MRI Fat-Water Separation Models: Correlation with CT Hounsfield Units in Human Subcutaneous White Adipose Tissue

Aliya Gifford[1,2], Theodore F Towse[1,3], and Brian Welch[1,4]

[1]*Institute of Imaging Science, Vanderbilt University, Nashville, Tennessee, United States,* [2]*Chemical and Physical Biology Program, Vanderbilt University, Nashville, TN, United States,* [3]*Department of Physical Medicine and Rehabilitation, Vanderbilt University School of Medicine, Nashville, TN, United States,* [4]*Radiology and Radiological Sciences, Vanderbilt University, Nashville, TN, United States*

Purpose: A reliable and non-invasive method for quantifying subtle changes and variations in white adipose tissue (WAT) may be beneficial in obesity research. This report shows the results of three methods of computing fat-water separation and how the resulting fat-water MRI (FWMRI) derived fat-signal-fraction (FSF) values correlate to CT Hounsfield Units (HU) in the lower abdominal subcutaneous white adipose tissue (WAT) in adult humans.

Materials and Methods: Twenty-one healthy adults (8 males, age: 21 to 34 years, BMI: 20.24 to 31.48 kg/m^2) were recruited to undergo whole-body MRI and CT scans. Both MRI and CT scans were performed twice, each scan on a separate day, once after two hours of cold (CA) (16°C) and once after two hours of thermoneutral (TN) (24°C) exposure. CT scans were acquired on a GE Discovery STE PET/CT scanner (General Electric Medical Systems, Milwaukee, WI, USA) with LightSpeed CT in 3D mode, with an acquired voxel size of 1.36 mm x 1.36 mm x 3.27 mm. MRI scans were performed on a 3.0 Tesla Achieva MRI scanner (Philips Healthcare, Best, The Netherlands), equipped with two-channel parallel transmit capability, a 16-channel Torso-XL surface coil and an X-tend tabletop (X-tend ApS, Hornslet, Denmark). FWMRI was acquired using a 2D multi-slice multi-gradient echo (mFFE) acquisition, and scanner software was modified to enable the acquisition of 8 echoes acquired as 2 interleaved sets of 4 echoes with TE1 = 1.024 ms and effective ΔTE = 0.779 ms. Additional acquisition details: TR = 83 ms, $\alpha = 12^o$, water-fat shift = 0.323 pixels, acq. voxel = 2 mm x 2 mm x 7.5 mm, and SENSE = 3. Three-dimensional water/fat separation and R_2* estimation based on a multi-scale whole-image optimization algorithm[1] was performed using three separate models. *Model A:* The first echo of each 4-echo train was discarded to avoid potential contamination by eddy currents in the complex water-fat signal model, fat was modeled using a 9-peak[2] model, and R_2* correction performed. *Model B:* All 8 echoes were used, fat was modeled using a 9-peak[2] model, and R_2* correction performed. *Model C:* Only echoes 1, 2, 3 were used, fat was modeled using a 3-peak[3] model, and no R_2* correction performed.

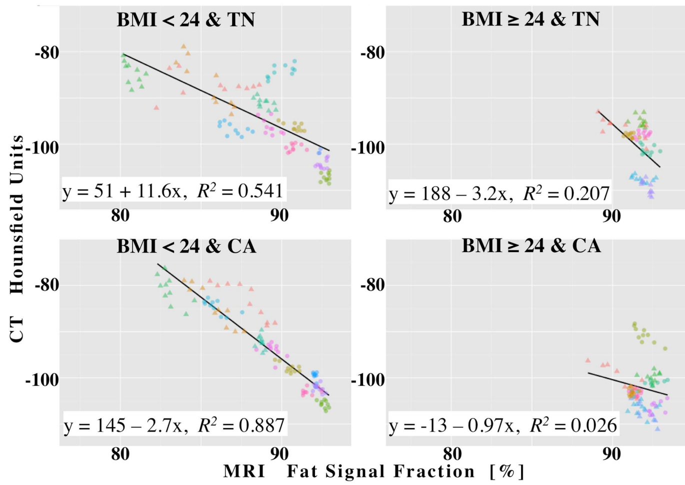

Figure 1. Plots of MRI FSF vs. CT HU for FWMRI water/fat separation Model A (6 echoes, 9 fat peak, R_2* correction), showing strong correlation between FSF and HU for lean subjects after exposure to cold (BMI < 24 & CA), with a Pearson's R^2 = 0.887.

F-W Model	BMI < 24 TN	BMI ≥ 24 TN	BMI < 24 CA	BMI ≥ 24 CA
A	R^2 = 0.541 FSF (80.2 – 93.0)	R^2 = 0.207 FSF (89.1 – 93.0)	R^2 = 0.887 FSF (82.3 – 92.9)	R^2 = 0.026 FSF (88.5 – 93.4)
B	R^2 = 0.165 FSF (51.6 – 90.0)	R^2 = 0.074 FSF (45.1 – 85.8)	R^2 = 0.573 FSF (42.2 – 91.5)	R^2 = 0.196 FSF (73.7 – 92.4)
C	R^2 = 0.001 FSF (51.8 – 90.4)	R^2 = 0.002 FSF (43.7 – 89.7)	R^2 = 0.085 FSF (51.4 – 90.2)	R^2 = 0.101 FSF (41.9 – 92.5)

Table 1. MRI FSF vs. CT HU Pearson's R^2 values for three fat-water separation models, after both TN and CA exposure. Subjects are separated based on BMI level. The FSF (in %) shown is the range of calculated FSF values for each water/fat separation model in subcutaneous WAT at the umbilical level for the subjects in each respective BMI group.

Results: The subjects were divided into two groups: BMI < 24 (n = 12, 4 male), and BMI ≥ 24 (n = 9, 4 male). Prior to analysis, the MRI and CT scans were registered to the same image space for each subject. Ten slices at the umbilical level were analyzed for each subject, acquiring MRI FSF and CT HU values in the subcutaneous WAT for both the CA and TN scans. **Fig. 1** shows plots of FSF derived from fat-water separation Model A vs. CT HU, for the two BMI groups at both TN and CA conditions. Each subject (10 points) is plotted in a different color with males and females plotted as triangles and circles respectively. The line of best fit, along with Pearson's R^2 value is displayed on each plot. **Table 1** shows Pearson's R^2 values along with the range of calculated FSF values for each of the three fat-water separation models.

Discussion: These results show that the FSF values as calculated using Model A are tightly correlated (R^2=0.887) to the density of tissue as measured by differences in CT HU values for subjects with BMI < 24 after exposure to cold. The strength of correlation drops dramatically for less lean subjects, under the TN condition and for fat-water separation models B and C. This could be the result of several factors: First, the FSF calculated by Model A for subjects with BMI ≥ 24 varies by 3.9% (TN) and 4.9% (CA), compared to the BMI < 24 group, which varies by 12.8% (TN) and 10.6% (CA). Therefore, any correlation with CT HU values would be more difficult to discern for such a small FSF range. Second, for the subjects with a BMI < 24, the FSF calculated by Model A may correlate with the CT HU values for the CA data better than the TN data because the leaner subjects get colder when exposed to the same temperature for the same duration as the heavier subjects. When the subjects get cold, we hypothesize that water signal not detected by the fat-water MRI scan, such as perfusing blood, retreats from the subcutaneous region, resulting in a more accurate measurement of WAT properties by MRI under the cold condition. Additionally, as shown in **Table 1**, it is interesting to note that both water/fat separation Models B and C do a poor job of determining FSF as is evidenced by the extremely low values of FSF in subcutaneous WAT. This supports previous research[3-5] showing the disadvantage of using the first echoes which may produce eddy-current contamination (as in Models B and C), as well as the risks of using fewer peaks in the fat spectrum (as in Model C).

Conclusions: Adipose tissue research using MRI requires precise measurements of fat-signal-fraction. Of the three fat-water separation models examined in this work, we conclude that Model A results in the most precise quantification of fat percentage in subcutaneous WAT as evidenced by very high correlation with CT HU measurements of lean subjects after cold exposure.

References: [1] Berglund J, et al. MRM 67(6):1684-93; 2012. [2] Hamilton G, et al. NMR Biomed 24:784-790; 2011. [3] Hernando D, et al. MRM 63(1):79-90; 2010. [4] Hernando D et al. MRM 64(3):811-22; 2010. [5] Yu H, et al. MRM 60(5):1122-34; 2008.

Funding: 1R21DK096282 from NIDDK/NIH & UL1 TR000445 from NCATS/NIH