AL-Qadisiya University-College of Medicine
Dept. of Physiology and medical Physics - Medical physics
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Chapter: 8

Physics of the Cardiovascular System

1- The heart:

For adult each contraction of the heart muscles forces about 80 ml of blood through the lungs from the right ventricle and similar volume to the systemic circulation from the left ventricle.

In order to circulate the blood through the much larger systemic network, the left side of the heart must produces pressures that are typically about 120 mmHg at the peak (systole) of each cardiac cycle. While in the pulmonary system the pressure is about 25 mmHg only.

Show the figure below:-

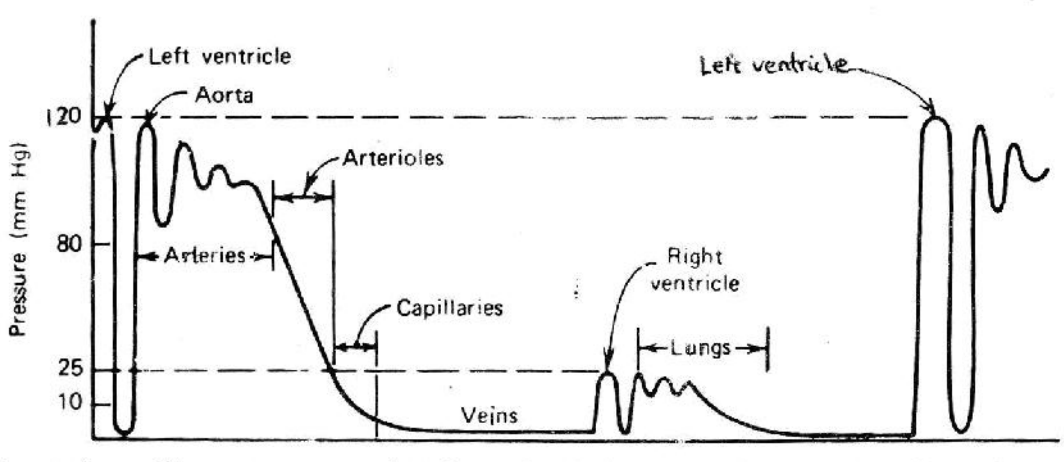


Figure 1 The pressure varies throughout the circulatory system. Note the low pressure in the veins and the relatively low pressure in the pulmonary system.

The left ventricle is more efficient than the right one because:-

1-The muscle driving the left ventricle is about three times thicker than the right one.

2- The circular shape of the left ventricle is more efficient for producing high pressure than the elliptical shape of the right ventricle.

Show the figure below:-

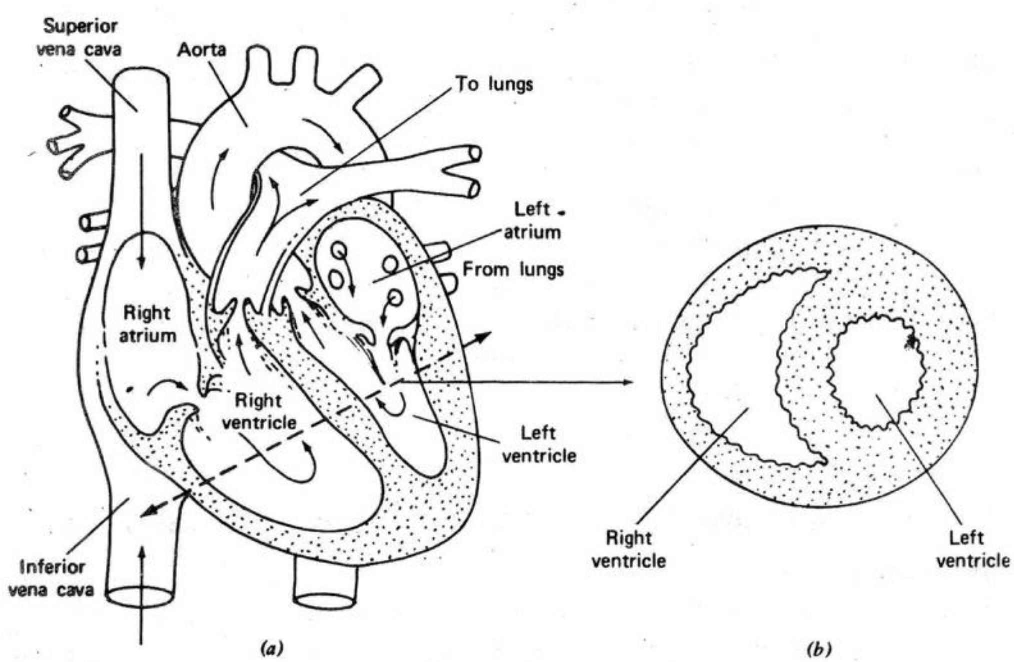


Figure 2 The heart. (*a*) Note the heavier and stronger muscular walls on the left side where most of the work is done. (*b*) The cross-section shows the circular shape of the left ventricle; this shape efficiently produces the high pressure needed for the general circulation.

<u>2-Work done by the heart</u>:

The work (W) done by a pump working at a constant pressure (P) is equal to the product of the pressure and the volume pumped (ΔV).

$$W = p \times \Delta V$$

where W in erg

P in dyne/cm^2

ΔV in cm^3 (ml)

[1 joule=10^7erg]

-The pumping action takes place in less than 1/3 cardiac cycle while the heart muscle rests for over than 2/3 of the cycle .

Ex: - A patient of heart rate of (120/min) his pressure is 150/90 mmHg. Calculate the work done by the left ventricle for 2 seconds.

Sol:-

W= p x ΔV

P= (150+90)/2 = 120 mmHg.

=120 x 1330 = 1.6 x 10^5 dyne/cm^2

ΔV = 120/60 sec x 80 ml =160 ml/sec.

W=120 x 1330 x 160 =2.6 x 10^7erq/sec

W/2sec = (120 x 1330 x 160) x 2=5.2 x 10^7 erq/sec.

<u>3- The Efficient of the heart:</u>-

The heart has an efficient less than 10%.

Efficiency % =[out put (work done)/input (energy consumed)] x100%

Ex:-calculate the efficiency of lower half of the heart if the power consumed is 40 watts.

Sol:-

W=P x ΔV

$W_{LV=}$ Systolic p. x volume of blood in LV

W_{LV}=120 x 1330 x160 erq/sec.

W_{RV}=25 x 1330 x 160 erq/sec

W_{LV+RV}= (120+25) x 1330 x 160 erq/sec

Eff %= (W_{LV+RV} /power consumed) x 100%

= [(145 x 1330 x 160 erq/sec)/ (40 x 10^7 erq/sec)] x 100% = 7.7%

4- Blood flow:-

There are two types of flow:-

1-Laminar flow: - It's the flow that is not companied with sound (stream line flow).

2-Turbulent flow: - It's the flow that has sound which is due to the collisions of molecules inside the fluid when it pass through:

a) Constriction or b) Obstruction or c) Bending

5- The kinetic energy of blood in different blood vessels:-

The general law for calculating the Kinetic energy of blood in different blood vessels was:

$$K.E = \frac{1}{2} \text{ mass x (velocity)}^2$$

In especial case,

If the tube radius reduced, the fluid velocity will increase until reach the critical velocity (Vc) when the laminar flow changes to turbulent flow.

The critical velocity of blood (Vc) can be calculated by using ***Renold equation***.

$$V_c = K \times (\eta / \rho R)$$

η = viscosity of blood = 3×10^{-3} to 4×10^{-3} pas.

ρ = density of blood = 1.04×10^3 kgm/m^3 =1.04 gm/cm3

R= Radius of blood vessels.

K= Renold No. = 1000

Ex1: Calculate the velocity of blood in an artery of 0.8 cm in diameter?

Sol:

$V_c = K \times (\eta / \rho R)$

$= 1000 \times [(3.5 \times 10^{-3}) / (1.04 \times 10^3 \text{ kg/m}^3 \times 0.4 \times 10^{-2} \text{ m})] = 0.84$ m/sec

Ex2:- Calculate the K.E of 3 gm of blood passes the capillary in 0.1 cm/sec?

Sol:

$$K.E = \frac{1}{2} \text{ mass x (velocity)}^2$$

$$= 0.5 \times 3 \times (0.1)^2 = 0.015 \text{ erq.}$$

6- Blood pressure and it’s measurement .(indirect methode)

The instrument that is commonly used is called a sphygmomanometer it consists of a pressure cuff and gauge on the upper arm and a stethoscope placed over the brachial artery at the elbow. The pressure cuff is inflated rapidly to a pressure sufficient to stop the flow of blood and the air is gradually released.

As the pressure in the cuff drops below the systolic blood pressure the turbulent flow of blood squirting through the artery causes sound vibrations that can be heard in the stethoscope. They are called Korotkoff or K sounds. This onset of K sounds indicates the systolic pressure level. As the pressure falls further, the K-sounds become louder and then begin to fade .The point at which the K-sounds die out or change indicates the diastolic pressure.

7- Pressure across the blood vessel wall (Laplace Law)

The blood pressure of arteries decrease as we go out from heart because we have resistance (with relation to the length and diameter) till it reach capillaries, it’s 30 mmHg at the beginning and 15 mmHg at the end till it collected in to vena cava which is 10 mmHg (see Fig.1). Reducing of pressure is due to many factors like friction, viscosity, resistance.

The capillaries have very thin walls (~1µm) that permits easy diffusion of O_2 and CO_2 .In order to understand why they do not burst we must discuss the Law of Laplace, which tells us how the tension in the wall of the tube is related to the radius of the tube and the pressure inside the tube.

T= RP

T: tension, R: radius, P: pressure

8- Bernoulli's principle applied to the CVS.

Bernoulli's principle is based on the law of conservation of energy.

TE=PE+KE………………. (1)

Where TE: Total Energy, KE: Kinetic Energy, PE: Potential Energy.

Pressure in a fluid is a form of potential energy (PE) since it has the ability to perform useful work .In a moving fluid there is kinetic energy due to the motion. This K.E can express as energy per unit volume such as ergs per cubic centimetre.

Since: 1 erg = 1 dyne .cm

1 erg /cm^3 = 1(dyne .cm)/cm^3= 1 dyne /cm^2

If fluid is flowing through friction less tube showing in the figure below. The velocity increase in the narrow section and the increased K.E of fluid is obtained by a reduction of the P.E of the pressure (see equation 1) in the tube .as the velocity. As the velocity reduces again on the far side of the restriction the K.E is converted back in to P.E and the pressure increases again as indicated in the manometer.

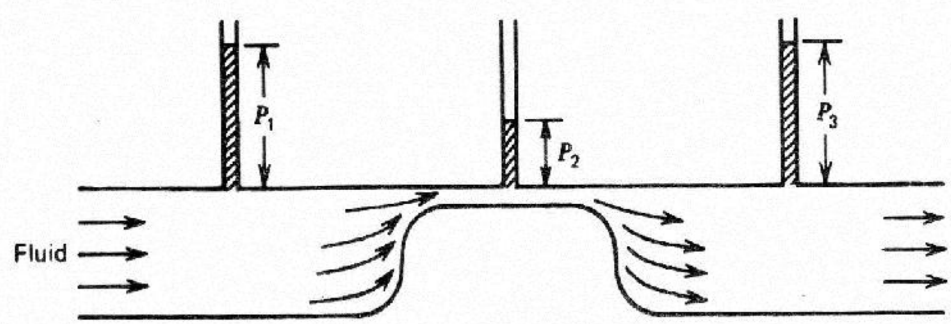


Figure 8.10. As the velocity of the fluid increases in the narrow section of the tube, part of the potential energy (pressure) is converted into kinetic energy so there is a lower pressure P_2 in this section. P_2 is less than P_1 and P_3.

We can calculate the average K.E per unit volume of (1 g) ~ (1 cm^3) of blood as it leaves the heart .remember that:

$K.E=1/2\ mv^2$

Since the average velocity is about 30 cm/sec

$K.E=1/2 \times 1 \times (30)^2 = 450$ ergs

This K.E is equivalent to a P.E of 450 dyne/cm^2.

During heavy exercise the velocity of blood being pumped by the heart may be five times its average value during rest.

9- How fast does your blood flow?

As the blood moves from the heart, the arteries branch and re-branch many times to carry out blood to the various tissues. The smallest blood vessels are the capillaries. The figure below shows that the blood velocity is related in an inverse way to the total cross- sectional area of the vessels carrying the blood

Velocity= Flow rate / cross-section area

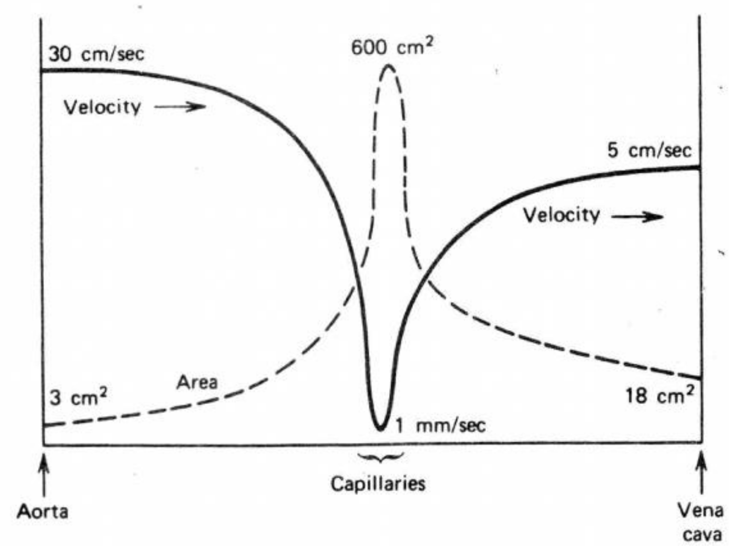
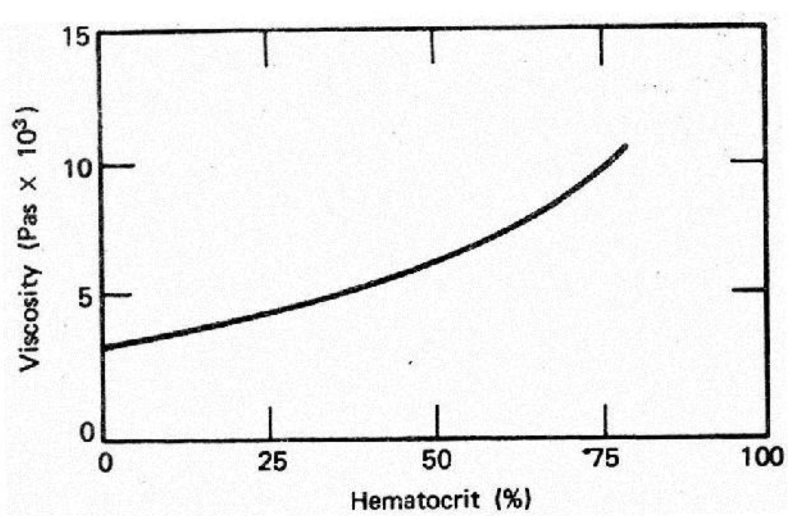


Figure 4 . The dashed curve shows schematically the change in cross-sectional area of the circulatory system. The velocity of blood flow (solid line) decreases as the total cross-sectional area increases. The total cross-sectional area is obtained by adding the areas of all the vessels at a given distance from the heart. Note that the vena cava returning the blood to the heart has a much larger cross-sectional area than the aorta.

Average velocity in the aorta is about 30 cm/sec. That is in capillaries it is only about 1 mm/sec. It is in the capillaries that the exchange of O_2 and CO_2 takes place and this low velocity allows times for diffusion of the gases to occur.

10- Blood viscosity:

The cgs unit used to measure viscosity is the *poise*. The SI unit for viscosity is the pascal second (pas), which equals 10 poises. The viscosity of blood is typical 3×10^{-3} to 4×10^{-3} pas but depends on the percentage of RBCs in the blood (the hematocrit).As the hematocrit increases, the viscosity increase. Show the figure below.



Persons with the disease *polycythemia vera* in which there is an overproduction of RBCs have a high hematocrit and often have circulatory problems. The viscosity of the blood also depends on temperature. As blood gets colder, the viscosity increases and this further reduce the blood supply to cold hands and feet. A change from 37 Ċ to 0 Ċ increases the viscosity of blood by a factor of 2.5. In addition to viscosity, other factors affect the flow of blood in the vessels: the pressure difference from one end to the other, the length of the vessel, and its radius.

In order to understand the laws that control the flow of blood in the circulatory system we must study the Poiseuille's law.

11- Poiseuille's Law:

Poiseuille's law states that the flow through a given tube depends on the pressure difference from one end to the other (P_A- P_B), the length of the tube (vessel), the radius (R) of the tube (vessel) and viscosity η of the fluid. If the pressure difference is doubled the flow rate also doubled. The flow varies inversely with the length and viscosity if either is doubled; the flow rate is reduced by one -half. The flow rate increased as the radius of the tube increased if the radius is doubled the flow rate increases, by 2^4 or a factor of 16.

$$\text{Flow rate} = (P_A\text{-}P_B) \times \frac{\text{®}}{8} \times \frac{1}{\text{¦}} \times \frac{R^4}{L}$$

Poiseuille's Law applies to rigid tubes of constant radius since:-

1-The major arteries have elastic walls and expand slightly at each heart beat; blood flow in the circulatory system does not obey the low exactly.

2-The blood viscosity changes slightly with flow rate, however this effect is negligible.

-In SI units the flow rate will be in m/sec if P_A-P_B is in N/m^2, η is in pas, and R and L in meters.