Rapid Cardiac T1 mapping within Two Heartbeats

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Introduction: T_1-mapping offers a mean to quantitatively assess structural changes in the myocardium. Pre-contrast T_1 mapping may assess areas at risk while post-contrast delayed-enhancement T_1 mapping may assess myocardial infarction [1-3]. Multi-point T_1 mapping approaches, such as Modified Look-Locker inversion recovery (MOLLI) [4], have been shown to detect changes in myocardial T_1 in both acute and chronic myocardial infarctions. However, pixel-wise multi-point T_1-mapping methods are sensitive to cardiac and respiratory motions, and to variations in heart rate, occurring over the typical 20s-long acquisition time, and leading to potential fitting errors. The purpose of this work is to develop a pixel-wise T_1-mapping method, adapted to perform rapid pre-contrast and delayed-enhancement (DE) myocardial T_1-mapping with minimal sensitivity to cardiac motion, in a short 2-heartbeat-long acquisition time.

Methods: The proposed T_1-mapping acquisition (**Fig. 1**) consists of a proton density-weighted (PDw) image in the first heartbeat, followed by a saturation recovery (SR) T_1w acquisition, with robust non-selective saturation pulse [5] and long SR delay time (TD) = 600 ms. The PDw image is acquired in order to normalize the T_1w image signal (S_{norm}), and correct for unknown equilibrium magnetization and RF field variations. Both PDw and T_1w acquisitions used centric k-space ordering. An ideal SR equation was obtained from the Bloch equations governing T_1 relaxation in the center of k-space [6-7]: T_1=-TD/log(1-S_{norm}). T_1w-images were normalized by a continuous PDw intensity surface, extrapolated from the epicardial surface in the PDw image, in order to account for cardiac motion between PDw and T_1w images. The method was evaluated in 8 healthy volunteers (32±13y.o.), imaged in a short-axis basal plane at 3T (Tim-Trio, Siemens) before and 10 min following a 0.05mmol/kg Gd-DTPA intravenous bolus injection. All images were acquired in mid-diastole with appropriate trigger delay. Relevant TurboFLASH imaging parameters included: FOV 350mm × 272mm, matrix 144×112, TE/TR 1.2/2.4 ms, flip angle 10º, in-plane resolution 2.4mm × 2.4mm, GRAPPA effective acceleration factor ~1.65, temporal resolution 162 ms, and receiver bandwidth 990 Hz/pix. For validation, T_1 measurements were compared against those measured using a multi-point SR method, in the left ventricular myocardium, before and at multiple time-points following gadolinium contrast injections (5 to 20 min, 5 min step). A series of T_1w SR images was acquired in mid-diastole with varying TD: 1 PDw-image, 12 T_1w-images with TD 100 to 600 ms every 100 ms, then 800 to 1800 ms every 200ms, ~ 20s-long breath-hold. Multi-point SR T_1 measurements were obtained using a 3-parameter nonlinear Levenberg-Marquardt algorithm to fit the T_1 relaxation SR data to $S_{norm}=S_0[1-(1-f)e^{-TD/T1}]$, with $S_0 = S(TD\rightarrow\infty)$ and f the fraction of the equilibrium longitudinal magnetization not effectively saturated. Contours for the blood and left ventricle were drawn manually. The proposed T_1-mapping method was also evaluated in 2 patients with arrhythmia, before and 20 min after a 0.15mmol/kg, 2cc/sec, contrast injection.

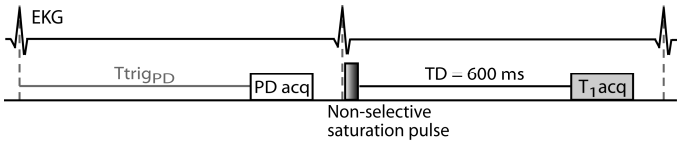

Fig. 1: Schematic diagram of the rapid T_1-mapping pulse sequence.

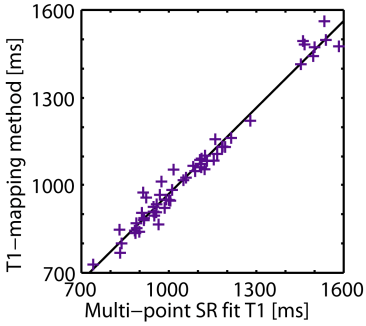

Fig. 2: T_1 measured in the myocardium with the proposed T_1-mapping method vs. multi-point SR fit, pre and 3 to 21 min post contrast injection, and linear regression.

Results: T_1 measured in the left ventricular myocardium with the T_1-mapping method was linearly correlated with multi-point SR T_1 measurements (**Fig. 2**, slope 0.99, bias -19ms, Pearson's coefficent r = 0.98, $P < 10^{-5}$). Both T_1-maps using the proposed method and the multi-point fit could be obtained in volunteers (**Fig. 3**). The proposed single-point method is inherently noisier than the multi-point method, because it relies on a single T_1w image acquisition. While the proposed method is sensitive to partial volume effect, especially on the myocardium free wall (lower apparent signal, i.e., longer apparent T_1), edges are typically further blurred on the multi-point T_1-map due to normal slight relative cardiac motion between image acquisitions. T_2-mapping was not performed in this preliminary evaluation, but it can be added to compare with the areas of longer T_1 observed on the edge of the myocardium. The proposed T_1-mapping method was also successfully applied in 2 patients with arrhythmia, pre- and post-contrast injection, while the multi-point method could not be. T_1-maps are not shown because no delayed-enhancement area was detected in neither of these patients during routine clinical exam.

Discussion: The proposed T_1-mapping method is a fast pixel-wise T_1-mapping technique with minimized sensitivity to cardiac motion. It offers an alternative to multi-point fitting methods for patients who cannot hold their breath or have irregular cardiac rhythm. Future work includes an extensive evaluation of the proposed T_1-mapping method in patients with myocardial areas at risk.

References: [1] Kim RJ et al. NEJM 2000; 343:1445-53; [2] Blume U et al. JMRI 2009;29:4840-7; [3] Goldfarb et al. Radiology 2007;245:245-50; [4] Messroghli DR et al. MRM 2007;58:34-40; [5] Kim D et al. MRM 2009;62:1368-78; [6] Cernicanu A et al. Acad Radiol 2006;13:686-93; [7] Breton E et al. ISMRM 2010.

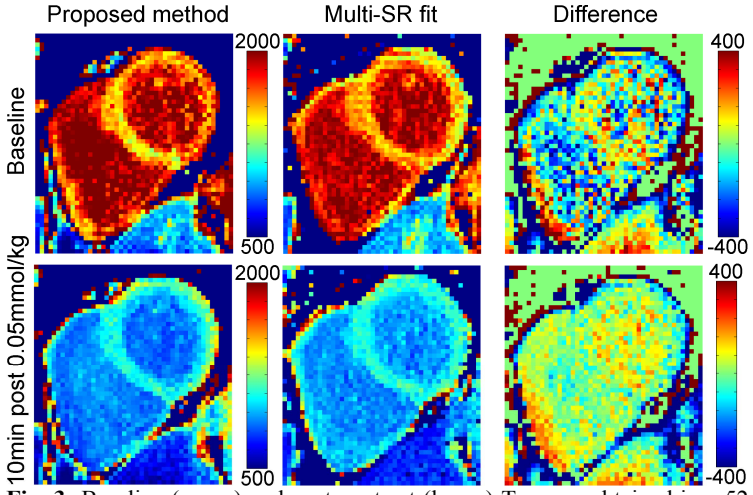

Fig. 3: Baseline (upper) and post-contrast (lower) T_1-maps obtained in a 52 y.o.-volunteer using the proposed method (left) and the reference multi-point SR method (center). T_1-difference maps are shown on a different colorscale.