COMPARISON OF ZERO PRESSURE GEOMETRY AND PRESTRESS METHODOLOGIES IN CARDIOVASCULAR IN-SILICO ANALYSIS

André Mourato (1), Rodrigo Valente (1) , José Xavier (1,2), Moisés Brito (1,2), Stéphane Avril (3), António Tomás (4) , José Fragata (4,5)

1. UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Universidade NOVA de Lisboa, Portugal; 2. LASI, Intelligent Systems Associate Laboratory, Portugal; 3. Inserm, Sainbiose, France; 4. Santa Marta Hospital, Department of Cardiothoracic Surgery, Portugal; 5. Department of Surgery and Human Morphology, NOVA Medical School, Portugal

Introduction

Advanced computational frameworks have been used to recreate the biomechanical behaviour of Ascending Thoracic Aortic Aneurysms (ATAA), aiming to develop tools that assist clinicians in stratifying the risk of acute complications [1]. These frameworks are often assisted by in-vivo patient-specific data, obtained via medical imaging exams. This data is used, among other applications, to reconstruct patient-specific anatomical models. Computational Solid Mechanics (CSM) requires the reference configuration which is not directly assessable through imaging data as the blood vessel in physiological conditions (image configuration) is always loaded. This work compared the numerical results of CSM simulations of the ATAA wall obtained by two different prestressing approaches.

Methods

The ATAA wall was generated by extruding with uniform thickness (1.5 mm) the patient-specific lumen segmentation of Computed Tomography Angiography (CTA) data (Figure 1a)) and was modelled as a Neo-Hookean, isotropic and incompressible material. The wall prestressing was performed resorting to two methodologies: (i) implementation of a minimization algorithm that estimates the reference configuration [2]; (ii) calibration of a prestress tensor that balances a specific hemodynamic load and is included in the formulation of the Cauchy's momentum equation [3].

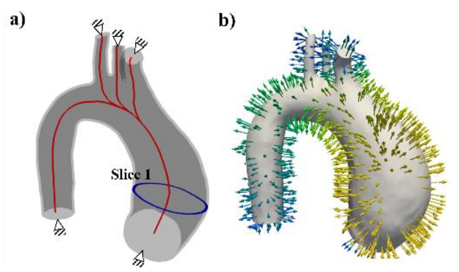

Figure 1: Visualization of the (a) ATAA wall domain and the (b)traction field applied at the inner surface.

Results

The results of the CSM simulations were obtained considering a Young Modulus of 1 MPa. Also, at the inner surface of the ATTA wall, a traction field obtained from 2-way Fluid-Structure Interaction simulations [4] was applied, and the domain extremities were fixed (Figure 1b)). In Figure 2, the average relative displacements and stresses for both methodologies at Slice 1 is presented. In both cases, the ATAA increases in diameter during systole in response to increased blood pressure. This diameter growth also induces an increase in the intramural stress field. During diastole, the blood pressure decreases as the blood injection stops, and the ATAA returns to its original shape. The zero pressure approach, however, overestimated the relative displacement magnitude and relative stress magnitude.

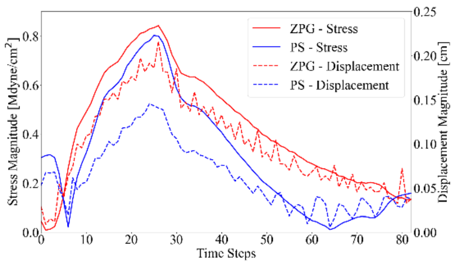

Figure 2: Evolution of relative displacement and stress magnitudes at Slice 1 estimated by the zero pressure geometry (red) and prestress (blue) approaches.

Discussion

The results evidenced that both methodologies produced similar evolutions (Figure 1b)) of the average relative displacement and stress. Nonetheless, these quantities were significantly overestimated by the zero pressure geometry. In future versions, it is intended to introduce the linearization of the material properties for the prestress methodology, which is expected to improve the agreement between the two approaches.

References

1. A. Mourato et al, Appl. Sci., 12 :1-38, 2022.
2. M. Raghavan et al, Ann Biomed Eng, 34:1414-1419, 2006.
3. M. Hsu et al, Finite Elem Anal Des, 47:593-599, 2011.
4. R. Valente et. al, Biomechanics, 2:189-204, 2022.

Acknowledgements

This research was funded by Portuguese Foundation for Science and Technology (FCT) under the project PTDC/EMD-EMD/1230/2021 and UNIDEMI UIDB/00667/2020. A. Mourato and R. Valente are also grateful to FCT for the PhD grants UI/BD/151212/2021 and 2022.12223.BD, respectively.