Absolute Quantification of In Vivo Water and Fat Content

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Introduction: Obesity is an increasingly severe health issue in western society. It causes increased adipose tissue volume as well as fat content in skeletal muscles, and organs and is related to increased risk of cardiovascular, endocrine and metabolic diseases. There is considerable interest in developing non-invasive methods of assessing the distribution of fat in the body. Accurate measurement of the fat fraction (fat content relative to total water and fat) in underlying tissues across the full imaging volume has been demonstrated with IDEAL (Iterative Decomposition with Echo Asymmetry and Least square estimation) [1]. However, knowing the absolute (instead of relative) fat and water content is valuable in many cases as it allows differentiation between the causes of changes in fat fraction. For example, knowing absolute fat and water content allows determination if a reduction in fat fraction is due to decreased fat or an increase in water content due to edema. Hu et al. [2] demonstrated absolute fat content measurement *in vitro*; however, their work was limited to volume coil data acquisition. This restricts its utility in human imaging, particularly in the abdomen where volume coil acquisition will limit SNR and preclude the use of parallel imaging methods to accelerate data acquisition, thus severely limiting image resolution and volumetric coverage. Furthermore, Hu *et al.* used a time consuming measurement of the transmit B_1^+ field that is incapable of measuring the 3D B_1^+ distribution in a breath hold compatible acquisition. In this work, we will demonstrate an extension of the work of Hu *et al.* to *in vivo* quantification of fat in humans using multichannel coil data acquisition and rapid B_1^+ measurement.

Image Reconstruction: T1 independent, T2* corrected chemical shift based fat-water separation methods with accurate spectral modeling of fat can be used to produce fat-only and water only images where signal intensity is proportional to proton density [3]. Placing a pure water or fat reference phantom in FOV during the measurement allows calibration of the signal intensity so it can be converted to absolute proton concentration [2,4], assuming the B_1^+ (transmit) and B_1^- (receive) fields can be measured. To acquire all the data necessary to produce fat-water separated images corrected for B_1^+ and B_1^- inhomogeneity we followed the following procedure: 1) Data suitable for IDEAL fat-water separation were acquired using a phased array. 2) B_1^- (coil sensitivity) maps were generated using the SENSE method [5]. 3) Noise covariance among the coils in the array was measured [5]. 4) Pixel by pixel B_1^+ transmit flip angle maps (C_{B1}) were obtained over the volume imaged in step 1 using the double angle Look-Locker technique [6]. 5) The noise covariance and B_1^- measurements were used to combine IDEAL data from the phased array using Roemer's uniform sensitivity SNR optimal method [7]. 6) The B_1^- corrected coil combined IDEAL data were reconstructed with T_2^* IDEAL method to produce fat-water separated images that were corrected for T_2^* variations. 7) The T_2^* corrected IDEAL images were corrected for flip angle variations using the B1+ map from step 4 [4]. 8) Finally, the pure water phantom (which has a known proton density) was used to calibrate the signal intensities of the water-only and fat-only images produced in step 7 and convert the signal intensities into units of proton density [4].

Methods: Phantoms used in this experiment are made with different concentrations of peanut oil and water (0%, 2.5%, 5.0%, 10.0%, 20.0%, 30.0%, 40.0%, 100% volume fraction of fat). Phantoms were imaged at 3.0T (Discovery MR 750, GE Healthcare, Waukesha, WI) using a multi-peak T2* IDEAL sequence [3,8]. Images were acquired with an 8 coil head array: TR=8.2ms, TE=[1.2, 2.2, 3.1, 4.1, 5.0, 6.0] ms, matrix 128×128, FOV=28 × 28cm, BW=±142.86kHz, slice thickness=5mm, flip angle =3°. The IDEAL images were corrected for B1+ and B1- inhomogeneity as described above, producing images with intensity units of proton density. The calibration was validated by comparing the calculated proton density maps to the known proton densities of the phantoms.

Following REB approval and obtaining informed consent, in vivo IDEAL data were collected from the calf of a healthy volunteer, using an 8 coil abdominal array and body coil. For both images parameters are as follows: TR=5.1ms, TE=[1.0, 1.4, 1.8, 2.2, 2.6, 3.0] ms, matrix 128×64, FOV=36×18cm, BW=±62.50 kHz, slice thickness=6 mm, flip angle =3º.

Results: Figure 1 compares the calibrated water/fat masses from ROIs in each phantom to the known water fat masses. A linear fit to these data demonstrates excellent agreement and validates the accuracy of the correction factors applied to the data. Figure 2 demonstrates the use of this method in vivo for imaging proton density in the calf. The proton density of an ROI in the calf muscle was determined to be 0.80 ± 0.08 g/mL, which is consistent with values reported in the literature of 0.78 g/mL[9].

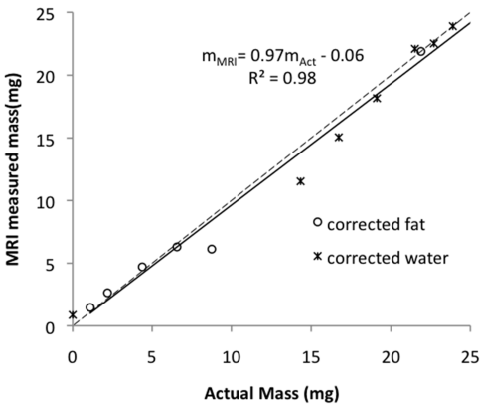

Figure 1: The water and fat IDEAL signal corrected to units of mass correlated with the known water/fat mass of the phantoms.

Discussion: Here we have improved existing absolute fat quantification methods to allow the use of phased array imaging and demonstrated its use in vivo. Crucially, a B1 mapping method fast enough to be used for breath hold applications is employed to compensate the inhomogeneous B1 transit field, thus making possible quantification of abdominal or thoracic water and fat content. Since these experiments allow phased array data acquisitions, application of parallel MRI to accelerate imaging is possible and will be investigated in the future.

Conclusion: As long as the relevant corrections are considered, precise estimation of absolute *in vivo* fat and water content can be achieved.

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References: [1] Radiology 2011;258:767-775. [2] JMRI 2008;28(6):1483-1491 [3] MRM 2007;58:354-364 [4] Neuroimage 2008;41:706-717 [5] MRM 1999;42:952-962 [6] Proc ISMRM 2010: 2837 [7] MRM 1990;16, 192-225 [8]JMRI 2011;33:873-881. [9] J Clin Invest; 50: 2091–2103

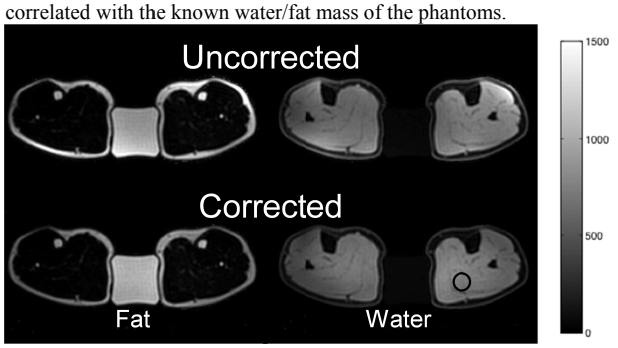

Figure 2: *In vivo* images of a volunteer's calves. (The object between the calves is a peanut oil proton density reference.) The corrected fat and water images are noticeably more uniform than the uncorrected images, particularly at the periphery. The mean value of water density measured in the ROI shown in the calf was 0.80 ± 0.08g/mL.