UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, April 2001

MIE 439 - BIOMECHANICAL ENGINEERING

Examiner: C. R. Ethier

STUDENT NAME: ______________________________

STUDENT ID NUMBER: ___________________________

Open book (Type X)
All calculator types allowed
Time allotted: 2.5 hours
Numbers in left margins are part marks for subquestions.

Question	Maximum Mark	Actual Mark
1	8	
2	16	
3	18	
4	22	
5	18	
6	18	
Total	**100**	

Note: you do not need to re-derive any results you use from the course notes.

Question 1.

The following questions are based on the in-class presentations. Answer any 2 of the following 4 questions. **Exception**: you may not answer a question based on your own group's presentation.

4 (a) How many muscles are there attached to the outside of the eye, and what is their (collective) function? Describe a recent discovery that has changed the way people think about ocular movement [Excluded group: Recent Developments in Ocular Mechanics.]

4 (b) List three potential applications of telesurgery and the advantages of using telesurgery in each application. [Excluded group: Telerobotic Surgery.]

4 (c) List at least 4 design considerations for total artificial knees. [Excluded group: Total knee replacement.]

4 (d) How are most myoelectric prostheses controlled? Describe in your own words some of the bioengineering issues associated with control of these prostheses. [Excluded group: Myoelectric prosthesis.]

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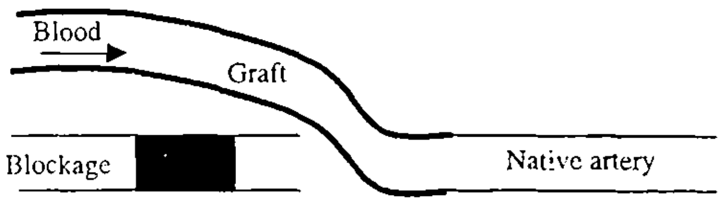
Question 2.

You decide to cure your hiccups by breathing into a paper bag. Assume that the bag is initially filled with 500 ml of air (referenced to BTP) having the composition given on p. 103 of the notes for ambient air. Assume a breathing rate of 12 breaths/minute, a CO_2 production rate of 235 ml/min at BTP, and an O_2 consumption rate of 284 ml/min at BTP. You can also assume that you begin by inhaling all the air in the bag (i.e. tidal volume is 500 ml for the first breath), and that on each subsequent breath you increase your tidal volume so as to completely empty the bag on inhalation. Compute the CO_2 concentration (in percent) in the bag after exhalation on the 10^{th} breath.

Question 3.

A common surgical procedure is bypass graft implantation, in which a natural or synthetic arterial substitute ("the graft") is used to carry blood around an obstructed portion of an artery. Data suggests that these grafts perform best if their compliance matches that of the native artery that they are attached to. Compliance is a measure of the elasticity of the vessel walls; here it is defined as $C = (D_s/D_d - 1)/(P_s - P_d)$ where D_s and D_d are systolic and diastolic diameter, and P_s and P_d are systolic and diastolic pressure, respectively.



(a) One material used for synthetic grafts is ePTFE (Teflon), which is very stiff compared to native
8 arteries. Knowing that Young's modulus for ePTFE is 40 times larger than that for an artery, and given the following properties measured from actual grafts, estimate the ratio of graft wall thickness to artery wall thickness. Hint: you may find certain formulas on pp. 50 and 51 of the notes to be useful.

Measured Quantity	Artery	ePTFE
Average Diameter (mm)	6·8	5·4
Average Compliance ($mmHg^{-1}$)	$8{\cdot}0 \times 10^{-4}$	$1{\cdot}2 \times 10^{-4}$

Data from: N. R. Tai; H. J. Salacinski; A. Edwards; G. Hamilton; A. M. Seifalian, British Journal of Surgery, 87: 1516-1524 (2000).

(b) One design approach is to make the wall of the graft thin enough so that the graft compliance matches that of the artery. Discuss the pros and cons of doing this from a biomedical engineering
4 design viewpoint.

6 (c) Why might compliance mismatch promote redevelopment of disease? It will be useful to think about what endothelial cells can "sense", and to know that there is a post-operative healing response that includes the growth of endothelial cells onto the new graft surface.

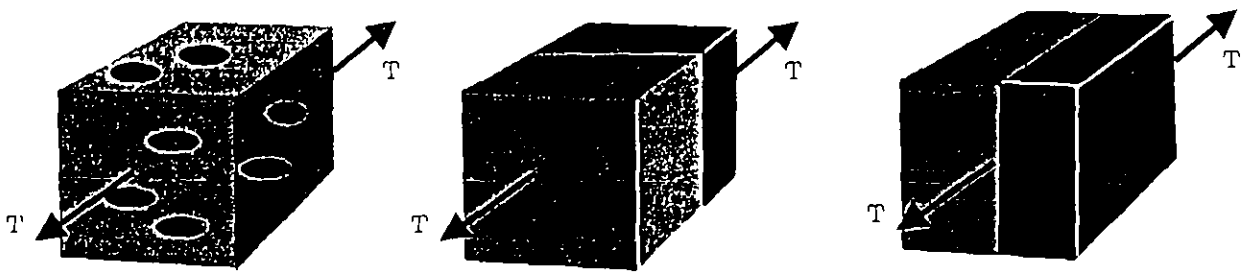
Question 4.

A cartilage sample consists of cells (chondrocytes, with effective Young's modulus E_{cell}) and extracellular matrix (ECM, with effective Young's modulus E_{ECM}), as shown in the left Figure. The volume fraction of cells (cell volume/total tissue volume) is ϕ. The tissue sample is subjected to a uniaxial tension, T, and has unstretched length L and cross-sectional area A. We wish to determine the Young's modulus for the tissue sample, E_{tissue}. In general this is a complicated problem; however, we can get bounds for E_{tissue} by considering two special cases. In the first case, we replace the real tissue configuration by a "series" configuration where a cell-containing volume is in series with an ECM-containing volume (see middle Figure). In the second case, we replace the real configuration by a "parallel" arrangement. In both cases, we require the total tension, T, applied to the tissue to match that for the real case, and the total elongation to also match that occurring in the real case.

6 (a) Considering the work done by the tension force T, show that the energy stored in the real tissue sample is $AL\, E_{tissue}\, \varepsilon^2/2$.

10 (b) Consider the series configuration. You should first convince yourself that in this configuration, the stress σ is the same for both tissue components and is equal to the true stress in the tissue, but the strain ε is different for the two components. Thinking about the energy stored in each of the two tissue components, show that the overall tissue modulus can be written as $1/E_{tissue} = \phi/E_{cell} + (1-\phi)/E_{ECM}$.

6 (c) Using a similar approach for the series configuration, show that $E_{tissue} = \phi\, E_{cell} + (1-\phi)\, E_{ECM}$. Hint: What is the same for the two components? (It's not the stress.)

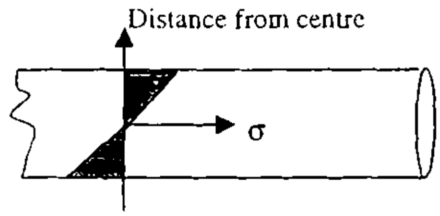


Real tissue (black = cells) Series configuration Parallel configuration

Question 5.

In the notes (pp. 140-144) we computed the weight that could be supported by the forearm of a hypothetical subject. Consider the radius bone in this same subject, who is holding a 31.2 lbm mass in his/her hand.

12 a) Using values given on pp. 140-144, calculate the maximum **tensile stress** in the bone. This occurs just distal to the insertion of the biceps. You should recall that the maximum bending stress occurs as a compressive stress on one side of the "beam" and as a tensile stress on the other side (see figure). To carry out this calculation you will need to include the effects of the "horizontal" component of the forces due to the muscles (which you can assume attach along the centreline of the bone). These components will create a compressive stress that modifies the maximum tensile stress from the bending moment. Treat the radius bone as a solid cylinder of radius r = 0.8 inches.

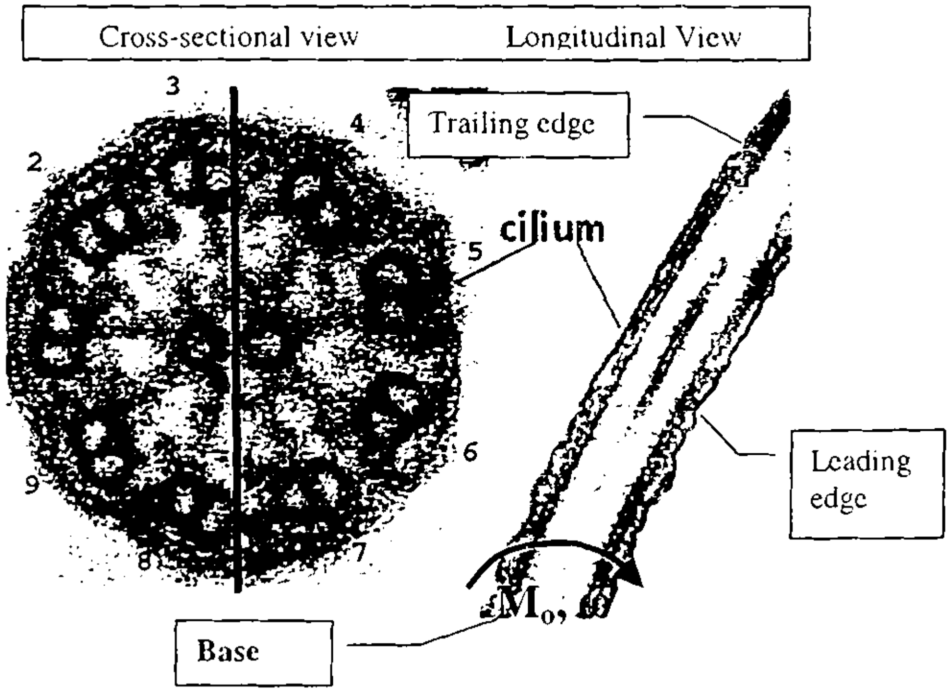


Shaded areas show stress vs. position distribution arising from a bending moment (c.f. equation 9.18)

6 b) If there is a 1 mm defect in the radius bone at the point of maximum tensile stress, how many times can the subject life the weight before his/her bone fractures? Assume fracture will occur when the crack grows to be 10 mm long. Note that 1 psi = 6.90 x 10^{-3} Mpa.

Question 6.

A cilium of length $L = 2\ \mu m$ and diameter $0.4\ \mu m$ sweeps through extracellular fluid ($\mu = 1$ cPoise) with constant angular velocity, ω. You can model this motion as rotation of the cilium about its base, assuming that the cilium has the form of a rigid cylinder.



8 (a) The drag force exerted per unit length on a cylinder is $f = k_1 \mu U$, where k_1 is a constant and U is the local fluid velocity passing over the cylinder. Show that the torque, M_o, exerted on the base of the cilium by the cell body must therefore be $k_1 \mu \omega L^3/3$.

10 (b) Assume that the 9 tubulin dimers (labelled 1 to 9 in the figure) are evenly spaced around the periphery of the cilium. Further assume that the perimeter to the left of the solid line is the trailing edge and the perimeter to the right is the leading edge (see Figure of cross-sectional view). All dimers to the right of this line are under maximum tension (tension = F_{max}); all to the left are under maximum compression (compression = $-F_{max}$). Compute the value of F_{max} at the base of the cilium, assuming that the dimers transfer the entire torque M_o from the cell body to the cilium. Take $k_1 = 2$ and $\omega = 0.2$ rad/s. Make and state other assumptions as needed.