Free-Breathing 3D Water-Fat Separation and R_2* Mapping in the Heart

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Introduction: Water-fat resolved cardiac MRI allows detection of fibro-fatty infiltration of the myocardium and improved characterization of tumors and masses [1]. Whole-heart water-fat imaging has also been suggested as an alternative to chemical-shift fat suppression to achieve better delineation of the coronary arteries [2]. However, conventional separation methods based on chemical-shift-encoded acquisitions do not account for the effect of T_2* decay, resulting in erroneous signal intensities in the separated water and fat images in regions of rapid T_2* decay [3]. Myocardial R_2* (=1/T_2*) estimation is therefore essential to achieve accurate fat-water separation, as well as to quantify myocardial iron concentration. Previous studies have shown that susceptibility variations due to the presence of tissue-air interfaces and deoxygenated blood in large epicardial veins hamper R_2* measurements in the myocardium, leading to increased R_2* values especially in the inferior and inferolateral segments when thick slices are used [4,5]. In this work we propose a 3D, interleaved, multi-echo acquisition strategy with thin slices and IDEAL (iterative decomposition of water and fat with echo asymmetry and least-squared estimation) to obtain robust myocardial R_2* measurements and improved whole-heart water-fat imaging during free breathing.

Methods: A 3D, spoiled gradient-echo, multi-echo pulse sequence was implemented on a 3T whole-body MR system (MR750, GE Healthcare, Waukesha, WI). Navigator gating and ECG gating with images acquired in mid-diastole were used to compensate for respiratory and cardiac motion. A T_2 preparation period with an effective TE of 48ms was played every R-R to improve contrast between the blood and the myocardium [6]. Six echoes (first TE = 1.3ms; echo spacing = 1ms) were acquired in two interleaves with fly-back gradients. Fifty axial slices with a 3mm slice thickness and a total of 160 views per slice (256 points per readout), segmented over 4 R-R periods, were acquired over a 34cm in-plane FOV. Other imaging parameters included: phase FOV = 0.8, receiver bandwidth = ±142kHz, flip angle = 15°, TR = 9.1ms. A total of 400 R-R intervals were needed to complete the acquisition, resulting in a scan time of about 12 minutes, assuming a heart rate of 60 beats per minute and a navigator efficiency of 50%.

The effect of increased susceptibility variations over the imaging FOV on the resulting R_2* values was simulated in a phantom by progressively increasing the z shim gradient amplitude and was also evaluated in healthy volunteers. The proposed 3D technique was compared to a previously reported 2D multi-echo pulse sequence for cardiac water-fat imaging acquired in a breath-hold [7]. Imaging parameters for the 2D 6-echo acquisition included: first TE = 1.8ms, echo spacing = 1.1ms, TR = 9.3, FOV = 35cm, matrix size = 224 × 192, slice thickness = 8mm, flip angle = 15°, receiver bandwidth = ±32kHz and a SENSE factor of 2, resulting in 16- to 20-second breath-holds per slice. All images were acquired using a receive-only 8-channel cardiac coil. Water/fat separation with R_2* correction and R_2* maps were obtained using IDEAL, which also accounted for the spectral complexity of fat [8].

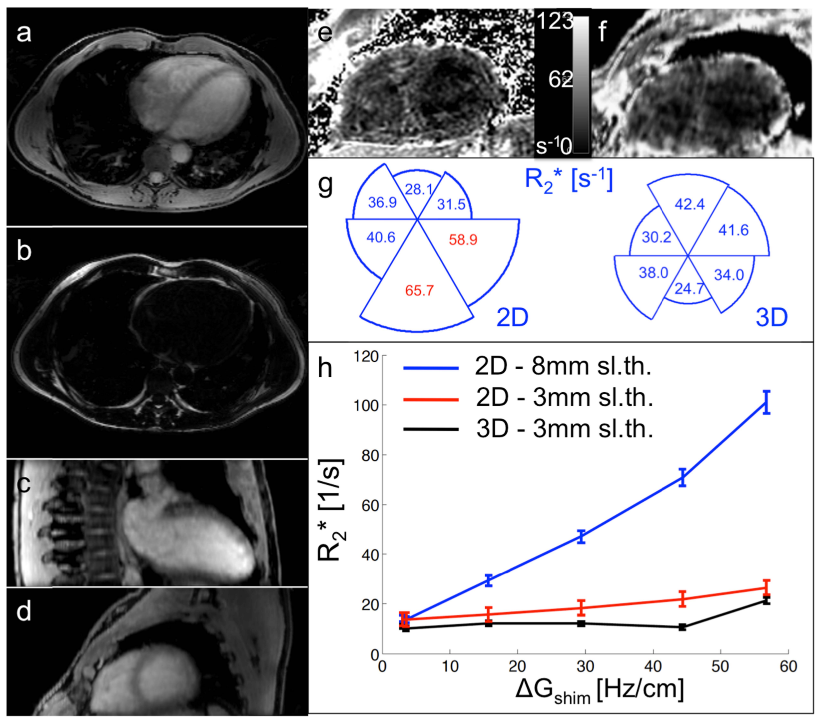

Figure 1: Water (a) and fat images (b) acquired in a healthy volunteer using the proposed 3D cardiac IDEAL technique, with long-axis (c) and short-axis (d) reformats of the water image. R_2* maps acquired with the 3D technique (f) resulted in a more uniform distribution of R_2* values (g) when compared to the 2D acquisition (e). Phantom data (g) confirmed reduced susceptibility-induced increase in R_2* when the 3D technique was used.

Results and discussion: Water and fat images acquired in a healthy volunteer using the proposed 3D cardiac IDEAL technique are shown in Fig. 1a and b, respectively, with Fig. 1c and d showing long- and short-axis reformats of the water image. R_2* maps acquired with the 2D technique (Fig. 1e) revealed increased R_2* values in the inferior and inferolateral segments (Fig.1g). A more uniform distribution of R_2* values was found with the 3D technique (Fig.1f-g) due to higher through-plane spatial resolution and reduced susceptibility-induced increases in R_2*. In a phantom, R_2* was found to increase significantly with the amplitude of the z shim gradient when the 2D acquisition and an 8mm slice thickness were used (Fig.1h). Using 3mm slices, the R_2* variation was reduced considerably. The 3D acquisition gave a uniform estimation of R_2* while maintaining high SNR, confirming the advantage of using a 3D whole-heart acquisition for accurate R_2* measurements and R_2*-corrected water-fat imaging.

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References: [1] Kellman P et al. MRM 2009; 61:215; [2] Koken P et al. Proc. ISMRM 2011; p.117; [3] Yu H et al. JMRI 2007; 26:1153; [4] Reeder SB et al. MRM 1998; 39:988; [5] Atalay MK et al. MRM 1999; 45:341; [6] Brittain JH et al., MRM 1995; 33:689; [7] Vigen KK et al. Proc. ISMRM 2009; p.2775; [8] Yu H et al. MRM 2008; 60:1122.