Retrospective CINE MRI of the mouse heart

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Introduction

In cardiac research in vivo studies of mice are indispensable to gain an improved understanding of cardiovascular disease mechanisms and to develop novel diagnostic tools as well as surgical and therapeutic interventions. MRI plays an important role in measuring the global functional parameters of the mouse heart, including end diastolic volume, end systolic volume and ejection fraction (1). These parameters can be determined from triggered cinematographic (CINE) MR images. Without any respiratory gating strategy these images have considerable motion artifacts due to the strong gradient fields of the CINE sequence (2). This can be solved by respiratory gating, at the expense of a fluctuating longitudinal magnetization induced by an idle time between the end of the CINE series and the next trigger event (3). This results in a poorly defined contrast, which makes automatic segmentation difficult and seriously limits the use of contrast agents. To solve this problem we propose a retrospective method for cardiac triggering and respiratory gating, which uses a navigator echo to derive heart and respiratory cycles retrospectively.

Methods and Materials

The synchronization of the cardiac images with the different heart phases and respiratory activity was accomplished by analyzing the slice refocusing signal of a FLASH sequence (see Figure 1). The parameters of this FLASH sequence with the in-slice navigator echo were: Gaussian-shaped RF-pulse, 300 μs; flip angle, 15°; TR, 7 ms; TE, 2,9 ms; acquisition window, 1.27 ms; field-of-view, 3 x 3 cm^2; matrix, 192 x 192; in-plane resolution, 156 μm; slice thickness, 1.1 mm; number of navigator points, 128. For comparison a short axis slice around the equator was measured with three FLASH measurement methods with equal parameters: 1) prospective ECG triggering without respiratory gating; 2) prospective ECG triggering and prospective respiratory gating; 3) retrospective triggering and retrospective gating based on the magnetization and the phase of the slice refocusing signal as provided by the Bruker retrospective gating package. The experiments were carried out on a 6.3 T/20 cm system operated with Bruker *AVANCE* electronics (Bruker BioSpin MRI GmbH, Ettlingen, Germany). The retrospective measurements were reconstructed by Bruker *ParaVision* software. CINE images of three Swiss mice (age, 18-20 wks; weight, 42-43 g) were examined. The myocardial wall was segmented manually and analyzed with a Matlab program to calculate the SNR of the myocardial wall. The noise was determined in a region without any signal and artifacts for normalization. Also a comparison was made between the heart and respiratory rates measured with an ECG/respiratory trigger unit and the Bruker *ParaVision* retrospective reconstruction program.

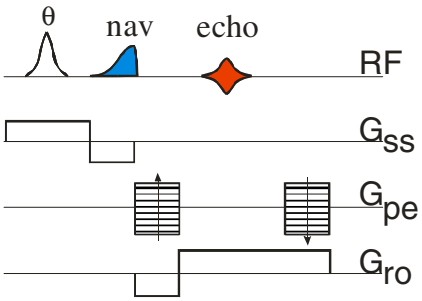

Figure 1: Flash sequence with in-slice navigator echo (nav). RF: RF-channel (RF pulse (θ and image echo (echo) ; G_{ss}: slice-selection gradient; G_{pe}: phase encoding gradient: G_{ro}: readout gradient.

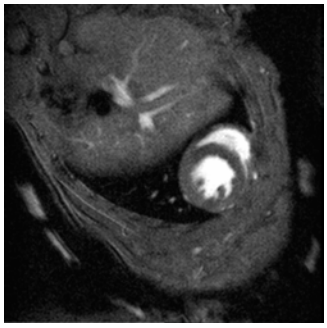

Figure 2: Retrospective reconstructed short axis slice through a mouse heart.

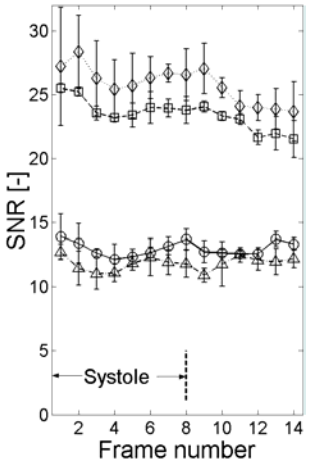

Figure 3: SNR (mean ± SD) values per heart frame of the myocardial wall of three mice measured with: prospective ECG triggering without respiratory gating (◊); prospective ECG triggering with respiratory gating (□); retrospective method 'one' (△); retrospective method 'two' (○) (see text for details).

Results

Figure 2 shows a retrospective reconstructed short axis view of the mouse heart at begin systole. The heart rate and respiratory rate of the mice ranged from 460 to 540 beats/min and 83 to 111 respirations/min, respectively. To make a fair comparison between the different methods an equal acquisition time of 5 minutes was used for all measurements. From the respiration rate the number of averages of the prospective triggering without gating method and the prospective triggering with respiratory gating method were determined to be 12 and 6, respectively. Two types of acquisitions were made with the retrospective method, which differed from the nesting of the k-line loop and the averaging loop. Retrospective method 'one' had the averaging loop inside the k-line loop and the retrospective method 'two' the other way around. For both methods the number of averages was 230. After retrospective reconstruction the number of averages of the retrospective method 'one' and 'two' ranged from 8.2 to 9.7 and 8.9 to 10.7, respectively with an inter-frame time of 7 ms. Figure 3 shows the mean SNR of the three mice for all the heart frames. The error bars represent the standard deviation of the SNR of the three mice. The prospective methods had a higher SNR compared to the retrospective methods because the loss of retrospective reconstructed k-lines was around 50% from the measured ones. However, the SNR of the prospective methods varied much more throughout the heart frames by the transient longitudinal magnetization. The SNR of the retrospective methods was only influenced by the heart phase itself. Although the images of the prospective ECG triggered without respiratory gating method had a higher number of averages, the SNR had the largest standard deviation compared to the other methods. We found an excellent agreement between the measured ECG and respiration rates and the rates extracted from the navigator echo analyzed by the retrospective reconstruction program.

Discussion

The retrospective triggering and retrospective respiratory gating method shows no artifacts due to respiration and a small variation of the SNR within the myocardial wall. This makes automatic analyses of the images much easier than with the prospective methods. It is evident from Figure 3 that the prospective methods have a higher SNR compared to the retrospective method. The retrospective method however has the potential to increase the SNR by increasing the TR with a CINE multi slice experiment covering the whole mouse heart, combined with an inflow saturation slice for increasing the contrast between the myocardial wall and the ventricle. Probably due to the higher number of analyzed averages the retrospective method 'two' had a slightly higher SNR than method 'one'.

Conclusions

We have presented a retrospective CINE FLASH sequence for mouse cardiac MRI. The method shows no artifacts due to respiration and cardiac activity and has the distinct advantage compared to prospective triggering methods of maintaining a steady-state longitudinal magnetization throughout the cardiac cycle.

References: 1. Wiesmann F et al, Am J Physiol Heart Circ Physiol 2000;278:H652-H657.
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