Dynamic Measurement of Blood T1 for Perfusion Cardiovascular Magnetic Resonance

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Introduction

For quantitative myocardial perfusion cardiovascular magnetic resonance (CMR) using contrast agent, an important issue is to know how the blood T1 changes as a function of time after injection. The purpose of this study is to optimize a multipoint saturation recovery (SR) FLASH technique for dynamic first-pass measurement. This technique uses both a very low flip angle for the FLASH readout and non-selective saturation to minimize fresh inflow effects. The short low resolution 50ms sequence and a centric-out phase-encoding order enabled acquisition with short SR delays. Therefore multiple SR images can be obtained during each cardiac cycle with timing optimized to give an accurate estimation of rapidly changing T1 values due to the passage of the contrast agent through the blood. This technique was validated on phantoms and then employed to investigate effects of injection rate and cardiac function upon the arterial input function (AIF) in patients.

Methods

A 1.5T scanner (Siemens Sonata) with 4-channel body array coil and gradient performance up to 40mT/m and 200T/m/s was used. Image acquisition was performed using an ECG-triggered FLASH prototype sequence which was optimized purposely for this study. A low resolution FLASH sequence (TE 0.35 ms, TR 1.06 ms, matrix 48 x 64) was adopted to shorten the data acquisition time (50ms), and the flip angle was reduced to 5º to minimize fresh inflow effects. A non-selective 90°saturation pulse was followed by a time delay (TD) and a train of low-flip-angle excitation pulses for data acquisition of a complete low resolution image. The reason for using a nonselective 90°pulse is that the pulse provides initial null longitudinal magnetization for all tissues and hence the measured signals are insensitive to inflow effects and not affected by the residual longitudinal magnetization from previous data acquisition. The short 50ms FLASH sequence and a centric-out phase-encoding order enabled acquisition with short SR delays. In each cardiac cycle during the first-pass, a series of SR low-resolution images with exponentially increasing SR delay times were obtained starting immediately after the R-wave. The SR delay times increased exponentially during each cardiac cycle, 10, 20, 40, 80, 160, and maximum 320ms. Normally, obtaining 5 points of the SR curve takes about 600ms, which is suitable for most patients with heartbeats under 100bpm.

40 Patients undergoing a CE-CMR study for late enhancement assessment had gadolinium (Magnevist) injected using a Medrad power injector in the right antecubital fossa (0.1 mmol/kg followed by 10 mls normal saline flush). A transversal plane through the ascending aorta (AA) was selected to minimize cardiac motion effects, and images were acquired for 45 cardiac cycles during peripheral injection. For the first two cycles, no saturation pulse was applied (equivalent to an infinite SR delay) to give the fully recovered signal level. The calculation of short T1s during peak gadolinium concentration in the AA was performed for each cardiac cycle by fitting mean ROI magnitude against SR delay times within each cardiac cycle. The duration of the AIF was also determined from the series of T1 measurements during these cycles.

T1 estimates were carried out with a Levenberg-Marquardt fitting algorithm (MATLAB curve fitting toolbox) using an empirically derived function:

$$SI = S0(1 - e^{-(TD-T0)/T1}) \quad (1)$$

Where SI represents signal intensity (mean of ROI in AA), S0 the fully recovered signal, and TD SR delay time. A similar equation has been used by Ridgway et al (1). One reason for using parameter T0 is the fact that imaging is during the approach to the steady state. Other factors studied include image weight, receiver gain and changing gadolinium concentration. Since a short TE (0.35 ms) is used, the signal decay due to T2* could be neglected (2), as we showed in Fig.1 with some complete first-pass acquisitions without saturation 90° pulse.

Results

The fast technique for measuring short T1 values was validated on phantoms with different gadolinium concentration, and multipoint inversion recovery (IR) T1 measurements were taken as the gold standard. The percentage error of T1 estimates provided by the method described above were less than 8% for samples of T1 ranging from 10ms to 150ms. Experiments conducted indicated that flow effects could be neglected for T1 measurements. This technique has been successfully applied to investigate the factors that influence the AIF in myocardial perfusion. Fig.2 is an example of multipoint SR curve from one of the patients. It was acquired within one cardiac cycle corresponding to the highest gadolinium concentration, and T1 is estimated as 24ms. It shows that the short FLASH sequence allowed several measurements before fully recovery was reached. Fig. 3 is the dynamically changing T1 value curve obtained during first-pass of the same patient.

Discussion

This is the first work that uses multipoint SR technique within a single cardiac cycle to estimate the rapidly changing blood T1 values during first pass of contrast agent in a myocardial perfusion study. It demonstrates that the inflow effect and the variation of magnetization during the data acquisition can be suppressed efficiently. Although this technique uses a low resolution scheme, it is sufficient for T1 measurements during first-pass of contrast agent.

The methods introduced here should allow relatively accurate and robust estimations of blood T1 after injection of contrast agent. It allows study of the factors influencing the AIF and therefore may serve as a promising means of improving both the accuracy and reproducibility of perfusion CMR. Furthermore, it may find potential application in studying the characteristics of different contrast agents.

References

(1) Ridgway JP *et al.* Proc Intl Soc Magn Reson Med 2001; 9:1905

(2) Zheng J *et al.* J Magn. Reson. Imag. 1999; 10:576–581

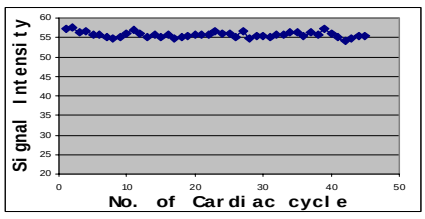

Fig.1. T2*effect during injection of gadolinium, no saturation pulse, single phase image per cycle

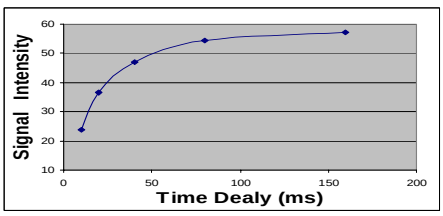

Fig. 2. Multipoint Saturation recovery Curve within one cardiac cycle during first-pass measurement

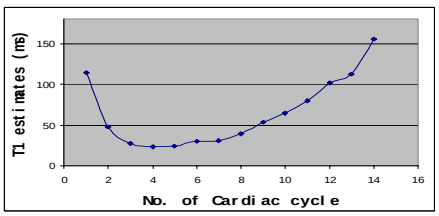

Fig.3. Dynamic T1 values of 12 cardiac cycles during first-pass measurement