A new method for accurate myocardial T1 mapping using Variable Angle Long Echo train Relaxometric Imaging (VALERI)

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Target Audience Researchers and clinicians interested in myocardial tissue characterization using T1 relaxometry.

PURPOSE While MRI is an established imaging method for assessing ischemic heart disease, its capacity to characterize myocardium in non-ischemic diffuse cardiomyopathies such as myocardial fibrosis and amyloidosis has been developed only recently (1-4). Currently, T1 mapping using the Modified Look-Locker Imaging (MOLLI) sequence (5) is commonly used to quantify myocardial tissue changes. However, this inversion recovery balanced steady-state free precession (IR-SSFP) based technique is prone to a variety of sources of errors, including short tissue T2 and imperfect inversion efficiency (6), non-rectangular flip angle (FA) profile (7), heart rate variability (8), as well as magnetization transfer (MT) (9), off-resonance, and blood flow effects. The gold standard IR spin echo (IRSE) technique is more robust than MOLLI, but requires lengthy acquisition unsuitable for clinical imaging. Here we propose a rapid fast spin echo (FSE) based T1 mapping sequence called Variable Angle Long Echo train Relaxometric Imaging (VALERI) and compare it with MOLLI for in vivo imaging at 1.5T and 3T.

METHODS The developed ECG-gated VALERI sequence consists of an inversion pulse followed by a specific inversion time (TI) delay and a single-shot FSE readout with variable refocusing FAs (10,11) during the mid-diastolic cardiac rest period. After a free relaxation period to allow full magnetization recovery (typically 4 sec for pre-contrast imaging), data is acquired with another inversion time, and the process is repeated until data for all TI's have been collected. Compared to FSE readout with constant refocusing FAs such as in the conventional IR-HASTE sequence, the variable FA schedule used in VALERI provides the dual benefits of minimizing T2 blurring (which is important for tissues with short T2 such as muscle and myocardium) and suppressing blood flow artifact (Fig.1), both of which may confound myocardial T1 quantification.

Imaging experiments were performed in healthy volunteers (GE HDxt scanner). First, the accuracy of MOLLI and VALERI was assessed in the calf muscle (similar T1/T2 as myocardium) by comparing with the reference standard IRSE sequence at 1.5T. Then, MOLLI and VALERI were used to obtain myocardial T1 at both 1.5T and 3T. Typical pulse sequence parameters were as follows: 1) IRSE: TR=6sec, 4TI's, 26 min; 2) MOLLI: TR/TE=3.3/0.9ms, FA=30°, 11 TI's, 16 heartbeats; 2) VALERI: echo spacing=4ms, echo train length=48, 4 TI's, 17 heartbeats. Both MOLLI and VALERI utilized parallel imaging (ASSET) with acceleration factor R=2.

RESULTS Fig.2 summarizes in vivo T1 values obtained with VALERI and MOLLI. In the calf muscle (n=7), VALERI provided excellent T1 agreement with the reference standard IRSE method, while MOLLI was found to underestimate T1 by 15.6% on average ($p<0.001$). A similar trend was observed in the myocardium (n=5), where MOLLI T1 values were lower than those obtained with VALERI by 12.6% at 1.5T and 9.2% at 3T ($p<0.01$). Figure 3 shows T1 maps of a stack of cardiac short-axis slices from one subject at 1.5T, demonstrating consistent T1 map quality.

DISCUSSION Our results show that the newly developed spin echo based VALERI sequence provides more accurate T1 than MOLLI, most likely due to its much reduced sensitivity to inversion efficiency, tissue T2, as well as off-resonance and blood flow effects. VALERI has the potential to replace the time-consuming IRSE sequence to obtain reference T1 values in comparison studies. The scan efficiency of this sequence can be further improved by interleaving slices, although further investigation of the MT effect (12) on multi-slice T1 quantification is warranted.

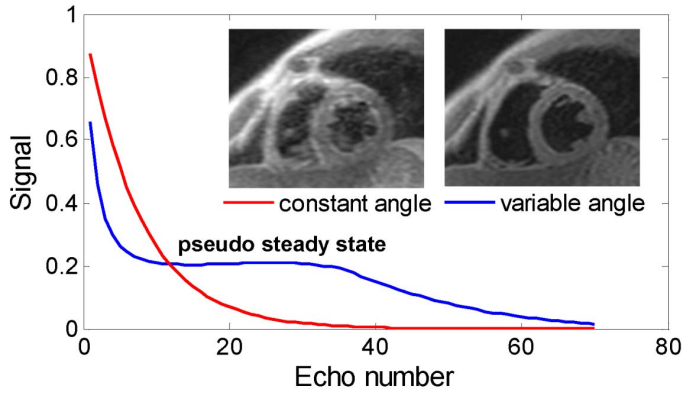

Fig.1. Simulated myocardial signal evolution with variable and constant refocusing angles and its effect on single-shot FSE images.

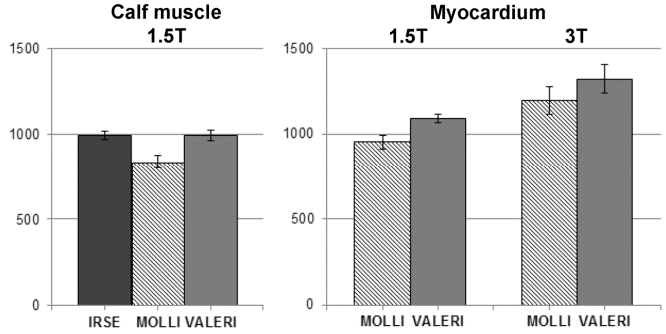

Fig.2.Comparison of T1obtained with IRSE, MOLLI and VALERI.

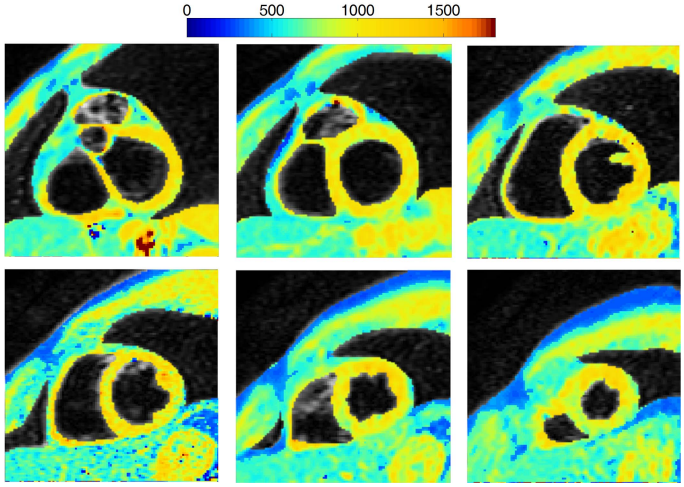

Fig.3. Examples of cardiac short-axis VALERI T1 maps (overlaid on

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