Rapid T2 measurement in the human heart based on multi-echo single shot EPI and parallel acquisition technique

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INTRODUCTION

The Blood-Oxygen Level Dependent (BOLD) contrast mechanism has been investigated for applications in the heart where local blood volume and oxygen consumption are expected to generate BOLD signal changes larger than in the brain. Several strategies have been adopted in order to overcome difficulties specific to cardiac BOLD imaging. Various ultra-fast imaging methods are applied to freeze the effects of respiratory and cardiac motion (EPI, spiral, True-FISP and TSE); T2 contrast rather than T2* contrast is selected to limit susceptibility artifacts and, relaxation times are measured instead of signal intensities to reduce the effect of signal drift and motion between separate physiological conditions. As most of the T2 imaging methods require the acquisition of data over separate heart beats, their sensitivity remains limited by physiological noise from beat-to-beat motion. Here, we evaluate the combined use of parallel imaging technique and single-shot multi spin echo EPI to reduce the acquisition of the T2 decay within a single heart beat and to repeat the T2 measurements at short time intervals within a single breath-hold.

METHOD

A single-shot multi spin-echo EPI pulse sequence (SSME) [1] has been implemented on a 1.5T Siemens system and combined with GRAPPA [2], a variant of the SMASH reconstruction technique. Single-slice short-axis cardiac images were acquired in healthy volunteers with a 4-element phased array coil and gated in end-systole (FOV 250- 330 mm^2, slice thickness 6 mm, matrix 64x64). Multi spin echoes were collected at TE, 2TE, 3TE and 4TE, with TE = 19-21 ms with GRAPPA and 30-33ms without GRAPPA. T2 measurements were repeated and subjects were instructed either to synchronize their breathing between acquisitions (SBI) or to hold their breath during the acquisition (BH). Repetition time was set to ~ 6s for SBI and ~ 1s for BH acquisitions, respectively (i.e. 4 ME images/6 heart cycles and 4 ME images/1 heart cycle). T2 map were obtained after weighted-least-square fit of the logarithm of the signal intensity as a function of time. T2-values were measured in 3 regions of the left ventricle (anterior lateral, lateral posterior and septum). Temporal standard deviation was computed for each series of repeated T2 measurements (NEX=12). Paired T2 measurements were collected with multi-echo spin echo and TE-stepping single spin echo EPI, using the same sets of 4 echo times for the two imaging methods. Acquisitions were performed with and without GRAPPA, in 9 healthy volunteers, using a synchronized breath-in protocol. The GRAPPA-SSME EPI sequence was then evaluated alone in three additional volunteers comparing two different modes of breathing (BH and SBI).

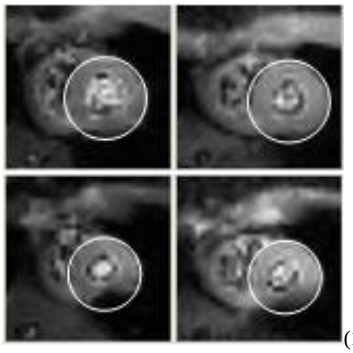
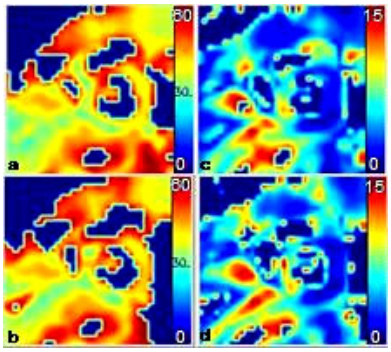
RESULTS

Parallel Acquisition Technique: the GRAPPA technique was applied in our SSME sequence to decrease in half the EPI read out time per spin echo. Shorter readout time reduced the image distortion and susceptibility artifacts in the EPI images. Improvements in image quality were most noticeable in the apical area of the myocardium, where susceptibility effects from heart-lung interface are severe (see Figure 1). In addition, the shorter readout time enabled us to reduce the echo time from 33ms to 19ms and to acquire all 4 spin echoes during the end-systolic phase (acq.time < 100 ms). Comparison of myocardial T2 measurements obtained with and without GRAPPA showed smaller T2 variations across subjects (7% vs. 11%) and smaller mean T2 values (10% decrease) (see Table).

Multi-echo versus TE-stepping: Comparison of the T2 measurements obtained with SSME and TE-stepping methods showed no significant differences in mean T2 values, independently of the use of GRAPPA (see Table). Without GRAPPA, the SSME EPI acquisition produced smaller temporal standard deviations compared to TE-stepping acquisition (25% lower in the anterior wall, 12% in the posterior wall, 35% in the septum, $p < 0.05$ and 63% across all LV walls). With GRAPPA, no significant differences of temporal standard deviations were observed between the two imaging methods. The use of GRAPPA decreased significantly the physiological noise measured using the TE stepping method, and did not affect the noise levels measured with SSME.

Breath-Hold (BH) versus Synchronized-Breath-In (SBI): The type of breathing had no effect on the average T2 values measured in the myocardium (43.25±4.35 ms vs. 43.31±5.83 ms). Although shorter repetition times were used during breath-hold acquisitions, T2 measurements did not appear to suffer from the associated loss in SNR. Instead, the use of BH acquisition reduced the temporal standard deviations compared to those obtained with the SBI acquisition (0.54±0.14 ms vs. 1.18±0.45 ms). Figure 2 illustrates the good agreement in T2 maps obtained with the two breathing modes and shows a slight decrease of temporal standard deviation in the septum wall.

		ant	n=9	post	n=9	Sept	n=9	global	n=9
GRAPPA off		**mean**	**stdev**	**mean**	**stdev**	**mean**	**stdev**	**mean**	**stdev**
T_2 values (ms)	**SSME**	50.61	6.59	45.85	5.51	54.47	6.09	51.21	6.20
	TE-step	48.59	5.44	45.04	4.93	56.12	5.74	51.02	4.60
temporal stdev (ms)	**SSME**	1.65		1.36		2.72		**1.40**	
	TE-step	2.41		1.55		4.18		**2.21**	
GRAPPA on									
T_2 values (ms)	**SSME**	44.45	3.51	42.00	4.78	44.68	5.62	44.45	3.15
	TE-step	46.59	4.18	44.04	3.40	50.59	3.06	48.10	3.56
temporal stdev (ms)	**SSME**	1.61		1.52		2.48		**1.41**	
	TE-step	1.76		1.16		1.89		**1.16**	


(1)


(2)

Figures - (1) magnitude images acquired without GRAPPA (left column) and with GRAPPA (right column) at two different levels: mid-ventricular (top) and apical (bottom), (2) T_2 (left column) and temporal T_2-standard deviation maps (right column) for BH (top) and SBI (bottom) acquisition.

DISCUSSION

Our interest was focused on the development of a T2 imaging method providing reliable BOLD contrast measurements in the myocardium, with limited physiological noise. We have investigated different methods for reducing the acquisition time and evaluated its effect on shot-to-shot T2 variability.

The SSME EPI sequence, which reduces the total acquisition time by a factor of 4, produced smaller temporal standard deviations compared to a standard TE-stepping method.

The GRAPPA technique, which reduces the image acquisition time, was investigated as well. A decrease of the physiological noise was found for the TE-stepping acquisition mode, however, no changes were observed for the SSME EPI sequence, suggesting that a new limit of temporal SNR might have been reached.

Breath-hold acquisitions, which reduce the total acquisition time of repeated measurements, appeared to produce lower temporal standard deviations compared to SBI acquisitions. Additional experiments are required to confirm this preliminary observation.

Comparison of the temporal standard deviation of the T_2-value between different acquisition techniques has allowed us to elaborate a robust protocol for repeated T_2 measurements in the human heart. These single-shot multi-echo EPI acquisitions may be an acceptable basis for reliable measurements of the BOLD contrast in the myocardium.

REFERENCES

[1] Poncelet *et al.*, Proc. of the 10th annual meeting of ISMRM, p.512 (2002), [2] Griswold *et al.*, MRM, 47, 1202-12 (2002).