2-Dimensional Blood Shear Modeling in a Blood Cooling Catheter

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Objective

- To model the effects of shear stress on a blood cooling catheter using computational fluid dynamics and determine the likelihood of hemolysis.

Introduction

- **Tissue damage associated with heart attack is the lead cause of death in the United States [1].**
- **A catheter system was developed to deliver 2-4 C temperature reduction within five minutes.**
- **The system pumps blood from the patient through an external heat exchanger, delivering it locally to cardiac tissue.**
- **Hemolysis may result from exposure to shear stress greater than 150 Pa [2].**
- **Previous lab experimental data allows for direct comparison to computational simulations.**
- **A 2-Dimensional concentric catheter was simulated within COMSOL using CFD.**

Governing COMSOL Equations

$$\rho(u \cdot \nabla)u = \nabla \cdot \left[-p\mathrm{I} + \mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\mu(\nabla \cdot u)\mathrm{I} \right] + F$$

$$\nabla \cdot (\rho u) = 0$$

Experimental Methods

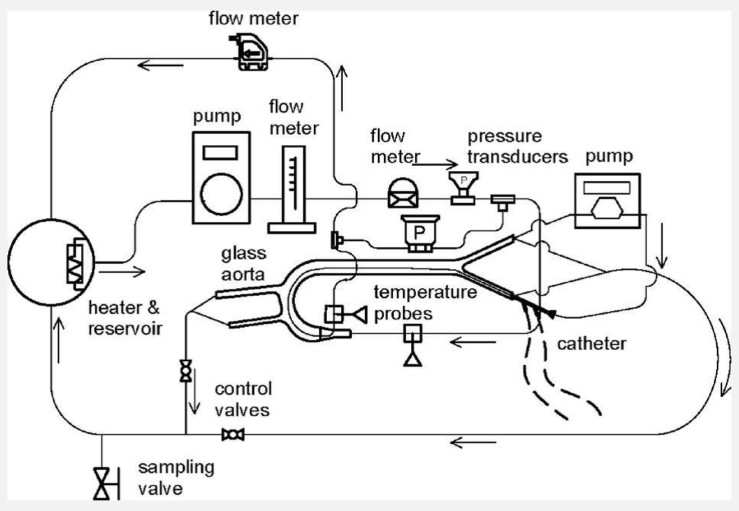

Fig. 1 Cooling Catheter Experimental Setup.

Boundary Conditions and Geometry

CFD Input Parameters			
Parameter	Variable	Expression	Unit
Catheter Inner Diameter	IDc	1.422E-3	[m]
Catheter Outer Diameter	ODc	2.000E-3	[m]
Guide Wire Radius	ODw	3.556E-4	[m]
Flow Cross Section Area	A	Pi*(IDc/2)^2	[m^2]
Flow Cross Section Area with Guide Wire	Aw	Pi*((IDc/2)^2-(ODw/2)^2)	[m^2]
Blood Analog Density	rho_b	1102	[kg/m^3]
Blood Analog Conductivity	k_b	0.477	[W/mK]
Blood Analog Viscosity	mu_b	0.01031*exp(-0.035*T)	[Pa*s]
Blood Analog Specific Heat	cp_b	7.1*(T-273.15)+3204.7	[J/kgK]
Catheter Wall Density	rho_c	830	[kg/m^3]
Catheter Wall Conductivity	k_c	0.437	[W/mK]
Catheter Wall Specific Heat	cp_c	2800	[J/kgK]
Aorta Temperature	T_inf	311.15	[K]
Lab Temperature	T_lab	293.15	[K]
Inlet Temperature	T_in	Input from Data – Appendix A. Range(285.15-308.15)	[K]
Blood Analog Flow rate	Q_cath	(50, 70, 90, 110, 130)/6E7	[ml/min] -> [m^3/s]
Blood Analog Velocity	U_in	Q_cath/A or Q_cath/Aw	[m/s]

Table 1: Input Parameters

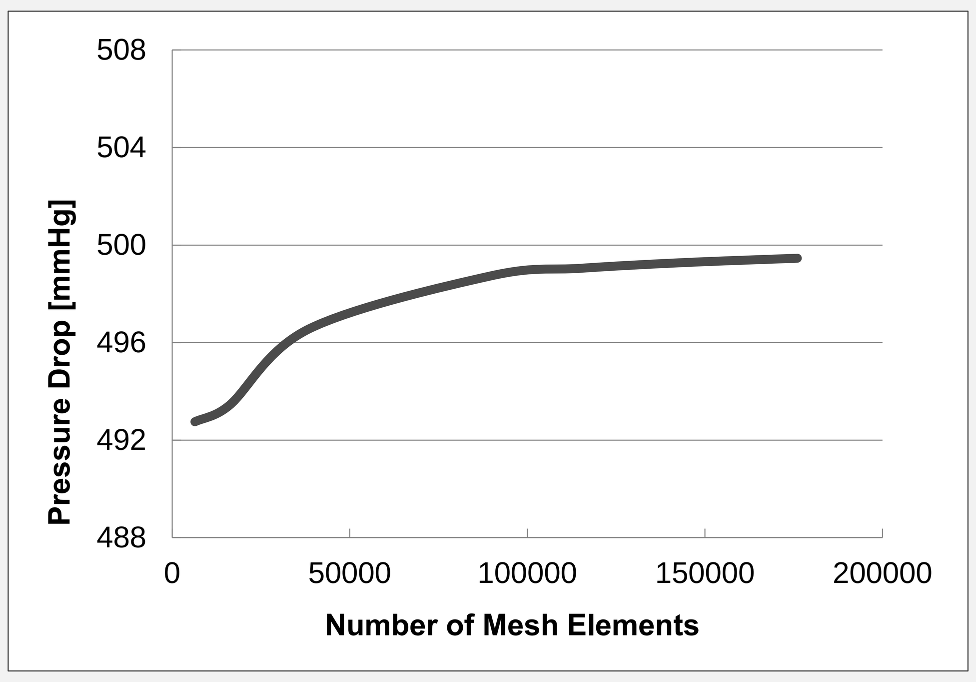

Fig. 2: Geometry values for final model.

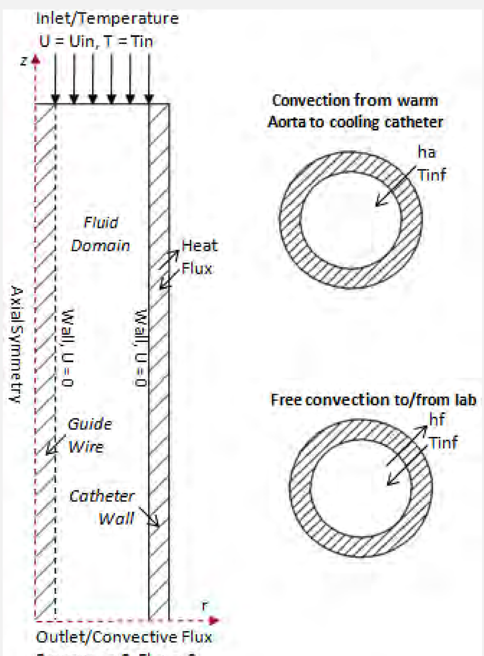

Fig. 3: CFD model geometry.

Results

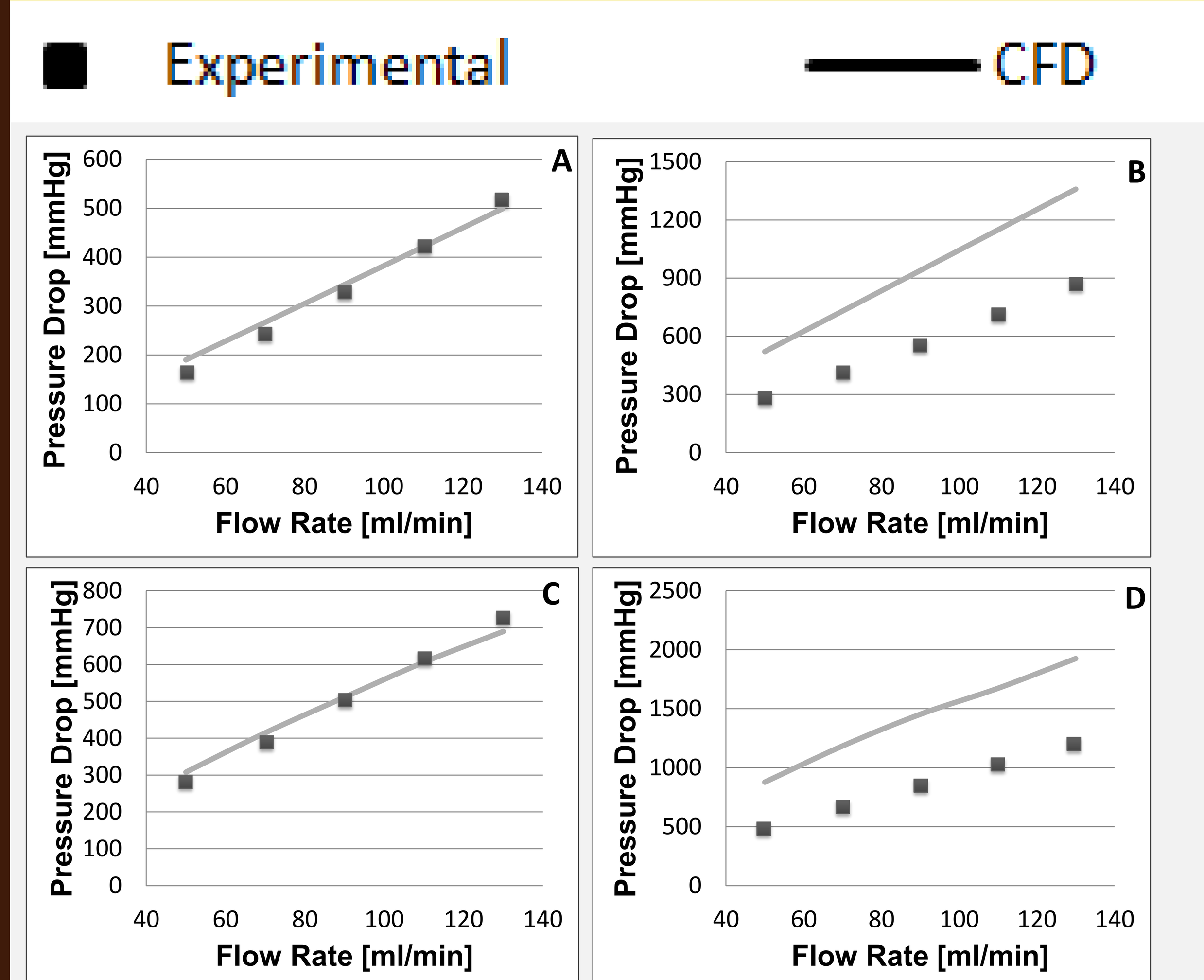

Fig. 4 Pressure drop, mmHg, as a function of flow rate, ml/min, for four configurations simulated. (A) Isothermal 6Fr catheter, (B) Isothermal 6Fr catheter with guide wire, (C) 6Fr catheter, (D) 6Fr catheter with guide wire.

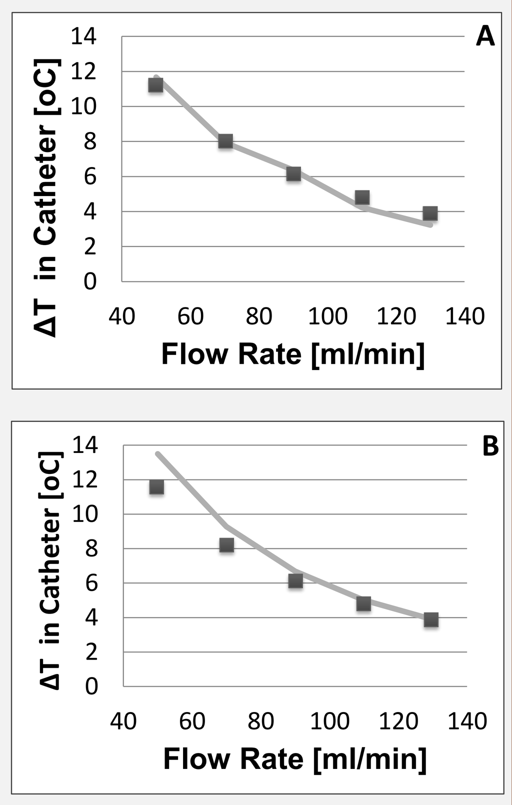

Fig. 5 Change in temperature, ºC, through catheter as a function of flow rate, ml/min. A) 6Fr hypothermic, B) 6Fr hypothermic with guide wire.

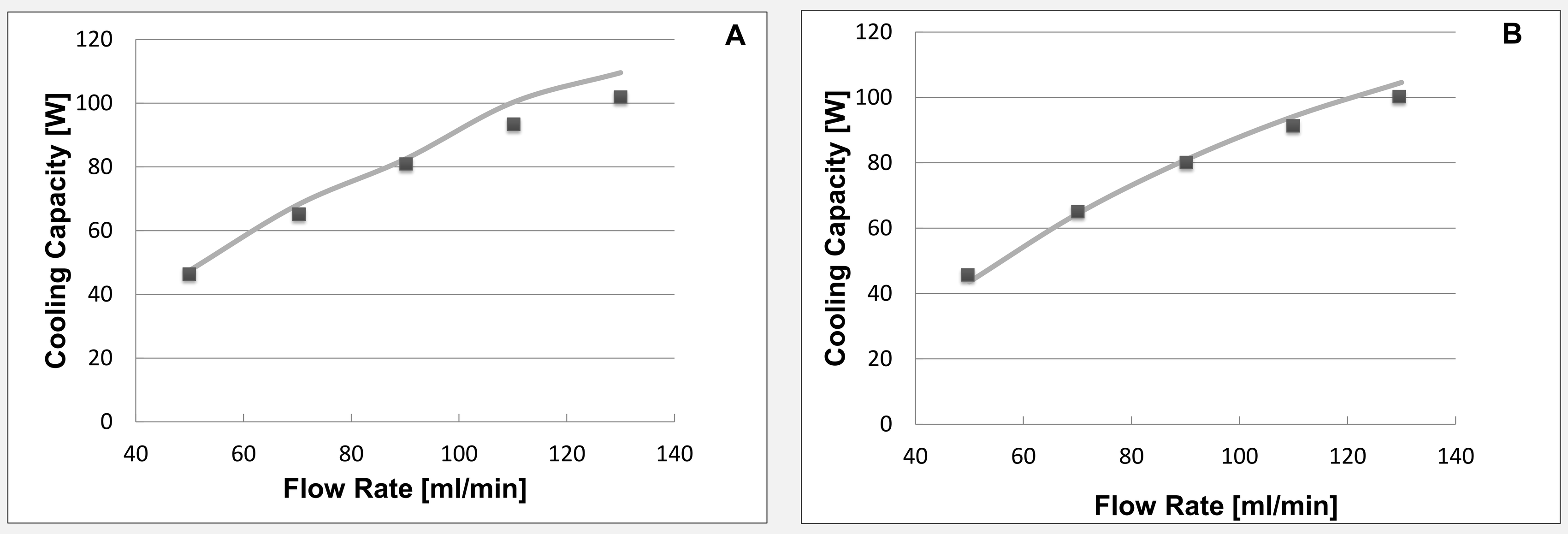

Fig. 6 Cooling capacity, W, as a function of flow rate, ml/min. A) 6Fr hypothermic, B) 6Fr hypothermic with guide wire.

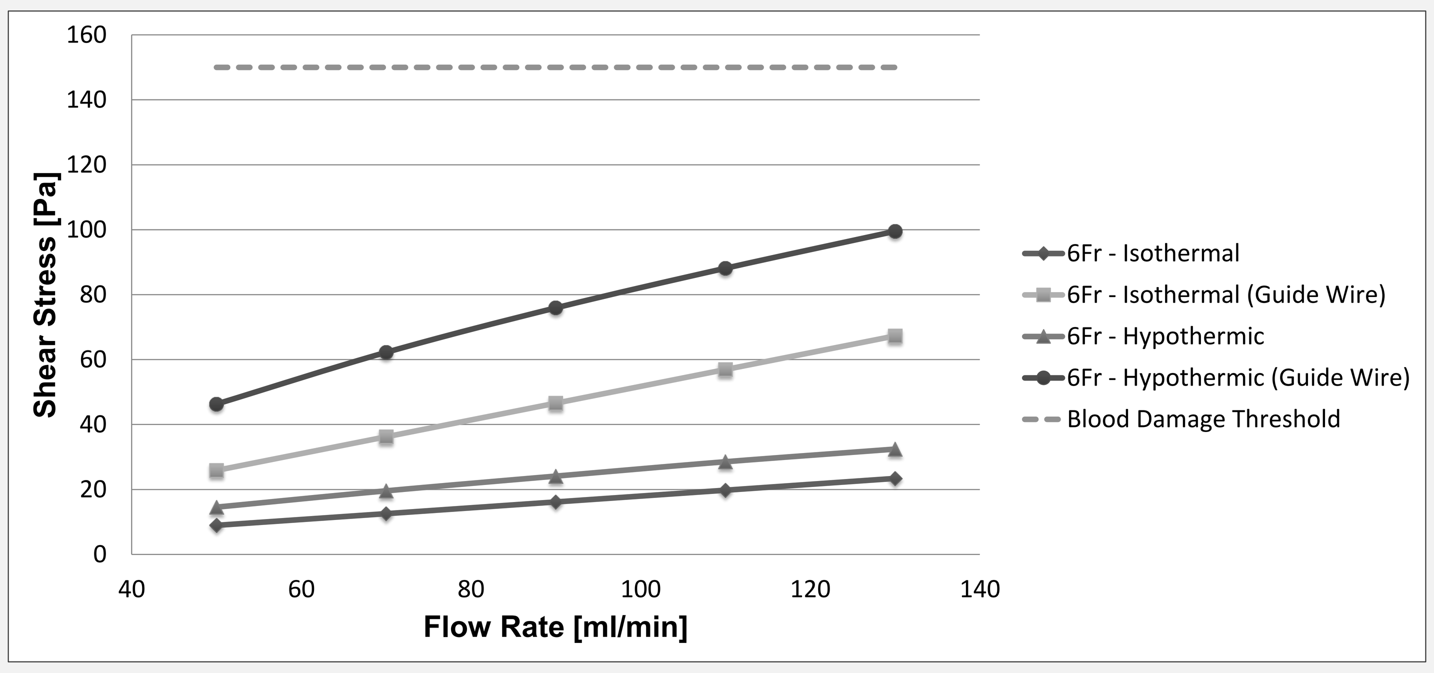

Fig. 7 Temperature of ICA and ECA outlet varied blood flow rates.

Conclusions and Future Work

- **Mean difference of 5.38% outlet pressure as compared to experimental**
- **Mean difference of 2.38% temperature change through catheter compared to experimental**
- **Highest shear stress of 99.5 Pa is below the Hemolysis threshold**
- **Future work to use an acentric implementation considerations and 3-Dimensional modeling**
- **Further thorough experimental testing necessary to conclude safety for local hypothermia**

References

1. Lloyd-Jones, D., Adams, R., and Carnethon, M., 2009, “Heart Disease and Stroke Statistics—2009 Update: A Report From the American Heart Association Statistics Committee and Stroke Statistics Subcommittee,” Circulation, 119.3, pp. 21–181.
2. Leverett, L.B. et al, 1972, “Red Blood Cell Damage By Shear Stress,” Biophysical Journal, 12.3, pp. 257 – 273.

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