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BIOPROSTHETIC VALVE MECHANICS AND THE ONSET OF TURBULENT SYSTOLIC BLOOD FLOW

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Aortic stenosis is one of the most common valvular heart diseases. In severe cases, the native valve must be replaced by an aortic valve prosthesis which may be either made of technical materials (mechanical valves) or of biological tissue (bioprosthetic valves). Although bioprosthetic valves offer better hemodynamics than mechanical valves, they are nevertheless known to lead to turbulent systolic blood flow which has been connected to blood trauma, leaflet fluttering and adverse events in the ascending aorta due to unphysiological stimulation of the endothelium. Therefore, it is desirable to reduce or even eliminate the production of turbulent systolic flow past bioprosthetic valves.

In this study, we aim at developing a better understanding of the mechanisms leading to turbulent flow past bioprosthetic valves which is a prerequisite for developing strategies to reduce turbulence. To this end, we have devised a computational model for fluid-structure interaction (FSI) in cardiovascular configurations (Nestola et al., 2018). The model comprises a finite-element solver for the full elastodynamics equations of the structure (aortic root, ascending aorta, bioprosthetic valve) and a high-order finite-difference solver for the Navier–Stokes equations for the direct numerical simulation of laminar and turbulent blood flow. The flow solver and the structural solver are coupled with the immersed boundary method where the fluid velocities and the mechanical responses of the structure are transferred between a Cartesian fluid grid and an unstructured finite element mesh by a variational approach.

We will present numerical results that were obtained with this FSI solver. We will discuss and quantify several mechanisms leading to turbulent flow, such as FSI instabilities between the soft leaflet tissue and blood flow resulting in leaflet fluttering, hydrodynamic instabilities of the systolic jet issuing from the valve orifice, and the interaction between the turbulent systolic jet and the confining wall of the ascending aorta. We will relate these mechanisms to the morphology of the bioprosthetic valve and the aortic root, and to the mechanical properties of the valve leaflets.

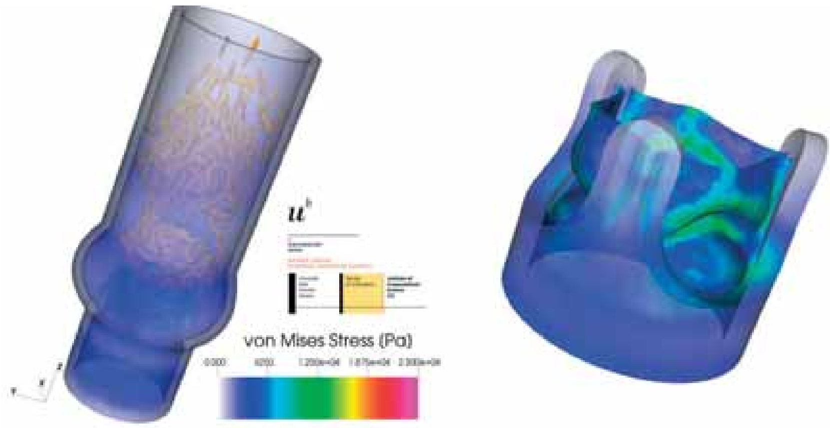

Figure Caption: Visualization of vortical flow structures in systolic flow (left) through a bioprosthetic heart valve exhibiting leaflet fluttering (right). (Colors on the structure indicate von Mises stress levels)

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References: Nestola, M. G. C., Becsek, B., Zolfaghari, H., Zulian, P., De Marinis, D., Krause, R., & Obrist, D. (2018). An immersed boundary method for fluid-structure interaction based on overlapping domain decomposition. arXiv preprint arXiv:1810.13046.