In Silico Evaluation of Local Hemodynamics Following Vena Cava Filter Deployment

J. Ferdous[1], M. Ghaly [2], V. B. Kolachalama [3], T. Shazly[4]

[1]Biomedical Engineering Program, University of South Carolina, Columbia, SC, USA
[2]Department of Biomedical Engineering, North Carolina State University, Raleigh, NC, USA
[3]Charles Stark Draper Laboratory, Cambridge, MA, USA
[4]Biomedical Engineering Program and Department of Mechanical Engineering, University of South Carolina, Columbia, SC, USA

Abstract

Introduction: Inferior vena cava (IVC) filters have become essential components in deep vein thrombosis treatment, and are particularly critical for preventing pulmonary embolisms in anticoagulation-resistant patients. Filter efficacy relies on maintaining IVC patency, or openness, by preventing filter-induced thrombosis following clot capture. Currently used metallic filters induce injury to the vessel wall and may require subsequent removal. Meanwhile, flow disturbances must be considered with all vascular implants as hemodynamic patterns affect the endothelial cells and can either promote or inhibit thrombosis. Our project studies the hemodynamic effects of a candidate resorbable filter design, with the filter initially considered as an impermeable implant.

Methods: We developed a computational fluid dynamics (CFD) model to determine if a candidate resorbable filter design elicits hemodynamic patterns that promote thrombus development. Filter and clot geometries were created based on filter explants after clot capture. Porous media flow within the clot was characterized via the Brinkman equations and Non-Newtonian blood flow within the IVC was modeled using the Navier-Stokes equations. The Carreau viscosity model was used to describe shear-induced blood viscosity variations. Model equations were solved using COMSOL Multiphysics®, a finite-element based software. Our CFD model yielded a steady-state flow solution describing blood velocity in the vicinity of an impermeable filter with various levels of clot accumulation. Thrombotic potential of flow is indicated by resultant vessel wall shear stress (WSS).

Results and Discussion: Decreasing clot porosity and permeability resulted in higher WSS, suggesting that clot maturity modulates thrombotic potential. Quantitatively, 28% increase in peak WSS is observed when clot porosity changes from 0.8 to 0.2, whereas 79% increase in peak WSS is observed when clot permeability changes from 10-5 to 10-10 [m2]. Moreover, increase in velocity around proximal and outer filter edge on unoccluded to occluded filter state indicates reduction of stagnant and recirculating flow regions that eventually promote thrombus formation. Non-uniform shear stress patterns along the radial positions suggest possible variation in

thrombogenicity with radial location.

Conclusions: Computational modeling provides an efficient tool to predict the hemodynamics following a vena cava filter deployment. Strategic computational optimization of WSS response can minimize the risk of thrombosis.

Acknowledgement: The authors acknowledge the support from Dr. Jeff Ustin for the clinical clot images and filter design.