Varied Sampling Patterns in Modified Look-Locker with Saturation Recovery for Flexible Cardiac T1 Mapping

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Introduction

Because of cardiac motion and respiratory motion, cardiac T1 mapping remains a challenging problem. Recently we proposed a Modified Look-Locker with saturation recovery (MLLSR) SSFP sequence for cardiac T1 mapping [1]. Without the need for relaxation-recovery heartbeats, segmented acquisition approaches (vs. single-shot methods) can be applied, and this enables shorter acquisition windows, which minimizes the impact of cardiac motion. This approach also enables greater flexibility in choosing signal recovery sample times (TI). This allows for tradeoffs and optimizations between signal sampling patterns and breath hold durations. Two different sampling patterns were evaluated on both phantom and human subject studies.

Methods

We compared the effectiveness of estimating T1 using a pattern requiring 2, 2 and 4 heartbeats (2+2+4) respectively for each Look-Locker block (Figure 1a) and one using a pattern requiring 1 and 3 heartbeats (1+3) (Figure 1b). 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. Phantom measurements were performed using a set of Gadolinium (Gd)-chelate contrast dilution phantoms with T1s ranging from 100 to 1700ms. Since our saturation recovery method has half of the dynamic range of inversion recovery methods, an SNR sensitivity simulation was performed. The ability to differentiate actual T1 populations based on [2] under different SNR conditions was explored. True T1 values of 333ms, 429ms, and 564ms, representing post contrast T1 values in CCF DE positive; CCF DE negative (CCF: congestive cardiac failure, DE: delayed enhancement) and control subjects respectively were used. Simulations were performed by adding Gaussian noise to the true decay curves, which were then sampled at times according to the 2+2+4 and 1+3 sampling patterns. T1 estimates were made based on fitting a saturation recovery curve to the sampled data. A total of 1000 repeat experiments were performed. An Expectation Maximization (EM) based algorithm was used to fit Gaussian peaks to the resulting T1 spectra. Finally, a patient presenting with a 30bpm heart rate was imaged using the 2+2+4 pattern with ASSET (17sec breath hold), and with the 1+3 pattern without ASSET (17 sec breath hold).

Results

T1 estimates in the phantom were compared with IR Spin Echo T1 values (Figure 2). Both patterns demonstrated accurate T1 estimates across the entire range of T1 values and experimental heart rates. SNR sensitivity simulation results (Figure3) show that for a typical in vivo noise level of the MLLSR sequence of 4%, the EM algorithm identified peaks with mean errors of 0.57, -1.03, and –0.67ms compared to the 3 true T1 values for the 2+2+4 sampling pattern; and 0.94, -3.77, and –20.68ms for the 1+3 sampling pattern. Images from the patient with a 30bpm heart rate are shown in Figure 5. In the same breath hold duration, the 1+3 sampling pattern is able to achieve a higher SNR per image, resulting in improved T1 mapping results (Figure 4 a, b, d, e). This is further illustrated by comparing simulated MDE images (Figure 4 c,f) based on the computed T1 and M0 maps to a standard delayed enhancement image (Figure 4g).

Conclusions

Different sampling patterns of MLLSR were evaluated on phantoms and human subjects and illustrate that the flexibility afforded by MLLLSR method can be used to sample a reduced number of signal recovery times while still maintaining clinically-relevant T1 accuracy. This may have implications in the clinical application of the technique by reducing overall breath hold times and in providing higher SNR protocols for select patients (e.g. with extremely low heart rates).

References [1] T. Song, et al, ISMRM 2009, pp483. [2] L. Iles, et al, JACC 2008; 52(19):1574-1579.

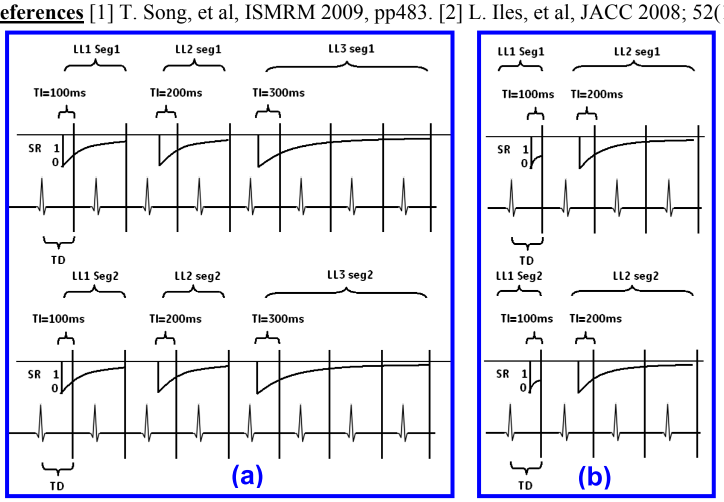

Figure 1. MLLSR sequence diagram. (a) A saturation recovery sequence with three Look-Locker blocks (2, 2, and 4 heartbeats respectively), (b) and two Look-Locker blocks (1, 3 heartbeats) were performed with increasing TIs.

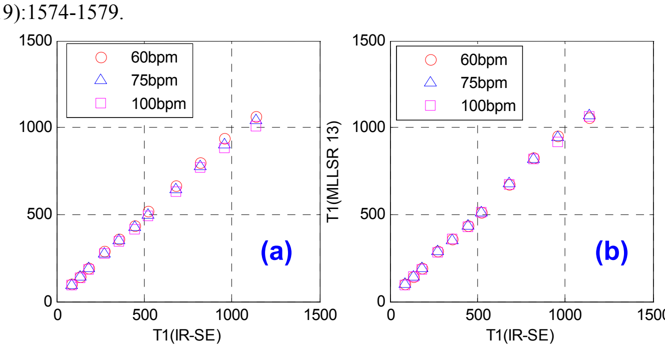

Figure 2. T1 estimation from MLLSR versus T1 estimation from IR-SE sequences is shown. With heart rates of 60, 75, 100 bpm, 2+2+4 (a) and 1+3 (b) are shown. X-axis is IR-SE, and Y-axis is estimated T1 values.

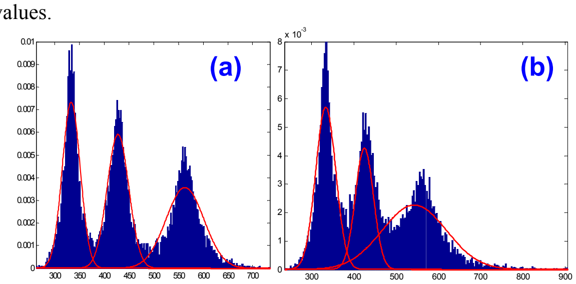

Figure 3. SNR sensitivity simulation results show that given noise standard deviation is 4%, Gaussian distribution with mean error of values of 0.57, -1.03, and –0.67 for 2+2+4 (a); and 0.94, -3.77, and –20.68 for 1+3 (b) pattern.

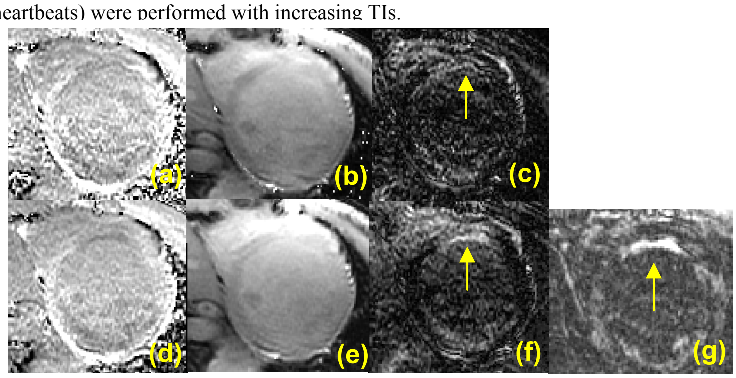

Figure 4. A patient with 30bpm heart rate using 2+2+4 with ASSET (top a-c), and 1+3 without ASSET (bottom d-f) was evaluated with T1 maps (a, d), M0 map (b, e), simulated MDE with TI of 150ms (c, f), and true MDE (g).