Hemodynamics: Biophysics For AP Biology

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"WHAT DOES PHYSICS have to do with biology?" grumbled a college student to me a few days ago. I responded, "Physics, like biology, deals with the laws of nature by which any living organism is governed." Because most students in AP biology will have completed at least one other science course, an advanced high school biology course provides a good opportunity to integrate the laws of nature into the curriculum.

The basic physics of fluids moving through vessels is the same whether one is dealing with a sewer pipe or a blood vessel (although different applications require different levels of detail and accuracy). The following programmed instruction in biophysics was devised to demonstrate the physics of blood traveling through the circulatory system. This particular model of hemodynamics deals with pressure change. It is based on the following equation:

$$\text{Pressure change (mm Hg)} = \text{flow rate (ml/min)} \times \text{resistance} \left(\frac{\text{mm Hg}}{\text{ml/min}}\right)$$

We have ignored the effects due to elasticity of the vessels and the time-dependent effects due to the difference between systolic and diastolic pressure in the arteries and arterioles. The model still allows us to demonstrate important aspects of the relationship between pressure change, flow rate, and resistance.

It is assumed that the student is familiar with the anatomy of the circulatory system and understands the cardiac cycle. This method of presentation is suitable for an advanced high school course emphasizing individualized instruction in an interdisciplinary field. It is designed to aid both teacher and student.


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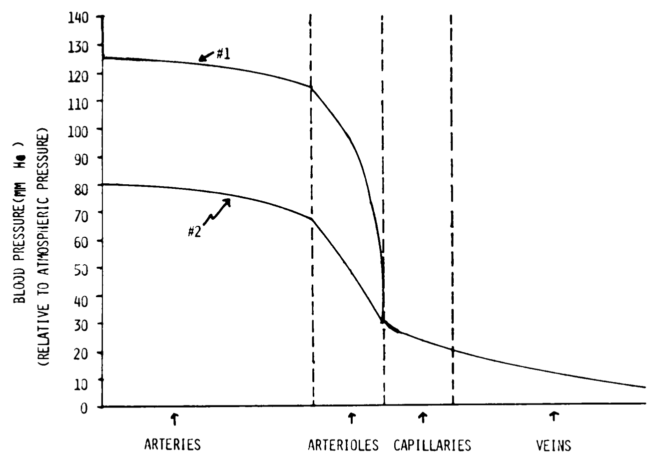

Fig. 1 Blood pressure in vessels of the circulatory system (Langley et al. 1969).

1. The three major classifications of blood vessels are *arteries, capillaries,* and *veins.* Arteries carry blood *away* from the heart while veins carry blood *toward* the heart. The exchange of materials between the blood and cells occurs in the capillaries. Examine fig. 1. During the cycle of the heart, at any given location in the veins, the blood flow is fairly constant at a pressure which varies only slightly. However, along the *length* of the vein the blood pressure decreases as it approaches the heart. The decrease in blood pressure along the length of the vein (and indeed along the length of other vessels) enables the blood to flow. In the arteries the blood pressure *does* vary at any given location. The peak pressure is termed *systolic* pressure while the lowest level reached is termed *diastolic* pressure.

(a) In fig. 1, line # 1 represents ________ pressure.
(b) In fig. 1, line # 2 represents ________ pressure.

1. (a) systolic
(b) diastolic

2. From fig 1., one can see that blood pressure decreases as the distance from the heart ________.

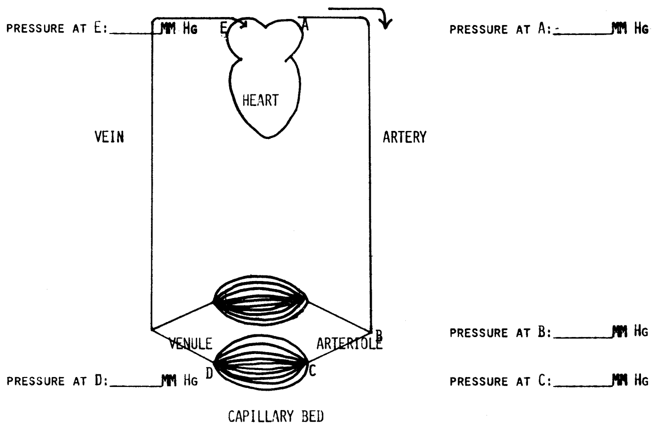

Fig. 2. Simplified diagram of the circulatory system. The degree of branching is given only for calculations, not as an accurate model of the circulatory system.

2. increases	3. Examine fig. 2. With the aid of fig. 1, estimate the systolic pressure at points A, B, C, D, and E in fig. 2.
3. Estimates are from fig. 1. A = 125 mm Hg B = 115 mm Hg C = 30 mm Hg D = 20 mm Hg E = 2 mm Hg	4. (a) The *pressure change* along a segment of an artery is (pressure at point A minus pressure at point B) ________ mm Hg. (b) Likewise, the *pressure change* along the arterioles is ________ mm Hg. (c) Likewise, the *pressure change* along the capillaries is ________ mm Hg.
4. (a) 10 mm Hg (b) 85 mm Hg (c) 10 mm Hg	5. You have just studied pressure change along the length of the circulatory system. Now let's look at the *flow rate* along the length of the circulatory system. Flow rate is expressed in terms of milliliters of blood per minute (ml/min). Therefore, if the flow rate *from* the heart (excluding circulation to lungs) is 5,000 ml/min, then the flow *into* the heart (excluding circulation from the lungs) is ______ ml/min.
5. 5,000	6. Likewise, you would find the *total* flow rate through all the *arteries* to be (a) ________ ml/min; through all the *arterioles* to be (b) ________ ml/min; through the entire *capillary bed* to be (c) ______ ml/min; through the total *venous system* to be (d) ______ ml/min.
6. (a) 5,000 (b) 5,000 (c) 5,000 (d) 5,000	7. In summary, slicing through the entire circulatory system at *any* point, one should find *the same/a different* (choose one) flow rate.
7. the same	8. Let your arm represent an artery. Let your fingers represent the next set of branching as seen in fig. 1 and fig. 2. Keep in mind that this is only an *analogy* of flow rate. Actual flow rate value for the arm is considerably less, and there is much more branching. (a) The fingers would represent ________. (b) Assuming all five fingers have equal flow, what is the flow rate in *one* finger (arteriole) if the arm (artery) has a flow rate of 5,000 ml/min?
8. (a) arterioles (b) 1,000 ml/min	9. Refer to fig. 2. Given: Flow in artery = 5,000 ml/min. (a) What is the flow in *one* arteriole (in fig. 2, assume that there are two arterioles per artery)? (b) What is the flow in *one* capillary (in fig. 2, assume that there are 50 capillaries per arteriole)?
9. (a) 2,500 ml/min (b) 50 ml/min	10. Now let's reconstruct fig. 2 and list the flow rate and pressure change for an artery, one arteriole, and one capillary, using the values calculated in #4 and #9.

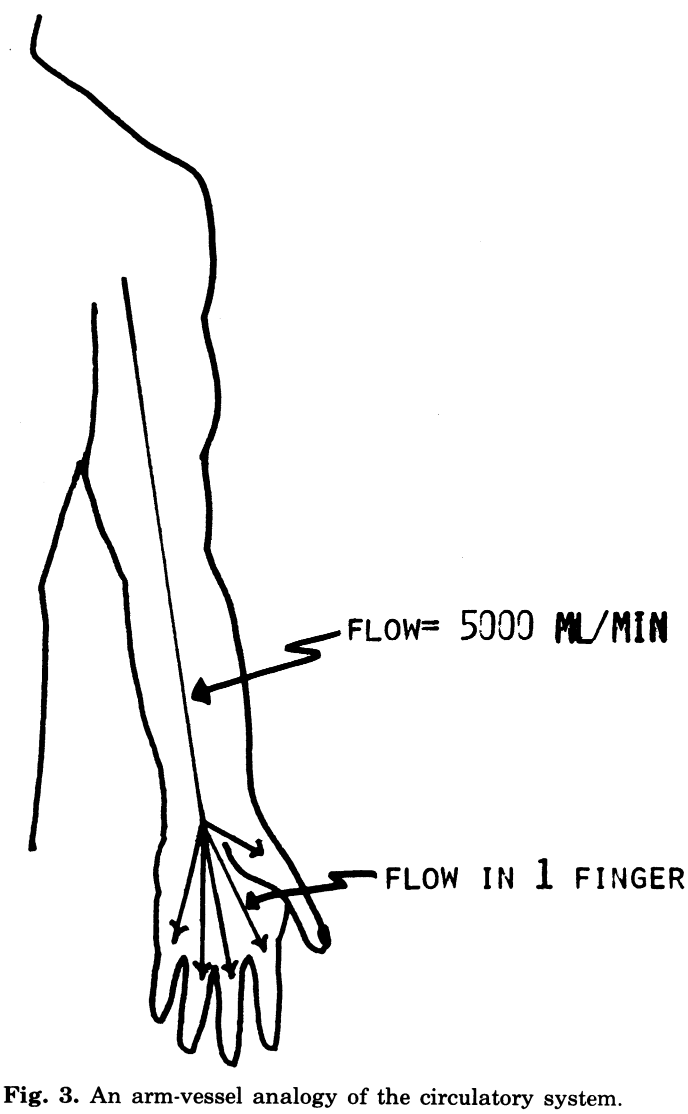

Fig. 3. An arm-vessel analogy of the circulatory system.

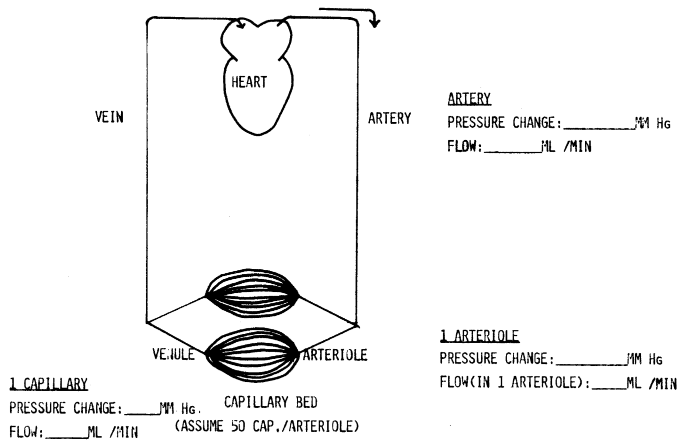

Fig. 4. Simplified diagram of the circulatory system. The degree of branching is given only for calculations, not as an accurate model of the circulatory system.

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10. *Artery*
Pressure change = 10 mm Hg
Flow rate = 5,000 ml/min

Arteriole
Pressure change = 85 mm Hg
Flow rate = 2,500 ml/min

Capillary
Pressure change = 10 mm Hg
Flow rate = 50 ml/min

11. Pressure change is directly proportional to resistance and flow rate. Complete the equation for the pressure change of fluid flowing through a vessel.

Pressure change = flow rate X ________.

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11. resistance

12. Calculate resistance (R) for one artery, one arteriole, and one capillary, using values from #10.

ARTERY

ΔP = flow rate X (R)
10 mm Hg = 5,000 ml/min X (R)

$$\frac{10 \text{ mm HG}}{5{,}000 \text{ ml/min}} = R$$

________ = R

ARTERIOLE ΔP = flow rate X (R)

________ = R

CAPILLARY ΔP = flow rate X (R)

________ = R

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12. *Artery*

$$R = 0.002 \frac{\text{mm Hg}}{\text{ml/min}}$$

Arteriole

$$R = 0.034 \frac{\text{mm Hg}}{\text{ml/min}}$$

Capillary

$$R = 0.20 \frac{\text{mm Hg}}{\text{ml/min}}$$

These values are for fig. 2 only and are only for demonstration of the phenomenon of increased resistance due to branching. The real value for resistance for one artery (excluding aorta), one arteriole, and one capillary are considerably higher due to much greater branching.

13. (a) In which of the above vessels was the resistance lowest?
(b) In which of the above vessels was the resistance highest?

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13. (a) artery
(b) capillary

14. Generally speaking, the cross-sectional area of one artery is greater than that of one arteriole, which is greater than that of one capillary. Compare the resistance values calculated in #12 for each vessel.

Resistance ________ as cross-sectional area decreases.

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14. increases

15. In summary,
(a) Pressure change = ____ X ____.

In terms of the entire circulatory system,
(b) there is generally *an increase/a decrease/no change* (choose one) in the rate of blood flow through the body.
(c) there is a general *increase/decrease* (choose one) in blood pressure as the blood increases its distance from the heart.
(d) there is an *increase/decrease* (choose one) in resistance as the cross-sectional area of the vessel decreases.
(e) there is an *increase/decrease* (choose one) in flow rate (ml/min) in a vessel as the cross-sectional area gets smaller due to branching of a larger vessel into many smaller vessels.

Velocity of blood flow vs. total cross-sectional area of vessels (Langley et al. 1969).

	Area (cm^2)	*Average velocity* (cm/sec)
Aorta	4.50	40.00
Arteries	20.00	9.00
Arterioles	400.00	0.45
Capllaries	4,500.00	0.04
Veins	40.00	4.50
Vena cava	18.00	10.00

15. (a) flow rate X resistance (b) no change (c) a decrease (d) increase (e) decrease	16. One should not confuse flow rate (volume/time) with velocity (distance/time). Assuming flow rate is constant for the entire circulatory system (see #15[b]), the velocity decreases with increasing total cross-sectional area. Mathematically, total blood flow rate = average velocity (over a given cross-section) X cross-sectional area. The total cross-sectional area of the various types of vessels and their average blood velocity are compared in the table. (a) Which vessel has the lowest average blood velocity? (b) Why is the lowest blood velocity advantageous in that vessel type?
16. (a) capillaries (b) It allows for more time for exchange of materials between cells and blood.	

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Audiotutorial Conference

The International Audio-Tutorial Congress Annual Conference will be held November 5-7 at the University of Louisville, Louisville, Ky. Information is available from Stanley Nelson, University of Minnesota, Waseca, Minn. 56093.

Bird Population Studies ...

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permit entry but have no exit, or in simple box traps sprung at a distance with a string.

Conclusion

I recognize that there are some who feel winter feeding of birds is unwise since it may result in larger populations than would exist naturally. There are also critics who view studies of populations at a feeder as worthless since the birds are not in a completely "natural" setting. I contend that winter feeding is harmful only if it is not continuous. As to whether a bird feeder study is unworthy of scientific examination, I would point out that with humans spreading into more and more wildlife habitats, there cannot be enough knowledge gained about those situations where man and other animals interact.

For the students, these population studies have provided more than experience in statistical manipulation and some wildlife handling techniques (fig. 2 and 3). They seem to be genuinely excited by the discovery of research opportunities in their own communities and to gain a heightened awareness and appreciation of their environment. For the instructor that is ample reward, and ample justification for continuing the studies.

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