendinous changes like changes of collagen fiber alignment. Strain ratio was significantly higher in shoulders with SIS compared to healthy shoulders ($P < 0.001$) even in the early phase of the disease ($P < 0.001$) in this study. Moreover, color scales were affected in 23 of 25 involved shoulders. This is a significant contribution to the diagnosis of SIS and evaluation of tendon mechanical properties.

Tudisco et al. conducted the first research on the elasticity of the injured supraspinatus tendon. They investigated the tendon mechanical properties in small unilateral supraspinatus tears using RTSE. They reported a correlation between functional test scores (Quick DASH, Constant-Murley score, Simple Shoulder Test, ASES score, and UCLA score) and RTSE strain ratio. This high correlation documented in partial supraspinatus tears may be due to exacerbation of both functional response and RTSE findings after the degeneration of anatomical integrity.[3] However, in this study, there was no correlation between functional scores and strain ratio. The impairment in functional scores might not correlate with radiological findings as reported for disc herniation and osteoarthritis before.[16,17] Similarly, in SIS, RTSE findings did not correlate with functional scores according to the results of this study.

Tendon rupture may be induced by trauma or develop spontaneously. However, apparent histopathological degenerative changes are demonstrated in torn tendons. These changes suggest a close association between underlying chronic degenerative process and tear.[16] Real-time sonoelastograpy may be of value in improving the diagnostic capability of conventional US by delineating differential stiffness of the injured tendon that may have B-mode US features similar to surrounding healthy tissue. Real-time sonoelastograpy seems to reflect disease-induced changes in mechanical tissue properties.[18] However, the issue, whether RTSE can diagnose tendon disorder earlier than other imaging techniques, is still unsolved. Park and Kwon[19] suggested the use of RTSE as a research tool to provide insight into the biomechanics and pathophysiology of musculoskeletal tissue abnormality in a recent review.

Real-time sonoelastograpy is an ultrasound-based imaging technique and has a number of advantages over other imaging methods. Noninvasiveness, the absence of radiation, relative low cost, short scanning time, and good patient acceptance are among the benefits of RTSE. Depending on the results of this study and the advantages of RTSE over other imaging methods, RTSE may be expected to be a feasible and promising tool for providing useful diagnostic information in SIS.

Several technical challenges associated with RTSE have been addressed in the literature. Real-time sonoelastograpy is a technique in which the resultant strain score is determined based on the mean elasticity of all tissues included in the user-defined window.[18] The standardization of window size is needed to ensure reproducible results between studies. The depth of the window is recommended to be 3 times the tendon size for longitudinal scans. It should be emphasized that the strain in the tissue of interest may vary depending on the stiffness of the adjacent tissues. For this reason, an RTSE produces the relative strain data rather than direct measurement of tissue elasticity.[20] However, the reliability and reproducibility of the strain ratio measurement have been shown to be good to excellent.[6,21] We also documented good interobserver agreement for both color scaling and strain ratio measurement.

The prospective study design, sample size assessment with a power of 95%, evaluation of RTSE images by 2 experienced radiologists who are blinded to clinical findings, strict inclusion and exclusion criteria, and obtaining both qualitative color codes and semiquantitative strain ratio are strengths of this study.

This study has several limitations. Real-time sonoelastograpy is ultrasound based, so it has methodological limitations as found in any other ultrasound-based technique. However, precautions were taken to avoid potential problems by applying standard recommendations including avoidance of high and low pressure during RTSE acquisition, and window size standardization according to tendon size.

Second, the ROI in this study did not analyze all areas of affected tendon. Therefore, ROI might not represent the state of the tissue appropriately. In this study, the most affected portion of the supraspinatus tendon was chosen. Because we thought that affected part would have more structural changes as documented by the color scale and would be more suitable to obtain semiquantitative strain ratio. The anterior part of the supraspinatus tendon was chosen for strain ratio measurement in the healthy shoulder as suggested by previous research.[22] However, other portions of this tendon should also be investigated in future studies.

Third, despite previous studies comparing RTSE findings with B-mode US findings, we did not perform a comparison between 2 US imaging modalities.[14] B-mode US findings of SIS and diagnostic ability of B-mode US in SIS are well described in literature.[23] Further studies may be conducted to compare results of different US imaging protocols in SIS.

Shoulder MRI were performed on different machines with different magnetic field intensities and image acquisition quality. Therefore, RTSE findings were not compared with MRI findings, which is another limitation for this study. Further studies comparing RTSE findings with MRI findings and histopathological findings in patients with SIS are needed before using RTSE in routine diagnostic tests.

CONCLUSIONS

Real-time sonoelastograpy can provide qualitative and semiquantitative information about tissue quality in musculoskeletal disorders. This study used RTSE to assess the stiffness of supraspinatus tendon in patients with SIS. Real-time sonoelastograpy demonstrated significantly decreased stiffness in the affected tendon when compared to healthy tendon with substantial interobserver variability. The high diagnostic ability together with good reproducibility of RTSE assessment methods may help to integrate RTSE to standard US examination protocols like color Doppler sonography in the future. In the light of findings of this study, it can be concluded that RTSE may show promise as a potential beneficial tool in the diagnosis of early supraspinatus tendinopathy.

Supplementary Checklist

STROBE Checklist: http://links.lww.com/PHM/A187

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