Improving the precision of arrhythmia-insensitive rapid (AIR) T1 mapping through optimization of saturation recovery time delay

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Purpose: Cardiac T_1 mapping pulse sequences are emerging as promising methods for assessment of diffuse cardiac fibrosis [1]. Among different cardiac T_1 mapping pulse sequences, arrhythmia-insensitive rapid (AIR) T_1 mapping is particularly promising for imaging patients with arrhythmia and limited breath-hold capacity [2]. The original AIR pulse sequence was designed with saturation recovery time delay (TD) of 600 ms, which affects both precision and scan time. We sought to perform numerical simulation to derive an optimal TD to achieve a good balance between precision and scan time.

Methods: All simulations were performed using MATLAB (MathWorks, Natick, MA, USA). Given effective saturation pulse [3] and centric k-space ordering [2], we used the Bloch equation describing T_1 relaxation in saturation recovery, Eq 1: $Mz = M_0\left(1 - e^{-TD/T_1}\right)$, where M_0 is equilibrium magnetization. In AIR cardiac T1 mapping, we acquire one proton density (PD), which in AIR is M_0, and one T1-weighted image (T1w), which is Mz. Rearranging terms, we derive Eq.2: $T_1 = -TD/\ln(1 - |T1w|/|PDw|)$. Adding noise modifies the equation as Eq.3: $T_{1noise} = -TD/\ln(1 - |T1w + noise|/|PDw + noise|)$. For convenience, we set $PDw = M_0 = 1$. The independent variables are TD and T1 (see Table 1 for ranges). Our previous study reported signal-to-noise ratio (SNR) of 110 for PD_w using flip angle of 35° at 3T. Step 1, we added white Gaussian noise to achieve SNR of 110 for PDw. Step 2, we calculated T1w=Mz using Eq.1 and added the same Gaussian noise level to calculate T1w with noise. Step 3, we calculated T1 with noise using Eq. 3. This process (steps 1-3) was repeated for each combination of TD and T1. We note that for each instance, a sample size of 3,000 was used to approach Monte Carlo simulation (i.e., multiple repetitions). Reported values represent the average of 3000 samples. We conducted this numerical simulation for 3 different settings: (i) pre-contrast, representing native myocardial and blood T_1, (ii) post-contrast, representing shorter myocardial and blood T_1, and (iii) combined setting, representing a wide range of T1 values (see Table 1). For each instance, we calculate the coefficient of variation (CV) as standard deviation divided by mean.

Table 1. *Summary of the simulated results showing the minimal CV and the corresponding TD for three combinations of tissue types of interest.*

Tissue type	T_1 values (ms) at 3T	CV_{min} (%)	TD with CV_{min} (ms)
Native myocardium & blood	1400, 2000	2.90	1450
Post-contrast myocardium & blood	400~700 (50 ms step)	2.92	440
Both native & post-contrast tissue types	400~2000 (10 ms step)	3.24	780

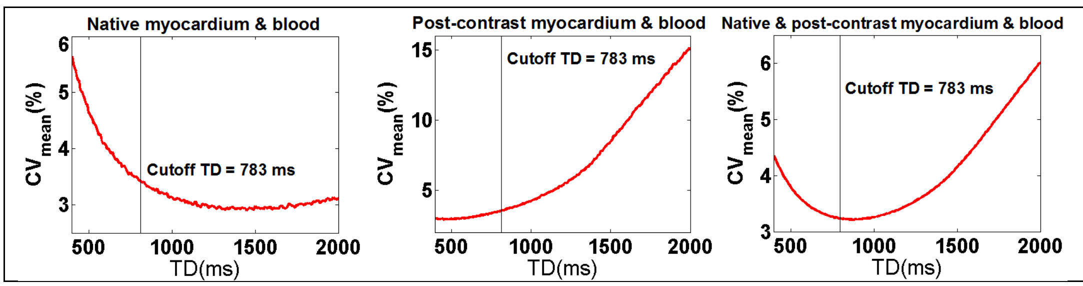

Figure 1. *Mean CV versus TD: pre-contrast (left), post-contrast (middle), and combined settings (right). Cutoff TD = 783 ms is based on the constraint to perform T1w acquisition in 1 s, where T1w readout is 217 ms.*

Results: Figure 1 shows plots of CV as a function of TD for three cases: (i) pre-contrast, (ii) post contrast, and (iii) combined setting (pre- and post-contrast). For pre-contrast setting, optimal TD is 1,450 ms. For post-contrast T1 setting, optimal TD is 440 ms. For combined setting, optimal TD is 780 ms.

Discussion: We performed numerical simulation to determine an optimal TD that will produce the highest precision (low CV) in AIR cardiac T1 mapping. Without scan time consideration, one could use TD = 1,450 ms for pre-contrast and TD = 440 ms for post-contrast settings, or TD = 780 ms for combined settings. However, in the context of cardiac T1 mapping, it is ideal to fit the T1-weighted acquisition within one heartbeat. Assuming heart rate of 60 bpm and given the AIR readout is 217 ms, the longest allowable TD for scan time of 1 s is 783 ms. Many patients, however, may have higher heart rates than 60 bpm. In such instances, it may be necessary to reduce TD to fit the T1w acquisition within one heartbeat. This framework is adaptable to different heart rates, and one can tune the simulation generate an optimal TD for given heart rate.

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References: **[1]** Moon JC, et al. *JCMR*. 2013; 15:92. **[2]** Fitts M, et al. *MRM*. 2013; 70(5) 1274-1282. **[3]** Kim D, et al. *MRM*. 2009; 62: 1368-1378.