Arrhythmia Insensitive Rapid Cardiac T1 Mapping Pulse Sequence: In Vitro Study

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Background: Late gadolinium enhancement (LGE) MRI [1,2] is the gold standard imaging modality for quantification of focal or patchy fibrosis. Diagnosis of fibrotic myocardium is based on the T_1-weighted signal difference between healthy and fibrotic myocardium, due to the prolonged washout rate of extracellular contrast agent in fibrotic tissue. However, LGE MRI cannot detect diffuse fibrosis due to the lack of a healthy reference tissue to differentiate from the fibrotic tissue. The only proven modality for assessment of diffuse myocardial fibrosis is LGE cardiac T_1 mapping [3]. The most widely used cardiac T_1 mapping pulse sequence is modified Look-Locker imaging (MOLLI) [4], which is based on inversion-recovery (IR) preparation. However, MOLLI requires a long breath-hold duration and is inherently sensitive to T_2 effects [5] and heart rate and rhythm conditions because of IR-based T_1-weighting. We propose an arrhythmia-insensitive, rapid (AIR) cardiac T_1 mapping pulse sequence based on saturation recovery (SR) T_1-weighting and compare its performance against MOLLI in phantoms with tachycardia and arrhythmia conditions.

Methods: The proposed AIR cardiac T_1 mapping pulse sequence is based on B_1-insensitive SR [6] T_1-weighting (insensitive to heart rate, rhythm) and two single-shot balanced steady-state free precession (b-SSFP) image acquisitions (proton density (PD) and T_1-weighted (T_1w)) with centric k-space ordering (rapid, insensitive to T_2 effects) [7,8], where T_1 is calculated from a ratio of T_1w (I_{T_1}) and PD (I_{PD}) images to correct for unknown equilibrium magnetization and cancel T_2 and scaling effects. Both MOLLI and AIR pulse sequences were implemented on a 3T whole-body MRI scanner (Tim Trio Siemens Healthcare, Erlangen, Germany). The relevant imaging parameters used for both MOLLI and AIR data acquisitions were: TR = 2.7 ms, TE = 1.1 ms, acquisition matrix = 192 (readout) x 144, slice thickness = 8 mm, flip angle (FA) = 35°, field of view (FOV) = 340 mm (readout) x 255 mm, GRAPPA parallel imaging factor R = 1.8, receiver bandwidth = 930 Hz/pixel. We elected to use SR time delay (TD) = 600 ms to achieve a good balance between T_1 sensitivity and signal-to-noise ratio of T_1w images [9]. We compared the performances of AIR and MOLLI in phantoms constructed from nine vials with different concentrations of manganese (II) chloride ranging from 0.016-0.183 mM, (T_1 ranging from 500 -2000 ms) at simulated heart rates of 60 beats-per-minute (bpm), 120 bpm, and arrhythmia. Image acquisitions were repeated 10 times to assess repeatability. For reference, we used an IR fast spin-echo (IR-FSE) sequence with 11 different inversion times (TI). Constant heart rhythms at 60 and 120 bpm were simulated using Siemens' patient monitoring unit (PMU) simulator. A customized triggering device was used to generate trigger pulses at 0, 400, 1100, 1600, 2500, 3000, 4000, 4400, and 4900 ms, and repeated continuously to achieve an irregular set with effective heart rate of 111 bpm. Reference T_1 from IR-FSE images was calculated by non-linear least square fitting for two parameters of the IR equation. For AIR, T_1 was calculated on a pixel-by-pixel basis using Eq. 1.

Equation 1. T_1 calculation based on SR.

$$T_1 = \frac{-TD}{\log(1 - \frac{I_{T_1}}{I_{PD}})}$$

Results: Figure 1 shows the MOLLI and AIR phantom T_1 maps at simulated heart rate and rhythm conditions of 60 bpm, 120 bpm, and arrhythmia, and bar charts summarizing mean T_1 measured over 10 repeated measurements. Compared with IR-FSE, MOLLI and AIR had normalized root-square mean error (NRMSE) of 8% and 3%, respectively, at 60 bpm, 28% and 3%, respectively, at 120 bpm, and 22% and 3%, respectively, at arrhythmia. In addition, MOLLI and AIR T_1 measurements had maximum coefficient of variation (CV) of 1.6% and 1.1%, respectively, at 60 bpm, 5.9% and 0.6%, respectively, at 120 bpm, and 10.2% and 0.8%, respectively, at arrhythmia. Furthermore, AIR T_1 maps demonstrate more uniformity than MOLLI T_1 maps, specifically at the edges.

Conclusions: Our AIR pulse sequence yields more precise and accurate T_1 measurements than MOLLI at different heart rate and rhythm conditions in vitro. More work is needed to validate the diagnostic accuracy and precision in patients with tachycardia and/or arrhythmias.

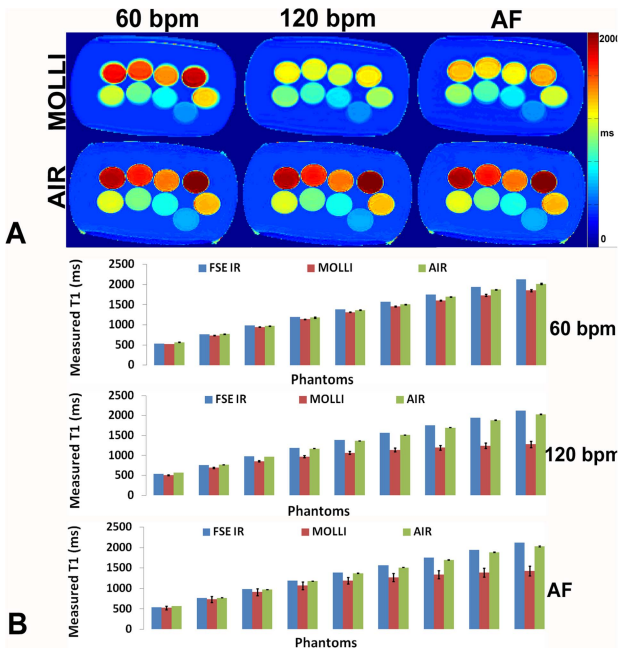

Figure 1. A) MOLLI and AIR T_1 maps for 60 bpm, 120 bpm, and arrhythmia. B) Corresponding bar charts representing mean T_1 values (n = 10) for MOLLI and AIR at 60 bpm, 120 bpm, and arrhythmia.

References: [1] Kim RJ, et al. Circulation 1999; 100(19):1992-2002. [2] Kim RJ, et al. N Engl J Med 2000; 343(20):1445-1453. [3] Mewton N, et al. J Am Coll Cardiol 2011; 57(8):891-903. [4] Messroghli DR, et al. MRM 2004; 52(1):141-146. [5] Gai N, MRM 2012; DOI: 10.1002/mrm.24251. [6] Kim D, et al. MRM 2009; 62(2):300-306. [7] Breton E, et al. SCMR 2011; O107. [8] Lattanzi R, et al. MRM 2011; 66(2):348-355. [9] Haacke et al. Magnetic resonance imaging. New York: Wiley-Liss; 1999: p. 637-667.