Determination of body compartments at 1.5 and 3 Tesla, combining three volume estimation methods

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Introduction: Insulin resistance and the metabolic syndrome are cardiovascular risk factors with enormous consequences for the individual patient and the health care systems all over the world. In order to characterize the phenotype of these patients and the effect of various treatments, MRI is increasingly used to determine whole body fat (WBF), visceral adipose tissue (VAT), lean body volume (LBV), and whole body volume (WBV). Several methods are available to determine these volumes based on a series of MR images (Fig.1A – 1C), including threshold algorithms [1], drawing of contours, or point counting methods [2,3]. At 1.5 Tesla, a threshold value can be determined with only little interaction by an operator. However, it becomes increasingly subjective and time-consuming at 3 Tesla, where rf-based image variations are pronounced (Fig.1A). Point counting [2] is a sparse sampling method that is well established in stereology [3,4] and is based on the fact that a sufficiently large number of points on a grid hitting a structure is strictly proportional to its area. According to equation 1, the volume of a structure in a multi-slice dataset can be determined (D = inter-slice distance, d = point spacing, C_i = number of points counted in slice i, n = number of pictures). In this study, a method is proposed and tested that uses point counting algorithms in two groups of age-, weight-, height-, and BMI-matched volunteers at 1.5 and 3 Tesla.

Equation 1: $$V = D \cdot d^2 \cdot \sum_{i=1}^{n} C_i$$

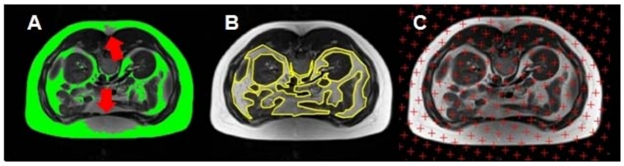

Fig.1: Simple threshold-only algorithms (1A) often fail to determine the fat-area correctly at higher fields with inherent rf-inhomogeneity. The determination of a threshold is often a compromise with over-estimation in one part of the image that is subjectively compensated by another, underestimated part of the image. On the other hand, contour methods (1B) and point counting without preparation (1C) are very time consuming and operator dependent.

Methods: Fig.2 shows how the proposed method combines the strengths of the three methods in Fig.1. and thus avoids their weaknesses: (i) the region of visceral fat is separated from subcutaneous fat by a simple (yellow) contour line (ii) the points for the point counting method are set or deleted by the program based on a threshold value, and (3) visual inspection of the points lets the operator correct for intensity variations resulting from rf-inhomogeneity or flow artifacts. The home-built program (MATLAB R2007a) calculates the volumes according to Equation 1. A T1-weighted fast spin echo technique (echo train length 7) was used (1.5T: TR= 486ms, TE=11ms and 3T: TR=452ms, TE=38ms). Axial slices from fingers to toes were recorded with a slice thickness of 10 mm, spacing between slices 20 mm, 5 slices per sequence, 147 phase encoding steps, 75% sampling, 75 % phase field of view, acquisition matrix 256 x 192, and pixel spacing 2 mm/pixel. 12 subjects were measured at 1.5 Tesla (41.1 ± 12.3 y, 87.8 ± 23.5 kg, 1.72 ± 0.09 m, BMI = 29.3 ± 6 kgm^{-2}) and an age-, weight-, and BMI-matched group of 12 subjects was examined at 3 Tesla (39.9 ± 11.1 y, 86.7 ± 15.2 kg, 1.71 ± 0.12 m, BMI = 29.5 ± 3.5 kgm^{-2}). All 24 datasets were analyzed by the threshold-only method [1] and by the proposed method.

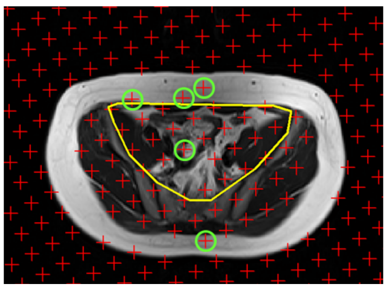

Fig.2 shows the proposed method, based on a threshold-prepared point counting that can distinguish areas inside/outside a yellow contour in order to separate VAT and subcutaneous fat. Because of the sparse sampling principle, only a few points have to be corrected by an operator (green circles). The time to analyze an image is comparable to a threshold-only method, however, in cases of intensity variations due to rf-inhomogeneity or flow artifacts, it is much more robust.

Results: The time that is needed to analyze a 3 Tesla whole body image series (typically 100-120 images) is comparable for the threshold-only method (about 30 min) to the proposed method (about 40 min). The threshold-only method required careful determination of the threshold, often ending in a compromise with under-estimation in one part and over-estimation in another part of the image. The agreement between the two methods (WBV illustrated for one volunteer in Fig.3) is very high for whole body volume (r^2 = 0.994), whole body fat volume (r^2 = 0.966), subcutaneous fat volume (r^2 = 0.966), and visceral fat volume (r^2 = 0.966), if images at all field strengths are used. The separate determination of the whole body volume at 1.5 Tesla resulted in a comparable accuracy for both methods (r^2 = 0.951 for both methods), while an analysis of the images at 3 Tesla lead to a slightly higher accuracy of the proposed method (r^2 = 0.978), as compared to threshold-only (r^2 = 0.964). A measure for the accuracy of the proposed method can be found, if the different volumes determined by MRI, translated to weight by the specific density of the various tissue types (WBF, LBV, bones estimated from body length), are compared with the weight of the volunteers determined by a scale. The proposed method shows an excellent agreement between MRI determined weight and the scale in Fig.4.

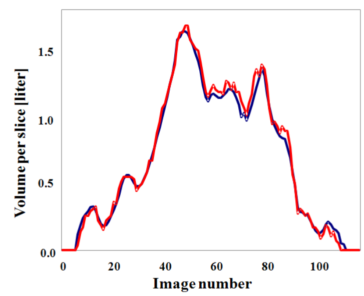

Fig.3 compares WBV profiles at 3Tesla (red = proposed method, blue = threshold-only)

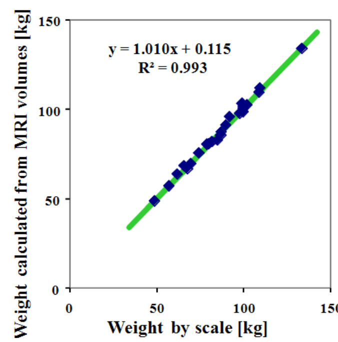

Fig.4 shows the accuracy of the MR based calculation of the weight as compared with the weight determined by a scale

Discussion and Conclusions: Determination of the volume of highly fragmented tissue types in the whole body with the proposed point counting method is accurate, feasible, and rapid if threshold and contour methods are used to prepare the points before manual interaction. In comparison with threshold-only methods (Fig. 1), the proposed method is robust and copes even with large variations in signal intensity as shown in vitro [2]. As threshold-only methods, it requires user-interaction but due to the sparse sampling principles, the number of necessary corrections is minimal, affecting typically only very few points (Fig.2). The proposed method is not limited to cope with rf-inhomogeneity at higher field strength but is also suited for every source of image variation, such as flow artifacts or surface coil acquisition.

References: [1] J.Machann et al. JMRI 2005, 21: 455. [2] T.Buehler et al. ISMRM 2009, 17: 2872. [3] M.Mazonakis et al. Magn.Reson.Imag. 2004, 22: 1011. [4] N.Roberts et al., Br.J.Radiol. 1994, 67: 1067.

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