USE OF HIGH-FIDELITY PATIENT-SPECIFIC NUMERICAL SIMULATIONS TO PREDICT SHORT-TERM TEVAR OUTCOME

Anna Ramella (1), Francesco Migliavacca (1), Jose F Rodriguez Matas (1),Tim J Mandigers (2), Daniele Bissacco (2), Maurizio Domanin (2,3), Robin H Heijmen (4), Santi Trimarchi (2,3), Giulia Luraghi (1)

1. Politecnico di Milano, Italy; 2. Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy; 3. Università degli Studi di Milano, Italy; 4. Radboud Univeristy Medical Center, Nijmegen, Netherlands

Introduction

Thoracic Endovascular Aortic Repair (TEVAR) is a minimally invasive technique used to treat various thoracic aortic pathologies, such as aneurysms, ulcerations, or dissections. It has demonstrated superior patient outcomes in comparison to open surgical repair since the Food and Drug Administration (FDA) authorized the first stent-graft in 2005 [1].

In the literature, computational models are widely adopted to analyze the behavior of stent-grafts in the post-TEVAR scenario, as they can provide valuable insights into device performance and aid clinicians in their decision-making. This study aims to employ a validated finite element (FE) methodology to reproduce the TEVAR procedure with a commercial stent-graft on patient-specific aortic anatomies. The outcomes of the simulations are also compared with short-term (<3 months) postoperative CT data.

Methods

Based on a previously validated methodology from our laboratory [2], FE models of commercial Valiant Captivia stent-grafts (Medtronic Inc.) were generated. Experimental crimping tests were performed on the device to calibrate the shape memory Nitinol (stent) and fabric PET (graft) material parameters and to validate the device models. The stent was discretized with beam elements and the graft with triangular membrane elements. The TEVAR procedure was validated in idealized and patient-specific rigid aortas by comparing the FE simulation results with an ad-hoc experimental set-up (performed under CT). The same numerical methodology was then applied to reproduce the stent-graft implantation in four patient-specific aortic anatomies segmented from preoperative CT images [3]. The aorta is modelled as an isotropic hyperelastic material, and the wall prestress due to blood pressure is considered. The vessel was discretized in ANSA (BETA CAE System) with three layers of tetrahedral elements. Postoperative CT images were used to determine the appropriate device size and landing zone for each patient. As further validation to assess the quality of the simulation, a comparison of the simulation results with the stent segmented from short-term postoperative CT scan was performed.

The simulations were carried out using the explicit FE LS-Dyna solver (Ansys Inc.).

Results

Fig.1-a. shows the four aortic anatomies reconstructed from preoperative CT images using VMTK (Orobix Srl.). For each anatomy, the last instant of the patient-specific FE simulations (deployed configuration) and the comparison between the stent reconstructed from CT images and the simulated one are reported in Fig.1-b. and 1-c., respectively.

Globally, the opening area errors between the simulated and segmented stent configurations are below 10%, lower with respect to other literature studies in which errors reached 30% [4].

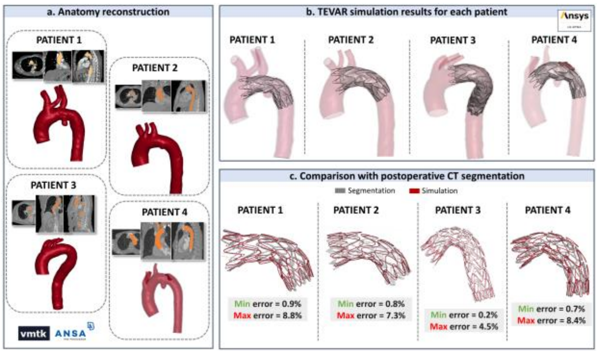

Figure 1: (a.) aortic anatomies segmented from preoperative CT images; (b.) TEVAR simulation outcomes for each anatomy; (c.) Overlap of the simulation results (red) with stent segmented from postoperative CT (grey). Max and min errors in opening areas of each stent strut are reported.

Discussion

The proposed methodology follows the V&V40 guidelines to develop high-fidelity stent-graft models and TEVAR simulations: after proper material calibration and simulation validation, the applicability of the model for patient-specific simulations is proved [3]. The comparison of the simulation results with the stent reconstructed from postoperative CT images reveals that the numerical model can predict the short-term outcome of the TEVAR procedure with good accuracy, given the uncertainties of the biological and clinical data. This suggests that the numerical model can be employed during the preprocedural planning phase as it can help in understanding the outcomes of the procedure in a realistic scenario before the actual clinical intervention.

References

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Acknowledgements

This project has received funding from the MIUR FISRFISR2019_03221 CECOMES.