7D Spiral Phase Contrast MRI for the Comprehensive Assessment of Aortic Flow in Mice

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:

Wall shear stress (WSS) has been correlated with the development and progression of atherosclerosis in humans and animal models. The ability to assess WSS in genetically-engineered mice would enable the investigation of the roles of individual genes in the relationship between WSS and atherosclerosis. Prior approaches in mice have included (a) using phase contrast (PC) MRI measurements of flow rates into and out of vessels as boundary conditions for computational fluid dynamic (CFD) models based on vessel geometry [1], and (b) directly estimating WSS from 2D PC data [2]. These methods have limitations such as the inability to model high order vessel wall compliance or poor spatial coverage.

The ideal method would cover large regions of the vessel of interest, directly measure WSS, and have high temporal resolution, as the spectral components of the WSS waveforms play a critical role in the development of atherosclerosis [3]. The curved nature of vessels necessitates that all vector components of velocity be measured. These requirements suggest that a 7D sequence (3 spatial dimensions for coverage, 3 dimensions to measure 3D velocity, and time) would be useful for this application. The implementation of a 7D sequence is technically challenging because (a) signal loss in mouse PC is common in regions of vessel curvature [4] and (b) long data acquisition time. We investigated the use of spiral trajectories to overcome these issues.

Methods:

All imaging was performed on a 7.0T ClinScan MR system (Bruker/Siemens, Germany) 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). Mice were anesthetized using isoflurane and body temperature was maintained using circulating water.

A 3D stack of spirals sequence was developed with 64 imaging interleaves and 64 partitions. Short 2 ms readouts were used to reduce blurring caused by off-resonance effects. A 128x128x64 matrix was collected over a FOV of 25.6x25.6x12.8 mm^3 resulting in 200 µm isotropic resolution. To reduce wrap-around artifacts in the partition encode direction, only 80% of the imaging volume was excited. A sinc RF-excitation of 35º was used to achieve time-of-flight effects and increase contrast of the arterial system and reduce contrast of the venous system. Velocity was encoded using a balanced four-point encoding strategy with a VENC of 130 cm/s [5]. Other imaging parameters included a 8ms TR and 2.6 ms TE. The sequence was respiratory and cardiac gated. Images were acquired throughout systole. Acquisition time was approximately 45 minutes. Prior to analysis, velocity vector fields were median filtered to remove outliers.

Results:

Figure 1A shows a surface reconstruction of the mouse aorta. The celiac trunk and renal arteries can be seen branching off of the abdominal aorta, illustrating the high spatial resolution of this method. In Figure 1B, a cross-section of streamlines is shown through the aorta during systole. Instantaneous velocity magnitudes are color coded. Figure 1C shows a velocity profile in the aorta illustrating the spatial velocity gradient. As expected with laminar flow, higher velocities occur near the center of the vessel.

Conclusions:

A 3D stack-of-spirals PC sequence was developed to acquire 7D data of the mouse aorta. High resolution geometry was obtained of the abdominal aorta along with all three-components of velocity throughout systole. These methods will enable future measurements of WSS through large regions of major arteries allowing the relationship between WSS and atherosclerosis to be further investigated.

References:

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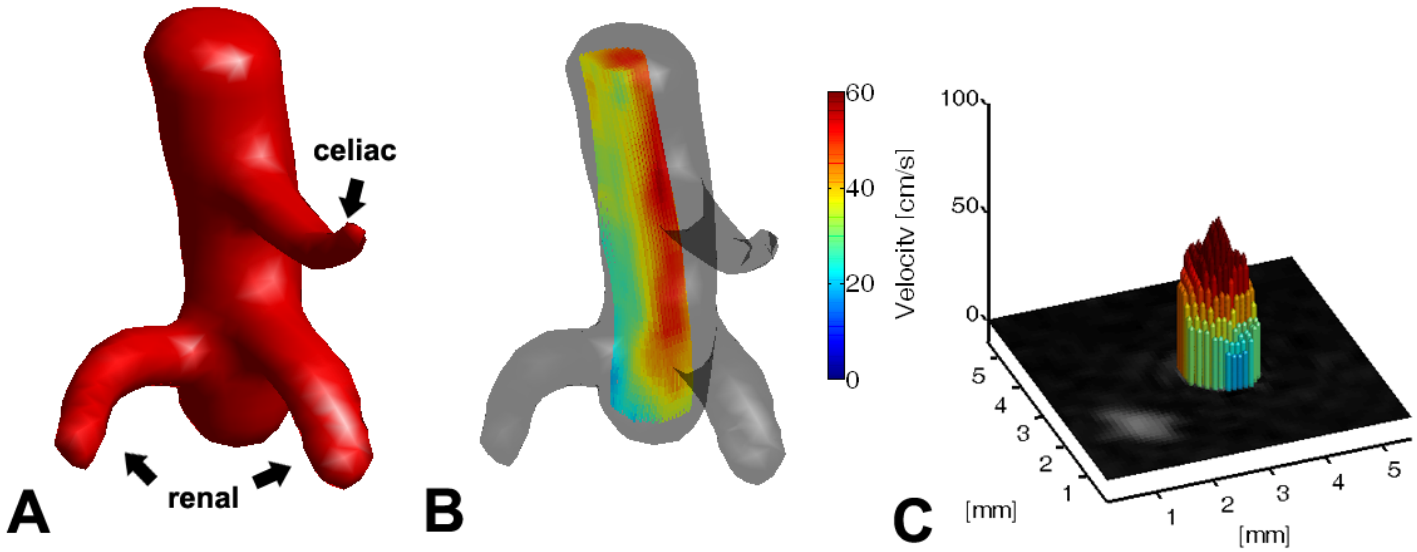

Figure 1. (A) Surface reconstruction of the abdominal aorta, celiac trunk, and renal arteries.(B) Streamlines through the aorta color-coded by instantaneous velocity. (C) Velocity profile in the abdominal aorta following interpolation by factor of 2.