Rapid T2 mapping of mouse heart using CPMG sequence and compressed sensing reconstruction

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Quantification of proton transverse relaxation time T_2 provides important information in a variety of pathological conditions. To date, mouse models have been widely used for the study of genetic factors in cardiovascular diseases. However, due to the small size of a mouse heart and its fast heart rate, an accurate T_2 measurement of mouse heart has been challenging. In our previous study, we proposed a rapid T_2 mapping method using a fast multi-echo spin-echo sequence with a model-based compressed sensing (CS) reconstruction [1]. In the current study, we further verified the accuracy of CS reconstruction using two different reconstruction methods and implemented this method in a manganese-enhanced MRI (MEMRI) study. Our results suggest that an accurate T_2 measurement of mouse heart can be obtained at a high temporal resolution of one minute using the current method.

Methods MRI experiments were conducted on a 7T Bruker (Billerica, MA) horizontal bore scanner. The standard Carr-Purcell-Meiboom-Gill (CPMG) sequence was modified for accurate and robust T_2 mapping. Specifically, variable crusher gradients were used to minimize the stimulated echo effect [2]. The slice thickness of the refocusing pulse was adjusted to three times of the excitation pulse to ensure a uniform 180 degree pulse across the imaging slice [3].

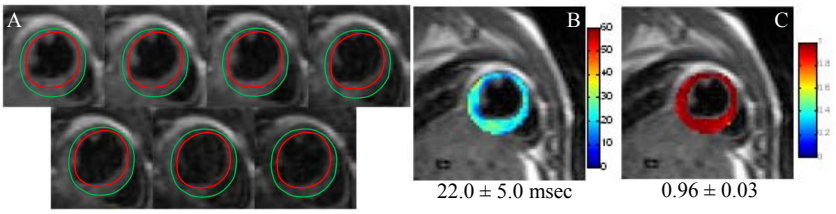

Fig. 1: (A) Representative fully-sampled T_2-weighted images from a mouse heart. Both the endocardial (red) and epicardial (green) contours were defined from the first echo image and then copied to the rest of images. (B) The corresponding T_2 map. (C) Map of squared correlation coefficient for the exponential T_2 fitting.

Further reduction of acquisition time was achieved through random under-sampling of the k-space lines followed by reconstruction of the images using compressed sensing. The accuracy of such an approach was evaluated by retrospectively under-sampling the fully-sampled images with a data reduction factor of 2 (R = 2). The under-sampled images were then reconstructed using either orthogonal matching pursuit (OMP, [4]) or nonlinear conjugate gradient method (CG, [5]). The T_2 maps were calculated from the reconstructed images and the results were compared to those obtained from fully sampled data set.

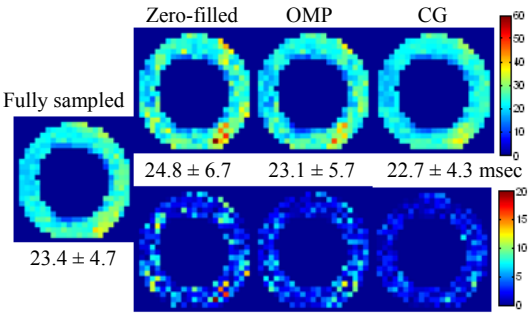

Fig. 2: Compressed sensing reconstruction from retrospectively under-sampled images. The NRMSE values were calculated for each reconstruction case.

The random under-sampling scheme was implemented and the reconstruction methods were evaluated in an MEMRI study using three-month-old FVB mice (n=5). $MnCl_2$ solution (126 mM) was injected via tail vein at a rate of 0.2 mL/h for 30 minutes, followed by 15-minute washout. Under-sampled T_2-weighted images (R = 2) were acquired with an ECG-triggered CPMG sequence at mid-ventricle. T_2 map was reconstructed with either OMP or CG method as described above. A TR of 400 ~ 600 msec was used, corresponding to triggering at every four cardiac cycles. Total data acquisition time for one under-sampled data set was about one minute. After the detection of R wave, a triggering delay of about 60% of the cardiac cycle was used to ensure that most of the data were acquired during mid- to end-diastole to minimize the motion artifact and signal dropout. Other imaging parameters were: minimal TE, 4.4 msec; number of echoes, 8; matrix size, 128×128; FOV, 3*3 cm; slice thickness, 1.5 mm; number of averages, 2. The dynamic R_2 changes were further compared to the results acquired from fully-sampled data set (n=1) or saline injection (fully-sampled, n=2).

Results Figure 1 shows the representative T_2-weighted images and the corresponding T_2 map acquired from fully sampled images. For the multiple T_2-weighted images, no clear wall motion was observed as indicated from the endocardial and endocardial contours traced from the first echo image. An average squared correlation coefficient close to one suggests a nice exponential T_2 fitting across the whole myocardium.

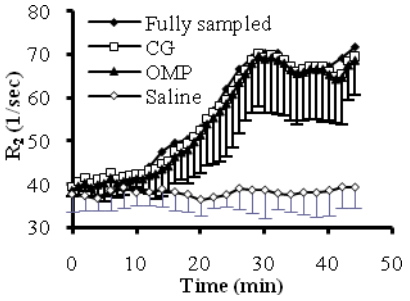

Fig. 3: Time course of R_2 changes for both $MnCl_2$ infusion (fully sampled or under-sampled) and saline infusion (fully sampled only).

Figure 2 demonstrates that accurate T_2 mapping can be obtained from CS reconstruction on retrospectively under-sampled images. With a data reduction factor of 2, T_2 values obtained from both OMP and CG methods agreed well with that of fully-sampled images. The lower NRMSE values of both methods further demonstrate a better reconstruction as compared to the direct zero-filled method.

Time courses of R_2 changes for both $MnCl_2$ infusion and saline infusion are shown in Fig. 3. Compared to the results of saline infusion, significant increase in R_2 was observed after 30-min $MnCl_2$ infusion. Similar R_2 changes were captured with either OMP or CG reconstruction method on under-sampled data set, which were in strong agreement with the fully-sampled results. All these results demonstrate that a high temporal resolution of one minute can be achieved in MEMRI studies using our rapid T_2 mapping method.

Conclusions In this study, a modified CPMG sequence was developed for rapid T_2 mapping of mouse heart. Using CS reconstruction, accurate T_2 mapping was achieved with highly reduced data sampling. The utility of the current method was demonstrated in a manganese-enhanced MRI study which yielded accurate T_2 mapping at a high temporal resolution of one minute.

References

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