Solutions to Homework Assignment – Module 8

1. [20 points] Which of the following statements about the circulation is the most correct? Briefly explain why each of the incorrect statements is, indeed, incorrect.

   A. The pulse pressure in the inferior vena cava is larger than the pulse pressure in the renal artery.

   Incorrect – the pulse pressure in the IVC is smaller than the pulse pressure in the renal artery. In general, pulse pressures on the venous side are smaller that pulse pressures on the arterial side. See Video 4, Slide 3.

   B. The total cross-sectional area of all of the arterioles taken together is less than the cross-sectional area of all of the large arteries (taken together).

   Incorrect – the total cross-sectional area of all of the arterioles taken together is greater than the cross-sectional area of all of the large arteries (taken together). See Video 4, Slide 3.

   C. Blood flow velocity is less in the capillaries than it is in the superior vena cava.

   Correct as written. See Video 4, Slide 3.

   D. Mean blood pressure in the large veins is about equal to mean blood pressure in the large arteries.

   Incorrect - mean blood pressure in the large veins is less than mean blood pressure in the large arteries. See Video 4, Slide 3.

2. [20 points] What are the physical characteristics/properties of blood and of blood vessels that affect blood flow through a blood vessel? Which of these characteristics/properties is under physiological control, and, if under control, in what (approximate) time frame? Briefly describe/discuss/explain the mechanism(s) of such control.

   Thinking of blood vessels as rigid cylinders, we can look at Poiseuille's equation, $Q = (\pi \cdot \Delta P \cdot r^4)/(8 \cdot \eta \cdot l)$, where the symbols are as defined on page 347 of B&L[7], to examine what factors affect flow through a vessel. The numerical constants are not characteristics of either a vessel or of blood, neither is ΔP, the pressure difference between the vessel inlet and outlet. This leaves r (vessel radius) and l (vessel length), which are physical characteristics of a vessel and η (blood viscosity), which is a physical characteristic of the blood.

Rev 0, 3/14/17 - adapted, with corrections/clarifications, from Spring 2015
Rev 1, 10/29/17 - revise language of Q2 to be consistent with HW as assigned; no content change in response
Rev 2, 10/31/17 - update to include refs to B&L[7]; no other change to content.
Rev 3, 10/29/1 - update to 601; no changes to content.
Rev 4, 11/7/18 - re-write response 2; no other changes.
Rev 5, 3/3/20 - Q3; remove reference to video 2, slide 4; refer instead to replacement slide for video 2, slide 4

Vessel length, at least for the purpose of regulating flow through a vessel, is not under physiological control; this leaves us with r, the vessel radius, which is under physiological control. Vessel radius is adjustable, within a time frame of seconds or less, by controlling the degree of contraction/relaxation in the vessel wall; this is determined by direct autonomic neural stimulation to the smooth muscle in the vessel wall and/or by levels of circulating hormones.

Because blood is not a Newtonian fluid its apparent viscosity can vary with vessel diameter (B&L[6+], Figure 17-9; B&L[7], Figure 17.8) and with flow velocity (video 3, slide 3) – these variations are a consequence of blood being a slurry rather than a true fluid. However, such variations in viscosity are not for the purpose of varying flow through a vessel.

Finally, you know that blood vessels are not rigid cylinders; rather vessel wall diameter can to some extent (depending on the amount of connective tissue and the status of smooth muscle in the vessel wall) vary with the transmural pressure difference (video 4, slide 5).

3. [20 points] Distinguish between laminar flow and turbulent flow. Where in the circulation is turbulent flow likely to occur? Briefly explain why turbulent flow is likely to occur in those locations.

The basic difference between laminar and turbulent flow is the movement of fluid in any direction NOT parallel to the primary direction of flow. In laminar flow fluid only moves parallel to the direction of flow; in turbulent flow fluid can (and does) move in directions not parallel to the direction of flow (see the ***replacement slide*** for slide 4 of video 2) - laminar flow is shown on the left; turbulent flow on the right). The Reynolds number for turbulent flow should be > 2300 (or 3000; depending on source of information); flow in the region between 2000 < N_R < 2300 (or 3000) is referred to as transitional flow. See B&L[7], page 349.

For pipe flow (i.e., flow in a cylindrical tube, such as a blood vessel) the Reynolds number (N_R) is given as (B&L[6+], Equation 17-12; B&L[7], Equation 17.12) …

$$N_R = \rho D v / \eta$$

where the symbols are as defined in the text book (page 334 in B&L[6+]; page 349 in B&L[7]; note that D is the inner diameter of the vessel and η is the dynamic viscosity). Fluid density and viscosity aren't going to vary significantly in different parts of the circulation; the only parameters of interest are then fluid velocity and vessel diameter – in both cases, the bigger the better for turbulence. Slide 3 in Video 4 shows that the highest velocities occur in the aorta and vena cavae, which, conveniently, have the largest diameters. Thus, the best chance for turbulence would be in the aorta or vena cavae. The velocity in the aorta is a

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bit higher than that in the vena cavae; the diameters of the vena cavae are a bit larger (20%) than that of the aorta (slide 2 of video 4). Prior experience leads me to favor the aorta as the most likely site for turbulent flow. NOTE that (1) this analysis ignores vessels with partial obstructions (e.g. a plaque) or stenosed valves – that sort of narrowing can lead to a significant increase in velocity (see B&L[6+], Figures 17-1 and 17-2; B&L[7], Figures 17.1 and 17.2) and/or to changes in flow pattern secondary to a change in vessel diameter – these sites are also likely locations for turbulent flow and (2) turbulent flow is likely to develop at abrupt changes ("steps") in vessel diameter; see, e.g., the Stewart et al. papers listed in the section titled "Module 8 Discussion – Papers of Interest" in Module 8.

4. [20 points] Which of the vessels in the circulation (aorta, artery … vein, vena cavae) has the least connective tissue? Discuss/explain the physiological/ functional reason(s) for this.

The capillaries contain the least amount of connective tissue (video 4, slide 2 and B&L[6+], Figures 17-28 and 17-29; B&L[7], Figures17.26 and 17.27). Functionally, capillaries need to have the thinnest possible walls to facilitate gas, nutrient and waste exchange between capillary blood and interstitial fluid.

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