4D Flow Evaluation of Abnormal Systolic Flow Patterns with Bicuspid Aortic Valve

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Introduction: Bicuspid aortic valve (BAV) is the most common congenital heart defect and may account for more morbidity and mortality than all other congenital cardiac malformations combined. Two theories are commonly discussed for the elevated risk of aortic aneurysm and dissection in patients with BAV: 1) an increased hemodynamic load placed on the proximal aorta results in progressive dilatation and 2) a genetic or developmental abnormality in the proximal aortic tissue leads to weakness of the aortic wall [1]. 4D Flow is well suited for evaluation of multidirectional blood flow velocity data in the thoracic aorta. This study utilizes 4D volumetric datasets to evaluate systolic flow patterns in the ascending thoracic aorta of patients with BAV with the goal of uncovering abnormal flow patterns that may inform our understanding of why these patients are at risk for developing aneurysms and dissections.

Methods: Time-resolved, 3D phase contrast MRI (4D Flow) was employed to assess thoracic aortic blood flow in 20 individuals: 12 patients with bicuspid aortic valve and 8 healthy subjects. The 4D Flow technique employed has been previously validated [2,3]. Measurements were performed on a 1.5T system (Signa CV/i, GE, Milwaukee, WI, *Gmax* = 40 mT/m, rise time = 268 µsec) using an RF-spoiled gradient echo pulse sequence and an oblique-sagittal slab encompassing the thoracic aorta. Scans were performed with an 8-channel cardiac coil, respiratory compensation, retrospective ECG gating and the following imaging parameters: VENC = 160-200 cm/s, fractional FOV= (300 x 270) mm^2, slab thickness = 78 mm, matrix = (256 x 192 x 30), spatial resolution = (1.17 x 1.56 x 2.60) mm^3, temporal resolution = 74-77 ms. Parallel imaging (GRAPPA) with an acceleration factor of 2 was used. A total of 735 heartbeats were required for data acquisition, resulting in scan time of 9 to 14 minutes with a mean scan time of 11.1 minutes. Prior to visualization, data were corrected for Maxwell phase effects, encoding errors due to the gradient field distortions, and effects from eddy currents [4-6]. Velocity data were then imported into 3D visualization software (EnSight, CEI, Inc. Apex, NC).

Results: 4D Flow evaluation of the ascending thoracic aorta revealed markedly abnormal systolic helical flow in 9 of 12 patients with bicuspid aortic valve. 8 of these patients demonstrated an eccentric right anterior systolic jet and right-handed helical flow (**Fig 2**); at least two of these patients had fusion of the right and left coronary cusps, and five had aneurysms of the ascending aorta along with aortic stenosis and/or regurgitation. The other patient had a left posterior jet with left-handed helical flow (**Fig 3**), dilation of the aortic root and fusion of the right and noncoronary cusps. The two BAV patients with normal systolic flow in the thoracic aorta had relatively central flow jets (**Fig 1**), similar to those seen in all 8 healthy subjects.

Discussion: Abnormal systolic helical flow is seen in the ascending thoracic aorta of patients with bicuspid aortic valve. Similar helical flow has been described in ascending aortic aneurysms associated with BAV [7], but we have demonstrated this flow pattern in three patients without aneurysm, suggesting that the pattern is not secondary to the dilated aorta, but may be implicated in the pathogenesis of aneurysm formation. The marked helical flow in the ascending aorta appears to be associated with eccentric flow jets in all 9 of our cases. In the single case of left-handed helical flow, fusion of the right and noncoronary cusps was found, a geometric configuration that may create a left posterior jet as we have demonstrated. Identification and characterization of eccentric flow jets in patients with BAV may help risk stratify for development of ascending aortic aneurysm and dissection.

References: [1] Davies RR et al. Ann Thorac Surg 2007;83:1338-44. [2] Markl M et al. J Magn Reson Im. 2003;17:499-506. [3] Bammer R et al. Magn Reson Med 2007;57:127-40. [4] Bernstein MA et al. Magn Reson Med 1998;39:300-08. [5] Markl M et al. Magn Reson Med 2003;50:791-801. [6] Walker PG et al. J Mag Reson Im 1993;3:521-30. [7] Hope TA et al. J Mag Reson Im. 2007;26:1471-79.

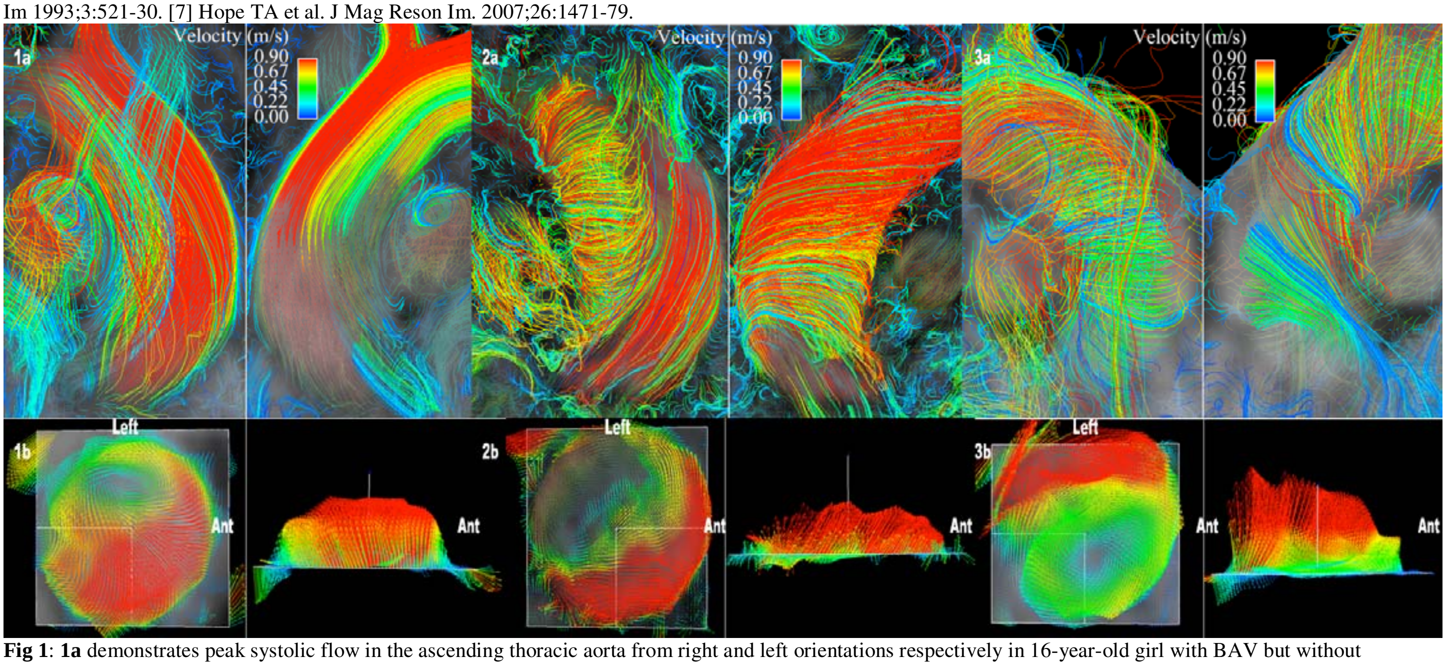

Fig 1: **1a** demonstrates peak systolic flow in the ascending thoracic aorta from right and left orientations respectively in 16-year-old girl with BAV but without ascending aortic aneurysm. No significant secondary flow features are noted. **1b** depicts vectors arising from a cross-section plane placed at the sinotubular at peak systole. A relatively central velocity profile is noted, with some right-sided predominance as is typical of normal aortic flow at this level.
Fig 2: **2a** and **b** show identical analysis in a 40-year-old woman with BAV and mild dilation of the ascending aorta. Marked right-handed helical flow is noted at peak systole with clear right-anterior skewing of the flow jet at the sinotubular junction.
Fig 3: **3a** and **b** apply the same analysis in a 6-year-old boy with BAV involving fusion of the right and noncoronary cusps, and mild dilation of the aortic root. Marked left-handed helical flow is seen in this context with skewing of peak-systolic flow to the left-posterior quadrant.