Visceral Fat Quantification on MRI: The Impact of Partial Volume Effect

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Introduction

Human body fat distribution imaging has gained renewed attention because obesity and physical inactivity have become global epidemics. It has been shown that excess fat in the central (visceral/intra-abdominal) part of the body is closely correlated with a variety of medical conditions such as diabetes, hypertension, and cardiac disease. Visceral fat imaging and quantification are very challenging because of motion artifacts, highly complicated anatomic components, and the disseminated nature of visceral fat. Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI) are the two imaging modalities widely used for human body composition studies. Compared to MRI, CT can generate images with much higher spatial resolution within much shorter imaging duration leading to more accurate fat quantification. However, CT is not preferable for repeated studies of infants, children, and healthy subjects due to the associated ionizing radiation exposure. With the development of a novel ultra-fast fat imaging MRI sequence called water-saturated balanced steady-state free precession (WS b-SSFP) [1], very high contrast fat-only MR images can be generated. In addition, the high quality images also enable a novel fat quantification approach based on a fat distribution model leading to accurate fat quantification on both full- and partial-volume fat on MR images with commonly used spatial resolution [2]. It is the goal of this article to study the impact of partial volume effect on the quantification of human visceral fat in MR images with typical spatial resolution.

Methods

9 healthy volunteers (average BMI=25.1) underwent abdomen imaging in a 1.5 T clinical MR scanner using a standard quadrature-body coil. The details of the imaging experiments are described in reference [1]. Briefly, an ultra-fast 3D WS b-SSFP scans were employed for fat-only abdominal imaging with breath hold. 8 slices at L2-L3 level were acquired in 11 seconds. Therefore, motion induced signal averaging was negligible. Acquired image spatial resolution was about $1.6\times1.6\times10$ mm^3. Image processing was accomplished using an automated fat quantification software package named "**Q-Fat**" developed in house. Several steps were taken to quantify both full- and partial-volume visceral fat voxel numbers. Each slice first underwent intensity correction to reduce the fat signal non-uniformity due to imaging system imperfection (e.g., B_0 and B_1 inhomogeneities). In the next step, visceral fat was automatically segmented and gray scale histogram was generated (**Fig. 1**). Curve-fitting was then performed to separate, and quantify the number of full- (N_f) and partial-volume fat voxels (N_p). The total N_f and N_p was the summation of the 8 N_f and 8 N_p from 8 slices of each subject, respectively. The volume of full-volume fat (V_f) is calculated as N_f times voxel size, and the volume of partial-volume fat (V_f) was calculated as half of N_p times voxel size. The details of curve fitting and the fat quantification method based on a fat distribution model have been given previously in reference [2].

Results

Results of N_p, N_f, N_p/N_f, and V_p/V_f of visceral fat are shown in Table 1 (N_f and N_p are shown as pixel numbers). In each subject, N_p are much larger than the corresponding N_f for each subject. The N_p/N_f values are between 1.18 and 3.21. The average N_p is more than twice the average N_f (N_p/N_f=2.1). In addition, the ratio is generally higher for subjects with lower BMI and less visceral fat. In these subjects, a larger portion of visceral fat is partial-volume fat on MR images. The corresponding volume of fat stored as partial-volume fat range from 59.2% to 161% of fat stored as full-volume fat. The average V_p is actually more than that of V_f (V_p/V_f=104.0%). Again, V_p/V_f is generally higher for subjects with less visceral fat.

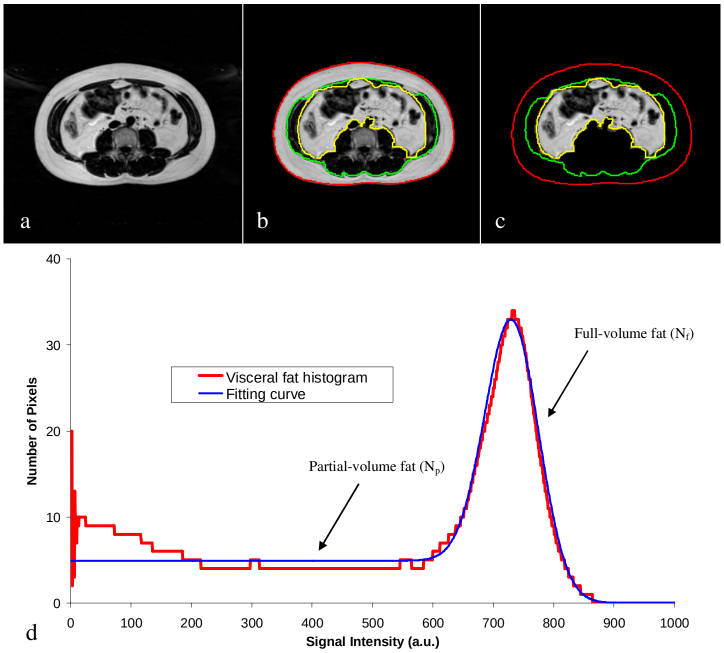

Fig. 1. Image processing steps for visceral fat partial-volume effect analysis. (a): Original WS b-SSFP abdominal fat image; (b): Automated regional segmentation on intensity-corrected image; (c): Visceral fat only image; (d): Visceral fat histogram (**red curve**) and the corresponding fitting curve (**blue curve**) for full- and partial-volume fat voxel number quantification.

Discussion

MR images are generally known to have much lower spatial resolution than CT images. This greatly reduces the accuracy of fat measurement on MRI since partial-volume fat may contribute a significant part to the total visceral fat. This concept is strongly supported by this study. Our results show that the average fat volume quantified from partial-volume fat voxels is 104.0% of that from full-volume voxels. This effect is more significant on subjects with less visceral fat. Quantification of partial-volume fat, however, is very important. For example, initial visceral fat volume response after therapeutic treatment or intervention may happen mainly on disseminated fat instead of on bulk fat. Unfortunately, most traditional manual or semi-automated visceral fat quantification methods are based on non-water-saturated MR images. In those images, partial-volume fat gives intermediate signal which overlaps with lean tissue signal, and is easily excluded from being quantified. Mainly full-voxel or bulk fat can be quantified. To make things worse, partial volume effect also contributes to the large inter- and intra-observer variations, as traditional fat quantification is usually very subjective. The exclusion of partial-volume fat from total visceral fat is a major limitation of MRI compared to CT because this large amount of fat may also play an important metabolic and endocrine role in human.

By using an improved fat quantification method on water-suppressed MR images, both full- and partial-volume fat can be quantified highly independent of the imaging resolution [2]. Therefore, much more accurate fat quantification can be achieved with nonsubjectivity and full automation. We believe that wider applications of the new fat imaging and quantification techniques will greatly increase the importance of MRI on body fat distribution research due to the significantly reduced cost/difficulties and significantly improved accuracy in visceral fat quantification.

Table 1. Comparison of N_p and N_f of Visceral Fat (n=9)

Subject #	BMI	N_f	N_p	N_p/N_f	V_p/V_f
1	29	30123	35663	1.18	59.2%
2	25	18394	32929	1.79	89.5%
3	23	14296	31152	2.18	109.0%
4	23	19977	44603	2.23	111.6%
5	25	20380	49683	2.44	121.9%
6	22	13931	44734	3.21	160.6%
7	23	18900	47822	2.53	126.5%
8	29	36659	57390	1.57	78.3%
9	27	28839	46016	1.60	79.8%
Std dev	2.7	7756	8546	0.6	30.8%
Mean	**25.1**	**22389**	**43332**	**2.1**	**104.0%**

References

1. Peng Q, *et al*, "Water-Saturated 3D Balanced Steady-State Free Precession for Fast Abdominal Fat Quantification", JMRI. 21(3):263-71, 2005.

2. Peng Q, *et al*, "Automated Method for Accurate Abdominal Fat Quantification on Water-Saturated Magnetic Resonance Images", JMRI. 26(3): 738-746, 2007