ASSUMPTION-RELATED SENSITIVITY ANALYSIS IN A FLUID-STRUCTURE INTERACTION STUDY OF AN ARTERIOVENOUS FISTULA.

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Introduction

Since the two-way coupled fluid-structure interaction (FSI) methodology has become a widely accepted numerical tool for solving biomedical engineering problems, several questions have arisen regarding the assumptions that should be made when using FSI [1]. This study focused on the assumption-related sensitivity FSI analysis of an arteriovenous fistula (AVF) case representing the widely accepted vascular access for hemodialysis, in which highly disturbed non-physiological blood flow is observed and mutual fluid-wall interaction is unneglectable [2].

Methods

Important assumptions playing a critical role in FSI simulations were analyzed: 1) damping of loose connective tissue (LCT) embedding the AVF vasculature, 2) Newtonian/non-Newtonian blood rheology, 3) outlet pressure conditions and dealing with pressurization phase; 4) compliance of LCT; 5) compliance of blood vessel walls.

Results

The spatial and temporal distributions of hemodynamic parameters (fluid domain) and stress, strain, and deformation (structural domain) obtained for different settings were compared. Fig. 1 shows the influence of the magnitude of damping on the maximal and averaged wall displacement. Dealing with the pressurization phase significantly affected WSS (fig. 2), however, correct coping with initial undesirable deformation provided similar WSS as rigid-walled simulation. The choice of material properties considerably influenced wall extension and resulting hemodynamics (e.g. turbulence kinetic energy).

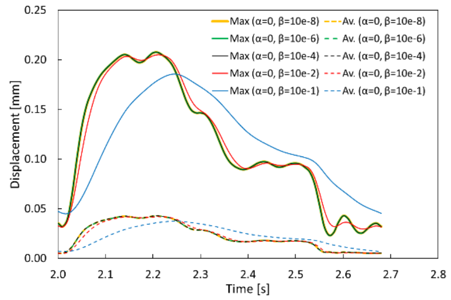

Figure 1: Influence of cushioning effect of LCT (modelled with a wide range of Rayleigh damping coefficients) on the maximum (solid lines) and average wall displacement (dashed lines).

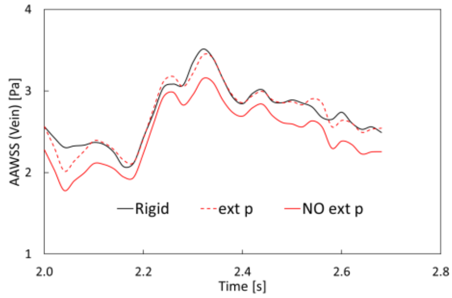

Figure 2: AAWSS determined in the AVF with the rigid-walled simulation and the FSI approach with (ext p) and without (NO ext p) coping with the pressurization phase.

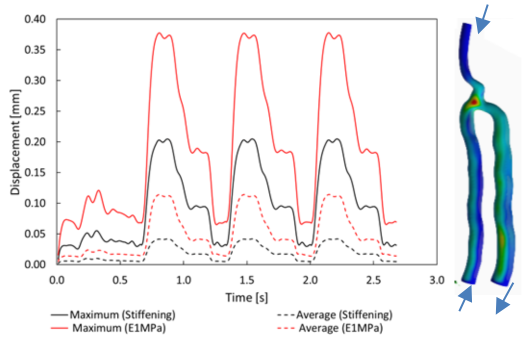

Figure 3: Wall displacement for the pressure peak for different material properties defining venous wall.

Discussion

All of the investigated assumptions affected the temporal quantitative results to some extent. 1) Lower damping may lead to wall vibrations (fig. 1); 2) As for high shear strain the Newtonian and non-Newtonian models overlap, blood rheology played a minor role here; 3) As data concerning the geometry of vasculature are acquired in the pre-stressed state, correct coping with the pressurization phase is necessary; 4&5) The total wall compliance resulting from the elasticity of LCT and material properties of tissue remains unknown but significantly affects wall extension and temporal progression of hemodynamic parameters. However, properly performed FSI provides comparable time-averaged results as the rigid wall approach that has to be considered due to the high computational cost of FSI.

References

1. Jodko et al., Int. J. Numer. Method. Biomed. Eng., 2022.
2. Bozzetto et al., Cardiovasc. Phys. Eng. Sci. Med. 47(1):187-197, 2024.

Acknowledgements

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