General Methodology for Accurate MRI Abdominal Adipose Tissue Quantification

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INTRODUCTION Fast and accurate quantification of abdominal adipose tissues has been a challenge. Traditionally, non-water-saturated (NWS), T1-weighted (T1W) techniques have been used for abdominal fat quantification on humans. Although fat signal is usually significantly higher than non-fat tissues, image quality is complicated by the relatively low signal-to-noise ratio and/or contrast-to-noise ratio, motion blurring, and other artifacts inherent to the abdomen and viscera such as blood flow and peristalsis. In addition, the signal intensity of different non-fatty tissues might be different due their own T_1 and T_2 differences. Despite the difficulties, a few fast fat quantification methods based on image gray-level histogram analysis have been proposed. These methods include manual, semi-automated, and fully-automated thresholding to identify fat voxels (1-3). Other approaches include curve fitting on image histogram to estimate total number of fat voxels (4). All these methods are based on histogram analysis, assuming that fat and non-fat tissue voxels can be successfully labeled solely based on their signal intensity. This approach, however, is inherently flawed because severe partial volume effects in human abdomen MR images are not taken into account leading to large systematic errors and variability, particularly during visceral adipose tissue (VAT) amount quantification. Here, we propose a general framework for VAT quantification based on a combination of fuzzy c-means (FCM) clustering and signal intensity thresholding, so that both full-volume (FV) and partial-volume (PV) fat amounts can be accurately quantified.

METHODS 11 healthy volunteers (8 males and 3 female, age=41±9yo, BMI=25.1±2.7kg/m^2) participated in this study. These subjects underwent abdomen imaging with both T1W TSE and WS T1W TSE on a 1.5 T clinical MR scanner using a standard whole-body quadrature coil. In each sequence, 6 axial slices centered at L2-L3 level were acquired in two consecutive expired breath-holds, with 14 seconds each. Image pairs were visually inspected to exclude images with severe fat amount or distribution changes between WS TSE and NWS TSE images due to peristalsis. Total 60 WS and NWS image pairs were included in this study.

Full-voxel fat maps were generated by a two-step segmentation procedure. The first step was to eliminate FV water voxels from the original image to generate a "pseudo-water-saturated" (pWS) MR image. In this step, we employed a FCM clustering method in combination with spatial information to separate the voxel types into two fuzzy clustering centers (water-only voxels and non-water-only voxels). In the second step, simple signal intensity thresholding was applied to the pWS MR images to generate the ultimate "fat-only" image used for fat quantification. A threshold value of $(S_f + S_w)/2$ was used so that PV fat amounts with signal above this threshold were compensated by the fat amounts in PV voxels with signal below this threshold value. The total fat amount was therefore calculated from the number of fat voxels multiplied by the voxel volume size. Both WS and NWS MR images underwent the same FCM and thresholding steps for fat quantification and the VAT amounts were compared. Welch's t-test, linear regression analysis, and Bland-Altman analysis were performed to study the difference between their results.

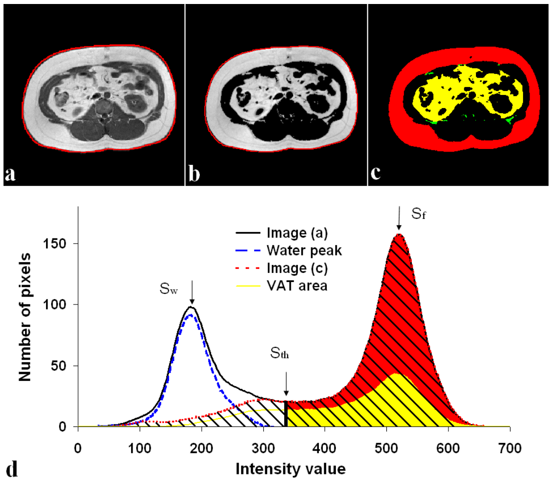

Fig. 1 Representative images and histograms to show the fat quantification steps for an NWS image. (a) Original image; (b) "pseudo-WS" image; (c) Final fat-only imag when S_{th} thresholding was applied; (d) Histograms of images or tissue

RESULTS A representative NWS MR image is shown in Fig 1a. The pWS image is shown in Fig. 1b, in which signal of FV water voxels are set to zero by FCM clustering algorithm. The corresponding histogram of Fig. 1b is shown as the dotted red curve in Fig. 1d. Fat-only image is shown in Fig. 1c after signal intensity thresholding with threshold value of S_{th}. The VAT and SAT voxels are shown in yellow and red in Fig. 1c and Fig. 1d, respectively. Linear correlation plot of VAT results of WS images and NWS images is shown in Fig. 2a. There was strong linear correlation with slope = 1.03 and $R^2 = 0.989$. VAT mean from NWS images was about 7.8% higher (134.2±64.4 vs. 144.7±62.3cm^3) but no significant difference (P=0.365). The corresponding Bland-Altman plot also shows consistency between the two methods (Fig. 2b).

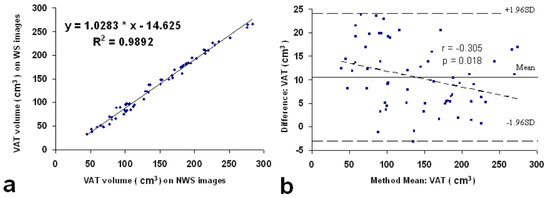

Fig. 2 Comparison of VAT quantification results of WS and NWS images. (a). Linear Correlation plot; (b) Bland-Altman plot.

DISCUSSION Fast, fully- or semi-automated quantification of VAT on standard T1W MRI has been a major challenge. Most of the early methods are inherently flawed because they lack careful consideration of the large fat amount in PV voxels. Our approach is based on a model in which both FV and PV fat voxels are considered. Significant amounts of fat within PV voxels are included in the quantification regardless of the fat-to-water contrast. This essentially improves quantification accuracy and greatly reduces VAT quantification variabilility. It has been shown the PV fat voxels exist mainly at bulk fat boundaries (5). This highly correlated spatial information is an important characteristic that can be used to aid the segmentation procedure. Therefore, most of the PV fat voxels are readily identified with the incorporation of spatial information. In addition, this method does not presume Gaussian peak distribution of either the water or the fat peak on the gray-level histogram, and does not require curve fitting for fat quantification. Importantly, the proposed procedure can be readily applied to both WS and NWS MR images without further parameter optimization. Relatively consistent quantification results can be obtained using the same algorithm. Overall, this method can be potentially applied to multi-site and/or longitudinal clinical or epidemiological studies when consistent fat quantification is needed for MR images with a wide range of image quality.

CONCLUSION The proposed two-step procedure is a feasible approach for fast and automated abdominal fat quantification. The new FCM clustering method, which combines voxel signal intensity with spatial information, has advantage over traditional methods because most PV fat voxels can be identified to reduce VAT quantification variability. It is therefore a non-subjective, reproducible, and fully-automated method for abdominal fat quantification on standard NWS abdominal MR images as well as on WS MR images.

REFERENCES 1) Lancaster et al, JMRI, 1991; 1:363-369. 2) Liu et al, Int J Obes Relat Metab Disord, 2003;27:1267-1273. 3) Poll et al, EJMR, 2002;7:347-352. 4) Positano et al, JMRI, 2004;20: 684-689. 5) Peng et al, JMRI, 2007;26:738-746.