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CHARACTERIZATION OF THE AORTIC ARCH BEHAVIOUR AND CFD SIMULATIONS VALIDATED WITH 4D CARDIOVASCULAR MRI

Marine Menut (1), Benyebka Bou-Saïd (1), H el ene Walter-Le Berre (1), Xavier Escriva (2), Pascale Kulisa (2), Yann Marchesse (3), Philippe V ezin (4), Loic Bousset (5), Antoine Millon (5)

1. Universit e de Lyon, INSA-Lyon, LaMCoS, France; 2. Universit e de Lyon, LMFA, France; 3. Universit e de Lyon, ECAM Lyon, France; 4. IFSTTAR, LBMC, France; 5. Hospices Civils de Lyon, France

Introduction

Cardiovascular diseases are the leading cause of death worldwide. Their analysis leads to multidisciplinary problems that require diversity, transversal and complementary approaches. This contribution is part of a research project in Computer Aided Surgery and intends to contribute to the improvement of TEVAR procedures in terms of accuracy and optimization of the operating strategy. The aim is first to identify the aortic arch mechanical behaviour using a stereo-correlation technique. A Fluid-Structure Interaction computation will be then made including non-Newtonian blood behaviour validated with 4D Cardiovascular Magnetic Resonance Imaging. This would provide a diagnostic tool and support for clinical planning.

Methods

Stereocorrelation technique was used during an expansion test to measure the strain field under the aortic arch. 9 samples (7 frozen and 2 fresh aortas) were collected on human subjects through the French voluntary corpse donation to Science program. Incompressible isotropic Mooney Rivlin hyperelastic material model was considered. Coefficients were calculated using Matlab  Levenberg-Marquardt algorithm and numerical and experimental strains were compared using an Abaqus  model [1].

Computational Fluid Dynamic simulations of blood flow in a healthy patient thoracic aorta were performed. Navier-Stokes equations for an incompressible fluid were solved using the OpenFOAM solver. Rigid wall was considered in a first step. The Windkessel model [2] was applied to consider the flow resistance encountered by the blood. The Poiseuille velocity profile at the inlet was based on the patient pulsatile flow. Modified Phan-Thien and Tanner model [3] was implemented to compare to the Newtonian model. 4D MRI was performed on a patient which resulted in time-dependent 3D sequences with the velocity vectors.

Results

Experimental strains showed significant differences between frozen and fresh aortas. Mooney Rivlin coefficients were calculated only for the fresh samples. Rheological models can be validated comparing the numerical velocity profiles with 4D IRM data. MPTT showed similarities for the systolic phase compared to the Newtonian model (Fig. 1). However, none of these models gave similar results during the diastolic phase for this patient and this set of MPTT parameters.

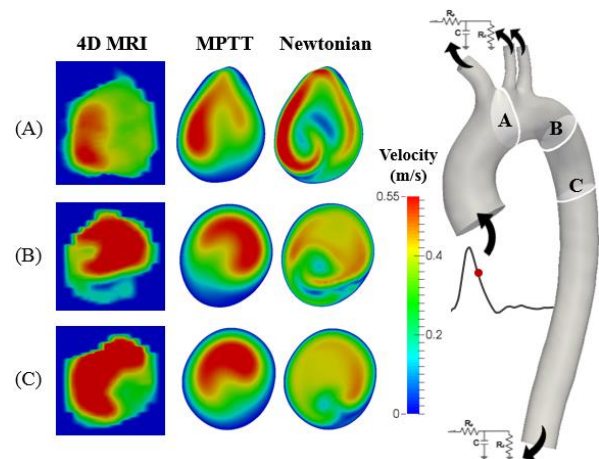


Figure 1: Different velocity profiles at $t=0.22s$ for 4D MRI results, MPTT and Newtonian models.

Discussion

Due to the Donation to Science program, information such as cause of death or health status were not known, even though those factors influence significantly the arterial wall behaviour.

Regarding the CFD simulations, the flow was considered laminar. Blood is a non-Newtonian fluid showing phenomena which cannot be represented by the traditional phenomenological models. Hence, it is necessary to account for the blood microstructure. The MPTT model derived from polymer rheology, considers viscous, shear thinning and other stress overshoot behaviours. Comparison with 4D IRM data did not validate MPTT model during the diastolic phase, but simulations assumed rigid walls while the thoracic aorta was moving during the 4D IRM acquisition.

The characterization of mechanical properties of the endovascular system, including blood behaviour, is a first step into the surgical procedure simulation. With these data, perspectives include accurate interaction between surgical tools and arterial tissue and a realistic customized solution for both a proper deployment system and a suitable stent recommendation.

References

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