PATIENT-SPECIFIC COMBINED FEA-FSI METHODOLOGY TO MODEL THE TEVAR PROCEDURE

Anna Ramella (1), Francesco Migliavacca (1), Jose Felix Rodriguez Matas (1),Tim J. Mandigers (2), Daniele Bissacco (2), Maurizio Domanin (2,3), Santi Trimarchi (2,3), Giulia Luraghi (1)

1. Politecnico di Milano, Milan, Italy; 2. Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy; 3. Università degli Studi di Milano, Milan, Italy.

Introduction

Thoracic Endovascular Aortic Repair (TEVAR) has been increasingly adopted to treat thoracic aorta pathologies since the first FDA stent-graft (SG) approval and it consists of placing a self-expandable SG into the pathological aortic region to recreate a more physiological condition [1]. Many SG-related complications are still to be investigated, and reliable computational models play a significant role in this context.

This study aims at reproducing the TEVAR procedure in a patient-specific aorta using the finite element (FE) analysis [2]. Then, a novel Fluid-Structure Interaction (FSI) simulation is set up to address the post-TEVAR hemodynamics and investigate the SG behavior during the cardiac cycle.

Materials and methods

The deployment of a commercial Valiant Captivia thoracic SG (Medtronic Inc.) in a patient-specific aortic model was simulated in Ls-Dyna (ANSYS) using a previously validated explicit FE method. The SG model was meshed in ANSA (BETA CAE System): the stent was discretized with beam elements and the graft with triangular membrane elements. Nitinol and PET material parameters were calibrated with experimental tests [2]. The aortic model was segmented from pre-operative clinical CTA images using the software VMTK (Orobix Srl) and discretized with three layers of tetrahedral elements. An isotropic hyperelastic material following the Yeoh constitutive formulation was assigned to the aortic wall with literature parameters [2] and the arterial wall prestress was included as well.

The stent deployed configuration resulting from the FE TEVAR simulation was compared with the stent segmented from post-operative CTA images as additional validation.

The FE simulation outcome was used as a starting point for the FSI modelling. In particular, a strongly coupled, two-way and boundary-fitted FSI simulation was carried out in Ls-Dyna (ANSYS). For the fluid domain, a physiological velocity waveform was imposed as inlet boundary condition (ascending aorta) and 3-elements Windkessel circuits were assigned to each outlet (three supra-aortic branches and descending aorta) to account for the downstream resistances [4]. The SG was modelled as an embedded body into the fluid mesh volume. For the structural domain, the SG and aorta meshes and stress/strain distributions at the end of deployment were imported from the FE simulation.

Results

In Fig.1(a), the CTA segmentation and the final stent-graft deployed configuration resulting from the FE simulation are depicted: a good agreement between the simulated and segmented stent reconstruction was obtained (difference below 11%).

Fig.1(b) shows the FSI simulation results in terms of blood systolic velocity streamlines and contact/no-contact map between the SG and aorta at the systolic peak. The latter was evaluated as a measure of the SG dynamic sealing: during systole, 94.6% of proximal stent elements are in contact with the aortic wall.

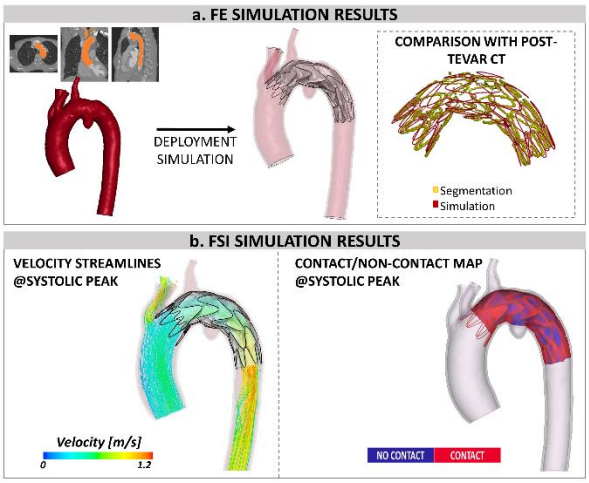

Fig. 1: (a) FE simulation results and comparison with post-TEVAR CT; (b) FSI simulation results: velocity streamlines and SG and aorta contact/no-contact map at systolic peak.

Discussion

The proposed study combines a previously validated high-fidelity FE methodology with a novel FSI approach that includes both the aorta and SG model and considers their interaction in the cardiac cycle. This FEA-FSI methodology can be applied to patient-specific cases and it can be useful for investigating TEVAR complications, designing new devices or supporting clinical decisions before intervention.

References

1. Daye et al, Cardio Diagn & Ther, 8:S138, 2018.
2. Ramella et al, Ann Biomed Eng, 50(12):1941-1953, 2022
3. Simsek et al, J Biol Phys, 41:173–20, 2022
4. Pirola et al, J Biomech, 60:15–21, 2017

Acknowledgements

This project has received funding from the MIUR FISRFISR2019_03221 CECOMES.