Hemodynamic Outcome in Patients after Bicuspid and Tricuspid Valve Sparing Aortic Root Repair: A 4D flow MRI Study

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Introduction: Thoracic aortic aneurysms (TAA) have an estimated incidence of 6 per 100,000 person-years. MR angiography (MRA) is gold standard non-invasive technique to quantify thoracic aortic size [1]. Independent of hemodynamic abnormalities, age, or body size, thoracic aortic aneurysms are frequently associated with the presence of a bicuspid aortic valve (BAV) [2]. For both tricuspid (TAV) and BAV morphology, aneurysm sizes exceeding 5-5.5cm constitute high risk of rupture or dissection. Treatment options include valve sparing aortic root repair to preserve the native valve by re-implantation into an aortic graft. However, the impact of surgical repair and native valve morphology on the post-intervention hemodynamic outcome is poorly understood. 4D flow MRI can provide information on temporal evolution of 3D blood flow throughout the thoracic aorta [3]. Recent studies show that 4D flow MRI can depict altered aortic hemodynamics associated with different valve morphologies [4], aortic dilatation [5], or type of aneurysm repair [6]. However, a systematic 3D flow analysis of baseline and post-surgical TAA repair for different types of valve morphology has not been performed. The aim of this study was to characterize blood flow patterns in patients following valve-sparing aortic root repair compared to pre-surgical cohorts matched by valve morphology, age, and aneurysm size.

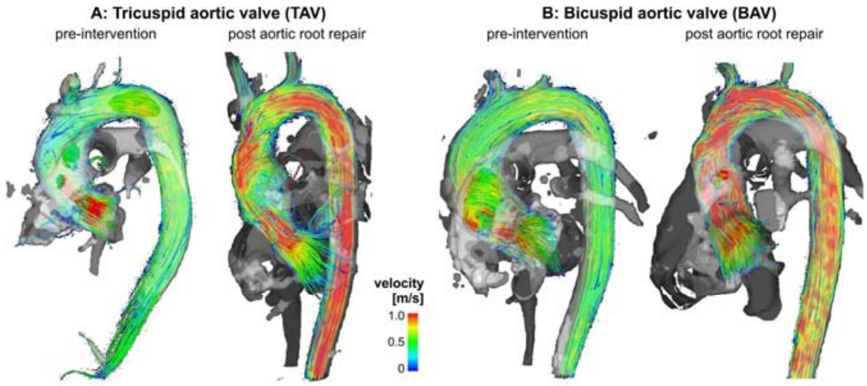

Fig. 1: 3D visualization of systolic blood flow characteristics in four representative patients of each group. Note that aortic valve repair resulted in reduce helix flow in the ascending aorta and substantially increased peak velocities throughout the thoracic aorta for both tricuspid and bicuspid valve morphology.

Table 1: Descriptive statistics of the quantification of peak systolic velocities and acceleration in the aorta in all 4 patient groups.

	peak velocity [m/s]				acceleration [m/s^2]	
	root	AAo	arch	DAo	root	AAo
BAV post root repair	2.0 ± 0.6	2.3 ± 0.6	1.5 ± 0.4	1.3 ± 0.6	7.8 ± 1.9	7.3 ± 2.4
BAV pre-intervention	1.6 ± 0.3	1.8 ± 0.4	1.0 ± 0.2	1.1 ± 0.3	6.8 ± 1.3	6.3 ± 1.3
TAV post root repair	2.0 ± 0.6	1.6 ± 0.4	1.3 ± 0.4	1.0 ± 0.3	6.9 ± 2.8	6.9 ± 2.3
TAV pre-intervention	1.7 ± 0.9	1.2 ± 0.7	0.9 ± 0.4	0.8 ± 0.2	6.3 ± 2.0	5.9 ± 2.2
pre BAV vs. post BAV	NS	**p = 0.037**	**p = 0.002**	NS	NS	NS
pre TAV vs. post TAV	NS	NS	**p = 0.026**	NS	NS	NS
pre BAV vs. preTAV	NS	**p = 0.039**	NS	**p = 0.039**	NS	NS
post BAV vs. post TAV	NS	**p = 0.017**	NS	NS	NS	NS

Methods: The study cohort comprised 33 patients divided into four groups. 13 subjects underwent aortic root repair with re-implantation of a bicuspid (n=7, age=41±12 years, pre-surgical aortic diameter = 4.7±1.3cm) or tricuspid (n=6, age=55±21 years, diameter = 4.0±1.2cm) aortic valves. Post-surgical patients were compared to pre-surgical TAA patients with bicuspid (n=10, age=42±10 years, 4.3±0.2cm) and tricuspid (n=10, age=61±12 years, 4.3±0.2cm) aortic valves. The study was approved by our local IRB. All studies were performed on 1.5T and 3T MR scanners (Avanto, Aera, Skyra, Siemens, Germany). Aortic blood flow was measured using ECG and respiration synchronized 4D flow MRI (venc 150cm/s, spatial resolution (2.0-2.8mm)^3, temporal resolution 40-44ms) covering the entire thoracic aorta. Data analysis included 3D blood flow visualization (EnSight, CEI, USA) based on time-resolved 3D pathlines and systolic 3D streamlines as illustrated in figure 1. Deviation from laminar aortic flow was quantified by segmental (AAo, arch, descending aorta) grading of helical flow on a 3-point scale (flow rotation during one cardiac cycle <180°, 180-360°, >360°). 3D pathlines were used to visually identify AAo flow jets and the quadrant of flow impingement on the aortic wall (right, left, anterior, posterior) in the proximal, mid, and distal AAo. Systolic flow uniformity was evaluated by identifying quadrants with systolic peak velocities >1m/s in analysis planes in the aortic root and AAo. Peak velocity and acceleration was quantified in analysis planes throughout the thoracic aorta.

Results: 4D flow MRI was successfully employed to visualize 3D blood flow in the thoracic aorta of all subjects (figure 1) and revealed pronounced AAo helical flow in control subjects with TAA (both BAV and TAV: average grading = 1.8±0.4). Helix flow was significantly reduced (average grading = 0.2±0.4, p<0.001) after aortic root repair independent of valve type. TAA with BAV resulted in clearly identifiable out-flow jets (9 of 10 patients) consistently impinging on the right-posterior aortic wall (figure 1C) while jet flow was less frequent in TAV (5 of 10 patients) and directed more towards the anterior wall. TAA flow uniformity in the AAo (figure 2, lower rows) depended strongly on the valve type and was highly eccentric for BAV subjects. Aortic root repair restored cohesive flow for both both groups with less eccentric flow profiles (figure 2, top rows) and absence of AAo flow jets. Flow quantification revealed generally increased systolic peak velocities and acceleration post-surgery compared to TAA control subjects (table 1). AAo peak velocities in root repair subjects with BAV were significantly higher compared to root repair with TAV (p=0.02).

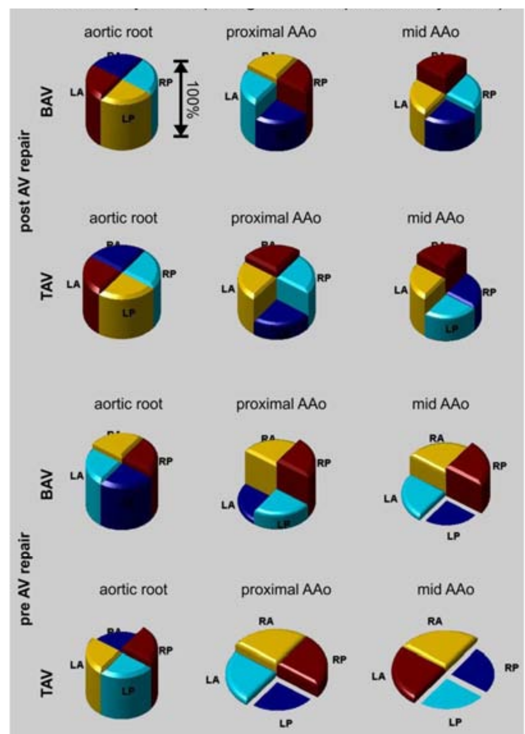

Figure 2: Aortic flow profiles. The individual pie charts represent the number of segments (% patients per group) in each group with peak velocity >1m/s. LA: left anterior, LP: left posterior, RA: right anterior, RP right posterior.

Discussion: Assessment of aortic 3D flow characteristics by 4D flow MRI demonstrates the ability of valve sparing aortic root repair to restore a cohesive flow pattern independent of the re-implanted valve morphology. Aortic valve repair generally results in reduced helical flow, reduced flow profile eccentricity, and absence of AAo jet flow compared to TAA control subjects. However, aortic root repair also resulted in increased peak velocities and flow acceleration. We speculate that these observations are related to the reduced compliance of the aortic graft and thus absence of the normal physiological Windkessel effect in the aortic root. **Limitations:** We compared pre- and post-repair aortic hemodynamics in cohorts of different patients. Although all cohorts were carefully matched with respect to age and pre-procedural aortic diameter, differences in aortic compliance between groups could influence our results. The long-term effects of increased flow velocities and acceleration are thus not fully understood but may indicate higher velocity gradients at the aortic wall and thus increased energy loss and ventricular loading.

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