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Quantitative Assessment of Fat Infiltration in the Rotator Cuff Muscles using water-fat MRI

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Abstract

Purpose—To evaluate a chemical shift-based fat quantification technique in the rotator cuff muscles in comparison with the semi-quantitative Goutallier fat infiltration classification (GC) and to assess their relationship with clinical parameters.

Materials and Methods—The shoulders of 57 patients were imaged using a 3T MR scanner. The rotator cuff muscles were assessed for fat infiltration using GC by two radiologists and an orthopedic surgeon. Sequences included oblique-sagittal T_1-, T_2- and proton density-weighted fast spin echo, and six-echo gradient echo. The iterative decomposition of water and fat with echo asymmetry and least-squares estimation (IDEAL) was used to measure fat fraction. Pain and range of motion of the shoulder were recorded.

Results—Fat fraction values were significantly correlated with GC grades (p< 0.0001, kappa>0.9) showing consistent increase with GC grades (grade=0, 0%–5.59%; grade=1, 1.1%–9.70%; grade=2, 6.44%–14.86%; grade=3, 15.25%–17.77%; grade=4, 19.85%–29.63%). A significant correlation between fat infiltration of the subscapularis muscle quantified with IDEAL versus a) deficit in internal rotation (Spearman Rank Correlation Coefficient=0.39, 95% CI 0.13–0.60, p<0.01) and b) pain (Spearman Rank Correlation coefficient=0.313, 95% CI 0.049–0.536, p=0.02) was found but was not seen between the clinical parameters and GC grades. Additionally, only quantitative fat infiltration measures of the supraspinatus muscle were significantly correlated with a deficit in abduction (Spearman Rank Correlation Coefficient=0.45, 95% CI 0.20–0.60, p<0.01).

Conclusion—We concluded that an accurate and highly reproducible fat quantification in the rotator cuff muscles using water-fat MRI techniques is possible and significantly correlates with shoulder pain and range of motion.

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INTRODUCTION

The relationship between fatty infiltration of the rotator cuff (RC) muscles and a rotator cuff tear has been previously documented (1–4). The natural history of fatty infiltration has been described as an irreversible process that is often progressive. It has been recommended that surgical repair of the rotator cuff tear should be performed prior to advanced fatty infiltration. The amount of fatty infiltration of the rotator cuff muscle is one of the main factors in the clinical decision making in the management of patients with RC tear (5,6). High grades of fatty infiltration are associated with higher rates of repair failure and more limitations in the achievable outcome in the post-operative period (6). Thus, an accurate determination of fatty infiltration in the rotator cuff muscles is of high clinical significance.

Both computed tomography (CT) and magnetic resonance imaging (MRI) have shown capability to detect fatty infiltration within the RC muscles. For the assessment of fatty infiltration, CT and MRI-based classifications have been established by Goutallier et al. (7) and by Fuchs et al. (8,9) respectively. These classifications have become widely used in the orthopaedic literature and have been accepted as a standard five-grade scoring system for muscle fatty infiltration of the RC. The limited soft tissue contrast and high exposure of ionizing radiation are substantial drawbacks of CT, which have led to adoption of MRI as the preferred modality for the assessment of fatty infiltration. Although the Goutallier grading has been widely used, multiple previous studies have shown that this system is highly observer-dependent (10,11). Given the significant implications of the grade of fatty infiltration on treatment recommendations, there is a need for a reliable and reproducible method for quantitative fat content measurements.

Imaging-based fat quantification has been performed in different skeletal muscles using multiple different techniques, including fat selective imaging (12) and T2-based water-fat separation (13). Previous fat quantification approaches applied in the rotator cuff muscles included single-voxel MR spectroscopy (14), spectroscopic gradient echo imaging (15) and two-point Dixon imaging (16). The development of new water-fat imaging techniques enabling the generation of accurate quantitative fat-fraction maps (17), makes MRI even more appealing for the assessment of RC in comparison to semi-quantitative Goutallier scores, which are based on the subjective evaluation of the readers (18). In this study, a chemical shift-based water-fat separation technique, accounting for different confounding factors, based on the iterative decomposition of water and fat with echo asymmetry and least-squares estimation (IDEAL (19,20)) was used to quantify fatty infiltration in the RC muscles. The purpose of this study was threefold: (i) to show the feasibility of applying water-fat imaging for fat quantification of the rotator cuff muscles and assess its inter-observer reproducibility, (ii) to compare the previously used semi-quantitative fat infiltration Goutallier's classification (GC) of RC muscles with a MRI-based fat quantification technique (IDEAL), and (iii) to compare GC grades and IDEAL-based fat fraction values in predicting functional measurements of shoulder range of motion and pain.

MATERIALS AND METHODS

Patients and clinical evaluation

The shoulders of 57 patients (31 men, 26 women; mean 52.44 years; range 17–76 years) with symptoms of rotator cuff tears were imaged using MRI. Previous shoulder surgery and MRI contraindication were criteria for exclusion. The study was approved by the Institutional Review Board and conducted in accordance with the Committee for Human Research. All subjects gave written informed consent prior to participation in the study.

Clinical exam notes from all patients were reviewed. The clinic visit closest and prior to the imaging study date was chosen for review. All range of motion and strength testing was performed by one of three senior orthopedic surgeons with fellowship training in Sports Medicine and Shoulder Surgery. Four patients were not tested due to a recent dislocation. Each patient was asked to report a pain level with a numeric value from 0 to 10, with 10 being the worst pain according to the Visual Analog Scale (VAS) (21). Range of motion was measured for forward flexion, abduction, external rotation and internal rotation. External rotation was performed with the elbows flexed to 90 degrees and held at the side of the patient. Internal rotation was recorded as the most proximal vertebral level that the patient could reach. Strength was measured and recorded on a standard 0–5 scale (22,23) with full strength to resistance rated as 5, strength to some resistance as 4, anti-gravity strength as 3, full range of motion in a plane without gravity as 2, muscle contraction without range of motion as 1, and no strength as 0. The supraspinatus was tested as forward flexion in the scapular plane. Infraspinatus was measured as external rotation with the elbows flexed to 90 degrees and held at the side of the patient. Subscapularis was tested with the lift-off test.

MR imaging

Shoulder MRI examinations were performed on a 3.0-T scanner (MR750; GE Healthcare, Milwaukee, Wis) using an 8-channel shoulder surface coil (Clinical MR Solutions, Brookfield, Wis). In addition to the standard clinical MRI protocol, which included T_2-weighted fat-suppressed fast spin-echo (FSE) sequences, T_1-weighted FSE sequences and proton density (PD) FSE sequences, a 3D fast gradient echo pulse sequence with 6 echoes was used for chemical shift-based water fat separation. From the clinical protocol only the sagittal PD weighted sequence was used to semi-quantitatively score fat infiltration using GC. IDEAL was used to quantitatively measure the amount of fat in the muscle bulk. The clinical sagittal T2-weighted sequence had a marginal role and was only used to double-check the boundaries of the muscles for the segmentation. The total acquisition time for the clinical protocol was about 25 minutes, excluding the 3 minutes used to run the IDEAL sequence. The IDEAL algorithm (19,20,24) was employed with T2* correction and a multi-peak model for the fat spectrum (25). A hybrid (complex/magnitude)-based approach was used to correct for eddy current effects (26). A small flip angle was used to reduce the T1-bias effect (17,27). A six-echo acquisition was employed as reconstructions of six-echo data have been previously frequently used in single T_2*-corrected water-fat separation and have been shown to be not affected by the susceptibility induced fat resonance shift effect in skeletal muscle (28). 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, slice thickness of 4 mm, and a field of view (FOV) of 12 cm for a final in-plane spatial resolution of 0.468×0.468 mm (Table 1). The fat fraction map defined as the ratio of the fat proton density weighted signal to the sum of the water and fat proton density weighted signals reflected the percentage amount of fat in each voxel.

Image analysis

Semi-quantitative grading of the fatty infiltration in the RC muscles—Following the protocol described by Fuchs et al. (9,29) for MRI, we identified the most lateral sagittal-oblique slice where the acromion, coracoid and scapular body were all visible, together with the next two consecutive lateral slices and with the next consecutive medial slice. From these slices, the presence of fatty infiltration was graded according to a 5-point semi-quantitative scale described by Goutallier et al. (18,30) and shown in Figure 1: (grade 0) normal, (grade 1) some fatty streaks, (grade 2) less than 50% fatty muscle, (grade 3) as much fat as muscle and (grade 4) more fat than muscle. After a calibration session during which two radiologists (L.N., T.M.L.) and an orthopedic surgeon (D.L.) reviewed 20 studies, all MRI studies were interpreted by a board-certified radiologist and an orthopedic surgeon, independently, using the modified GC as proposed by Fuchs et al. (9). The two readers reviewed these twenty studies on two separate occasions separated by three weeks. A second radiologist (T.M.L., 25 years of experience) was consulted in case of disagreement; all images were reviewed on a picture archiving communication system workstation (Agfa, Ridgefield Park, NJ). Inter-reader agreement was assessed between two readers. Intra-reader agreement was assessed for each individual reader.

Quantitative grading of the fatty infiltration in the RC muscles—The segmentation of the RC muscles was performed by one radiologist (L.N.) and one orthopedic surgeon (D.L.) using proprietary software written in MATLAB (The Mathworks, Inc., Natick, MA). Inter-operator reproducibility of mean fat fraction values between both operators was assessed. To standardize segmentation the sagittal-oblique intermediate-weighted FSE sections were identified, where the scapular body, coracoid process, and acromion were all depicted and formed the "ScapularY". This section and the adjacent medial section as well as the next two consecutive lateral sections were used for muscle segmentation. The regions of interest (ROIs) for the 4 RC muscles (Supraspinatus, Infraspinatus, Subscapularis and Teres Minor) were defined so that the boundaries of the ROIs were within 1–2 mm from the muscle boundaries and the muscle fascia, as visually inspected on the T_2-weighted images. This was done to assure that fat regions in the periphery of the muscle compartments were excluded from the ROIs. The only exception was the subscapularis muscle: its caudal part was not included in the segmentation in order to avoid the inclusion of low-signal regions. The caudal boundary of this muscle was identified as a horizontal line passing through the "L" point (Figure 2). The "L" point was determined as the most anterior point of the scapula surface, 10 mm distant from the tip of the scapular. Mean intramuscular fat fraction values were computed in all ROIs based on the IDEAL-fat fraction maps. Total time to process an IDEAL sequence from its acquisition to obtain quantitative score was about 15 minutes per study, including 6–8 minutes for the segmentation.

Statistical analysis

Statistical analysis was performed using JMP software Version 7 (SAS Institute, Cary, NC) and SPSS Version 14 (IBM, Chicago, IL). Fisher's exact test was used to compare GC grades and IDEAL fat fraction values. Spearman rank correlation was used to compare GC grades and IDEAL fat fraction values to clinical variables. Inter-reader agreement was assessed using Cohen's kappa coefficient, while the absolute precision error was used to assess the reproducibility of mean fat fraction quantification based on the IDEAL fat fraction maps. The level of significance for all calculations was defined at $p < 0.05$.

RESULTS

Figure 2 demonstrates a sagittal proton density-weighted FSE image of the shoulder with the segmented ROIs of the rotator cuff muscles. Segmentation of all four RC muscles took between six and eight minutes, while GC assessment took approximately two minutes for each MRI study and all four muscles.

Comparison of GC grades and IDEAL fat fraction values

Significant differences of the mean fat fraction values between the individual Goutallier grades were found (p<0.001). The mean fat fraction and standard deviation values calculated for the RC muscles, as well as the corresponding clinical grade based on GC, are presented in Figure 3. The Goutallier grade was greater than 2 for 4 patients in the supraspinatus, 8 patients in the infraspinatus, 5 patients in the subscapularis, and 3 patients in the teres minor. The mean fat fraction values consistently increased with Goutallier grade: grade 0 ranged from 0% to 5.59%, grade 1 from 1.1% to 9.70%, grade 2 from 6.44% to 14.86%, grade 3 from 15.25% to 17.77%, and grade 4 from 19.85% to 29.63%. A significant correlation between the semi-quantitative clinical grading and IDEAL fat fraction values was found in all muscles. The mean fat fraction for grade 2 was significantly different from the mean fat fraction for grade 3 in all muscle compartments of the shoulder (p<0.01). A statistically significant difference was also found when comparing Goutallier grade less than 3 with grade 3 and higher (p<0.01). Both IDEAL and GC could significantly distinguish two groups of patients with fatty infiltration classified as GC 2 and GC >2 (Fisher's exact test and simple kappa tests both > 90%).

The mean IDEAL fat fraction values were significantly lower than the corresponding mean fat fractions commonly associated with each Goutallier grade (Figure 3). For example, eighteen muscles were graded as Goutallier grade 3 or 4 (which would be associated with a fatty infiltration above 50%), and none of them had an IDEAL fat content greater than 50%.

Relationship of GC grades and IDEAL fat fraction values with clinical variables

Table 2 summarizes the results of the comparison of GC grades and IDEAL fat fraction values with clinical variables. The observed correlations suggest that correlations with pain and clinical measurements for IDEAL are higher than those for the Goutallier classification: Spearman rank Correlation coefficients and p values showed a trend towards a stronger relationship between clinical scores and IDEAL fat fraction values yielding higher Spearman Rank Correlation coefficients.

The only statistically significant correlation of Visual Analog Scale pain assessment with fatty infiltration was observed in the subscapularis muscle, and only for the IDEAL fat fraction values (Spearman Rank correlation coefficient=0.313; p= 0.02).

Regarding the supraspinatus muscle, abduction strength was significantly correlated with high IDEAL fat fraction values (Spearman Rank Correlation coeffient=0.45; p< 0.01) but not with Goutallier scores (p=0.12). However, forward flexion strength was not statistically significantly correlated with either Goutallier score (p=0.82) or IDEAL fat fraction values (p=0.14). In the subscapularis muscle semi-quantitative internal rotation muscle strength grading was significantly correlated with both Goutallier score (Spearman Rank Correlation Coefficient=0.30, p=0.04) and IDEAL fat fraction values (Spearman Rank Coefficient: 0.39; p<0.01). In the infraspinatus muscle external rotation strength was statistically significantly correlated with both Goutallier score (SRC=0.37, p<0.01) and IDEAL fat fraction values (SR: 0.37; p<0.01).

B$_0$ Fieldmaps and T2* Relaxation

Figure 4 demonstrates reconstructed IDEAL images of a subject with GC of 3 at the subscapularis. Shown are the water only images, the fat only images, the B$_0$ fieldmaps and the R2* relaxation maps. The mean off-resonances in the muscle regions were -19.5 ± -5.5 Hz. The R2* maps revealed a mean of 44 ± 14 [1/s]. This corresponds to a T2* mean value of 22ms.

Reproducibility Analyses

As shown in Table 3, comparing the readings of D.L. and L.N., a Cohen's kappa value for inter-observer agreement on presence/absence of fatty infiltration of 0.84 was calculated. The Cohen's kappa values for intra-observer agreement were 0.90 for D.L. and 0.92 for L.N. These values correspond with good reader agreement.

The absolute precision errors for inter-user reproducibility of intramuscular fat quantification based on ROIs generated by manual segmentation of the RC muscles ranged between fat fractions of 0.6% and 1.0% with 0.60%, 0.65%, 0.87% and 1.0% for supraspinatus, infraspinatus, subscapularis, and teres minor, respectively considering all muscles separately.

DISCUSSION

In this study, semi-quantitative fat infiltration based on GC was compared with an MR-based fat quantification approach using the IDEAL water-fat separation technique. To this end, muscle regions of interests were defined using anatomical landmarks. Intra- and inter-reader reproducibility of GC, inter-user reproducibility of IDEAL fat quantification, and correlation of both techniques with clinical parameters were investigated. A high correlation between GC and the IDEAL based fat quantification was found. Furthermore, good levels of intra- and inter-reader agreement for GC, good inter-user reproducibility for the IDEAL-based technique, and correlation of both techniques with clinical parameters were found. However, IDEAL fat quantification showed higher and more consistent correlation coefficients with clinical parameters compared to those found for GC grades.

The accuracy of IDEAL fat quantification has previously been validated by Hines et al. (31) in the liver of obese mice. The authors found high correlation between IDEAL imaging and lipid extraction, and quantitative histologic analysis. The authors concluded, that IDEAL can be used to accurately quantify fat in vivo and that correction for T2* decay and accurate spectral modeling are essential for accurate fat quantification in the liver. In another recent study, Hu et al. (32) investigated the accuracy of IDEAL-based fat mass measurement using chemical analysis as the reference standard and found a high correlation between MR fat mass quantification and chemical analysis in samples from different organs. The present study attempted to quantify the amount of fatty infiltration in the RC muscles of patients with a novel water-fat MRI technique. Different approaches such as CT, MRI, and proton MR spectroscopy have been used in the past for fat quantification within the muscle (14). Proton MR spectroscopy resulted in a reliable quantification of fat compared to biochemical measures (33) but does not allow spatially resolved measures. Chemical shift-based water-fat separation pulse sequences accounting for different confounding factors have shown to be accurate, reproducible, and fast (34). They also offer the unique advantage of spatially distributed information of the fat content. The fat content is determined as a ratio of signals and therefore independent of the receive coil profile effects, which are prominent while imaging the shoulder using surface coils (9). For all the above reasons, a chemical shift-based water-fat separation technique was selected amongst the other techniques for this study.

Fatty infiltration and atrophy in the RC muscles have been shown to be negative prognostic factors for successful outcomes following rotator cuff repairs (35–40). Radiographic grading systems as proposed by Goutallier et al (37) and Fuchs et al (35) assess fatty degeneration in a semi-quantitative and subjective manner with poor reproducibility as previously reported (41). Nevertheless, outcomes of RC repair are dependent on the Goutallier grade of the RC muscles. Using an optimized IDEAL computerized quantification approach, fatty infiltration could be determined in each RC muscle in an objective and reproducible way. The IDEAL-based fat content range that corresponded to the clinical Goutallier grade was determined. Surprisingly, the percentage of fat within the RC muscles was very different compared to the original GCs. Grades 3 and 4, according to GC, should correspond to more than 50% fat content in the muscle. However, the range of IDEAL fat content within the muscle was 15.25% to 17.77% for grade 3, and 19.85% to 29.63% for grade 4. One possible explanation for the overestimation of the fat content using GC is the heterogeneity of the tissues within the muscle (vessels, connective tissue, fat) which cannot be appreciated using a FSE intermediate-weighted sequence and may result in a signal intensity similar to fat. Furthermore small differences of the fat fraction within a single voxel are difficult to detect using an intermediate-weighted sequence and may cause misinterpretation of the findings. For instance, GC grading of Proton density weighted images cannot differentiate a voxel with intermediate fat fraction from a voxel with high fat fraction. Therefore, using GC, the reader would usually assign individual voxels either to fat or to muscle depending on its signal intensity, whereas IDEAL quantification is a continuous variable that provides an exact number for each voxel between 0 (no fat) and 100 (only fat). This approach allows a wider range of values to characterize and quantify more precisely the fat infiltration with high spatial resolution within the muscle. Further studies based on clinical outcome may redraw the limits for different degrees of fat infiltration.

Goutallier grade 2 is considered a transition point from normal to pathologic fatty infiltration. A GC higher than two is commonly considered a negative prognostic factor and a relative contraindication for surgical repair of a rotator cuff tear (5,42). In our work we used a regression model to analyze the difference in mean fat fraction between Goutallier grade 2 and grade 3. The mean fat fraction in grade 2 was significantly different from grade 3 in all muscle compartments of the shoulder and both IDEAL and GC could distinguish these two groups.

To the best of our knowledge our study is the first that used quantitative chemical shift based water-fat imaging to combine quantitative MR imaging strategies and clinical data. It is also the first study that applies advanced IDEAL fat quantification MRI to the shoulder. Compared to GC, IDEAL showed a trend towards a stronger relationship with clinical data. Previous studies have not found any correlation between RC tear and symptoms and have demonstrated that the physical examination had low sensitivity and specificity for detecting tears (43). However, none of these publications correlated the fatty infiltration with the symptoms. The limited range of motion or strength may depend on the substitution of the fat within the muscle, which, in turn may result in less elasticity of the muscle limiting the motion of the articulation itself. It is important to develop an objective measure of fatty infiltration to aid clinical decision-making. While it has been shown that a high grade of fatty infiltration is a negative prognostic factor for surgical repair, the current GC grading system is a qualitative assessment with large variability and poor reliability: Slabaugh et al. (41) reported an inter-reproducibility for Goutallier score below 60% and Oh et al. (44) reported a very wide range of reproducibility with a Cohen's kappa value ranging from 26% to 81%. The quantitative scoring system we are proposing has values of absolute precision errors for inter-user reproducibility ranging between fat fractions of 0.6% and 1.0%. Given the strong importance of the fat infiltration on the decision making process for or against intervention and the prognosis of rotator cuff tears, a test with high reproducibility should be

considered. Our methods described here provide an objective measure of fatty infiltration, which allows following muscle deterioration longitudinally and also possible recovery following successful surgical repair. We are currently following patients longitudinally after non-operative and operative repair of rotator cuff injuries. A quantitative approach will allow us to better stratify injuries and predict success of treatment.

The additional scan time needed for performing the 3D 6-echo gradient-echo sequence with the present resolution and without parallel imaging is of the order of 3 minutes. The resolution of the quantitative sequence could be potentially further reduced or parallel imaging could be used to reach scan times between 1 and 2 minutes, to increase time efficiency for wide spread use in clinical setting. This study is not without limitations. First, the number of subjects with high-grade fatty infiltration (Goutallier classification >2) was small. This bias towards patients with less fatty infiltration is likely responsible for the wider distribution of fatty infiltration values with higher GC scores. A second limitation was the lack of a histological proof regarding fatty infiltration in the muscle of the shoulder. Previous animal studies have demonstrated a strong correlation. Hence, there is little to suggest that the same would not be true with regards to the shoulder musculature. Moreover, examining at a single time-point may limit the conclusions we can draw from the clinical data. Furthermore, the calibration session before the independent reading of the study for fat infiltration may have inflated the inter-reproducibility of Goutallier Classification and might have rendered the difference between the subjective Goutallier Classification and the objective IDEAL fat quantification less appreciable.

In conclusion our work demonstrated that IDEAL-based fat quantification can be used as a reproducible and objective assessment tool for the fatty infiltration within the muscles of the RC, providing a continuous variable for characterizing fat content. This improved method of evaluating fatty infiltration will allow for further studies on the effects of treatment on altering the progression of this pathologic change. The IDEAL-based fat quantification methodology as outlined here has the potential to become an important clinical resource in evaluating the muscles of the rotator cuff and objectively monitoring fatty infiltration changes over time. Furthermore, IDEAL-based fat quantification correlated with strength and range of motion of the shoulder muscles and may be superior to standard GC measurements. Further data collection to compare the performance of IDEAL-based fat quantitation to GC grading as a predictor of surgical outcome is needed to assess the full potential value of the technique.

Acknowledgments

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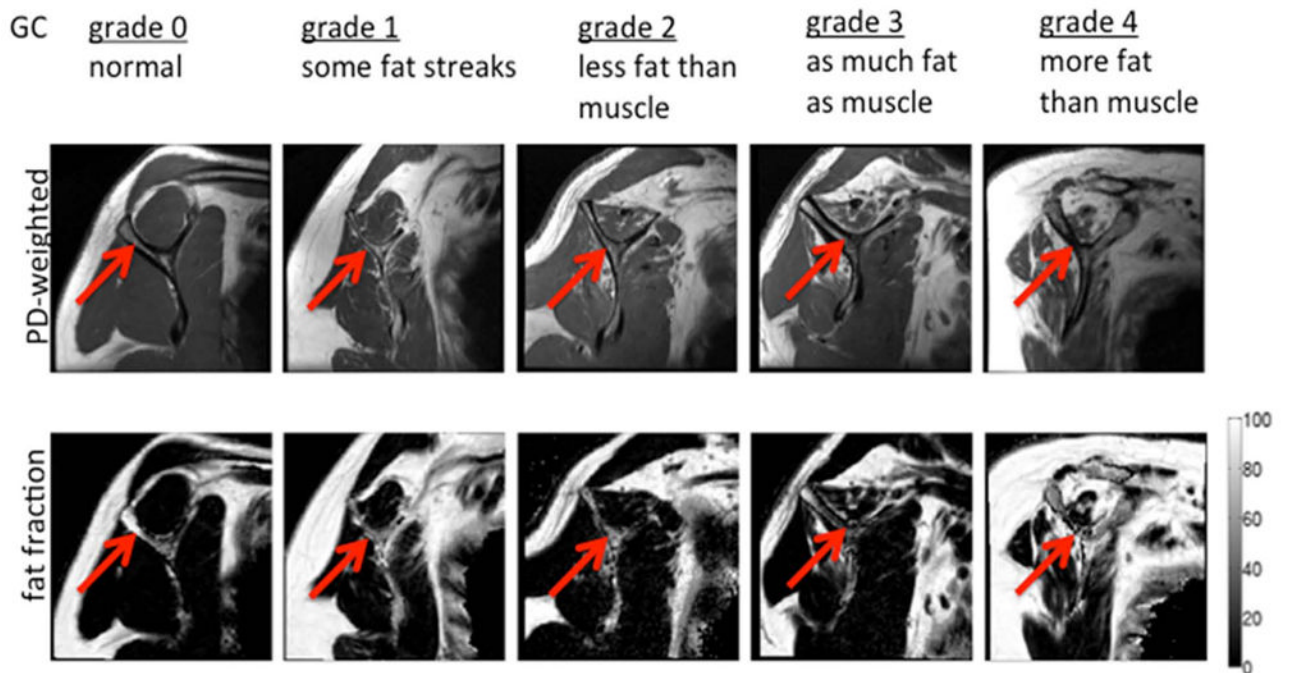
Figure 1.
Representative proton density-weighted images and fat fraction maps for different degrees of fat infiltration of the supraspinatus muscle using the GC scale. The images were obtained in the sagittal-oblique plane. Gray scale bar corresponds to fat fraction values (in %).
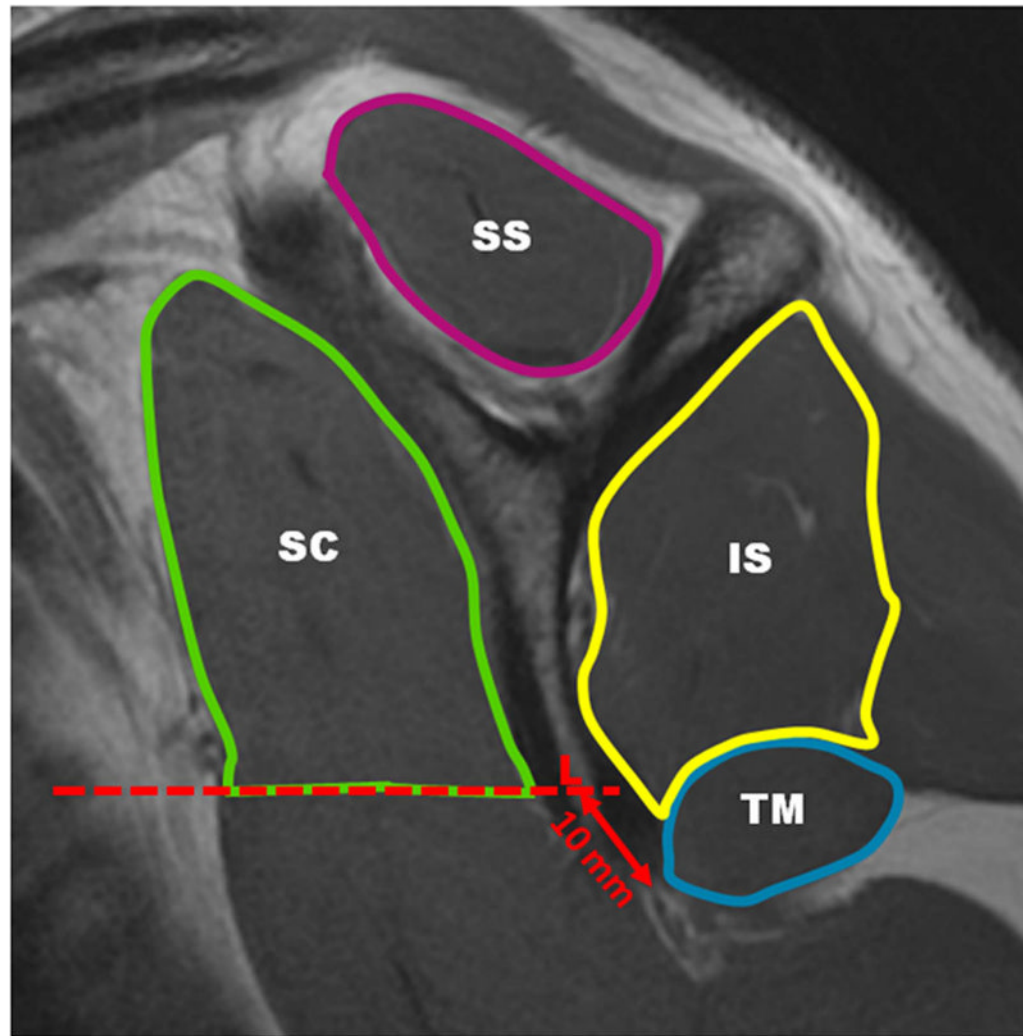
Figure 2.
Muscle regions on an proton density-weighted image, sagittal-oblique plane.
IS= infraspinatus; SC= subscapularis (caudal boundary drawn using horizontal line passing through L point); SS= supraspinatus; TM= teres minor
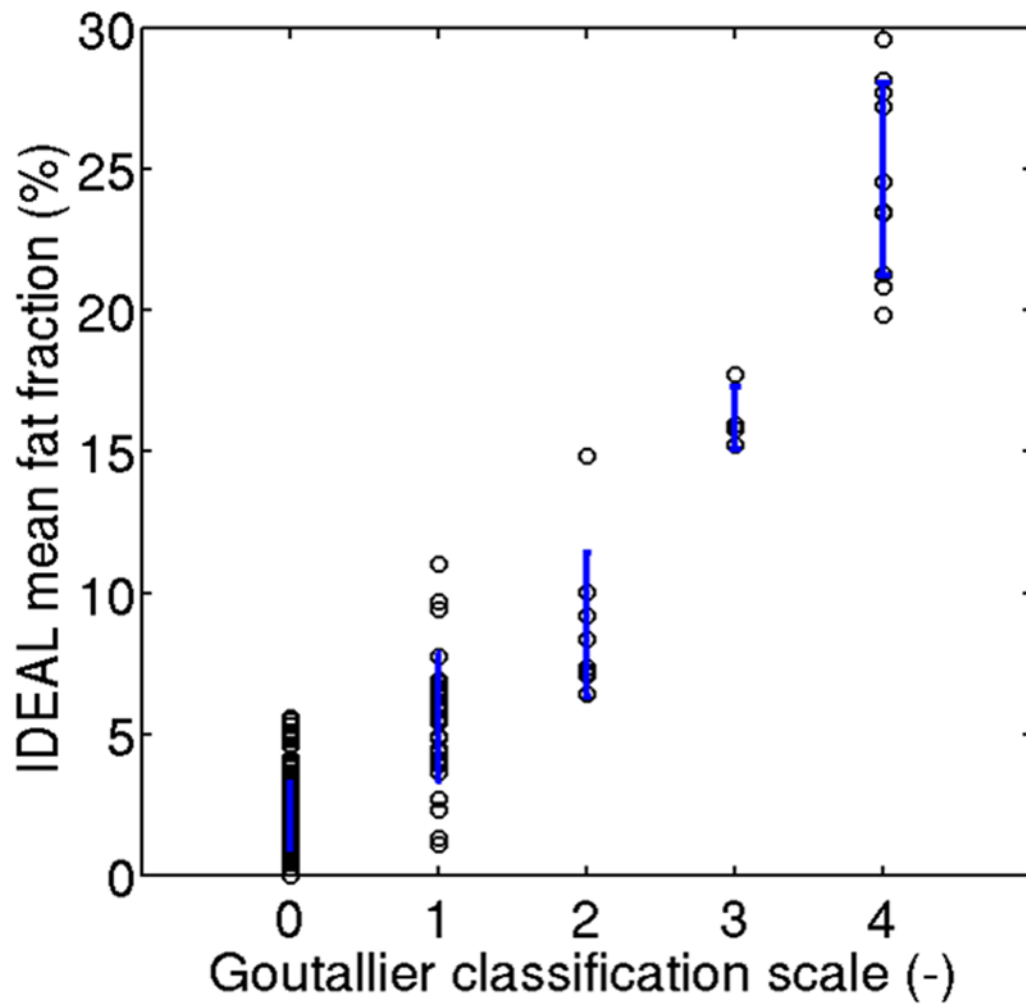
Figure 3.
Comparison of computerized fat fraction metrics with Goutallier grade in all four muscle compartments. The vertical lines represent the standard deviation values for the computerized fat fraction metrics at every Goutallier grade.
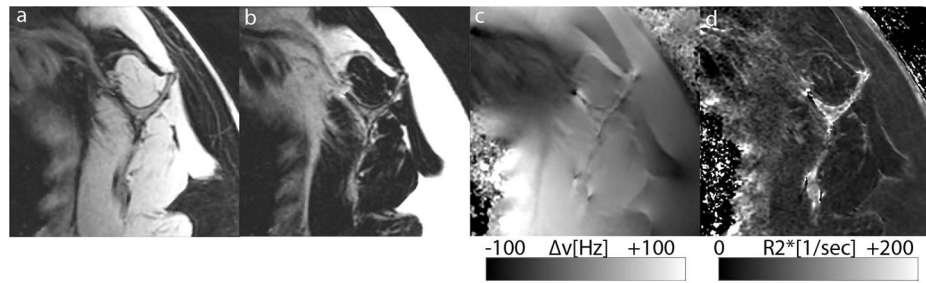
Figure 4.
Examples of IDEAL reconstructed water only (Figure 4a) and fat only (Figure 4b) images are shown. Furthermore the B_0 fieldmaps are presented demonstrating the off-resonance distribution in the regions of interest (Figure 4c). Finally, Figure 4d depicts the R2* relaxation map of the same subject.

Table 1

Parameters of oblique sagittal proton density 2D FSE and oblique sagittal 3D SPGR MRI sequences

Imaging Sequence	Relevant Acquisition Parameters	Resolution (mm³)	Purpose
Oblique sagittal proton density 2D FSE	TR/TE = 2200/25 ms, rBW = 62.5 kHz, ETL = 10, NEX = 4 FOV = 12 cm AT= 3 min	0.23×0.23×4	Goutallier classification
Oblique sagittal 3D SPGR	6 points, ETL = 2, TE/ΔTE = 2.1/1.0 ms TR = 10.8 ms, flip angle = 3° rBW = 62.5 kHz, NEX = 1 FOV=12 AT= 3 min	0.46×0.46×4	Fat quantification

TR= relaxation time; TE= echo time; FOV= Field of View; ETL= echo train length; rBW= receiver bandwidth; NEX= number of excitations; AT= acquisition time

Table 2

Spearman rank correlation coefficients of fat infiltration metrics (computerized IDEAL-based quantitative fat fraction and Goutallier grade) compared with clinical data.

Muscles	Spearman Rank Correlation quantitative	Spearman Rank Correlation Goutallier	Spearman p-values quantitative	Spearman p-values Goutallier
IS Variables				
Pain	0.119	0.087	0.3910	0.5336
ER	0.368	0.370	**0.0067**[*]	**0.0064**[*]
SC Variables				
Pain	0.313	0.193	**0.0214**[*]	0.1625
IR	0.39	0.30	**0.0051**[*]	**0.0357**[*]
SS Variables				
Pain	0.128	0.012	0.3557	0.9318
FF	0.206	0.032	0.1382	0.8215
Ab	0.448	0.223	**0.0011**[*]	0.1201

IR= intra-rotation; ER= extra-rotation; Ab= Abduction; FF= forward flexion; IS= infraspinatus; SC= subscapularis; SS= supraspinatus

[*] statistically significant p-value

Table 3

Cohen's Kappa values for the clinical GC reading for both inter- and intra reproducibility are presented separately for each muscle and for the four muscle compartments together.

	SS	IS	SC	TM	All muscles
Intra-reproducibility LN	0.96	0.84	0.92	0.96	0.92
Intra-reproducibility DL	0.85	0.87	0.82	0.96	0.90
Inter-reproducibility	0.81	0.84	0.81	0.91	0.84

SS= Supraspinatus; IS= infraspinatus; SC= subscapularis; TM= teres minor