GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

Ph.D. Qualifiers Exam - Fall Quarter 1996

BIOENGINEERING
EXAM AREA

Assigned Number **(DO NOT SIGN YOUR NAME)**

-- **Please sign your name on the back of this page** --

1. Blood flow in the cardiovascular system is three dimensional, unsteady and complex.

a. What is the Wormersley number and what affect does it have on the hemodynamics?

b. Describe methods to quantify the turbulence levels in the cardiovascular system.

c. How do arteries adapt and respond to changes in local hemodynamics?

d. As a stenosis progresses in the carotid artery, what happens to the pressure and flow through this artery? Describe the physiological mechanisms for your answer.

CELLULAR BIOMECHANICS

Consider the cell adhesion model shown in Figure A in which a spherical cell forms a circular contact area (Figure B) on a substrate surface. Fluid flow applies a shear force, F_s, and torque, T, to the cell. Assume that the cell is in mechanical equilibrium and that stress is constant over the contact area (Figure C).

T...Torque about the center of the cell O due to fluid flow.

F_s...Shear force due to fluid flow

R...Radius of spherical cell

a...Radius of the circular contact area

Given the above parameters:

A) Draw a free body diagram showing all forces acting on the cell in equilibrium

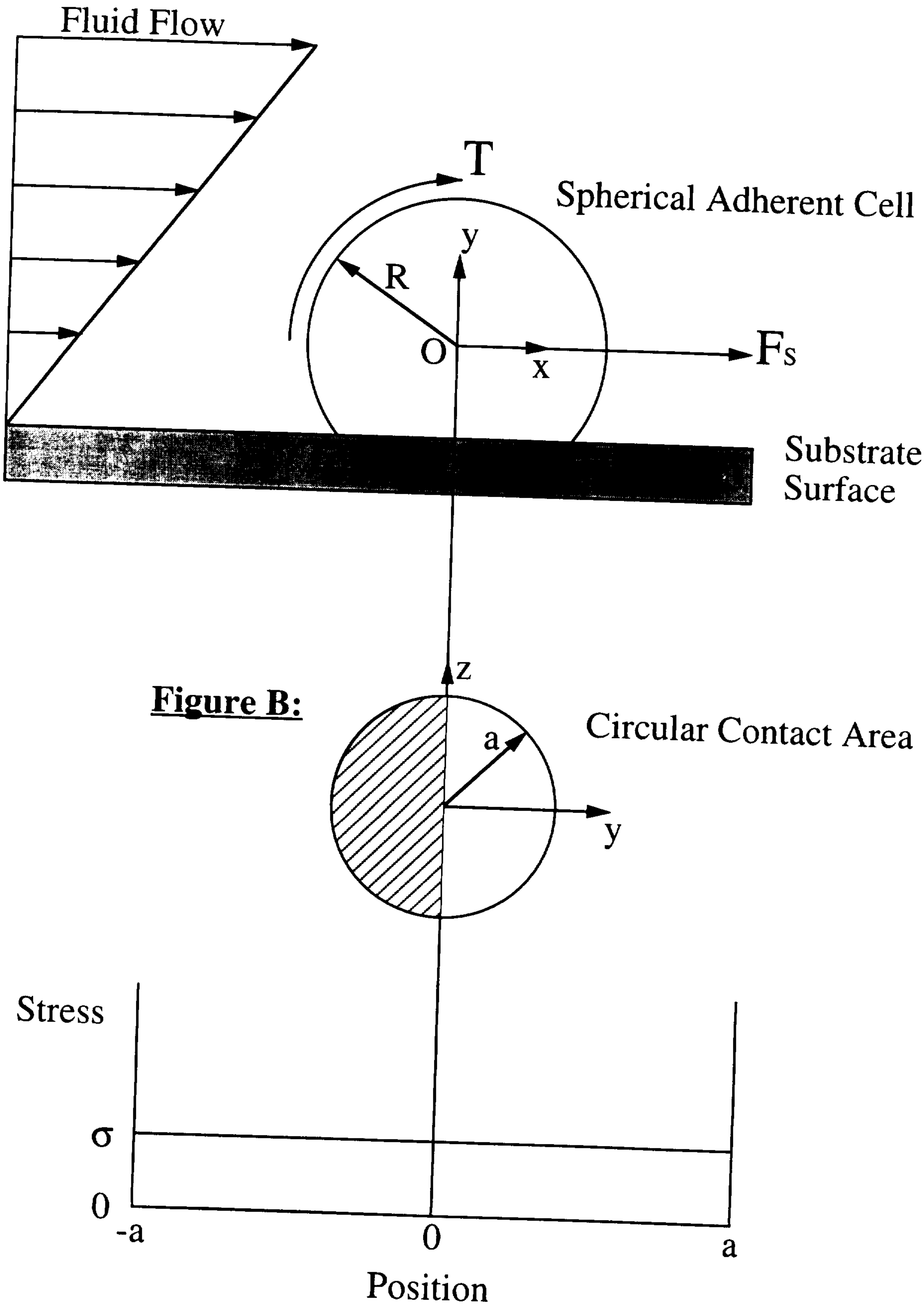
B) Calculate the x component of the resultant adhesion force acting on the contact area between the cell and substrate.

C) Calculate the resultant force normal to the contact area (i.e. in the y direction) acting on the cross-hatched semi-circle area.

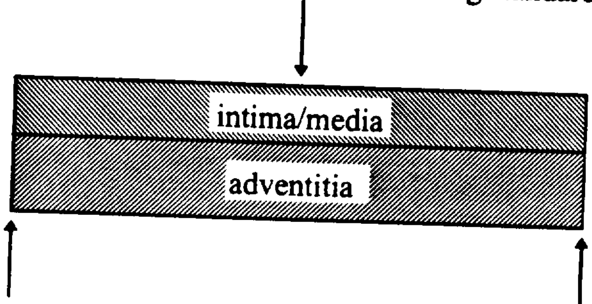
D) Propose a simple discrete mechanism by which the cell adheres to the substrate. What implications does our assumption that stress is constant over the contact area have on this mechanism? Note that reaction forces near the center of the contact area can not effectively resist torque applied to the cell due to a small moment arm. Propose a different stress distribution by drawing on Figure C which accounts for this fact.

CELL ADHESION MODEL

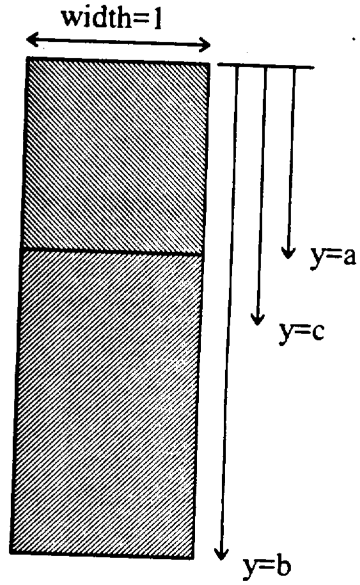
Figure A: **Figure B:** **Figure C:**



Y.C. Fung has begun using bending studies as a supplement to the standard uniaxial and biaxial stress-strain experiments in the determination of material constants in arteries. In these studies, the arterial wall can be thought of as 2 distinct layers if the intima (which is very thin) is lumped with the media. In the bending studies, a section of the artery is opened radially to obtain the zero stress state. The bending moment is then applied to the artery wall in the orientation shown in the figure below. An analysis may then be carried out using standard beam theory.



Part a) Assume that the intima/media and the adventitia are linearly elastic with Young's moduli of E_1 and E_2, respectively. Derive an equation describing the neutral axis location in the arterial wall subjected to pure bending of the type seen in the previous figure. The figure to the right defines the locations of the various planes in the cross section (a: intima/media thickness, b: total thickness, c: location of the neutral axis). Use the following dimensionless quantities in your analysis: $n=E_2/E_1$, $\alpha=a/b$, $\gamma=c/b$. Your objective is therefore to find a relation between γ, n, and α.



Recall that for prismatic beams in pure bending, $\varepsilon = \dfrac{c-y}{\rho}$, (this is true irrespective of the composition of the beam) where ε is the strain, y is the distance from the upper surface, c is the location of the neutral axis, and ρ is the curvature of the neutral axis. Also, $\int \sigma dA = 0$ over the cross section of the beam.

Part b) Is it possible to determine the actual values of E_1 and E_2 from a bending experiment? Note that in this experiment, the following are known: The relative thickness of the two layers, the bending moment, the curvature of the vessel wall, and the relative position of the neutral axis. Please recall that $\dfrac{1}{\rho} = \dfrac{M}{EI}$ for a beam composed of one material (ρ is the radius of curvature, M is the bending moment, E is Young's modulus, and I is the moment of inertia). Note that you are not required to write down any equations for this section.

- 1996 Winter Bioengineering Qualifier Examination
Closed book. Closed Notes.