Rapid Quantification of Systolic and Diastolic Transverse T1ρ Relaxation Times in the Human Left Ventricle

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Introduction: Post infarction, left ventricular remodeling is responsible for almost a quarter of heart failure instances (1-2) and it is evident that infarct expansion and dilatation is an important factor for initiating and sustaining this process (3). Understanding the pathophysiology that occurs after an infarction is necessary for limiting infarct expansion and ventricular remodeling. Clinically, the most common methods for diagnosis of infarct expansion and remodeling are surface ECG and serum chemistry. Delayed contrast enhancement MRI has also shown to be a useful tool for assessing left ventricular remodeling. The purpose of this work was to develop a rapid pulse sequence for cardiac T1ρ (spin lattice relaxation in the rotating frame) imaging by k-space-weighted image contrast (KWIC) reconstruction and to measure 1H relaxation times in vivo. We hypothesize that there are measurable transverse relaxation time changes during the cardiac cycle, which may be used as a surrogate measure of cardiac stress.

Materials and Methods: In Vivo MRI: Three volunteers (22-30 years of age) gave informed consent to participate in this study. Each volunteer was scanned 4 times at 1.5T (Tim Ispeed Model, Siemens Medical Solutions, Malvern, PA, USA) equipped with 18 mT/m nominal gradients. A posterior, spine matrix coil, together with an anterior body matrix coil, was used. A gradient echo localization was used to obtain short axis cardiac views. Pulse Sequence Design: T1ρ-prepared, diastimetric, k-space undersampled gradient echo acquisition was programmed in IDEAS (Siemens). Two free-breathing, T1ρ maps were acquired; one each during systole and diastole by ECG triggering at 300 ms (systole) and 650 ms (diastole) from the R wave. The parameters used for acquisition were as follows: TR = 2000 ms, 2.41 ms, bandwidth/pixel = 403 Hz, slice thickness = 5 mm, matrix = 128 x 128, FOV = 240 mm2 or 280 mm2, flip angle = 15°, 2-4 shots, TSL = 6-48 ms in 6 ms increments, radial views = 40-60, scan time = 5.5 minutes. The spin lock pulse cluster consisted of five rectangular pulses, which made use of an integrated spin lock and spin echo approach to compensate for B1 and B2 homogeneity. KWIC Reconstruction: Raw data was reconstructed using k-space-weighted image contrast (4), accelerating acquisition by a factor of 8. A detailed explanation is shown in Figure 1. Data Analysis: T1ρ relaxation maps were generated by pixelwise, linear, least squares fitting to the linearized exponential T1ρ decay. Prior to fitting, each T1ρ-weighted image was smoothed using a Gaussian filter. Following mapping, each image was noise filtered on the basis of goodness of fit (χ2 ≥ 1), maximum and minimum signal intensity, and the appropriateness of T1ρ relaxation times for the cardiac tissues (0 ≤ T1ρ ≤ 250 ms). In vivo images were overlaid on T1ρ-weighted images (TSL = 48) and the left ventricle was segmented with the ROI placed in the medial portion of the interventricular septum. Statistical analysis was performed by studentized, two-tailed t-test.

Results: In vivo relaxation times measured in the interventricular septum were significantly different between systole (T1ρ = 63.5 ± 7.4 ms) and diastole (T1ρ = 72.0 ± 7.4 ms) (p < 0.005) (Table 1). No spatial variations in relaxation times were observed as a function of wall radial dimension or between the papillary muscles and the ventricle, although it is likely that such differences may exist. 4 sets of data from one volunteer during systole and diastole are displayed in Figure 2. Data was of moderate reproducibility, and coefficients of variation were between 8 and 13%. No significant differences were observed between right and left ventricular relaxation times. It is also possible to measure the relaxation times of blood in both ventricles, although it must be assumed that some saturation effects occur because of the shorter delay between triggered R-R intervals and blood T1. The use of undersampled, radial acquisition followed by KWIC reconstruction enabled scan times to be reduced 8-fold, from 28 to less than 5 minutes.

Discussion: We suspect that the observed increase in 1H transverse relaxation times between systole and diastole is related to the change in the rotational correlation time of the nucleus during the cardiac cycle. Normal contraction and relaxation exert a time-dependent stress/strain on the extracellular matrix and myocytes, which modulates the rate of rotation of water molecules. It is likely that spin locking suppresses competing mechanisms of relaxation such as susceptibility, chemical exchange and diffusion, such that these differences become observable. T1ρ is probably insensitive to changes in the rotational correlation time because the water 1H T1 in heart muscle is typically longer than the cardiac cycle, giving way to a time-averaged relaxation time throughout. Partial volume effects and motion can shift the heart location, such that between a set of TSL times, the heart is no longer stationary. We are working to develop techniques that use self-navigation or acquire single slice data in a single breathhold, so that these artifacts are reduced. T1ρ MRI may be used for the diagnosis of acute or chronic MI to distinguish or follow the area of infarct after ischemia. Early increases in T1ρ may be because of edematous changes to the myocardium, which again modulate the rotational correlation time of the water protons. Later deposition of collagen scar, during chronic ischemia may also increase T1ρ. This latter study is the focus of Abstract 1493. The method of KWIC reconstruction is quite general and may be used for the acquisition of T2 or diffusion-weighted data in the myocardium following a similar fashion.

Conclusion: T1ρ imaging and relaxation mapping was performed in the human myocardium using a T1ρ-prepared, multiecho, radial acquisition, from which KWIC reconstruction was performed to accelerate image acquisition by a factor of 8-fold. These techniques may be used to study infarct expansion and dilatation in patients undergoing left ventricular remodeling. A significant advantage of T1ρ imaging is for the use of patients with kidney disease, for which a delayed contrast enhanced MR scan is not possible.


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