EXPERIMENTAL AND NUMERICAL INVESTIGATIONS ON A DEFECTIVE PROSTHETIC HEART VALVE

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INTRODUCTION

Valve stenosis or incompetence at severe levels reduce the performance of the heart and place additional stress and strain upon it. In many cases, surgical replacement of the diseased valve with a bioprosthetic or mechanical heart valve is necessary to restore normal heart function. Due to a longer lifespan, 55% to 65% of valve replacements worldwide are mechanical valves. One of potential complication associated with mechanical heart valves is valve dysfunction (usually an incomplete opening of one or both leaflets in bileaflet mechanical heart valves (BMHV)); the predominance of such problem is 0.2%-6% patients/year [1] which could be due to pannus (prevalence 0.14-0.65% patients/year [2] and/or thrombosis formation. Non-invasive diagnosis and evaluation of the severity of BMHV dysfunction using Doppler echocardiography is not straight forward, usually due to theoretical, technical or accessibility limitations. Therefore, the flow through a dysfunctional BMHV will be invistegated to better understand its impact on blood components and to improve the current diagnosis techniques.

METHODS

Wilcox's low-Reynolds turbulent model was selected to simulate five 2-D models. Only the lower leaflet of the BMHV was moved from fully opened position to fully closed position. In order to calculate the level of platelet activation ($\sum \tau * \Delta t$) (summation of shear stress magnitude multiplied by the exposure time) across different paths, we used the Lagrangian approach of particulate two phase flow. The calculations were carried out during the deceleration phase (100 ms- 150 ms after the peak) wherein the platelet is significantly aggregated [3].

In order to validate and compare some of the results obtained using the numerical study, in-vitro Doppler echocardiographic measurements were performed. Maximal echo-Doppler velocity, mean and maximal echo-Doppler transvalvular pressure gradients, (TPGmean and TPGmax, respectively), were evaluated for the BMHV with 0%, 50% and 100% malfunctions. These results were compared to the ones obtained through the numerical study.

RESULTS AND DISCUSSION

Platelet trajectories for different percentages of malfunctions, during the deceleration phase, are shown in figure 1. Platelet paths changed significantly with increasing the percentage of BMHV malfunction. With the presence of leaflet malfunction the flow became more vortical which, in turn, could increase platelets residential time in the wake of the valve, hence, increasing the level of platelet activation.

The echo Doppler measurements were compared with the numerical results as shown in figure 2. In the healthy case, there was a good agreement between TPGmax values obtained by echo-Doppler measurements and numerical simulations. In the mean time, the discrepancy between numerical and experimental TPGmax was proportional to the malfunction. Both of numerical and experimental results showed that, in the defective BMHV, the TPGmax and TPGmean are up to three times higher than for the healthy case.

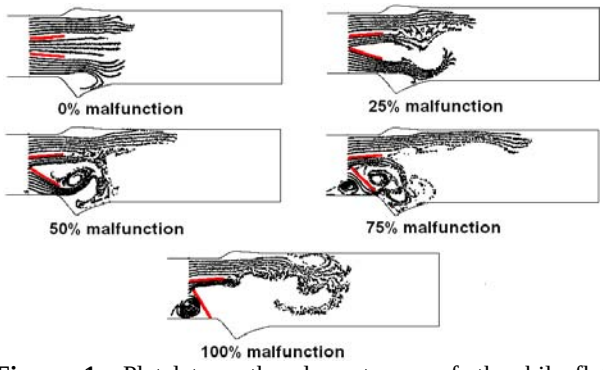

Figure 1: Platelets paths downstream of the bileaflet mechanical heart valve during the deceleration phase (100-150 ms after the peak) for different percentages of malfunction.

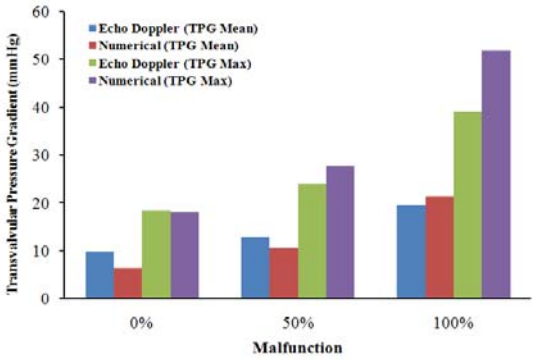

Figure 2: Comparisons between numerical and Echo Doppler results by depicting the mean and the maximum Transvalvular Pressure Gradients (TPG).

CONCLUSIONS

In this study, we showed that the flow through a defective BMHV was highly influenced by malfunction severity and this resulted in discrepancies between Doppler echocardiographic and numerical simulations pressure gradients. Moreover, a significant elevation in shear stress and a considerable increase in number and scale of formed vortices downstream of the valve were found which in turn, could increase the level of platelet activation. Finally, clinicians should be aware of checking the maximal velocity position not only at the central orifice but also through the lateral orifices, when possible. Finding the maximal velocity in the lateral orifice could be an indication of valve malfunction.

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