Fast quantitative measurement of T1 in cardiac delay enhanced studies

M. Milanesi[1], L. Marinelli[2], C. J. Hardy[2], V. Positano[1], P. Masci[1], A. Barison[1], M. F. Santarelli[3], L. Landini[4], M. Lombardi[1], and T. K. Foo[2]
[1]"G. Monasterio" Foundation, Pisa, Pisa, Italy, [2]Global Research Center, General Electric, Niskayuna, NY, United States, [3]Institute of Clinical Physiology, National Research Council, Pisa, Italy, [4]Department of Information Engineering, University of Pisa, Pisa, Italy

Introduction: Contrast delayed enhancement (DE) is a well established MRI technique for the evaluation of various cardiac diseases in magnetic resonance imaging. Healthy and injured myocardium show a different distribution of contrast agent (CA) 10-20 minutes after a bolus injection. This difference can be used in ischemic heart disease to detect like infarction and fibrosis, and in cardiomyopathies. Pulse sequences take advantage of the T1 decrease in paramagnetic CA like gadolinium, in order to produce T1 weighted images, where injured regions appear brighter. Typically, inversion-recovery (IR) fast-gradient-echo pulse sequences are used for this purpose, and clinical evaluation relies on visual inspection or customized software. Still, there is a clinical need for robust and reliable methods that provide quantification of myocardial T1. Cine inversion recovery (Cine-IR) has been recently proposed as a method for sampling longitudinal relaxation after an inversion pulse in DE studies [1-3]. In this study a Cine-IR pulse sequence is proposed to quantify myocardial T1s and distinguish between viable and non-viable areas.

Methods: The pulse sequence consisted of 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 (TD) after the inversion pulse and thus shows a different T1 weighting. The cine acquisition was carried out through a 2D Fast Spoiled Gradient-Echo (FastSPGR) pulse sequence with radio frequency (RF) spoiling. Phase-encoding rewinding was also applied to ensure that gradient area didn't vary from TR to TR as required for spatially independent spoiling . The acquisition was interrupted during the second heartbeat after each inversion pulse to allow T1 relaxation, unlike in [1]. However, it is important not to interrupt RF excitation during the second heartbeat to maintain the steady state of the spin system. Linear retrospective interpolation was performed on the cine data acquired in a single breath-hold, to allow full R-R coverage of the cardiac cycle. For curve fitting a simple mono-exponential model was employed, i.e. $s(t)=A+Bexp(-t/T1)$. This choice can be made if the pulse sequence used for relaxation curve sampling employs low flip angles (5°-10°) and the time between two inversion pulses is about 4 times the T1 to be estimated [4]. To perform exponential fitting, signal polarity for magnitude images was assigned using the approach described in [5].
The pulse sequence results were first compared to a standard spin-echo inversion recovery (SE-IR) on a phantom consisting of four water tubes with different gadolinium concentrations. This experiment aimed at both validating the exponential fitting model for Cine-IR and drawing up a range of T1s that can be correctly estimated depending on sequence parameters. For this purpose, Cine-IR was acquired with different flip angles (FA=5°, 10°, 20°) using an electronic device to emulate the ECG triggering. Cine-IR was then tested on four patients (two males, two females, age=60±10 years old) with suspicion of heart disease and two control subjects, after providing informed written consent. Acquisition was carried out with 1.5T scanner (Signa Excite General Electric, Waukesha, WI, USA) and 8 channel phased-array coil. The pulse sequence was run 5 minutes after a gadolinium bolus injection of 0.1 mmol/Kg (Gadovist®; Bayer Schering Pharma; Berlin, Germany,) before standard delay enhancement acquisition. Region of interests (ROIs) were traced respectively for the viable (remote) and suspected non-viable myocardium as well as blood pool. To ensure that the same myocardium region was analyzed throughout the different heart phases, the ROI was moved to correctly register the images.

Results: Table 1 shows phantom T1 estimations obtained both with SE-IR (TD=50-100-200-400-700-1000-1300-1600, TR=4s+TD, matrix 128x128) and Cine-IR (TE/TR=1.1ms/3ms views per segment=8, matrix 128x128, simulated heart rate=60 heart beats per minute) using different flip angles. For the first 3 T1s, Cine-IR gives T1 estimation similar to SE-IR for flip angles of 5° and 10° (respectively 2.5% and 3.0% lower), but it tends to produce significant T1 underestimation (8.6%) for FA=20°. Considering a 2R-R effective TR of 2 seconds, Cine-IR cannot estimate a T1 of about 1300ms regardless of the FA. For *in vivo* experiments 8mm short axis slice was acquired with Cine-IR using a matrix 224x224 and FA=10°. Although FA=5° gave better T1 estimations, FA=10° was chosen since it ensures higher SNR, which is really important in *in vivo* studies. Two out of four patients presented different myocardium myocardial T1 values due to infarction as elucidated by subsequent DE studies. For these patients non-viable ROI's T1=273±28ms (mean value ± std), remote ROI's T1=440±56 and blood pool ROI's T1=338±10ms. Figure 1a shows one Cine-IR image acquired in short axis (about 0.250 sec of TD after IR pulse) for one of the patient with infarction, along with DE (Figure 1b) and T1 curves obtained for three selected ROIs (Figure1c). The other two patients were found affected by dilated cardiomyopathy with diffusive DE, and presented a blood pool's T1=310±14ms and myocardium's T1=340±17ms, whereas the two control subjects showed myocardial T1=466±28ms and blood pool's T1=315±5ms.

	T1(ms)			
SE-IR	201	405	696	1295
Cine-IR 5°	197	386	690	2454
Cine-IR 10°	197	382	686	2353
Cine-IR 20°	193	348	641	2406

Table1: Estimated T1 values on the phantom using SE-IR and Cine-IR with different flip angles.

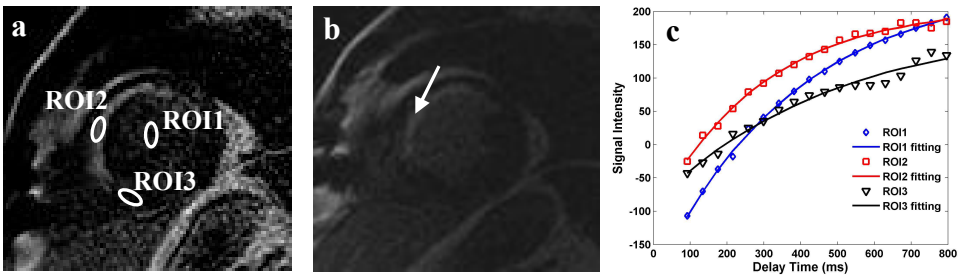

Figure 1: (a) One selected image from a Cine-IR experiment run with TE/TR=1.3ms/4.5ms, views per segment=16, FOV=40cm^2, patient's heart rate 69 beats per minute. Three ROISs were placed on viable myocardium (ROI1), non-viable myocardium (ROI2) and blood pool (ROI3). (b) Subsequent DE where subendocardial infarction is highlighted by an arrow. (c) Signal intensity values for each of the three ROIs traced on (a): ROI1's T1=346ms, ROI2's T1= 294ms, ROI3's T1=480ms.

Discussion and conclusions: Cine-IR proved to be a fast and reliable pulse sequence for T1 estimation, with results very close to SE-IR on phantom studies, though increasing the FA can lead to T1 underestimations as observed in [4]. Overall, in *in vivo* experiments, for viable myocardium and blood pool, T1 results were close to those presented in [6] under the same Gd-DTPA dose and after the same delay time from injection. For non-viable scarred myocardium, Cine-IR estimated a T1 significantly lower than for remote area and blood pool, confirming the trend found in [3,6,7]. Interesting, we found a T1 decrease also in the myocardium of patients affected by dilated cardiomyopathy although not as much as in those with infarction. When T1 values approached patient's heart rate, some overestimation happens as demonstrated by our phantom studies. This limitation can be overcome by properly increasing the number of heart beats used for spin relaxation in patients with high cardiac frequency.

References: [1] Foo T K *et al.*, ISMRM 2004. [2] Gupta A *et al*., Radiology 2004. [3] Goldfarb J Q *et al*, JMRI 2009. [4] Jivan A *et al.*, JMR 1997. [5] Nekolla S *et al*, JCAT 1992. [6] Sharma P *et al*,JMRI 2006. [7] Messroghli D R *et al*, MRM 2004.