

Rapid, volumetric segmentation of visceral adipose tissue with quantitative chemical shift MRI at 3T

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INTRODUCTION. Accurate measurement of visceral adipose tissue (VAT) volume is important for accurate risk assessment in patients with metabolic syndrome (1-2). Anthropometric measurements of waist circumference, waist-hip ratio, and body mass index (BMI) are routinely used in lieu of VAT to assess risk in the clinical setting (3), but correlate poorly with true VAT volume (4-5) and are prone to systematic error (6-7). Direct measurement of VAT with MRI is preferable, but manual segmentation of VAT requires hours of tedious manual processing which is impractical for routine clinical use. Chemical shift-based MRI methods (Figure 1) potentially permit rapid adipose tissue segmentation (8-9) by applying a simple fat-fraction threshold. However, the quantitative accuracy of these methods is confounded by relaxation effects (10-12) and spectral complexity of fat (11, 13), resulting in significant errors in fat-fraction values (14-15). Also, to avoid partial volume effects at signal boundaries, the fat-fraction threshold for adipose tissue is typically defined as 50%, implicitly assuming a maximum fat fraction (η_{MAX}) of 100%, but in vivo adipose tissue also contains organelles, blood vessels, and water components which result in a true $\eta_{MAX} < 100\%$. Therefore, $\eta_{MAX}/2$ is a more physiologically meaningful choice for adipose tissue thresholding, which can be directly measured from the fat-fraction images. **The purpose of this work** is to implement a quantitative chemical-shift-based fat-water imaging technique that corrects for confounding errors to obtain truly quantitative fat-fraction maps, and in vivo estimation of η_{MAX} , permitting rapid semi-automatic segmentation of VAT in minutes.

METHODS. Ten normal subjects (4 male, 6 female) were recruited with IRB approval and informed consent. MR images were acquired from liver dome to pelvic floor in a single breath-hold (16) on a clinical 3.0 T MRI scanner (GE Healthcare, Waukesha WI) using a 32-channel phased-array body coil (Neocoil, Pewaukee WI). The subjects' height, weight, waist, and hips were measured to calculate BMI, waist circumference, and waist-hip ratio. Image data was acquired using a single-slab 3D multi-echo SPGR pulse sequence (17) with 6 echoes/TR and 1.2 ms echo spacing (11, 13), and flip angle of 3° to minimize T1-weighting bias (10). Data was acquired in the sagittal plane with 48 cm FOV, 148 x 148 matrix and 160 slices of 3 mm, interpolated to 1.9 x 1.9 x 1.5 mm³. Auto-calibrated parallel imaging (ARC) (18) accelerated the acquisition by a factor of ~5.3, for total scan time of 26 sec. Fat and water images were reconstructed offline and used to generate quantitative fat-fraction maps with full dynamic range of 0-100% (10). A thresholding algorithm was applied to fat and water data to automatically suppress background noise and air cavities. The maximum fat-fraction value η_{MAX} was estimated in each subject using histogram analysis, with mean value 0.93 ± 0.01 . An “adipose mask” (Figure 2) was then defined as all voxels of the noise-masked fat-fraction map with values $\geq \eta_{MAX}/2$. VAT was rapidly segmented from the adipose mask by tracing the interior of the abdominal cavity and avoiding vertebral regions on a slice-by slice basis using ImageJ software (NIH, Bethesda MD). VAT volume was then obtained by multiplying number of voxels of VAT by the single-voxel volume. VAT was also segmented manually from the fat-only image with SliceOMatic software (Tomovision, Magog, PQ).

FIGURE 2. The adipose tissue mask (a) permits rapid segmentation (green line) of the VAT (b) and SCAT (c) tissue compartments.

RESULTS. VAT measurements from the semi-automatic method required significantly less time to process, 30 ± 13 minutes vs. 3.6 ± 1.1 hours for the manual method ($p < 0.0001$). The semi-automated VAT was significantly predictive of manual VAT (Figure 3) with slope of 1.03 ± 0.02 statistically equal to unity ($p = 0.33$), and intercept = $189 \text{ cc} \pm 30 \text{ cc}$ ($p < 0.05$). Anthropometric measurements correlated poorly to manual VAT (Pearson coefficient $r = 0.33$).

DISCUSSION. The semi-automatic method provided equivalent volumetric measurement of VAT as the manual method, but required an order of magnitude less human intervention. The semi-automated method is also more reproducible than manual segmentation, and may be less susceptible to partial volume effects, since adipose tissue is not defined on the basis of qualitative fat or T1-weighted signal, but instead defined according to a quantitative, physiological fat-fraction threshold. This method potentially makes direct, quantitative VAT measurement practical in a clinical setting.

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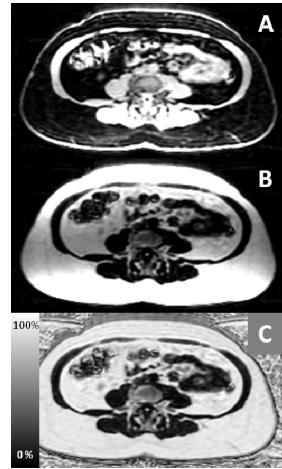


FIGURE 1. Axial images from chemical shift fat/water MRI in high VAT subject:

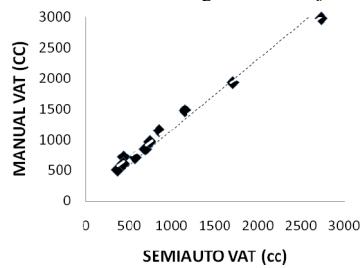


FIGURE 3. Scatter plot of semi-automatic VAT measurements vs. manual VAT; $r^2 = 0.99$.