Automated technique for the segmentation of deep and superficial subcutaneous adipose tissues: Association with insulin sensitivity in normal and overweight Chinese men

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Introduction. Obesity is associated with increased insulin resistance, a risk factor for type 2 diabetes or cardiovascular disease. Accumulation of fat in different depots may have different effects on insulin resistance. Visceral adipose tissue (VAT) is thought to have greater impact on insulin resistance than subcutaneous fat [1,2]. More recently, it has been observed that subcutaneous adipose tissue (SAT) has two sub-compartments, deep SAT (DSAT) and superficial SAT (SSAT)), which may have different effects on insulin resistance [3,4]. While there are many automated methods to accurately segment SAT and VAT [5-7], there is currently no technique to separate DSAT and SSAT. We have implemented a fully automated approach to segment DSAT and SSAT and evaluated it on normal and overweight Chinese adults.

Methods. The study consisted of 50 normal weight Chinese male adults (BMI 18 to 22.99 kg/m^2) and 51 overweight Chinese male adults (BMI 23 to 30 kg/m^2). All subjects were between 21 and 40 years of age and were non-diabetic. Anthropometric measurements and the metabolic profiles were obtained from all subjects. Insulin sensitivity index (ISI) was determined using hyperinsulinemic euglycemic glucose clamp. Percentage body fat was measured by dual-energy X-ray absorptiometry (DEXA). Abdominal MR data were acquired on a 3T MR scanner (Tim Trio, Siemens) using two-point Dixon sequence (TR=5.28 ms, TE1=2.45 ms, TE2=3.68 ms, FA=9 deg, 80 axial slices).

We employed a fully automated graph theoretic segmentation algorithm [7] to separate the SAT and VAT between L1-L5 lumbar vertebrae. The segmentation algorithm is a two-step process. First, the fat tissues are separated from the non-fat ones by thresholding. The extracted fat tissues are then classified into SAT and VAT using graph cuts. In order to separate DSAT and SSAT compartments from SAT, we used distance regularized level set evolution (DRLSE) [8], which is a new variant of level set without re-initialization. The advantages of this technique are (i) significantly larger step can be used (ii) level set function (LSF) can be initialized as a simple binary functions that are computationally efficient and (iii) level set evolution can be implemented using simple finite difference schemes. The energy function is defined as $\varepsilon(\phi) = \mu R_p(\phi) + \varepsilon_{ext}(\phi)$, where $R_p(\phi)$ is the distance regularization term, $\varepsilon_{ext}(\phi)$ is the external energy depending on edge-based image information.

Results. All abdominal fat depots (DSAT: r = −0.48, SSAT: r = −0.54, VAT: r = −0.54) and total body fat (r = −0.52) had statistically significant (all p values < 0.01) negative correlations with ISI. The amount of DSAT increased from 29% of SAT in normals to 40% in overweight adults, whereas the proportion of SSAT reduced from 71% of SAT in normal subjects to 60% in overweight subjects. Increase in SSAT was associated with steeper fall in ISI when compared to DSAT or VAT (Figure 3).

Conclusion. We have proposed a new approach for the automated segmentation and quantification of DSAT and SSAT. Among abdominal fat depots, increasing SSAT was associated with steeper decline in ISI. There was an increase in the ratio of DSAT to SAT and decrease in the ratio of SSAT to SAT when the subjects became overweight.

References. [1] Fox et al. Circulation 2007;116:39-48. [2] Matsushita et al. Diabetes Care 2010;33:2117-2119. [3] Koska et al. Obesity 2008;16:2003-2009. [4] Kelley et al. AJP E&M 2000;278:E941-E948. [5] Peng et al. JMRI 2007;26(3):738-749. [6] Positano et al. JMRI 2004;20(4):684-689. [7] Vitali et al. Intl. Patent WO/2011/139232, 2011. [8] Li et al. IEEE Trans. Image Process. 2010; 19(12):3243-3254.
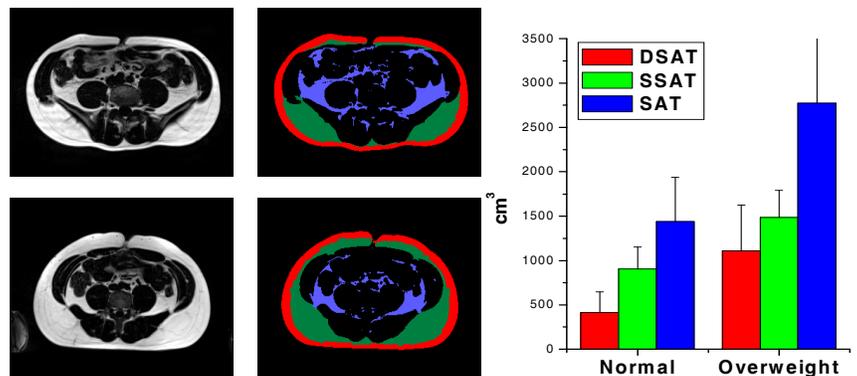
Fig 1. Typical SSAT (red), DSAT (green) and VAT (blue) distribution in normal (above) and overweight (below) Chinese.

Fig 2. Mean DSAT and SSAT levels of normal and overweight Chinese men
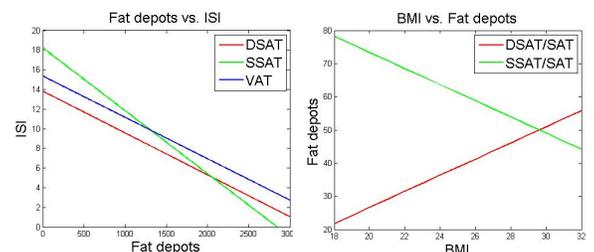
Fig 3. Relationships between BMI, ISI and fat depots