A Spiral k-space Trajectory Enables Phase Contrast Measurements of Blood Flow in Curved Sections of the Mouse Aorta

R. L. Janiczek[1], B. R. Blackman[1], R. J. Roy[2], S. T. Acton[1,3], C. H. Meyer[1], and F. H. Epstein[1,2]

[1]Department of Biomedical Engineering, University of Virginia, Charlottesville, VA, United States, [2]Department of Radiology, University of Virginia, Charlottesville, VA, United States, [3]Department of Electrical and Computer Engineering, University of Virginia, Charlottesville, VA, United States

Introduction:

The preclinical use of phase-contrast (PC) MRI in mice may have utility for elucidating the relationship between wall shear stress and atherosclerosis. However, PC-MRI is technically challenging in mice due to high blood velocities relative to anatomical size. Aortic velocities are comparable between mice and humans; however, the size of the aorta is orders of magnitude smaller in the mouse.

Conventional rectilinear *k*-space trajectories can result in displacement artifacts due to movement of spins between excitation and data acquisition, and signal loss due to phase dispersion. Spiral trajectories have long been used for human MRI due to their desirable flow characteristics caused by their short echo-times and low gradient moments [3,4]. However, these methods have yet to be applied to imaging small animals on high-field small-bore MRI systems.

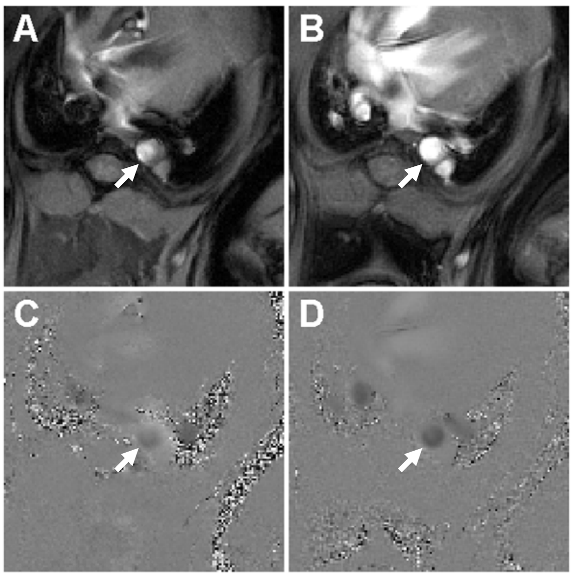

Figure 1. Phase contrast measurements of the abdominal aorta (arrow). Magnitude for the rectilinear (A) and spiral (B) and corresponding phase for the rectilinear (C) and spiral (D) acquisitions. Both trajectories have strong signal in the vessel of interest.

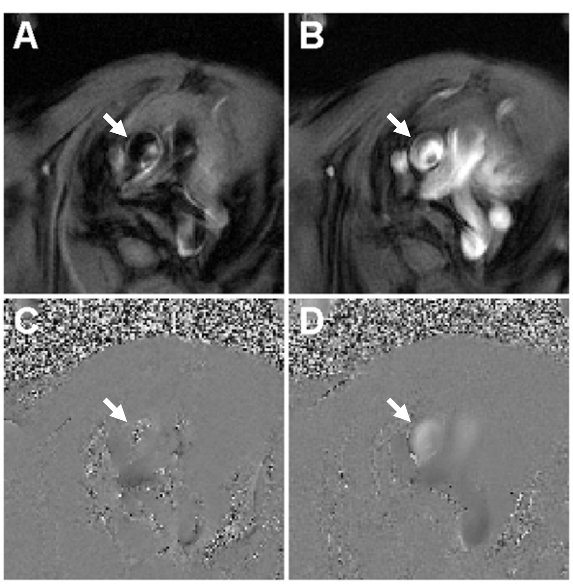

Figure 2. Phase contrast measurements of the aortic root (arrow). Magnitude for the rectilinear (A) and spiral (B) and corresponding phase for the rectilinear (C) and spiral (D) acquisitions. Severe signal loss occurs with the rectilinear acquisition.

Methods:

All imaging was performed on a 7.0T MR system using a 30 mm diameter cylindrical birdcage radiofrequency (RF) coil (Bruker Biospin; Ettlingen, Germany) and an MR-compatible physiological monitoring and gating system for mice (SA Instruments, Inc., Stony Brook, NY). All mice were anesthetized using isoflurane and body temperature was maintained at 37º using circulating water. All sequences were respiratory and cardiac gated. Images were acquired at two locations within the mouse; the abdominal aorta and the aortic root. The abdominal aorta was chosen for its straight geometry and the aortic root for its complex, curved geometry.

The spiral and rectilinear sequences both had a 8ms TR, 1 mm slice thickness, 1 ms sinc RF-excitation, 100 µm in-plane resolution, 25.6 x 25.6 mm^2 FOV, and 200 cm/s velocity encoding in the through-plane direction. The spiral sequence had a 1.3 ms TE and used 116 interleaves. To minimize blurring due to field inhomogeneity, short 3ms readouts were used. Further deblurring was performed using a low-resolution field map scan acquired with 12 interleaves [5]. The GRE sequence had a 5.0 ms TE and was flow compensated in the readout direction. To keep the number of imaging heartbeats the same, the spiral sequence used twice as many averages, 8, than the rectilinear sequence, 4. Due to gradient duty cycle limits, the spiral trajectory was imaged every two triggers while the rectilinear trajectory was imaged every four triggers, resulting in scan times of approximately 12 and 24 minutes, respectively.

Results:

Figure 1 displays the magnitude and phase images for the abdominal aorta. Both the spiral and rectilinear sequences performed well when the geometry was simple. However, as shown in Fig. 2, the rectilinear scan failed to measure velocities at the aortic root. The rectilinear sequence suffered from signal loss and severe displacement artifacts due to the complex geometry of the aortic arch. Both the magnitude and phase images show complete loss of signal. Meanwhile, the images obtained with the spiral readout had little signal loss. Figure 3 shows a flow vs. time curve for the aortic root. The flow curve obtained with the spiral readout is continuous and peaks as expected during systole. The flow curve obtained with the rectilinear readout only holds for the later phases when flow is low.

Conclusions:

Spiral acquisition was used to obtain PC data in regions with high flow and complex geometries. Spiral trajectories allowed for shorter echo-times and more favorable flow characteristics compared to a conventional rectilinear trajectory. These advantages allow PC data to be obtained in more regions of the mouse vasculature than a rectilinear trajectory.

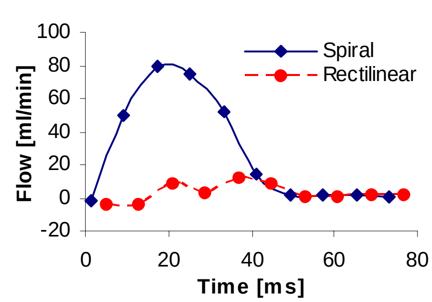

Figure 3. Flow versus time in the aortic root for spiral and rectilinear trajectories.

References:

[1] Gelfand et al. JMRI. 2006;24(6):1386-92.

[2] Greve et al. AJP Heart Circ Physiol. 2006;291(4):H1700-8.

[3] Pike et al. MRM. 1994;32(4):476-83.

[4] Nayak et al. MRM. 2003;50(2):366-72.

[5] Irarrazabal et al. MRM 1996; 35:273-282