Pulse Wave Velocity in Patients with Bicuspid Aortic Valve and Normal Controls: Discriminatory Ability among Multiple Analysis Techniques

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Introduction: Aortic compliance has become a surrogate marker in a variety of cardiac and aortic diseases, including atherosclerotic aortic aneurysms and Marfan syndrome. Beyond the morphologic and functional abnormalities of the aortic valve, patients with bicuspid aortic valve (BAV) also have intrinsic pathology of the aortic wall, manifested by potentially lethal complications such as aortic aneurysm or dissection. Similar abnormalities of compliance are felt to occur in the setting of BAV, though this has been little studied with velocity-encoded magnetic resonance imaging (VENC-MRI). Assessment of pulse wave velocity (PWV) with VENC-MRI is an attractive and promising strategy as this measurement does not depend on knowledge of central arterial pressure or geometrical assumptions that may limit other measurement tools. While PWV is a powerful assessment tool, there are multiple techniques to assess the time delay of the velocity waveform, each of which may have different discriminatory abilities, and as a result lead to different PWV values, thresholds, and accuracy. We sought to assess thoracic aortic PWV measurements from VENC-MRI in patients with bicuspid aortic valve using 3 analysis techniques previously defined in the literature, and assess the accuracy via ROC analysis in differentiating patients with BAV and normal controls.

Methods: Cardiac MRI was performed in a total of 70 subjects: 40 BAV patients and 30 controls (trileaflet aortic valve without dysfunction, and no aortic aneurysm) using a 1.5-tesla MRI scanner (Avanto; Siemens Medical Solutions, Erlangen, Germany). After scout imaging to locate the cardiac axes, ECG-triggered non breath-hold black blood prepared HASTE (Half Fourier Acquisition in Steady State) images were acquired in the axial orientation for a total of 40 slices. The imaging parameters were: TE = 20 ms, TR = 800 ms, refocusing flip angle = 160°, slice thickness = 6 mm, FOVx = 240-360 mm, FOVy = 300-380 mm; typical matrix size = 124 x 192, and typical acquired spatial resolution = 2.4 x 1.8 mm. VENC-MRI was acquired using a retrospectively ECG-gated gradient-echo pulse sequence at the level of the pulmonary trunk to measure through-plane flow in the mid-ascending and mid-descending aorta with the following parameters: TE = 3.1 ms, TR = 5.0 ms, flip angle = 30°, slice thickness = 6 mm, FOVx = 240-360 mm, FOVy = 300-380 mm; typical matrix size = 128x 256, and typical acquired spatial resolution = 2.3 x 1.3 mm; temporal resolution = 30-50 ms, and velocity encoding = 200 cm/s.

Using dedicated cardiovascular image analysis software (Argus; Siemens Medical Solutions), the contours of the mid-ascending and mid-descending aorta were drawn. The flow (in m/s) at these two levels was obtained from the velocity data of each voxel in all phases of the cardiac cycle. From the corresponding flow-time curves, 3 analysis techniques [1-3] (Figure 1) were used to assess the time delay: 1) the arrival of the foot of the pulse wave measured as the point of interception of the linear extrapolation of the steep early systolic slope and the baseline [1], 2) the arrival of pulse wave at the level when the mean velocity reached its half maximum value [2], and 3) the best cross-correlation of the upstroke portion with normalized velocity value between 0.2 and 0.4 [3]. Multiplanar reconstructions of the axial HASTE images were performed to measure the aortic path length. The centerline was drawn on a reconstructed sagittal view from the level of the mid-ascending aorta to the mid-descending aorta, corresponding to the same level where the VENC-MRI image was acquired. The PWV assessed between the mid-ascending and mid-descending aorta, was calculated according to the following formula:

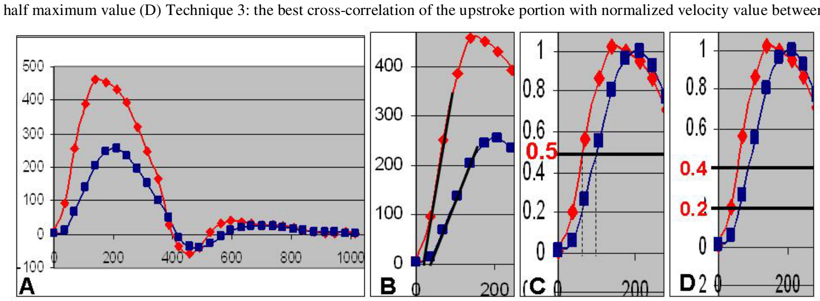
$$PWV = \frac{\Delta x}{\Delta t} \quad \text{(m/s)}$$

where Δ x was the aortic path length between the mid-ascending and mid-descending aorta, and Δ t was the time delay between the arrival of the foot of the pulse wave at these levels. To determine reproducibility, inter-observer variability was performed in a subset of 10 patients randomly selected.

Results: BAV patients revealed increased PWV compared to controls using all 3 methods (method 1; 10.34 vs. 3.76 m/s; $p < 0.0001$, method 2; 7.77 vs. 4.78 m/s, $p < 0.0001$, and method 3; 7.41 vs. 5.29 m/s, $p < 0.0001$). ROC analysis revealed significantly different areas under the curve for the various analysis techniques in differentiating BAV and normal controls (method 1 = 0.93, method 2 = 0.72, and method 3 = 0.60). Using the cut-off value of 4.20 m/s, technique 1 yielded sensitivity of 90% and specificity of 77.4%. For inter-observer variability, mean difference between 2 measurements was 0.27±1.32 m/s for technique 1.

Conclusions: BAV patients have increased PWV compared to normal controls with all 3 PWV analysis techniques. There is impaired aortic compliance in patients with BAV suggesting an important parameter for enhanced surveillance in this high risk group. However, the results also emphasize the different discriminatory abilities of the 3 PWV analysis techniques with technique 1 (the arrival of the foot of the pulse wave measured as the point of interception of the linear extrapolation of the steep early systolic slope and the baseline) providing the greatest AUC by ROC analysis. This technique should be the preferred analysis device for PWV measurements with good reproducibility for clinical application..

Figure 1 Analysis techniques for the time delay of pulse wave (A) The flow-time curve (B) Technique 1: the arrival of the foot of the pulse wave measured as the point of interception of the linear extrapolation of the steep early systolic slope and the baseline (C) Technique 2: the arrival of pulse wave at the level when the mean velocity reached its half maximum value (D) Technique 3: the best cross-correlation of the upstroke portion with normalized velocity value between 0.2 and 0.4



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