Accelerated MPIO-Labeled Cell Imaging in the Heart

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INTRODUCTION

Super-paramagnetic iron oxide (SPIO) particles can label macrophages and monocytes in circulation; the effects of these labeled cells can then be detected by T2*-weighted MRI [1]. This has enormous potential for imaging inflammatory responses in the heart, but it has been difficult to do *in vivo* using conventional methods for free-breathing, ungated imaging. Subspace imaging with temporal navigation and sparse sampling of (**k**, *t*)-space has previously been used to accelerate several cardiac imaging applications [2], conventionally alternating between acquiring navigator data and sparse data every other T_R. Here we describe a more efficient self-navigated pulse sequence to acquire both navigator and sparse data in the space of a single T_R, doubling imaging speed to approach 100 frames per second (fps). We show the feasibility of using the resulting method to assess myocardial inflammation in a pre-clinical rodent ischemic re-perfusion injury (IRI) model using micron-sized paramagnetic iron oxide (MPIO) particles to label immune cells in circulation.

METHODS

We sparsely sampled (**k**, *t*)-space to image the infiltration of MPIO-labeled macrophages in myocardial tissue. Sparse sampling was performed using a novel self-navigated FLASH pulse sequence for low-rank imaging; data were reconstructed using the method in [3]. Fig. 1 illustrates pulse sequences using conventional navigation and self-navigation. Our implementation of self-navigation separates the slice rephasing, read dephasing, and phase encoding gradients, acquiring navigator data during the first two gradients (although other self-navigation strategies are feasible). We also replaced the conventional 1D constant read dephase gradient with a 2D "music note" (♪) trajectory designed to keep gradient slew rates low.

We employed an IRI model using Brown Norway rats with 45 min transient left anterior descending coronary artery occlusion followed by re-perfusion. Macrophages/monocytes were labeled in circulation by intravenous administration of MPIO particles, and the infiltration of MPIO-labeled macrophages in the heart is evaluated by *in vivo* T2*-weighted MRI using self-navigated low-rank imaging. The hearts were then harvested for *ex vivo* T2*-weighted MR microscopy (MRM).

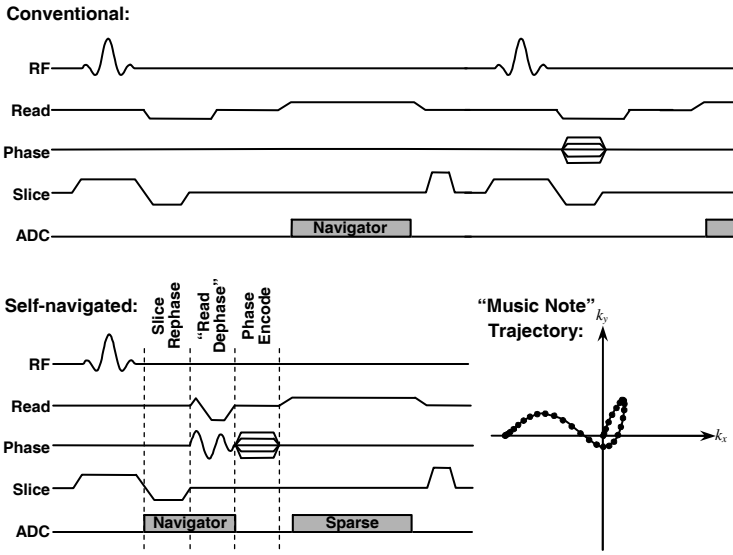


Fig. 1: Illustrative FLASH pulse sequences with conventional 2-pulse navigation and 1-pulse self-navigation. The "music note" trajectory shown here was used in place of a read dephase pulse, but other trajectories are also feasible.

In vivo scans were performed on a Bruker Avance 4.7 T scanner with a 4-channel array coil. Typical imaging parameters were T_R/T_E=10.5/5.0 ms, FOV=40×40 mm^2, matrix size= 256×256, in-plane spatial resolution=0.16×0.16 mm^2, and slice thickness=1.0 mm. Data were collected continually with neither ECG-gating nor breath holding. Images were reconstructed according to [3] with L_1=16, L_2=24, P=2, and 32 ACS lines. *Ex vivo* scans were performed on a Bruker Avance 11.7 T scanner with a single-channel volume coil using a multislice multiecho (MSME) sequence for T2*-mapping. Imaging parameters were T_R=1000 ms, echoes=8, echo spacing=8 ms, T_E=8 to 64 ms, FOV=12.5×12.5 mm^2, matrix size=128×128, slice thickness=1.0 mm.

RESULTS AND DISCUSSION

Fig. 2 shows spatiotemporal slices using conventional navigation at 47 fps and self-navigation at 95 fps from a control rat with no injury. The self-navigated images are noticeably sharper than those acquired with conventional navigation. Fig. 3 shows a self-navigated *in vivo* T2*-weighted short-axis slice from a rat with IRI on post-operational day 4, as well as a T2* map computed from *ex vivo* MRM. The dark patches of myocardial tissue visible in the *in vivo* image are shown to have shorter T2* in the *ex vivo* images. The self-navigated images also indicated myocardial akinesis in the region surrounding the inflamed tissue, consistent with IRI.

CONCLUSION

This work demonstrates low-rank cardiac imaging of inflamed myocardial tissue with sparse sampling. MPIO accumulation was observed *in vivo* and validated *ex vivo*, with MPIO patches corresponding to akinetic myocardial tissue. The self-navigated pulse sequence used here doubled the imaging speed compared to conventional navigation. Extension of this method to 3D imaging can potentially provide whole-heart detection of MPIO accumulation. Self-navigation can also accelerate other cardiac imaging applications beyond that explored here.

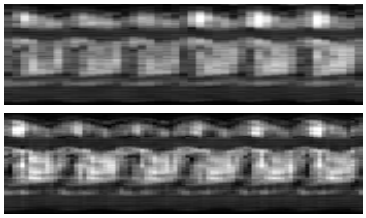
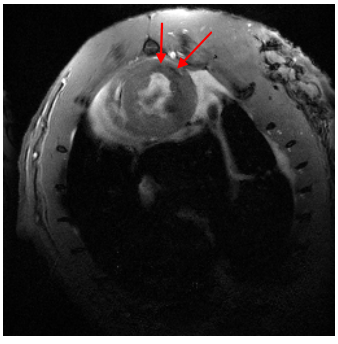


Fig. 2: Spatiotemporal slices of cardiac images using conventional navigation (*top*) and self-navigation (*bottom*). Self-navigation increases the frame rate from 47 fps to 95 fps.



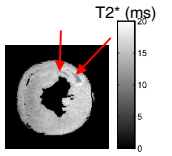


Fig. 3: *In vivo* T2*-weighted self-navigated image (*left*) and *ex vivo* T2* map of excised heart (*above*). The dark patches of myocardial tissue are present in both *in vivo* and *ex vivo* images.

REFERENCES

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