Determination of whole body fat and visceral adipose tissue, combining three volume estimation methods

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Introduction: Whole body fat (WBF) and particularly visceral adipose tissue (VAT) are of paramount importance as cardiovascular risk factors related to the metabolic syndrome. MRI followed by threshold methods has been successfully used to estimate WBF and VAT at 1.5 T [1], however, because these measurements are often combined with other MR methods that benefit from the higher field strength, e.g. MRS, 3 Tesla MR systems are increasingly used for these examinations. Inhomogeneity of the radiofrequency field in the abdominal region at 3 Tesla jeopardizes the estimation of VAT and WBF and makes it necessary to find a more robust and accurate method to measure these volumes. This study combines the strengths of three volume determination methods, thus avoiding the inherent weaknesses of the methods: (a) threshold techniques are fast but fail as soon as the rf-inhomogeneity reduces the signal intensity of fat below that of water in T1-weighted sequences (b) manual planimetric (contour) methods [2] can overcome intensity variations but are almost unfeasible in the visceral region with small areas of fat between bowel and other abdominal organs, and (c) point counting [3] is an established method in stereology but is rather time consuming, in particular in the fragmented visceral fat.

Methods: The proposed method (Fig.1) is based on three sequential steps: (1) the region of visceral fat is separated from subcutaneous fat by a simple (yellow) contour line (2) 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.
The program has been programmed in MATLAB R2007a (The MathWorks, Natick MA) and handles in vivo (Fig.1) as well as phantom data (Fig.2). In order to test the accuracy of the proposed method against a known volume, phantom sets of 8, 7, 6, 5, 4, 3, 2, and 1 bottle(s) of sun flower oil (average weight per bottle: 929 g ± 2 g) arranged between 6 bottles of water of 1.5 liters each, has been imaged on a 3T MR system (SIEMENS TRIO) using a T1 weighted FSE sequence (TR = 452 ms, TE = 38 ms). Following an imaging series without extra rf-inhomogeneity, small pieces of aluminum foil were introduced around some of the sun flower oil bottles to generate rf-inhomogeneity (Fig.2). The calculation of the fat volume is obtained as follows,

$$V = D \cdot d^2 \cdot \sum_{i=1}^{n} C,$$

where D is the slice thickness in cm, d the grid size in pixels times the pixel spacing in cm, C the number of remaining counted grid points within or outside the contour and n the number of pictures in one data set. Three subjects counted the data set twice following an instruction session. The threshold value was defined halfway between the histogram peaks for the water and the fat voxel-intensity.

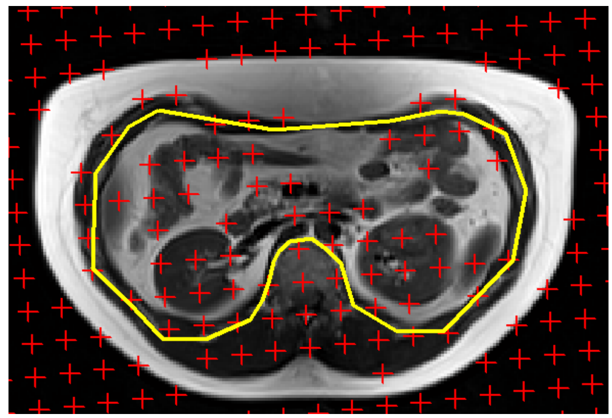

Fig. 1: Determination of visceral fat using the proposed method (Typically, up to 10 crosses have to be edited manually per slice)

Results: While threshold-only and the proposed method agree very well with the gold standard in the homogenous images, the threshold determination underestimates the volume systematically in the inhomogeneous images (Fig.2). All R^2 values of the subjects and threshold determination are above 0.997, however, the average systematic deviation varies considerably between -1.8% for the proposed method without and -4.4% with the aluminum foil, compared to -5.9% of the threshold method in the homogeneous images and -28.4% in the inhomogeneous images. The intercepts of all regression lines are indistinguishable from 0, except the regression for threshold-only in inhomogeneous images (p = 0.001).

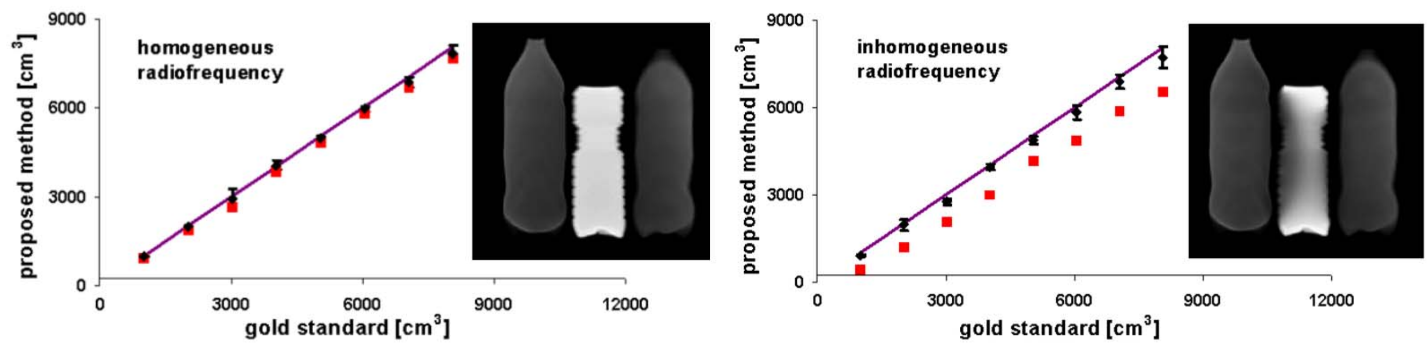

Fig. 2: left without, right with aluminum foil to generate rf-inhomogeneity. Red squares: automatic determination of volumes based on threshold method, black symbols show the mean from three individuals who determined the volumes twice using the proposed method. Error bars indicate the standard deviation (to a great deal hidden by symbols). The solid line represents unity.

Discussion and Conclusions: Determination of the fragmented VAT depots 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. While threshold-only methods fail as soon as rf-inhomogeneity reduces the intensity of fat voxels to that of a voxel with water/non-fat-organs, the proposed method leads to acceptable results.

References: [1] J.Machann et al. J.Magn.Reson.Imaging 2005, 21: 455. [2] M.Mazonakis et al. Magn.Reson.Imag. 2004, 22: 1011.
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