Myocardial T2* Mapping Free of Distortion Using Susceptibility Weighted Spin-Echo Based Imaging: A Feasibility Study at 1.5 T and 3.0T

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Introduction

Myocardial T_2* mapping is of proven value for the assessment of myocardial iron content and tissue oxygenation [1, 2]. Conventionally, T_2*-weighting is accomplished with gradient echo based or echo-planar imaging techniques. However, the disadvantages of T_1-related saturation effects, artefacts due to ventricular blood flow and image distortion must be addressed to pave the way for a broader clinical acceptance. Hence, spin-echo based acquisition strategies, which generate T_2* contrast free of distortion, represent a valuable alternative. This study demonstrates the promise of cardiac and navigator gated, susceptibility weighted, fast spin-echo imaging in conjunction with ventricular black blood preparation, for anatomically accurate T_2* mapping of the heart.

Methods:

The proposed cardiac gated imaging technique comprises (i) a double inversion recovery module for ventricular blood suppression, (ii) a navigator module for respiratory motion compensation and (iii) a fast spin echo acquisition [3]. T_2*-weighting was accomplished by implementing displaced UFLARE [4, 5] using an extra evolution time tau (τ) between the initial excitation pulse and the first refocusing pulse. Studies in a phantom, ferrofluid samples and volunteers were conducted using a 5-element / 6-element cardiac coil array at 1.5 T / 3.0 T (Philips Achieva, Best, The Netherlands). Images were acquired with: scan matrix 192x192, FOV 250 mm, echo train length 20, TR=2 R-R intervals, 3 slices with a thickness of 8 mm each. To test the navigator gating in the UFLARE sequence, an oil phantom was placed on two artificial lungs (Test Lung 160, Siemens, Erlangen, Germany). T_2*-maps were generated from a series of images with τ ranging from 0 to 40 ms at 1.5 T and 0 to 25 ms at 3.0 T using susceptibility weighted UFLARE. For comparison, a modified multi-echo echo-planar approach was employed [6]. For T_2* relaxometry, a dilution series of a dodecanoate stabilized ferrofluid [7] using an iron content ranging from 3.0×10^{-5} to 0.25 µmol Fe/ml was prepared .T_2* relaxation maps were created using the Levenberg-Marquardt fit algorithm together with ΔB_0 correction [6].

Results:

Unlike EPI, UFLARE of a standard head phantom produced distortion free images (Figure 1) which are vital for the desired cardiac MRI applications. Figure 2 shows T_2* maps derived from multi-echo gradient-echo images (Figure 2a) and UFLARE images without (Figure 2b) and with respiratory motion emulation using the lung phantom (Figure 2c) at 1.5 T (top row) and at 3.0 T (bottom row). At 1.5 T / 3.0 T measured mean T_2* values of the oil phantom were 23.1±0.6 / 13.4±0.7 ms for multi-echo gradient-echo. For comparison, the UFLARE approach yielded T_2*=(22.1±1.7 / 13.1±2.2) ms under static conditions. In the case of respiratory motion simulation, mean T_2* values of T_2*=(23.6±1.5 / 12.4±2.2) ms were determined from UFLARE images. It should be noted that the standard deviation obtained for T_2*-mapping with UFLARE is inferior to that of multi-echo gradient-echo. This behaviour is caused by (i) UFLARE's increased sensitivity to B_1-inhomogeneities, which are pronounced at 3.0 T and (ii) by phantom vibrations induced by UFLARE's gradient switching scheme. From T_2* relaxometry of the dodecanoate stabilized ferrofluid relaxation rates of $R_2^* = 478 \pm 17$ $mM^{-1}s^{-1}$ and $R_2^* = 450 \pm 13$ $mM^{-1}s^{-1}$ were derived from UFLARE and multi-echo gradient-echo imaging respectively. Figure 3 depicts short axis views of the heart using free breathing UFLARE in conjunction with double IR preparation without (Figure 3a) and with T_2*-weighting using an evolution time of τ=10 ms (Figure 3b) and τ=20 ms (Figure 3c). Image quality, signal-to-noise ratio (*τ=0 ms:* SNR=20 at 1.5 T, SNR=120 at 3.0 T; *τ=10 ms:* SNR=17 at 1.5 T, SNR=73 at 3.0 T) and ventricular blood suppression are suitable for clinical applications. Even with strong T_2*-weighting the images are free of distortion due to B_0-inhomogeneities and free of physiological motion artifacts. Figure 3d depicts T_2*-maps derived from UFLARE data sets obtained at 1.5 T (top) and 3.0 T (bottom). The mean T_2* value of the inferoseptal myocardium was found to be 29.9 ± 6.6 ms at 1.5 T and 22.3 ± 4.8 ms at 3.0 T which is consistent with previous reports [8-12]. For posterior myocardial areas close to the vena cava T_2*-values of 24.0 ± 6.4 ms (1.5 T) and 15.4 ± 1.8 ms (3.0 T) were observed.

Discussion and Conclusions:

The feasibility and anatomical fidelity of T_2*-weighted fast spin echo imaging have been demonstrated together with the image quality advantage over EPI. The proposed susceptibility-weighted spin-echo based approach promises to extend the capabilities of CVMR, including mapping and quantification of myocardial iron content, assessment of endothelial function, detection of stress induced angina pectoris, and differentiation of arteries and veins, which have all been elusive hitherto (1,2). It also holds the promise to potentially obviate the need for contrast agents for the detection of myocardial perfusion deficits while avoiding the drawbacks of commonly used EPI and gradient echo based approaches [13]. In conclusion, we anticipate the extension of this work to a broader clinical study at 3.0 T (i) to exploit the SNR and contrast-to-noise (CNR) advantage at high fields, (ii) reducing scan time using parallel imaging and (iii) to moving towards three-dimensional, distortion free, blood oxygen level dependent (BOLD) imaging of the heart.

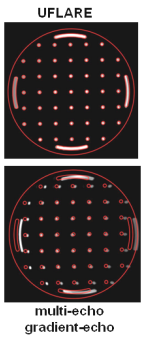

Figure 1: T_2^*-weighted images overlaid on a contour plot of the test object derived from UFLARE **(top)** & EPI **(bottom)**.

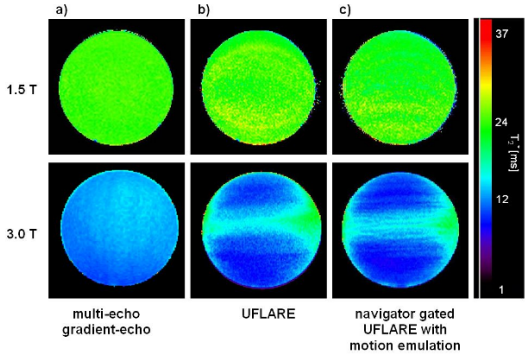

Figure 2: T_2* maps of an oil phantom derived from multi-echo gradient echo imaging **(a)**, UFLARE imaging under static conditions **(b)** and in the presence of motion **(c)** using a lung ventilator at 1.5 T **(top)** and 3.0 T **(bottom)**.

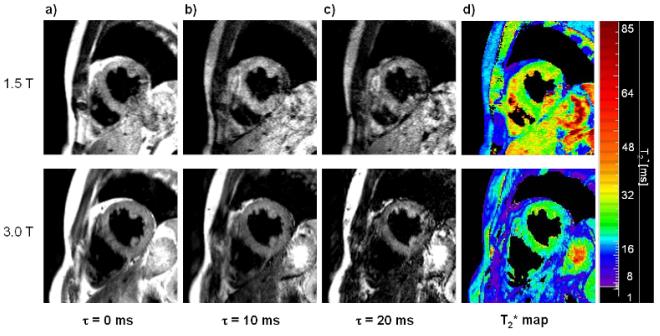

Figure 3: Short axis views of the heart of a healthy subject derived from free breathing UFLARE in conjunction with blood suppression. Images were acquired at 1.5 T **(top)** and 3.0 T **(bottom)** without T_2*weighting **(a)**, with T_2*-weighting of τ=10ms **(b)** and τ=20 ms **(c)**. The corresponding T_2-maps are shown in **(c)**.

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