Free-breathing myocardial T2* mapping using single-shot GRE-EPI and automatic non-rigid motion correction

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Introduction

Cardiac failure caused by myocardial iron overload is the most common cause of death in patients with thalassemia (1), and myocardial T2* mapping is widely used to detect and quantify myocardial iron in these patients (2). The standard myocardial T2* mapping approach uses an ECG-triggered segmented black-blood multi-echo gradient echo (mGRE) sequence (3). As with any segmented k-space acquisition, data are acquired over multiple heart beats and patient breath-hold is required to avoid respiratory motion artifacts; this strategy fails in severely ill patients and others unable to breath-hold. Methods for mapping myocardial T1 and T2 have successfully addressed this issue via a strategy of single-shot acquisition combined with image registration (4, 5). In this work, we apply a similar strategy and describe a new technique for myocardial T2* mapping using single-shot gradient-echo echo-planar imaging (GRE-EPI) coupled with automatic non-rigid motion correction. The proposed technique is expected to accurately quantify T2* values in the heart with less sensitivity to respiratory motion than the standard, segmented k-space acquisition.

Methods

Sequence A pulse sequence strategy was implemented to acquire a series of T2*-weighted images using a single-shot, black-blood GRE-EPI sequence at 8 different echo times (TE = 1.2, 3, 5, 7, 9, 11, 13 and 14 ms) with a flip angle of 18°, a TR of 20 ms, an echo-train-length of 5, a sampling bandwidth of 1500 Hz/pixel, a slice thickness of 10 mm, a GRAPPA acceleration rate of 2 with 24 reference lines, a field-of-view (FOV) of 380 mm and a matrix = 192 × 86. This yields a voxel size of 3.3 × 1.9 × 10 mm^3. A frequency-selective fat-suppression pre-pulse was used to minimize chemical displacement artifacts from fat. For black-blood imaging, the double inversion pulses were applied at the R-wave trigger and the inversion time was set to extend into diastole. Each of the eight different echo time images was acquired in a single heart beat with an acquisition window of 280 ms.

MRI All imaging was performed using a 1.5 T MAGNETOM Avanto clinical scanner (Siemens Medical Solutions, Erlangen, Germany) with body matrix and spine coils for signal reception.

Phantom studies Nine T2* phantoms were constructed with Falcon tubes filled with water and doped with 0.25, 0.31, 0.5, 0.62, 0.75, 0.87, 1, 1.12, 1.25 mmol/L $MnCl_2$ to produce a wide range of T2* values. T2* measurements were performed using the proposed black-blood GRE-EPI sequence with a simulated heart rate of 60 beats/min and 16 signal averages. For comparison, T2* maps were also acquired using the standard ECG-triggered segmented black-blood mGRE sequence with 4 signal averages.

Volunteer studies Experiments were conducted in six healthy volunteers. Myocardial T2* images were acquired in the short axis view using both the black-blood GRE-EPI sequence during free breathing, and the standard ECG-triggered segmented black-blood mGRE sequence during one breath-hold of 14 heart beats

Data Processing In volunteer studies, T2*-weighted images from GRE-EPI sequence were motion corrected using automatic non-rigid motion correction to reduce image mis-registration due to respiratory motion (6). No motion correction was performed for phantom images. T2* maps were calculated by fitting pixel intensities to a two-parameter mono-exponential model (Signal = M0 * exp(-TE/T2*)). Regions-of-interest (ROIs) were placed in the tubes in phantom images and in the interventricular septum in volunteer images. The mean T2* values within the ROIs were calculated using both sequences and compared using a pair-wise t-test.

Results

Phantom studies A strong correlation was observed between the mean T2* measured using GRE-EPI and the mean T2* measured using mGRE ($r = 0.992$) (**Fig. 1**). No statistically significant difference was observed between the T2* values measured using the two methods ($p = 0.234$).

Volunteer studies Myocardial T2* maps were successfully acquired in 5 subjects; both methods failed in one subject due to the inability to breath hold during mGRE acquisitions and severe respiratory motion observed during GRE-EPI acquisitions. **Fig 2** shows example GRE-EPI source images and the effect of the automatic non-rigid motion correction on single-shot GRE-EPI images acquired during free-breathing. GRE-EPI images at TE = 1.24, 5, 7, 11 ms pre motion correction (top row) and post motion correction (bottom row) are shown. Contours were drawn on TE = 1.24 ms image and projected to the images at later TEs. The automatic non-rigid motion correction successfully reduced image mis-registration due to respiratory motion. **Fig 3** shows the representative myocardial T2* maps acquired in one volunteer using the breath-hold mGRE and free-breathing GRE-EPI techniques. The mean T2* of the interventricular septum in 5 volunteers were 33.37 ± 2.64 ms from mGRE measurement and 32.45 ± 2.94 ms from GRE-EPI measurements; while the sample size is small, these measures were not significantly different ($p = 0.156$).

Conclusion

We have developed the novel free-breathing myocardial T2* mapping combining multiple single-shot black-blood GRE-EPI images with automatic non-rigid motion correction. The approach provides accurate myocardial T2* measurements and is insensitive to respiratory motion, and is likely to reduce sensitivity to arrhythmia as well since each image is acquired in a single heart beat. While image registration does not account for through-plane motion, the same approach has proven successful for myocardial T1 and T2 mapping.

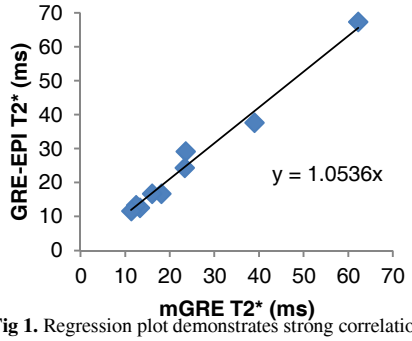

Fig 1. Regression plot demonstrates strong correlation between the T2* measured using mGRE and GRE-EPI in phantoms over a wide range of T2* values.

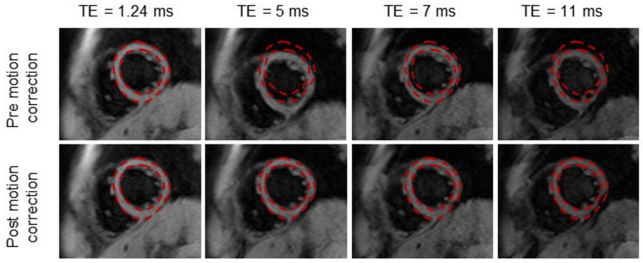

Fig 2. Effects of non-rigid motion correction on GRE-EPI images acquired during free-breathing. GRE-EPI images at TE = 1.24, 5, 7, 11 ms pre motion correction (top row) and post motion correction (bottom row) are shown. Contours are drawn on image at TE = 1.24 ms and projected to images at later TEs. Motion correction successfully reduced image mis-registration due to respiratory motion.

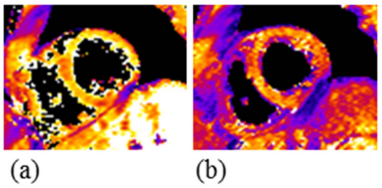

Fig 3. Representative myocardial T2* maps acquired using breath-hold mGRE (a) and free-breathing GRE-EPI with motion correction (b). Septal T2* values showed no significant difference between the techniques in five volunteers.

References

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