Myocardial T1 Mapping Using Inversion Recovery SSFP Cine

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Introduction

Estimation of T1 in the myocardium is challenging due to cardiac motion, and limitations in scan acquisition time due to the need to constrain acquisition time within a single breathhold. The Look-Locker approach [1] has been used to measure myocardial T1 in sectors [2], but with relatively poor spatial resolution and a resulting limited ability to determine T1 in small areas of interest. SNR in this approach has also been shown using SSFP [3,4]. The MOLLI technique [5] is an adaptation of the Look-Locker technique that combines three Look-Locker experiments interleaved to obtain a sufficient number of datapoints along the longitudinal relaxation curve at the same point in the cardiac cycle to allow parametric map generation. However, the data acquisition window in this single shot approach is on the order of 200 ms, and thus cardiac motion may still impact image quality especially in patients with high heart rates. In addition breath-hold times are on the order of 17-18 heartbeats, with SENSE rate 2. In this study, we propose to use a standard Lock-Locker SSFP based sequence with optimized parameters to permit both high resolution regional T1 analysis and parametric map generation, within a 15 heartbeat breath-hold.

Methods

For initial validation, we used a liquid phantom (per 1000g H2O distribution, 1,24g NiSO4 * 6H2O /2,62g NaCl) at room temperature. The SSFP protocol was TR/TE = 2.4/1.2 ms; Segment = 7; flip angle =30; inversion pulse spacing = 2 cardiac cycles. An IR-TSE sequence was then applied with TR/TE = 5000/12 ms; echo train length = 7; TI = [50 100 200 250 300 350 400 500 600 1000 1400 2000 2800] ms as well as an IR-GRE sequence protocol with parameters: TR/TE = 2000/3.6 ms; Segments = 3; flip angle = 15, Inversion pulse spacing = 2 cardiac cycle; TI = [50 100 200 250 300 350 400 500 600 1000 1400 2000 2800] ms. Additional gel phantoms doped with varying concentrations of Gd-DTPA were also studied. For SSFP: TR/TE = 3.64/1.82 ms; flip angle = 30; acquisition window = 6000 ms; segments = 15; bandwidth = 965 Hz/Px; voxel size = 1.3*1.3*0.8 mm, temporal resolution 55 ms. Since the expected maximum T1 value was around 1200 ms, the acquisition window was set at 6000 ms (around 5 times T1) in order to have a sufficient recovery of the longitudinal magnetization. IR-TSE acquisitions were used as a gold-standard method with parameters: TR/TE = 6000/7.6 ms; acquisition window = 6000 ms; bandwidth = 299 Hz/Px; turbo factor = 7. Inversion time = [100 200 300 400 600 800 1000 1500 3500 5500] ms.

For *in vivo* studies, five patients and one healthy volunteer were studied on a Siemens 1.5T Avanto. Parameters were selected to balance spatial and temporal resolution while keeping the acquisition under 15 heartbeats. Acquisition window (total time over which cine images were acquired) was selected as 2800 ms pre contrast and 1500 ms post contrast to account for shorter T1. For pre-contrast imaging: TR/TE= 3/1.5 ms; flip angle = 30º; FOV = 285 × 380 mm; matrix size = 179 × 256; voxel size = 2.1×1.5×8.0 mm; acquisition window = 2800 ms; Segments = 31; bandwidth = 977 Hz/Px resulting in high-resolution images of the heart with temporal resolution 93 ms. For post-contrast imaging: TR/TE= 3/1.5 ms; flip angle = 30 º; FOV = 306× 360 mm; matrix size = 256 × 256; voxel size = 1.4×1.4×8.0 mm; acquisition window = 1500 ms; Segments = 31; bandwidth = 977 Hz/Px with temporal resolution 95 ms. Further improvements in spatial resolution and breath-hold time could be achieved with parallel imaging but that option was not investigated in the present study in order to maximize SNR. Images were obtained in the short axis view before and 10-30 minutes post Gd-DTPA administration (0.2 mmol/kg).

Sector analysis as well as parametric mapping were performed. For the sector analysis, endocardial and epicardial contours were drawn on each frame of the IR-SSFP image series (Argus, Siemens), and each image was divided into 16 sectors. For each sector, the average signal intensity was determined. For derivation of T1, due to the smaller voxel size and resulting higher noise level near zero, an interative fitting method proposed by Nekolla et al [6] was used to determine the zero crossing point, and the fitting method proposed by Schmitt et al [4] was used to derive T1.

For the parametric method, 3-5 images were selected in early systole or late diastole, spanning the acquisition window with the idea that these images are close to the same position and can be combined to derive T1 maps. The same fitting method was applied as in the sector based approach except that a 3x3 spatial filter was first applied to reduce pixel-to-pixel noise.

Results

For the liquid phantom valdiation, T1 was determined to be 295 ms for the SSFP approach, 294 ms for the IR-TSE and 293 ms for the IR-GRE sequence. For the gel phantoms T1's ranged from 145 – 1224 ms as determined by IR-TSE. The mean difference overall the range of T1's between the IR-TSE and the IR-SSFP T1 estimates was 7.4 ms +/- 30 ms. For the *in vivo* studies, myocardial T1 pre contrast in normal regions was in the range 1100-1300 ms, and post contrast in the range 300-500 ms, consistent with previous studies. Figure 1 shows a sample parametric map in a patient with an anterior infarct, and Figure 2 shows a patient with Duchene's muscular dystrophy with fibrosis involving the inferolateral wall and additional small areas of anteroseptal mid-myocardial fibrosis, which were also seen on the late enhancement images.

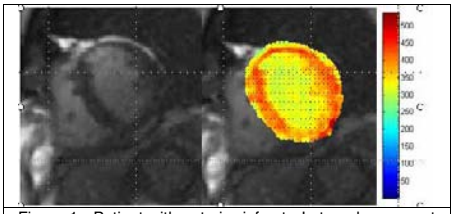

Figure 1. Patient with anterior infarct. Late enhancement image (left) shows thinned anterior wall and signal enhancement, and T1 map (right) shows shortened T1 in the infarct region, similar to the blood T1.

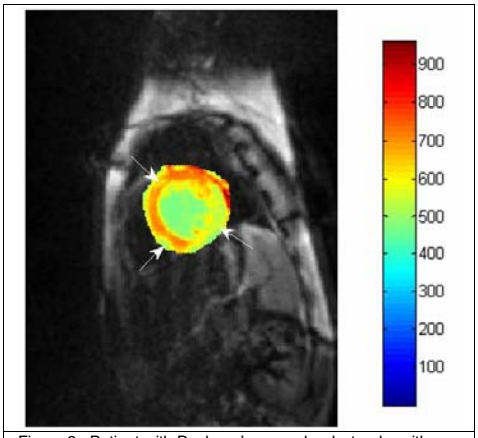

Figure 2. Patient with Duchene's muscular dystrophy with inferolateral wall fibrosis with decreased T1, and also a small mid-myocardial area of shortened T1 in the anterior wall. The high spatial resolution of the technique allowed for detection of fine structures in the T1 map.

Discussion

IR SSFP cine with resolution on the order of 1.4 mm in-plane and a relatively short breath-hold (15 heartbeats) can be used to do either regional based analysis of myocardial T1 or to generate parametric maps. The IR SSFP technique is available on most clinical scanners and has potential for incorporating high resolution T1 measurement into exams for clinical research.

References

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