BIOLOGICAL FRAMEWORKS FOR ENGINEERS

Exam #2 [Due 12/9/11] by email

Work on this on your own; do not discuss it with other members of the class. You can use any web or library resources to help, and you can ask me for clarification. This exam is due via email to nsniadec@uw.edu by 5:00 pm on its due date or via paper copy that you turn in at the start of class.

I. Short Answers

1. Describe the three parts of signal transduction in general terms.
2. Describe three functional roles for each filament of the cytoskeleton.
3. Why is CapZ and tropomodulin important in a sarcomere?
4. Describe the difference between a kinase and a phosphatase.
5. What roles do integrins have in cell migration?
6. What is the difference between fused and unfused tetanic tension?
7. How does troponin regulate actin-myosin contraction?
8. Briefly describe the difference between adherens junctions, tight junctions, and gap junctions.
9. Describe the activation of G-Protein Linked Receptors.
10. Choose one 'hot' ethical topic in biotechnology and describe two pros and two cons for research or applications in this area.

II. Short Problems

A. A 75 kg person doing light work requires about 3000 kcal of food energy per day, 40% of which is actually used by the body's cells and 60% is lost as heat and waste products. All of this energy is stored as ATP before being used by the cells. When cleaved into ADP and Pi, ATP releases 12.5 kcal per mole.

   a. How many moles of ATP are turned over per day in this fashion? What mass of ATP does this correspond to? (The molecular weight of ATP is 507 g/mol)

   b. The body actually contains approximately 5 grams of ATP at any given time. Estimate the average recycle time for an ATP molecule. (*You will see it is much more efficient to reuse ADP rather than synthesis it from scratch.*)

B. The flexural rigidity of a rod-like structure like a microtubule is a measure of its bending stiffness. Flexural rigidity is given by EI, where E is the Young's modulus and I is the geometrical moment of inertia of the rod cross-section (i.e. moment of inertia). Assuming that the microtubule behaves like a slender rod of length L, the critical force P_{cr} at which buckling occurs is given by Euler's formula

$$P_{cr} = \frac{\pi^2 EI}{L^2}$$

Applying this equation, the flexural rigidity is estimated by measure the force at which the microtubule of known length is observed to buckle.

a. Suppose that microtubules have a Young's Modulus of 4.5 GPa. What would be critical load for a hollow microtubule that is 10 μm long?

b. Suppose that actin filaments have a Young's Modulus of 2 GPa, what is the critical load for an actin filament that is 10 μm long. How does it compare to microtubule buckling?

C. In a previous homework, a three-element model for muscle was presented, consisting of a linear spring (k), a viscous dashpot (η), and a contractile force-generator (T_0). For this problem, the force-generator turns on at t = 0 and remains constant with magnitude T_0 for a period C and then shuts off. The muscle studied is in an *isotonic* set-up with external tension T_1. The muscle length before stimulus is L_0 and upon relaxation, the muscle cannot stretch past L_0.

a. Give the equations that describe the muscle length L for t>0. You can assume that $L = x_1 + x_2$.

b. Graph your prediction on a plot of L versus t for $0 < t < 1$ second. Let η= 0.06 dynes*s/cm, k = 0.3 dyne/cm, C = 0.4 seconds, T_0 = 4 dyne. Include several traces on your curve for T_1 = 1, 2, 3, and 4 dyne.

c. How do different values of external tension affect muscle dynamics?

D. In cardiopulmonary bypass, a heart-lung machine is connected to your heart and replaces its pumping action. This allows the surgeon to operate on a heart that isn't moving and full of blood. A tube is placed in your heart to drain blood into the machine. The machine removes carbon dioxide from your blood, adds oxygen, and then pumps the blood back into your body.

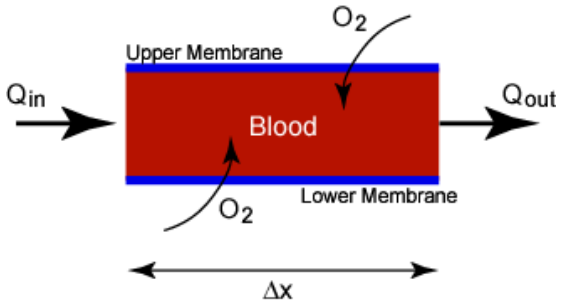

Figure 2. Control volume of length Δx of the membrane oxygenator.

In the heart-lung machine, blood flows at a rate of Q_b = 5 L/min through a membrane oxygenator, which transfers 200 mL/min of oxygen to the blood flowing through it (Figure 2). The semi-permeable membrane allows oxygen transport from the high concentration of oxygen outside membrane. (Here, it is approximated as the two flat, parallel membranes). The concentration of oxygen in the blood C relates to flux of oxygen J through the membranes and is given by

$$J = D\frac{C_{O2} - C}{t} \tag{2}$$

where diffusivity of oxygen in the membrane is $D \approx 1\text{x}10^{-6}$ cm^2/s, concentration of pure oxygen outside the tube is C_{O2} = 0.204 cm^3 of O_2 per cm^3 of blood, and thickness of the membrane is t = 5 μm. The mass balance of oxygen through the control volume of the oxygenator is

$$Q_b\, C\big|_x + 2Jw\Delta x = Q_b\, C\big|_{x+\Delta x} \tag{3}$$

where $C\big|_x$ is oxygen concentration at the entrance of the control volume, $C\big|_{x+\Delta x}$ is the concentration at the exit, and the width of the membrane is w = 10 cm (out of the page).

Please answer the following equations:

(1) What is the differential equation for the concentration of oxygen through the oxygenator? Note, in the limit of $\Delta x \rightarrow 0$:

$$\frac{C\big|_{x+\Delta x} - C\big|_x}{\Delta x} = \frac{dC}{dx} \tag{4}$$

(2) What should the length of the oxygenator channel be in order for the oxygen concentration of the blood going back to the body to be 0.14 cm^3 of O_2 per cm^3 of blood? Assume blood enters the oxygenator at 0.10 cm^3 of O_2 per cm^3 of blood.

E. In this question we will assess the strength of cortical and trabecular bone. Stress-strain curves in a compression test have been obtained for cortical and trabecular bone (Figure 3). The two samples of trabecular bone came from patients with healthy and osteopenic bone. From these results, we can determine the mechanical properties for each bone sample. These values are shown in Table 1.

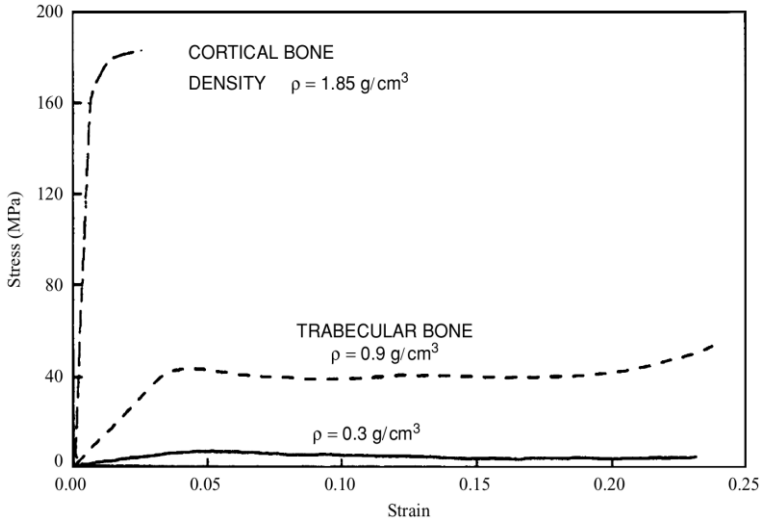

Figure 3. Stress-strain curves of bone under compression

Table 1. Mechanical Properties of Bone in Compression

	Cortical	Trabecular (ρ=0.9 g/cm³)	Trabecular (ρ=0.3 g/cm³)
Yield Strength (MPa)	165	35	5
Ultimate Strength (MPa)	180	60	5
Yield Strain (m/m)	0.01	0.03	0.04
Ultimate Strain (m/m)	0.025	0.235	0.23
Elastic Modulus (GPa)	16.5	1.2	0.125
Anelastic Modulus (MPa)	N/A	120	0
Strain-Energy Density (J/cm³)	?	?	?

Please answer the following questions:

(1) The strain energy density U of a material gives a measure of the amount of energy it can absorb before fracture. This relationship is given by

$$U = \int_0^{\varepsilon_u} \sigma d\varepsilon \tag{5}$$

where σ is the compressive stress, ε is the strain, and ε_u is the ultimate strain at failure. Estimate U for the three bone samples.

(2) What does your result indicate about the function of healthy trabecular versus cortical bone in absorbing energy?

(3) Describe the structure of the two bone types and how it governs the difference in strain energy density.

(4) What does your result in part (1) indicate about the risks of osteoporosis?

III. Essay

You are hanging out minding your own business at Earl's on the Ave and from across the bar you notice someone with a line of empty long island iced tea glasses playing darts. All of a sudden, his aim amiss, he hits a buddy of his with the dart right in the thigh. It was a pretty hard shot and the dart pierces the skin and comes to rest with its tip touching his femur. The victim crumples to the ground as, for some reason his lower leg muscles 'give out'. He is also bleeding pretty good on his jeans.

Your job is to retrace the events of the dart from a biologic perspective. Pretend that you are infinitesimally small and situated on the tip of the dart. Make a list of the tissues that you are going to pass through on your way up to the femur. Include the common name of the tissue, its type, structure, and function. Specifically note the cellular and extracellular matrix characteristics of each tissue and any special features or functions of those regions. Complete this descriptive question in one page or less.