Relative pressure measurement in thoracic aorta and pulmonary artery of healthy volunteers and repaired Tetralogy of Fallot patients using the 4D Flow sequence of cardiac magnetic resonance

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Purpose: Pressure gradients are an important parameter in the clinical practice to determine the diagnosis, severity, follow up and surgical planning of different cardiovascular diseases such as valvular stenosis, aorta coarctation and congenital heart disease. Cardiac catheterization is the gold standard technique to measure pressure. Nevertheless, this method is invasive, patients have to be exposed to X-Ray and non-exempt of risk. Echocardiography is used to estimate pressures indirectly through the Bernoulli equation: ($\Delta p = 4V_{max}^2$), however, it is very sensitive to the V_{max}, may have poor acoustic windows, is operator dependent, and its values are overestimates respect to catheterism. Therefore, this technique cannot be used to measure small changes of pressure or to complex flows. Recently it has been shown that relative pressure maps can be obtained by simulating the Navier-Stokes equations using data from 4D Flow MRI. In this work we propose to use this method to obtain and compare pressure maps in aorta (Ao) and pulmonary artery (PA) of healthy volunteers and patients with repaired Tetralogy of Fallot (rTOF).

Methods: 4D flow data was acquired from 10 healthy volunteers, mean age $32,1 \pm 6,6$ years (24-45, 7F) and 10 rTOF patients, mean age $16,5\pm5,2$ years (11-25, 3F) on a 1.5 T MR system (Achieva, Philips Healthcare). The protocol was approved by the local ethics committee and informed consent was obtained. Visualization of the data and pressure maps were generated using the software GTFlow 2.0.4 (Gyrotools LLC, Zurich, Switzerland). Masks were generated in order to get separate areas of interest (Ao and AP). Relative pressure maps were obtained solving Pressure Poisson Equation:

$$\nabla p^2 = \nabla(-p \frac{\partial V}{\partial t} - p \, V \cdot \nabla V + u\nabla^2 V)$$

Five points in different positions along the aorta were selected to measure relative pressure respect to a reference point (**0**) in the descending aorta (DsA): (**I**) Ascending aorta (AsA) at the level of the PA, (**II**) AsA before the braquiocefalic trunk, (**III**) after of the left subclavian artery, (**IV**) in the DsA at the level of the reference point and (**V**) in the DsA 4 cms under the reference point. Furthermore, relative pressures were measured in the right (RPA) and left (RPA) pulmonary artery respect of the pulmonary artery trunk. Comparison of relative pressure maps between volunteers and patients was done using a Student *t*-test.

Results: Relative pressure in Aorta and Pulmonary Artery of healthy volunteers and rTOF patients are shown in figure 1 and 2. The shape of the curve in the aorta was similar in both study groups, but the diastolic phases of the curve in the pulmonary artery of patients was different, with lower diastolic pressures and a slower recovery. rTOF patients had relative pressure differences between maximum and minimum values higher than volunteers in aorta and pulmonary artery. Values in the aorta were not statistically significant, though in the pulmonary artery p-value was <0,05. Additionally, relative pressure of the aorta shown in this work had excellent correlation with other published values using 4D Flow and catheterization. For instance Tyszka[1] and Bock[2] got maximum and minimum values of 11/-5 and 7/-3 between the points I and V, our maximum values were 7,8/-1,4. Mills[3] measured a difference pressure of 8 mmHg in the same points through cardiac catheterization.
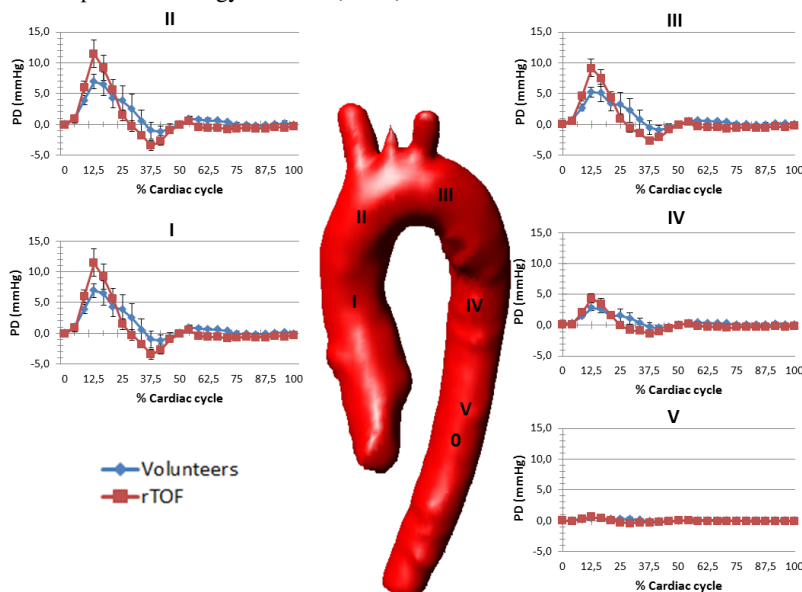

Fig. 1: Relative pressure curves in the Ao from volunteers (Blue curve) and rTOF patients (Red curve). Measurements were made in five points (I to V) respect to a reference point (0). PD: Pressure difference.
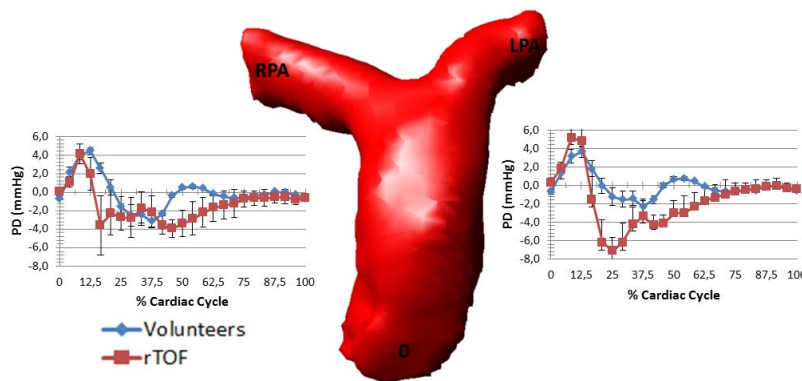

Fig. 2: Relative pressure curves in the PA from volunteers (Blue curve) and rTOF patients (Red curve). Measurements were made in two points (RPA and LPA) respect to a reference point (0). PD: Pressure difference.

Conclusion: In this work we have shown that relative pressure maps in rTOF patients had increased and statistically significant pressure difference in the pulmonary system compare to healthy volunteers. The differences of maximum and minimum relative pressures in rTOF patients could be a novel parameter that can be used to study right ventricular function. Our future work involves validating these pressure maps through cardiac catheterization on a pulsatile model of the great vessels.

References: [1] Tyszka et al. J Magn Reson Imaging 2000. [2] Bock et al. Magn Reson Med 2011. [3] Mills et al. Cardiovasc Res 1970.