Ultrasound elastography in detection of supraspinatus muscle atrophy and fatty degeneration in the reference to MRI

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Rotator cuff tears (RCTs) are common upper extremity injuries the incidence of which continues to rise [1]. Small and medium-sized RCTs usually treated with nonsurgical management initially, while massive tears are the subject for primary surgery.

Despite the development of arthroscopic techniques, clinical success rates in treating RCTs have remained relatively constant. Many factors contribute to the success of a rotator cuff repair. Muscle quality appears to have a major role in determining clinical outcomes [2].

Massive tears have been found to be associated with atrophy, fibrosis, and fatty degeneration (FD) of the muscles. Clinically, supraspinatus (SS) muscle atrophy (MA) and fatty degeneration (FD) have been correlated with poor functional outcomes following RCT repair [3].

MRI is the gold standard for detecting RC injury as well as SS MA and FD. SS MA is graded by the transverse size of the muscle belly relative to the supraspinatus fossa according to the Thomazeau 3-point staging scale [4].

FD is graded based on the modified Goutallier classification it is qualitative and depends on the amount of fat in the muscle itself [5].

Ultrasound elastography is a new technique being used for characterizing tissue stiffness in breast, thyroid, prostate and lymph nodes [6]. Musculoskeletal pathology was one of the first applications of sonoelastography, but, nevertheless the method is not yet standardized. Sonoelastography is an US method evaluating tissue stiffness which can be useful for evaluation of SSM FD.

A combination of MRI with real-time high resolution ultrasound (US) known as Fusion imaging may improve understanding of sports medicine injuries, and may provide more accurate measurements of musculoskeletal (MSK) disorders.

The objective of our study was to investigate the possibilities of US sonoelastography (SE) in detection of supraspinatus muscle atrophy (SS MA) and fatty degeneration (FD) with reference to MRI
Methods and materials

Patient characterization

29 pts: (11 female +18 male) with shoulder pain and disability underwent US with and without SE before MRI study.

18 cases involved the right side and 11 cases the left side.

17 cases involved the dominant arm and 12 cases the nondominant arm.

There were 6 full thickness rotator cuff tears, 9 partial thickness rotator cuff tears, 11 rotator cuff tendinopathy, 1 adhesive capsulitis, 2 calcific tendinitis.

Shoulder MRI protocol

MRI of the shoulder was reformatted on GE Signa HDx 1.5 Tesla with a shoulder coil. The MRI protocol included standard sequences for shoulder exams Fig. 2 on page 7. 3D reconstruction was added for the protocol for further Fusion navigation, which was performed in 6 cases.

FD of the SSM 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.

The grade of fatty atrophy of the supraspinatus muscle belly was assessed according to Goutallier et al. [5] classification Fig. 3 on page 8.

The severity of SS MA was achieved according to the Thomazeau [4] 3-point staging scale Fig. 4 on page 8. The occupation ratio (R) of the SS fossa by the SS muscle belly was calculated on oblique sagittal T1 WI Fig. 1 on page 7.

Shoulder US protocol

Sonoelastography and US study were performed using:

• MyLab Class-C (ESAOTE) with a linear probe BL433 (3-18MHz)
US examination protocol performed with a standard technique according to Zanetti [7]. The muscle belly of the SSM 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 SSM; this plane corresponded to the oblique sagittal MRI plane. In order to obtain careful evaluation of the occupational ratio of SSM to SS fossa Fusion US/MRI study was performed in 6 cases.

SE examination results were represented in color over the conventional B-mode image using the standardized settings, recommended by manufacturer. The SE images were obtained using mild compression; based on the quality factor. The SE images are composed of 256 degrees color map, which is configured such that the soft tissue is shown in yellow, green and red and the hard tissue in blue.

**US evaluation of SS MA and FD**

The amount of FD was graded according to the modified Zanetti et al [7] 3-point grading scale based on the analysis of the echogenicity and echostructure of the SSM in comparison to the trapezius Fig. 5 on page 9

The occupation ratio (R) of the SS fossa by the SSM belly was calculated on transverse US scan through the SS fossa Fig. 6

The amount of FD by SE was evaluated qualitatively based on the color differences between muscle and fat tissues with a modified 3-point grading scale previously described by Seo et al [8] Fig. 7

SS MA was evaluated using SE pattern as a mask above the grey scale image to increase visualization of the SSM. Stiffness of the fat tissue is significantly lower than of the muscle. Fat usually presented in yellow and red colors. These helped to delineate the border between the SSM and trapezius muscle which was of value for proper measurements Fig. 8 on page 11.

The severity of SS MA by US was achieved also according to the Thomazeau 3-point staging scale Fig. 4 on page 8

**Fusion US/MRI protocol**

Fusion US/MRI was performed also on My LAB Class-C (ESAOTE) with a linear transducer BL433 (3-18MHz). Magnetic tracking sensor was placed over the US probe. And a special electromagnetic transmitter placed near the patient which
generated the magnetic field. As recommended by the manufactures the main magnet was placed less than 70cm from the organ.

3D DICOM series of the shoulder were loaded. A special landmarks were choosed for Fusion. This technique involves the co-registered display of live ultrasound with a reference series from 3D MRI. The MRI image was displayed side-by-side with the live ultrasound Fig. 9 on page 12

Statistical analysis

All data was compared to MRI for atrophy and FD.

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 FD and MA was determined as a measurement of the grade determined by two blinded observers to evaluate interobserver reliability.

Spearman's correlation coefficient was used to estimate the correlation of the SE images with the MR images and conventional US images. Weighted kappa (k) coefficient was used to estimate the interobserver reliability in the evaluation of the SE images; an interobserver reliability was classified according to the kappa 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 grades of FD (0 and 1), the US grade 0 and the SE grade 0 indicated "absence". The FD grades 2, 3 and 4, the US grades 1 and 2 and the SE grades 1 and 2 indicated "presence" of FD.
Fig. 1: MRI principles of the SS Ma calculation

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<table>
<thead>
<tr>
<th>Type of MRI image</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>oblique coronal T2</td>
<td>TR 4400; TE 87; 3 mm; FOV 16 cm</td>
</tr>
<tr>
<td>oblique coronal PD FS</td>
<td>TR 2400; TE 12; 3 mm; FOV 16 cm</td>
</tr>
<tr>
<td>oblique sagittal PD FS</td>
<td>TR 3300; TE 12; 3 mm; FOV 16 cm</td>
</tr>
<tr>
<td>oblique sagittal T1</td>
<td>TR 620; TE 12; 3 mm; FOV 16 cm</td>
</tr>
<tr>
<td>transverse PD FS</td>
<td>TR 3300; TE 12; 3 mm; FOV 16 cm</td>
</tr>
</tbody>
</table>

**Fig. 2:** MRI shoulder protocol

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<table>
<thead>
<tr>
<th>Grade of FD</th>
<th>Amount of fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>No fatty deposits</td>
</tr>
<tr>
<td>Grade 1</td>
<td>Some fatty streaks</td>
</tr>
<tr>
<td>Grade 2</td>
<td>Less fat than muscle</td>
</tr>
<tr>
<td>Grade 3</td>
<td>As much fat as muscle</td>
</tr>
<tr>
<td>Grade 4</td>
<td>More fat than muscle</td>
</tr>
</tbody>
</table>

**Fig. 3:** Modified Goutallier 5-point grading scale

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### Fig. 4: 3-point grading scale for evaluation of SS MA according to Thomazeau.

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<table>
<thead>
<tr>
<th>Stage of SSMA</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>1-0.6  normal or slight atrophy</td>
</tr>
<tr>
<td>Stage 2</td>
<td>0.6-0.4  moderate atrophy</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Less 0.4  severe atrophy</td>
</tr>
</tbody>
</table>

### Fig. 5: Evaluation of FD graded according to the modified Zanetti et al * 3-point grading scale

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<table>
<thead>
<tr>
<th>Grade of FD on US</th>
<th>Echogenicity</th>
<th>Echostructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>Isoechoic to trapezius</td>
<td>Typical pennate pattern</td>
</tr>
<tr>
<td>Grade 1</td>
<td>Slightly increased echogenicity</td>
<td>Partial visibility muscle pennate pattern</td>
</tr>
<tr>
<td>Grade 2</td>
<td>Markedly increased echogenicity</td>
<td>Absence of visibility of the muscle pennate pattern</td>
</tr>
</tbody>
</table>
**Fig. 6:** Method of calculation of SS MA by US

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<table>
<thead>
<tr>
<th>Grade of FD on SE</th>
<th>Color type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>Blue and green no red above the SSM</td>
</tr>
<tr>
<td>Grade 1</td>
<td>Red as much as blue and green above the SSM</td>
</tr>
<tr>
<td>Grade 2</td>
<td>More red than blue and green above the SSM</td>
</tr>
</tbody>
</table>

**Fig. 7:** SE qualitative evaluation of the FD of the SSM.

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Fig. 8: SE evaluation of the SS MA. SE helps to delineate the SSM from the fat tissue.

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Fig. 9: Fusion US/MRI image with sonoelastography performed in the oblique sagittal slice through the supraspinatus muscle.

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Results

For SSM atrophy US SE had a positive correlation (r = 0.829, p <=0.001), without SE (r = 0.679, p <=0.05) with reference to MRI.

For FD grades US SE also had a positive correlation (r = 0.873, p <=0.001), US alone (r = 0.713, p <=0.05) with reference to MRI.

Conventional grey scale US could not clearly differentiate muscle from the fat in 6 cases of 9 partial tears, because the echogenicity was equal. US SE improved the diagnosis of fatty degeneration and atrophy in comparison to US alone. SE helps to delineate the SSM from the fatty tissue. Fatty tissue coloured red, yellow and green (low stiffness areas) in comparison to the muscle (high stiffness object), which coloured blue Fig. 10 on page 16

#SE was more sensitive in RC full tears than in partial RC tears. #We had 100% sensitivity for prediction of SS MA and FD in full thickness tears and only 66% of sensitivity in partial RCTs. SE provided more accurate measurements of occupational ratio of SSM atrophy by highlighting area of FD Fig. 11 on page 16

We also had limitations of the study:

#SE is a subjective modality and strongly depends on the quality factor and expirience of the examiner. We had "almost perfect interobserver agreement" of SE data with a kappa value of 0.83 (for all pathology). This agreement turned to "substantial", 0.66 only for partial tears.

#Limited FOV during SE study could not sometimes carefully occupy the whole SSM with fatty tissue for comparance. There was difficulty in estimation caused by the posterior acoustic shadowing of the superior border and the spine of the scapula. We had an artifact of the region close to the scapula, which decreased the measurement of the real size of the muscle Fig. 12 on page 17

Fusion US/MRI helped to overcome this limitations of US. A limited #eld of view of US was enlarged by adding Fusion with MRI, that allows an evaluation of the whole cross-sectional area of the region Fig. 13 on page 18 Therefore, the combination of evaluating the same structure with two imaging modalities simultaneously improves the understanding of anatomy and at the same time pathologic conditions.
We had a group of consecutive patients with different RC pathologies. We had a small number of patients with RCTs. The intraobserver reliability of SE was not investigated in this study.

SE was not sensitive in patients with increased body mass index that were excluded from the study.
**Fig. 10:** The case of a partial SS tendon tear. Comparance of MRI and US and US with SE data. MRI oblique sagittal T1-WI (left part of the image showed a moderate MA (R=0.56). The SSM is not clearly seen on the grey scale US (right part of the image), but with SE (in the middle) SSM accurately delineated by the green colored fatty tissue. Occupational ratio measured by US with SE was also 0.56.

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Fig. 11: The case of a full thickness SS tendon tear. Comparance of MRI and US and US with SE data. MRI oblique sagittal T1-WI (left part of the image showed a severe MA (R=0.34). The SSM is only partially seen on the grey scale US (right part of the image) due to a slight increase in echogenicity, but with SE (in the middle) SSM accurately delineated by the green colored fatty tissue. Occupational ratio measured by US with SE was 0.36.

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**Fig. 12:** The case of a partial thickness SS tendon tear. Comparison of MRI and US and US with SE data. MRI oblique sagittal T1-WI (left part of the image) showed a moderate MA (R=0.55). The SSM is partially seen on the grey scale US (middle part of the image) due to a slight increase in echogenicity (R=0.49), but with SE (in the right part of the image) SSM was delineated by the green and red colored fatty tissue, with an artifact appeared close to the scapula. Occupational ratio measured by US with SE was 0.35.

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**Fig. 13:** Fusion US/MRI of the oblique sagittal view of the supraspinatus muscle. US image was placed over the MRI image as a mask for better comparisons.

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Conclusion

US with SE had excellent interobserver reliability and better correlation with MRI findings than conventional ultrasonography for SSM atrophy and FD.

Fusion technology improves understanding of shoulders anatomy enlarges the FOV of US image, thus providing more accurate measurements and could be helpful in the follow-up tool for shoulder injuries.
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