Fully Automated Quantification of Subcutaneous and Visceral Abdominal Adipose Tissue using Water and Fat Acquisition and Graph Cuts

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Introduction. Distribution rather than amount of adipose tissue across the body appears to influence the metabolic consequences of obesity. Many studies have found that visceral adipose tissue (VAT), which covers internal organs within the abdomen, has stronger association with metabolic risk factors, such as insulin resistance, dyslipidemia, hypertension, and elevated cholesterol level, compared to subcutaneous adipose tissue (SAT), which is the fat accumulated under the skin [1]. Magnetic Resonance Imaging (MRI) provide the most direct, validated and non-invasive method of evaluating adipose tissue distribution, but a substantial amount of labour is required to manually segment multislice or 3D MR images. Several automated SAT-VAT segmentation techniques have recently been proposed [2,3,4], but these have reported inadequate reproducibility (coefficient of variation CV in measured VAT volumes 7-13%) and rank poorly compared to semi-automated solutions. We propose and evaluate a novel graph cut based measurement technique that achieves both high correlation with manually segmented volumes and excellent reproducibility of VAT volumes (CV=2.3%).

Methods. Our algorithm is designed for water and fat acquisition (Dixon sequences), which results in simultaneous acquisition of aligned fat-only and water-only images [5]. The proposed algorithm pipeline consists of a fat-fraction image thresholding for adipose/non-adipose tissue separation, followed by graph-cut based algorithm that cuts connections formed between subcutaneous and visceral compartments. Fat fraction images are fat-only images divided by the sum of fat-only and water-only images. They offer advantages compared to fat-only or T1W images, in being free from arbitrary scanner scaling and containing almost no intensity nonuniformity (intensity nonuniformity contained in the fat-only and water-only images get cancelled when these images are divided). This allows segmentation by comparing intensities of fat-fraction images to a *fixed* global threshold, empirically set at 0.6, rather than using a dynamic threshold, which has to be estimated for each image slice. Dynamic threshold estimation is a difficult problem in itself, and assumes a certain shape of the histogram, which we have found often violated in practice. The graph-cut procedure to separate SAT and VAT is inspired by our earlier work on skull stripping [6] and uses the fact that the bridges formed between SAT and VAT compartments are narrower than the fat depositions themselves. By representing the image as a graph, and setting the weights of the edges to be equal to the distance from the edge to the nearest fat/non-fat border, the minimum cut on the graph can be made to separate the compartments along the desirable narrow connections.

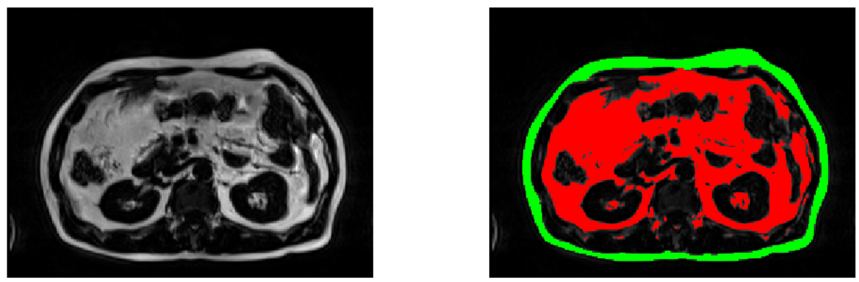

Fig. 1. Results of the fat segmentation algorithm of a Male (69 years); BMI: 15.9 ; WHR: 0.70. VAT is highlighted in red, SAT in green.

Our algorithm was evaluated on two sets of subject scans. The first dataset consisted of 9 subjects, 5 males, age 65±5, BMI 24.5±4.7, each scanned once on Siemens Tim Trio 3T scanner using a 6-channel body matrix and the 2-point Dixon sequence (TR 4.20, TE 1.225/2.45, FA 10, bandwidth 850 Hz/Px, FOV 380 x 285mm, 80 axial slices, 256 x 192 matrix, 2.5mm slice thickness). Subjects held their breath for 16 s to minimize motion artifacts. This dataset was manually segmented at every 10^{th} slice by a board certified radiologist, and was used to evaluate the measurement accuracy of our algorithm. The second dataset consisted of 10 subjects, 4 males, age 25±3, BMI 21.6±2.2, each scanned three times under the same conditions as the first dataset. After each scan, the subjects were taken out of the scanner and repositioned, to make sure the effects of repositioning are taken into account. This dataset was used to evaluate the reproducibility of our algorithm.

Results. Fig. 1 show typical segmentation output of our algorithm. We intentionally had chosen a subject with very low BMI=15.9 to highlight the large amount of visceral adipose tissue that is sometimes observed in subjects that appear thin on the outside and deemed underweight or normal by anthropometric measures. The relationship between automatically and manually derived volumes is shown in Fig. 2. Both SAT and VAT volumes were highly correlated with the manual measurements, r=0.998 for SAT and 0.957 for VAT. These correlations were much higher than those we obtained by using HippoFat algorithm [2] on the same data, r=0.92 for SAT and r=0.88 for VAT.

As the measure of reproducibility we used the coefficient of variation (CV), averaged over three pairwise measurements (scans 1-2, scans 2-3, and scans 1-3). CV for both SAT and VAT were 1.5% and 2.3% respectively. This is a remarkably good reproducibility, especially for VAT, and compares favourably with VAT measurement reproducibility reported for existing fully automated approaches (7-13%). Note also that the relatively young group of subjects, which tend to have less VAT compared to older subjects. Since CV tends to decrease with the absolute volume measured, this suggests that even lower CVs would be obtained for older or more overweight subjects.

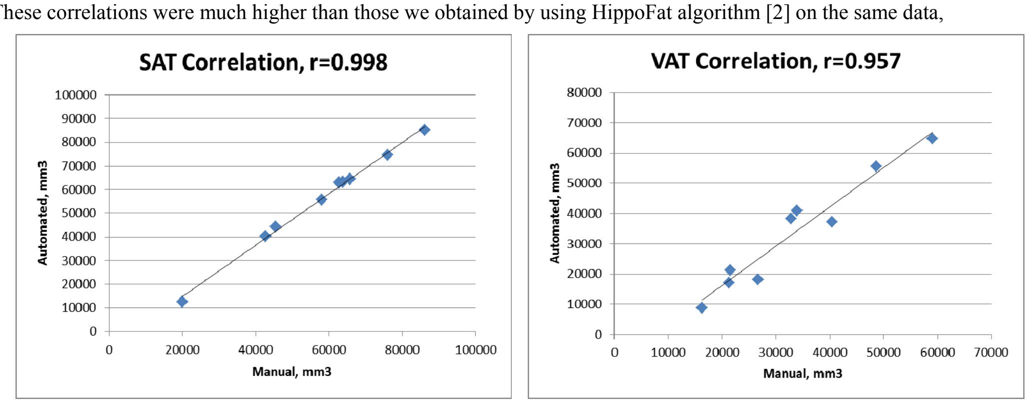

Fig. 2 Relationship between manual and automated SAT/VAT measurements

Conclusions. We proposed and evaluated a fully automated algorithm for segmentation of subcutaneous and visceral abdominal adipose tissue, which combines fat-fraction image thresholding and graph-cut segmentation. The obtained automated measurements were highly correlated with the manual measurements, for both VAT and SAT volumes, and had excellent reproducibility. On all measures our algorithm performed better than HippoFat [2].

References: [1] Bjorntorp, P. (1997). "Body fat distribution, insulin resistance, and metabolic diseases." Nutrition 13(9, [2] Positano, V., et al. (2004). "An accurate and robust method for unsupervised assessment of abdominal fat by MRI." JMRI 20(4):., [3] Kullberg, J., H., et al. (2007). "Automated and reproducible segmentation of visceral and subcutaneous adipose tissue from abdominal MRI." IJO (Lond) 31(12). [4] Liou, T. H., et al. (2006). "Fully automated large-scale assessment of visceral and subcutaneous abdominal adipose tissue by magnetic resonance imaging." IJO (Lond) 30(5). [5] Ma, J. (2008). "Dixon techniques for water and fat imaging." JMRI 28(3)., [6] Sadananthan, S. A.,et al. (2010). "Skull stripping using graph cuts." NeuroImage 49(1).