Accuracy of wholebody fat quantification with MRI: A comparison to Air-Displacement Plethysmography

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Introduction Besides the total amount of adipose tissue, its distribution has recently been recognized as an important factor in the pathogenesis of metabolic diseases like diabetes mellitus [1]. MRI is capable for space-resolved imaging of fat distributions in the human body and various segmentation techniques have been introduced, which are based on MRI data [2,3]. In these studies, fat related voxels are typically summed up for fat quantification neglecting partially filled fat voxels. In this work, we present a fully automatic algorithm for fat quantification in MRI two-point Dixon data with an explicit weighing of fat voxels for the correction of these partial volume effects. Furthermore, the proposed algorithm includes compensation of B1-inhomogeneities in the MR images and the separation of subcutaneous and inner fat in the abdomen. MR quantification results were compared to air-displacement plethysmography (ADP) measurements, which served as a standard of reference.

Materials and Methods To evaluate the accuracy of the proposed method, phantom measurements were performed. Seven phantoms (capacity: 2l) with varying fractions of peanut oil (0, 20, 40, 50, 60, 80, 100%) and solid peaces of pure agarose gel (2% w/v, doped with 0,3ml Magnevist per litre) have been built and arranged in a bundle to simulate the fat-water distribution within the human body. MRI was performed on a 1.5T wholebody scanner (Magnetom Espree, Siemens Medical Solutions, Erlangen. Germany) using a continuously moving table axial 2D gradient echo sequence with two bipolar readout gradients. Sequence parameters were: TE_1=2.38ms (opposed-phase), TE_2=4.76ms (in-phase), TR=93ms, FOV=450x366mm^2, flip angle=70°, matrix size=320x259, and slice thickness=5mm. For each slice position one fat and one water image were provided by a two-point-Dixon reconstruction method.
Furthermore, a volunteer study has been performed including 10 men and 1 woman (average age 30±10, Body Mass Index BMI 23.8-38.7). MR measurements from the head to the ankle were conducted using the presented sequence parameters whereas the FOV was adapted to the object size (FOV=450x(310-394)mm^2). For comparison, each volunteer underwent an additional ADP examination (BodPod, LifeMeasurement Inc.), which served as a standard of reference. To test the reproducibility of fat quantification results based on MRI data, the abdominal region of one volunteer has been repeatedly measured ten times on two consecutive days.

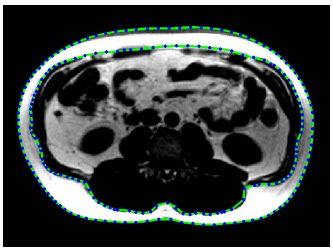

Fig. 1: Subcutaneous and inner fat was separated via an active contour algorithm (snakes).

For all in vivo MR measurements, subcutaneous and inner fat were first separated slice by slice whereas the boundary between both fat compartments was found via an active contour algorithm (snakes) [4] as exemplarily shown for one 2D axial slice in Fig. 1. A binary fat mask was used for the segmentation. One snake detected the outer border of the subcutaneous fat. In a next step, each pixel in the mask outside this border was set to 1 and another snake detected the inner border of the subcutaneous fat compartment. The segmentation procedure was once performed fully automatic with fixed parameters to evaluate the performance of the automatic segmentation and a second time with additional manual corrections of detected borders. The fat volume of the phantoms as well as the volume of segmented fat compartments within the in-vivo study was quantified. Background noise was eliminated in fat images via thresholding (5% of the signal-maximum). Further, the noise corrected fat image was divided by the in-phase image on a pixel-by-pixel basis to derive an image with signal fractions of fat voxels. In these images, pure fat voxels were identified for each slice if respective signal values exceed 95% of the maximum [5]. Due to B1-inhomogeneities, these pure fat voxels do not have the same signal intensity in the fat images but rather reflect the receiver coil sensitivity profiles. To compensate for this effect, this profile was interpolated for all image voxels in each slice based on the signal distribution observed for pure fat voxels similar to the method proposed in [6]. Fat images were finally divided by the interpolated sensitivity profiles and signal non-uniformities were compensated. Each fat voxel was weighted according to the corrected signal intensities of identified pure fat voxels and summed up [7]. Multiplication with voxel volume and fat density (0,9kg/l) resulted in the total fat mass.

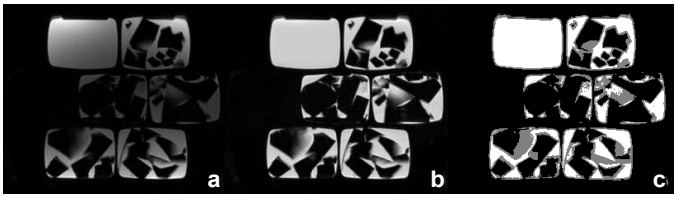

Fig. 2: (a) Fat image of the phantom, with 7 compartments, each with a different fraction of peanut oil and agarose pieces before (a) and after correction of B1-inhomogeneities (b). (c) Corresponding fat mask with identified pure fat voxels (white) and partially filled fat voxels (gray).

Results An axial MR image of the manufactured phantom is shown in Fig.2 before and after the correction for B1-inhomogeneities. Pure fat voxels identified by the presented algorithm are highlighted in Fig.2c. The fat volume in the bundle of phantoms was overestimated by 2.7% compared to the volume known from the manufacturing process. The results of the volunteer study are presented in Fig. 3 where the total fat volumes achieved with the proposed technique are illustrated as well as the results provided by the ADP measurements. Compared to the standard of reference, fat masses of volunteers with a BMI≥28 were overestimated by (10±6)%. This trend becomes even more evident for volunteers with a BMI<28. Results in Fig.3 are based on the fully automatic segmentation procedure. Fat volume calculation with additional manual corrections in the segmentation procedure yielded slightly different results (deviation to fully automatic evaluation: (0.2±1.3)%). In repeated MR measurements of one volunteer, the quantified total fat volume varied with a standard deviation of 0.7%. Standard deviations for the subcutaneous and inner fat volumes were 0.9% and 1.2%, respectively. Standard deviations for measurements performed within one day had even been smaller.

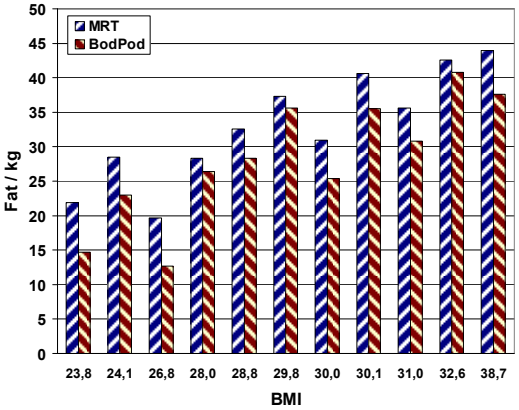

Fig. 3: Fat volumes quantified via the proposed algorithm based on MRI data and evaluated in ADP measurements. The study included 11 volunteers with a BMI of 23.8 to 38.7.

Discussion and Conclusion Phantom measurements demonstrated the accuracy of the proposed method for fat quantification in MRI data. B1-inhomogenities were reliably compensated (Fig.2b). Small deviations to the known filling volume might rely on the fact, that MR images do not exactly reproduce the original object in general. In in-vivo studies, however, higher differences between MR and ADP results could be observed than expected by the phantom measurements. However, adipose tissue in the body is a compound of pure fat, water, proteins and minerals, which has been neglected in this study. Thus, even identified pure fat voxels do not only consist of fat. This would also explain higher deviations observed for volunteers with a low BMI where fat volume results are more affected by such systematic errors. Nevertheless, the evaluation in repeated measurements of one volunteer demonstrated the reproducibility of the presented quantification method and is promising for future studies which should track changes in fat distributions (subcutaneous and inner fat) of patients.

References: [1] Powell M, Nature 2007; 447(7144):525-7. [2] Positano V et al., JMRI 2004; 20(4):684-9. [3] Kullberg, J et al., JMRI 2009; 30(1):185-93. [4] Kass M et al., IJCV 1988; 1(4):321-31. [5] Leinhard OD et al., Proc. ISMRM 2008; #1519. [6] Knutsson H et al., Proc. of IEEE 1993; 515-23. [7] Hu HH et al., MRI 2008; 28:1483-1491.