Sonoelastography findings of supraspinatus tendon in rotator cuff tendinopathy without tear: comparison with magnetic resonance images and conventional ultrasonography

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Abstract

Background and purpose Sonoelastography (SE) is a new technique that can assess differences in tissue stiffness. This study investigated the performance of SE for the differentiation of supraspinatus (SSP) tendon alterations of tendinopathy compared to magnetic resonance imaging (MRI) and conventional ultrasonography (US).

Methods One hundred and eighteen consecutively registered patients with symptoms and MRI findings of SSP tendinopathy were assessed with US and SE. Coronal images of the SSP tendon were obtained using US and SE. Increased signal intensity on T2-weighted images in the coronal planes were graded according to the extent of the signal changes from ventral to dorsal. SE images were evaluated by reviewers using an experimentally proven color grading system.

Results Using SE, 7.6 % of the SSP tendons were categorized as grade 0, 30.5 % as grade 1, 19.5 % as grade 2, and 42.4 % as grade 3. Evaluation of the interobserver reliability of the SE findings showed “almost perfect agreement”, with a weighted kappa coefficient of 0.83. By comparing the MRI findings with the SE findings, grades of MRI and SE had a positive correlation ($r = 0.829$, $p = <0.001$). Furthermore, grades of US and SE also had a positive correlation ($r = 0.723$, $p = <0.001$).

Conclusions SE is valuable in the detection of the intra-tendinous and peritendinous alterations of the SSP tendon and has excellent interobserver reliability and excellent

correlation with MRI findings and conventional ultrasonography findings.

Keywords Rotator cuff · Tendinopathy · Ultrasonography · Sonoelastography

Riassunto

Obiettivi La sonoelastografia (SE) è una nuova tecnica in grado di valutare le differenze di rigidità dei tessuti. Questo studio ha valutato le capacità della SE nella differenziazione delle alterazioni tendinee da tendinopatia del sovraspinato (SSP) rispetto a risonanza magnetica (MRI) ed ecografia convenzionale (US).

Materiali e Metodi Centoventuno pazienti con sintomi e reperti MRI di tendinopatia del SSP sono stati valutati con US e SE. Si sono realizzate immagini coronali del tendine SSP utilizzando US e SE. Sono state valutate immagini T2-pesate, per la maggiore intensità del segnale, nei piani coronali, da ventrale a dorsale. Immagini di SE sono state valutate da revisori che utilizzavano un sistema di grading di colore sperimentale.

Risultati Utilizzando la SE, 7,4 % dei tendini SSP sono stati classificati come di grado 0, 29,8 % di grado 1, 19,8 % di grado 2, e 43,0 % di grado 3. La valutazione inter-osservatori dei risultati SE ha mostrato “accordo quasi perfetto”, con un coefficiente kappa pesato di 0,83. Confrontando i risultati della risonanza magnetica con i risultati della SE, risonanza magnetica e SE hanno avuto una correlazione positiva ($r = 0,849$, $p = < 0,001$). Inoltre, anche US e SE hanno avuto una correlazione positiva ($r = 0,706$, $p = < 0,001$).

Conclusioni La SE è valida nella rilevazione delle alterazioni intra-tendinee e peri-tendinee del tendine SSP e ha un’ottima affidabilità inter-osservatori e un’eccellente correlazione con RM e reperti di ecografia convenzionale.

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Introduction

Disorders of the rotator cuff (RC) or associated tissues are the most common problem of the shoulder [1, 2]. The prevalence of RC disease, specifically partial and full-thickness RC tendon tears, has been shown to increase as a function of age starting at 40 years and the prevalence is in excess of 50 % by the age of 60 years [3, 4]. RC disease has been classically described as a progressive disorder of the RC tendons which begins with an acute tendinitis, progresses to tendinosis with degeneration and partial thickness tears, and results in full-thickness rupture [5]. Tendinopathy is the preferred term, and is used to indicate a clinical problem without knowing the specific underlying mechanism or tendon pathology [6, 7]. Since the clinical differentiation between tendinopathy, partial tears and acute tendinitis is difficult, imaging is necessary for the diagnosis. The imaging modalities most commonly used are ultrasonography (US) and magnetic resonance imaging (MRI) [8–11].

Sonoelastography (SE) is a new technique that can assess differences in tissue stiffness [12]. Ophir et al. [13] first described the principle of strain imaging in 1991; in 1999, Pesavento et al. [14] developed a fast cross-sectional technique based on elastography to allow its use in clinical practice. The principle of SE is that tissue compression produces strain within the tissue, which is less pronounced in harder tissue than in softer tissue [15]. Using conventional ultrasonography, it is sometimes difficult or even impossible to distinguish pathologic tissue because it often presents with the same echogenicity as the surrounding healthy tissue [16]. However, it is well known that inflammation and tumors lead to changes in tissue elasticity [16]. Although sonoelastography is not yet used in routine clinical practice, it has been shown to be useful in the differential diagnosis of breast [15, 17], thyroid [18], and prostate [19] cancers and recently was applied to lymph node characterization [20]. However, estimation of tissue elasticity might also be a useful tool for the characterization of intratendinous focal lesions in patients presenting with rotator cuff tendinopathy.

We hypothesized that SE findings have some correlation with the MRI and US findings. Using the clinical diagnosis made with MRI as the standard of reference, the purpose of this study was to evaluate the ability of SE to assess supraspinatus (SSP) tendon alteration, and to compare the alterations as seen on MRI and the conventional US findings.

Materials and methods

Subjects

The institutional review board approved the study, a retrospective analysis, which was performed between March

2012 and May 2013 on 118 consecutive patients (56 women, 62 men; mean age 58.8 years; age range 40–76 years) who complained of chronic shoulder pain (>3 months) and had a signal intensity abnormality or thickening (>10 mm) of the SSP tendon without disruption or associated findings suggesting a partial thickness tear in the MRI. In all patients, neuromuscular disease, biceps or labral lesions, shoulder instability, acromioclavicular joint arthritis, humeral head arthritis, adhesive capsulitis, calcific tendinitis, rotator cuff tear, previous surgery on the affected shoulder, and suspected cervical lesions were ruled out by clinical examination and radiologic findings with simple radiography and MRI.

Clinical examination was performed by an orthopedic surgeon with 20 years of experience and included assessment of pain with motion, tenderness, and the “painful arc” sign. The usual complaint was pain during activity and constant chronic pain. The mean duration of symptoms was 13.2 months (range 3–48 months).

In this study, rotator cuff tendinopathy was diagnosed when patients had positive signs on the physical examination with focal degeneration of the SSP tendon on the MRI (grade 1). Clinical examination was performed at the first visit of patients before the radiologic evaluations. All radiologic evaluations (MRI, US and SE) were performed in a week.

MRI findings

The magnetic resonance imaging protocol included oblique coronal proton density T1-weighted and T2-weighted fat-saturated spin-echo images [3,300/14–95 (repetition time ms/echo time ms); section thickness 4 mm; intersection gap 0.8 mm; field of view 16 cm], oblique coronal T1-weighted fat-saturated spin-echo images [777/12 (repetition time ms/echo time ms); section thickness 3 mm; intersection gap 0.6 mm; field of view 16 cm], oblique sagittal T1-weighted spin-echo images (images (600/12 [repetition time ms/echo time ms]; section thickness 4 mm; intersection gap 1.2 mm; field of view 16 cm)) and transverse T1-weighted spin-echo images (images (600/12 [repetition time ms/echo time ms]; section thickness 3 mm; intersection gap 0.9 mm; field of view 16 cm)).

Magnetic resonance images were evaluated by consensus by one experienced musculoskeletal radiologist who was blinded to the exposure status and symptoms. Alterations in the SSP tendons were graded as described in Table 1 [21]. Increased signal intensity on T2-weighted images in the coronal planes were graded as 1A, 1B, or 1C according to the extent of the signal changes from ventral to dorsal. Grade 1A, the extent of signal changes was less than 25 % of the tendon thickness; grade 1B, the extent of the signal changes was less than 50 % of the tendon

Table 1 Grade of MRI findings of supraspinatus tendon

	MRI findings	Classification criteria
Grade 0	Normal	Normal signal intensity and morphology
Grade 1A	Focal degeneration (<25 %)	Increased signal intensity on T2-weighted images in coronal planes, graded 1A, 1B, or 1C according to the extent of signal changes from ventral to dorsal
Grade 1B	Focal degeneration (<50 %)	
Grade 1C	Focal degeneration (≥ 50 %)	
Grade 2	Partial tear	Focal areas of tendon discontinuity with T2 bright fluid signal
Grade 3	Full-thickness tear	Focal complete discontinuity of tendon fibers from articular to bursal surfaces
Grade 4	Complete tear	Complete discontinuity of the tendon with atrophy of the muscle

thickness; and grade 1C, the extent of the signal changes was more than 50 % of the tendon thickness. This study was intended for only grade 1; cases more than grade 2 were excluded because only rotator cuff tendinopathy without tears were targeted in this study.

SE and US imaging

The patient sat on a chair, with the examiner standing behind the patient. The US examination was standardized according to a previously published technique [22]. The US assessment was performed with the arm in the internal rotation position. The arm was positioned in pronation on the patient's back. The transducer was perpendicular to the SSP tendon, US and SE images were obtained only on long axis view of the SSP. This plane corresponded to the coronal MR image plane (Fig. 1). The area from the most anterior to the most posterior portion of the SSP tendons was evaluated in this position and static images were acquired when SSP tendons were most altered.

SE and US were performed using a Siemens Acuson S2000 (Siemens Medical Solutions USA, Inc., Malvern, PA) with a linear array transducer with a frequency of 12 MHz. The calculation of the tissue elasticity distribution was in real time (up to 30 frames/s) and the examination results were represented in color over the conventional B-mode image [16] using the following standardized settings. SE images were obtained when the transducer was perpendicular to the tendons with mild compression, and the degree of compression was based on the quality factor shown on the monitor of the ultrasonic apparatus. We set the quality factor of 65 as the standard. SE images were

Fig. 1 The US assessment is performed with the arm in internal rotation. The transducer was perpendicular to the SSP tendon, and this plane corresponded to the coronal MR image plane

composed of a 256° color map and configured so that soft tissues showed a red color and hard tissues showed a blue color.

Ultrasonography (US) and SE were performed by an orthopedic surgeon with 15 years of experience in scanning US who was blinded to the clinical and MRI findings. The images were interpreted after the initial scanning by the same orthopedic surgeon. To evaluate interobserver variability, a second orthopedic surgeon with 5 years of experience assessed the same SE images. Both orthopedic surgeons were blinded to the clinical results and results of the MR images. Rotator cuff tendinopathy was defined as a measurement of the grade determined by the two blinded observers. In cases where the grade differed between the two blinded observers, the mean value of the grades was rounded and used as a representative value.

Ultrasonography (US) images were graded as follows: grade 1, normal-appearing tendon (parallel margins, homogeneous echotexture); grade 2, enlarged tendon (tendon thickness > 10 mm, bowed margins) or mild abnormal echogenicity (the extent of heterogenous echogenicity was less than 25 % of the tendon thickness); and grade 3, moderate-to-severe abnormal echogenicity (the extent of heterogenous echogenicity was more than 25 % of the tendon thickness) without fiber dehiscence as a sign of a partial or complete tear.

Sonoelastography (SE) images were evaluated for the presence of focal lesions, which were defined as red to yellow (soft) areas on the SE. Focal lesions were counted to evaluate the dimensions of the focal lesions, according to the following grading system: 0, no focal lesion or blue to green (hard) tendon; 1, one focal lesion; 2, two focal lesions; and 3, more than two focal lesions [23]. At least three scans of each tendon were performed and the mean of the grades of the three scans was used as the representative value.

Statistical analysis

Spearman's correlation coefficient was used to estimate the correlation of the SE images with the MR images and conventional US images. A weighted kappa (κ) coefficient was used to estimate the interobserver reliability in the evaluation of the SE images. Interobserver reliability was classified according to the κ coefficients: "slight agreement", 0.00–0.20; "fair agreement", 0.21–0.40; "moderate agreement", 0.41–0.60; "substantial agreement", 0.61–0.80; and "almost perfect agreement", 0.81–1.00. All statistical analyses were performed with SPSS version 19.0 (SPSS Inc., Chicago, IL, USA) and the level of significance was set at $P < 0.05$.

Results

MRI analysis of the SSP tendons showed grade 1A in 37.3 %, grade 1B in 29.7 % and grade 1C in 33.1 %. US examination of the SSP tendons showed grade 1 in 9.3 %, grade 2 in 44.9 % and grade 3 in 45.8 %. Interobserver reliability of the US findings was in "substantial agreement", with a weighted kappa coefficient of 0.73. Using SE, 7.6 % of SSP tendons were categorized as grade 0, 30.5 % as grade 1, 19.5 % as grade 2, and 42.4 % as grade 3 (Figs. 2, 3). Interobserver reliability of SE findings was in "almost perfect agreement", with a weighted kappa coefficient of 0.83.

By comparing the MRI findings with the SE ones, the grades of MRI and SE were shown to have a positive correlation ($r = 0.829$, $p = <0.001$). Furthermore, grades of US and SE were also observed to have a positive correlation ($r = 0.723$, $p = <0.001$) (Tables 2, 3).

Discussion

The term RC tendinopathy is used to signify a combination of pain and impaired performance associated with RC tendons [24, 25]. Tendinopathy is the preferred term to indicate a clinical diagnosis when the specific underlying

mechanism or tendon pathology is unknown [6, 7]. Tendinopathy is clinically characterized by the gradual onset of stiffness in the tendon, activity-related pain, decreased function, and sometimes localized swelling and palpable crepitations [7, 26].

Fig. 2 **a** T2-weighted coronal image of magnetic resonance images of grade 2 supraspinatus tendinopathy shows the extent of signal changes, which was less than half the supraspinatus tendon thickness. **b** Ultrasonography of grade 2 supraspinatus tendinopathy shows mild heterogeneous echogenicity of the supraspinatus without fiber dehiscence. **c** Sonoelastography of grade 2 supraspinatus tendinopathy shows two focal lesions. SSP supraspinatus, dotted lines contour of supraspinatus, arrowheads focal degeneration of the supraspinatus

Fig. 3 **a** T2-weighted coronal image of magnetic resonance imaging of grade 3 supraspinatus tendonopathy shows the extent of the signal changes that were more than half the supraspinatus tendon thickness. **b** Ultrasonography of grade 3 supraspinatus tendonopathy shows moderate heterogenous echogenicity of the supraspinatus without fiber dehiscence. **c** Sonoelastography of grade 3 supraspinatus tendonopathy shows more than three focal lesions. SSP supraspinatus, dotted lines contour of supraspinatus, arrowheads focal degeneration of the supraspinatus

Table 2 Overall findings in shoulders of patients: grade of MRI, US and SE findings

MRI		US		SE	
Grade	N = 118	Grade	N = 118	Grade	N = 118
0	0	1	11 (9.3 %)	0	9 (7.6 %)
1A	44 (37.3 %)	2	53 (44.9 %)	1	36 (30.5 %)
1B	35 (29.7 %)	3	54 (45.8 %)	2	23 (19.5 %)
1C	39 (33.1 %)			3	50 (42.4 %)

Despite the debate over the pathogenesis, evidence indicates that the etiology of RC tendonopathy is multifactorial, and it is likely that both intrinsic and extrinsic mechanisms play a role. Intrinsic mechanisms, such as alterations in RC tendon mechanical properties, composition, and vascularity, and extrinsic mechanisms, such as alterations in scapular and glenohumeral kinetics that contribute to either internal and external impingement, appear to be particularly significant factors of RC tendonopathy [27].

US and MRI are considered as modalities that can be used to evaluate tendonopathy [28–30]. The extreme sensitivity of MRI means that structural abnormalities revealed by imaging may not correlate precisely with the symptoms [31]. With conventional ultrasonography, it can be difficult or even impossible to differentiate tissues affected by degenerative disease from healthy tissues because damaged tissue often has the same echogenicity as the surrounding healthy tissue [16]. However, it is well known that inflammation and degeneration cause changes in tissue elasticity [16]. Thus, estimation of tissue softening may be a useful tool for the characterization of an intratendinous focal lesion or peritendinous involvement in patients with RC tendonopathy.

Tendonopathy involves collagen breakdown that softens and weakens the tendon, eventually leading to tendon tear or rupture [32]. These histopathologic alterations of tendonopathy have been found to increase the compressibility of tissue on ultrasound scans and may cause softening of the tissue on SE [33]. De Zordo et al. reported that SE is valuable in the detection of intratendinous and peritendinous alterations in lateral epicondylitis or Achilles tendonopathy [23, 34]. In this study, distinct focal lesions were detected with SE and scored as grade 0 in 7.6 % of cases, grade 1 in 30.5 %, grade 2 in 19.5 %, and grade 3 in 42.4 %. SE findings had a positive correlation with the US findings ($r = 0.723$, $p = <0.001$) and MRI findings ($r = 0.829$, $p = <0.001$) (Tables 2, 3).

In this study, interobserver reliability of SE ($k = 0.83$) was higher than interobserver reliability of US ($k = 0.73$).

Table 3 Correlation of MRI, US and SE findings

Correlation between MRI and SE		Correlation between US and SE		Correlation between MRI and US	
<i>P</i> value	Correlation coefficient	<i>P</i> value	Correlation coefficient	<i>P</i> value	Correlation coefficient
<0.001	0.829	<0.001	0.723	<0.001	0.611

Fig. 4 **a** Ultrasonography of supraspinatus, *arrowhead* indicates artifact. There is hypoechoogenicity in the articular side proximal supraspinatus. **b** Sonoelastography of supraspinatus, *arrowhead* indicates artifact. It shows multiple focal lesions in the articular side proximal supraspinatus

This result could be explained by the different grading systems used in US and SE. US images were graded as the proportion of heterogeneous echogenicity, whereas SE images were graded as the number of focal lesions. Counting assessment of the number of focal lesions could be more objective than evaluating the proportion of heterogeneous echogenicity.

Our study had the following limitations: first, our study population was relatively small and the study design was a retrospective one; second, the study involved only patients, but further comparison with a normal healthy group is needed to evaluate the sensitivity, specificity, and accuracy of SE; third, there was a lack of consensus regarding the definition of RC tendinopathy and SE techniques; fourth, we correlated the SE findings with only the US and MRI findings, but a further

comparison with arthroscopic findings and histopathology results would be very interesting; fifth, artifacts in the SE images may have led to some confusion during assessment. It is known that it is difficult to stabilize the operator's hand when performing tissue compression, because of the rounded shape of the greater tuberosity. Consequently, there are a lot of out-of-plane movements of the transducer, known to result in color alterations that may be artifacts [35]. Therefore, comparing SE and US images is necessary to recognize and minimize artifacts in the SE images (Fig. 4). Furthermore, SE is a technique with relatively high operator dependency in terms of the application of pressure to the probe and the differentiation of artifacts from the diagnostic imaging information. Although operator dependency is a known challenge in SE. We tried to obtain appropriate images by maintaining a similar level of pressure on the probe while monitoring the quality factor. Although interobserver reliability is high ($k = 0.83$) in this study, SE images were obtained by only one operator. Due to the high operator dependency of SE, further assessment of images of SSP tendons obtained by more operators could be useful for a more accurate evaluation of interobserver reliability.

Conclusion

Sonoelastography (SE) is valuable in the detection of intratendinous and peritendinous alterations of the SSP tendon and has excellent interobserver reliability and excellent correlation with MRI findings and conventional ultrasonography findings.

Conflict of interest The authors (Joong-Bae Seo, Jae-Sung Yoo, and Jee-Won Ryu) have no conflict of interest.

Informed consent All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 (5). All patients provided written informed consent to enrolment in the study and to the inclusion in this article of information that could potentially lead to their identification.

Human and animal studies The study conducted in accordance with all institutional and national guidelines for the care and use of laboratory animals.

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