

A Method to Remove Heart Rate Dependence with Modified Look Locker Inversion Recovery (MOLLI) T1 Quantification

James W Goldfarb^{1,2}

¹Research and Education, St Francis Hospital, Roslyn, New York, United States, ²Biomedical Engineering, SUNY Stony Brook, Stony Brook, NY, United States

Introduction: T1 measurements are the first step in the quantitative measure of myocardial fibrosis via the assessment of gadolinium pharmacokinetics. Precontrast and post contrast T1 measurements of tissue and blood are the input to gadolinium contrast agent concentration calculations and eventual calculations of physiological variables such as tissue-blood partition coefficients (λ) and volume of distributions (V_d). The Modified Look Locker Inversion Recovery (MOLLI) T1 Quantification method [1] has been used in a number of clinical studies for both pre- and post contrast T1 measurements of blood and myocardium. The method provides single breath-hold cardiac synchronized images at multiple inversion times at a single ECG delay, allowing user friendly processing for T1 calculations. Heart rate dependence of the MOLLI method has been reported in phantoms [2] and in normal subjects [1]. We sought to study the heart rate dependence of the MOLLI method in phantoms, provide a means to correct the dependence based on improved modeling of the MOLLI signal which takes into account incomplete magnetization recovery of long T1 species and apply the correction method in a series of patients.

Materials and Methods: All imaging experiments were performed on a 1.5T clinical whole body MRI system. MOLLI imaging was performed using a IR single shot bSSFP pulse sequence with 11 images at increasing inversion times (Fig 1). (TR/TE/FA=2.5/1.2/35); 3 inversions, 3 heartbeat acquisition, 3 recovery heartbeats, TI=100 ms, TI increment=80 ms, voxel size=2.1x1.7x8mm³, BW=1180 Hz/pixel). Note the times between inversion pulses TD₁₈₀¹ and TD₁₈₀² which with a regular heart rhythm would be 6 heartbeats. Ex vivo imaging was done with 27 vials of gadolinium doped tap water (T1 times ranging from 60 ms to 2450 ms, determined by inversion recovery spin echo imaging TR= 10s, TE =6 ms, TIs = 50-1500 ms). RR intervals were simulated by the scanner software from 500 to 2000 ms in increments of 150 ms. 15 subjects participated in this study (ages: 57±12 years). A mid left-ventricular (LV) short axis slice was imaged in each subject. Regions-of interest were drawn in each vial, the LV cavity (blood) and intraventricular septum (myocardial) to measure mean signal intensities as a function of inversion time. For all MOLLI acquisitions, each curve was fitted with the conventional standard inversion recovery equation $S(TI) = Mo(1-2\exp(-TI/T1))$ and a new equation (Fig 2) which takes into the account the possible incomplete recovery of magnetization when T1 is on the order of time between inversion pulses (TD₁₈₀) using the Nelder Mead minimization in Matlab R2009b. The coefficient of determination (R^2) was calculated for each fit. Linear regression was used to determine if there was a relation between measured T1, R^2 and RR interval. A Student's t-test was used to determine if the new equation provided a better fit and significantly different T1 values.

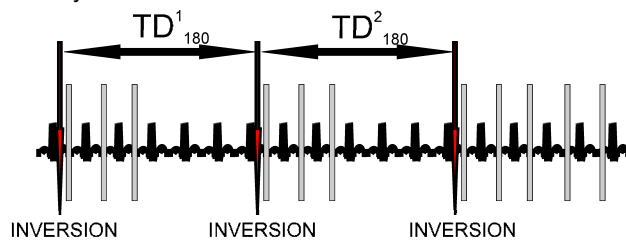
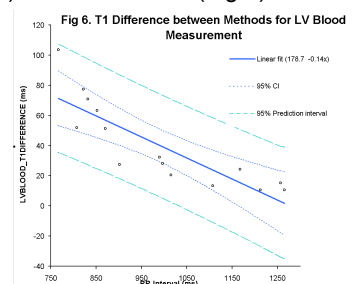
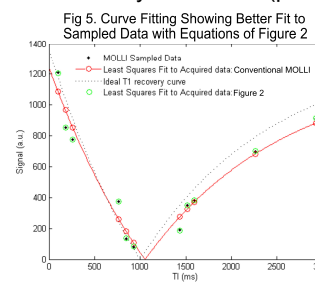
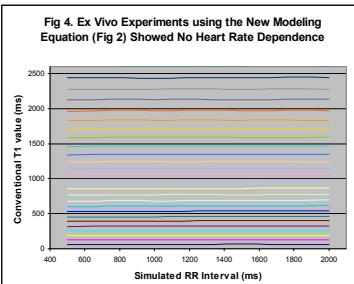
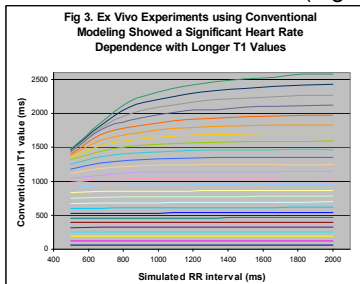


Fig 1. MOLLI schematic showing TD times used for new fitting algorithm.

$$S[n] = \begin{cases} Mo \left(1 - 2e^{-\frac{TI[n]}{T1}} \right) & n = 1, 2, 3 \\ Mo \left(1 - 2e^{-\frac{TI[n]}{T1}} + 2e^{-\frac{TD_{180}^1 + TI[n]}{T1}} \right) & n = 4, 5, 6 \\ Mo \left(1 - 2e^{-\frac{TI[n]}{T1}} + 2e^{-\frac{TD_{180}^1 + TI[n]}{T1}} - 2e^{-\frac{TD_{180}^1 + TD_{180}^2 + TI[n]}{T1}} \right) & n = 7, 8, 9, 10, 11 \end{cases}$$

Fig 2. New curve fitting equations used for removal of heart rate dependence in MOLLI T1 calculations.

Results: In phantom experiments, a heart rate dependence was shown for longer T1 values (Fig 3). There was a nonlinear relationship over the wide range of T1 values and RR intervals studied. T1 values were underestimated at shorter RR intervals ($p < 0.001$). Use of the equation shown in Fig 2 removed the heart rate dependence and provided accurate T1 estimates across a range of T1 values (Fig 4, $p > 0.05$). In Figure 5, one can see the effects of shorter TD₁₈₀ on the sampled data and its deviation from the ideal T1 recovery curve and fitted curve data points (green vs red circles) in relation to the sampled data points (black filled circles). Significantly better R^2 ($P < 0.05$) was achieved both in phantoms and in vivo data (Fig 5, green circle vs. red circles). Correction factors for LV blood measurements (Fig 6) were between 10 and 100 ms and were linearly correlated ($p < 0.01$) with RR interval (Fig 6).



Conclusions: Proper modeling of the MOLLI inversion recovery signal provides heart rate independent estimates of T1. T1 values are only dependent on heart rate when native T1 are on the order of time between inversion pulses (TD₁₈₀). This is more significant for pre contrast blood T1 measurements than precontrast myocardial T1 measurements. Due to the shorter T1 values of post contrast acquisitions, the conventional equation would also be accurate.

References: [1] Messroghli, DR et al. Magn Reson Med 52(1):141-6, 2004. [2] Liu S et al. J Cardiovasc Magn Reson. 13(Suppl 1): 10, 2011.