Assessment of blood flow patterns in the Pulmonary Artery with 4D Flow MRI

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Introduction: 4D Flow has been used to study flow patterns, mainly in the aorta. In the Pulmonary Artery (PA) one VOrtex (VO) has been associated with Pulmonary Hypertension (PH) [1]. However, a systematic analysis of flow patterns has not yet been performed. The objective of this work is to analyze flow patterns in the PA from healthy subjects and patients with Congenital Heart Diseases (CHD).

Methods: Eighteen volunteers (30.3 ± 5.7 years old) and four patients with CHD (two after Glenn procedure (14 and 13 y.o.), one with uncorrected Atrial Septal Defect (ASD) and Partial Anomalous Pulmonary Venous Connection (PAPVC) (46 y.o.), and one with repaired aortic coartation and a cardinal vein (19 y.o.)) underwent a 4D Flow scan on a Phillips system. The sequence was acquired with retrospective cardiac gating (20-25 phases, temporal resolution of ≈ 38ms, spatial resolution of 2.5mm^3) and with self respiratory navigation [2] in volunteers. Flow was visualized by streamlines and particle traces using the GTFlow software (Gyrotools Ltd.). 2D planes placed in 5 locations were used to grade flow patterns: 1) just after the pulmonary valve, 2) before the PA bifurcation, 3) between plane 1 and 2, 4) in the right-PA (RPA), and 5) in the left-PA (LPA). Sagittal and coronal planes were also analyzed. VOs that lasted at least 2 frames were evaluated according to: start, finish and peak-frame, direction, size, location and distance between vortex-center and vessel-center. The study was approved by the local ethics committee.

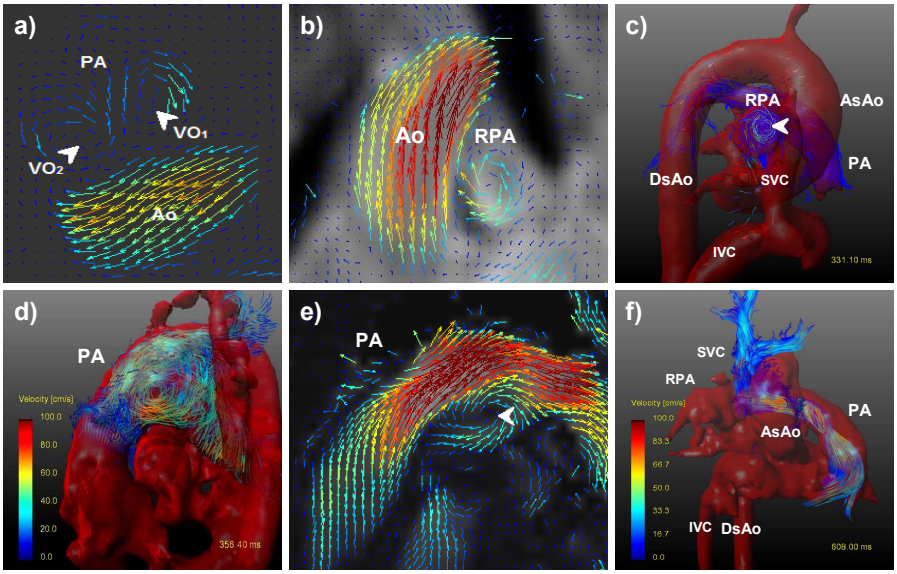

Figure 1.a) VOs seen in the main PA in one healthy subject. b) and c) VO in the right PA. d) and e) VO associate to backward flow in the patient with ASD and one patient after Glenn procedure respectively. f) Retrograde flow from the SVC to the PA and right ventricle in one patient after Glenn procedure.

Results: Two VOs were identified in the PA from volunteers (Fig. 1a). VO_1 was observed in all volunteers and VO_2 in sixteen of them. Both VOs started at peak-systole and ended at late-systole. VO_1 was located on the posterior wall and VO_2 on the anterior wall, with clockwise and counterclockwise directions, respectively. VO_1 was smaller compared to VO_2 (24%±7% vs. 31%±7% of the vessel area, p-value=0.03). VO_1's center was located closer to the vessel center compared to VO_2's center (10.1mm ± 2.0mm vs. 11.4mm ± 2.3mm, p-value=0.02). A clockwise VO was also observed in RPA of 15 volunteers (Fig. 1b and 1c), starting at peak-systole and ending at early-diastole. VO size was on average 49%±20% of the RPA area (Table 1).
Abnormal blood flow patterns and VOs were detected in patients with CHD. At systole a VO in the PA associated to backward flow was found in two patients (one Glenn and the patient with ASD and PAPVC), suggesting PH [1] (Fig 1d and 1e). In Glenn patients, a retrograde blood flow was found at diastole from the Superior Vena Cava (SVC). Particle traces showed that up to 90% (in one frame) of SVC flow went toward proximal RPA and more than 70% reached the main PA (Fig 1f). Indeed, most of the backward flow during diastole originated from the LPA and from the proximal RPA (before the SVC) as seen in figure 2 (note that there is no backward flow from distal RPA, i.e. after the SCV).

Conclusion: VOs were normally present in the PA of healthy subjects. Abnormal blood flow patterns were observed in the PA in patients with CHD. These findings demonstrate the utility of 4D Flow to evaluate complex hemodynamics in the PA. Knowledge of normal helical flow patterns in the PA could enhance the urderstanding of the pathogenesis of diseases affecting PA, such as PH or pulmonary embolism, and eventually help in therapeutic decisions in patients with cavopulmonary connections.

	VO_1	VO_2	VO (RPA)
Start (frame)	6.1 ± 1.1	5.9 ± 1.1	6.1 ± 1.5
End (frame)	9.7 ± 1.5	9.8 ± 1.2	13.7 ± 3.5
Peak (frame)	7.3 ± 1.0	7.2 ± 1.0	8.5 ± 2.1
Direction	clockwise	counterclockwise	clockwise
Distance (mm)	10.1 ± 2.0*	11.4 ± 2.3*	3.7 ± 1.7
Size (% of lumen)	24.1 ± 7.1*	30.5 ± 6.8*	49.4 ± 19.5
Location	posterior	anterior	

Table 1. Grading of vortical flow patterns using five 2D planes as described in the methods section. VO_1 and VO_2 were seen in the main PA. *Statistically significant difference (p<0.05) between data.

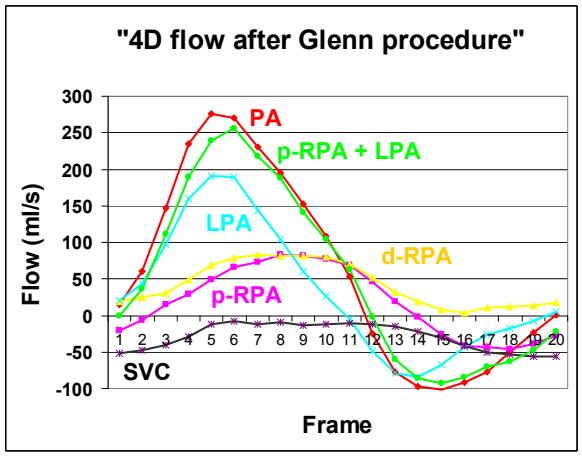

Figure 2. Blood flow quantification after Glenn procedure from 4D flow data in various vessels: SVC: Superior Vena Cava; PA: Pulmonary Artery; LPA: Left Pulmonary Artery: p-RPA: proximal-Right Pulmonary Artery (before SVC anastomosis); d-RPA: distal-Right Pulmonary Artery (after SVC anastomosis).

References: 1. Reiter, G. et al. Circ Cardiovasc Imaging 2008.
2. Uribe, S. et al. Magn Reson Med 2009.
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