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

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Background: The gold standard imaging modality for assessment of focal or patchy myocardial infarction/fibrosis is late gadolinium enhancement (LGE) MRI [1,2]. This imaging modality, however, cannot assess diffuse fibrosis because it requires a normal reference tissue to distinguish the fibrosis. LGE cardiac T_1 mapping is the only proven method for quantification of diffuse myocardial fibrosis [3]. The most widely used cardiac T_1 mapping pulse sequence is MOLLI [4], which is based on inversion-recovery (IR) magnetization T_1-weighting and Look-Locker imaging. Unfortunately, MOLLI is sensitive to heart rate and rhythm and T_2 effects [5] and requires a long breath-hold duration. We present an arrhythmia-insensitive, rapid (AIR) cardiac T_1 mapping pulse sequence, which is also insensitive to T_2 effects, and compare its performance against the conventional IR-based MOLLI method.

Equation 1. T_1 calculation based on SR.

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

Methods: We developed the AIR cardiac T_1 mapping pulse sequence based on B_1-insensitive saturation recovery (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 blurring) [7,8]. Both MOLLI and AIR pulse sequences were implemented on two 3T whole-body MRI scanners (Tim Trio and Verio, Siemens Healthcare, Erlangen, Germany). 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 = 35°, field of view (FOV) = 340 mm (readout) x 255 mm, GRAPPA parallel imaging factor R = 1.8, receiver bandwidth = 930 Hz/pixel, and temporal resolution = 217 ms. The MOLLI acquisition was performed in a breath-hold of 17 heart beats, using inversion time (TI) values as specified by Messroghli et al [3]. The AIR image acquisition was performed in a breath-hold of 2-3 heart beats, depending on the heart rate, with SR time delay (TD) = 600 ms. We elected to use TD = 600 ms to achieve a good balance between T_1 sensitivity and signal-to-noise ratio of T_1w images [9]. T_1 was calculated pixel-wise by dividing the T_1w image, I_{T1w}, by PD image, I_{PD}, to correct for the unknown equilibrium magnetization, cancel T_2 effects and compensate for receiver coil inhomogeneity, and then solving the Bloch equation governing T_1 relaxation that describes the ideal SR experiment (Eq.1). Customized software in MATLAB was used to manually segment the regions of interest (ROI) (left ventricular myocardium, blood pool). T_1 was calculated on a pixel-by-pixel basis and averaged within the ROI. For statistical analysis, T_1 measurements by MOLLI and AIR were compared using the Pearson's correlation and Bland-Altman analyses. Inter-scan agreements for MOLLI and AIR T_1 measurements were assessed using the Bland-Altman analysis. We compared the performances of AIR and MOLLI in ten human subjects and 17 large animals in sinus rhythm pre-contrast and 5, 10, and 15 minutes after contrast agent (Gd-BOPTA, 0.1 mmol/kg dose for humans, 0.15 mmol/kg dose for animals) administration. Pulse sequence order was randomized to minimize bias due to their slightly different imaging times relative to the contrast agent administration time.

Results: Mean heart rates in humans, dogs, and goats were 57 ± 9 beats-per-minute (bpm), 86 ± 15 bpm, and 107 ± 15 bpm, respectively. Compared with AIR T_1 maps, MOLLI T_1 maps yielded lower values and more spatial blurring (Fig.1). T_1 measurements made by MOLLI and AIR were strongly correlated (Pearson's correlation coefficient =0.99) but in poor agreement (Fig.2, mean difference =161.77 ms, upper and lower 95% limits of agreements = 348.4ms and -24.4 ms, respectively). Averaging results over 10 humans, AIR T_1 measurement for left ventricular myocardium (1501 ± 69 ms) agreed better than MOLLI T_1 measurement (1198±46 ms) compared with a previous study which measured T_1 (1471 ms) of an excised heart using a rigorous IR pulse sequence with 35 TI values with 2 averages [10]. For inter-scan repeatability, the coefficient of repeatability (CR) was 49 ms (5% of mean) for MOLLI and 79 ms (7% of mean) for AIR.

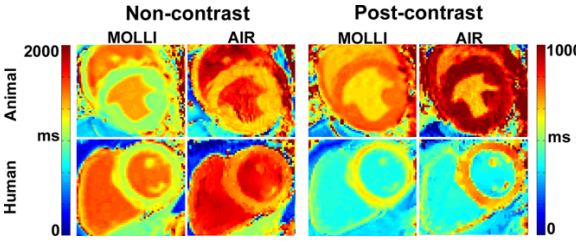

Fig. 1. Non-contrast and 15 minutes post-contrast MOLLI and AIR cardiac T_1 maps for a baseline dog and 38-year-old male volunteer. MOLLI yielded consistently lower T_1 values than AIR.

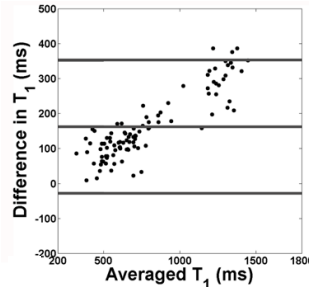

Fig. 2. Bland-Altman analysis of AIR and MOLLI T1 results.

Conclusions: Rapid and repeatable cardiac T_1 mapping can be performed using our proposed AIR pulse sequence. This rapid cardiac T_1 mapping pulse sequence may be clinically useful for assessment of myocardial fibrosis in patients. It may be particularly useful for imaging whole heart and for imaging patients with irregular heart rates or difficulty suspending respiration.

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. [10] Stanisz GJ, et al. MRM 2005; 54(3):507-512.