POLITECNICO DI MILANO

CFD characterization and thrombogenicity analysis of a prototypal polymeric aortic valve

Filippo Piatti[1], Matteo Selmi[1], Alessandra Pelosi[1], Thomas E. Claiborne[2], Danny Bluestein[2], Alberto Redaelli[1]

[1]Dept. of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy
[2]Dept. of Biomedical Engineering, Stony Brook University, New York, USA

Introduction

The recent growth of cardiovascular diseases, primarily due to heart valve failures such as stenosis and regurgitation, led to an increasing need of valve replacement procedures.

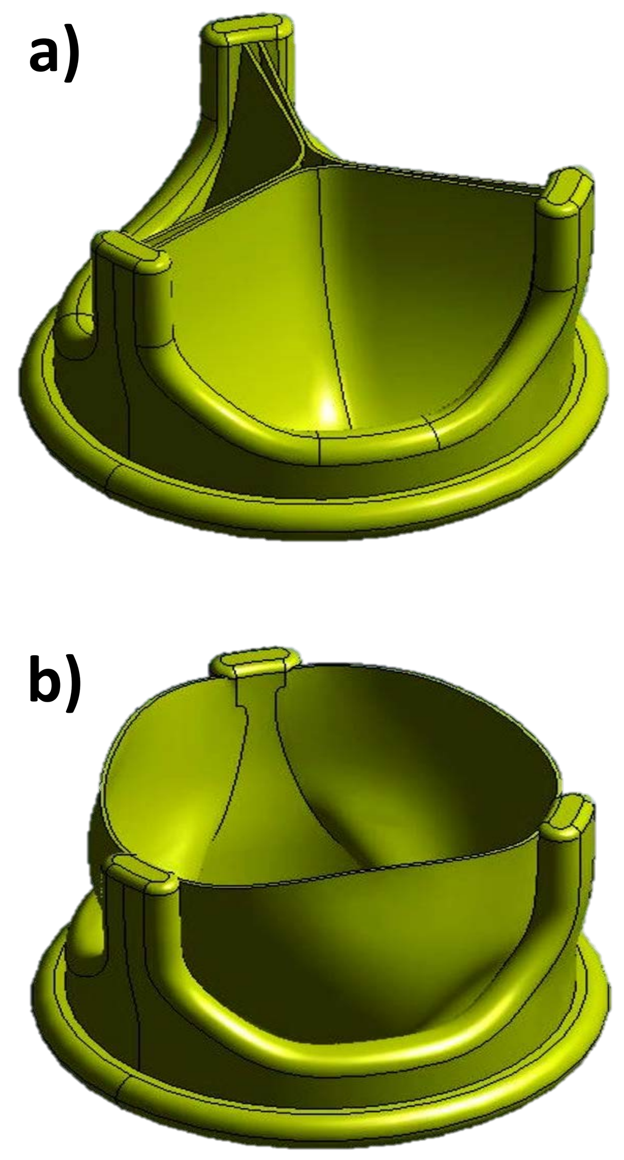

Figure 1 – CAD images of the closed (top) and open (bottom) configurations of the optimized polymeric valve.

Polymeric prosthetic valves seem to gain advantages over both tissue and mechanical valves, as they combine excellent fluid dynamic features with long lasting performance [1]. Moreover, they can be grafted via minimally invasive transcatheter aortic valve implantation (TAVI), reducing related surgical risks and complications.

Besides, heart valve optimization requires specific analysis regarding the effects of blood contact. In particular, shear-induced platelet activation can be investigated in order to estimate thrombongenicity [2, 3].

This work presents a CFD approach for characterizing the fluidynamics of a novel hemodynamically and functionally optimized polymeric prosthesis for aortic valve replacement and to evaluate its thrombogenic potential.

Materials and Methods

Geometry

Starting from the closed valve CAD model (Fig. 1a), a FEM simulation was performed, on **SIMULIA© Abaqus 6.10**, with a symmetrical boundary condition and an homogeneous loading reproducing systolic transvalvular pressure. The systolic valve configuration was therefore obtained (Fig. 1b).

The fluid domain (Fig. 2) was reconstructed on **ANSYS© 13.0 Workbench Platform**, in order to reproduce the Valsalva Sinuses and the aortic arch with its three upper branches.

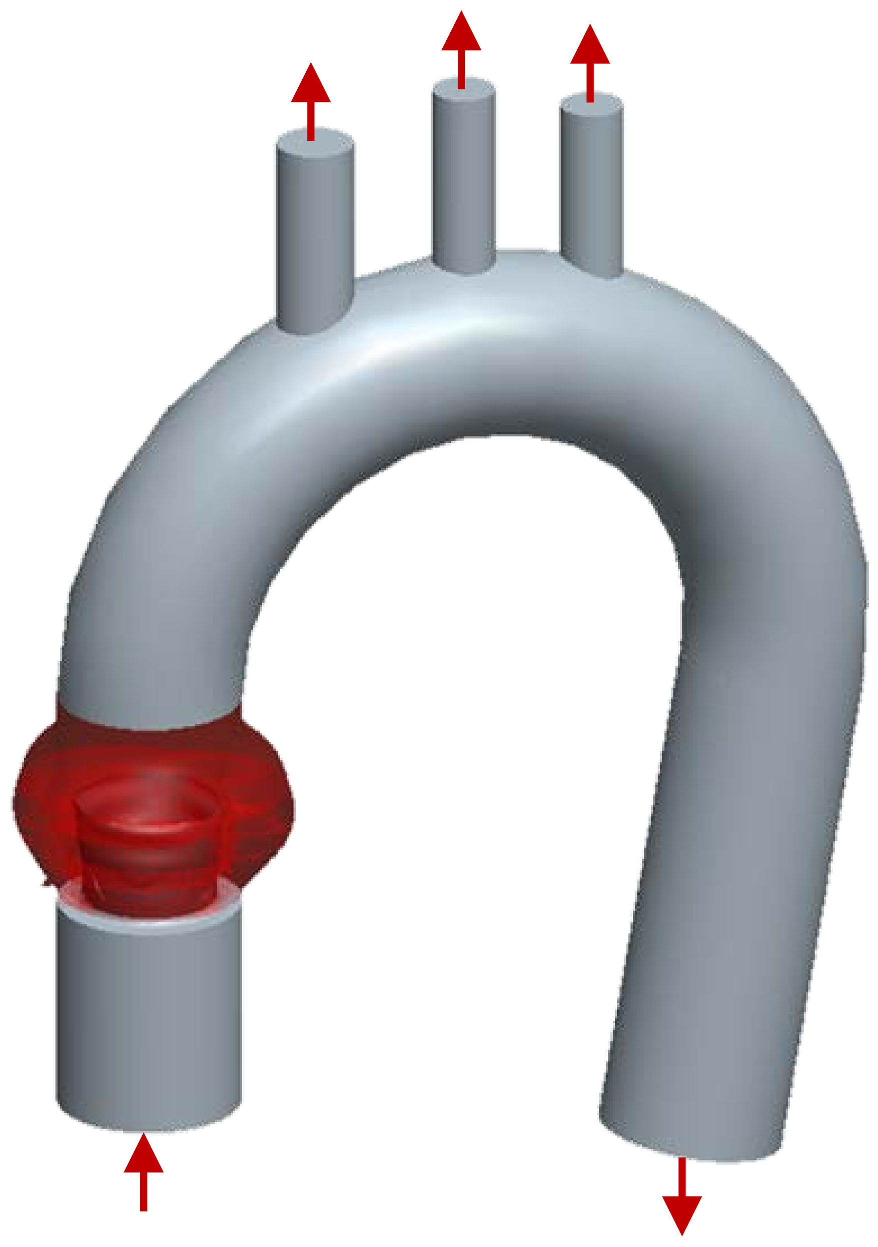

Figure 2 – CAD 3D geometry of the flow domain within the aortic arch. The red zone represents the Valsalva Sinuses where the prosthetic valve is placed.

CFD computational setup

Transient CFD simulations were run on **ANSYS Fluent v13.0**.

A systolic ejection waveform was applied to the inlet section and outflow boundary conditions (constant flow rates) were imposed to the four outlets. A k-ω turbolence model with low Reynolds corrections was adopted and blood was characterized with density equal to 1060 kg*m^{-3} and viscosity equal to 3 cP.

Particle tracking

Neutrally buoyant spherical particles (Φ = 3 μm), representing platelets, were injected into the fluid domain from the inlet surface through a two-phase, **Discrete Phase Modeling** approach.

Particles loading history was computed over 300 ms (time step 0.1 ms) and, via a statistical analysis, the Stress Accumulation (SA) distribution was extrapolated.

Results and Discussion

The maximum velocity value, located downstream of the valve housing, was equal to 1.58 m/s, while blood stagnation phenomena were detected within the Valsalva Sinuses. The peak transvalvular pressure drop was equal to 2.41 mmHg. Velocity magnitude contours are shown in Fig. 3, at the ejection peak (T = 150 ms).

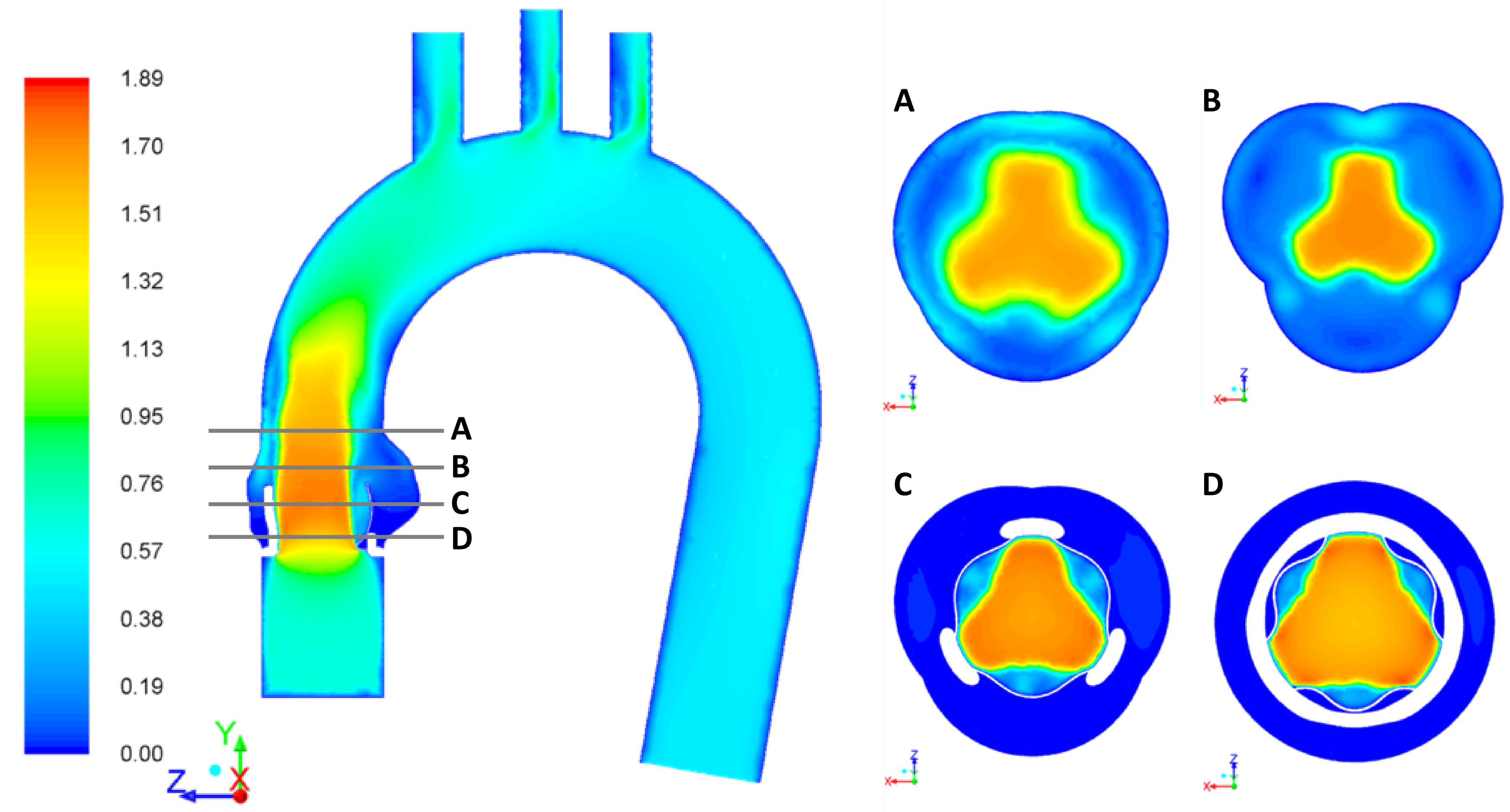

Figure 3 – Contours of Velocity Magnitude [m/s] in the aortic arch and in four different locations within the Valsalva Sinuses.

The valve prototype did not induce significant alterations into the aortic fluid dynamic thanks to its morphological similarity with the anatomy of the aortic valve. Pressure drop and maximum velocities were comparable with those reported for other bioprosthetic valves [1].

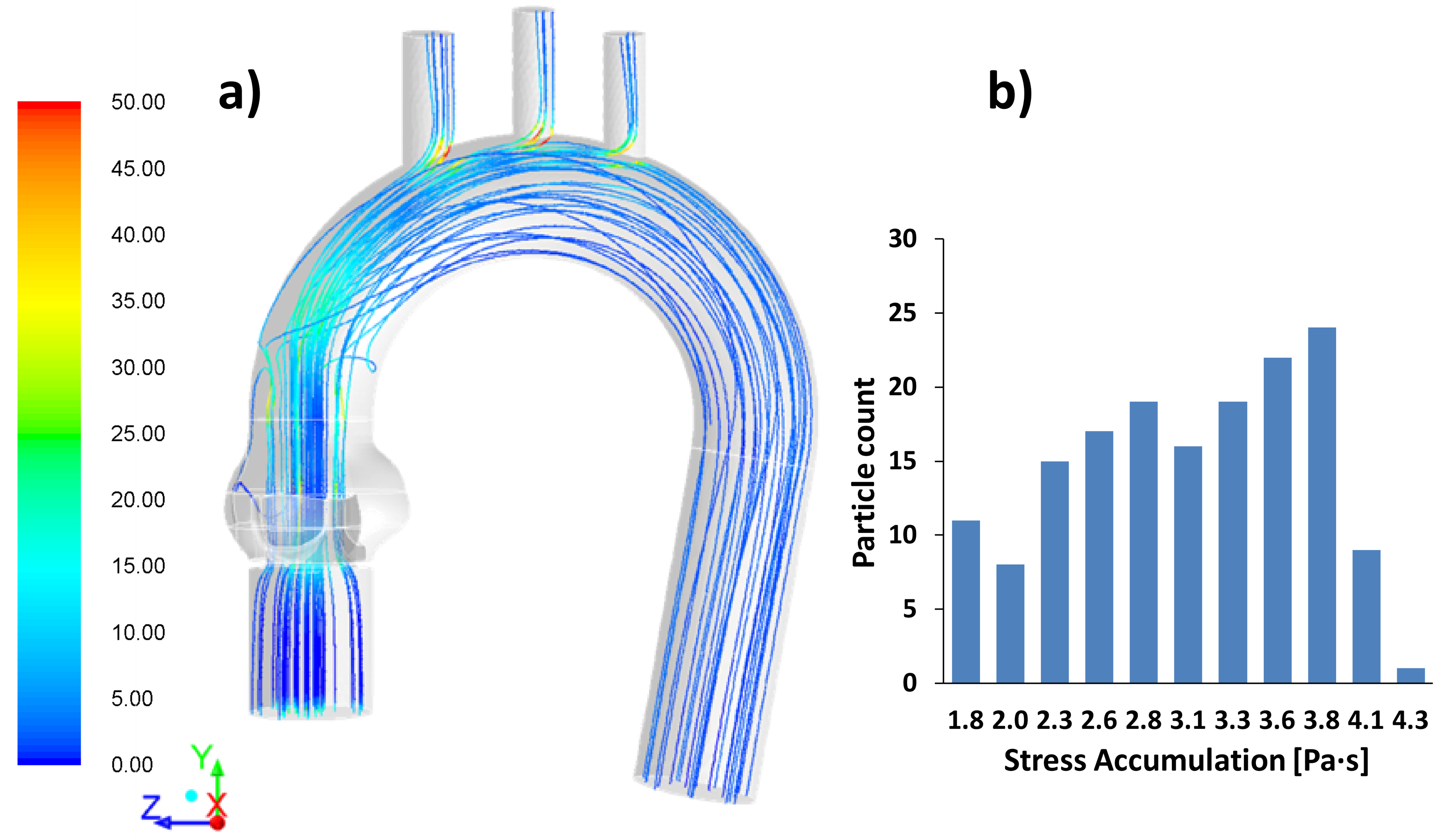

Figure 4 – (**a**) Particle trajectories coloured by Scalar Stress [Pa]; (**b**) Frequency distribution of the Stress Accumulation [Pa·s] in the model.

Particle trajectories (Fig. 4a) were analyzed in order to quantify the level of platelet activation due to shear stress. Scalar stress and particle residence time were combined to calculate SA. The statistical distribution of SA (Fig. 4b) allowed to identify particle trajectories with a high thrombogenic risk.

Conclusions

The present study combined FEM and CFD simulations to evaluate the hemodynamic and thrombogenic performances of a novel hemodynamically and functionally optimized polymeric trileaflet valve.

Acknowledgements

The research leading to these results has received fundings from the Cariplo Foundation Project, Grant Agreement N° 2011-2241.

References

1. T. E. Claiborne et al. (2012) *Expert Review of Medical Devices*
2. D. Bluestein et al. (2010) *Annals of Biomedical Engineering*
3. A. Pelosi et al. (2012) *Biomechanics and Modeling in Mechanobiology*

alessandra.pelosi@polimi.it