Two Dimensional Blood Sheer Modeling in a Blood Cooling Catheter

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Abstract

Tissue damage associated with heart attack is the leading cause of death in the United States, responsible for 30% of cardiac patient deaths within a year following initial trauma [1]. Researchers are developing regional cooling systems through the use of a catheter to administer therapeutic hypothermia locally to cardiac tissue. Therapeutic hypothermia has proven benefits in numerous studies [2-6]. The catheter is designed to reduce local tissue temperature by 2 - 4°C within five minutes. In vivo animal tests have shown that therapeutic hypothermia has the ability to limit post traumatic reperfusion injury [7]. Blood flows inside relatively small pathways (~ 1 mm) impose shear stress on red blood cells. Mechanical blood damage (hemolysis) may result from exposure to a shear stress magnitude greater than 150 Pa. [8]. For safe application local hemolysis must remain under this threshold [9]. A finite element computational fluid dynamic (CFD) catheter model (Figure 1) was developed in COMSOL. Using laminar Newtonian flow modules for which geometric configuration, model input parameters, and physics settings were considered. A 1.003m long 6F catheter with inner diameter of 1.42E-3m was simulated with and without a 3.35E-4m diameter guide wire. Validation of the model was performed by comparing temperature change with output pressures to analytical and experimental data of a mock cardiac loop. Based on the 2D modeling it is unlikely the administration of therapeutic hypothermia with a 6F catheter with and without a guide wire will result in clinically significant blood damage. Shear stress magnitude may surpass the blood damage threshold at higher flow rates, but short expose times will reduce the chance of significant damage (Figure 2). Mesh independence for the results were performed in COMSOL using pressure drop as the convergence criteria; determine a final mesh of 118,400 mapped elements (Figure 3). Further study into a 3D CFD model would allow for conditions where the guide wire is not placed along the centerline of the axial coordinate systems. However, despite the limitations associated with 2D simulations, it is unlikely the usage of the CCS will cause damaging blood cell shear.

Reference

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Figures used in the abstract

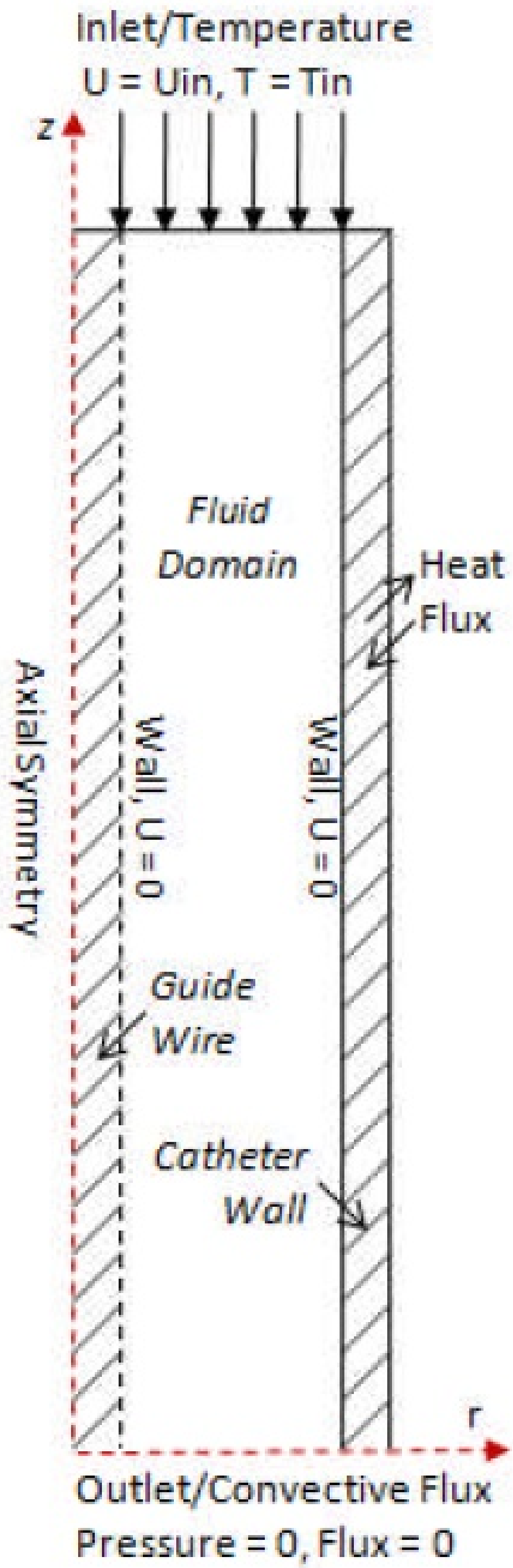

Figure 1: Diagram of axial symmetric CFD computation domain which consists of three sub-domains: insert, fluid domain, and catheter wall.

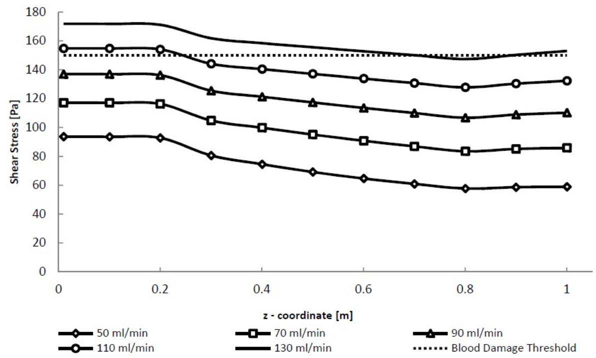

Figure 2: Mesh independence study of pressure drop as the convergence criteria.

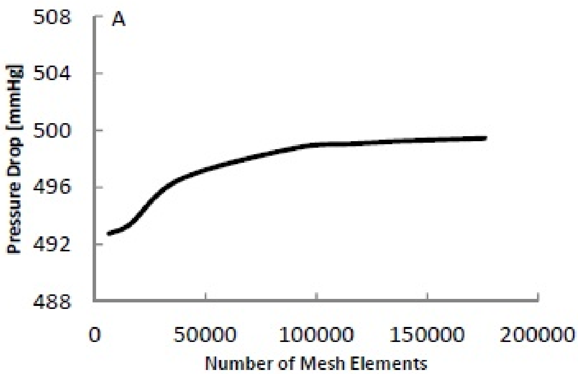

Figure 3: Mesh independence study of pressure drop as the convergence criteria.