Improved Accuracy and Smoothed Lipid Content by Maximum A Posteriori Estimation in CHESS Ratio Images

W. C. Wong[1], D. Johnson[2], C. Flask[3], P. Ernsberger[4], and D. Wilson[2,3]

[1]Computer Science and Engineering, The Hong Kong University of Science & Technology, Kowloon, Hong Kong, [2]Biomedical Engineering, Case Western Reserve University, Cleveland, OH, United States, [3]Radiology, University Hospitals of Cleveland, Cleveland, OH, United States, [4]Nutrition, Case Western Reserve University, Cleveland, OH, United States

Abstract

We are using MR to quantify fat depots (e.g., visceral, subcutaneous, hepatic, muscular) so as to determine the role of genetic, environmental, and therapeutic factors on lipid accumulation, metabolism, and disease states. In this report, we studied lean spontaneously hypertensive rats (SHRs), a genetic variant prone to obesity (SHROBs), and animals given a high fat, high sucrose diet creating dietary obese animals (SHR-DOs). Animals were imaged with and without CHESS water-suppression. Ratio images exactly compensate for receive coil sensitivity inhomogeneity and enable the creation of gray-scale based automated analysis. A ratio image model was created for measuring lipid content in subcutaneous and visceral depots. We analyzed the statistical property of the ratio of two noisy signals and developed a maximum *a posteriori* (MAP) estimate of the lipid content in each voxel. We simulated the partial volume effect in a digital phantom with known fat content in each voxel. Even if relaxivities were corrected, ratio images overestimated the true volume of fat by 23%. In a cohort of rats, the MAP correction reduced visceral adipose tissue volume by 20%. We identified obesity phenotypes and characterized this model of metabolic syndrome.

Introduction

The Koletsky rat (SHR/SHROB) is metabolic syndrome model which provides insight into both dietary and hereditary obesity. Genetically obese SHROBs are predisposed to obesity and metabolic syndrome, in contrast to the lean SHRs which becomes obese only on a high fat, high sucrose dietary supplement (i.e. milkshakes) [1]. Previous research has established that dietary obesity may actually be worse than genetic obesity [2]. MR provides a unique capability to make reproducible measurements of lipid distribution in animal models. We used ratio imaging because it exactly removes coil inhomogeneity and because ratio values are stable across time and animal, allowing us to build this into our analysis [3]. Here we advance a much improved method for automated image analysis.

Methods

Twelve SHROB, six SHR-DO, and six non-obese SHR animals were chosen to cover a variety of ages and body weights for measurement of adipose tissue depots and total body volume and weight. High resolution, T1-weighted coronal images were acquired with a spin echo sequence (TR/TE = 1240/13ms, resolution = 0.78x0.78x2mm, matrix = 256x128) both with and without water suppression on a clinical scanner. We divided the fat-only (i.e. water-suppressed) images by the fat+water (unsuppressed) images to obtain an estimate of per-voxel lipid content. We also measured adipose tissue volumes by manually segmenting the abdominal cavity and applying a threshold to label fat. We measured the reproducibility of our method by making repeated measurements of the same rat. To recover the true fraction of fat, α, we modeled the MR ratio signal as function of (α, *TR, TE, T1F, T1W, T2F,* and *T2W*) as given in Eq (0.1). The corrected signal intensity in the ratio image (I_R) is an estimate of α, the true fraction of fat in the voxel. MR values are either set from the literature or measured.

$$I_{R(x,y)} = I_F(x,y)/[(1-e^{-TR/T1F})e^{-TE/T2F}]\Big/\Big(I_F(x,y)/[(1-e^{-TR/T1F})e^{-TE/T2F}]+\big(I_{FW}(x,y)-I_F(x,y)\big)/\big((1-e^{-TR/T1W})e^{-TE/T2W}\big)\Big) \quad (0.1)$$

We modeled the histogram of intensities in the ratio image. We analyzed the statistical property of the ratio of two noisy signals and developed a probability distribution to model the histogram as a weighted sum of three components: a pure adipose tissue (fat) peak with a Gaussian distribution (G), a pure water peak with a Rician distribution (R), and a finite mixture model of Gaussians that model different partial-volume fractions of fat mixed with water (*f*) in Eq (0.2). The weights w_f, w_w, and w_m must sum to 1. The w's and the finite mixture model of equally spaced Gaussians are appropriately constrained.

$$P(\alpha) = w_f G(\alpha \mid \mu_f, \sigma_f^2) + w_m f(\alpha) + w_w R(\alpha \mid v_w, \sigma_w^2) \quad (0.2)$$

To reduce effects of noise, we included Markov random field priors and obtained maximum *a posteriori* estimates of lipid content. So as to evaluate the accuracy of our method, we created a high resolution spherical phantom with varying fat content, and used averaging to model the partial volume effect.

Results

The Finite Mixture Model was a good fit both for rat data sets (Fig 1) and for digital phantoms (not shown). With the digital phantom, we compared estimated results to ground truth and determined that ratio images overestimated the total volume of fat in the phantom by 23%, whereas MAP was within 1.5%. Contrast between adipose tissue and adjacent muscle groups was improved (Fig 2). The volume of visceral adipose tissue in rats was ~20% higher if the ratio or relaxivity-corrected ratios were used relative to the MAP volumes (Fig 3). The total volume of a rat varied <1 ml when repositioned and rescanned three times. Visceral adipose tissue volume was elevated eightfold in genetic obesity and fourfold in dietary obesity relative to lean controls (P<0.05). Subcutaneous adipose tissue volume was elevated only in SHROBs, not SHR-DO. We identified 6 SHROBs with increased fat content in the liver (0.17 vs 0.05, P<0.01).

Discussion

MAP estimation was useful for estimating lipid concentration enabled accurate phenotyping. The elevated liver fat in SHROB is a new phenotype in this rodent model. Subcutaneous adipose tissue volume was increased in genetic but not dietary obese rats. These observations are consistent with distinct metabolic roles for these depots.

References and Acknowledgements

[1] Ernsberger et al. Am J Hypertens. 1988;1:153S-157S. [2] Johnson et al. Obes. Res. 2005; 13:A113-A114. [3] Johnson et al. JMRI (submitted). This work was supported by NIH 5R01EB004070-03 (Quantitative Image Quality for Optimization of MRI) and NIH 1T32EB007509-01 (Interdisciplinary Biomedical Imaging Training Program).

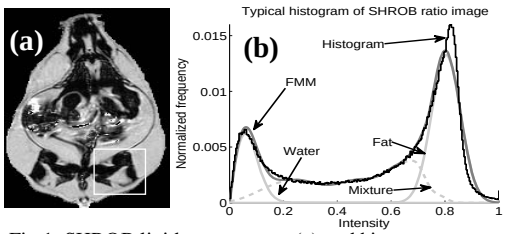

Fig 1. SHROB lipid content map (a) and histogram model (b) show that the fat peak, water peak, and Gaussian mixtures are a good fit to real images.

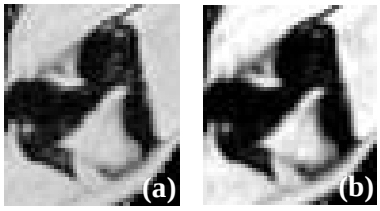

Fig 2. Zoomed-in view of hindlimb muscles (see Fig 1.a white box) shows the noisy distribution of dividing the magnitude images (a). The MAP estimation is much smoother in the muscle groups (b).

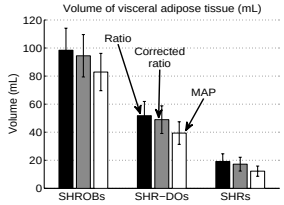

Fig 3. The MAP estimation of visceral adipose tissue volume is smaller in all types of rats.