Using Wall Shear Stress and Platelet Stress Accumulation in the Design of a Bioartificial Kidney

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Study: A computation fluid dynamics (CFD) study was conducted to guide the flow path design for the hemofiltration section of a MEMS-based bioartificial kidney. Platelets are known to achieve activation through accumulated shear stress. The accumulated stress can be predicted using Eulerian scalar values or Lagrangian particle trajectories within the blood flow. Regions of low wall shear stress are known to be susceptible to thrombus formation. The goal for this study was to apply platelet stress accumulation methods and evaluate wall shear stress values in designing the blood flow path for a full-size bioartificial kidney.

Methods: CFD analyses (Fluent and CFX, ANSYS, Inc., Canonsburg, PA) were used to determine the flow distribution, pressure drop, wall shear stress, and predicted platelet stress accumulation (SA). Linear and nonlinear power law formulations of shear stress and exposure time models were used to calculate the platelet SA. The predicted platelet SA levels were verified by comparison with theoretical values for fully developed, laminar flow through a straight tube and compared with observations from animal studies. Small-scale, single flow channel and full-size flow path designs were modeled.

Results: The CFD results for the initial single-channel design showed regions of sustained low wall shear stress (< 10 dyne/cm2) and thrombus formation in animal studies. A second-generation single flow channel design (Figure 1), with a helical inlet, removed low shear regions and did not show indications of thrombus formation during several 28-day animal trials. For the full-size devices, a long, single-channel flow path device provided more uniform wall shear stresses, but higher levels of platelet SA relative to a multi-channel flow path design. Additional work is planned to refine the flow paths for both full-size designs to improve the wall shear stress distributions and reduce platelet SA values prior to their evaluation in upcoming animal studies.

Figure 1 – Small Scale Helical Inlet Device: Platelet SA along Particle Paths