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SCALE-UP OF BILEAFLET MECHANICAL HEART VALVE FOR ENHANCED RESOLUTION OF THE USTEADY FLOW FIELD

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INTRODUCTION

The design of effective mechanical heart valves (MHVs) represents a major challenge for biomedical engineering, because it requires thorough comprehension of a complex fluid-mechanical problem and because of its potential impact on life expectancy and quality for patients. The intrinsic complexity of the 3D unsteady turbulent flow involved couples with the need to investigate its effects on the small scales of blood cells, in order to assess how the mechanical load can damage them, leading to thrombosis and haemolysis. However, these small scales are beyond the capability of current measurement techniques.

To resolve the smallest scales of the unsteady turbulent field, a novel scaled up model of a mechanical heart valve was developed and investigated by Particle Image Velocimetry. The measured velocity and derived quantities are presented and discussed in this paper.

MATERIALS AND METHODS

The experimental model is a 5.8:1 scaled-up mechanical heart valve, whose design is based on the 27 mm St. Jude Medical HP bileaflet valve. The model is made from PMMA (Perspex™) and water is used as fluid. The ascending aorta is modelled as a straight tube, in which the model valve is housed. Experimental similarity with physiological-scale valve is preserved by keeping the same values of relevant parameters, namely Reynolds number, Strouhal number and dimensionless mass moment of inertia. A computer-controlled piston pump provided either steady or pulsatile flow conditions.

The flow field is characterised by using Particle Image Velocimetry, which benefits from the scaling of the model to achieve time and space resolutions of 1.75 kHz and 120 μm respectively (in equivalent physiological scale). Temporal resolution is 118 times the standard PIV sampling frequency and the spatial resolution is unprecedented for studies on MHVs [1].

RESULTS

Measurements were collected in steady and unsteady flow conditions. The former was achieved by keeping the Reynolds number constant at the peak systole value, Re=6000. The latter condition is based on a realistic aortic flow waveform, reproduced by means of the piston pump. In both cases the leaflets were fixed in the fully open position.

The evolution of the transient flow field was characterized from early acceleration to peak systole and then the deceleration phase. Figure 1 reports the velocity field measured at peak systole. Along with the instantaneous velocity field, the vorticity field and the distribution of viscous stress were also evaluated. It was observed that the flow develops a regular pattern of eddies shed during the acceleration phase. The progressive growth of turbulence is also demonstrated by the analysis of the viscous stress distribution, which shows during the acceleration phase a gradual shift from few large structures to a finer and more irregular organization. After peak systole the observed patterns appear even less regular, although progressively weaker.

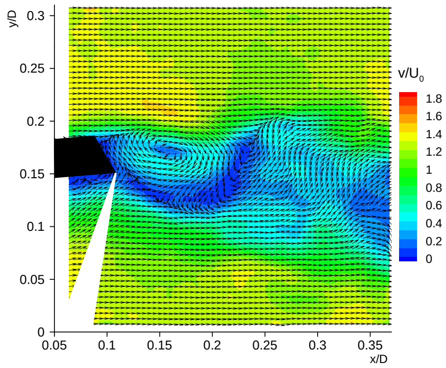

Figure 1. Instantaneous velocity vectors and colour map of velocity magnitude at systole peak.

DISCUSSION

The investigation of a scaled-up model allowed for space and time resolution unprecedented for PIV measurements of flow through MHVs. The turbulent flow field was characterized, revealing the development of shear stress up to 10 N/m^2, potentially damaging for platelets. Turbulent structures were observed down to the current resolution limit. Future improvement of this experimental limit is expected to provide better insight on mechanical load at cellular scale.

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REFERENCES

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