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Integrating *In Vitro* Experiments, Animal Studies, and Computational Simulations to Predict Thrombus Formation in Ventricular Assist Devices

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INTRODUCTION

Ventricular assist devices (VADs) are used substantially across the world to assist ailing patients with congestive heart failure by either allowing them to await heart transplants or by providing a temporary means to allow the heart to fully recover after surgery. Even with the routine VAD implantation, one of the major problems still associated with their use is thrombosis. Designing VADs such that the rate of thrombi occurrence is below the rate associated with prosthetic heart valves is a challenge. In an effort to improve the design process for blood pumps, we are integrating computational fluid dynamics (CFD), particle image velocimetry measurements, *in vitro* platelet adhesion studies, and bovine studies to develop a thrombus susceptibility parameter that will enable us to compare designs more readily but is grounded based on experimental data.

METHODS

We measured the flow using particle image velocimetry (PIV) in the V-2 Penn State 50cc VAD [1]. A wall shear rate post-processing algorithm was applied to the PIV data [2]. Concurrently, a CFD algorithm computed the flow [3]. Subsequently, we conducted platelet adhesion studies using the polyurethane (urea) blood contacting material to determine platelet adhesion characteristics. Upper and lower bounds for shear rate were identified. Finally, a bovine study using the V-2 Penn State 50cc VAD was completed and the blood contacting sac evaluated using confocal and scanning electron microscopy. All the measurements and simulations were completed at 75 bpm. A thrombus susceptibility parameter (TSP), equation below, was used to predict the potential locations for adhesion, where N was the number of time steps taken through the cardiac cycle, Δt was the amount of time between image acquisitions for PIV, γ_w was the wall shear rate, γ_{peak} was set to 500 s^{-1} (based on platelet studies), γ_{cutoff} was set to 1000 s^{-1} (based on platelet studies), and t_{crit} was set to twice the value of Δt.

$$TSP = 1 - \sum_0^N \frac{\Delta t \gamma_w}{\gamma_{cutoff} t_{crit}} \times \frac{e^{\left(\frac{\gamma_w - \gamma_{peak}}{\gamma_{cutoff} - \gamma_{peak}}\right)} - 1}{e^1 - 1}$$

RESULTS AND DISCUSSION

The wall shear rates for the CFD and PIV show very good agreement [3]. When compared to the microscopy data collected from the explant at a fixed beat rate of 75 bpm, there is further evidence that the CFD and PIV, both also at 75 bpm, are able to demonstrate that the wall shear measurements correlate with fibrin and platelet adhesion. The TSP based on the PIV data [1] also correlated well with the microscopy analysis of the blood sac, as shown in Figure 1. A TSP value of 1 indicates high potential for deposition where a TSP value of 0 indicates a low potential.

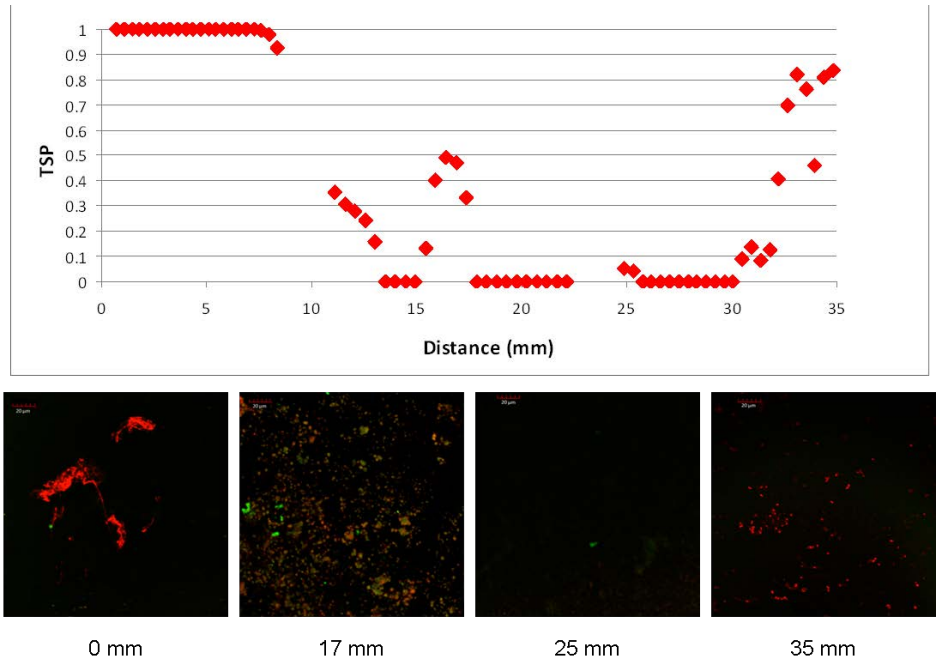

Figure 1: Comparisons of confocal microscopy and SEM images at 0, 17, 25, and 35 mm along the explanted sac surface on the 50.8 mm normal plane with the TSP, based on PIV data, along the same 50.8 mm plane.

CONCLUSIONS

We have demonstrated strong correlations of our TSP to platelet and fibrin adhesion but more work is needed. Currently, the TSP can be used to compare designs but not as an absolute determinant/predictor of a particular design or comparing technology to other technology.

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