Systolic pressure gradients derived from 4D flow in a physiological healthy and aortic coarctation phantom versus cardiac catheterization

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Purpose: Aortic coarctation (AoCo) disease accounts for 4 to 6 % of all congenital heart defects with a reported prevalence of about 4 per 10,000 live births[1]. Peak to peak pressure gradient through the aortic coarctation is the clinical standard to determine the severity of this disease and to refer patients to surgery repair. However, such a gradient sometimes need to be revealed by the use of isoprenaline to mimic physical exercise. Pressure gradient can be measured with echocardiography, though this technique obtains over estimated pressure values. Catheterization is the gold standard method, though is an invasive technique and patient are exposed to x-rays. During the last years, 4D flow has emerged as a MRI technique capable to measure hemodynamic parameters, including pressure gradients. However, due to the long acquisition time of 4D flow data, it is difficult to evaluate the accuracy of pressure gradients derived from 4D flow data in patients under different hemodynamic conditions. The purpose of this work is to evaluate the accuracy of pressure gradients derived from 4D flow in controlled experiments using a physiological healthy and aortic coarctation phantom at rest and stress conditions.

Methods: 4D flow data of the heart and great vessels were acquired (1.5 T, Philips) (spatial resolution of 0,9x0,9x0,9 mm) in 8 settings: healthy phantom and aortic coarctation phantoms of 9, 11 and 13 mm AoCo at rest (75 bpm) and stress (136 bpm) conditions. The normal diameter of the descending aorta was 22 mm. The phantom was equipped with a catheterization unit to measure the pressure gradient across the coarctation (two Angyodynamics catheters). Pressure from the phantom data were compared with pressure derived from 2 unrepaired AoCo patients (coarctation index of 0.7 and 0.8). Peak to peak pressure gradients from catheterization were compared with pressure gradient from 4D flow data and from the modified Bernoulli equation ($\Delta P=4V^2_{max}$). Pressure values from 4D flow were obtained using the software GT Flow 2.2.6 (Gyrotools LLC, Zurich, Switzerland).

Results: Figure 1 summarizes the pressures in the phantom experiments, the peak to peak pressure gradient measured with catheterization, 4D flow and the Bernoulli equation using the Vmax values from 4D flow data. Physiologic pressure values and waveforms were obtained in all cases. Relative pressure maps of the descending aorta of the phantom without AoCo at rest and with a 13 mm AoCo at rest and stress conditions are shown in figure 2.

Discussion: In the phantom experiments, the peak to peak pressure gradient measured using 4D flow through different grade of AoCo had an excellent agreement respect to pressure values obtained with cardiac catheterization at rest and stress, except for the 9 mm coarctation case. This is probably due to the small number of pixels in the coarctation area. Bernoulli value in some cases had good agreement, though in other cases pressure gradient were over-estimated respect to catheterization values. Peak to peak pressure gradient derived from 4D flow measured in two unrepaired AoCo had also an excellent agreement with the catheterization values.

Conclusion: 4D flow can be used to derive peak to peak pressure gradient with great accuracy in patients with mild coarctations. However its use in patients with severe coarctations or in small babies, in which the number of pixels in the coarctation area are small, need to be further study.

		Peak to peak pressure gradient (mmHg)							
		Rest				Stress			
Condition	Catheter position	Pressure	Cath	GT Flow	Bernoulli	Pressure	Cath	GT Flow	Bernoulli
Phantom without AoCo	AAo DAo	131/58 133/57	-2	-2,4	0,8	164/63 167/61	-3	-2,7	0,88
Phantom with 9 mm AoCo	AAo DAo	133/50 103/52	30	9	32,7	161/69 117/65	44	22,5	58,4
Phantom with 11 mm AoCo	AAo DAo	127/51 117/51	10	9,3	14	149/68 135/68	14	15,8	16,97
Phantom with 13 mm AoCo	AAo DAo	124/56 117/57	7	7,5	6,5	154/84 141/87	13	12	11,5
Patient 1	AAo DiaphAo	120/51 100/49	20	21,7	24,4				
Patient 2	AAo DiaphAo	87/39 76/39	11	12,4	10,89				

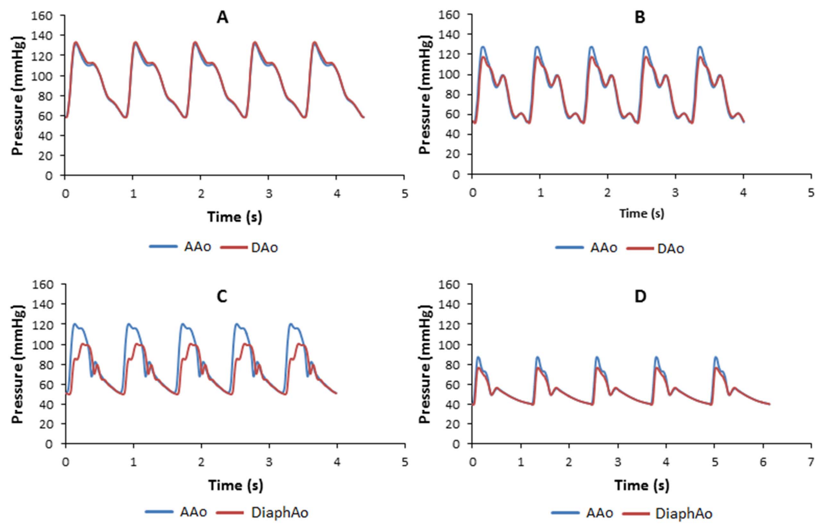

Fig 1: Pressure values and waveforms of the phantom experiments and 2 unrepaired AoCo patient are shown. AoCo: Aortic coarctation. Cath: Catheterization values. AAo: Ascending aorta. DAo: Descending aorta. DiaphAo: Diaphragmatic aorta. A: phantom without AoCo in rest. B: Phantom with an 11 mm AoCo in rest. C: Patient 1 in rest. D: patient 2 in rest.

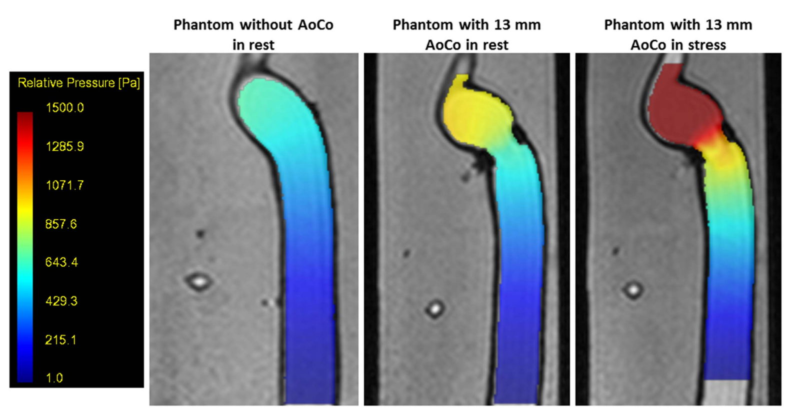

Fig 2: Relative pressure maps of the descending aorta of the phantom without AoCo and a 13 mm AoCo in rest and stress conditions. Relative pressures are expressed in Pascal

References: [1]Hoffman JI, Kaplan S. The incidence of congenital heart diseases. J Am Coll Cardiol. 2002;39(12):1890. [2]Jesús Urbina et al. A realistic MR compatible thoracic aortic phantom to study coarctations using catheterization and cine PC-MRI sequences. ISMRM 2014. Abstract N° 6916.