Spatiotemporal Study of Thrombosis incorporating Recent Rheological Findings

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September 2020

Motivation

- Hemostasis stops internal bleeding
- Clinical Relevance
  - Under-active -> hemorrhage
  - Over-active -> thrombosis (blood vessel occlusion)
  - Unaddressed thrombosis can lead to heart attack or stroke

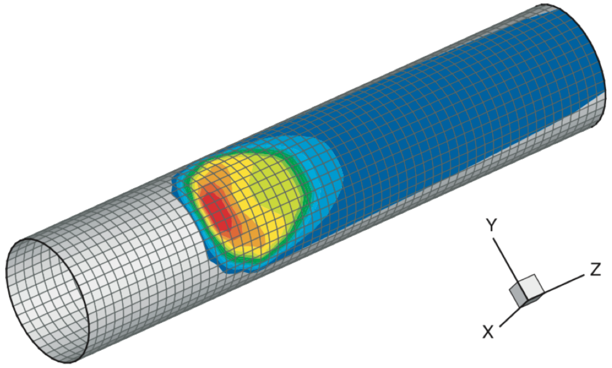
[1] Becatti M, Emmi G, Bettiol A, Silvestri E, Di Scala G, Taddei N, Prisco D, Fiorillo C. Behçet's syndrome as a tool to dissect the mechanisms of thrombo-inflammation: clinical and pathogenetic aspects. Clinical & Experimental Immunology. 2019 Mar;195(3):322-33.

Background

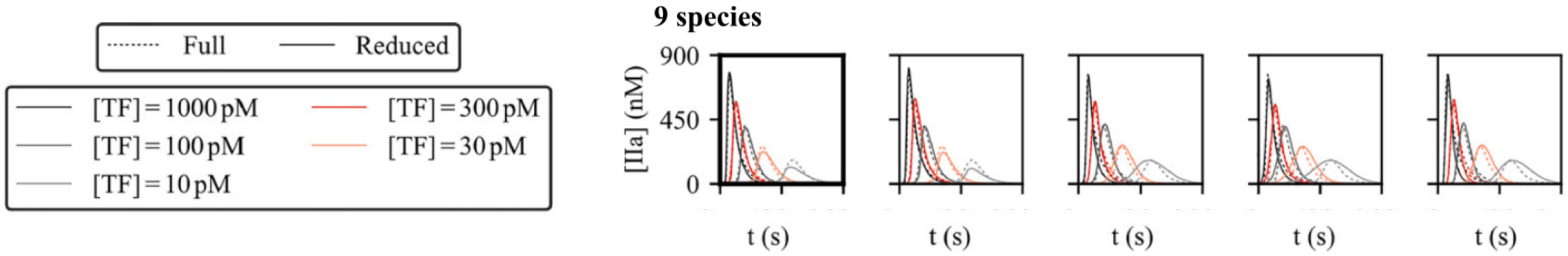
- Few thrombosis models include rheological feedback

- Variable Viscosity Constitutive Equation
  - Dependence on shear rate and chemical concentration

- Reduced blood coagulation model
  - Optimizes computational cost while capturing kinetics



[2] Bodnár T, Sequeira A. Numerical simulation of the coagulation dynamics of blood. Computational and Mathematical Methods in Medicine. 2008 Jun 1;9(2):83-104.



[3] Hansen KB, Shadden SC. Automated reduction of blood coagulation models. International journal for numerical methods in biomedical engineering. 2019 Oct;35(10):e3220.

Project Scope

- Build a COMSOL Simulation App to Evaluate Thrombosis Formation
  - Computationally efficient
  - Easy to Manipulate

- Apply to Test Coagulation Respond to Injury and Device Insertion

- This App will use the “Reacting Flow” library

COMSOL MULTIPHYSICS®

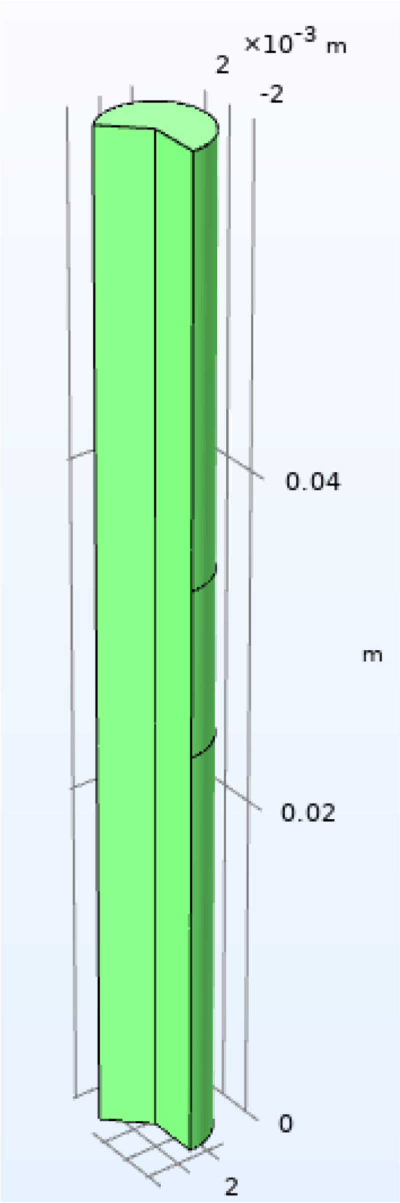
Geometry

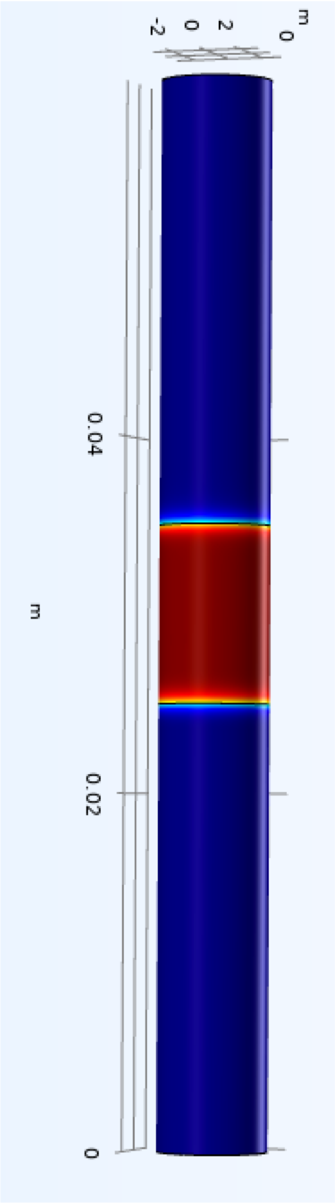
Artery

- 0.06 m length
- 0.0031 m radius

Wound Site

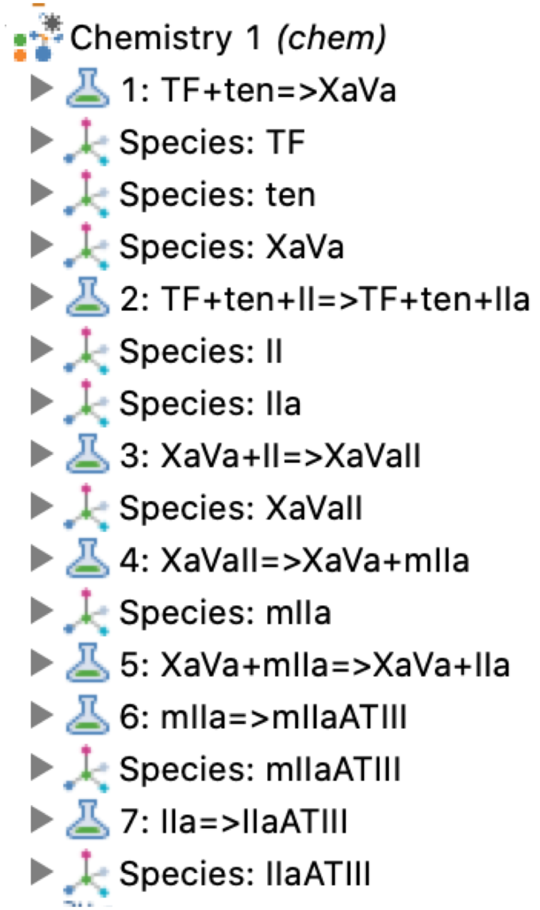
- 2D Axis Symmetry
- 0.025 - 0.035 m





Chemokinetic implantation

- Using Reaction Engineering Module to generate space-dependent model with Chemistry and Transport of Dilute Species Modules



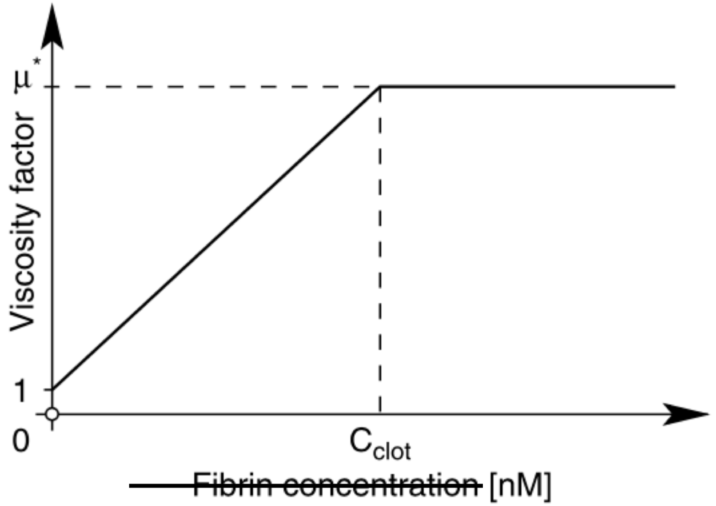
Parameter	Value	Unit
TF Wall Flux	1e-6	mol / (m^2 s)
Initial X Concen.	1.6e-4	M
Initial V Concen.	2e-5	M
Initial II Concen.	1.4e-3	M
Diffusivities	1e-7	m^2 / s
Reaction Rates	See [3]	varies

[3] Hansen KB, Shadden SC. Automated reduction of blood coagulation models. International journal for numerical methods in biomedical engineering. 2019 Oct;35(10):e3220.

Flow Implementation

- Laminar Flow Module with Fully developed inlet
- User defined viscosity

Concentration Dependent Pre-factor

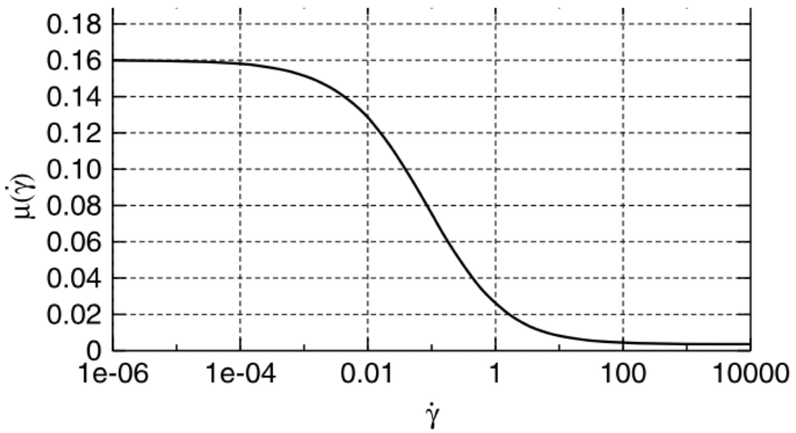


Thrombin Concentration

X

X

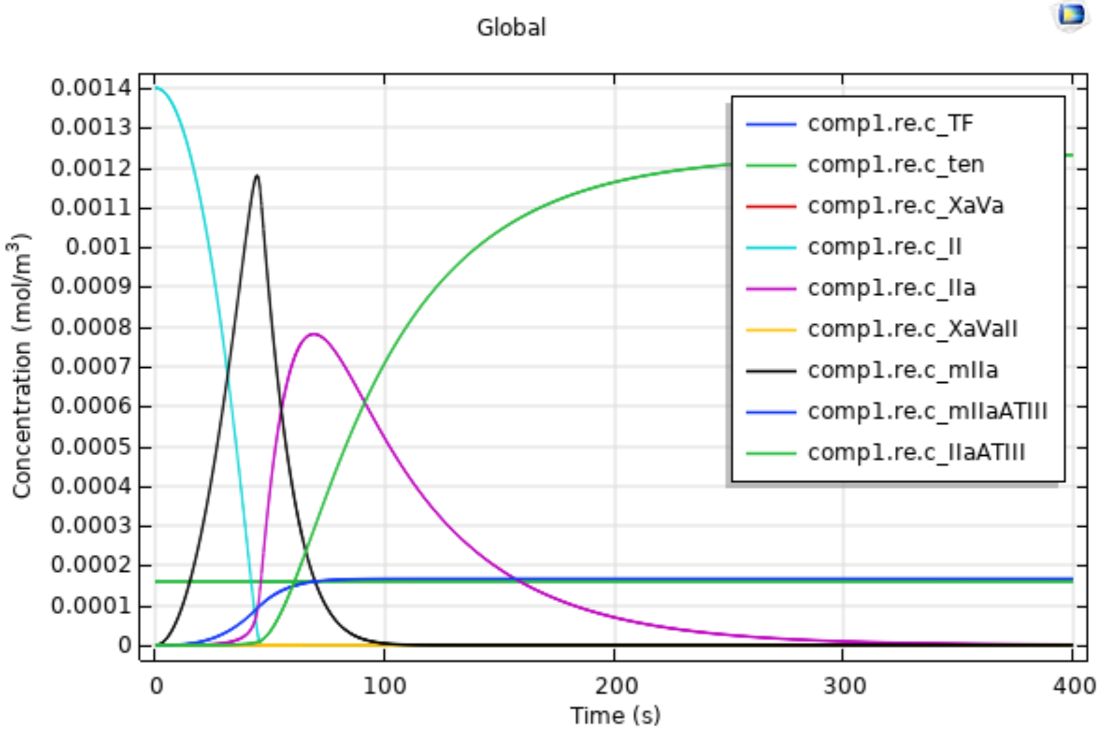
Generalized Cross Model for Shear-thinning



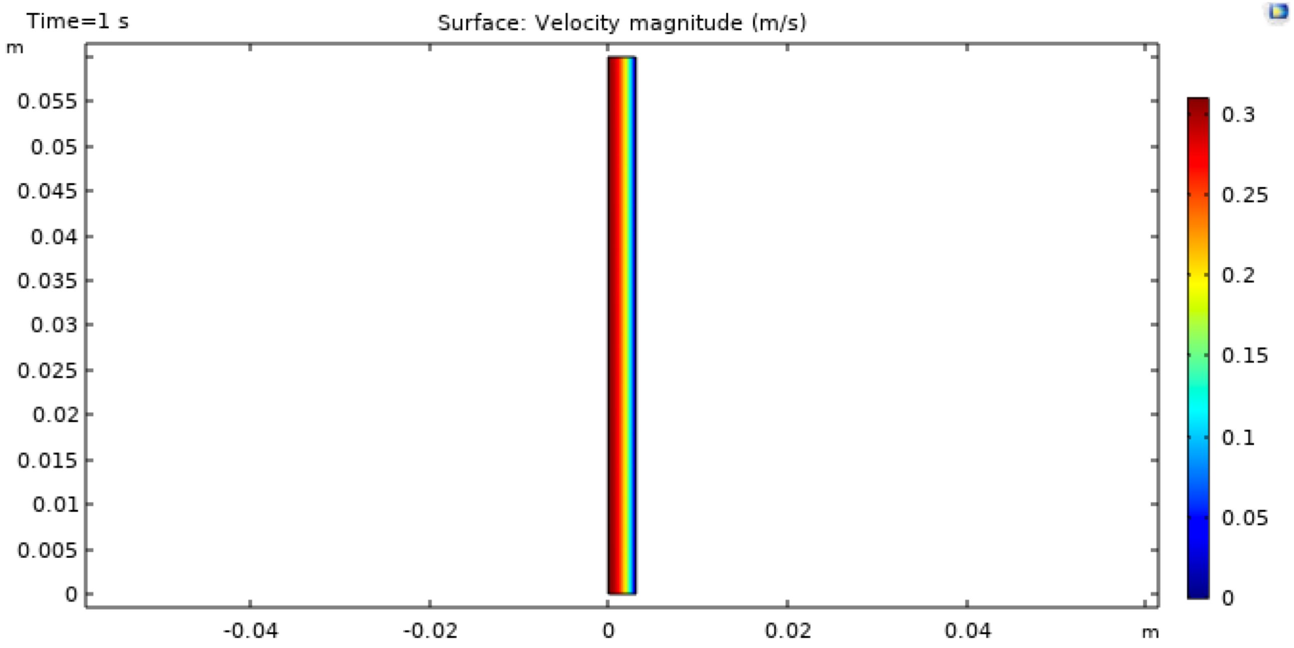
$$\frac{\mu(\dot{\gamma}) - \mu_\infty}{\mu_0 - \mu_\infty} = \frac{1}{(1 + (\lambda\dot{\gamma})^b)^a}$$

[2] Bodnár T, Sequeira A. Numerical simulation of the coagulation dynamics of blood. Computational and Mathematical Methods in Medicine. 2008 Jun 1;9(2):83-104.

Independent Tests

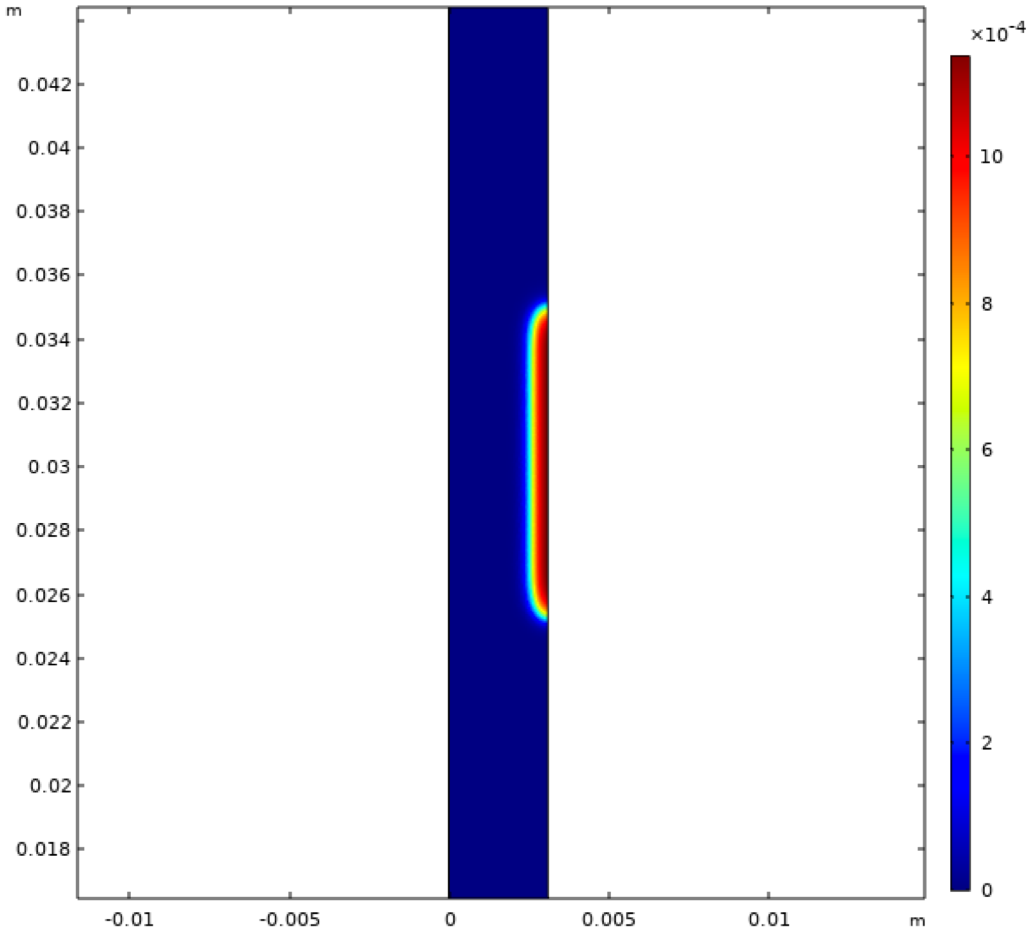


0D Batch Reactor

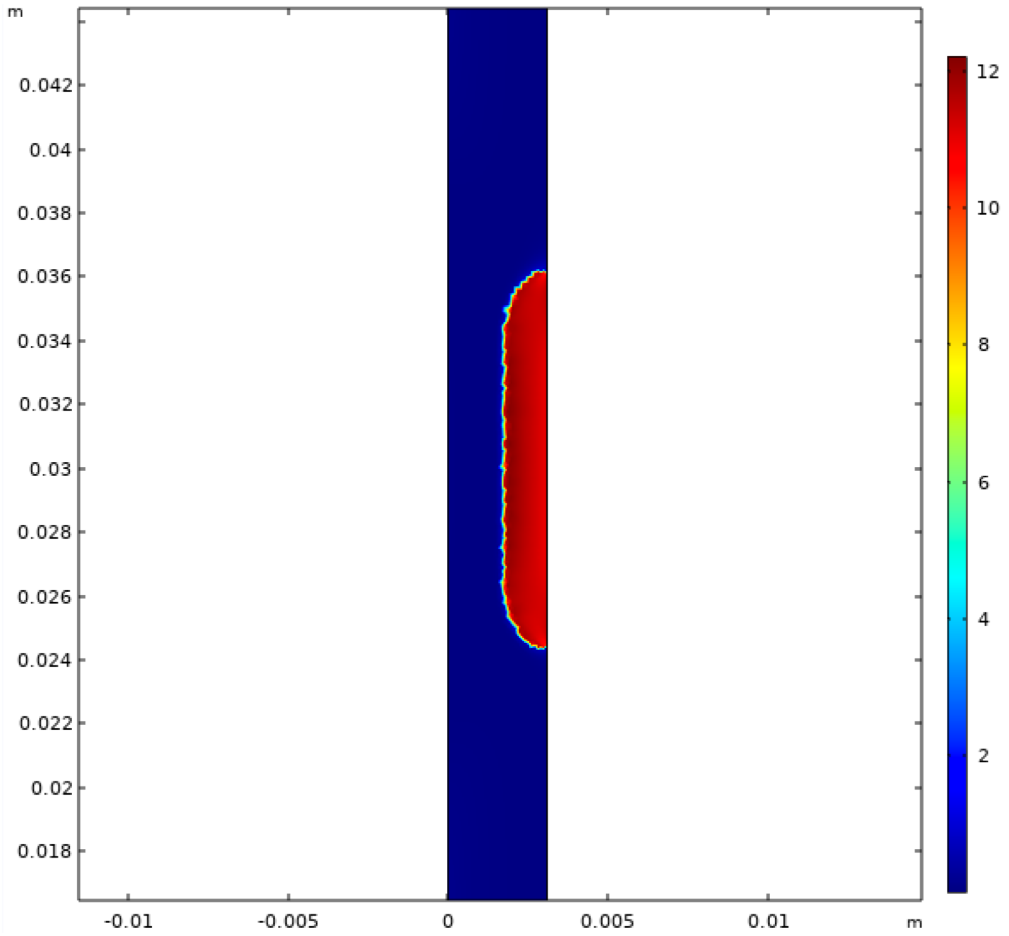


Test of Pipe Flow to Verify Centerline Velocity

Fully Coupled Reacting Flow

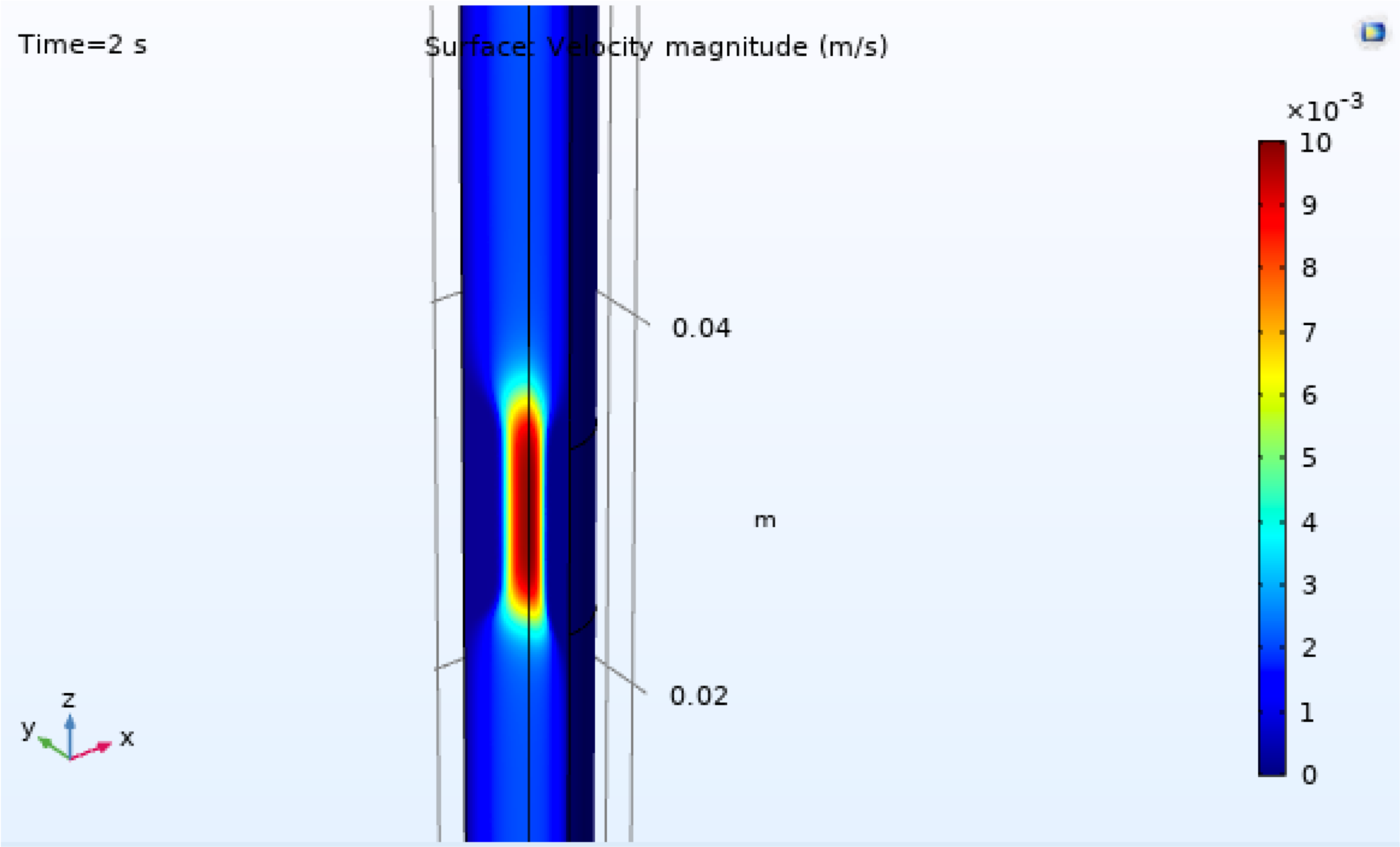


Thrombin Concentration (mol/m^3), t = 2 s

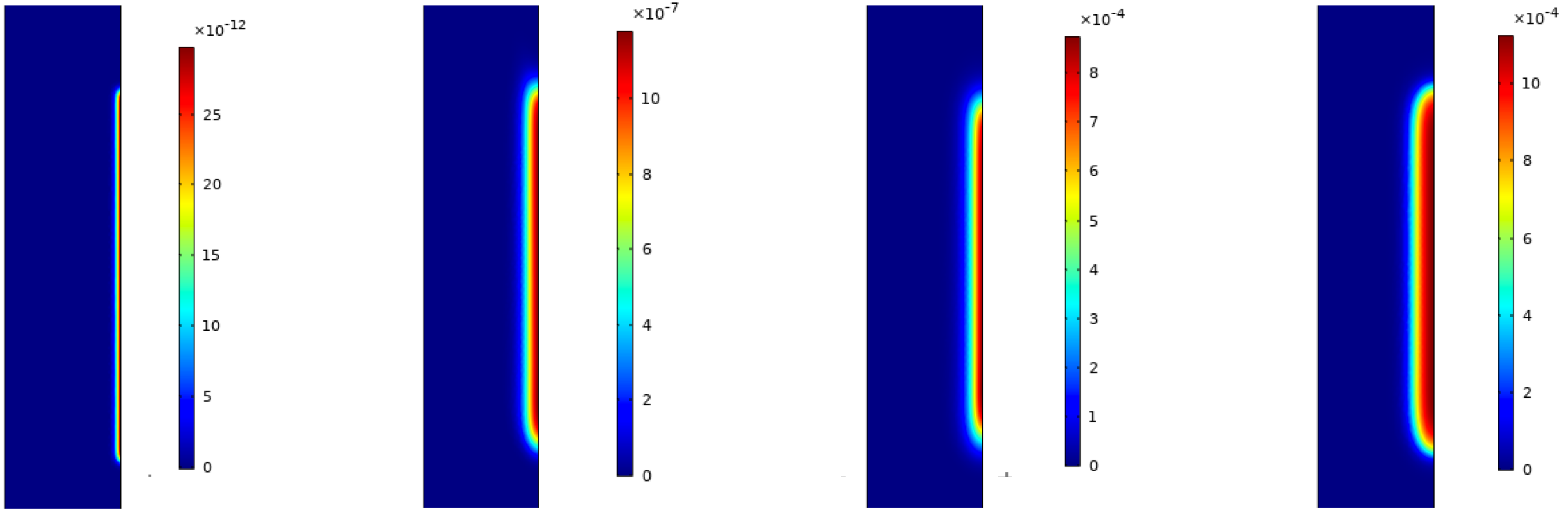


Dynamic Viscosity (Pa*s), t = 2 s

Velocity Around the Thrombosis

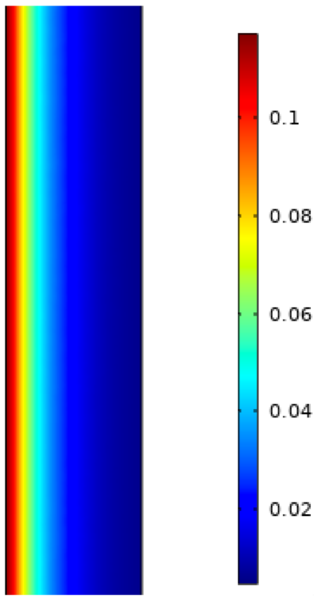


Thrombin Concentration (mol/$\mathbf{m}^3$)

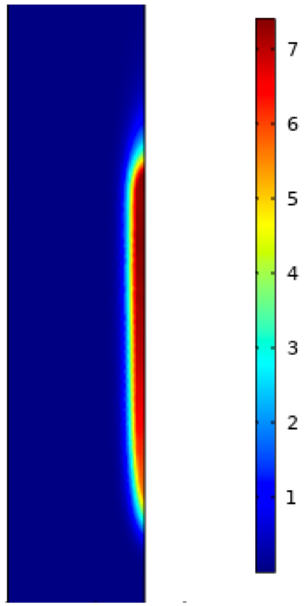


t = 0.1 s t = 0.8 s t = 1.8 s t = 2.0 s

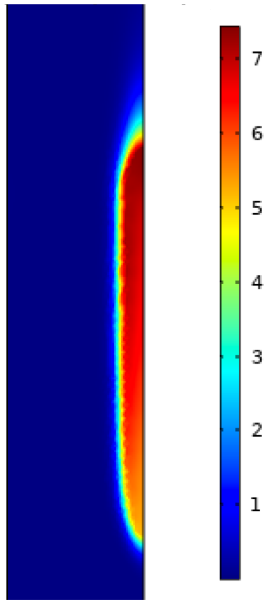
Dynamic Viscosity (Pa*s)



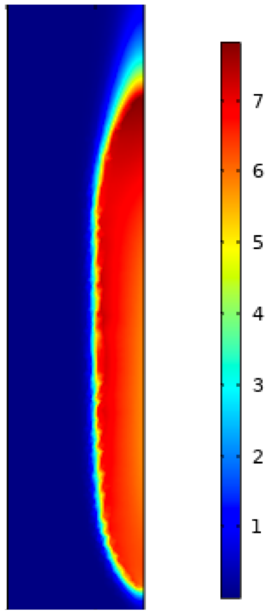
t= 0.1 s



t= 1.2 s



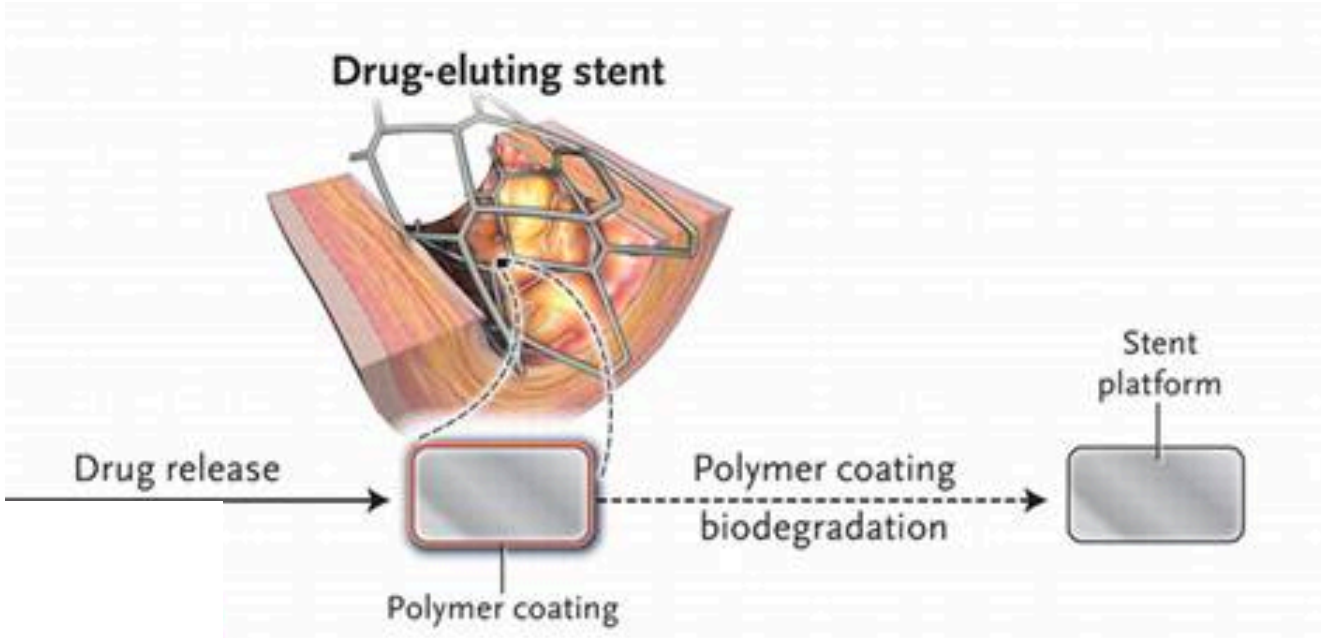
t= 1.4 s



t= 2.0 s

Future Direction

- Investigate thrombosis on drug-eluding stent



https://resident360.nejm.org/clinical-pearls/drug-eluting-coronary-stents

Acknowledgements and Questions

Larson Lab

NSF Fellowship (DGE 1841052)

If you have any questions please reach out to cerice@umich.edu