Modeling Acute Blood Flow Responses to a Major Arterial Occlusion

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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
Pa = 140 mmHg
Pv = 0 mmHg

Vascular Network Model

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

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

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

$$0 < A < 1 \quad \uparrow A \rightarrow \downarrow D$$
Activation and Stimulus

Activation is a sigmoidal function

\[ A_{\text{total}} = \frac{1}{1 + \exp(-S_{\text{tone}})} \]

\( S_{\text{tone}} \) is the stimulus that determines the level of smooth muscle tone

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

\[ \uparrow S_{\text{tone}} \rightarrow \uparrow A \rightarrow \downarrow D \]
Oxygen Saturation

Krogh cylinder model describes delivery of oxygen to tissues.
Oxygen Saturation

Non-occluded

Distance (cm)

COL, LA, SA, CAP, SV, LV

Low O₂ Demand, High O₂ Demand
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

Graphs showing the relationship between oxygen demand and diameter or activation for different conditions.
Preliminary Results: Vascular Tone

\[ S_{\text{tone}} = C_{\text{myo}} T - C_{\text{shear}} \tau - C_{\text{meta}} S_{\text{CR}} + C''_{\text{tone}} \]
Preliminary Results: Blood Flow

Ziegler et al., 2016

![Graph showing blood flow against oxygen demand](image)
Preliminary Results: Blood Flow

Number of Collaterals

Total Calf Blood Flow (mL/min)

Non-occluded

Collaterals

Capillaries

×10^6
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
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