Implementation of a Fast Inversion Recovery Sequence to Assess Delayed Enhancement of Myocardial Infarction in Mice

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Introduction

Assessment of myocardial function and viability by delayed contrast enhancement has become a widely used technique in patients and for research in large animals. However, the technique has not been so readily applied to small animals due to limitations of physiology and the significant increase in the T_1 of myocardium at high fields. For these reasons delayed enhancement in mice has primarily been assessed using only T_1-weighted gradient echo sequences, however, IR sequences have recently been demonstrated on mice at both 4.7T[1] and 9.4T[2]. Substantial increases in contrast-to-noise can be achieved by selecting the appropriate inversion time required to null normal myocardium. In our experience the relatively fast decline in hyperenhancement of non-targeted gadolinium contrast agents, prevents full coverage of the heart using standard IR sequences. In this abstract we present the implementation of a fast IR gradient echo sequence which acquires multiple IR frames and multiple slices in the same time as a standard IR sequence, minimising the problem of dynamic changes in hyperenhancement during long acquisition times.

Methods

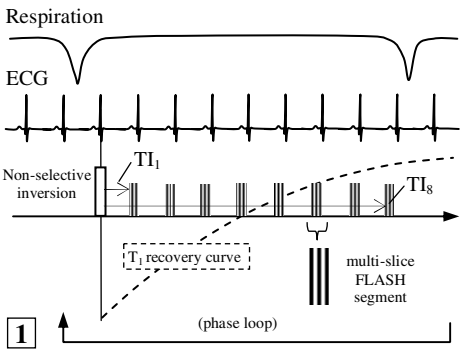
Animal Preparation: All experiments complied with the UK Animals (Scientific Procedures) Act, 1986 and local ethical guidelines. Healthy female C57/BL6 mice were given baseline MRI scans prior to surgery. Myocardial infarction was induced by permanent ligation of the left descending artery. Infarcted mice were scanned at a minimum of 7 days post surgery. For delayed contrast enhancement 0.6 mmol/kg Gd-DTPA (Magnevist, Schering AG, Germany) was injected through the tail vein after initial baseline scans had been collected.

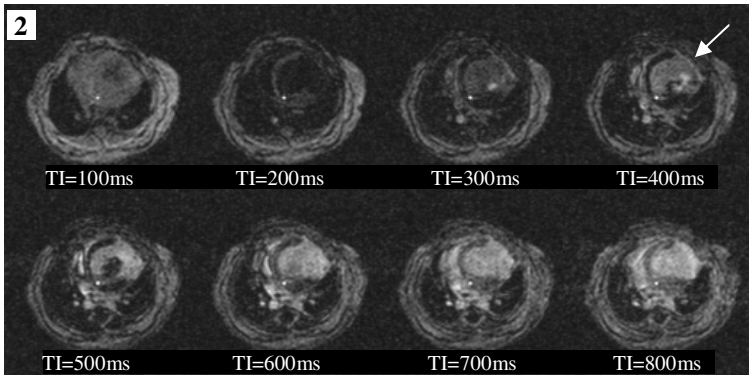
Cardiac MRI: All imaging was performed on a 9.4T Varian Inova system (Palo Alto, USA) equipped with 130mm 20G gradient set and a 30mm quadrature volume resonator. The cine FLASH imaging sequence used to assess contractile dysfunction and to provide visual comparison for the delayed enhancement images acquired 10 images per cardiac cycle, covering the first 75-85% following the R-wave. The sequence parameters consisted of: matrix =128x128, FOV=40x40mm, slice thickness=1mm TE=1.7ms, TR_{cine}=~8ms, FA=20°, Averages=1, TA~20s per slice.

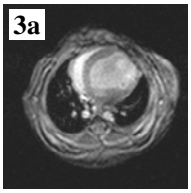
The inversion recovery FLASH sequence (Figure 1) acquired multi-slice image sets at a number of TI values following a gated non-selective adiabatic inversion pulse. Typically this consisted of 8 TI values ranging from 100-800ms and 3-5 sequential slices acquired following the inversion pulse. Alternatively both inversion and individual TI frames could also be ECG gated, leading to all images being collected from the same section of the cardiac cycle, except with TI values arrayed in multiples of the R-R interval, typically 100-140ms. Additional parameters consisted of: matrix =128x128, FOV=40x40mm, slice thickness=1mm TE=1.7ms, TR=1-2s, FA=10°, Averages=1, TA~2 minutes or 4 minutes if one respiratory cycle is omitted to allow for further recovery of longitudinal magnetisation.

Results and discussion

The implementation of the IR recovery sequence described above (illustrated in Figure 1) allows for the acquisition of several IR images. Following a gated non-selective 180 inversion pulse a number of multi-slice FLASH segments are collected within the resting plateau of the respiratory cycle. The individual FLASH segment can also be ECG gated incorporated a QRS delay to allow for all slices and TI frames to be acquired at the same part of the cardiac cycle (for example a 5 slice FLASH segment can be acquired in ~16ms at end-diastole for each TI time point), obviously this results in the TI range stepping in R-R intervals (typically 100-140ms). The images in Figure 2 show 8 IR images from a single slice at TI points ranging 100-800ms at fixed 100ms intervals. The delayed enhancement in the infarct region is most prominent in the TI=400ms image (indicated by arrow), where adequate nulling of the normal myocardium has also been achieved. Figure 3 shows the end-diastolic (3a) and end-systolic (3b) frames from the cine FLASH sequence to highlight the contractile dysfunction of the infarct region. The images shown in Figure 2 demonstrate that it is possible to collect images of sufficient SNR and contrast to be able to clearly identify the infarct region even in animals at the late stages (in this case 6 weeks post MI surgery) of remodelling when myocardium has thinned significantly. The fast collection of multiple TI images can then allow for acquisition of higher resolution single TI images using large flip angles for increased SNR in order to more accurately measure the infarct region.







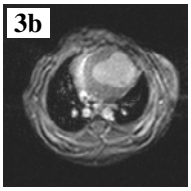


Figure 1: Pulse diagram of the IR sequence used to acquire multiple TI images showing the timings in relation to the physiological parameters.
Figure 2: Single slice of multiple IR images of a mouse with MI (EF~20% 6 weeks post MI) acquired approx. 5-10 minutes after i.v. injection of Gd-DTPA.
Figure 3: The corresponding end-diastolic (3a) and end-systolic (3b) frames of the cine FLASH sequence.

Conclusion

This study has demonstrated that fast inversion recovery sequences can be applied in order to assess delayed contrast enhancement in mice at high fields despite the problems of rapid heart rates and long T_1 relaxation times. Whilst inversion recovery sequences offer the highest level of contrast for delayed enhancement imaging, they often require relatively long acquisition times. However, the acquisition of multiple TI frames and slices in the same TR allows for full coverage of the heart without loss of SNR caused by changes in enhancement often seen using the standard non-targeted contrast agents.

References:

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