

## Increased Growth with Eccentricity: 4D Flow evaluation of valve-related aortic disease

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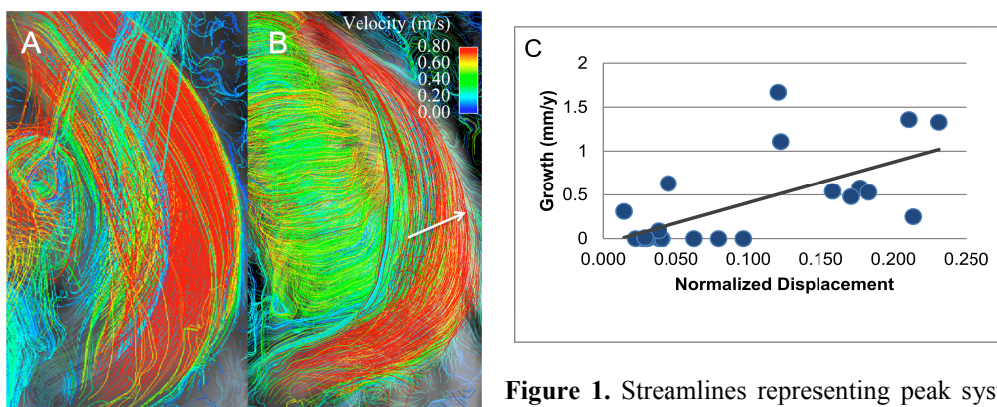
**INTRODUCTION** Bicuspid aortic valve (BAV) is a common congenital cardiac anomaly that is strongly associated with ascending aorta (AsAo) dilation and aneurysm. Although the exact pathophysiology underlying this association is debated, unique systolic hemodynamics with BAV have been reported. Time-resolved, 3D phase-contrast MR (4D Flow) is well suited for quantitative evaluation of AsAo blood flow [1] and has demonstrated eccentric systolic blood flow with helical patterns in patients with BAV [2]. Quantitative parameters describing the degree of flow eccentricity, including flow displacement, have been developed [3]. It is hypothesized that the degree of abnormal flow directly impacts the development of aortic pathology in patients with BAV. The coexistence of eccentric flow and enlarged AsAo dimensions at a single time point has been preliminarily examined [4], but causality and temporal evaluation has not been addressed. Here we investigate the relationship between eccentric flow and AsAo growth rates in patients with BAV.

**METHODS** Serial MRA or CTA studies were retrospectively reviewed in 25 patients evaluated with 4D Flow, including 13 BAV patients and 12 tricuspid aortic valve (TAV) controls. AsAo diameters were measured at standardized levels by two reviewers, and the growth rate of the maximally enlarged segment was determined. Using previously described techniques, AsAo blood flow was qualitatively graded as normal, mildly or markedly eccentric [2]. Normalized flow displacement from the vessel center was calculated [3]. Growth rates were compared between the controls and BAV patients, and within the BAV group based upon the degree of eccentric flow. Growth rates were correlated with the flow displacement variable using linear regression.

**RESULTS** Average time of follow-up was  $4.3 \pm 2.9$  years. The growth rates of BAV patients were significantly higher than those of TAV controls (1.0 vs 0.1 mm/yr, p-value < 0.001). Amongst patients with BAV, those with abnormal flow patterns demonstrated significantly higher growth rates than those with normal flow (1.0 vs 0.0 mm/yr, p-value = 0.02). Furthermore, BAV patients demonstrating markedly eccentric flow exhibited more rapid growth than other BAV patients (1.2 vs 0.3 mm/yr, p-value = 0.02). Linear regression between flow displacement and growth rate showed good correlation ( $r = 0.66$ ).

**DISCUSSION** We have examined the relationship between AsAo growth rates and eccentric systolic flow observed using 4D Flow in a cohort of BAV and control TAV patients. Significantly higher growth rates are observed in patients with BAV and eccentric systolic AsAo blood flow. Patients with markedly eccentric flow demonstrate the most rapid AsAo growth (Fig. 1). Two such patients in our cohort have since required surgical aortic repair. Good correlation is found between the growth rate and normalized flow displacement, which reflects flow eccentricity (Fig. 1). These results, along with those recently reported evaluating wall shear stress [5] in BAV, suggest both qualitative and quantitative 4D Flow measures can identify and risk-stratify patients with BAV who are likely to develop clinically significant AsAo dilation. Larger and prospective studies are warranted.

**REFERENCES** [1] Markl M et al. *J Magn Reson Imaging*, 2003;17:499-506; [2] Hope et al. *Radiology*, 2010, **255**: 53-61; [3] Sigovan et al. *J. Magn Reson Imaging*, 2011, **34**: 1226-1230; [4] den Reijer et al. *J. Cardiovasc Magn Reson*, 2010, **12**:4; [5] Hope et al. *JACC: Cardiovasc Imaging*, 2011, **4**: 781-787



**Figure 1.** Streamlines representing peak systolic flow in the ascending aorta of two representative BAV patients. Normal appearing streamlines that smoothly course through the AsAo (A) are seen in an 18 year-old woman who had stable aortic dimensions. Eccentric streamlines resulting in helical AsAo flow (B) are shown for a 32 year-old man with interval aortic growth of 1.3 mm/year. Growth occurred at the level highlighted (arrow) where eccentric flow and wall shear stress were maximum. (C) AsAo growth rates vs. normalized displacement ( $r = 0.66$ ).