Fully-Automated Abdominal Fat Quantification on Water-Saturated MRI

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Introduction

Fat distribution measurements on humans are important for a cluster of obesity related diseases (diabetes, cardiovascular disease) generally referred to as metabolic syndrome. Monitoring the change of fat distribution longitudinally for patients with metabolic syndrome after pharmaceutical intervention or life style change is also important for improved drug development and disease treatment. Rapid and accurate fat quantification on MR images obtained in the human abdomen has been a challenge on MR images due to the complicated abdominal fat distribution. Manual contour drawing still seems to be the most accepted approach for fat quantification, although it is slow and suffers greatly from inter- and intra-observer variations. We present here a fully-automated abdominal fat quantification method for rapid and accurate subcutaneous adipose tissue (SAT) and visceral adipose tissue (VAT) measurement. Furthermore, comparison of this fully-automated method with a slower semi-automated approach on 64 slices of water-saturated MR images [1] is also presented.

Automated Fat Quantification Method

The fully-automated abdominal fat quantification algorithms were implemented in IDL (Interactive Data Language) as a software package named "**Q-Fat**". The overall idea of this automated fat quantification method is to combine an automated abdominal fat segmentation algorithm with an automated threshold method which has been described earlier [2]. Specifically, the following steps are taken to process each water-saturated MR image. First, each slice is intensity corrected to reduce the fat signal non-uniformity due to imaging system imperfection (e.g., B_0 and B_1 inhomogeneities). Second, automatic regional segmentation is performed to generate the following three contours using a chain code algorithm for boundary detection. The first contour is one surrounding the abdominal region. The second one is a contour at the internal SAT margin. The third contour covers VAT but carefully excludes intra-muscular and vertebral fat as shown in **Fig. 1b**. After all three contours are generated, a gray-scale histogram is then generated for all the image voxels inside the first contour, as shown in Fig. 1d. Curve-fitting is then performed to calculate the mean full-voxel fat signal (S_{max}), and a global threshold value (S_{th}) is set to half of S_{max} to include both full- and partial-volume fat into quantification. The details of the thresholding method are described in [1]. Fig. 1c shows the resultant binary fat-only image with regional color-coded mask. The fat area of SAT is calculated as voxel size times the number of fat pixels between the first contour and the second. The VAT is calculated as voxel size times the number of fat pixels enclosed by the third contour. The resultant fat volumes for each slice are automatically saved in a text file which can be viewed by MS WordPad or MS Excel for further data handling. It takes approximately one second on a typical PC to finish processing one MR slice.

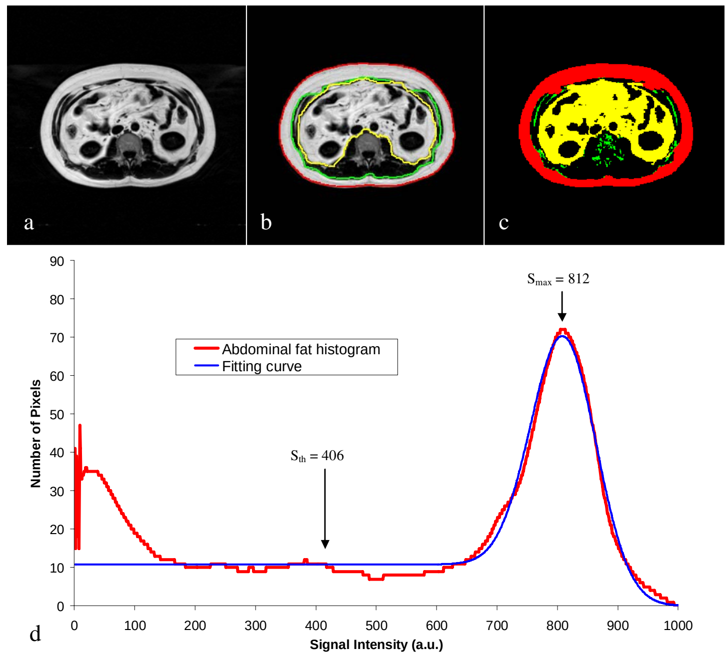

Fig. 1. Fully automated steps for regional abdominal fat quantification. (a): Original WS b-SSFP abdominal fat image; (b): Automated regional segmentation on intensity-corrected image; (c): Color-coded regions to show SAF (red) and IAF(yellow) after automatic image thresholding; (d): Abdominal fat histogram (**red curve**) and the corresponding fitting curve (**blue curve**) used to determine a global threshold value.

Method Verification

8 healthy volunteers each with 8 slices of WS b-SSFP images [1] were fat quantified using both the fully-automated method and a semi-automated method (manual contour drawing to generate the aforementioned three contours). The two approaches shared the same thresholding technique for fat quantification, and the manual contour was also drawn using an interactive manual ROI tool within the **Q-Fat** package. SAT and VAT were both derived for each slice using the two approaches. The manual contour drawing took ~2-5 minutes for each slice, and was used here as a reference technique to evaluate the accuracy of the fully-automated contour drawing algorithm. Statistical analysis was performed to study the difference of SAT and VAT obtained using the two approaches.

Results

For all the 64 slices studied, the correlation between the two approaches on both SAT and VAT is strong (r^2=0.993 and 0.997, respectively). The Bland-Altman plots for SAT and VAT are shown in **Fig. 2**. The SAT and VAT quantified using the automated method are slightly smaller (4.4% and 2.7%, respectively) than those obtained by the manual contour method. There are ~2-4 points outside of the ±1.96SD lines in both SAT and VAT cases, representing compromised automatic regional segmentation. However, those slices had a very small amount of abdominal fat. About 95% of the slices were segmented with excellent accuracy.

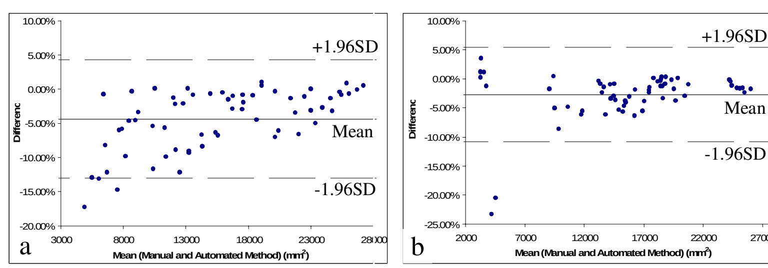

Fig. 2. Bland-Altman plot for 64 slices of SAT (a) and VAT (b). In both cases, the automated method under-estimate fat volume compared to the manual method. The average differences on SAT and VAT are 4.4% and 2.7%, respectively. The automated segmentation method is prone to fail on slice with small amount of fat, but is robust on slices with normal or large amount of fat.

Discussion and Conclusions

Rapid and accurate abdominal fat quantification has been a challenge. The fully-automated method we present here is extremely fast, and is accurate for ~95% of the slices we tested in this study. This fully-automated method included procedures such as intensity correction, background noise elimination, arm cropping, regional fat segmentation and vertebral fat exclusion, automated curve fitting and gray-scale threshold determination, automated SAT and VAT volume calculation, and resultant file output. The whole algorithm takes less than one second to process each slice. We conclude that fully-automated abdominal fat quantification is feasible, and further research is underway to optimize the current automated segmentation algorithm to improve the performance of this method.

References

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2. Peng Q, *et al*, "Automated Method for Accurate Abdominal Fat Quantification on Water-Saturated Magnetic Resonance Images", JMRI. 26(3): 738-46, 2007