

Quantitative evaluation of fat infiltration in the rotator cuff muscles using chemical shift-based water/fat separation

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Introduction: The assessment of the degree of muscular fat infiltration is critical for rotator cuff pathology since it is correlated with the patient outcome after treatment [1]. Goutallier's classification of T₁-weighted or proton density-weighted images is a well-established grading scale for evaluating the fat within the muscles [2]. However, it is a semi-quantitative grading system and therefore depends on the individual assessment of the radiologist. Recently, chemical shift based water/fat separation MRI techniques (such as Dixon and IDEAL) [3,4] have been used to assess the fatty infiltration within muscles in a quantitative way [5,6]. A fast, reproducible, quantitative technique would be advantageous to overcome the subjectivity introduced by the semi-quantitative Goutallier grading. Therefore, the goals of the present study are to show the feasibility of characterizing the fat infiltration of rotator cuff muscles using chemical shift-based water/fat separation, to establish the reproducibility of the mean fat fraction measurement within the shoulder muscles and to compare the fat fraction results with the semi-quantitative Goutallier's classification.

Methods: The shoulder joint of 31 subjects was scanned in a 3.0 T MR scanner (MR750; GE Healthcare, Milwaukee, WI) using an 8-channel shoulder surface coil (GE Healthcare, Milwaukee, WI). Six subjects were also scanned for a second time on the same day to address the reproducibility of the mean fat fraction measurement. MRI sequence selection included a sagittal oblique T₁-weighted FSE and a sagittal oblique proton density (PD) weighted FSE. An investigational version of a 6-point 3D multi-echo spoiled gradient gradient (SPGR) echo sequence was used to measure fat content (TR/TE/ΔTE=10.8/1.97/0.97 ms, ETL=2, bandwidth=62.5 kHz, 128x128 matrix size. A 3° flip angle was used to minimize T₁ bias in the fat fraction [6,7]. The same volume coverage with a slice thickness of 4 mm and a field of view (FOV) of 12 cm was maintained for both the 2D FSE and the 3D SPGR sequences. The computation of fat fraction was based on the IDEAL algorithm with multi-peak spectral modeling of fat and single T₂* correction [8], using the precalibrated fat spectrum as in [9] and the magnitude discrimination approach to remove noise-induced bias at low fat fractions [7].

For the image analysis, the most lateral slice where the shoulder Y was completely shown was defined as a reference slice. The reference slice plus one slice medial to the reference slice plus two slices lateral to the reference slice, resulting in a total of 4 slices, were segmented. The computed fat fraction maps were manually segmented on the above 4 slices to define 4 different rotator cuff muscles: infraspinatus, supraspinatus, teres minor and subscapularis muscles (Fig. 1). Each rotator cuff muscle was graded using Goutallier's classification: (grade 0) normal muscle, (grade 1) muscle with some fatty streaks, (grade 2) less fat than muscle, (grade 3) as much fat as muscle and (grade 4) more fat than muscle. A correlation analysis was performed between the mean fat fraction values and the Goutallier grades of the 4 muscles of all the 31 scanned subjects. To assess the reproducibility of IDEAL, the absolute precision error was calculated over the 4 muscles of the 6 subjects that were scanned twice.

Results & Discussion: Fig. 2 shows representative proton density-weighted images of the shoulder with different Goutallier scales of the supraspinatus muscle. The group results showed mean fat content values ranging from 0-5.5%, 4-7.7%, 6.3-12.5%, 15.3-17.5 and 18.3-27.3% for Goutallier grades 0, 1, 2, 3, 4, respectively. Pearson's correlation coefficient was calculated to compare IDEAL fat fraction values to Goutallier score ($r>0.9$; $p<0.001$). For the reproducibility of the mean fat fraction measurement over four muscles the absolute precision errors ranged between fat fractions of 0.6% and 1.0%.

The group comparison results show that there is a significant correlation between the mean fat fraction calculated using chemical shift based water/fat separation and the Goutallier classification scale. However, the mean fat fractions calculated were much lower than the muscle fat description of the corresponding clinical Goutallier grades. A possible explanation for the observed overestimation of fat content using the clinical grading is the spatial heterogeneity of the muscle fat infiltration. The clinical grading based on the visual assessment of the PD-weighted images cannot differentiate a voxel with intermediate fat fraction from a voxel with high fat fraction. For example, a Goutallier scale 3 would characterize the fat infiltration in a muscle where there is as much fat as muscle visible on the PD-weighted image. However, the present results show that the mean fat fraction value for the muscle with Goutallier scale 3 would be much lower than 50%.

Conclusion: Clinical semi-quantitative grading of fat infiltration using the Goutallier classification and quantitative fat-fraction values derived using chemical shift-based water/fat separation were strongly correlated. In addition chemical shift-based water/fat separation permitted a quantitative and well-reproducible measurement of fatty infiltration within the rotator cuff muscles, which can be used as a more objective and reliable criterion in the decision-making process by orthopedic surgeons.

References: [1] Cheung et al., *Arthroscopy* 27: 463, 2011, [2] Fuchs et al., *J Shoulder Elbow Surg.* 8:599, 1999, [3] Dixon et al., *Radiology* 153:189, 1984, [4] Reeder et al., *MRM* 54:636, 2005, [5] Gaeta et al., *Radiology* 259:487, 2011, [6] Karampinos et al., *Magn Reson Med* 66:1312, 2011, [7] Liu et al., *MRM* 58:354, 2007, [8] Yu et al., *MRM* 60:1122, 2008, [9] Middleton et al., *ISMRM* 2009, p. 4331.

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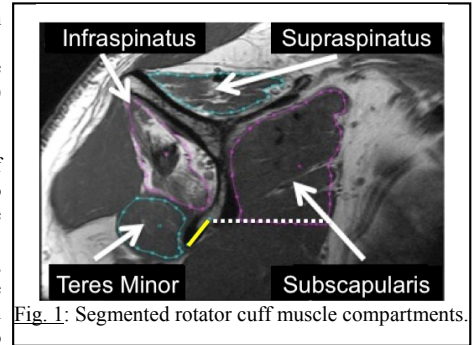


Fig. 1: Segmented rotator cuff muscle compartments.

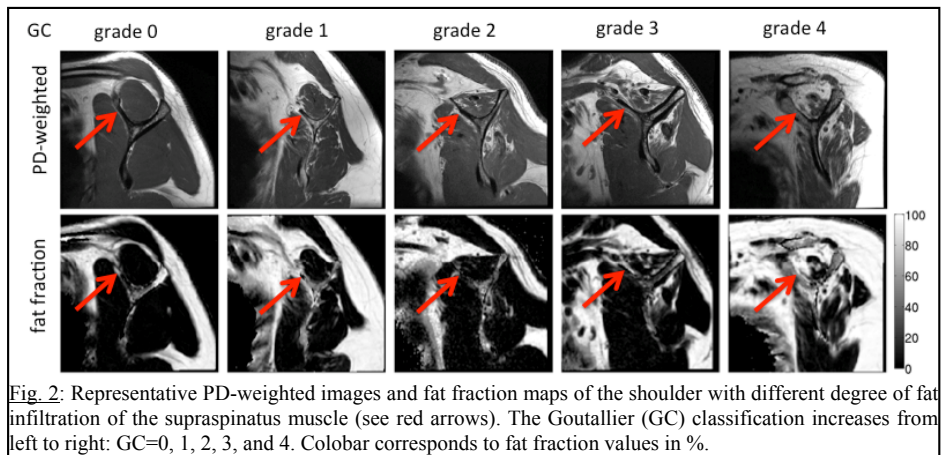


Fig. 2: Representative PD-weighted images and fat fraction maps of the shoulder with different degree of fat infiltration of the supraspinatus muscle (see red arrows). The Goutallier (GC) classification increases from left to right: GC=0, 1, 2, 3, and 4. Colobar corresponds to fat fraction values in %.

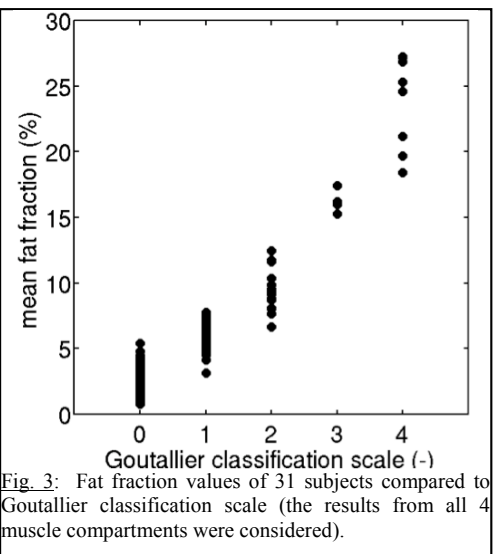


Fig. 3: Fat fraction values of 31 subjects compared to Goutallier classification scale (the results from all 4 muscle compartments were considered).