Problem Set 5.3
Hemodynamics and Microcirculation

1. A normal individual experiences a deep cut that severs the radial artery near the elbow. Ignoring air resistance, approximately how high will the blood spurt? (Hint: the specific gravity of blood is 1.050 g cm^{-3} and the specific gravity of mercury is 13.6 g cm^{-3}.)
2. At the bifurcation of the femoral artery, the pressure is 100 mmHg. The pressure in the veins draining either the left or right femoral artery is 10 mmHg. The resistance in the right femoral artery is 1.67 times the resistance through the left femoral artery. The total flow at the bifurcation is 800 mL min^{-1}. How does the flow divide into the left and right femoral arteries? (Hint: what is the conservation of flow? Use this to solve one of the resistance values.)
3. A subject has normal values of 125/80 mmHg blood pressure, heart rate of 65 bpm, and a cardiac output of 5 L min^{-1}.
   A. If the subject's blood pressure rises to 140/80, what is the new stroke volume? (Hint: compliance of the aorta does not change.)
   B. What is the new mean arterial pressure?
   C. If the heart rate does not change, what is the new peripheral resistance?
   D. Is this an increase or a decrease?
4. An arteriole has a radius of 25 μm and it is 1000 μm long. The viscosity of blood is 3×10^{-3} Pa s and its density is 1.055 g cm^{-3}. Assume the arteriole is a right circular cylinder.
   A. Assuming laminar flow, what is the resistance of this arteriole?
   B. If it constricts to 20 μm, what is its resistance?
   C. What is the resistance of 20 of these arterioles (as in (A)) arranged in parallel?
   D. If the input pressure to these arterioles is 100 mmHg and the output pressure at the arteriolar end of the capillaries is 35 mmHg, what is the flow?
   E. What is the average velocity of blood through the arteriole?
   F. How much time does the blood spend in the arteriole?
   G. What is the Reynolds number for flow through the arteriole under these conditions?
5. An arteriole with a radius of 30 μm and a length of 1000 μm feeds into a set of 200 capillaries each with a radius of 4 μm and a length of 500 μm. The viscosity of blood is 3×10^{-3} Pa s and its density is 1.055 g cm^{-3}. The input pressure to the arteriole is 100 mmHg and the output pressure at the end of the capillary is 15 mmHg. Assume that the capillaries all come off the arteriole at the same place.
   A. What is the resistance of the arteriole?
   B. What is the resistance of a single capillary?
   C. What is the resistance of the set of capillaries?
   D. What is the pressure at the arteriolar end of the capillary?
   E. What is the total resistance through arterioles and capillary?
   F. What is the flow through the system?
   G. What is the velocity of flow through the arteriole?
   H. What is the velocity of flow through the capillaries?
   I. How much time does blood spend in the capillary?
   J. What is the Reynolds number for flow through the arteriole?
   K. Do the values for pressure and flow and resistance seem reasonable to you?
6. The net filtration across relaxed skeletal muscle capillaries is about 0.005 mL min^{-1} per 100 g of tissue. Assume the following values: the density of muscle is 1.08 g cm^{-3}; the length of the capillaries is 500 μm and their cross-sectional density is 250 capillaries mm^{-2}; their average radius is 4 μm. Pressure at the arteriolar end of the capillary is 40 mm Hg and it decays linearly to 15 mmHg at the venule end. The oncotic pressure of plasma is 25 mmHg. Interstitial fluid pressure in relaxed muscle is −1 mmHg and intersitial fluid oncotic pressure is 5 mmHg.
   A. Calculate the surface area of the capillaries per 100 g of muscle. (Hint: calculate the mass of muscle 1 mm^2 in cross section and 500 μm long.)
   B. Does the capillary filter fluid along its entire length, or does it reabsorb fluid at the venule end?
   C. Calculate the L_p for the capillary, assuming $\sigma = 1.0$. You will need to integrate the rate of filtration along the length of the capillary.
7. About 20% of the cardiac output at rest goes to the kidneys. What fraction of the TPR is due to the kidneys?

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8. The arterial glucose concentration is usually between 80 and 120 mg%. Assume it is 90 mg% (this is mg per dL (0.1 L) of blood) in this problem.
   A. The blood flow to a muscle at rest is $0.025\ \mathrm{mL\ min^{-1}\ g^{-1}}$. Its venous glucose concentration in the blood draining the muscle is 80 mg%. What is the glucose consumption rate, in $\mathrm{mol\ min^{-1}\ g^{-1}}$? The molecular weight of glucose is $180.2\ \mathrm{g\ mol^{-1}}$.
   B. The interstitial fluid glucose concentration is about 75 mg%. What is the solute extraction at rest?
   C. What is the diffusing capacity, equal to the surface area times the permeability?
   D. Suppose there are 250 capillaries open per $\mathrm{mm^2}$ cross section of the muscle, and that each capillary is 500 μm long. Assume each capillary has a radius of 4 μm. If the density of muscle is $1.08\ \mathrm{g\ cm^3}$, how much area of capillaries is available for glucose exchange?
   E. Using the results to C and D, calculate the permeability of the capillaries to glucose.
   F. Net filtration of fluid across the capillaries in muscle is about $0.005\ \mathrm{mL\ min^{-1}}$ per 100 g of tissue. If glucose is dragged across with this bulk flow, what percent of glucose transport across the capillary is due to diffusion and what per cent to bulk flow?
   During exercise, glucose consumption increases to $60\ \mu\mathrm{mol\ min^{-1}}$ per 100 g. Assume arterial [glucose] does not change. Blood flow increases to $0.60\ \mathrm{mL\ min^{-1}\ g^{-1}}$.
   G. What is the venous concentration of glucose during exercise?
   H. The number of open capillaries increases to $1000\ \mathrm{mm^{-2}}$ cross section. How much area is now available for glucose exchange?
   I. Assuming that p is unchanged, what is the new solute extraction during exercise?
   J. What is the interstitial fluid concentration of glucose during exercise?
9. The radial artery in a person has an inner diameter of 4 mm and it is 25 cm long. The viscosity of blood is 3×10^{-3} Pa s and its density is $1.055\ \mathrm{g\ cm^{-3}}$.
   A. Assuming laminar flow, what is the resistance of the radial artery?
   B. The average blood velocity in the radial artery is about $20\ \mathrm{cm\ s^{-1}}$. What is the total flow?
   C. What is the Reynolds number for flow in this radial artery?
   D. From A and B, calculate the pressure difference between the beginning and end of the artery.
10. A defensive back for the Ohio State University football team weighs 89 kg. His blood is 7.5% of his body mass. Its density is $1.06\ \mathrm{g\ cm^{-3}}$, the hematocrit ratio is 0.45 and hemoglobin is 15 g %. His plasma albumin is 4.5 g%, and his globulins are 3.1 g%.
   A. Calculate the contribution to the osmotic pressure of plasma made by albumin and globulin according to Eqn [5.10.17].
   B. During a heavy work-out in August preseason camp, he loses 3 L of protein-free fluid as sweat. If all of this fluid came from his plasma, calculate his new hematocrit, new albumin, and new globulin concentration.
   C. From part B, calculate the contribution to the osmotic pressure this albumin and globulin concentration would make to plasma.
   D. What effect would this have on the balance of fluid across tissue capillaries?
11. The Law of Laplace for a cylinder differs from that in a sphere. For a sphere, $P = 2T/r$; for a cylinder, $P = T/r$.
   A. Consider the abdominal aorta with $r = 0.8$ cm. What is the tension at systolic pressure if $P = 120$ mmHg?
   B. What is the tension in the radial artery if $r = 2$ mm and systolic pressure is 120 mmHg?
12. The brachial artery has an inner diameter of 5 mm. The viscosity of blood is 3×10^{-3} Pa s and its density is $1.055\ \mathrm{g\ cm^{-3}}$.
   A. Assuming laminar flow, what is the resistance of the vessel per unit length?
   B. If the brachial artery is 20 cm long, what is its resistance?
   C. If it constricts to 4 mm, what is its resistance?
13. The diastolic pressure is 80 mmHg and the systolic pressure is 120 mmHg. The cardiac output is $5\ \mathrm{L\ min^{-1}}$. The mean systemic pressure is 7 mmHg with a stressed volume of 1 L and an unstressed volume of 4 L. The right atrial pressure is 2 mmHg.
   A. Calculate the TPR.
   B. If $C_V = 18C_A$, calculate C_V and C_A from the stressed and unstressed volumes.
   C. Calculate the slope of the vascular function curve. Compare it to Figure 5.12.6. Is it comparable?
   D. Estimate C_A from the stroke volume and pressure pulse. How does it compare to C_A calculated in part B?
14. Assume the following numbers for the arterioles: There are 1×10^7 of them; diameter is 50×10^{-4} cm; length is 1 cm; viscosity of blood is 3×10^{-3} Pa s. Calculate the aggregate resistance of the arterioles assuming Poiseuille flow.
15. An individual was studied by echocardiography and it was determined that his end diastolic volume was 125 mL, end systolic volume 65 mL and his heart rate at this time 75 bpm.
   A. What is his stroke volume?
   B. What is his ejection fraction?
   C. What is his cardiac output?