The accuracy of sonoelastography in fatty degeneration of the supraspinatus: a comparison of magnetic resonance imaging and conventional ultrasonography

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Abstract

Objective Sonoelastography (SE) technique is one of the new functional ultrasonic imaging techniques, which was developed in the past few years and can obtain the distributions of elasticity in tissues. Using magnetic resonance imaging (MRI) as the standard of reference, the purpose of this study was to evaluate the ability of SE to assess the fatty degeneration of supraspinatus (SSP) and to compare it to the MRI and the conventional ultrasonography (US) findings.

Materials and methods The institutional review board approved the study, and a retrospective analysis between January 2013 and September 2013 was performed on 101 shoulders of 98 consecutive patients using MRI, US, and SE for the evaluation of shoulder lesion. Oblique sagittal images of SSP were obtained using SE. The SE images were evaluated by reviewers using an experimentally proven color grading system.

Results When comparing SE to standard MRI findings, the mean sensitivity of SE was 95.6 %, the specificity 87.5 %, and the accuracy 91.1 %. The interobserver reliability of the SE findings was “almost perfect agreement” with a weighted kappa coefficient of 0.81. On comparing MRI with the SE findings, the grades of MRI and SE have a positive correlation ($r = 0.855$, $P = <0.001$). Furthermore, the grades of US and SE also have a positive correlation ($r = 0.793$, $P = <0.001$).

Conclusion SE is valuable in the quantitative assessment of the severity of the fatty atrophy of the supraspinatus and has an excellent accuracy, an excellent correlation with

MRI and the conventional US, and an excellent interobserver reliability.

Keywords Supraspinatus · Fatty degeneration · Ultrasonography · Sonoelastography

Riassunto

Sfondo La tecnica Sonoelastografia (SE) è una delle nuove tecniche di imaging funzionale ad ultrasuoni; sviluppato negli ultimi anni, e' in grado di ottenere informazioni quantitative sulle distribuzioni di elasticità nei tessuti. Utilizzando la risonanza magnetica (MRI) come standard di riferimento, lo scopo di questo studio era di valutare la capacità di SE nel verificare la degenerazione grassa del sovraspinato (SSP) e di confrontarla con i risultati della risonanza magnetica MRI e dell'ecografia convenzionale (US).

Metodi Il consiglio di revisione istituzionale ha approvato lo studio, ed è stata eseguita un'analisi retrospettiva fra il gennaio del 2013 e il settembre del 2013 in 101 spalle di 98 pazienti consecutivi ai quali sono stati eseguiti MRI, US, e SE per la valutazione delle lesioni della spalla. Le immagini sagittali oblique di SSP sono stati ottenuti utilizzando lo SE. Le immagini SE sono stati valutati da revisori che utilizzano un sistema di analisi del colore provata sperimentalmente.

Risultati Quando si confrontano i risultati del SE e del MRI standard, la sensibilità media di SE era del 95.6 %, la specificità del 87.5 %, e l'accuratezza del 91.1 %. L'affidabilità interosservatore del SE è stato “un accordo quasi perfetto”, con un coefficiente kappa pesata di 0.81. Confrontando i risultati del SE con il MRI, i gradi del MRI e del SE hanno una correlazione positiva ($r = 0.855$, $P = <0.001$). Inoltre, le classi del US e del SE hanno anche una correlazione positiva ($r = 0.793$, $P = <0.001$).

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Conclusione SE è importante nella valutazione quantitativa della gravità della atrofia grassa del sovraspinoso e ha un'ottima precisione, una correlazione eccellente con MRI e US convenzionale, ed un'eccellente affidabilità interosservazione.

Introduction

The fatty degeneration of the rotator cuff muscles associated with tendon tears is an important prognostic factor for the anatomic and functional results after a surgical repair of the cuff [1, 2]. Melis et al. [3] suggested that the rotator cuff repair should be performed before the appearance of fatty infiltration (stage 2) and atrophy (positive tangent sign), especially when the tear involves multiple tendons. The classification of fatty degeneration is commonly performed at computed tomography (CT) [4]; magnetic resonance imaging (MRI) is also appropriate for assessing the grade of the fatty atrophy [5, 6].

Although MRI is considered by many authors as the standard of reference in evaluating shoulder joint derangements, ultrasonography (US) is also accurate in the diagnosis of rotator cuff tears in the hands of experienced investigators [7, 8]. Although some authors have tried to diagnose a substantial fatty degeneration of the supraspinatus (SSP) muscle, the accuracy of the diagnosis is not satisfying [9]. In recent years, the ultrasonic imaging technique has transformed into functional imaging from an anatomical imaging. Sonolastography (SE) technique is one of the new functional ultrasonic imaging techniques, which was developed in the past few years and can show the distributions of elasticity in tissues [10–12].

We hypothesize that SE findings have correlation with MRI and US findings. Using the MRI as the standard of reference, the purpose of this study was to evaluate the ability of SE to assess the fatty degeneration of supraspinatus (SSP) and to compare it to the MRI and the conventional US findings.

Materials and methods

Subjects

The institutional review board approved the study, and a retrospective analysis between January 2013 and September 2013 was performed in 101 shoulders of 98 consecutive patients who were suspected of having shoulder lesion and underwent MRI, US, and SE. There were 56 men and 42 women, with a mean age of 53.9 years (23–76 years). 59 cases involved the right side and 42 cases the left side. 63

cases involved the dominant arm and 38 cases the non-dominant arm. There were 46 full thickness rotator cuff tears, 29 partial thickness rotator cuff tears, 11 rotator cuff tendinopathy, 8 adhesive capsulitis, 4 calcific tendinitis, and 3 labral lesions.

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); the section thickness, 4 mm; the 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); the section thickness, 3 mm; the 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); the section thickness, 4 mm; the 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) the section thickness, 3 mm; the intersection gap, 0.9 mm; field of view, 16 cm)].

The fatty degeneration of the supraspinatus was evaluated on the most lateral of the oblique sagittal T1-weighted images in which the scapular spine remained in contact with the scapular body [13]. The grade of fatty atrophy of the supraspinatus muscle belly was assessed according to Goutallier et al. [4] classification : grade 0, no intramuscular fat; grade 1, some fatty streaks; grade 2, fat less extensive than the muscle; grade 3, fat equal to the muscle; and grade 4, fat more extensive than the muscle.

The MRI was interpreted by a consensus readout of two blinded observers using the measurement software of the PACS system (picture archiving and communication system). The fatty degeneration was determined as a measurement of the grade determined by two blinded observers on the oblique sagittal MRI slices to evaluate interobserver reliability.

SE and US imaging

The patient sat on a chair, with an examiner standing behind the patient. The US examination was standardized according to a previously published technique [14]. The muscle belly of the supraspinatus muscles was evaluated while the patient was asked to place his or her hand on the anterior ipsilateral thigh for the examination. The transducer was perpendicular to the muscle belly of the SSP muscle; this plane corresponded to the oblique sagittal MRI plane (Fig. 1).

Sonolastography and US were performed using a Siemens Acuson S2000 US System (Mochida Siemens

Medical System, Tokyo, Japan) with a 9 MHz linear transducer. 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 [15] using the following standardized settings. The SE images were obtained when the transducer was perpendicular to the SSP with mild compression; the degree of the compression was based on the quality factor that was shown on the monitor of the ultrasonic apparatus to minimize the difference of pressures. We set the standard of the quality factor as 65. Three SE images were obtained when the quality factor was 65 to minimize interobserver variability by using the average values of three SE images. The SE images are composed of

Fig. 1 Investigation of the supraspinatus muscle belly. The transducer was perpendicular to the muscle belly of the SSP muscle; this plane corresponded to the oblique sagittal magnetic resonance image plane

256 degrees color map, which is configured such that the soft tissue is shown in red and the hard tissue in blue. US and SE were performed by an orthopedic surgeon with 7 years of experience in musculoskeletal imaging; he was blinded to the MRI findings. The images were interpreted after the initial scanning by the same orthopedic surgeon. To evaluate the interobserver variability, a second orthopedic surgeon with 4 years of experience assessed the same SE images.

The US images were graded as follows: grade 0 = isoechoic to the trapezius and clearly visible intramuscular tendons or identifiable muscle pennate pattern; grade 1 = slightly increased echogenicity compared to the trapezius or partially visible intramuscular tendons and muscle pennate pattern; grade 2 = markedly increased echogenicity compared to the trapezius or no discernible intramuscular tendons or muscle pennate pattern (Table 1) [16].

The SE images were evaluated according to the following standards: grade 0 = absolute dominant blue region (a few focal lesions) in elasticity image; grade 1 = relative dominant blue region ($>1/2$ of desired region) in elasticity image; grade 2 = non-dominant blue region ($\leq 1/2$ of desired region) in elasticity image. The focal lesion is defined as red to yellow (soft) areas on SE (Table 1).

The US and SE images were interpreted by two blinded observers using the measurement software of the PACS system (picture archiving and communication system). The fatty degeneration was determined as a measurement of the grade determined by two blinded observers to evaluate interobserver reliability.

Statistic analysis

Spearman's correlation coefficient was used to estimate the correlation of the SE images with the MR images and conventional US images. Weighted kappa (κ) coefficient was used to estimate the interobserver reliability in the evaluation of the SE images; an interobserver reliability was classified

Table 1 Grade of ultrasonography and sonoelastography findings of the fatty degeneration of the supraspinatus

	Ultrasonography finding		Sonoelastography finding
	Echogenicity	Architecture	
Grade 0	Isoechoic to the trapezius	Clearly visible intramuscular tendons and identifiable muscle pennate pattern	Absolute dominant blue region (a few focal lesions) in the elasticity image
Grade 1	Slightly increased echogenicity compared with the overlying muscle	Partially visible intramuscular tendons and muscle pennate pattern	Relative dominant blue region ($>1/2$ of the desired region) in the elasticity image
Grade 2	Markedly increased echogenicity compared with the overlying muscle	No discernible intramuscular tendons or muscle pennate pattern	Non-dominant blue region ($\leq 1/2$ of the desired region) in the elasticity image

Table 2 Overall findings in shoulders of patients: grade of MRI, ultrasonography and sonoelastography findings

Magnetic resonance imaging		Ultrasonography		Sonoelastography		Correlation between MRI and SE		Correlation between US and SE		Correlation between MRI and US	
Grade	N = 101 (%)	Grade	N = 101 (%)	Grade	N = 101 (%)	P value	Correlation coefficient	P value	Correlation coefficient	P value	Correlation coefficient
0	31 (30.7)	0	44 (43.6)	0	51 (49.5)	<0.001	0.855	<0.001	0.793	<0.001	0.825
1	25 (24.8)	1	33 (32.7)	1	33 (33.7)						
2	19 (18.8)	2	24 (33.7)	2	17 (16.8)						
3	15 (14.9)										
4	11 (10.9)										

Table 3 Sensitivity, specificity, and accuracy of sonoelastography

Magnetic resonance imaging	Ultrasonography		Sonoelastography	
	Grade 0	Grade 1 and 2	Grade 0	Grade 1 and 2
	N = 44	N = 57	N = 51	N = 50
Positive finding of fatty degeneration (Goutallier grade 2, 3, 4)	3	42	2	43
Negative finding of fatty degeneration (Goutallier grade 0, 1)	41	15	49	7

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; “almost perfect agreement”, 0.81–1.00. The MRI, US and SE grades were collapsed to a dichotomous scale (i.e., absence or presence of fatty infiltration) to investigate the agreement on the presence of a fatty degeneration. The Goutallier MRI grades 0 and 1, the US grade 0 and the SE grade 0 indicated “absence”. The Goutallier grades 2, 3 and

4, the US grades 1 and 2 and the SE grades 1 and 2 indicated “presence”. All statistical analyses were performed with SPSS version 20.0 (SPSS Inc., Chicago, IL, USA) and the level of significance was set at $P < 0.05$.

Results

The MRI finding of fatty degeneration of SSP showed grade 0 in 30.7 %, grade 1 in 24.8 %, grade 2 in 18.8 %, grade 3 in 14.9 % and grade 4 in 10.9 %. The interobserver reliability of the MRI findings was “almost perfect agreement” with a weighted kappa coefficient of 0.84. The US examination of fatty degeneration of SSP showed grade 0 in 43.6 %, grade 1 in 32.7 % and grade 2 in 33.7 %. The interobserver reliability of the US findings was “substantial agreement” with a weighted kappa coefficient of 0.72. Using SE, 7.4 % of SSP tendons were categorized: 49.5 % as grade 0, 33.7 % as grade 1 and 16.8 % as grade 2. The interobserver reliability of the SE findings was “almost perfect agreement” with a weighted kappa coefficient of 0.81.

Fig. 2 **a** T1-weighted oblique sagittal image of magnetic resonance imaging of a 42-year-old man showing grade 0 supraspinatus fatty degeneration. **b** Oblique sagittal view of the ultrasonography of grade 0 supraspinatus fatty degeneration showing clearly visible intramuscular tendons and identifiable muscle pennate pattern; the *arrowhead*

indicates intramuscular tendons. **c** Oblique sagittal view of the sonoelastography of grade 0 supraspinatus fatty degeneration showing absolute dominant *blue* region (a few focal lesions) in the elasticity image. TR trapezius, SSP supraspinatus, *solid lines* indicate supraspinatus fossa

Specificity, sensitivity, accuracy and correlation

When comparing US and SE to standard MRI findings, the mean sensitivity of US was 93.3 %, specificity 73.2 % and the accuracy 82.2 %; the mean sensitivity of SE was 95.6 %, specificity 87.5 % and the accuracy 91.1 % when only distinct elasticity alterations of grade 1 and 2 were considered as pathological (Table 2).

On comparing MRI with the SE findings, the grades of MRI and SE had a positive correlation ($r = 0.855$, $P = <0.001$). Furthermore, grades of US and SE also had a positive correlation ($r = 0.793$, $P = <0.001$) (Table 3; Figs. 2, 3).

Discussion

Several imaging modalities can be used to evaluate the fatty degeneration of SSP. Although the original Goutallier grading system was based on the axial CT images [4], the agreement between CT and MRI was not satisfactory. Recently, MRI has become the accepted modality for the diagnosis and the grading of fatty degeneration [5, 6].

US have a lot of advantages including: cost effectiveness, a good tolerance level and reliability for patients with metallic implants or claustrophobia. It also provides a dynamic and global evaluation of the cuff muscles in real time, whereas MRI provides a static and more limited evaluation of the cuff

Fig. 3 **a** T1-weighted oblique sagittal image of magnetic resonance imaging of a 67-year-old woman showing grade 4 supraspinatus fatty degeneration. **b** Oblique sagittal view of the ultrasonography of grade 2 supraspinatus fatty degeneration showing loss of intramuscular tendons or a muscle pennate pattern. **c** Oblique sagittal view of the

sonoelastography of grade 2 supraspinatus fatty degeneration showing a non-dominant blue region ($\leq 1/2$ of desired region) in the elasticity image. TR trapezius, SSP supraspinatus, solid lines indicate supraspinatus fossa. Dotted lines indicate the supraspinatus

Fig. 4 **a** T1-weighted oblique sagittal image of magnetic resonance imaging of a 37-year-old man showing grade 0 supraspinatus fatty degeneration. **b** Oblique sagittal view of the ultrasonography of grade 0 supraspinatus fatty degeneration; the arrows indicate a posterior acoustic shadowing of the superior border and the spine of scapula.

c Oblique sagittal view of the sonoelastography; the arrowheads indicate artifact (low elasticity area). TR trapezius, SSP supraspinatus, SU superior border of scapula, SP spine of scapula, solid line indicates an artifact

muscles [16]. However, Strobel et al. [9] reported that the use of the US images for the evaluation of fatty degeneration of SSP may only provide moderate accuracy (75 %).

With conventional US, it can be difficult or even impossible to differentiate the tissue affected by degenerative disease from a healthy tissue because the damaged tissue often has the same echogenicity as the surrounding healthy tissue [15]. However, it is well known that inflammation and degeneration cause changes in the tissue elasticity [15]. Thus, the estimation of tissue softening may be useful for characterizing fatty degeneration of SSP.

Wall et al. [16] reported that the accuracy of US for the detection of fatty degeneration of SSP was 92.5 %, and the agreement between US and MRI for the detection of fatty degeneration in the supraspinatus was 0.83. In this study, the accuracy of SE for the detection of fatty degeneration of SSP was 95.6 %, and the agreement between SE and MRI ($r = 0.855$, $P = <0.00$) in the present study was better than the reported agreement between US and MRI.

The interobserver reliability of US was 0.72 and the interobserver reliability of SE was 0.81 in our study. These findings were comparable with the interobserver reliability of US reported in the study of Wall et al. [16], in which the reliability was 0.71. Although it is not possible to directly compare the different grading systems in the US and the SE findings, our findings suggest that the interobserver reliability of SE may be at least comparable with those of US and MRI.

Our study has the following limitations: first, our study population was relatively small and it was a retrospective study; second, there is lack of consensus regarding the definition of fatty degeneration with use of SE techniques; third, the intraobserver reliability of SE was not investigated in this study, since it was deemed impractical to ask the patients to return for a second examination; fourth, quantitative assessment was not performed, but only grading was compared in this study; fifth, there was difficulty in estimation caused by the posterior acoustic shadowing of the superior border and the spine of scapula (Fig. 4b); sixth, there was confusion in the assessment caused by a low elasticity signal around the scapula (Fig. 4c). This signal is not true softening, but an artifact. This artifact explains that the reaction force of the tissue near the scapula is bigger than the reaction force of the tissue far from the scapula [17]. Furthermore, SE is a technique which is relatively highly operator dependant, in terms of the application of the pressure to the probe and the differentiation of the artifacts from the diagnostic image information. Although the operator dependency is a known challenge in US, we tried to obtain appropriate images by maintaining a level of pressure on the probe with monitoring of the quality factor. Nevertheless, this study is meaningful because it attempted to analyze the correlation

of SE findings with the MRI and US finding in the fatty degeneration of SSP for the first time.

Conclusion

Sonolastography is valuable in the detection of fatty degeneration of SSP and has an excellent accuracy, an excellent correlation with MRI and conventional US, and an excellent interobserver reliability.

Conflict of interest Joongbae Seo, Jaesung Yoo, and Jeewon Ryu declare that they have no conflict of interest.

Informed consent All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (Dankook University Hospital Institutional Review Board). All patients provided written informed consent for enrollment in the study and for inclusion in this article of information that could potentially lead to their identification.

Human studies The study was conducted in accordance with all institutional and national guidelines for the care.

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