Non-Cartesian Navigation for Subspace 3D Myocardial Perfusion Imaging

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INTRODUCTION

Myocardial perfusion imaging has potential for tissue assessment and early detection of coronary artery disease, among other applications. 3D myocardial perfusion imaging methods have a number of advantages over 2D multislice methods, including better spatial coverage without slice gaps, matched cardiac phases across slices, and no need for preparation pulses [1-3]. However, imaging speed is a major concern for 3D myocardial perfusion imaging. Previous studies have shown success in accelerating 3D myocardial perfusion imaging using sparse sampling of (**k**, *t*)-space and low-rank (subspace) image models [1,2]. In this work, we investigate 2D and 3D non-Cartesian **k**-space navigator trajectories for subspace myocardial perfusion imaging. These trajectories replace the common 1D Cartesian navigators, which are highly sensitive to readout direction. We evaluate our imaging method on a rodent ischemic re-perfusion injury (IRI) animal model.

METHODS

We performed sparse sampling of (**k**, *t*)-space, alternating between measuring navigator data (repeated measurements from a limited portion of **k**-space at a very high temporal rate) and sparse (**k**, *t*)-space data [4]. When collecting the navigator data, we replaced the widely-used 1D Cartesian lines with 2D spiral and 3D cone readouts, which are more robust to readout direction than Cartesian navigators. Fig. 1 shows projections of a numerical phantom with vertical translational motion onto rank-24 temporal subspaces estimated from horizontal and vertical Cartesian line navigators (k_y=0 and k_x=0, respectively) and 2D spiral navigators (pitch angle ϕ=0°, 90°). The horizontal Cartesian navigator fails to capture vertical translation, but both spiral navigators provide good results despite having different pitch angles.

For IRI experiments, we imaged male Brown Norway (BN) rats with 45 min transient left circumflex (LCx) coronary artery occlusion followed by re-perfusion. A 0.2 mmol/kg bolus of gadolinium contrast agent (Gd-DTPA) was administered to each subject 5 min after the start of data acquisition. Data were collected on a Bruker Avance AV1 4.7 T / 40 cm scanner with a 4-channel phased array coil. 3D data were collected using a FLASH pulse sequence with a cone navigator and the following imaging parameters: T_R/T_E=6.8/2.5 ms, FA=10°, FOV=40 mm × 40mm × 24mm, matrix size=128 × 128 × 24, spatial resolution=0.31mm × 0.31mm × 1.0mm, 24 ACS lines, and parallel reduction factor R=2. Images were reconstructed according to [5] with L=24 for a final frame rate of 74 fps. At 16 minutes, imaging time was short enough to remain practical and long enough to collect both first-pass and delayed myocardial perfusion images. All data were collected continually with neither ECG gating/triggering nor breath holding. We also used the 2D Bruker IntraGate method to image a mid-ventricular short-axis slice before and after each 3D imaging experiment. IntraGate images were collected using T_R/T_E=7.3/3.6 ms, FA=18°, FOV=40 mm × 40mm, matrix size=256 × 256, spatial resolution=0.16mm × 0.16mm, slice thickness=2 mm, 32 ACS lines, and R=2.

RESULTS AND DISCUSSION

Fig. 2 shows pre- and post-contrast images from an IRI subject on the day of surgery. The figure shows 2D IntraGate images as well as the corresponding slice from the 3D cone-navigated low-rank images. The LGE perfusion defect has the same in-plane extent in both the 2D IntraGate image and the 3D images, specifically in the mid-ventricular anterior and anterolateral myocardial segments. Fig. 3 shows bullseye plots depicting time to peak concentration (TPC) of the first pass of Gd-DTPA through the myocardium of a control subject and of the IRI subject depicted in Fig. 2, with all TPC values calculated from the 3D images. The bullseye plots conform to the American Heart Association 17-segment standard. The first-pass perfusion measurements indicate extensive myocardial damage in the IRI subject compared to the control subject, particularly to the apical anterior, mid-ventricular anterior, mid-ventricular anterolateral, and apical lateral segments, consistent with the 3D LGE images.

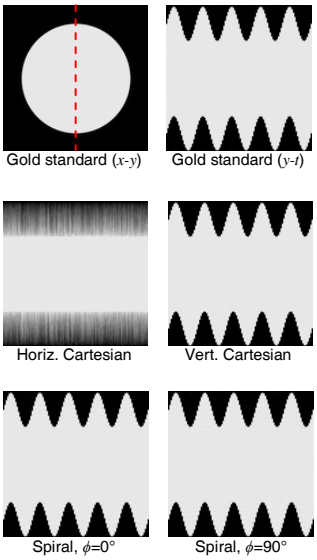

Fig. 1: Projections onto low-rank subspaces estimated from different navigators.

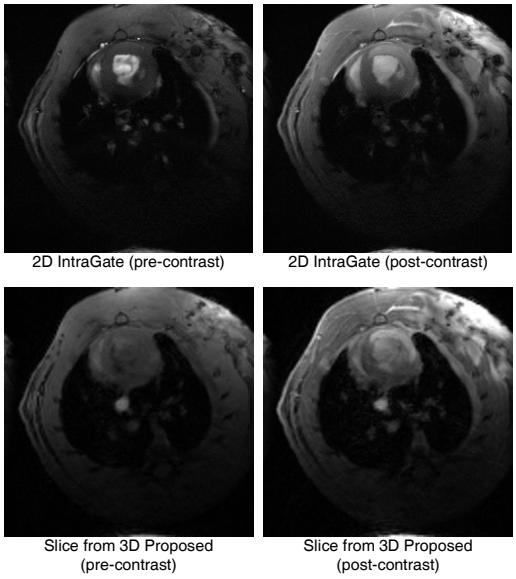

Fig. 2: Pre-and post-contrast mid-ventricular short-axis slices using 2D IntraGate and the proposed 3D method on an IRI subject on the day of surgery.

CONCLUSION

We have performed whole-heart 3D first-pass and delayed myocardial perfusion imaging in rats. We employed sparse sampling of (**k**, *t*)-space with 3D cone navigation and reconstructed data using a low-rank imaging model. The resulting images have high spatiotemporal resolution (0.31mm × 0.31mm × 1.0 mm, 74 fps) and enabled analysis of both the first-pass of contrast and late enhancement. We anticipate that the method will prove useful for practical 3D myocardial perfusion imaging.

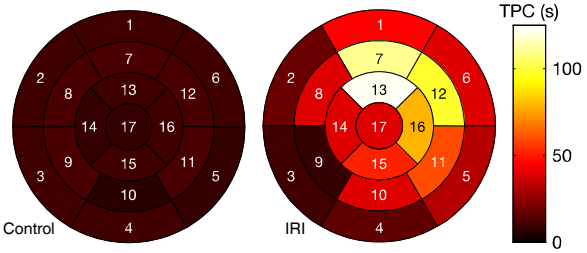

Fig. 3: 17-segment bullseye plots showing time to peak concentration (TPC) for a control rat and the IRI subject in Fig. 2.

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