World Academy of Science, Engineering and Technology
International Journal of Biomedical and Biological Engineering
Vol:16, No:10, 2022

Optimization of Perfusion Distribution in Custom Vascular Stent-Grafts Through Patient-Specific CFD Models

Authors : Scott M. Black, Craig Maclean, Pauline Hall Barrientos, Konstantinos Ritos, Asimina Kazakidi

Abstract : Aortic aneurysms and dissections are leading causes of death in cardiovascular disease. Both inevitably lead to hemodynamic instability without surgical intervention in the form of vascular stent-graft deployment. An accurate description of the aortic geometry and blood flow in patient-specific cases is vital for treatment planning and long-term success of such grafts, as they must generate physiological branch perfusion and in-stent hemodynamics. The aim of this study was to create patient-specific computational fluid dynamics (CFD) models through a multi-modality, multi-dimensional approach with boundary condition optimization to predict branch flow rates and in-stent hemodynamics in custom stent-graft configurations. Three-dimensional (3D) thoracoabdominal aortae were reconstructed from four-dimensional flow-magnetic resonance imaging (4D Flow-MRI) and computed tomography (CT) medical images. The former employed a novel approach to generate and enhance vessel lumen contrast via through-plane velocity at discrete, user defined cardiac time steps post-hoc. To produce patient-specific boundary conditions (BCs), the aortic geometry was reduced to a one-dimensional (1D) model. Thereafter, a zero-dimensional (0D) 3-Element Windkessel model (3EWM) was coupled to each terminal branch to represent the distal vasculature. In this coupled 0D-1D model, the 3EWM parameters were optimized to yield branch flow waveforms which are representative of the 4D Flow-MRI-derived in-vivo data. Thereafter, a 0D-3D CFD model was created, utilizing the optimized 3EWM BCs and a 4D Flow-MRI-obtained inlet velocity profile. A sensitivity analysis on the effects of stent-graft configuration and BC parameters was then undertaken using multiple stent-graft configurations and a range of distal vasculature conditions. 4D Flow-MRI granted unparalleled visualization of blood flow throughout the cardiac cycle in both the pre- and postsurgical states. Segmentation and reconstruction of healthy and stented regions from retrospective 4D Flow-MRI images also generated 3D models with geometries which were successfully validated against their CT-derived counterparts. 0D-1D coupling efficiently captured branch flow and pressure waveforms, while 0D-3D models also enabled 3D flow visualization and quantification of clinically relevant hemodynamic parameters for in-stent thrombosis and graft limb occlusion. It was apparent that changes in 3EWM BC parameters had a pronounced effect on perfusion distribution and near-wall hemodynamics. Results show that the 3EWM parameters could be iteratively changed to simulate a range of graft limb diameters and distal vasculature conditions for a given stent-graft to determine the optimal configuration prior to surgery. To conclude, this study outlined a methodology to aid in the prediction post-surgical branch perfusion and in-stent hemodynamics in patient specific cases for the implementation of custom stent-grafts.

Keywords : 4D flow-MRI, computational fluid dynamics, vascular stent-grafts, windkessel
Conference Title : ICBBM 2022 : International Conference on Biomechatronics and Biofluid Mechanics
Conference Location : Los Angeles, United States
Conference Dates : October 27-28, 2022