A Comparison of Flow Patterns in Ascending Aortic Aneurysms and Volunteers Using Four-Dimensional Magnetic Resonance Velocity Mapping

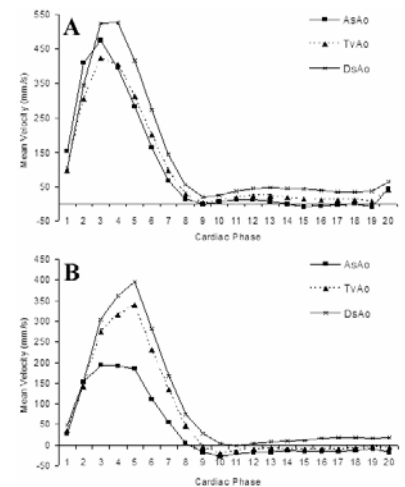**T. A. Hope[1], M. T. Alley[1], D. C. Miller[2], and R. J. Herfkens[1]**

[1]Department of Radiology, Stanford University, Stanford, CA, United States, [2]Department of Cardiothoracic Surgery, Stanford University, Stanford, CA, United States

INTRODUCTION: Phase-contrast (PC) magnetic resonance imaging (MRI) leverages MRI's intrinsic velocity sensitivity in order to acquire multidirectional blood velocity data. In time-resolved 3D MRI, or Four-Dimensional flow profiling (4D), images are retrospectively gated to create cine volumetric data. This study utilizes 4D flow profiling to aid in the comparison of patients with ascending aortic aneurysms and healthy volunteers. Visualization tools, such as streamlines, particle traces and vector fields, were utilized to present unusual flow characteristics. Our technique provides data regarding individual flow patterns throughout the systolic and diastolic phases of the cardiac cycle, providing insight into the difference in flow profiles between patients with ascending aortic aneurysms and healthy volunteers.
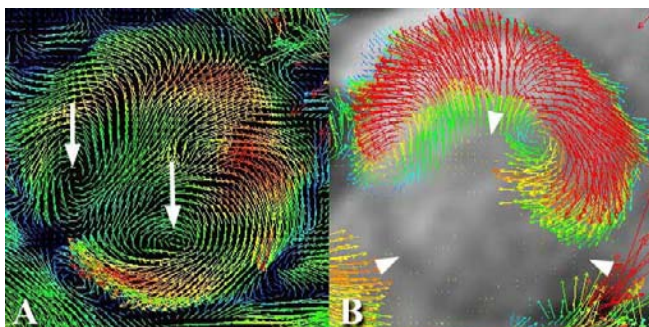
MATERIALS AND METHODS: Cine time-resolved velocity encoded PC MRI was employed to assess blood flow velocities in 19 healthy volunteers (10 male, 9 female, age range 20-70 years old, mean age 40.4 years) and 13 patients with ascending aortic aneurysms (10 male, 3 female, age range 25-73 years old, mean age 55.8 years). All measurements were performed on a 1.5-T system (Signa CV/i, GE Healthcare, Milwaukee, WI, G_{max} = 40 mT/m, rise time = 268 µsec). The technique used has been previously validated (1). Respiratory compensation was incorporated; measurements were retrospectively gated to the ECG cycle, and interpolated over twenty time frames evenly distributed over the cardiac cycle. For visualization, the data was imported into EnSight Version 8.0.7(g) (CEI Inc. Apex, NC). Visualization of flow patterns was done using streamlines, particle traces and vector fields. Four planes were placed orthonormal to the thoracic aorta, velocity vectors were displayed on each plane, and vortices in the aortic were visually graded (Figure 2). Retrograde flow was graded on the same slices. Additionally, velocity information was analyzed from three planes placed perpendicularly to the long axis of the thoracic aorta at the ascending (AsAo), transverse (TvAo) and descending aorta (DsAo). Magnitude data was used to precisely outline the boarders of the aorta in each plane throughout the cardiac cycle, allowing for computation of the velocity component normal to the plane within the aortic lumen.

RESULTS: In the volunteers, flow progressed as follows: an initial jet of blood is skewed towards the anterior right wall of the ascending aorta, blood is reflected laterally off the anterior right wall around the vessel towards the inner curvature creating opposing helices seen as clockwise and counterclockwise vortices, and subsequently retrograde flow develops between the two helices along the inner curvature. In the descending aorta, flow forms a clockwise helix. This may be caused by the geometry of the aortic arch, which curves inferiorly before descending along the spinal column. In patients, the most common pattern seen was where flow travels along the anterior right wall of the ascending aorta and then folds inferiorly along the inner curvature instead of entering the transverse aorta, creating a large region of retrograde flow (Figure 3). Streamline analysis of flow from the aortic valve showed a dominant right handed helical flow in nearly 80% of volunteers. Using graded vortices from extracted planes, we found that in fact volunteers had two opposing helices, while in patients only 21% of patients had two helices. Also, we found that in every volunteer where two vortices were present, one was clockwise and one counterclockwise. This was the case in only 75% of patients with two vortices; while in the remaining 25%, both vortices were clockwise. In every subject studied with opposing helices, the counterclockwise vortex was to the left of the clockwise one. Quantitative data confirmed the observed decrease in velocity at the transverse aorta at peak systole (Figure 1). In the volunteers, there was a 10% decrease in the mean velocity at peak systole across the aortic lumen (V_{avg}) from AsAo to TvAo (47.9 mm/s decrease with SD of 82.6, p = 0.023) and a marked 29% increase in V_{avg} from TvAo to DsAo (125 mm/s increase with SD of 75.6, p < 0.001). In the patients, there was a 57% increase in V_{avg} from AsAo to TvAo (145 mm/s decrease with SD of 112, p < 0.001) and a smaller statistically insignificant 12% increase in V_{avg} from TvAo to DsAo (47.3 mm/s increase with SD of 108, p = 0.16). Additionally, the ascending aortic aneurysm patients had larger proportion of the cardiac cycle with net retrograde flow (41% of cardiac cycle *vs* 17% of cardiac cycle, p < 0.001).

Figure 1: Mean velocity throughout the cardiac cycle across the aortic lumen during peak systole at the level of the AsAo, TvAo and DsAo for healthy volunteers (A) and ascending aortic aneurysm patients (B).

CONCLUSIONS: We have both qualitatively and quantitatively described the different flow profiles in patients with ascending aortic aneurysms and healthy volunteers. The velocity and flow profiling such as that described in this study can be a valuable tool for the pre-operative work-up and post-surgical care of patients with aortic aneurysms, and potentially could help risk-stratify patients who are congenitally pre-disposed to this condition.

Figure 2: Extracted planes from mid-systole orthonormal to the ascending aorta from a healthy 66-year-old female. (A) Magnitude data hidden allowing grading of vortical flow patterns. Two vortices can be seen (arrows). (B) With magnitude data present, retrograde flow (arrowheads) can be analyzed.
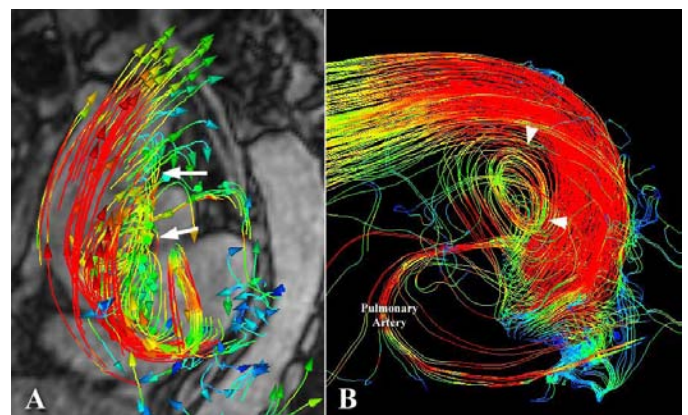
Figure 3: Example flow pattern in a 66-year-old man with an ascending aortic aneurysm. (A) Particle traces in mid-systole from left anterior oblique view demonstrating retrograde flow developing along the inner curvature of the arch (arrows). This is the most common pattern seen in patients. (B) Streamlines re-demonstrating the vortical flow pattern (arrowheads) along the inner curvature.

REFERENCES: 1. Markl M, Chan FP, Alley MT, Wedding KL, Draney MT, Elkins CJ, Parker DW, Wicker R, Taylor CA, Herfkens RJ, Pelc NJ. Time-resolved three-dimensional phase-contrast MRI. J Magn Reson Imaging 2003;17(4):499-506.