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FLUID DYNAMICS AND BLOOD DAMAGE IN ARTIFICIAL HEART VALVES: BIOLOGICAL VS. MECHANICAL AORTIC PROSTHESES

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Thanks to considerable improvements in prosthetic heart valve design and surgical procedures achieved in the last decade, about 280000 artificial valves are now implanted worldwide [1]. Approximately half are mechanical valves and half are bio-prosthetic valves. The bi-leaflet valve is the most popular mechanical design: the valve is made of two semilunar rigid disks attached to a rigid valve ring by small hinges. Biological (or tissue) valves are composed of three deformable leaflets that open closely resembling the native tri-leaflet aortic valve.

Mechanical valves are long lasting and have relatively superior haemodynamics with very low aerodynamic resistance. However, their non-physiological flow patterns are responsible for high shearing of blood cells and platelets, requiring a life-long anticoagulation therapy. On the other hand, biological valves do not require anticoagulants due to their similarity to the native valve geometry and haemodynamics, but have a reduced life (about 10-15 years).

In this work, a numerical approach is presented, that combines a finite-difference flow solver with a finite-element structural solver in order to accurately investigate the flowfield in such configurations. A suitable version of the immersed boundary technique [2] is employed for handling rigid and deformable geometries, while direct numerical simulation is utilized to solve the complex fluid-structure-interaction problem and obtain detailed information of the flow patterns, considering realistic geometries for the valves and the initial tract of ascending aorta.

During the forward phase, a three-jet configuration is distinctive of bi-leaflet mechanical valves, with high turbulent shear stresses immediately distal to the valve leaflets, while a jet-like flow emerges from the central orifice of bio-prosthetic valves, with high turbulent shear stresses occurring at the edge of the jet (Figure 1).

In order to evaluate hemolysis, a large number of Lagrangian tracer particles are released at the inlet of the computational domain (upstream of the valve), and blood damage is evaluated along each trajectory using classical stress-based models [3], based on the action of instantaneous shear stress on the blood cells, and a strain-based model [4], that accounts for the finite response time of cell deformation and relaxation. Higher level of blood damage is observed in the case of mechanical valve. Moreover, turbulent stress level maps at different instants during the cardiac cycle show higher values in the mechanical valve case, indicating that the prosthesis is more likely to induce thromboembolic complications.

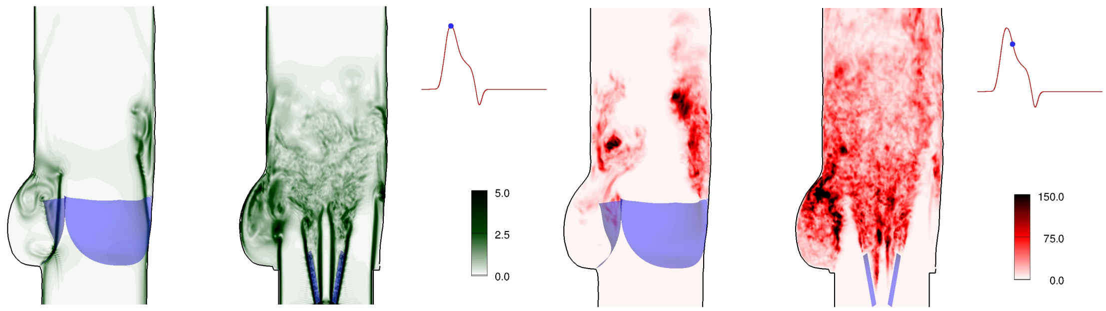

Figure 1: *Contours of the phase-averaged equivalent viscous stress at flowrate peak (left), and maximum turbulence shear stress during deceleration phase (right) for both models (in N/m^2).*

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