

Characterizing 3D Fatty Infiltration Patterns in the Supraspinatus Muscle in Aged and Torn Rotator Cuffs

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INTRODUCTION: The lifetime prevalence of a rotator cuff (RC) tear is as high as 20% for the general population, with prevalence increasing with age. With age and pathology, fatty infiltration of the supraspinatus muscle is commonly observed, which is closely related to surgical intervention and outcome measures for RC tear repair. This term fatty infiltration is often used interchangeably with fatty atrophy and fatty degeneration, which are terms that have distinct biological meanings. Fatty atrophy is a normal response to disuse, where the muscle itself reduces in size, resulting in the accumulation of epimuscular fat (Figure 1a). Fatty degeneration is the accumulation of damage to the muscle, resulting in fatty replacement of muscle tissue which presents as intramuscular fat (Figure 1b). Single-plane based semiquantitative grading systems (i.e. Goutallier score) have been developed to estimate the degree of fatty infiltration of the RC. However, recent studies have demonstrated that these 2D assessments do not accurately describe the true 3D fatty infiltration of the muscle, which often contains both epimuscular and intra-muscular fat, which may have differential effects on muscle function. The regional distribution of fat may be an important biomarker considered for presurgical planning or predicting outcomes. However, regional distribution has not been considered when describing fatty infiltration of this muscle, partially because the tools and techniques to perform this analysis have not been adequately described. Thus, the goal of this study was to investigate regional fatty atrophy and fatty degeneration along the length and radially across the supraspinatus muscle in intact and torn RC.

METHODS: *Cadaveric Specimens:* Seven formalin-fixed cadaveric human shoulders were used in this study. The samples were scanned using a 3T MRI scanner (GE, MR750, Milwaukee, MI). A high resolution FSPGR (TE=2.49ms, TR=5.16ms, FOV 32cm, 1x1x1 mm³ voxel size) and a fat-water separation scan was performed (IDEAL) (TE=2.97msec, TR=6.01msec, FOV=15.6cm, 1.0x1.0x1.0mm³ voxel size) from which a fat fraction map could be calculated. MRI images were loaded into Horos and the supraspinatus muscle was segmented using a semi-automated approach. Two masks were made for each muscle, one mask was traced along the fascial plane of the supraspinatus, including both epi- in intra-muscular fat and the second mask was traced to exclude the epi-muscular fat. Fat fraction maps and masks were then loaded into Matlab for analysis. First, the whole muscle length was calculated and an axis from the origin to the insertion of the supraspinatus was fit. Then, fat fraction and muscle anatomical cross sectional area as a function of muscle length was calculated for the epi-muscular, intra-muscular, and whole muscle masks. Then for each sagittal slice, the centroid of the whole muscle mask was found, and the radial distribution of fat fraction normalized by anatomical cross sectional area (ACSA) was calculated and averaged across all slices. Regional averages of fat fraction for the superior posterior (1°-90°), inferior posterior (91°-180°), inferior anterior (181°-270°), and superior anterior (271°-360°) regions were calculated. A repeated measures 1 way analysis of variance with post hoc Tukey test was performed to determine regional differences between muscles. All data reported as mean±std.

RESULTS SECTION: Of the 7 specimens included in this study, 1 specimen was found to have a full thickness RC tear and one specimen was found to have a partial thickness RC tear. Unsurprisingly, the highest overall fat fraction was found in the epi-muscular region, with the intramuscular region having lower fat fraction across the entire length of the muscle (Figure 2a). The distribution of muscle ACSA across the length of the muscle was normally distributed for the intramuscular region, and highly variable in the epimuscular region. For the radial distribution of fat fraction, a main effect of region was observed (p<0.0001). Overall, a trend toward elevated fat fraction was observed in the superior region of the supraspinatus compared to the inferior region (p= 0.07), with no significant differences observed between anterior and posterior regions (Figure 3).

DISCUSSION: This was a preliminary study investigating the distribution of fatty degeneration and fatty atrophy of the supraspinatus muscle advanced 3D analytical approaches.

The distribution of fat and ACSA along the length of the supraspinatus is similar to what has been previously reported for the whole muscle, but has not been previously reported for the epimuscular and intramuscular regions. The radial distribution of fatty degeneration highlights that the degenerative process in heterogeneous and there may be protection of some regions of the supraspinatus muscle to support gross muscle function.

SIGNIFICANCE: Muscle atrophy and fatty infiltration are currently clinically evaluated on a single MRI image, which does not accurately depict the disease state of the entire muscle. This study demonstrates a novel analytical approach that considers the atrophy and degeneration of the entire volume of muscle, which may more accurately predict muscle function in the presence of pathology.

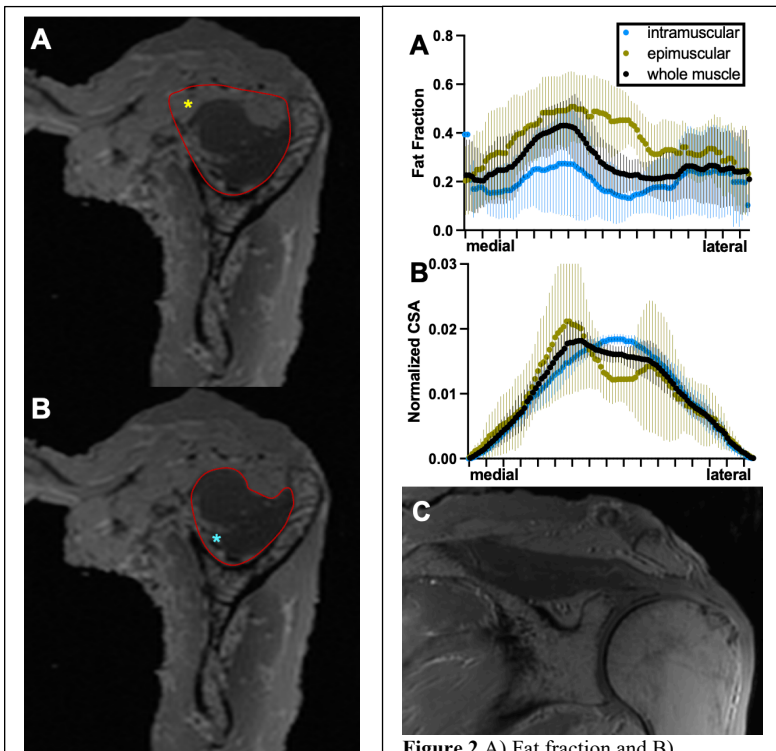


Figure 1. Sagittal oblique MRI with a region of interest (red) drawn around the A) fascial planes and B) excluding epi-muscular fat of the supraspinatus. Yellow asterisk indicates a region of epi-muscular fat. Blue asterisk indicates a region of intramuscular fat.

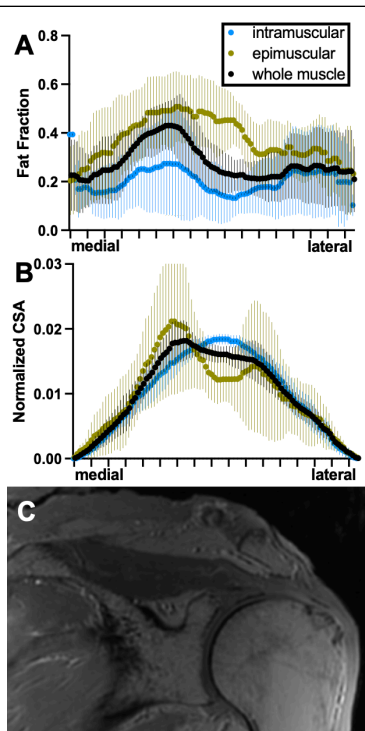


Figure 2 A) Fat fraction and B) Normalized cross sectional area as a function of supraspinatus length for the whole muscle mask (black), intra-muscular mask (blue), and epimuscular mask (yellow). C) Coronal oblique MRI of the supraspinatus from its origin (left) to insertion on the humeral head (right).

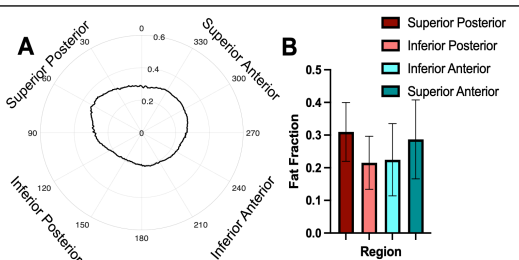


Figure 3 A) Radial distribution of fat fraction along the multifidus averaged across all subjects. B) Mean + std fat fraction in the radial compartments of the supraspinatus for each subject. A significant effect of region was found (p<0.0001), however post hoc tests revealed no significant differences between individual regions (p>0.07)