Myocardial T_2^* mapping free of distortion using susceptibility weighted RARE imaging at 7 Tesla

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Target audience: This work is of interest for basic MR researchers, imaging scientists and clinical scientists.

Purpose: Emerging cardiovascular magnetic resonance (CMR) applications include T_2^* mapping, which is increasingly used for non-invasive myocardial tissue characterization [1]. The linear relationship between magnetic field strength and microscopic susceptibility renders it conceptually appealing to pursue myocardial T_2^* mapping at ultrahigh fields (UHF) [2]. The relatively strong T_2^* weighting required to make gradient echo (GRE) based sequences sensitive to changes in magnetic susceptibility asks for a long evolution time (TE) between RF excitation and data acquisition. This approach increases the propensity for susceptibility artifacts and signal void, which is pronounced at UHF. Rapid Acquisition with Relaxation Enhancement (RARE) imaging is largely free of image distortions related to B_0 inhomogeneity because of the use of radiofrequency (RF) refocused echoes, which also provide intrinsic blood suppression of fast flowing blood. RARE also runs the benefit that T_2^* weighting can be adjusted from zero upwards [3,4]. Notwithstanding these benefits, RF inhomogeneities and power deposition constraints render cardiac RARE imaging at 7 T challenging. Realizing the challenges and opportunities of myocardial T_2^* mapping at ultrahigh fields this works investigates the feasibility of RARE based T_2^* mapping of the heart at 7 T.

Methods: Volunteer experiments were performed on a 7 T whole body MR system (Magentom, Siemens Healthcare, Erlangen, Germany). A cardiac array consisting of 8 bow tie antennas (4 elements posterior, 4 elements anterior) was used for signal transmission and reception [5,6]. All eight elements are supplied with equal-intensity signals, while phase adjustments are achieved by inserting phase-shifting coaxial cables into the setup. After volume selective B_0 shimming myocardial T_2^* mapping was performed for midventricular short axis views using T_2^* weighted RARE (TR = 1 R-R interval, TE = 45 ms, echo spacing (ESP) = 6.5 ms, spatial resolution = (1.2 x 1.2 x 5) mm^3, nominal flip angle = 180°, τ = 0-14 ms, phase encoding H-F). For comparison, multi-echo gradient echo (ME-GRE, TR = 13 ms, 8 equidistant echoes with TE = 2.04-10.20 ms, spatial resolution = (1.2 x 1.2 x 5) mm^3, nominal flip angle = 10°, phase encoding A-P) was used as a reference. For RARE T_2^* weighting is accomplished by inserting an evolution time τ after the excitation pulse whereby an additional phase is accrued reflecting the dimension of T_2^* [3]. To avoid destructive interferences between odd and even echo groups in the RARE echo train a split-echo variant was employed [7]. Two images were reconstructed separately and added afterwards to restore the full available signal intensity. Fat suppression was performed using the slice selection gradient reversal (SSGR) technique [8]. A high resolution RARE image was acquired for anatomical reference exhibiting a spatial resolution of (0.8 x 0.8 x 3) mm^3. Data acquisition was triggered to mid-diastole using a MR stethoscope (easyACT, MRI.TOOLS GmbH, Berlin, Germany). After offline-reconstruction the images were co-registered and fitted to a mono-exponential decay.

Results: High spatial resolution T_2^* weighted RARE imaging using bow tie antennas yielded uniform signal intensity across the myocardium and high myocardium/blood contrast as illustrated in Figure 1. Blood suppression inherent to RARE worked mainly well, however slowly flowing blood surrounding the trabeculae remained visible (Fig. 1). Figure 2A shows a series of T_2^* weighted images derived from RARE using evolution times τ ranging from 0 ms to 14 ms. It should be noted that the geometric integrity of the RARE images is maintained over the range of T_2^* weighting. Subcutaneous fat is mostly suppressed in the RARE images while fat surrounding the myocardium remained present in some areas despite SSGR fat suppression. Myocardial T_2^* mapping was feasible for the RARE based technique (Fig. 2C). For the septum a T_2^* of (16 ± 6) ms was observed for RARE based T_2^* mapping. In comparison, ME-GRE imaging exhibited less blood to myocardium contrast since signal contributions from the blood pool were not suppressed. Despite using volume selective shimming susceptibility artifacts occurred in the inferolateral segment of the heart when using ME-GRE together with echo times larger than 6 ms (Fig. 2B). A T_2^* map derived from ME-GRE acquisitions is depicted in Figure 1D with T_2^* = (15 ± 6) ms for the septum.

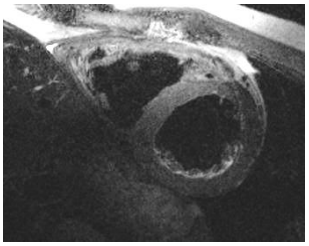

Figure 1: High spatial resolution ((0.8 x 0.8 x 3) mm^3) RARE image which was used as an anatomical reference.

Discussion and Conclusion: Our results demonstrate that the RF power deposition and RF non-uniformity constraints of RARE imaging can be offset at 7 T if cardiac arrays of bow tie antennas are used for transmission. Myocardial T_2^* mapping at 7 T using split-echo RARE is feasible and presents a valuable alternative for T_2^* mapping free of distortion. Myocardial T_2^* derived from RARE imaging matches T_2^* obtained from gradient echo imaging. The intrinsic blood suppression of RARE can be enhanced by inserting a double-inversion recovery preparation module. This would be beneficial for improving the delineation of the myocardium which is challenging for gradient echo based T_2^* mapping. To conclude, RARE based T_2^* mapping at 7 T is of high relevance for advancing the capabilities of UHF-CMR with the ultimate goal to foster explorations into cardiac myocardial microstructure and myocardial tissue characterization.

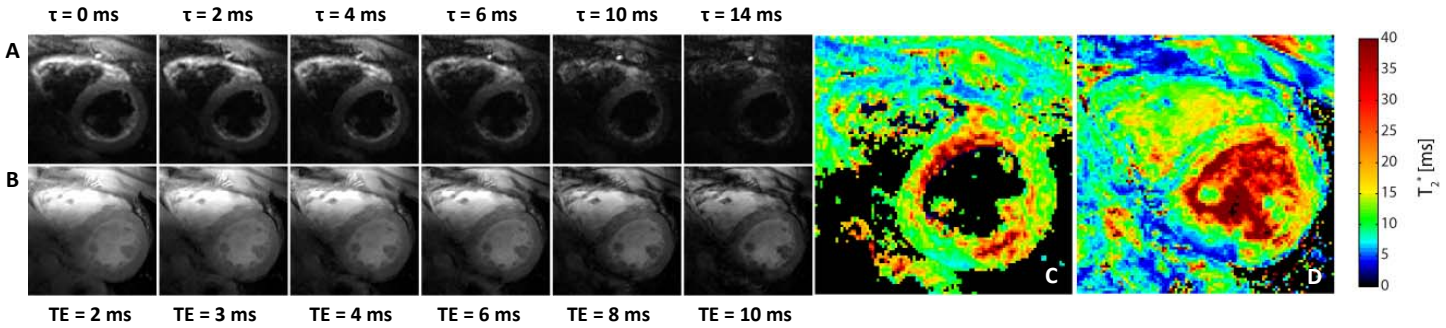

Figure 2: (A) T_2^* weighted split-echo RARE images employing evolution times τ from 0 ms to 14 ms. **(B)** ME-GRE images with TE ranging from 2ms to 10 ms. T_2^* maps calculated from the data in **(A)** and **(B)** are depicted for the RARE based technique **(C)** and for the ME-GRE approach **(D)**.

References: [1] Hezel et al, *PLoS ONE* 2012; 7:e52324; [2] Meloni et al, *MRM* 2013; DOI 10.1002/mrm.24856; [3] Norris et al, *MRM* 1992; 27:142; [4] Heinrichs et al, *MRM* 2009; 62:822; [5] Winter et al, *PLoS ONE* 2013; 8:e61661; [6] Oezerdem et al, *Proc. Intl. Soc. Mag. Reson. Med. 20* (2012), p.2641; [7] Schick, *MRM* 1997; 38:638; [8] Park et al, *MRM* 1987; 4:526