Visualization of Aortic Root Vortex and Aortic Flow for Symptomatic Marfan Syndrome Patients by Phase-Contrast MRI

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Introduction: The Marfan syndrome (MFS) is a heritable gene mutation of FBN1 that encodes fibrillin-1 protein which is in charge of specifying the synthesis or processing of a constituent of the extracellular matrix (1). One of the most life-threatening complications is aortic dissection or rupture (2). Medical therapy to reduce the rate of aortic dilatation and risk of dissection, once MFS has been diagnosed, is now advocated (3). In previous study, noninvasive phase-contrast magnetic resonance imaging (PC-MRI) has been used to derive several reliable hemodynamic parameters (4). Geiger et al. have qualitatively investigated the flow patterns of MFS by flow-sensitive 4D MRI and reported that local helix flow in the ascending aorta (AAo), which was only seen in MFS patients, was closely associated with the presence of an enlarged aortic sinus (5). However, a detailed investigation of the vortex and the quantification of vorticity in the aortic root is still absent. The purpose of this study is to observe the aortic root vortex and to quantify vorticity in specific sites along the aorta with usage of PC-MRI so as to realize the impact of vortical flow on the risk of aortic dissection.

Table1. Positions of 10 planes.

Plane	Location
1	Sinuses of valsalva
2	Sinotubular junction
3	In the middle of plane#2 and #4
4	Proximal aortic arch
5	In the middle of innominate artery and left common carotid artery
6	In the middle of left common carotid artery and left subclavian artery
7	2 cm distal to left subclavian artery
8	In the middle of plane#7 and #9
9	At the level of diaphragm
10	2 cm distal to diaphragm

Methods: To establish quantified indices, 5 healthy volunteers (age: 23.8±4.7 y/o, female: 3, male: 2) and 15 MFS patients (age: 32.73±14.0 y/o, female: 4, male: 11) were included in the study population in the study. The mean aortic root diameter (ARD) were measured in MR left ventricular outflow track (LVOT) view and the values are 23.4±3.5 and 40.9±9.7 mm ($p<0.001$) for controls and MFS, respectively. All subjects underwent flow-sensitive 4D PC-MRI with FLASH sequence to acquire flow data in a 3.0 Tesla MR scanner (Trio, Siemens, Erlangen, Germany). The parameters are TR/TE = 43.2/2.92 ms, flip angle = 7°, VENC=1.5 m/s, voxel size = 1.17×1.17×3.5 mm^3, sampling 90% of the cardiac cycle. Prospective ECG-triggering and navigator-echo gating technique were performed to synchronize with heart beating and respiratory motion. The analysis of hemodynamic indices was accomplished by commercial software for 3D flow and vascular visualization (EnSight, CEI, Apex, NC) and home developed program (6) for quantification of hemodynamic indices. Ten vessel planes were placed at specific sites along the aorta, as listed in Table 1.The velocity vector fields in a LVOT view were used to observe vortex in aortic root. The vorticity, quantifying the vectors of spinning flow, is defined as: $Vorticity = \nabla \times \vec{v}$, where v is the velocity of blood flow. The mean vorticity of each plane was analyzed. The pathlines were used to visualize the flow patterns along the aorta.

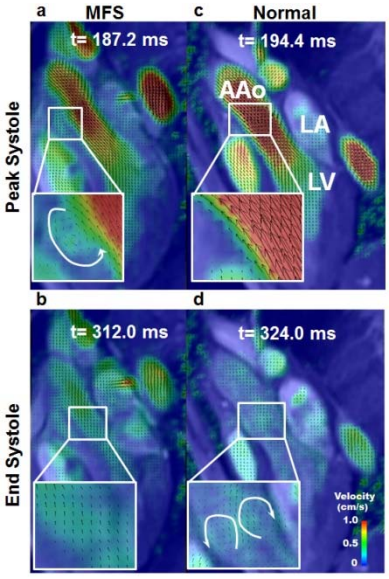

Fig. 1. The velocity vector fields at peak systole and end systole in LVOT view of (a,b) one MFS patient (22 y/o male, ARD: 37.8 mm) and (c,d) one normal subject (22 y/o male, ARD: 21.4mm). ARD: aortic root diameter. AAo: ascending aorta. LA: left atrium. LV: left ventricle.

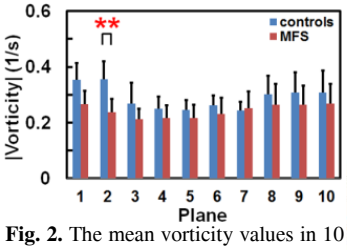

Fig. 2. The mean vorticity values in 10 planes along the aorta of normal controls (blue) and MFS patients (red). **p<0.01.

Results: At peak systolic phase, MFS showed a distinct vortex (Fig.1a), which may attribute to dilated aortic root, and this vortex was absent in normal control (Fig.1c). At end systolic phase, normal subject displayed two vortices with reversal directions after the closing of aortic valve. However, MFS patient did not show vortices at end systolic phase. In Fig.2, the quantification of vorticity demonstrated significant lower values in plane#2 (sinotubular junction) in MFS patients, reflecting the disturbing flow and thus decreased vorticity within dilated aortic root. As for the visualization of flow patterns in MFS, we also observed different specific patterns. As shown in Fig.3(a), the young MFS patient without dilated aortic root exhibited similar flow patterns with normal control (Fig.3d). In contrast, young MFS with dilated aortic root showed significant helical flow in AAo (see arrow in Fig. 3b). As for elder MFS patient with dilated aortic root (Fig.3c), the helical flow is absent but the flow velocity is decreased compared to normal control.

Discussion & Conclusion: In previous study, the 4D flow analysis revealed marked differences of the aortic flow patterns between MFS patients and controls (5). In this study, we have a detailed investigation on the flow within aortic root and the vorticity values were quantified along the aorta. In the velocity vector fields in LVOT view, the presence of vortical flow at peak systole and the absence of vortices at end systole may attribute to the dilated aortic root in MFS patients. Since disturbing flow presented in dilated aortic root in MFS patients, the quantified vorticity also showed decreased values for MFS patients, particular in the sinotubular junction (Fig.2). With visualization of aortic flow, we also observed different patterns for MFS patients with different ages and severity of dilated aortic root. However, a semi-quantified scoring analysis for the flow patterns is necessary in the future work. In conclusion, using flow-sensitive 4D PC-MRI to acquire flow data and to visualize flow patterns as well as to quantify vorticity for MFS patients is feasible. Observing the aortic root vortex in a LVOT view may be helpful to realize the impact of vortical flow on the risk of aortic dissection. Measuring vorticity along the aorta may provide useful information of predicting potential sites with high risk of dissection.

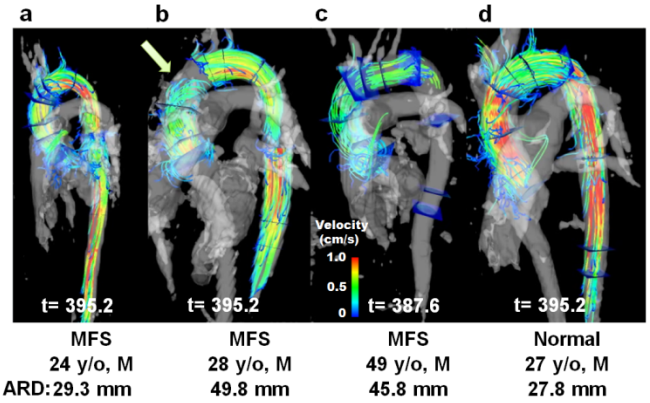

Fig. 3. The pathlines demonstrated the flow patterns in three MFS patients and one normal subject. The age and aortic root diameter of each subject were listed. Green arrow: helical flow.

References: **1.** Ammash et al. *Curr Probl Cardiol*. 33(1):7-39 (2008). **2.** Milewicz et al. *Circulation*. 111:e150-e157 (2005). **3.** Dormand et al. *J Cardiovasc Magn Reson*. 15:33 (2013). **4.** Gerald et al. *J Am Coll Cardiol*. 43: 5S–12S. (2004)**. 5.** Geiger et al. *J Magn Reson Imaging*. 35(3):594-600 (2011). **6.** Stalder et al. *Magn Reson Med.* 60:1218–1231 (2008).