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4d Flow in CMR. Comparison with 2d flow and new perspectives

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1. Introduction – Background 2d Flow

- Cardiac and vessel Flow is multi-dimensional and multi-directional
- Current imaging modalities provide calculation of flow in only 1-direction (2dimensional image) and cannot visualize flow patterns.
- Great dependance on positioning:
  - i) image must be perpendicular to the vessel of interest (image1)
  - ii) should avoid placement near valves due to partial volume effects
  - iii) acquisition once during scan and cannot be further analyzed
  - iv) when possible, should avoid great angles to minimize gradient derived artifacts

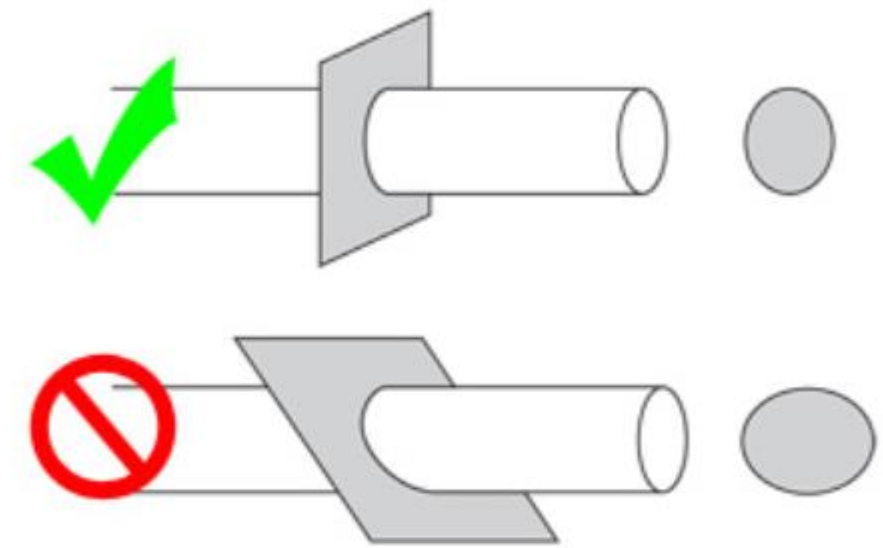

Image 1. Planning of flow slice to properly image the vessel avoid overestimation

1. Introduction – Background 4d flow

- 4d flow imaging is a new promising technique used to quantify flow
- 4d flow allows for simultaneous velocity encoding in all three directions
- Provides 3D volumetric information resolved over time (4D= 3 spatial dimensions + time)
- Requires post processing and
  a) Provides flow visualization and orientation (image2)
  b) Allows, in retrospect, users to correct and/or examine different positioning angles
  c) Allows measurement anywhere in the imaged volume.
- Can help understand the impact of cardiovascular disease on flow and vessel integrity and vice versa

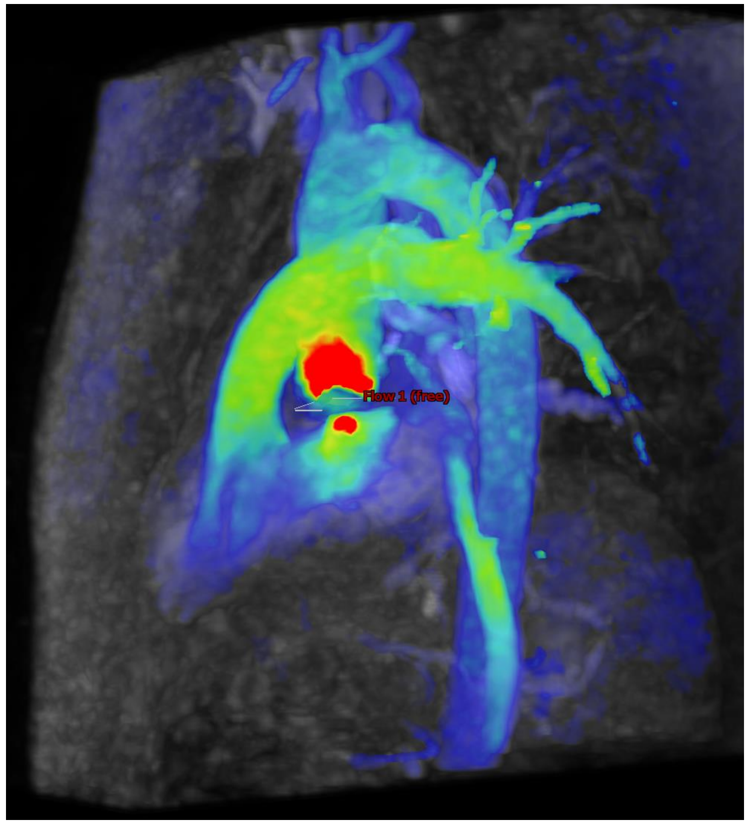

Image 2. 4d flow view of the heart and great vessels

1. Introduction – Mri`s Role

- The 4D flow CMR data acquisition is based on the ECG-gated phase contrast (PC) technique including time-resolved spoiled gradient echo pulse sequences.
- Respiratory motion should be compensated. Usually achieved through navigator gating of the diaphragm motion
- Acquisition time is increased, so acceleration approaches are important (i.e. parallel imaging, compressed sensing). Caution is needed because acceleration of the image acquisition impacts scan parameters such as SNR, spatial and temporal resolution
- The sensitivity of velocity encoding (Venc) should be set by the operator prior to the image acquisition as 10% higher than the maximum expected velocity

1. Introduction - Aim

The purpose of this study is :

- to compare 4d and 2d flow measurements
- to evaluate possible limitations in 2d and 4d flow measurements
- to evaluate the advanced hemodynamic metrics that 4d flow provides: Wall Sheer Strain (WSS) and vessel Pressure

2. Materials & Methods

- For this study we included a patient with aortic valve replacement and repair of an ascending aorta aneurysm

- He underwent a full CMR examination including a 4d flow sequence (TR=5,2ms, TE=3,1ms, FA=10º, voxel size=1,56x1,56x2mm^3, 24 frames/cardiac cycle, scan time=9:38min) and two 2d flow sequences (one positioned above the aortic valve and one at the pulmonary trunk)) with (TR=4,7ms, TE=2,8ms, FA=10º, voxel size=1,23x1,23x8mm^3, slice thickness=8mm, 30 frames/cardiac cycle, scan time=0:14sec)

- CMR analysis was performed using the software Circle cmr42

- Total forward volume(TFV), peak velocity(PV) and regurgitant fraction(RF) were calculated for both 4d and 2d flow sequences, Wall Sheer Strain and vessel Pressure for 4d sequence.

3. Results: 2d-4d flow

The results of the 2d and 4d flow measurements are presented a)in table 1 for the ascending aorta and b)in table 2 for the Pulmonary Artery

Ascending Aorta			
	TFV (ml)	**PV (cm/s)**	**RF (%)**
2d	69.68	161.52	74.22
4d	74.22	146.64	2.1

Table 1. Total Forward Volume(TFV), Peak Velocity(PV) and Regurgitant Fraction(RF) of the Ascending Aorta as measured from 2d and 4d flow sequences

Pulmonary Artery			
	TFV (ml)	**PV (cm/s)**	**RF (%)**
2d	69.94	109.39	6.51
4d	62.61	94.77	4.12

Table 2. Total Forward Volume(TFV), Peak Velocity(PV) and Regurgitant Fraction(RF) of the Pulmonary Artery as measured from 2d and 4d flow sequences

From the 4d flow analysis the ascending aorta presented higher values of Wall Sheer Strain and Vessel Pressure compared to the descending aorta. The results are presented in Table 3 and visually in image 3a, b.
WSS and pressure of the pulmonary trunk was steady for the whole vessel as visually displayed in image 2c, d.

	WSS (Pa)	VP (mmHg)
Ascending Aorta	0,28	19,65
Descending Aorta	0,42	0,22

Table 3. Wall Sheer Strain and Vessel Pressure for the ascending and descending aorta

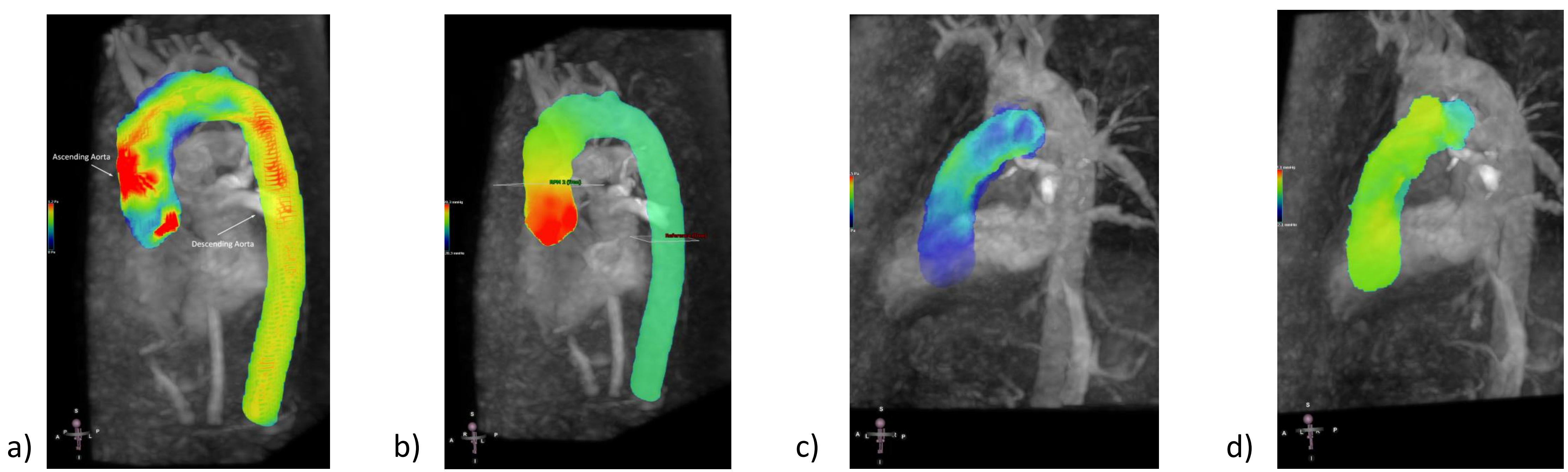

Image 3. Visual presentation of a) WSS of aorta, b) VP of aorta, c) WSS of pulmonary artery and d) PV of pulmonary artery

4. Conclusions

2d-4d Flow

- 2d flow has an inherit error ($\pm$10ml) in Total Forward Volume measurement. There is need for more accurate results
- The values between the 2 flow techniques are close and builds confidence in 4d flow analysis
- The difference can, also, be attributed to a)different angle position, b)the lower heart phases and c)larger voxel sizes in 4d flow

4d Flow

- Repaired ascending aorta presents higher values of Wall Sheer Strain in surgically repaired area
- Advanced metrics such as Wall Sheer Strain and Vessel Pressure can monitor vessel integrity and possibly predict the need for future surgical repair

Future Perspectives

- Beter understanding of flow patterns across the heart and connections with heart integrity
- More accurate estimations (i.e. jet estimation)
- Beter understanding of vessel integrity. Vital for surgery evaluation of the repair or even determining possible need for reoperation (i.e. aneurysm detection)

5. References

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