

Normal values of Wall Shear Stress in the Pulmonary Artery from 4D flow Data

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Background: Approximately 5–10% of adults with Congenital Heart Disease (CHD) develop Pulmonary Arterial Hypertension (PAH), mainly due to systemic to pulmonary shunting. Chronically raised pulmonary blood flow causes abnormal endothelial shear stress and a progressive pulmonary vasculopathy (1). Quantification of Wall Shear Stress (WSS) in the pulmonary circulation might be helpful to identify patients with CHD at risk for developing PAH. Using 4D flow MRI, the quantification of WSS has been recently reported in the aorta (2). However, there are few reports that have studied this parameter in the Pulmonary Artery (PA). The objective of this work was to develop a reproducible method to calculate WSS using a Strain Rate Tensor based on cylindrical coordinates obtained from 4D flow data. The method was applied to calculate WSS values in the main, right and left PA (MPA, RPA and LPA) of healthy volunteers and patients with CHD.

Method: 4D flow data of the Whole Heart (reconstructed spatial resolution = 2.5 mm³, temporal resolution = 38 ms) was acquired on 17 volunteers and 5 patients with Congenital Heart Diseases (CHD) (repaired Transposition of the great arteries, two after one and a half ventricle repair, and two with partial anomalous pulmonary venous return, one of them with Atrial Septal Defect).

Using a homemade software, three slices were reformatted perpendicular to the MPA, RPA and LPA. Subsequently, we segmented the blood pool, and calculated Magnitude (WSS-M), Axial (WSS-A), and Circumferential (WSS-C) WSS using a Strain Rate Tensor based on cylindrical coordinates. For each slice, we generated three contiguous slices to include variations of the velocity along the direction of the vessel. Two independent observers processed the data to study the reproducibility of the proposed method with our software.

Result: The average WSS-M in volunteers was: MPA = 0.11±0.01N/m²; RPA = 0.22±0.05N/m²; LPA = 0.17±0.02N/m². In comparison, the average WSS-M in the group of patients was: MPA = 0.28±0.14N/m²; RPA = 0.36±0.1N/m²; LPA = 0.34±0.19 N/m². Figure 1 shows the average WSS-M calculated along the cardiac cycle for each segment. Figure 2 depicts Bland Altman plots of the mean WSS measured by the two observers, showing a small bias and standard deviations (mean difference of 0.0157N/m², 0.0076N/m² and 0.005N/m² for the WSS-M in the PA, RPA and LPA respectively). Table 1 shows the average of WSS-M, WSS-A and WSS-C, acquired by each observer, in the three sections of the pulmonary artery.

Conclusions: In volunteers, we found a greater WSS in the RPA compared with the LPA, which is probably associated with helical flow pattern in the RPA, previously described (3). The WSS obtained in patients with CHD showed larger values and great variability of WSS. In conclusion, we proposed a reproducible method to calculate WSS derived from 4D flow data in the main PA, RPA and LPA, which may be helpful to identify patient with CHD at risk of developing PAH.

References: 1. Hoey ET., et al. Eur Radiol 2009; 19:2557-68. 2. Stalder A., et al. Magn Reson Med 2008; 60:1218-31. 3. Bächler P., et al. J Cardiovasc Magn Reson 2011; 13(Suppl 1):P66

Acknowledgment: Fondecyt-11100427, Anillo ACT-079.

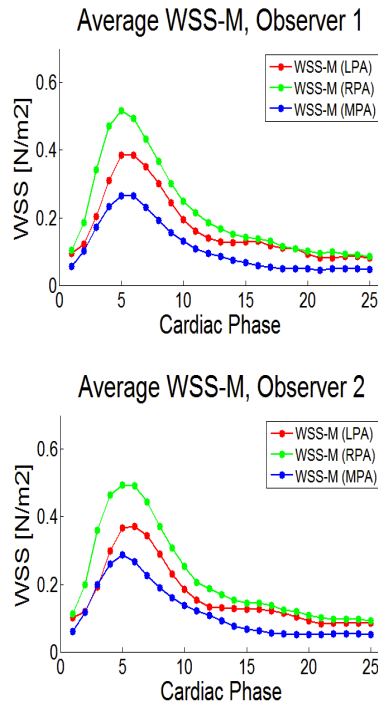


Figure 1. Average of the WSS-M in volunteers. (Main PA, Right PA and Left PA), acquired by each observer.

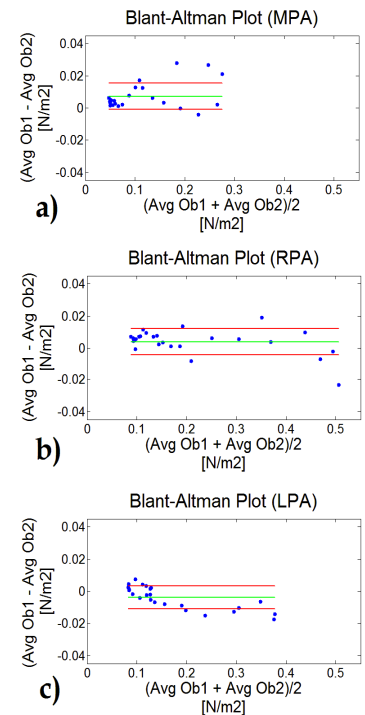


Figure 2. Depicts Bland Altman plots of the mean WSS-M in Volunteers, measured by the two observers. a) Main PA, b) Right PA and c) Left PA.

			AVG. MPA	AVG. LPA	AVG. RPA
Ob1	Healthy Volunteers	WWS mag	0.11 ±0.01	0.17 ±0.02	0.22 ±0.05
		WWS axi	0.08 ±0.01	0.13 ±0.02	0.15 ±0.04
		WWS cir	0.013 ±0.01	0.004 ±0.02	0.003 ±0.02
	Patients	WWS mag	0.28 ±0.1	0.34 ±0.2	0.36 ±0.1
		WWS axi	0.21 ±0.1	0.25 ±0.1	0.29 ±0.1
		WWS cir	0.003 ±0.04	-0.013 ±0.07	0.039 ±0.08
Ob2	Healthy Volunteers	WWS mag	0.12 ±0.03	0.17 ±0.04	0.22 ±0.06
		WWS axi	0.09 ±0.02	0.13 ±0.03	0.17 ±0.04
		WWS cir	0.015 ±0.011	0.0004 ±0.02	0.019 ±0.02
	Patients	WWS mag	0.29 ±0.2	0.30 ±0.2	0.38 ±0.1
		WWS axi	0.21 ±0.1	0.22 ±0.1	0.26 ±0.1
		WWS cir	0.01 ±0.03	0.039 ±0.03	0.059 ±0.2

Table 1. Average of Wall Shear Stress in MPA, LPA and RPA position, acquired by each observer.