

Cardiac T1 mapping: A comparison of methodologies for quantifying cardiac T1 values

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Introduction

Cardiac T₁ mapping provides a quantitative way to characterize tissue abnormalities, such as myocardial infarction and amyloidosis [1]. However, cardiac T₁ mapping is a challenging problem due to cardiac and respiratory motion. A reliable and robust cardiac T₁ mapping method is essential. IR prepared SSFP [2], CINE-IR [3], and the modified look-locker saturation-recovery (MLLSR) [4] have all been proposed as methods suitable for T₁ mapping in the heart. These methods were evaluated on both phantoms and human studies. The dependence of T₁ measurements on heart rate and flip angle were compared among these T₁ mapping methods.

Methods

Phantom validation measurements were performed using a Gd dilution T₁ phantom with T₁s ranging from 100 to 1700ms. The various T₁ mapping sequences were evaluated under different heart rate conditions using a heart simulator. Flip angles were varied from 45, 30, 20, to 10 and heart rates were changed from 60, 75, to 100 bpm. Reference T₁ values were obtained using a standard IR-prepared FSE acquisition and correlations between IR FSE and the three methods were evaluated. IR-SSFP uses a non-selective inversion pulse placed at an operator-defined trigger delay in the cardiac cycle during a normal SSFP-CINE acquisition (TR/TE 3.5/1.6, 45° flip angle, 192x192, 1NEX, 16 VPS, 8mm slice thickness). The CINE-IR sequence plays an inversion pulse immediately after the R-wave and then follows with a standard GRE-CINE acquisition (TR/TE 6.6/3.1, 12° flip angle, 256x160, 0.5NEX, 8 VPS, 8mm slice thickness). The MLLSR pulse sequence uses a saturation recovery with three look-locker imaging blocks. Balanced SSFP imaging was performed at each of the TI times with the following parameters: TR/TE 3.9/1.7, 45° flip angle, 256x160matrix, 0.5 NEX, 38 VPS, 8mm slice thickness, 350msec trigger delay. Data are fit for apparent T₁ estimation using all images following the inversion pulse(s) played in each sequence. An in-vivo comparison of T₁ maps in a mid-ventricular short axis image slice was also performed without contrast administration to evaluate the capability of these sequences of generating T₁ maps under endogenous myocardial contrast conditions, which is more reflective of the amyloidosis evaluation.

Results

For the phantom validation study, T₁ values from MLLSR, IR SSFP, CINE IR and IR FSE for all flip angles and heart rates are shown in Figure 1 (A-I). The mean correlation coefficient between three methods versus IR FSE was 0.9952, 0.9855, and 0.9797 (HR=60bpm); 0.9955, 0.9473, 0.9684 (HR=75bpm); and 0.9955, 0.8666, 0.8757. With T₁ values beyond 600ms and heartbeats higher than 75bpm, only MLLSR showed consistent and reliable correlation above 99%. A volunteer pre-contrast study is shown in Figure 1 (J-L). With Cine-IR and IR-SSFP each TI image is acquired at a different cardiac phase, so cardiac motion limits the ability to do pixel-wise T₁ mapping, as can be seen from Figures 1K and 1L. Approaches where only TI images corresponding to diastole have been attempted with some success, though these are still limited by the time window over which signal recovery is evaluated and by residual motion-induced blurring. Whereas the phantom results (A-I) demonstrate fundamental limitations of the techniques for accurately estimating T₁ values, the in vivo data illustrates the sensitivity of each technique both to the inherent error in the technique for estimating long T₁ values in addition to sensitivity to cardiac motion.

Conclusions

This study compared three T₁ mapping sequences across a range of flip angles and heart rates. The MLLSR sequence gave consistent, reliable results across the widest range of T₁ values, flip angles and heart rates. In particular it gave the most robust measurements for long T₁ signals that are typical of myocardial tissue pre-contrast.

References [1]D. R. Messroghli, et al, Radiology vol 138(3): 1004-1012 2006. [2] J.S. Detsky et al, ISMRM 2008, p 3164. [3] Ho et al, ISMRM 2005, p1675. [4] G. S. Slavin, et al, SCMR 2007.

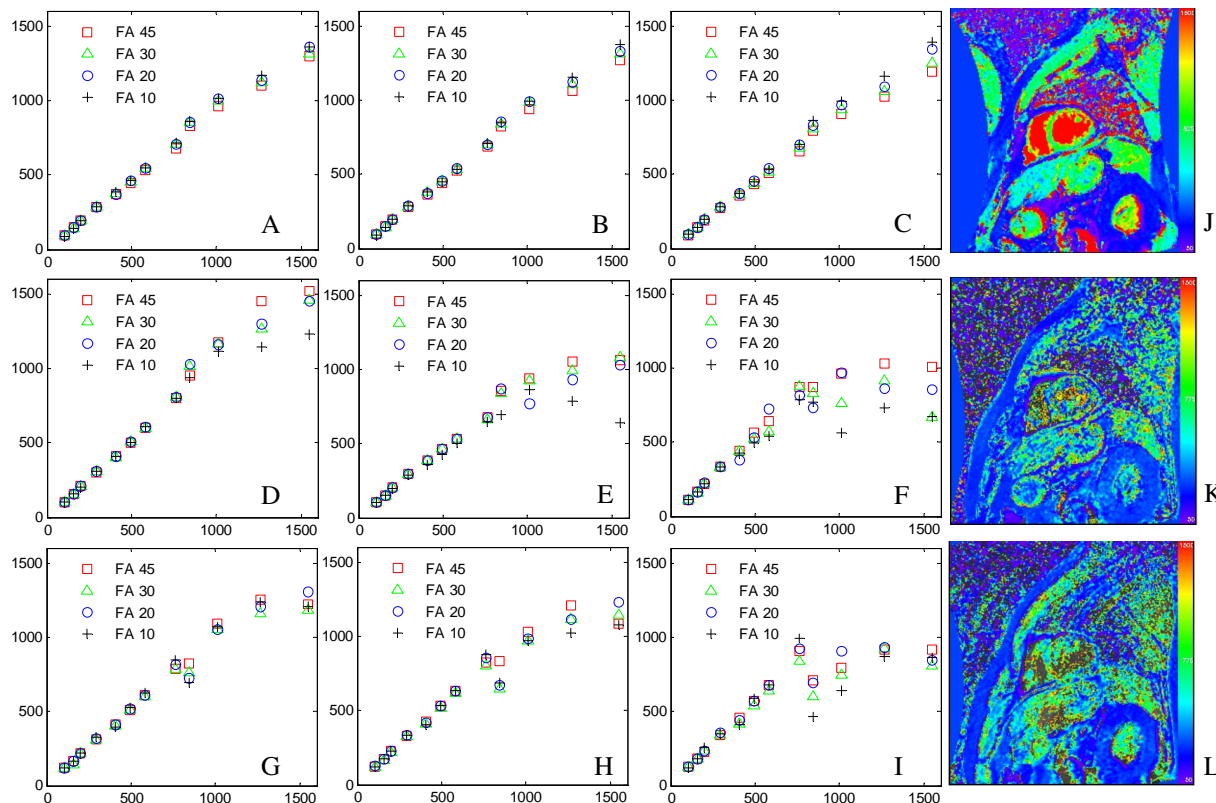


Figure 1. Phantom and pre-contrast human T₁ maps based three different methods. A, B, C are MLLSR results with increasing heart rate (60 to 100bpm); D, E, F are IR SSFP results with increasing heart rates; G, H, I are CINE IR results. A pre-contrast volunteer study using MLLSR (J), IR SSFP (K), and CINE IR (L) are shown. Colormap ranges from 50msec to 1500msec. The X-axis is the T₁ estimated by IR FSE, and the Y-axis is the estimated T₁ values by each of other methods.