Quantitative comparison of abdominal adipose tissue volume segmentation on MR images acquired with body and phase array coils.

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Target Audience: MR researchers interested in abdominal adipose tissue quantitation in obesity and type 2 diabetes mellitus.

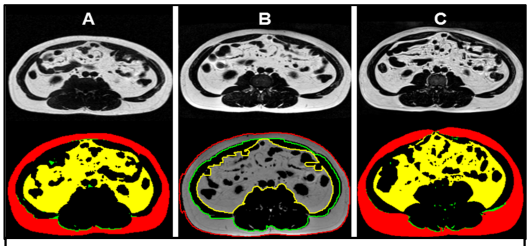

Fig 1. A. Body coil T_1W WS MRI and color contoured fat-only image red - SAT: yellow - VAT and green – IMAT **B.** T_1W WS with matrix coils after intensity correction (IC) and contours separating SAT and VAT in fat image **C.** Dixon fat image - IC.

Introduction: Excessive body fat, particularly visceral adipose tissue (VAT) correlates with adverse metabolic consequences related to Type 2 diabetes (T2DM) and cardiovascular diseases. MRI T_1-weighted (T_1W) sequences can provide moderate to good contrast between fat and nonfat tissue enabling segmentation based fat quantification (1-3). Two-point Dixon MRI can provide high spatial resolution, field map-sensitive chemical shift-based water/fat separation and the signal fat fraction is independent of RF coil sensitivity profile effects. However, these approaches rely heavily on the signal intensity contrast and is particularly challenging for VAT quantification since fat and nonfat tissue contrast are easily compromised by imaging artifacts associated with intestinal peristalsis, respiratory motion, and blood flow (4). Compared with body coils that provide homogeneous signal but moderate SNR that limits spatial resolution, phase array coils provide two-to-four fold improvement in SNR, has parallel imaging capabilities which can reduce the scan time for breath-hold acquisitions; however also produces image non-uniformities at locations further away from the coil elements. These non-uniformities of the image intensity greatly complicate further automatic analysis such as registration and tissue segmentation (1, 4). The purpose of this study was to compare the performance of 3.0T MRI T_1W water-saturated acquisition with body coil (BC-WS), T_1W water-saturated (BMC-WS) and two-point Dixon water/fat imaging (BMC-DF) with body matrix coils corrected for image non-uniformity in the application of subcutaneous (SAT), visceral (VAT), inter-muscular (IMAT) adipose tissue quantitative volumetric assessment using semi–automated fuzzy c-means (FCM) clustering algorithm.

Methods: Seven T2DM Subjects (5 m, 2 f, age: 55.1 ± 6.5 yrs, BMI: 31.3 ± 3.2 kg/m^2) participated in this study approved by IRB. All image acquisitions were performed on 3T Siemens TIM TRIO MRI scanner. T_1W GRE sequence with water-saturation (WS) (TR / TE = 112 / 2.66 ms, α = 50º, FOV = 300 ~ 500 mm, matrix size = 1.95 x 1.95 mm^2, BW = 560 Hz/Px, slice thickness = 5 mm, slice gap = 5 mm, and NSA = 1) were acquired using quadrature body coil. T_1W (WS) was acquired with GRAPPA = 2 and body and spine matrix coils keeping the other parameters constant. 11 contiguous axial slices centered at the L4–L5 level of the abdomen were acquired for each technique. Two-point Dixon was acquired with TR / TE = 5 / 2.45, 3.69 ms, α = 10º, FOV = 300 ~ 500 mm, slice thickness = 5 mm, 11 slices per slab, GRAPPA = 2. Each sequence lasted 20–24 s depending on patient size and was acquired within one to two breath-holds.

Data Analysis: T_1W and Dixon fat images were corrected for spatial intensity variations (bias field or RF inhomogeneities) using FSL FAST v4.0 (7). Adipose tissue quantification analysis was performed using QFAT 2.2 (IDL, Research Systems, Boulder, CO) software developed using fuzzy c-means (FCM) clustering algorithm (4). 2D polynomial field correction was iteratively applied to find the minimal entropy of the image grayscale histogram and correct for non-uniform intensities. Fat pixels were segmented from nonfat pixels by a fully automated algorithm to generate a fat-only image. In such an image all nonfat pixels were set to zero (dark) and were excluded from fat quantification. SAT, VAT voxels were identified based on contours separating the exterior and internal boundary of SAT, intra-abdominal cavity, generated with an automated chain-code algorithm for boundary detection. The automated VAT contour was then manually corrected to include accurate localization of visceral fat by excluding inter-muscular tissue, and other intra-abdominal organs. Average volume per slice (cm^3) of SAT, VAT and IMAT were calculated by averaging fat areas from all 11 slices for each technique. The consistency of VAT, SAT and IMAT results from three methods quantified using FCM was studied using one-way Anova, linear regression analysis, and the Pearson correlation coefficients (r). Bland–Altman plots were also generated for VAT to test if the three imaging methods can be used interchangeably. All statistical analyses were performed with R 3.0.2 statistical software. $P < 0.05$ was considered statistically significant.

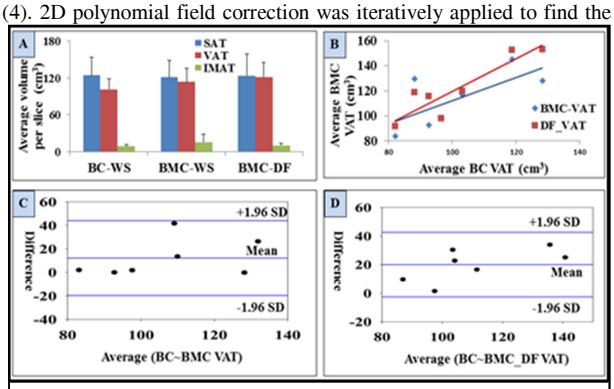

Fig 2. A. Quantitative average volume per slice (cm^3) of SAT, VAT and IMAT from three methods (mean ±SD) **B.** Scatter-plot of VAT from body coil and matrix coil acquisitions shows correlation **C.** BA plot between VAT (BC-WS ~ BMC-WS) **D.** BA plot between VAT (BC-WS ~ BMC-DF) showing a positive bias caused by under estimation in body coil WS MRI.

Results and Discussion: One-way anova comparison of average volume per slice (cm^3) measurements for SAT ($p = 0.981$), VAT ($p = 0.236$) and IMAT ($p = 0.226$) showed no statistical significance between groups. Strong significant correlations were observed for SAT, VAT and IMAT between the three methods. Fig 2 [B] shows a scatter plot and regression analysis between the methods for VAT and the Pearson coefficients BC-WS vs. BMC-WS ($r = 0.690$); BC-WS vs. BMC-DF ($r = 0.901$); BMC-WS vs. BMC-DF ($r = 0.851$) exhibited good correlation. Bland Altman plots in Fig 2. (C-D) produced higher bias (19.96) between BC-WS and BMC-DF compared to BC-WS vs. BMC-WS (12.15) for VAT volumes and all data points are within the 95% limits of agreement suggesting these methods can be used interchangeably. Our results indicated that strong concordance can be observed between the SAT, VAT and IMAT calculated from breath-hold BC-WS, BMC-WS and BMC-DF acquisitons. Limitations of this study include small number of subjects. T_1W and Dixon MRI at 3T have strong B_0 and B_1 inhomogeneities particularly when the patient size is large, leading to image intensity non-uniformities (1). These non-uniformities were effectively corrected in this study by prescan normalization and high-order intensity correction procedures. T_1W WS and Dixon water-fat MRI acquisitions produced good image contrast between fat and nonfat tissues enabling SAT, VAT and IMAT volumes with reduced systematic errors and variability.

Conclusion: This study has demonstrated the ability to correct for image non-uniformities observed with phase-array coil acquisitions for body MRI and accurately quantify regional abdominal adipose tissue segments using FCM algorithm. Results obtained are very similar to those obtained by standard manual segmentation methods (1, 4) and this approach could be used to effectively assess body fat for large-scale clinical imaging studies.

References: [1] Anqi Zhou et al. JMRI 2011; 34:852–860 [2] Thormer G. et al. JMRI 2013; 37(5): p. 1144-50 [3] Poonawalla A. et al., JMRI 2013; 37(3): p. 707-16. [4] Zhou A. H. Murillo, Q. Peng et al. JMRI. 2011; 34(4): p. 852-60. [5] Boettcher M. et al. JMRI 2009; 29(6): p. 1340-5. [6] Bonekamp S. et al. Int J Obes., 2008; 32(1): p. 100-11 [7] Zhang, Y. et al. IEEE Trans Med Imaging, 2001; 20(1): p. 45-57.