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Magnetic resonance rotator cuff fat fraction and its relationship with tendon tear severity and subject characteristics

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Background: Compared with the Goutallier classification, chemical shift-based magnetic resonance (MR) fat quantification has superior reliability and accuracy in evaluation of muscle fatty infiltration. We used this method to assess the relationship between rotator cuff (RC) muscle fat fractions, tendon disease severity, and subject characteristics.

Methods: In total, 182 subjects with shoulder symptoms underwent shoulder MR imaging including additional sequences for fat quantitation. Then, fat fraction maps were manually segmented, and custom software was used to compute the fat fraction. Goutallier scores were also obtained. The relationship between fat fraction and tendon tear severity and subject characteristics was assessed with descriptive statistics, analysis of variance, Student *t* test of different subgroups, and simple and multiple linear regression analysis.

Results: Statistically higher supraspinatus fat fractions were observed in subgroups with tendon tears >3 cm, retraction >1 cm, age >50 years, body mass index (BMI) >30, higher Goutallier score, female gender, and longer symptom duration. A significant linear relationship was seen between RC fat fraction and tendon disease severity, age, and BMI but not symptom duration. Multiple regression models with fat fraction and tendon disease, age, BMI, and gender were significant for all 4 muscles ($P < .001$). The slope of fatty infiltration increase with age was reduced after adjustment for tendon disease, BMI, and gender.

Conclusion: RC fat fraction assessed by chemical shift MR demonstrated a significant linear relationship with tendon tear severity, age, BMI, and gender but not with symptom duration.

Level of evidence: Level III, Diagnostic Study.

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Keywords: Rotator cuff tear; tear size; fatty infiltration; muscle degeneration; MRI evaluation

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Rotator cuff (RC) muscle fatty infiltration is a degenerative change that has been reported to have strong correlation with increasing RC tendon tear size, chronicity, neuropathy, and age of the subject.[4,9,31,41] Fatty infiltration is a significant factor to consider in deciding on management of RC tears as it has been associated with a higher rate of postsurgical failure.[12,15,39,40]

A significant challenge lies in the reliability and accuracy of current methods of evaluation. The current ''gold standard'' in evaluation of muscle fatty infiltration is the Goutallier classification, a semiquantitative 5-point scale subjective evaluation using computed tomography or magnetic resonance imaging (MRI).[10,14] However, the interobserver reliability has been reported to be in the low to moderate range.[28,38,45,46,48] The output range of the 5-point ordinal classification is limited in the ability to discriminate between mild differences within or between the subjects. In the last few decades, there have been vigorous efforts to improve methods of assessment of fatty infiltration. These include more qualitative techniques based on T1-weighted MRI, T2-weighted MRI, frequency-selective MRI, and quantitative approaches such as single-voxel spectroscopy and chemical shift imaging.[3,13,27,41,43,49] Recently, a chemical shift-based water-fat separation technique that accounts for different confounding factors, using the 6-point Dixon technique, based on the iterative decomposition of water and fat with echo asymmetry and least squares estimation (IDEAL),[42] has been used to quantify fat in soft tissue. IDEAL has been shown to accurately and reliably quantify intramuscular fat content in vitro and in vivo, and it has been validated by chemical and histologic analysis.[16,17,20] IDEAL has also been applied to the shoulder and has been shown to be highly reproducible and clinically feasible. In addition, it demonstrated a better correlation with clinical parameters such as shoulder pain and range of motion compared with the Goutallier classification.[37] Furthermore, compared with most other imaging techniques, IDEAL provides a fat fraction map with high spatial resolution.[18]

Previous studies have reported factors that can influence fat fraction, which included age, tear size, retraction, and number of tendons involved. However, those studies have been limited by the methods used to evaluate fatty infiltration. These include either Goutallier classification or magnetic resonance (MR) quantification methods that have not been tested as extensively for accuracy and may involve techniques that are difficult to apply widely.[41]

Accurate fat quantification would help better define the relationship with other subject factors and may help us identify those who will benefit from surgical repair with greater sophistication. Our goal in this study was therefore to use the novel, widely clinically applicable IDEAL chemical shift-based MRI technique to evaluate the association between RC fat fraction and severity of tendon disease along with pertinent subject characteristics.

Materials and methods

From June 2011 to December 2013, the IDEAL sequence was added to routine noncontrast shoulder MR studies for 207 subjects who visited our tertiary orthopedic surgery center with shoulder complaints. Inclusion criteria were subjects with (1) age older than 16 years; (2) noncontrast MR examination of the shoulder with IDEAL fat fraction map; (3) acquisition of fat fraction map with >3 slices medial to the scapular Y view; and (4) sagittal proton density imaging including Y view, allowing optimal Goutallier classification grading. Exclusion criteria were (1) previous shoulder surgery (n = 12); (2) other radiographic findings that suggested the symptom to be related to a cause other than RC disease, such as fracture (n = 4), avascular necrosis (n = 1), or infection (n = 1); and (3) MRI examination inadequate for analysis, such as inadequate field of view coverage (n = 6) or suboptimal quality due to motion (n = 1). In total, 182 subjects were included. The study was approved by the Institutional Review Board and conducted in accordance with their guidelines.

MRI protocol

Shoulder MRI examinations were performed on a 3.0T scanner (MR750; GE Healthcare, Milwaukee, WI, USA) using an 8-channel shoulder surface coil (Clinical MR Solutions, Brookfield, WI, USA). The MRI protocol included an intermediate-weighted fat-suppressed fast spin-echo (FSE) sequence in an oblique coronal, oblique sagittal, and axial plane; a T1-weighted FSE sequence in a coronal and sagittal plane; and a proton density-weighted FSE sequence in a sagittal plane without fat saturation as detailed in Table I. In addition, IDEAL was used with a 3D fast gradient-echo pulse sequence and 6 echoes for chemical shift-based water-fat separation as previously presented in the shoulder.[37] A small flip angle was used to reduce the T1 bias effect. The IDEAL reconstruction was performed online and produced water-only, fat-only, in-phase (water and fat), and out-of-phase (water minus fat) images and fat fraction maps. All sequences were acquired with a sagittal oblique orientation, a slice thickness of 4 mm, and a field of view of 12 cm for a final in-plane spatial resolution of 0.468 × 0.468 mm. Each voxel of the fat fraction map represented the percentage ratio of the fat proton density-weighted signal to the sum of the water and fat proton density-weighted signals and reflected the percentage of fat.

Image analysis

Quantitative grading of the fatty infiltration in the RC muscles

Following the fat fraction quantification protocol, manual segmentation of each RC muscle was performed using in-house MATLAB software (MathWorks, Inc., Natick, MA, USA) (Fig. 1).[37] A total of 4 slices were segmented for each subject, beginning with the most lateral scapular Y view image in the sagittal oblique plane, the adjacent medial slice, and the next 2 consecutive lateral slices. The boundaries of the region of interest were placed within each muscle and <2 mm from the muscle fascia. The caudal part of the subscapularis muscle that was

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