Cardiac Imaging in the Mouse at 7T Using Projection Reconstruction for Improved Suppression of Motion Artifacts

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Introduction: Cardiac MRI in the mouse requires high static magnetic field strengths (> 3 T) to achieve sufficient signal-to-noise ratio (SNR) to support the microscopic voxels needed to resolve murine anatomy. However, as magnetic field strength increases, the intensity of ghost artifacts from cardiac and breathing also increases, degrading image quality and obscuring the anatomy of interest. Projection reconstruction (PR) sequences have been shown to exhibit superior tolerance to motion artifacts compared to conventional Cartesian sampling techniques at clinical field strengths [1]. This work investigated the application of PR to murine cardiac imaging at high field in terms of its motion artifact sensitivity.

Methods: Male C57BL/6J mice (Jackson Lab, Bar Harbor, MA) weighing 20–30 g were anesthetized and ventilated by a custom MR-compatible ventilator tailored for the mouse [2]. Tidal volumes of 0.2-0.5 mL were delivered at 85 breaths/min. Cardiac activity was measured by an ECG and by a fiber-optic stethoscope [3] that was immune to electromagnetic interference from gradient switching. Imaging was performed on a 30-cm horizontal-bore 7.1 T magnet (Magnex Scientific, Concord, CA) with gradients up to 400 mT/m controlled by a GE (General Electric Medical Systems, Milwaukee, WI) LX system console. A custom-built 3-cm-radius surface RF coil was used. Data acquisition of the free induction decay (FID) was initiated immediately after slice selection on the rising edge of the readout gradient for an effective TE of 1 ms. View acquisition order was randomized to achieve a more regular distribution of motion artifacts in k-space. Non-uniformly spaced data acquired on the gradient ramp were interpolated to uniform samples during reconstruction. Data reconstruction was performed offline using a gridding routine [4]. Specific scan parameters for each experiment are noted in the figure captions.

Results: Figure 1 compares ungated scout images of the mouse heart acquired with spoiled gradient echo (a) vs. projection reconstruction (b). Whereas ghost artifacts from cardiac and breathing motion severely compromise image quality in (a), motion artifacts are much less apparent in the PR image (b), resulting in significant improvement in the visualization of cardiac anatomy.

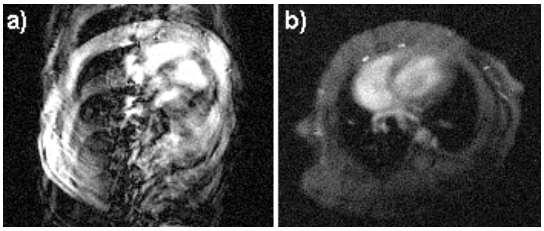

Figure 1. a) Ungated gradient echo image in the mouse. TE/TR=2.8/20 ms, BW=62 kHz, α=30°, NEX=6. b) Ungated projection reconstruction image. TE/TR=1/20 ms, BW=62 kHz, α=30°, #views=1600.

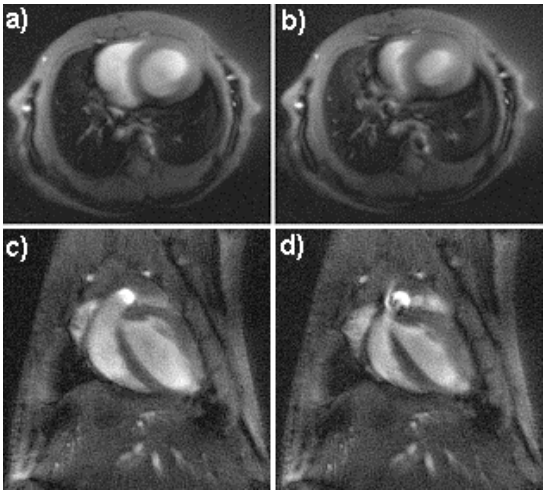

Figure 2. Cardiac-gated PR images of the mouse heart in the axial (left column) and coronal (right column) planes acquired during 10-ms intervals in diastole (left column) and systole (right column). TE/TR=1/10 ms, BW=62 kHz, α=30°, #views/img=3200, scan time=10 min.

Figure 2 shows cardiac-gated cine PR images of the mouse heart in the axial (top row) and coronal planes (bottom row) acquired during the diastolic (left column) and systolic (right column) phases of the cardiac cycle. Excellent delineation of the blood pool and myocardium is possible in the absence of discrete ghost artifacts. Although these images were not synchronized with ventilation, no breathing motion artifacts were visible. No significant blurring from off-resonance was observed owing to the fast readout bandwidth.

Discussion: Projection reconstruction exhibits greater motion tolerance than conventional gradient echo sequences because of two important properties. First, PR is inherently flow compensated in the readout direction due to the lack of prephasing gradients in FID acquisition [5]. Second, artifacts from view-to-view inconsistencies in PR are distributed as diffuse radial streaks at a distance from the object of interest, rather than as coherent ghosts along the phase-encoding direction that overlap the object, as in Cartesian techniques [1]. This tolerance to motion becomes increasingly important at high fields, where artifact energy increases. While motion also degrades image quality at lower fields, the extensive signal averaging typically necessary to improve SNR reduces the intensity and appearance of motion artifacts.

The development of high-resolution, artifact-free cardiac imaging tailored for the mouse is important for the assessment of cardiac structure and function in murine models of cardiovascular disease. The PR technique presented here is robust to artifacts from cardiac and breathing motion at high field during both ungated scout scans as well as cardiac-gated cine imaging.

References:

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