Quantitative measurement of myocardial T1 with a modified cine inversion recovery pulse sequence

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Introduction: In cardiac MRI it is possible to rely on the structural changes that happen in the myocardium during a cardiac disease to distinguish between healthy and pathological myocardial tissues. With this aim, the development of techniques for the quantification of myocardial T1 relaxation time has received significant attention in the past few years. Pulse sequences like the Modified Look Locker Inversion recovery (MOLLI) [1-3] and the Cine Inversion Recovery approach (Cine-IR) [3-5] have proved to be extremely reliable in the estimation of T1 values usually exhibited by the myocardium after the administration of gadolinium-based contrast agents in delayed enhancement studies. However, a method for the estimation of pre-contrast T1 is still challenging given its high value (~900ms at 1.5T) relative to the human cardiac cycle. For this reason, methods that correct T1 values for the heart rate have been introduced, but they all are specific to the pulse sequence to which they apply [4] and/or based on empirical data [2]. In this work we present a modified version of the original Cine-IR pulse sequence (MCine-IR) in which the effective repetition time is adapted according to the heart rate of the subject so that no additional correction is required in the T1 estimation model.

Methods: MCine-IR principle is illustrated in the pulse sequence of Figure 1. Like the original Cine-IR [3-5], it includes a non-selective adiabatic inversion pulse applied immediately after the ECG's R-wave trigger. The inversion pulse is followed by a cine acquisition, where each cardiac phase experiences a different time delay after the inversion pulse and thus shows a different T1 weighting. Unlike the original Cine-IR, where cine acquisition was limited to the first heart cycle following the inversion pulse and the second cycle was left for T1 recovery, in MCine-IR the acquisition is extended to further heart cycles. That is, for each cardiac phase, the same segment of k space is repeatedly acquired in subsequent heart beats to track signal recovery after the inversion pulse. This allows the pre-contrast myocardium to fully recover its longitudinal magnetization and its time evolution to be monitored by the cine acquisition. The number of heart beats used for the acquisition is given by: $N_{RR}=|(TR_{eff})/\Delta_{RR}|+1$ where the symbol | | denotes integer division. Δ_{RR} is the RR interval of the subject in *ms* and TR_{eff} is the effective TR between two successive inversion pulses. The addition of *+1* in the formula avoids any underestimation of TR_{eff} by rounding up its value to the next heart beat.

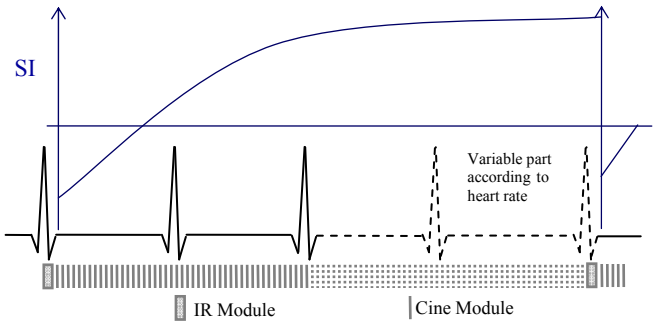

Figure 1 Modified Cine-IR pulse sequence

The pulse sequence was firstly compared to a standard spin-echo inversion recovery (IR-SE) using seven water tubes with different gadolinium concentrations. The ECG was emulated with an electronic device with a heart rate of 60bpm (Δ_{RR}=1000*ms)* and the number of heart cycles (#RR) used in the acquisition was progressively increased from 2 to 7 to simulate different TR_{eff} scenarios.
Next, 24 cardiac patients scheduled for CMR-DE examinations were enrolled in the study, after providing informed written consent. The MCine-IR sequence was run on all patients before and at fixed time intervals (5-min, 10-min, 15-min) after the administration of contrast agents (Gadodiamide-OMNISCAN™, 0,2 mmol/Kg). In 14 patients, DE areas were visually identified in one or more segments. Segments with DE areas were classified as patchy, midwall, or ischemic depending on size and shape of the areas [6], whereas the other segments were classified as remotes. Results from MCine-IR were used to measure the T1 of those segments along with segments from patients negative for DE. Acquisition was carried out with 1.5T scanner (Signa Excite General Electric, Waukesha, WI, USA) and using an 8-channel cardiac phased-array coil as a receiver.

Results: For the IR-SE sequence used in phantom experiments we set the time delays (TD) (ms): 50-150-500-400-1200-1800-2400-3500, TR=10s+TD, matrix 128x128. MCine-IR was a Fast Spoiled Gradient Echo (FastSPGR) pulse sequence with Flip Angle (FA)=8°, matrix=128x128, TE/TR=1.1ms/3ms, views per segment (VPS)=8, simulated heart rate=60bpm. In Figure 2 we can see the phantom T1 estimations with MCine-IR. For curve fitting a simple mono-exponential model was employed. Results suggest that in order to ensure a true estimation of both pre and post-contrast myocardial T1, a TR_{eff} of 4000ms can be used in subsequent experiments. For the MCine-IR *in vivo* study, the following parameters were used: FOV=38x38/48x38cm^2 depending on patient size, Matrix=224x192, FA=8°, VPS=12-24 depending on heart rate, number of averages=0.5-1, TE/TR=2.4-2.6/5-6ms. The total time of acquisition ranged between 14 and 18sec, and fit well into a reasonable breath hold time. Table 1 shows T1 values for *in vivo* analysis. First, a one-way ANOVA test was performed on healthy subjects between all segments and separately for pre-contrast, 5-min, 10-min, 15-min measurements. The test was not statistically significant (P>0.30) confirming that T1 measurements are not significantly affected by susceptibility and geometrical artefacts. Then, to study the dependence of T1 on the presence and type of DE, areas one-way ANOVA analysis was performed on segmental T1 values in patients with DE. A significant dependence was found (P=0.001) for pre and all post-contrast measurements. More specifically, segments with ischemic DE showed a significantly longer pre-contrast T1 and significantly shorter post-contrast values with respect to remote segments at 10-min and 15-min. Mean T1 pre-contrast value in segments with patchy or midwall DE were higher with respect to non-DE segments but did not reach statistical significance. Imaging at 10-min was able to detect also patchy and midwall DE (both shorter than remote areas). T1 values at 5-min do not show a consistent behaviour, probably because gadolinium distribution had reached equilibrium.

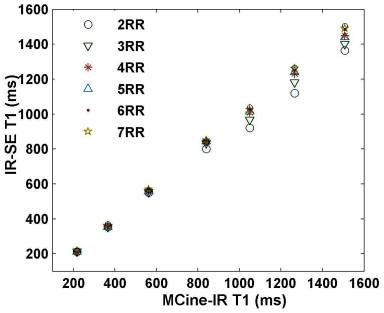

Figure 2. Phantom results

Conclusions: This study introduced a modified version of the Cine-IR pulse sequence, specifically designed to be independent of the heart rate, because the effective TR is adjusted according to the specific heart rate of the subject. Myocardial estimated values were in the range indicated by previous studies [1-5]. Future investigations will be devoted to monitoring the relative variation of myocardium and blood T1values before and after contrast agent administration.

Cardiac Segments	T1 pre	T1 post 5min	T1 post 10min	T1 post 15min
Healthy subjects:	818±78	372±34	404±30	425±30
Patients with DE:				
Remote	811±82	365±29	391±25	431±32
Patchy	841±69	343±32	360±19*	398±10
Midwall	847±76	319±31	345±40*	411±17
Ischemic	935±15*	378±33	332±33*	355±35*

Table 1. In vivo myocardial T1 quantifications.
(*) indicates significant difference with respect to remote areas

References: [1] D R Messroghli et al, MRM 52:141-146(2004). [2] D R Messroghli e al, Radiology 238(3):1004-1012(2006). [3] T Song et al, ISMRM 2009. [4] J W Goldfarb et al, JMRI 30:763-770 (2009). [5] M Milanesi et al, ISMRM 2010. [6] M Vohringer et al, Herz 32:129-137 (2007).