Modeling Acute Blood Flow Responses to a Major Arterial Occlusion

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January 27, 2019

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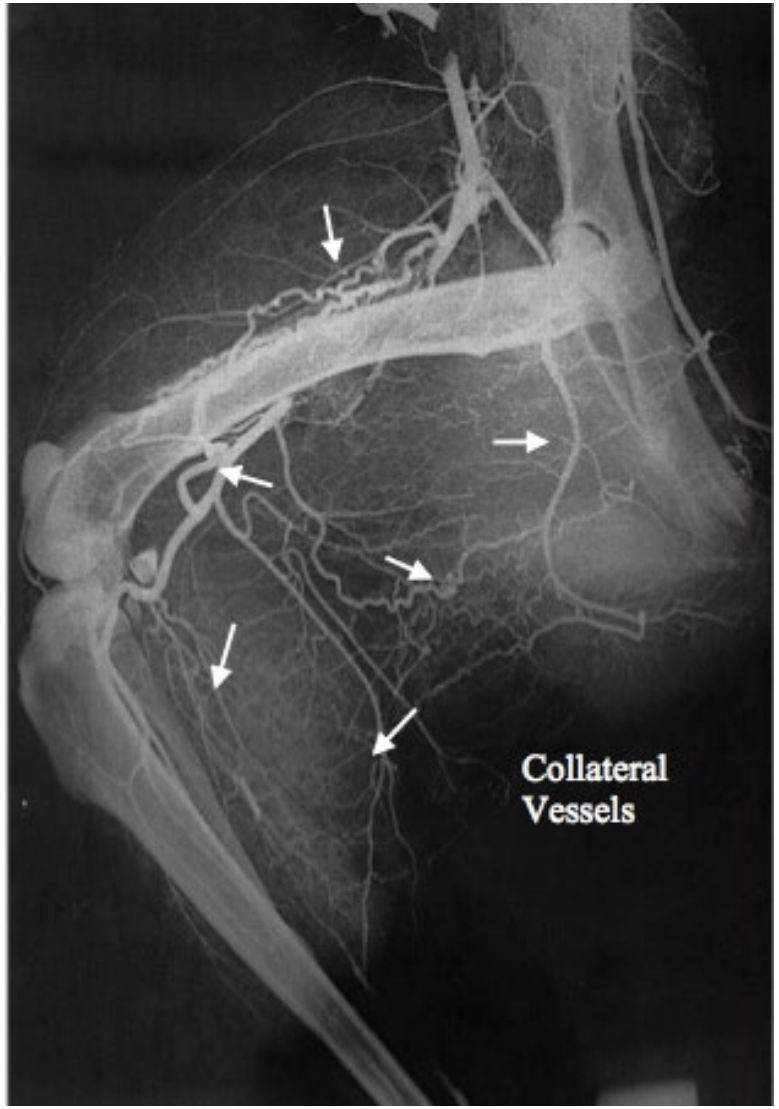
Peripheral Arterial Disease (PAD)

- **Occlusion**: blockage of the blood vessel
- **Collateral vessels**: pre-existing vessels that help redirect blood flow around the blockage

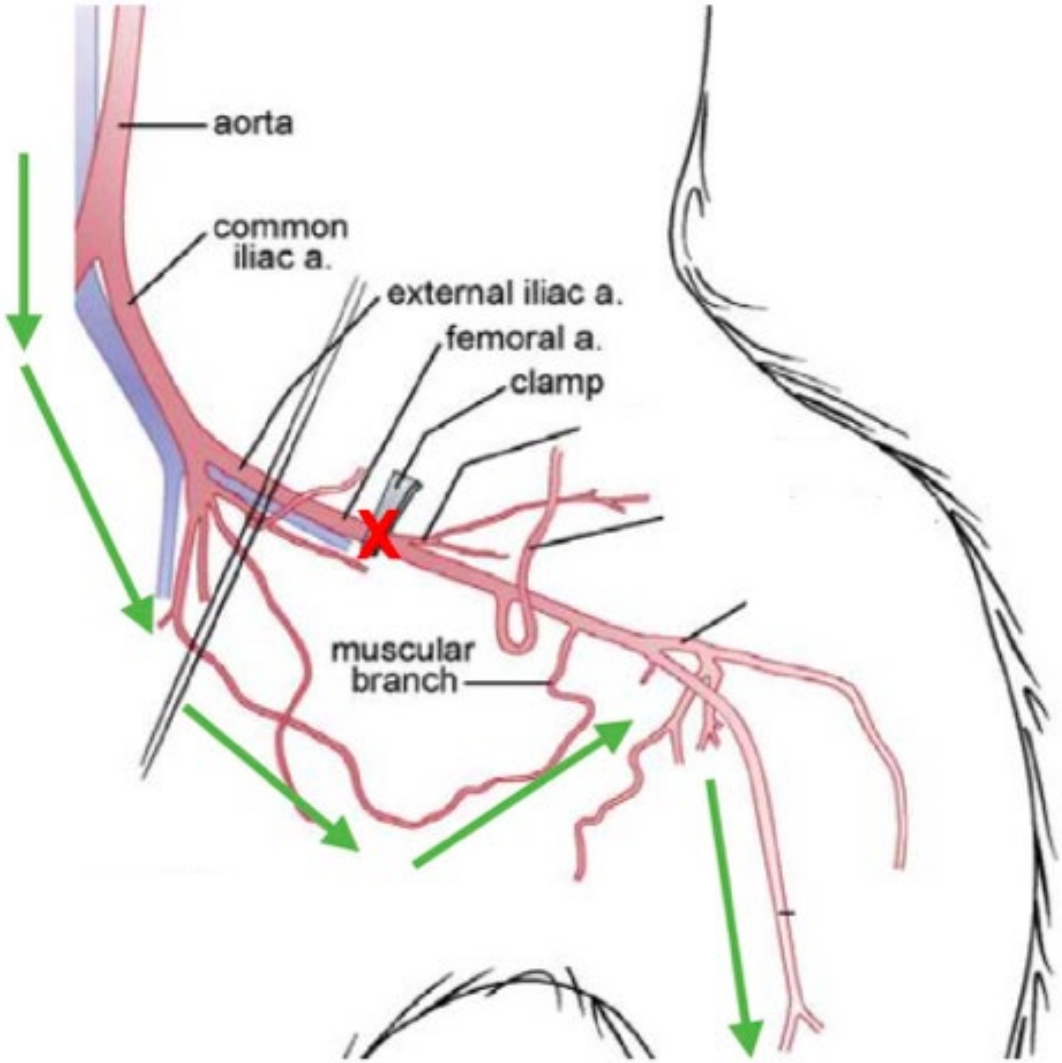
http://healthletter.mayoclinic.com/content/preview.cfm/n/382/t/Peripheral%20artery%20disease/

Objectives



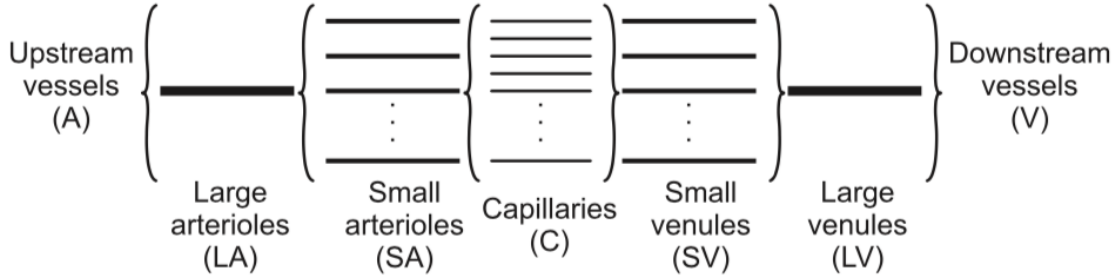
- To model blood flow in the rat hindlimb using vessel wall mechanics
- To compare vessel dynamics before and after occlusion to understand the body's immediate (acute) response

Anatomic Schematic of Rat Hindlimb

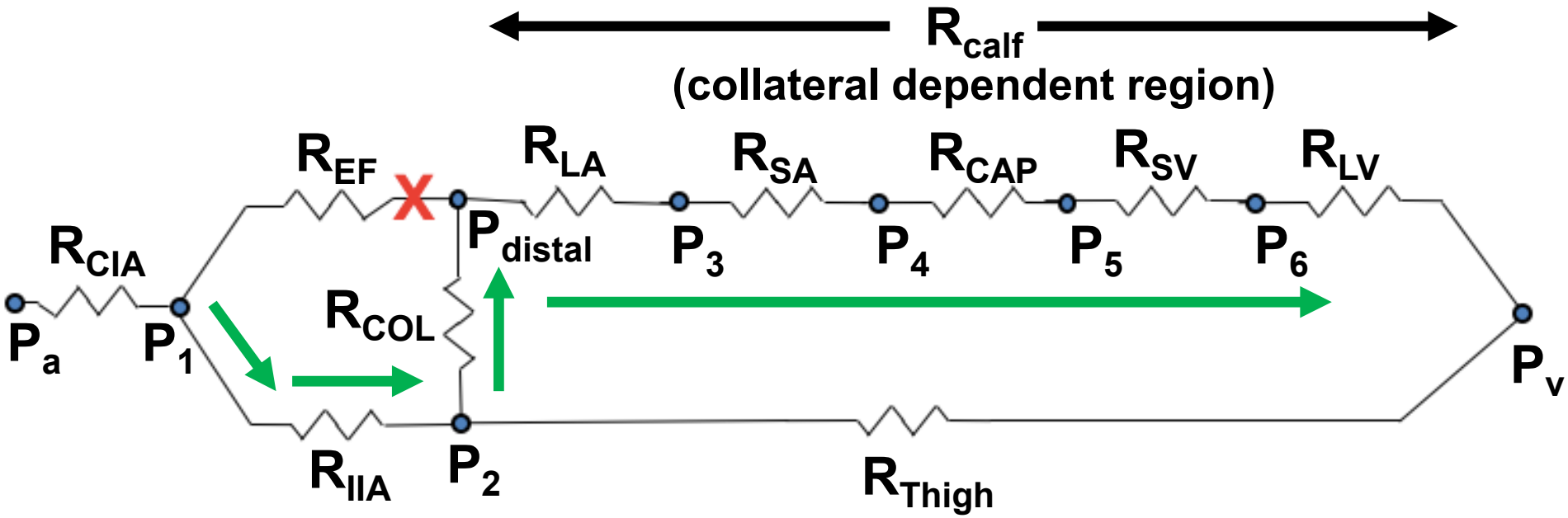


Vascular Network Model

P_a=140 mmHg
P_v=0 mmHg



Arciero et al., 2008



Hemodynamic Principles

Q: Blood Flow
R: Resistance
P: Pressure
D: Diameter
L: Length
μ: Viscosity of Blood

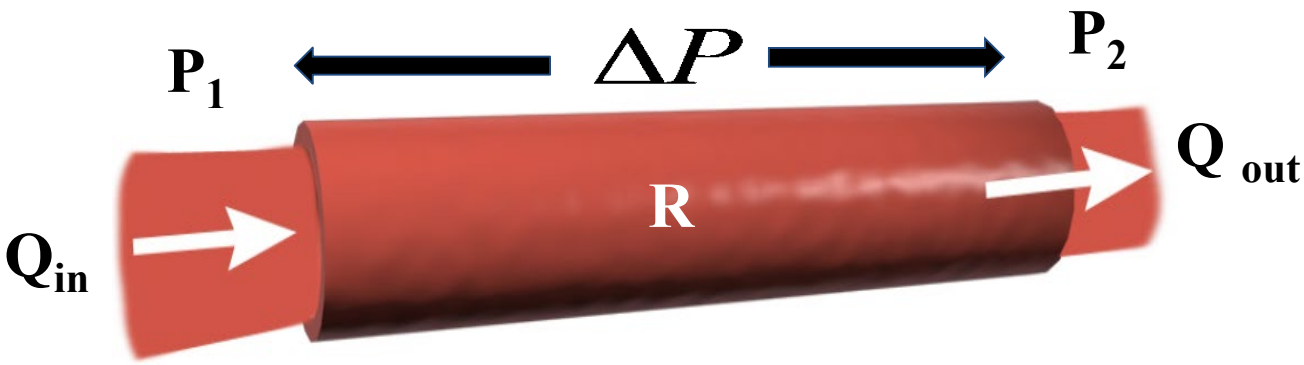
Ohm's Law

$$Q = \frac{\Delta P}{R}$$

Poiseuille's Law

$$Q = \frac{\pi D^4 \Delta P}{128 L \mu}$$

$$R = \frac{128 L \mu}{\pi D^4}$$

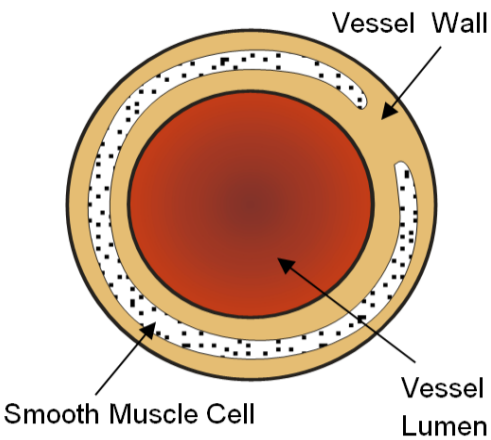


Vessel Wall Mechanics

Vessel wall is under tension **T**

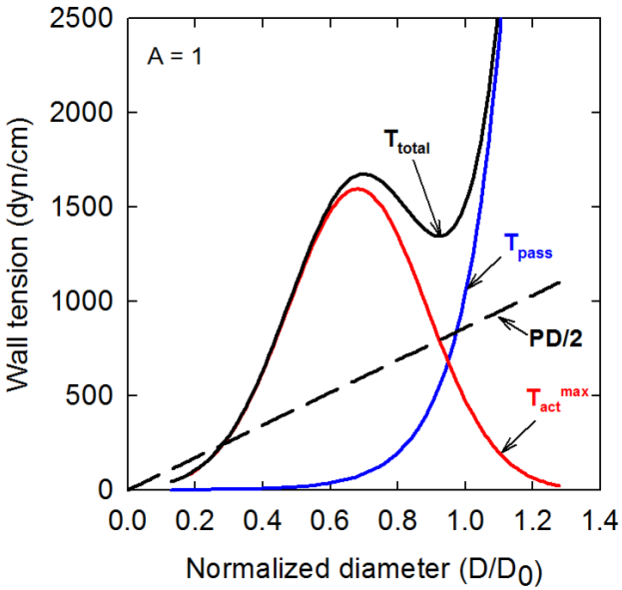
$$T_{total} = T_{pass} + AT_{act}^{max}$$

$$T = \frac{PD}{2}$$



Activation, **A** represents degree of smooth muscle tone

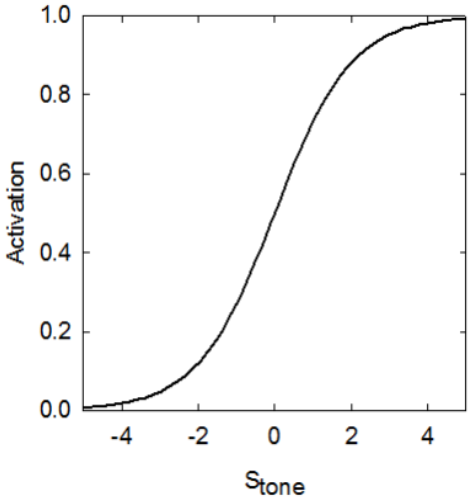
$0 < A < 1$ $\uparrow A \longrightarrow \downarrow D$



Activation and Stimulus

Activation is a sigmoidal function

$$A_{total} = \frac{1}{1+\exp(-S_{tone})}$$



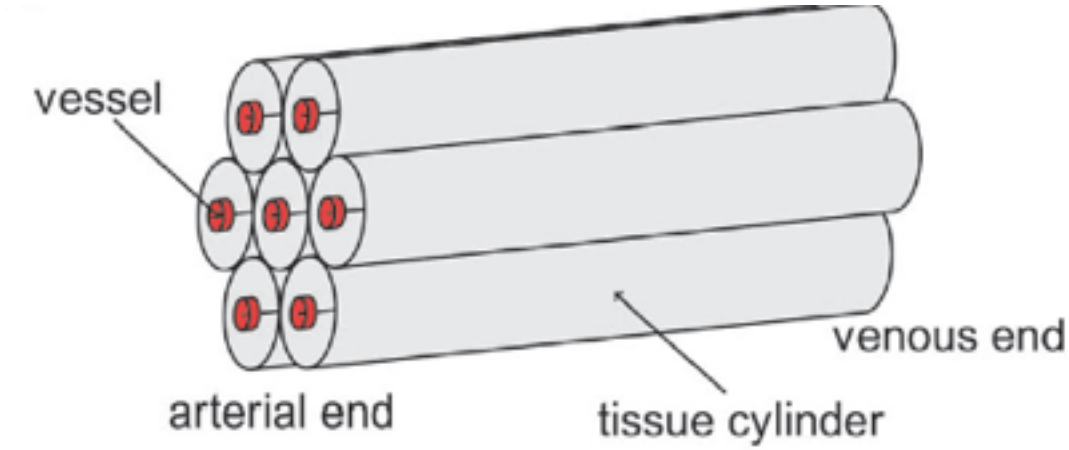
S_{tone} is the stimulus that determines the level of smooth muscle tone

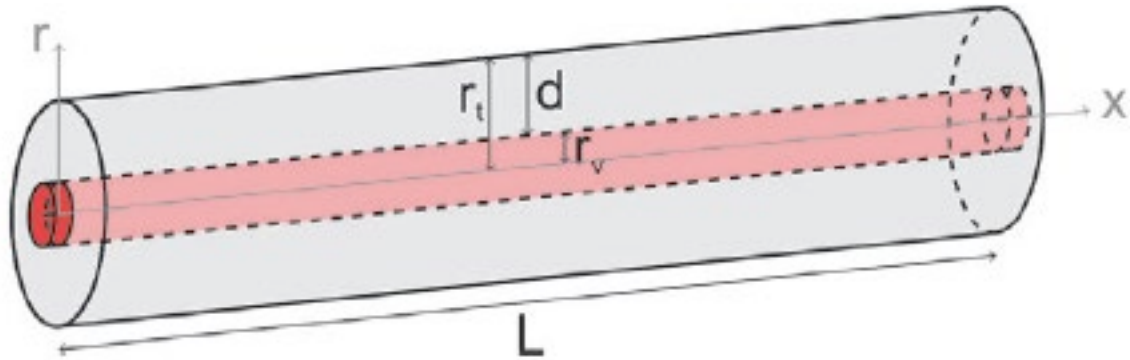
$$S_{tone} = C_{myo}T - C_{shear}\tau - C_{meta}S_{cr} + C''_{tone}$$

$$\uparrow S_{tone} \rightarrow \uparrow A \rightarrow \downarrow D$$

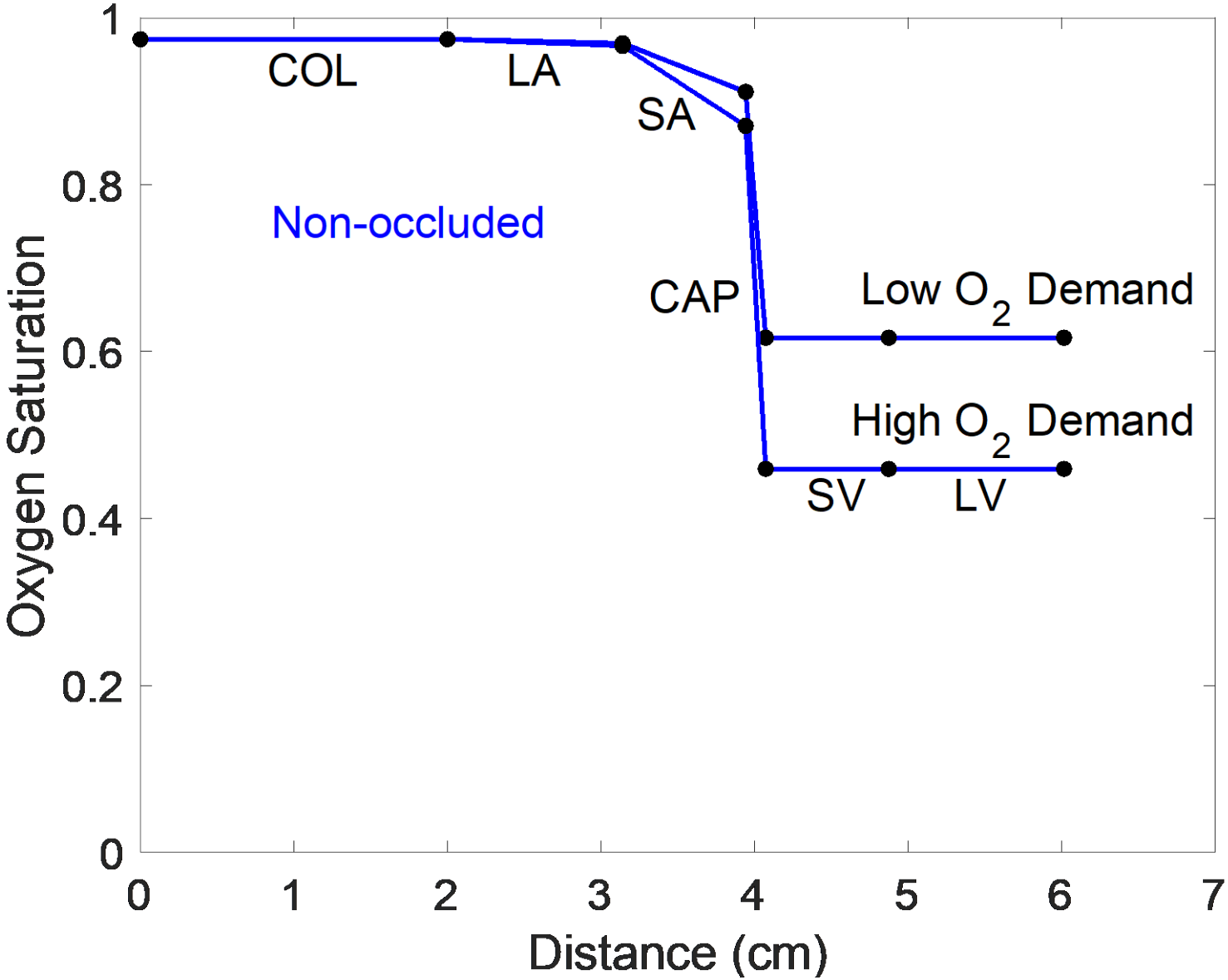
Oxygen Saturation

Krogh cylinder model describes delivery of oxygen to tissues

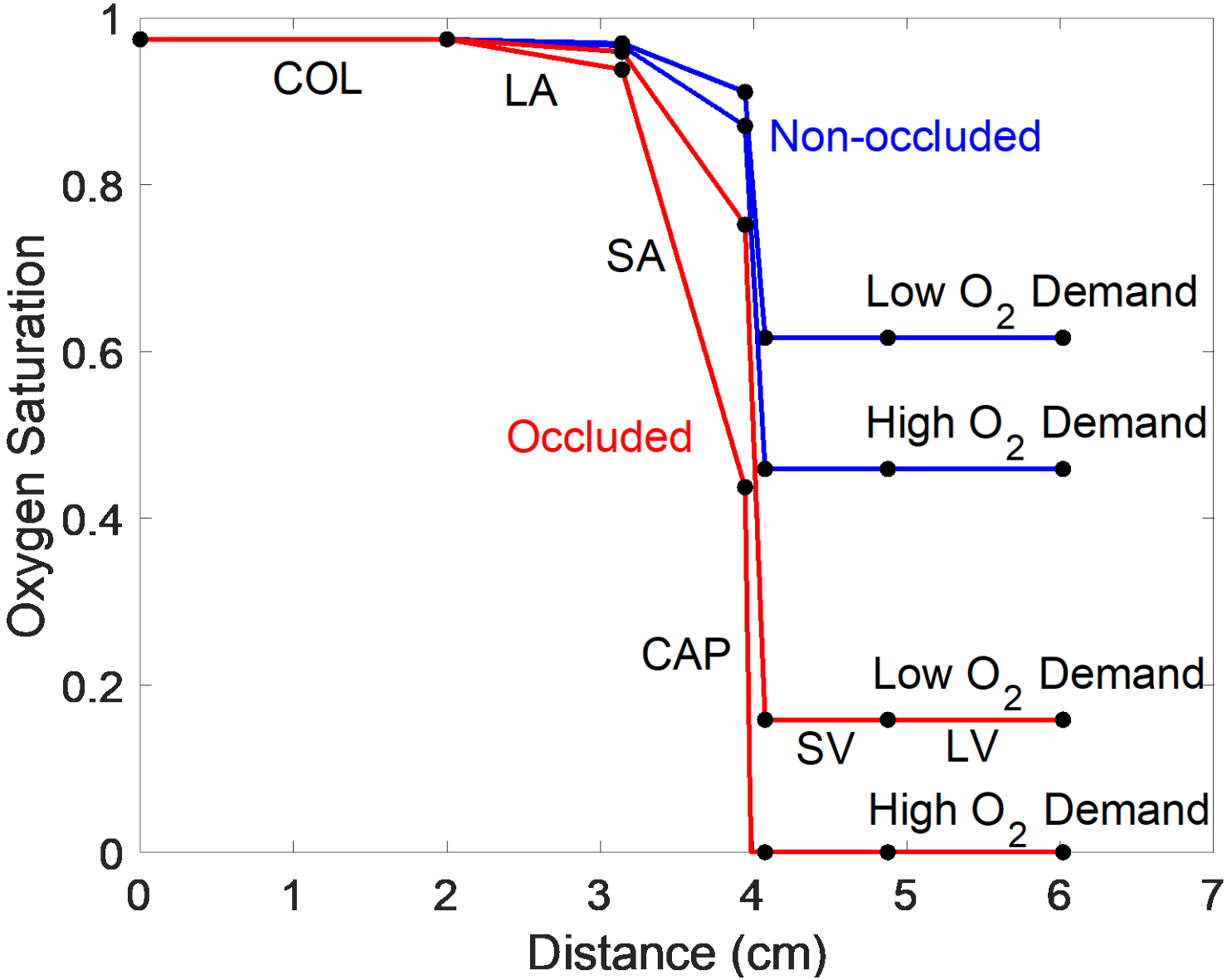




Oxygen Saturation



Oxygen Saturation



Diameters and Activations

$$\frac{dD}{dt} = \frac{1}{\tau_d}\frac{D_c}{T_c}(T - T_{total})$$

$$\frac{dA}{dt} = \frac{1}{\tau_a}(A_{total} - A)$$

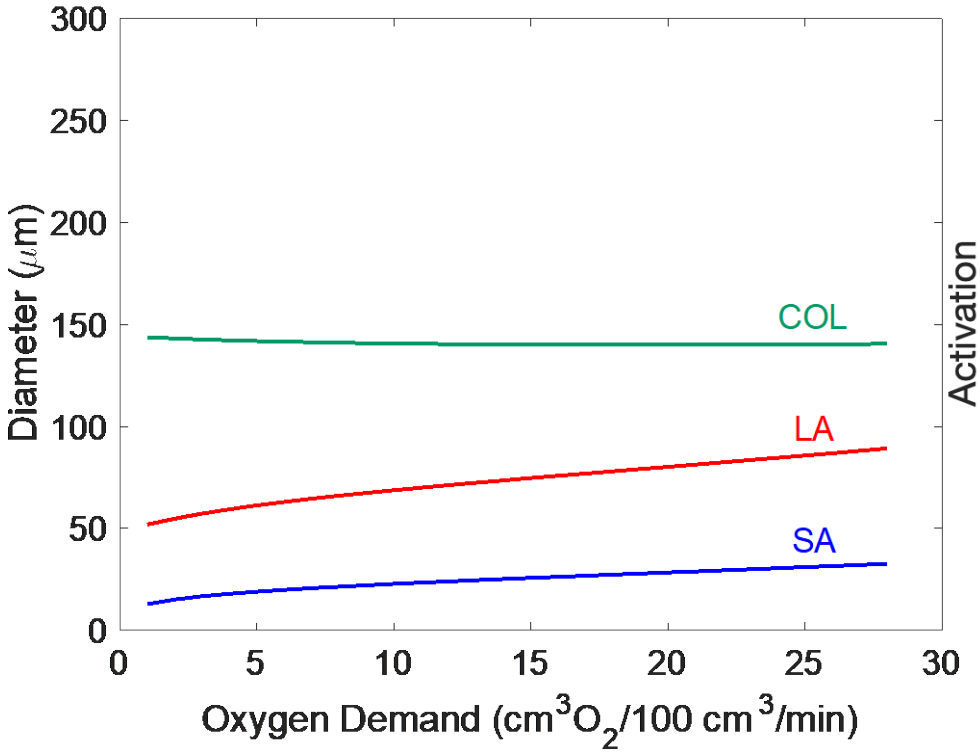
Non-occluded control state assumptions:

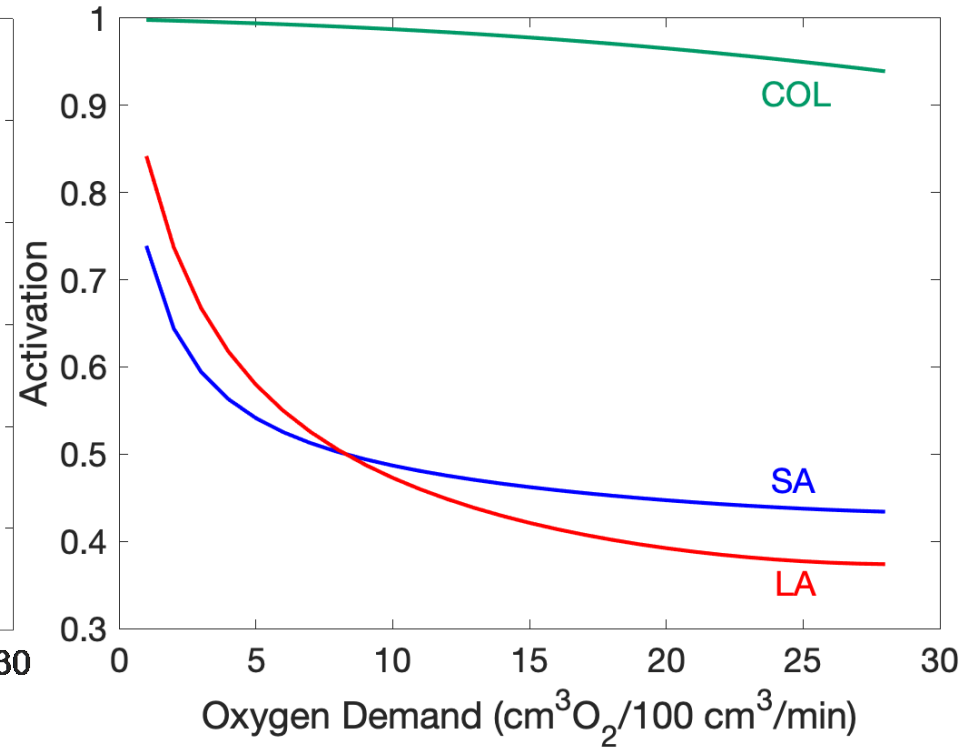
- A = 0.5 in LA and SA compartments
- A = 0.99 in collateral

Occluded Assumptions:

- No flow through the femoral artery

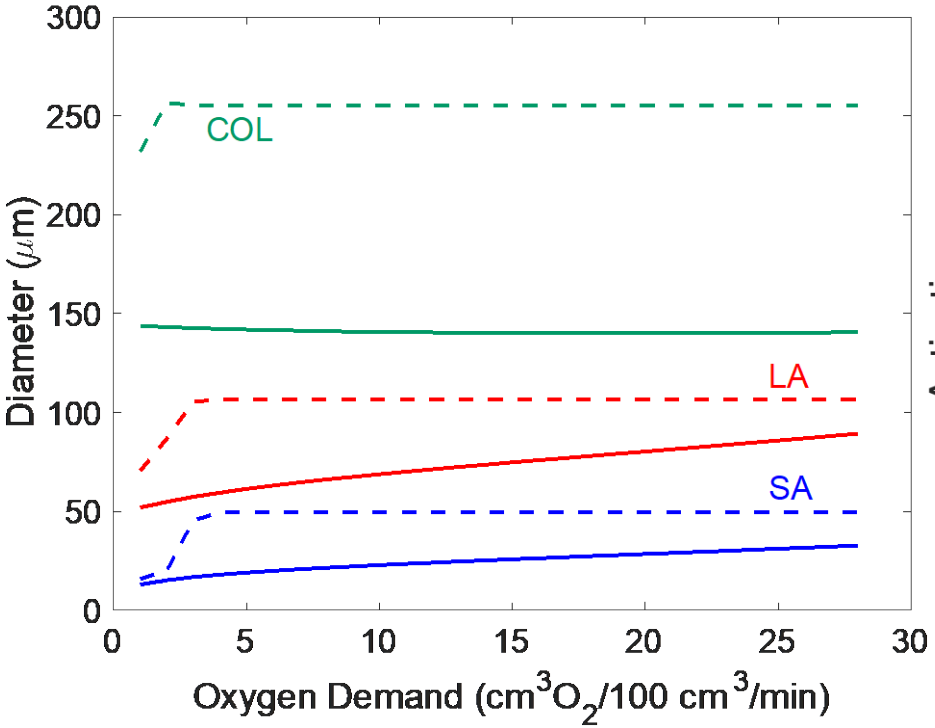
Preliminary Results: No Occlusion

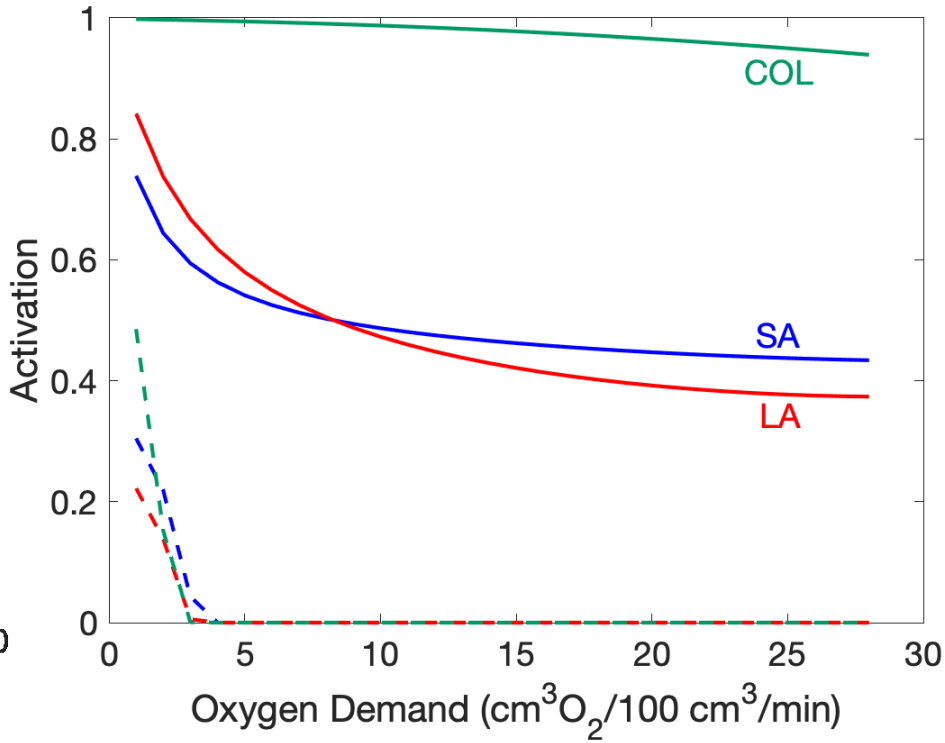




Preliminary Results: Occlusion

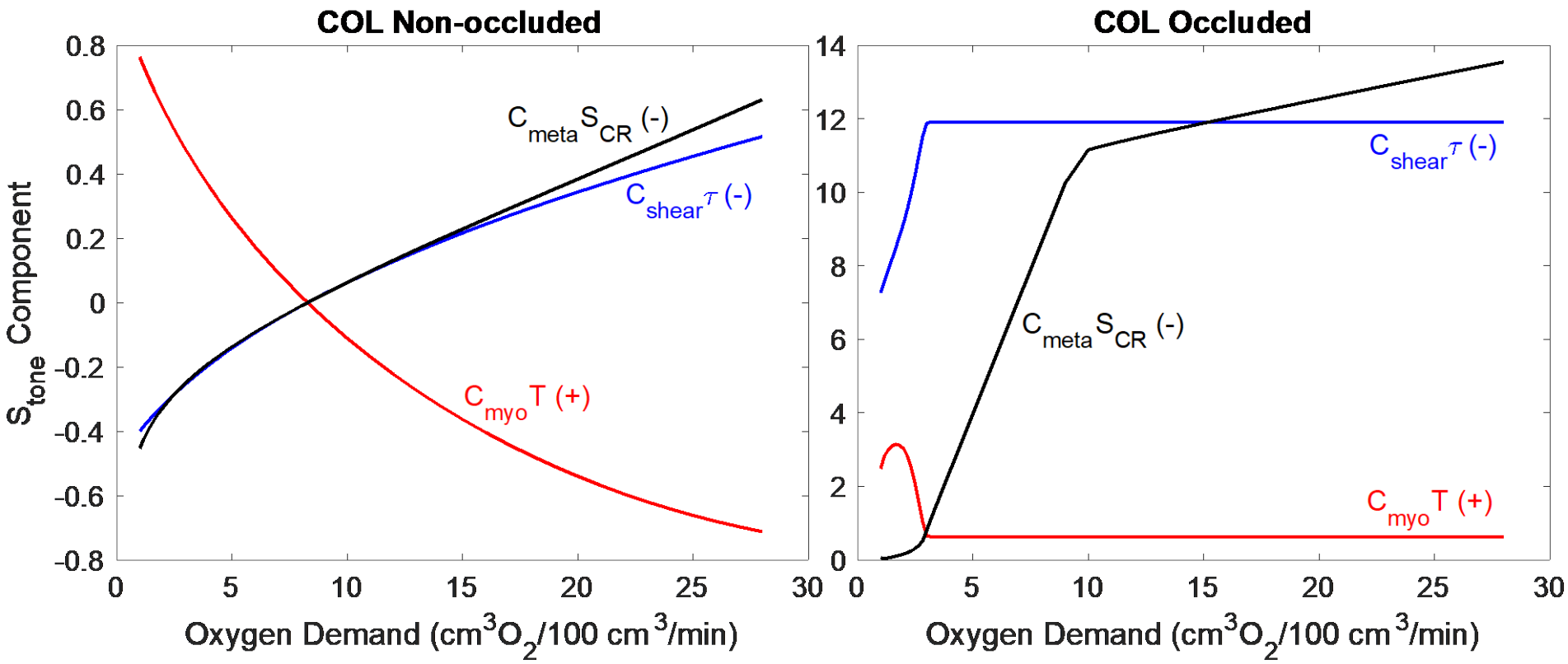
Solid: Non-occluded
Dashed: Occluded



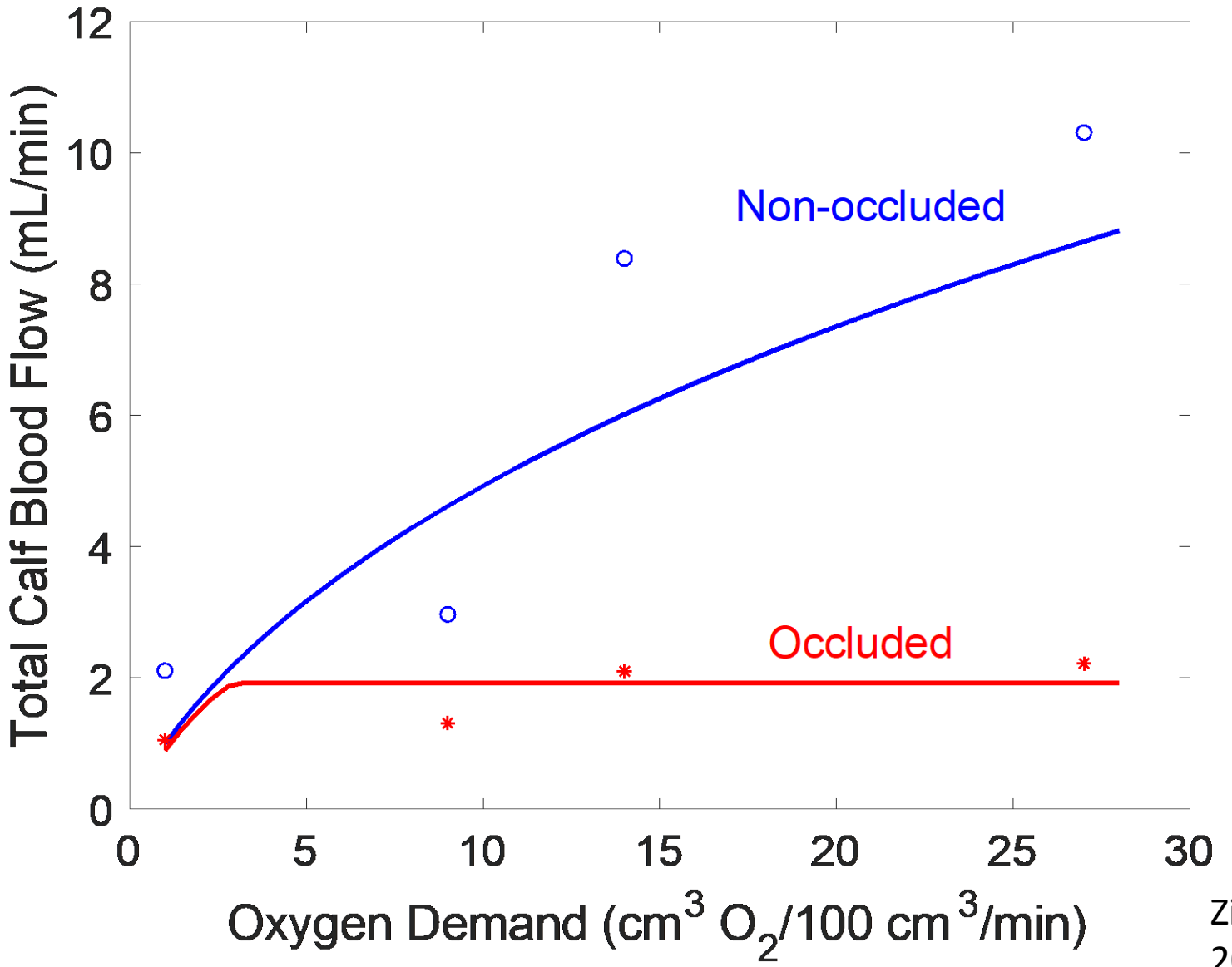


Preliminary Results: Vascular Tone

$$S_{tone} = C_{myo}T - C_{shear}\tau - C_{meta}S_{CR} + C''_{tone}$$

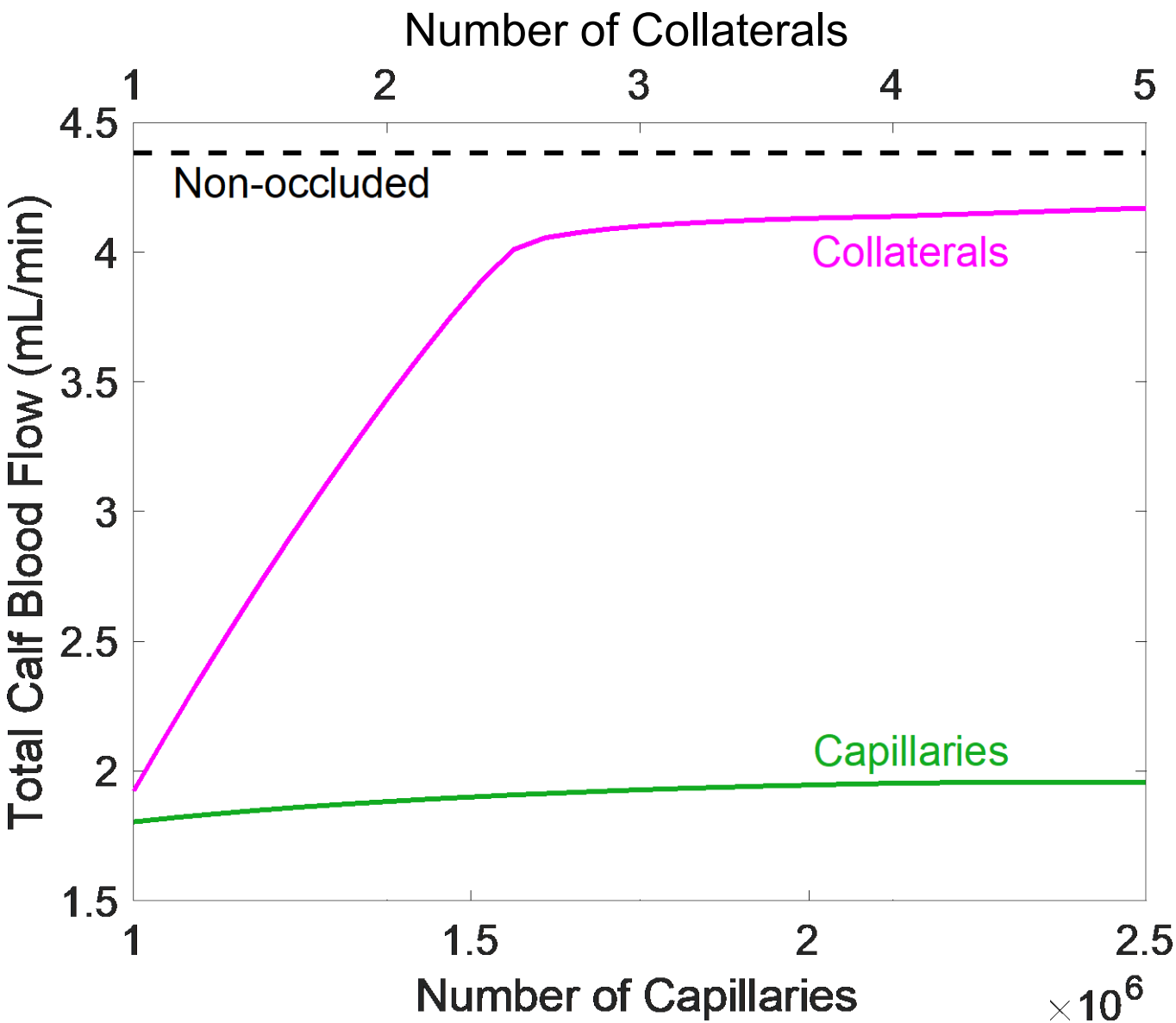


Preliminary Results: Blood Flow



Ziegler et al., 2016

Preliminary Results: Blood Flow



Discussion

- Dilation of vessels indicates the body possesses a limited compensatory ability
- Occlusion significantly reduces blood flow and oxygen saturation
- Preliminary results suggest PAD treatments that target the collateral circuit may be more effective
- Addition of chronic vascular responses to current model

Acknowledgements

IUPUI
CENTER FOR RESEARCH AND LEARNING
Division of Undergraduate Education

- Julia Arciero (Mathematics, IUPUI)
- Jared Barber (Mathematics, IUPUI)
- Joseph Unthank (Vascular Surgery, Indiana University School of Medicine)
- Myson Burch (Purdue University)
- Thomas Freestone (IUPUI)
- Emma Brewer (Rose-Hulman Institute of Technology)
- Jordan Pellett (University of Wisconsin-La Crosse)
- Elizabeth Franko (University of Scranton)
- Lauren Lembcke (Clemson University)
- NSF DMS-1654019
- IUPUI Center for Research and Learning