MRI/CFD-based methodology for realistic blood flow simulations: In-vitro validation and in-vivo applications

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Introduction

We present a numerical chain which aims at providing functional imaging for arteries. It relies heavily on advanced MRI (magnetic resonance imaging) protocols and CFD (computational fluid dynamics) methods. The relevant data (velocity field, wall shear stress, pressure gradient ...) are the output of the computation of the blood flow that is coherent with the input medical data.

Materials and methods

An entirely non-invasive 4D MRI protocol provides time varying geometry and flow rates of the vessel as input to the chain. The MRI protocol consists of True FISP (fast imaging with steady-state precession) and 2D Phase-Contrast (2D-PC) sequences. The True FISP MRI sequence provides the vessel 3D geometry corresponding to several instants over the cardiac cycle. 2D-PC sequences are performed at the inlets/outlets of the region of interest in order to obtain blood flow rates needed for computations. An appropriate segmentation and 3D reconstruction algorithm is then used in order to account for the wall motion in the computational model of the region of interest[1].

CFD code is then used in order to generate the unique (at least statistically speaking) blood flow coherent with the time varying morphological and hemodynamic data obtained from MRI.

Results and discussion

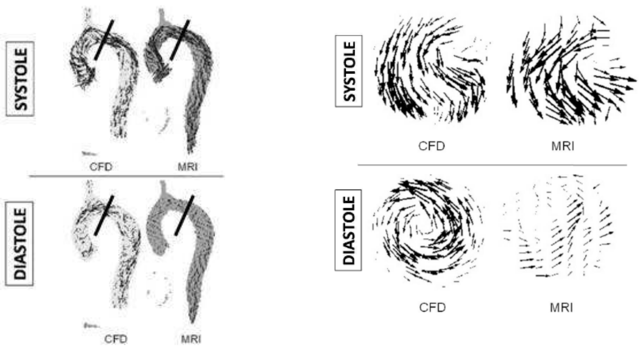

Fig. 1: velocity vectors obtained from CFD simulation and MRI measurement on a sagittal (left) and an axial (right) plane. Bold lines indicate the location of the axial plane.

The method is applied to an in vitro test case consisting in a pulsatile flow inside a compliant aortic phantom. A detailed hemodynamic characterization is obtained using the MRI/CFD-based methodology. On top of the hemodynamic measurements required for generating the inflow/outflow boundary conditions, supplementary sagittal 3D-PC acquisitions with three velocity encoding directions were performed for validation purpose. Comparisons between direct MRA and MRI/CFD-based velocity data are made at two instants over the cardiac cycles which are representative of the systole phase and the diastole phase. The general agreement is good (see fig.1): both MRI and CFD show an intense swirl motion, a reversal flow at diastole, and a jet zone at the outer part of the arch during systole. More detailed in-vitro validation can be found in [2].

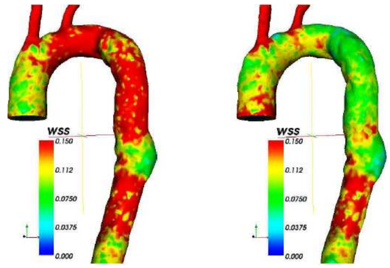

Fig. 2: WSS computed at diastole for a patient specific aortic arch without (right) and with (left) wall motions.

In-vivo applications of the method will also be presented, as exemplified in Fig. 2 for an actual patient aortic arch. Comparisons are made between computations made with or without accounting for the wall motion. Although the geometry changes are small, the effect on the computed wall shear stress (WSS) is significant (see Fig.2), thus showing the necessity to account for realistic wall motions as proposed in the present methodology.

Conclusion

The numerical chain presented aims at generating realistic functional imaging for arteries and accounts for the physiological wall motions over the cardiac cycle. Comparisons to direct measurements are made and a generally good agreement is found. The method is directly transposable to clinical cases.

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References

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