Localized linearization technique for FSI analysis of patient-specific aortic aneurysm

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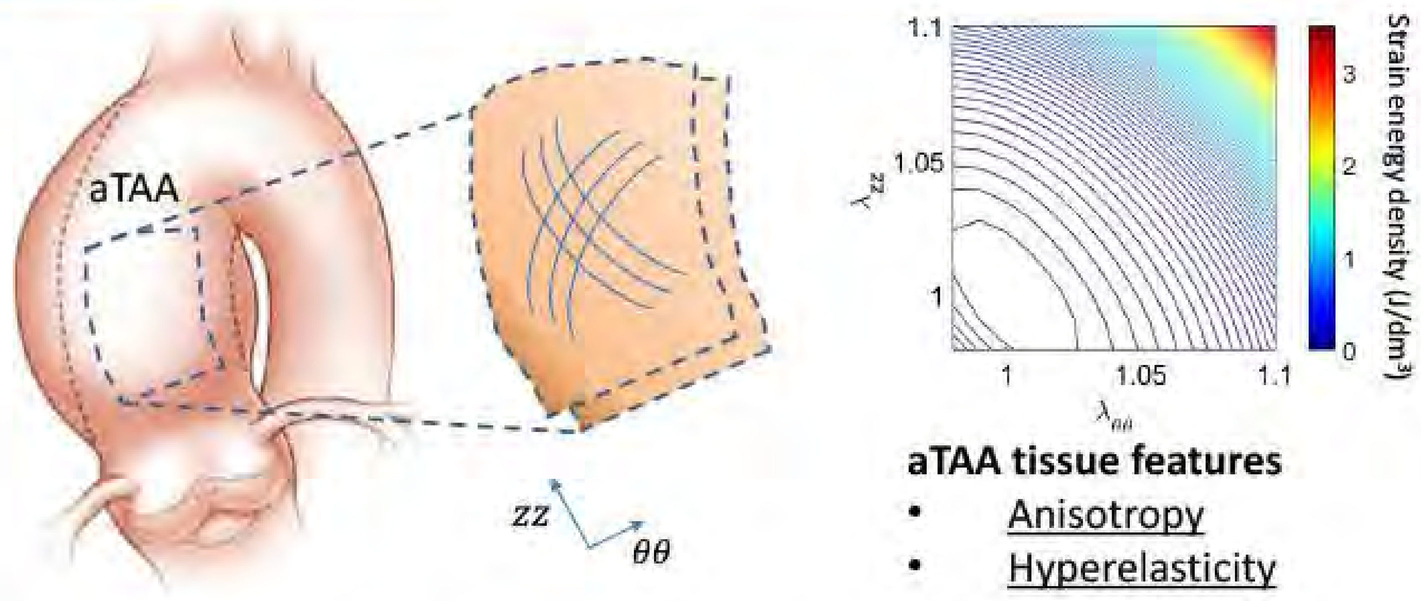
Introduction

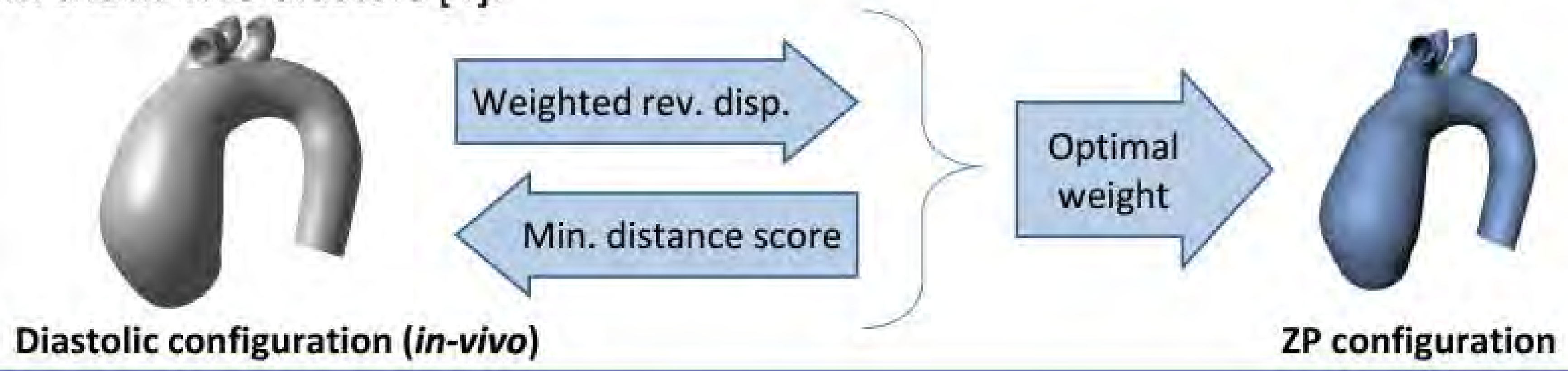
Different approaches are available to obtain numerical simulations of hemodynamics and biomechanics of pathologies like the ascending aortic thoracic aneurysms (aTAA) [1]. Within this landscape, the Fluid-Structure Interaction (FSI) emerges as a reliable tool. Isotropic linear elastic material approximation is usually included for the FSI analysis of the aorta [2]. However, the neglection of the anisotropic and hyperelastic nature of the material, due to the presence of collagen fibers within the microstructure, remains a strong assumption. A compromise between elastic linearization and hyperelasticity is given by the Small on Large (SOL) approach [3]. The simulation is split in a first large deformation step from the zero-pressure (ZP) to the diastolic phase, and a second step in which small deformations are assumed between diastole and systole.



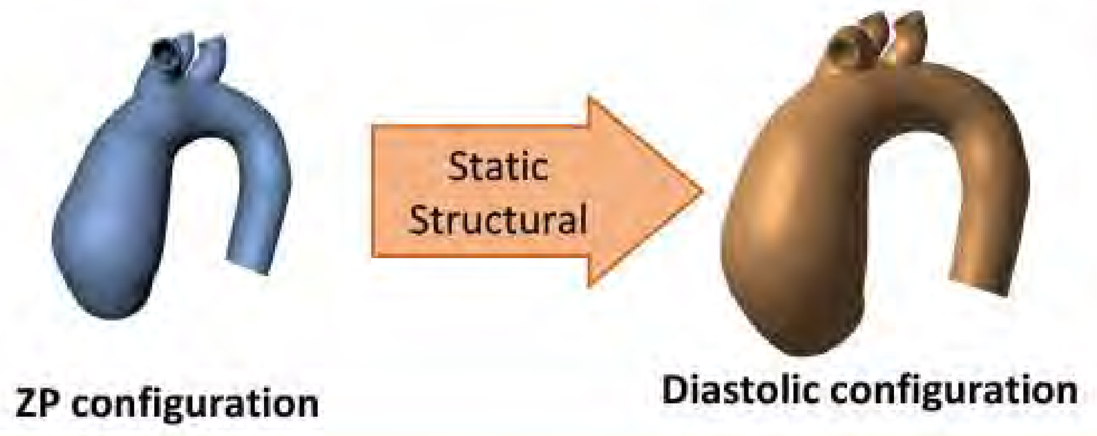
Aim of the study - This work aims to present a computational framework for the implementation of the Small On Large linearization approach for a patient-specific aTAA model. A two-way FSI simulation with heterogeneous material properties was performed in the ANSYS environment

Materials and Methods

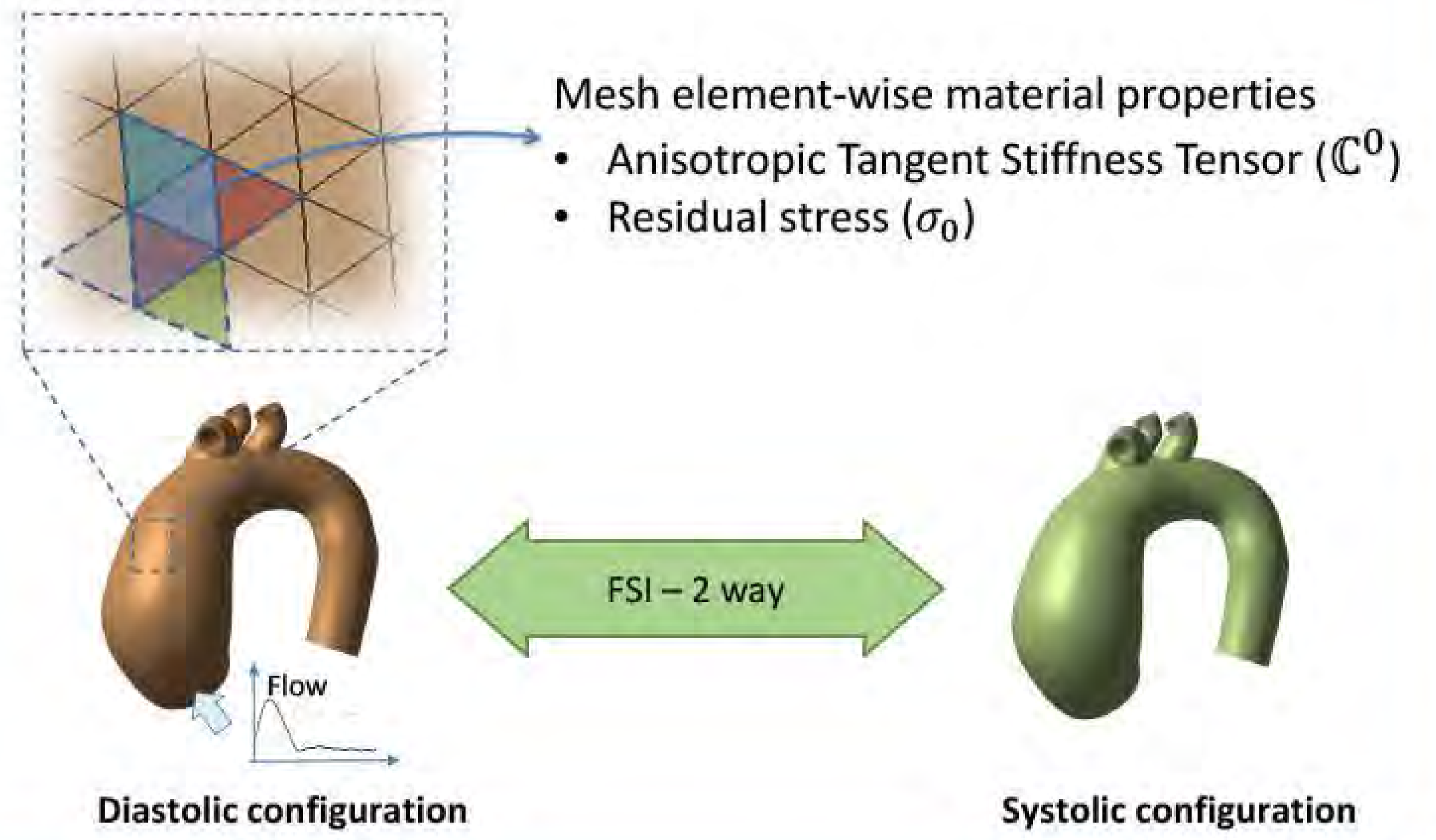
ZP geometry definition – A patient specific geometry of an aTAA case in the diastolic phase was reconstructed from CT data segmentation. An iterative reverse displacement algorithm was implemented for the evaluation of the ZP geometry from the *in-vivo* diastole [4].



Large Deformation (LD) step – Static structural simulation to obtain the deformed geometry with hyperelastic fiber-based model [5] through an 80 mmHg pressurization.



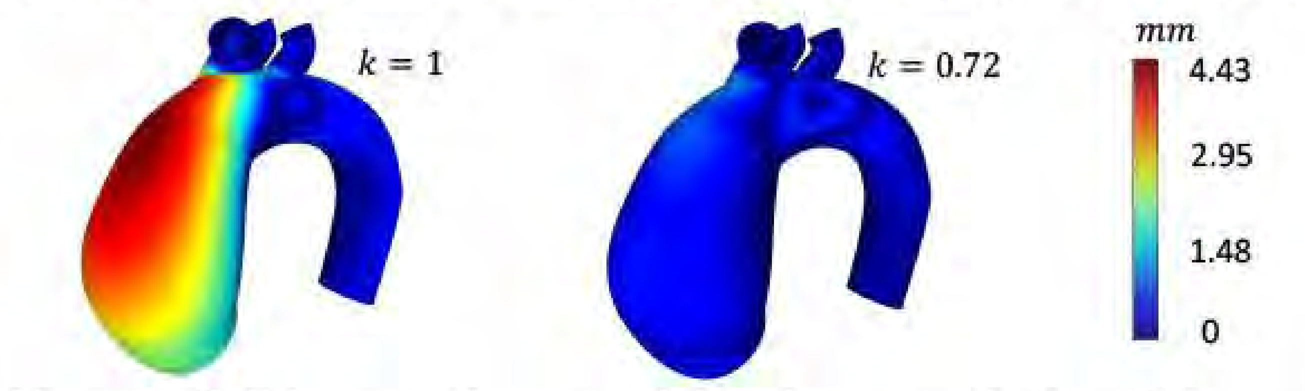
Small Deformation (SD) step – Linearized material properties from the previous LD simulation step, accounting for local anisotropy and residual stresses



Results and Discussion

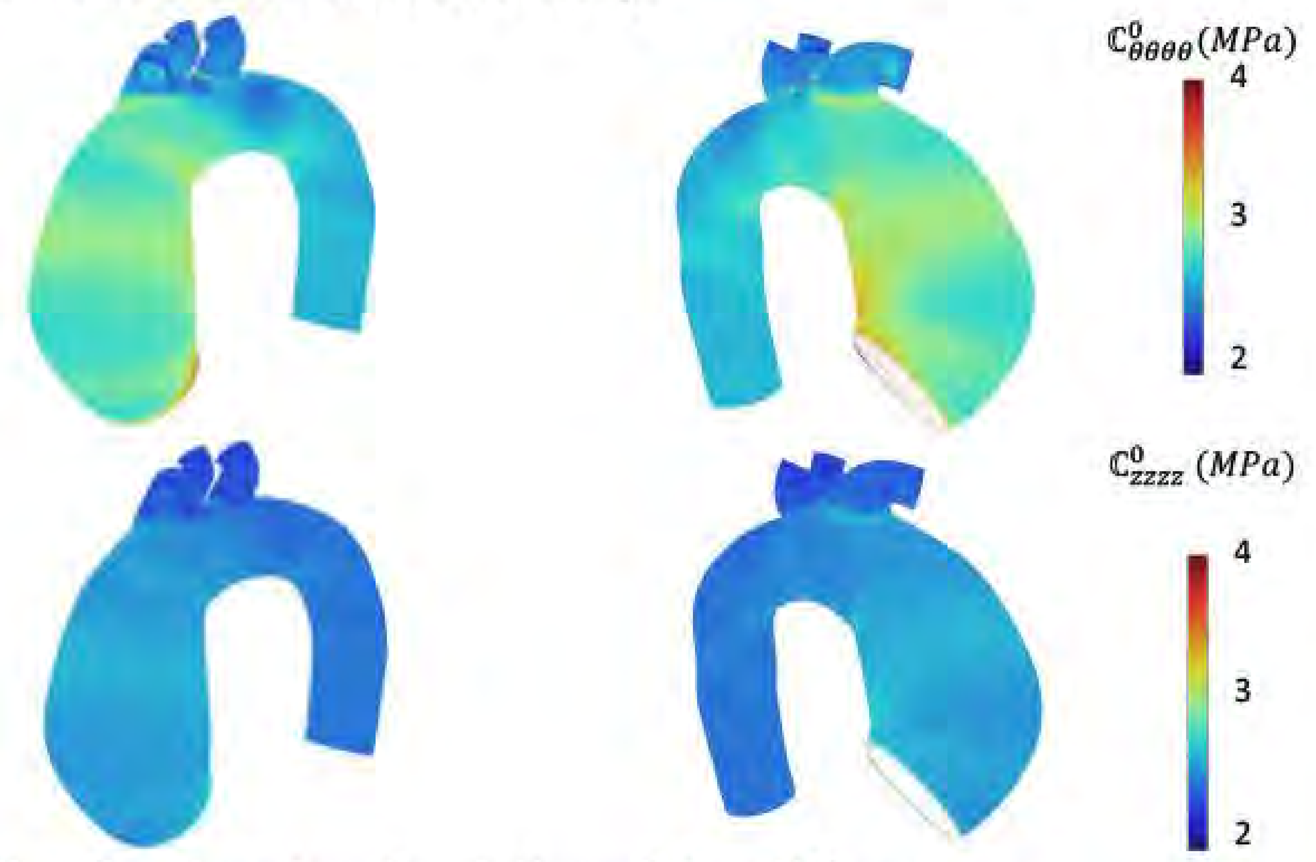
ZP geometry calculation

Distance from diastolic target geometry after pressurization



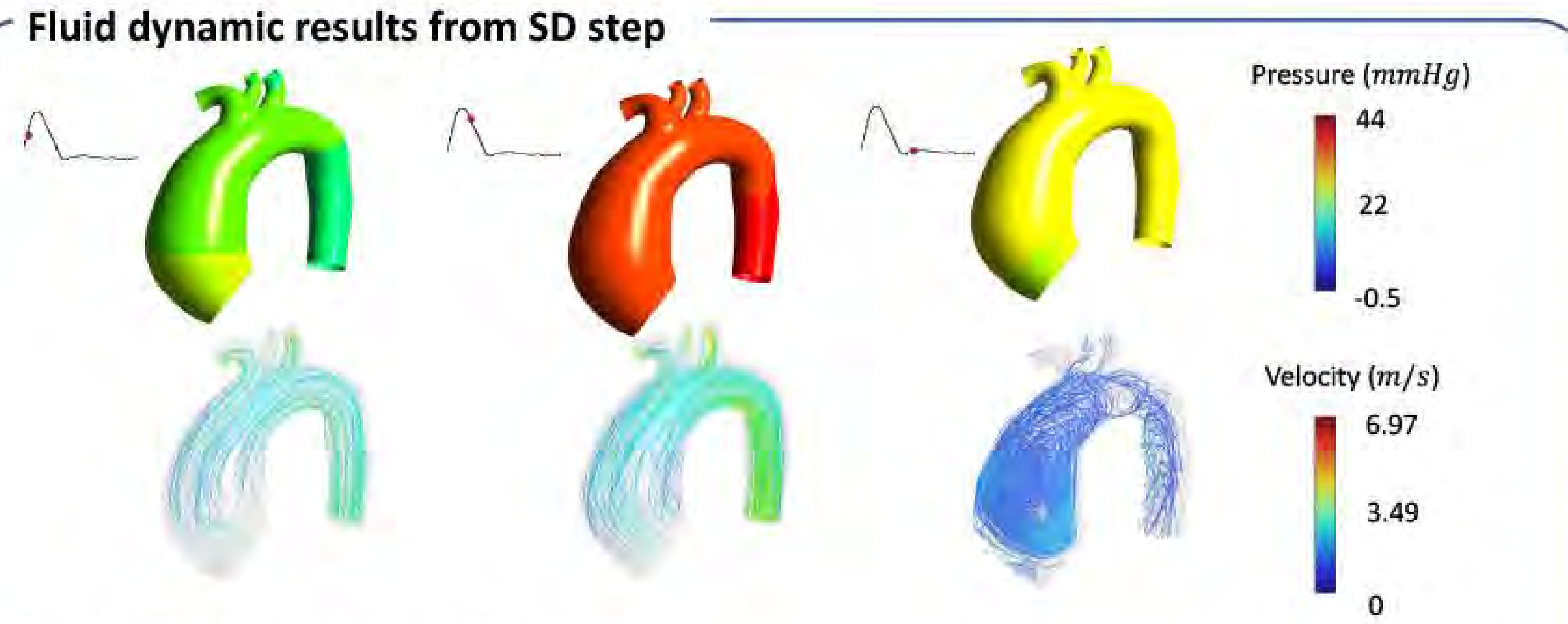
- Non-negligible error for unweighted approach ($k = 1$)
- Approximatively null error in the aTAA area for $k = 0.72$

Stiffness distribution from LD step

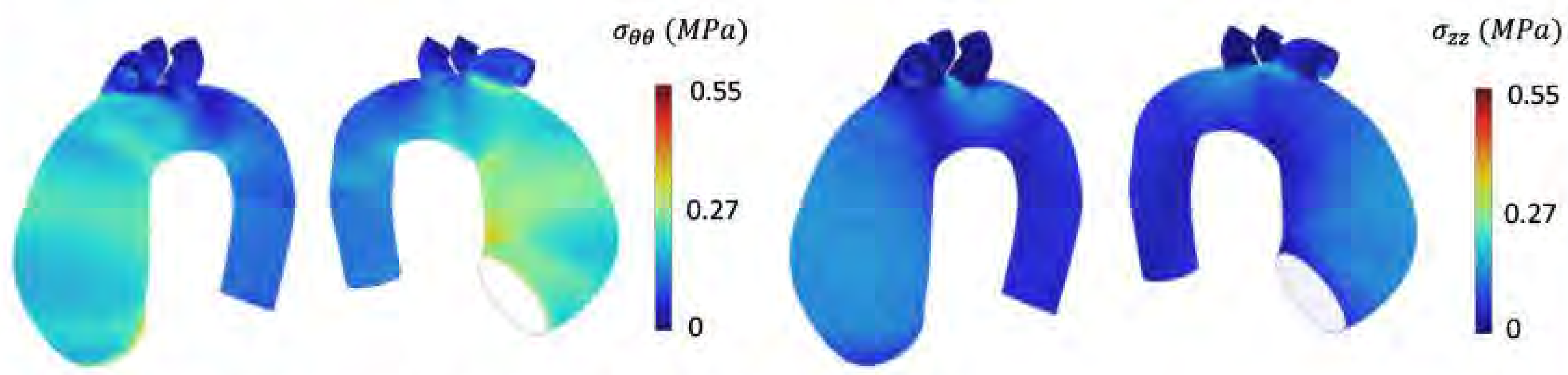


- Significant regional variation of the stiffness
- Stiffness along $\theta\theta$ direction more dispersed and higher
- Maximum values of $\mathbb{C}^0_{\theta\theta\theta\theta}$, in the inner curvature of the aTAA

Fluid dynamic results from SD step



Stress distribution from SD step



- Distribution following the trend of tangent stiffness
- Stiffening effect due to the complete alignment of the fibers

Computation time* for five cardiac cycles:

- ~24h **with SOL** linearization
- ~ 72h **without SOL** linearization

*Processor: Intel Core i7-6700, 4 cores, CPU@3.4 GHz. RAM: 16GB

Conclusion

A workflow for the computational analysis of a patient-specific aTAA case with SOL linearization to obtain a two-way FSI analysis with heterogeneous local stiffness is presented. The results revealed regional variations and anisotropy of tangent stiffness properties, with a significant stiffening in the inner aTAA section

[1] Capellini et al, Med eng phys, 2020.
[2] Lantz et al, Int J Appl Mech, 2011.
[3] Ramachandra et al, J Biomech,, 2019.
[4] Raghavan et al, Ann Biomed, 2006. biomaterialia, 2019.
[5] Niestrawska et al, Acta

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