PhD Qualifying Exam – ME-BE

Biofluid Mechanics

A. Describe the shape of atherosclerotic disease and why this can cause clinical symptoms of angina pectoris and myocardial infarction.

B. The normal left anterior descending (LAD) coronary artery has a diameter of 4 mm with a peak flow rate of 300 ml/min and a mean flow rate of 170 ml/min. Assume the kinematic viscosity of blood is 0.04 cm^2/s.

i. What are important non-dimensional parameters for this physiologic flow?

ii. Estimate values for these parameters and describe the flow patterns you would expect with these parameters.

iii. What would you expect the velocity profiles to look like given a Womersley analysis.

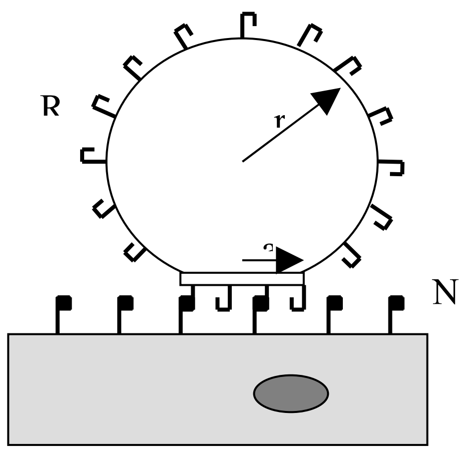
C. With severe disease, the LAD can become stenotic. If the angiogram shows an 80% diameter stenosis

i. Would you expect turbulence and why?
ii. What might happen to the pulsatility of the flow?
iii. What would happen to the wall shear stress?
iv. What might happen to the intralumenal pressure in the stenosis?
v. What might happen to platelets under these conditions?

Use quantitative estimates to justify your answers.

Cellular Engineering

Consider the cadherin-mediated adhesion of a nearly spherical keratinocyte to an epithelial cell.



R_T	total number of cadherins per keratinocyte (#/cell)
N_s	surface density of cadherins on epithelial cell sheet (#/μm^2)
r	keratinocyte radius (μm)
a	radius of contact area (μm)
k_f	forward reaction rate constant for cadherin-cadherin binding (μm^2/s)
k_r	reverse reaction rate constant for cadherin-cadherin binding (s^{-1})

(a) Assuming no depletion of cadherins on the epithelial cell, derive an expression for the rate of accumulation of bonds B and the equilibrium bond number B (#/cell) in terms of cell geometries, cadherin densities (R_T, N_s), and binding constants (k_f, k_r). HINT: only receptors in contact area participate in binding reactions.

(b) You use a centrifugation assay that applies a normal force F_c to quantify adhesion. Assuming that the force applied to the bonds influences only k_r as described below,

$$k_r = k_r^0\left(1+\frac{F_c}{F_b}\right)$$ where F_b is the total bond force and k_r^0 is a constant.

- Obtain an expression for the equilibrium bond number B_{force} in terms of F_c and binding and mechanical parameters. Clearly state all assumptions.

- Derive an expression for the detachment force F_{crit}.

Tissue Mechanics

You are asked to evaluate the cortical bone phenotype in a mutant mouse model in which the gene for a specific protein known to be present in bone is knocked out. You are given femurs from mutant mice as well as wild-type controls from the same background strain.

A. Describe what kind of mechanical test you would perform on the bones and why? Sketch the corresponding stress distribution on a cross-section of the femoral diaphysis.

B. What assumptions would you make about the material properties of the cortical bone? Show mathematically the form of an appropriate constitutive model.

C. What parameters would you measure from your mechanical test?

D. Explain how you would determine material properties of the cortical bone.

E. Assuming you find differences in both the structural and material properties, what additional measurements would you make to help explain your results?

F. If you find no differences in either the structural or material properties, what are the possible explanations for this finding?