RESIDUAL AORTIC DISSECTION NUMERICAL MODELLING

Deplano Valérie (1), Guivier-Curien Carine (1)

1. CNRS, Aix Marseille Université, Centrale Marseille, IRPHE UMR7342, Marseille, France

Introduction

Thoracic aortic (TA) dissection (TAD) involves a tear in the aortic wall that propagates within it, resulting in the creation of a false lumen (FL) in which the blood flows. FL is separated from the true lumen (TL) by the neo-intimal flap (NIF). According to Stanford classification TAD type A concerns those with an initial tear on ascending TA whereas for type B it is located on descending TA. In most of the cases, type A is a surgical emergency requiring replacement of the ascending aorta with a prosthesis. Residual AD (RAD) may persist in the descending segment. It is managed, like other uncomplicated type B TAD, by drug treatment. However, in 45% of cases RAD badly evolves. The current clinical indicators to evaluate RAD evolution are unfortunately not discriminating enough to predict a risky evolution of RAD. TAD, and even more RAD, have been the subject of very rare numerical modelling. To our knowledge only two studies [1, 2] out of our group performed Fluid Structure Interaction (FSI) numerical simulations of RAD. They considered fluid behavior as Newtonian and none of these works has associated biomechanical markers with RAD adverse evolution through longitudinal follow up. The goal of the present work is to go further analyzing different configurations for structural domain to highlight which structure plays or not a major role and linking some biomechanical markers with adverse RAD evolution thanks to longitudinal follow up.

Methods

Fluid and mechanical solid solvers with system coupling of ANSYS (Inc, USA) were used to perform all the simulations. The RAD geometry derived from patient specific morphology (figure 1a). The unsteady and incompressible flow was assumed to be laminar and the fluid behaved as a shear thinning one using the Carreau Yasuda model. Both the prothesis and aortic wall were modeled as linear elastic and isotropic materials. The Young modulus (E) of the aortic wall, E_{wall} was set to 1.2MPa, those of Dacron prothesis to 3.1GPa. The fluid and solid domains were discretized in 1,276,255 and 541,715 elements respectively. At the entrance, inlet Womersley velocity profiles were derived from an ascending aorta flow rate. At the outlets (3 aortic arch outlets and descending aortic outlet), a 3 elements Windkessel model was tuned for each of them, allowing pressure profiles to be defined [3]. 3 configurations were investigated. i) Rigid: all structural parts are assumed rigid, ii) NIF FSI: only NIF is deformable (E_{NIF}=1.2 and 0.6MPa were tested), iii) Full FSI: all structural parts are deformable. For NIF FSI, element faces facing the aortic wall were embedding. For Full FSI, face prosthesis entrance and main descending outlet were embedding. Normal displacements of aortic branches outlet were not allowed. A initial pressure condition of 80mmHg was imposed at walls and resulting constraints were applied to start the simulation with zero displacements. The mean Reynolds value and Womersley number were 1279 and 27.6 respectively.

Results

Compared to rigid modelling, NIF FSI does not show any significant difference on the flow behavior and NIF displacements are negligible even for the most compliant NIF. In relation to Full FSI, Rigid modelling induces an overestimation of velocity values and flow rates in TL and FL whereas pressure overestimation is so small that it can be considered negligible. Rigid modelling underestimates the surfaces of low WSS and TAWSS. NIF and aortic wall maximum displacements exhibit the same curve shape with maximum value around 1.2mm for Full FSI (figure 1b).

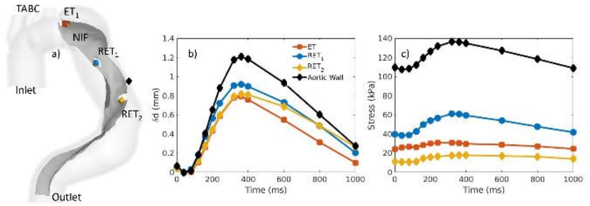

Figure 1 a) RAD geometry with entry (ET) and re-entry tears (RET). NIF in dark grey. Temporal evolution for Full FSI of b)δd and c) stress.

Discussion

The results will be discussed according to the mechanical behavior of the different structures and more particularly on the difference between E_{wall} and E_{NIF}. The relationship between NIF motion, whatever its amplitude, and the small pressure difference between FL and TL that never exceeds 5mmHg is not trivial. This point seems to be an essential key to understand mechanisms implicated in RAD main remodeling characteristics. Finally, it is important to underline that despite differences all models can predict thrombus formation at early stage though WSS cartographies and vortical structures evolution.

References

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Acknowledgements

We thank the Department of Vascular Surgery of the Timone Hospital and more particularly Gaudry M., PhD, Md.