

Highly Accelerated Single Breath-hold Myocardial T_2^* Mapping Using Susceptibility Weighted Fast Spin-Echo Imaging

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Introduction

Myocardial T_2^* mapping is a valuable tool for the assessment of myocardial iron content and tissue oxygenation. Fast spin-echo (FSE) imaging represents an alternative to offset the inherent limitations gradient echo based techniques. The feasibility of navigator gated, susceptibility weighted FSE for anatomically accurate myocardial T_2^* mapping has been demonstrated previously [1]. However, imaging speed and navigator efficiency constraints can inadvertently lengthen scan time and hence diminish image quality due to patient motion. This study examines the applicability of acceleration techniques to accomplish clinically acceptable scan times for myocardial T_2^* mapping. Towards single breath-hold T_2^* mapping, FSE is combined with reduction techniques which exploit spatial (k) and temporal (t) correlations in conjunction with partial-Fourier acquisitions, inner volume imaging, and regional blood suppression.

Methods

The proposed approach comprises a ventricular blood suppression and a fast-spin-echo based UFLARE imaging module [1]. T_2^* weighting is accomplished by using an extra evolution time τ between the initial excitation pulse and the first refocusing pulse. Scan acceleration is accomplished (i) by rectangular inner-volume imaging adapted to the size of the left ventricle resulting in a reduction in the number of phase encoding steps by a factor of 2-3 while providing 1-2 mm in-plane spatial resolution [2], (ii) by replacing the double IR based blood suppression preparation module by regional saturation slabs placed in the left and right atria and across the pulmonary veins facilitating black blood preparation and T_2^* sensitized imaging in a single heartbeat instead of the traditional 2 R-R interval approach; (iii) by 60% partial Fourier acquisition, and (iv) by k-t-BLAST [3] using undersampling factors of $R=2,3,4$ and 6. Short axis views were acquired in healthy volunteers ($n=7$) using a 6-element cardiac coil array at 3.0 T (Philips Achieva, Best, The Netherlands). For T_2^* map generation, sets of 12 images were acquired using $\tau=0-20$ ms, slice thickness=8 mm and $TE=35$ ms, $FOV=(320 \times 173)$ mm², $TR=1$ R-R interval. For comparison, a series of double IR prepared, full FOV, full k-space, T_2^* weighted images was acquired.

Results

The use of rectangular inner-volume imaging resulted in a 2-fold gain in scan time without impairing image quality. Nominal scan time, which does not consider navigator efficiency, was reduced from 256 s to 128 s. Replacing the double IR blood suppression method by a regional saturation slab allowed to reduce TR from 2 R-R intervals to 1 R-R interval resulting in an overall 4-fold scan acceleration. Accordingly, nominal scan time was further reduced to 64 s. Applying k-t acceleration ($R=6$) and partial Fourier acquisition shortened scan time to 12 s permitting single-shot FSE acquisition within a breath-hold period. Figure 1 shows short axis views of conventional and accelerated UFLARE for $\tau=0$ and $\tau=11$ ms. Please note the respiratory motion artifacts which occurred for the conventional approach. These artifacts can be attributed to the long scan time of approximately 9 min caused by a navigator efficiency of 50 %. For the accelerated scans the corresponding T_2^* maps are shown in Figure 2 b)-d). Figure 2a) demonstrates an overlay of a 4-fold accelerated T_2^* map with the corresponding CINE image, showing the high geometric consistency and quality of blood suppression. Among all subjects the average T_2^* value in the inferoseptal myocardium was 17.2 ± 3.6 ms, while posterior myocardial regions showed an average T_2^* value of 12.5 ± 1.9 ms. The inter-subject variability in T_2^* values between 2-fold and 4-fold accelerated UFLARE T_2^* mapping was 1.4 ms for the inferoseptal myocardium and 1.8 ms for posterior myocardial areas.

Discussion

Four-fold acceleration is feasible without compromising image quality and the accuracy of calculated T_2^* values. The low inter-subject variability and the uniform T_2^* values observed promises accurate, reproducible blood oxygen level dependent (BOLD) tissue differentiation and characterization of the heart. Further research is anticipated (i) to further reduce scan time by decreasing the number measurement points along the T_2^* relaxation curve, (ii) to improve the spatial fidelity of T_2^* maps derived from k-t accelerated scans by using k-t PCA [4] instead of k-t BLAST and (iii) to move towards ultrahigh field strengths to exploit the super-linear relationship between magnetic field strength and microscopic, blood oxygenation related B_0 inhomogeneities.

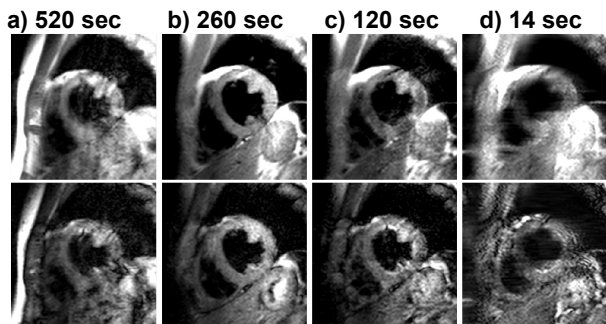


Figure 1: UFLARE short axis views for $\tau=0$ ms (top) and $\tau=11$ ms (bottom) **a)** conventional with a total scan time of ~ 9 min **b)** inner-volume (~ 4 min) **c)** inner-volume+regional blood saturation (~ 2 min), and **d)** c)+ k-t BLAST (14 s) resulting in net acceleration factor of 24, which facilitated T_2^* mapping in a single breathhold.

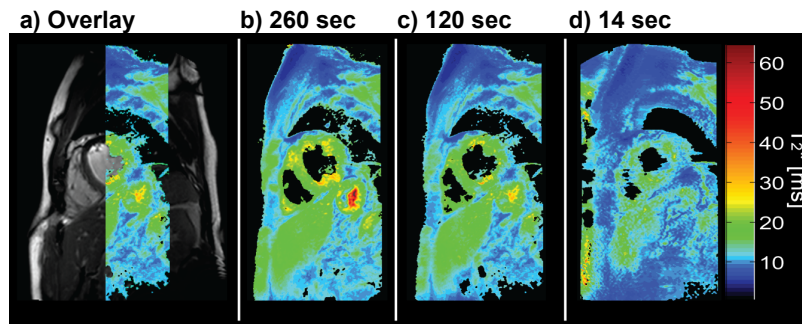


Figure 2: T_2^* maps. **a)** Overlay of 4-fold accelerated T_2^* map with the corresponding 2D CINE SSFP image **b)** T_2^* map derived from inner volume FSE (~ 4 min), **c)** T_2^* map obtained with inner-volume FSE in conjunction with saturation slab based blood saturation (~ 2 min), and **d)** T_2^* map derived from a single breath-hold (14 s) acquisition using inner-volume FSE together with 1 R-R interval blood suppression and k-t BLAST imaging.

References: 1.) Heinrichs, U., et al., Myocardial T_2^* mapping free of distortion using susceptibility-weighted fast spin-echo imaging: a feasibility study at 1.5 T and 3.0 T. *Magn Reson Med*, 2009. 62(3): p. 822-8. 2.) Feinberg, D.A., et al., Inner volume MR imaging: technical concepts and their application. *Radiology*, 1985. 156(3): p. 743-7. 3.) Tsao, J., P. Boesiger, and K.P. Pruessmann, k-t BLAST and k-t SENSE: dynamic MRI with high frame rate exploiting spatiotemporal correlations. *Magn Reson Med*, 2003. 50(5): p. 1031-42. 4.) Pedersen, H., et al., k-t PCA: temporally constrained k-t BLAST reconstruction using principal component analysis. *Magn Reson Med*, 2009. 62(3): p. 706-16.