MRI Simulation-Based Evaluation of ECV Calculation using MOLLI T1 Maps

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Abstract

Quantification of myocardial extracellular volume (ECV) fraction based on pre- and post-gadolinium MOLLI T1 maps is a research tool that has the potential to become an important prognostic tool for assessing specific cardiomyopathies. In this study, we utilized advanced MR simulations of the MOLLI pulse sequence for a wide range of physiological T2 values for pre-gadolinium blood and myocardium in order to investigate the dependency of MOLLI-based ECV measurements on T2. Simulations show that MOLLI underestimates ECV measurements in shorter pre-gadolinium myocardial T2 and longer pre-gadolinium blood T2 values with the ECV underestimation error being higher with pre-gadolinium myocardial T2 values than with pre-gadolinium blood T2 values.

1. Introduction

Quantification of myocardial extracellular volume (ECV) fraction has been recognized as a potential important biomarker for assessing specific cardiomyopathies. ECV maps are derived from pre- and post-gadolinium T1 maps of myocardium and blood, calibrated by the blood hematocrit value [1], based on the following equation:

$$ECV = (1 - hematocrit)\frac{(\frac{1}{T1_{myoPost}} - \frac{1}{T1_{myoPre}})}{(\frac{1}{T1_{bloodPost}} - \frac{1}{T1_{bloodPre}})}$$

The Modified Look-Locker Inversion-recovery (MOLLI) [2] is the most widely used pulse sequence for T1-mapping. A previous study [3] has shown a T2-dependent error in the MOLLI estimate of T1 with increased underestimation of T1 values at lower T2s. However, the dependency of MOLLI-based ECV measurement on T2 has not been explored yet.

In this study, we investigated how T2 affects ECV measurements by means of MR simulations of the MOLLI pulse sequence for a wide range of physiological T2 values for pre-gadolinium blood and myocardium.

2. Methods

A recently developed GPU-based (Graphics Processing Units) MR physics simulator was utilized [4]. A clinical MOLLI pulse sequence was simulated for a large number of physiological combinations of T1 and T2. A MOLLI acquisition scheme of 5-3s-3 was selected. The IR pulse was a hyperbolic secant adiabatic pulse and the bSSFP readout used a sinc shaped RF pulse with 35^o excitation flip angle. A linear k-space trajectory, a SENSE acceleration factor of 2 and a linear ramp up preparation of 10 pulses in order to reach steady state prior to the bSSFP readout were utilized. The noise-free simulated signal was sampled at the inversion times (TIs), resulting in a database of a large number of possible physiological signal intensities. The MOLLI T1 estimates were then calculated for every database signal based on a 3-parameter fit [2].

For the ECV calculation [1], the following "true" values were selected based on the literature: pre-gadolinium-T1-myocardium = 1045 msec, pre-gadolinium-T1-blood = 1669 msec, post-gadolinium-T1-myocardium = 407 msec, post-gadolinium-T1-blood = 252 msec and blood-hematocrit = 0.4, resulting in a "true" ECV value of 26.7%. For the investigation of ECV's T2-dependency, the ECV was calculated based on the MOLLI T1 estimates from the database for a wide range of physiological T2 values for pre-gadolinium blood (200 – 300 msec) and myocardium (20 - 100 msec).

3. Results and Discussion

The dependency of ECV measurement on T2 values of pre-gadolinium blood and myocardium is shown in figure 1. MOLLI-based ECV calculation consistently demonstrated underestimation that became greater for low T2 values of pre-gadolinium myocardium and high T2 values of pre-gadolinium blood. Figure 1 demonstrates also higher dependency of ECV calculation on pre-gadolinium myocardial T2 values compared to the T2 values of pre-gadolinium blood.

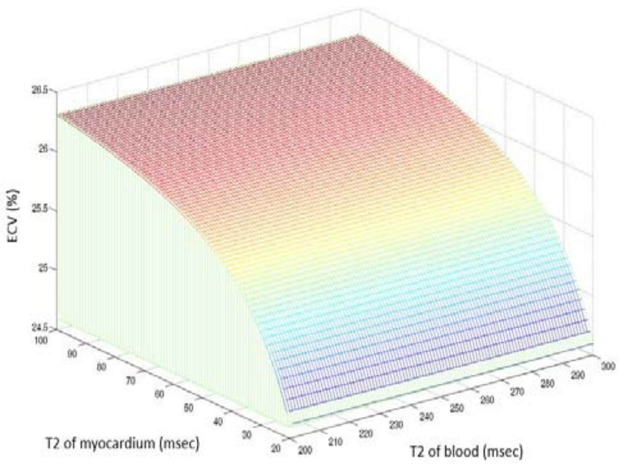

Figure 1. Dependency of ECV on T2 values of pre-gadolinium blood (pre-gadolinium-T1-blood = 1669 msec) and myocardium (pre-gadolinium-T1-myocardium = 1045 msec). Reference “true” ECV was 26.7% for post-gadolinium-T1-myocardium = 407 msec, post-gadolinium -T1-blood = 252 msec and blood-hematocrit = 0.4

Figure 2 presents the dependency of the ECV underestimation error on pre-gadolinium myocardial T2 value for a normal pre-gadolinium blood T2 value of 250 msec [4]. Higher ECV underestimation error was presented for lower pre-gadolinium myocardial T2 value. Figure 2 demonstrates also that for pre-gadolinium myocardial T2 values of 45, 65, and 85 msec (corresponding to normal [4], edematous and infarcted myocardium [5] respectively) and pre-gadolinium blood T2 value of 250 msec, the measured underestimation was 3.6%, 2.5% and 1.8% respectively.

Figure 3 shows the dependency of ECV underestimation error on pre-gadolinium blood T2 value for three different myocardial tissue types: normal myocardium, edematous myocardium and infarcted myocardium with pre-gadolinium T2 values of 45, 65, and 85 msec respectively. Higher ECV underestimation error was presented for higher pre-gadolinium blood T2 value. Moreover, figure 3 demonstrates that normal myocardium presented consistently higher underestimation error compared to edematous and infarcted myocardium for the entire range of pre-gadolinium blood T2 values (200 – 300 msec).

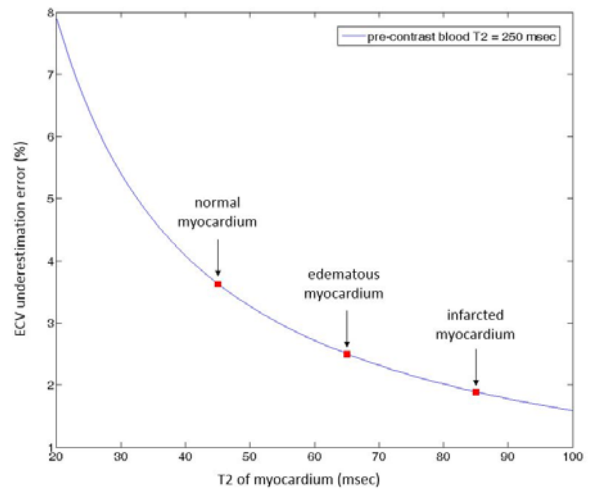

Figure 2. ECV underestimation error (%) versus pre-gadolinium myocardial T2 value for a pre-gadolinium blood T2 value of 250 msec. The measured ECV underestimation for pre-gadolinium myocardial T2 values of normal, edematous and infarcted myocardium is presented in red rectangles.

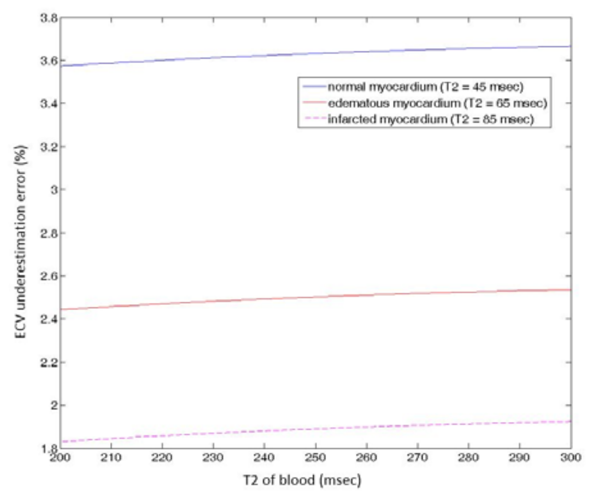

Figure 3. ECV underestimation error (%) versus pre-gadolinium blood T2 value for normal, edematous and infarcted myocardium.

4. Conclusions

MOLLI underestimates ECV measurements in shorter pre-gadolinium myocardial T2 and longer pre-gadolinium blood T2, as shown by simulations. However, the ECV calculation demonstrates stronger dependency on pre-gadolinium myocardial T2 than on pre-gadolinium blood T2.

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