BIOE 599, Physiology for Engineers
HW 1
Due Monday 2/5 by 11 am
Turn in to Adam's office, Johnson 316B

1. Consider the MATLAB model of the systemic circulation described in section 1.12 of the Hoppensteadt and Peskin textbook (code is provided on Canvas).
    a. Adjust the compliance of the systemic arteries (Csa) by trial and error to achieve the normal blood pressure of 120/80 mmHg. Set this as the "normal" value in the in_sa.m file. What value did you get?
    b. The aging process often results in a reduction in the compliance of blood vessels. Model the aging process by reducing Csa by a factor of 2. What happens to the systolic and diastolic pressures? What about the mean pressure (approximately)? Can you explain these results?
    c. During exercise, systemic resistance falls because of autoregulation in the working muscles. Consider the following scenario. Systemic resistance Rs goes down by a factor of 2 and heart rate goes up by a factor of 2 while stroke volume remains unchanged. To implement this in the model, we must reduce all 3 times T, TS and TMAX by a factor of 2 and increase QMAX by a factor of 2. What happens? Explain your answer.

2. The MATLAB code from problem 1 uses a finite differences approach to numerically solve the differential equation for the arterial pressure. Revise the MATLAB code to solve this differential equation using one of MATLABs built in ODE solvers (e.g., ODE45). Confirm that the revised code matches the predictions of the original code.

3. Solve problem 1.3 on pg. 70 of the Hoppensteadt and Peskin textbook. Explain the trends.

4. An elderly woman has a relatively low hemoglobin concentration of 10 g/dL. Her resting O_2 consumption rate is 225 mL/min. What must her cardiac output be to keep arterial and venous O_2 pressures at normal levels ($P_{O_2,a}$ = 95 mm Hg, $P_{O_2,v}$= 40 mm Hg, which corresponds to hemoglobin saturation of 98% and 75% respectively).

5. At the bifurcation of the femoral artery the pressure is 100 mm Hg. The venous pressure after either the left or right femoral artery is 10 mm Hg. The resistance in the right femoral artery is 1.67 times the resistance through the left femoral artery. The total flow rate at the bifurcation is 800 mL/min. How does the flow divide into the left and right femoral arteries?

6. The net filtration across relaxed skeletal muscle capillaries is about 0.005 mL/min per 100 g of tissue. Assume the following values: the capillary surface area per 100 g of tissue is 0.58 m^2; the length of the capillaries is 500 μm; pressure at the arteriolar end of the capillary is 50 mm Hg; pressure at the venule end of the capillary is 15 mm Hg; the oncotic pressure of plasma is 25 mm Hg; interstitial fluid pressure is -1 mm Hg; interstitial fluid oncotic pressure is 5 mm Hg.
    a. Does the capillary filter fluid along its entire length, or does it reabsorb fluid near the venule end?

b. Calculate Lp for the capillary assuming $\sigma = 1$. You will need to integrate the rate of filtration along the length of the capillary.

7. Under normal resting conditions the rate of CO_2 production Q_{CO2} = 200 mL STP/min, tidal volume V_T = 510 mL (BTP), dead volume V_D = 150 mL BTP and breathing rate v_R = 12 breaths/min. During exercise, Q_{CO2} increases to 1000 mL/min and v_R increases to 20 breaths/min.
   a. What would the tidal volume be if the arterial CO_2 pressure P_{ACO2} remains unchanged at 40 mm Hg?
   b. If the respiratory quotient R = 0.8, determine PAO2?

8. Jack Bauer is a highly trained field agent for a special government organization called the counter terrorism unit. To stop a terrorist attack, Jack must enter a building containing nerve gas at a concentration of 0.2 mg/L and unfortunately he forgot his gas mask. If the nerve gas becomes lethal when the alveolar concentration reaches 0.15 mg/L, how long can Jack spend in the building? You may assume that he breathes normally and that the following data for the average human at rest apply (even though it is obvious that Jack Bauer is much better than the average human):

   Tidal volume = V_T = 500 ml
   Dead space = V_D = 150 ml
   Average alveolar volume = V_A = 3000 ml
   Breathing frequency = v_r = 15/min

   You can neglect mass transfer of nerve gas from the lungs to Jack's blood stream. You can also assume V_T is the same for exhaling and inhaling.

9. The following experiment is used to estimate the glomerular filtration rate. Inulin is infused into the blood stream until a steady state plasma concentration of 20 mg% (mg/dL) is established. Then infusion is stopped and the decay in plasma inulin concentration is measured, as well as the inulin concentration in urine.
   a. A total of 500 mL urine was collected over 8 h after stopping inulin infusion. The average inulin concentration in the urine was 560 mg%. What is the extracellular fluid volume?
   b. After stopping inulin infusion the plasma inulin concentration falls from 20 mg% to 7.2 mg% after 2 h. What is the glomerular filtration rate?

10. A person has a total body water volume of 42 L, an extracellular fluid volume of 14 L and a plasma osmolarity of 300 milliosmoles/L. After losig 4 g of NaCl and 2 L in sweat, what is the new extracellular fluid volume and osmolarity?

11. Use the following variable definitions to solve this problem: C_{Bo} is the urea concentration in the blood stream leaving the dialysis machine (i.e., prior to entering the patient); C_{Bi} is the urea concentration in the blood entering the dialysis machine (i.e., after leaving the patient); R_0 = 50 min/cm and A = 1 m^2 are the overall mass transfer resistance and the surface area for mass transfer in the dialysis machine, respectively; $\dot{V}_B$ is the volumetric flow rate of blood out of the patient, through the dialysis machine and back into the patient; $\dot{V}_D$ is the volumetric flow rate

of dialysate entering (and exiting) the dialysis machine, and C_{Di} = 0 and C_{Do} are the urea concentrations in the dialysate entering and exiting the dialysis machine.

a. If C_{Bi} = 20 mmol/L, $\dot{V}_B$ = 300 ml/min, $\dot{V}_D$ = 500 ml/min, what is the value of C_{Bo}? What is the clearance K?

b. Assuming that the initial blood urea concentration is 20 mmol/L, how long would it take to reduce the person's blood urea concentration to 10 mmol/L using blood and dialysate flow rates of 300 ml/min and 500 ml/min, respectively. Urea readily crosses the capillary endothelial and cell membranes and thus distributes to all fluid compartments within the body. The person weighs 80 kg and you can assume that 60% of this mass is water.