Optimization and Validation of a Modified Look-Locker Saturation-Recovery (MLLSR) Sequence Applied to Cardiac T1 mapping

T. Song[1], M. N. Hood[2], V. B. Ho[3], S. N. Gupta[4], and J. A. Stainsby[5]

[1]Applied Science Laboratory, GE Healthcare, Bethesda, MD, United States, [2]Radiology, Uniformed Services University of the Health Sciences and National Naval Medical Center, Bethesda, MD, United States, [3]Radiology, Uniformed Services University of the Health Sciences and National Naval Medical Center, Bethesda, Bethesda, MD, [4]GE Global Research, Niskayuna, NY, United States, [5]Applied Science Laboratory, GE Healthcare, Toronto, ON, Canada

Introduction

Cardiac T_1 mapping enables signal quantification on a standard scale compared to conventional T_1-weighted images where image intensity variations can result from factors other than inherent tissue T_1-relaxation characteristics. T_1 mapping is an alternative methodology to myocardial-delayed enhancement (MDE). Furthermore, based on measured T_1 and proton density values, simulated MDE images with various TI values can be generated through post-processing [1,2]. Cardiac T_1 mapping is a challenging problem due to cardiac and respiratory motion, and a reliable and robust cardiac T_1 mapping method must address these. A modified Look-Locker saturation-recovery (MLLSR) [3] sequence was evaluated on both phantoms and human studies. Saturation recovery has benefits over inversion recovery methods in quantification of T_1 as it obviates the need for dummy heartbeats used for relaxation to recover to equilibrium, and fitting of the data is not confounded by the phase of the MR signal.

Methods

The MLLSR pulse sequence uses a saturation recovery sequence with three Look-Locker imaging blocks (2, 2, and 4 heartbeats respectively) as illustrated in Figure 1. For example if the heart rate is 60 bpm, eight heartbeats are acquired with TIs of 100, 200, 300, 1100, 1200, 1300, 2300, and 3300msec. Fiesta imaging was performed at each of the TI times with the following parameters: TE/TR 1.7/3.9ms, 45° flip angle, 256x160matrix, 0.5 NEX, 38 VPS, 8mm slice thickness, 350msec trigger delay. Data was fit to estimate T_1. Simulated MDE images were generated assuming an IR-GRE acquisition. Phantom validation measurements were performed using a set of Gadolinium (Gd)-chelate contrast dilution phantoms with T_1s ranging from 100 to 1700ms. MLLSR was evaluated under different heart rate conditions using an ECG-gating heart simulator. Flip angles were varied from 45, 30, 20, to 10 degrees and heart rates were changed from 60 to 100 bpm. T_1 values were also obtained using a standard IR-prepared FSE acquisition and correlated with MLLSR. On an IRB-approved protocol, a patient with myocardial infarction was evaluated using both standard IR-GRE MDE imaging and MLLSR based T_1 mapping, pre- and post-Gd injection. Relative mean error was calculated as the mean of relative differences between IR FSE and MLLSR estimation for all T_1 values.

Results

For the phantom validation study, T_1 values from MLLSR and IR-FSE were strongly correlated for all flip angle and heart rate combinations (correlation coefficients > 99%) as shown in Figure 2. Table I shows the relative mean error values for all cases in percentage (%). As seen from Table I and Figure 2, faster heart rates and larger flip angles result in larger errors. This may be a result of less optimal TI sampling for long T_1 signals and a greater perturbation of the T_1 relaxation process due to the SSFP readout. However, initial volunteer and patient data suggests that a flip angle of 45° gives the best balance of SNR and estimation error. MI patient images pre- and post-contrast are shown in Figure 3. Furthermore, T_1 maps, proton density maps and simulated MDE maps are shown. Simulated images with a TI of 250ms shows similar contrast and pathology as the traditional MDE image with the appropriately chosen TI time.

Conclusions

The MLLSR T_1-mapping sequence is shown to be robust for cardiac applications across a range of flip angles and heart rates, across a wide range of T_1 relaxation times. T_1 maps generated using this acquisition may provide useful in characterizing myocardial tissue, in characterizing tissue in and around myocardial infarcts and in retrospectively generating MDE images with optimized tissue contrast.

References [1] J. Warntjes, et al, ISMRM 2008. [2]D. R. Messroghli, et al, Radiology vol 138(3): 1004-1012. [3] G. S. Slavin, et al, SCMR 2007.

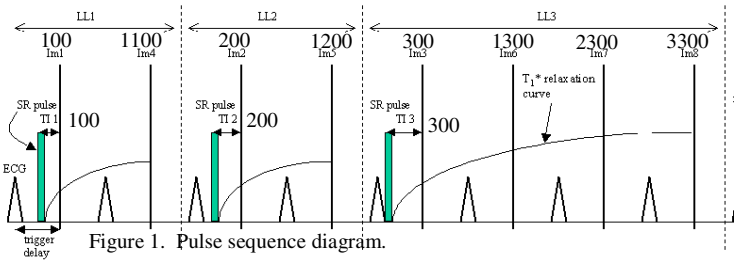

Figure 1. Pulse sequence diagram.

Table I. Relative mean error of T_1 estimation.

Heart Rate /Flip Angle	60bpm	75bpm	100bpm
45°	7.36%	8.67%	11.82%
30°	6.40%	6.93%	9.51%
20°	5.42%	5.89%	7.25%
10°	5.48%	6.52%	6.14%

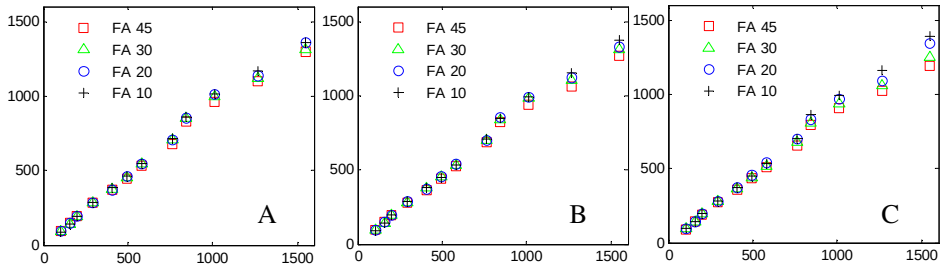

Figure 2. T_1 estimation from MLLSR versus T1 estimation from IR FSE sequences is shown. A, B, and C are with heart rates of 60, 75, 100 bpm. Different flip angles were evaluated. X axis is IR FSE, and Y axis is estimated values.

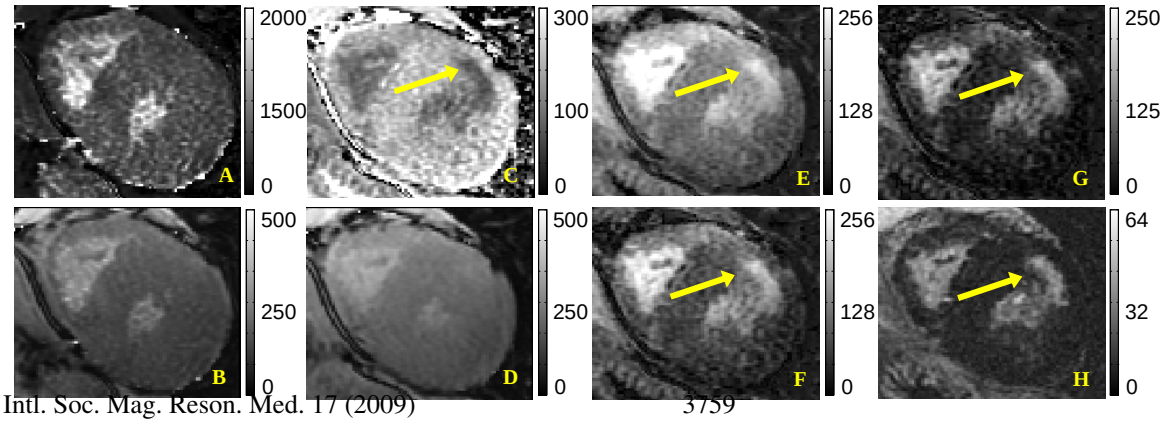

Figure 3. A patient with prior anterior and anterolateral myocardial infarction (arrow). A) Pre-contrast T_1 map; B) Pre-contrast proton density M0 map; C) Post-contrast T_1 map; D) Post-contrast proton density M0 map; E, F, and G) Simulated MDE images with TI of 350ms, 250ms and 200ms; H) MDE with TI = 250ms.