Blood Flow through a Dysfunctional Mechanical Heart Valve

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***Abstract*— Heart valves act as fluidic control structures. In severe cases of valve malfunction, a replacement with artificial bioprosthetic or mechanical valves is often necessary. Comparison of velocity and vorticity profiles for different leaflet angles of a commercial bileaflet mechanical heart valve that represent valve dysfunctions was performed using computational fluid dynamics. The results show variations in velocity and pressure gradients through the heart valve with valve dysfunction. These changes would affect blood flow through the valve and in the vicinity of the mechanical leaflets during valve motion.**

I. Methods: Modeling And CFD Analysis

A 3D bileaflet mechanical heart valve (Fig.1a) with a geometry similar to the commercial 25-mm St. Jude heart valve [1] (Fig.1b) was created in SolidWorks and imported to STAR-CCM+ for CFD analyses.

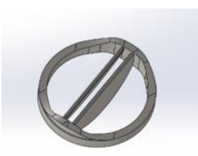

Figure 1a.

Figure 1b.

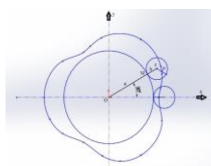

Figure 1c.

Figure 1. (a) Modeled Heart Valve (b) St. Jude Medical Valve (c) Cross-Section of Three-Leaflet Aortic Root Sinuses

Cross-section of a three-leaflet aortic root sinuses was represented as an epitrochoid, Fig. 1c. Tracing a point (distance of λ from the center of small circle) inside a small rotating circle (of radius b) rolling on the perimeter of a bigger circle (distance of a for center to center with an angle of α) results in a shape called epitrochoid [2]:

$$x = (a+b)\cos\alpha - \lambda b\cos((a+b)/b\alpha) \quad (1)$$

$$y = (a+b)\sin\alpha - \lambda b\sin((a+b)/b\alpha) \quad (2)$$

Flow domain was divided into four main parts the flow direction (Fig.2): upstream (1), bileaflet mechanical heart valve (2), aortic root sinuses (3) and downstream (4).

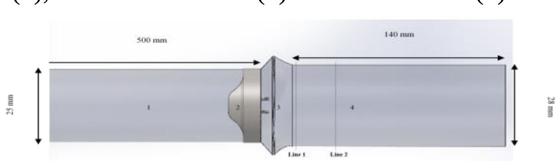

Figure 2. Flow Domain: upstream (1), bileaflet mechanical heart valve (2), aortic root sinuses (3) and downstream (4).

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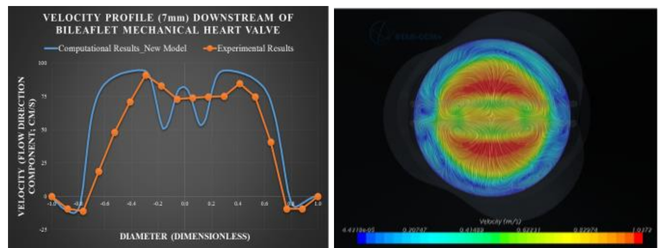
II. Results

In this in vitro analysis the following conditions were imposed: ambient outlet pressure, inlet mass flow rate of 18 l/min., laminar, incompressible, and Newtonian flow with a density of 1050 kg/m3 and viscosity of 0.0035 kg/m.s, which matches human blood properties at 37C.

Results showed a maximum velocity magnitudes of 1.43 m/s, 1.62 m/s and 2.09 m/s for 0% dysfunction, 50% dysfunction and 100% dysfunction, respectively.



(a) **(b)**

Figure 3. Steady-State Blood Flow (Validation and Velocity Profiles)

The flow upstream and downstream of a dysfunctional mechanical heart valve was highly influenced by the dysfunction severity. In 50% dysfunction of one leaflet, the relatively high shear stress areas covered most of the domain downstream of the valve; i.e.; the dysfunctionality can lead to potentially higher level of platelet activation and larger vortices downstream of the bileaflet mechanical heart valve.

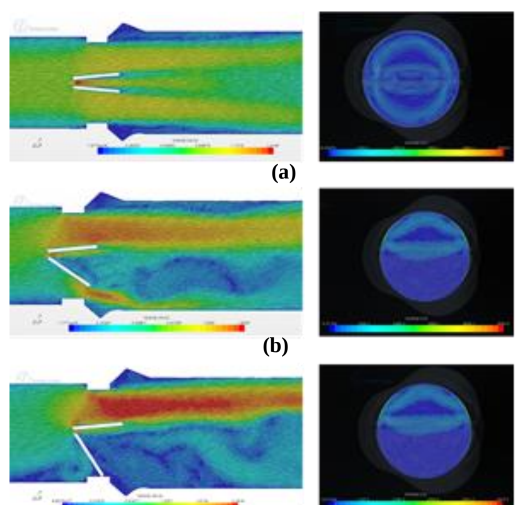


Figure 4. (a) 0% Dysfunctional Leaflet (b) 50% Dysfunctional Leaflet (c) 100% Dysfunctional Leaflet

References

[1] "Structural Heart Products," St. Jude Medical, [Online]. Available: http://professional.sjm.com/products/sh/mechanical-valves/aortic-mitral

[2] H. Ruel, A. Vahlbruch, M. Giersiepen, T. Schmitz-Rode, V. Hirtz and S. Effert, "The Geometry of the Aortic Root in Health, at Valve Disease and after Valve Replacement," J. Biomechanics, vol. 23, no. 2, pp. 181-191, 1990.