Accurate T1 and T2 Quantification in Look-Locker 2D SSFP Imaging with Flip Angle Profile Correction

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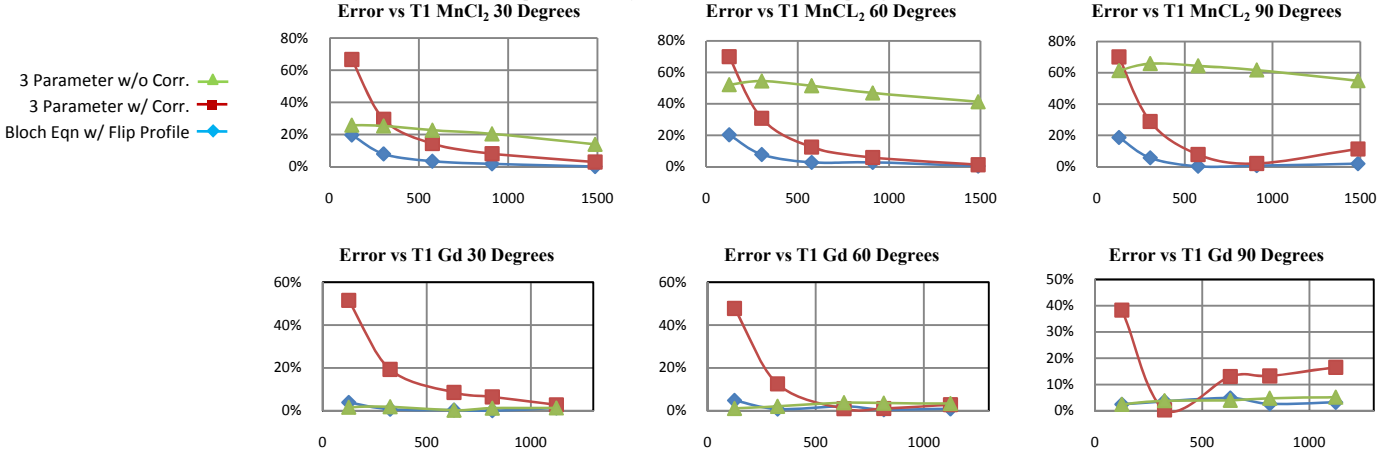
Background: Accurate assessment of myocardial T1 is important for cardiac MRI, especially for quantifying myocardial fibrosis (1) and infiltrative cardiomyopathies such as amyloid (2) on delayed contrast enhanced images. SSFP based inversion and saturation recovery mapping sequences have been widely used to quantify myocardial T1. (3,4,5). While current T1 mapping methods assume a constant flip angle across the imaging slice, the flip angle is known to vary due to a non-ideal RF excitation profile (6) which is present in two-dimensional imaging; a standard for cardiac imaging. This study investigated a method that utilizes the Bloch equations and accounts for the flip angle profile in a standard 2D SSFP IR Look-Locker sequence to fit for T1, T2 and M_o.

Theory: Using the Bloch Equations, the signal evolution S_{MODEL}, which is a function of T1, T2 and M_o, was determined for the Look-Locker SSFP sequence used to acquire sampled data S_{MEAS} (7, 8, 9,10). Integration of the signal over the slice profile was performed numerically to generate the signal model for fitting measured data. Our method can be summarized as: S_{FIT}=argmin(abs(S_{MEAS}-S_{MODEL}). All data was fit using a non-linear solver to search for T1, T2 and M_o over 0-1800 ms for T1, 0-900 ms for T2 and 0-20,000 for M_o . For comparison, two additional T1 values were calculated according to previous T1 mapping methods based on SSFP. The standard three-parameter A-Bexp(-t/T1*) model ignoring slice profile effects was used to fit the measured data for the apparent T1 as done in (1,4) and correction was performed on the three-parameter fit to find T1 by T1= (T1*)((B/A)-1) as done in reference (3, 12). For all fits in volunteer data, noise caused the IR signal to flip around an offset value that was non-zero. To allow for proper polarity assignment without loss of the dynamic range, we implemented the correction proposed in (11). This method generated a look-up table by using a probability density function for the magnitude image that could be used to find the true signal without noise when given a measured signal with noise. After this correction, the correct polarity was found and the relaxation curve was fit.

Methods: An inversion recovery 2D Look-Locker SSFP pulse sequence with continuous readout was implemented on a GE 1.5T Signa scanner. One phase was obtained per inversion for each TI (150 TI for volunteer studies; 256 TI for phantoms). A total of 64 phases were acquired with half phase field of view, for a total of 128 phase encoding lines in the final images. Gadolinium and Magnesium Chloride phantoms were imaged. T1 ranged from 125 to 1487 ms for $MnCl_2$ and 125 to 1123 ms for Gd, and T2 ranged from 12 to 268 ms for $MnCl_2$ and 114 to 756 ms for Gd. Phantom data was acquired for flip angles of 30, 60, and 90 degrees in a birdcage coil. A Hamming-windowed half-sinc excitation profile was used for all scans. In addition, a spin-echo inversion recovery and a spin-echo with varied TE scan were done to obtain gold standards for T1 and T2. For the IR SSFP Look-Locker sequence, signal recovery curves were fit for T1, T2 and M_O in a 5x5 ROI in phantoms using our proposed method and the corrected/uncorrected three-parameter fit. Healthy volunteers (n=6) were scanned in accordance with IRB regulations at our institution. Imaging was done in the thigh to allow for the long spin-echo inversion recovery scan to be carried out in-vivo. Each volunteer was then scanned with spin-echo inversion recovery and a 60 degree flip angle IR SSFP Look-Locker scan using an eight channel cardiac coil. A 3x3 ROI in the proximal thigh (adductor muscle) was fit using our proposed method and the corrected three-parameter fit. Fits took 1.19 ± .15 seconds. In addition, in four of the volunteers we were able to run a spin-echo scan to measure gold standard T2 for comparison. For volunteer ROI comparison, a two-tailed paired t-test was performed to show difference (or no difference) between gold standard values and the techniques used.

Results: Plots in the figure below show that the absolute relative errors in T1 estimation were substantially lower for short T1 components using our proposed method (Bloch Eqn. with Flip Profile) compared to the traditional corrected three-parameter fit. T2 values were calculated also but are not shown for phantom studies. In addition, for the $MnCl_2$ phantoms the apparent T1 from the uncorrected three-parameter fit had substantial error. This error increased with flip angle. Error for the uncorrected three-parameter fit was minimal however in the GD phantoms, where T1 and T2 are similar. Error was substantially reduced in all cases when the slice profile effects and signal behavior from the Bloch equations were accounted for using our proposed method. T1and T2 values fit for a ROI in the thigh and gold standard values from the same ROI are reported in table one, again showing improvement in T1 estimation versus the corrected three parameter equation that has been previously used and accurate T2 estimation.

Figure 1: $MnCl_2$ and Gd phantom data for SSFP scans at various flip angles.



Discussion: A method is presented to fit T1, T2, and M_O from Look-Locker SSFP data, which accounts for variability in the flip angle profile. For both phantom and human subjects, this method consistently reduced error as compared to standard approaches. The magnitude of improvement was greatest with prolonged T1. Larger errors occurred for all approaches at short T1 times. Future studies are necessary to apply this novel method directly to a T1 mapping sequence that can be used in cardiac imaging to allow for quantification of T1 values in routine clinical practice.

References: 1 Iles. JACC 52: 1574-1580 (2008). 2 Maciera. Circul. 111:186-1993 (2005); 3 Messroghli. MRM 52:141-146 (2004) 4 Song. ISMRM 2009; 5 Slavin ISMRM 2010. 6 Parker. MRM 45:838-845 (2001); 7 Scheffler. MRM 49 781-783; 8 Schmitt. MRM 51:661-667 (2004); 9 Look/Locker. Rev of Sci Instr 41: 250-251 (1970); 10 Goldfarb. MRM 53: 367-371 (2005); 11 Constantinides. MRM 38: 852-857 (1997); 12 Deichmann. JMR 96:608–612 (1992)

Table 1:Volunteer ROI Analysis for our method vs. the standard corrected 3 parameter fit.

	Spin Echo IR T1	Three Parameter T1	Bloch Eqn w/ Profile T1	Spin Echo T2	Bloch Eqn w/ Profile T2
Volunteer 1	964	852	944	30	30
Volunteer 2	1029	878	960	28	31
Volunteer 3	1004	874	972	--	--
Volunteer 4	1033	963	1043	--	--
Volunteer 5	1006	895	981	28	30
Volunteer 6	1011	898	996	29	28
Mean ± Std	**1008±25**	**893 ± 38**	**980 ± 34**	**29 ±1**	**30 ±1**
P Value		**.0001**	**.06**		**.35**