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physics of the cariovascular system

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Work done by heart

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 .

$W = p \Delta v$

We can estimate the physical work done by the heart by multiplying it's a verge pressure by the volume of blood that is pumped

Exp

- Let average pressure = 100 mm Hg or about 1.4×10^5 dyns/cm^3

  If 80 ml of blood is pumped each second (a pulse rote of 60/min)

  $\therefore$ the work per second = $80 \times 1.4 \times 10^5 = 1.12$ j/sec or a power of 1.12 w

- In order to circulate the blood through the much larger systemic network the left side of the heart must produced pressures that are typically about 120 mm Hg at peak (systole) of each cardiac cycle .

- During the resting phase (diastole) of the cardiac cycle the pressure is typically about 80 mm Hg

Note

-the greater thickness of muscles on the left side of the heart .

Blood pressure and its measurement

The instrument that is commonly used is called a sphygmomanometer

1. It consist of a pressure cuff and gauge on the upper arm and a stethoscope placed over the brachial artery at the elbow .

2. The pressure cuff is inflated rapidly to a pressure sufficient to stop the flow of blood and the air is gradually released .

3. The turbulent flow of blood squirting through the artery causes sound vibrations that be heard in the stethoscope . they are called korotk off or K sound . K sound indicates the systolic pressure level as the pressure falls further .

4. The K sound become louder and then begin to fade . the point at which the K sound die out or change indicates the diastolic pressure .

Pressure across the blood vessel wall (Laplace Law)

Law of Laplace : which tells us how the tension in the wall of a tube is related to the radius of the tube and the pressure inside the tube

Consider along tube of radius R corrying blood at pressure P (Fig 8.9) we can calculate the tension T in the wall .the pressure is uniforn on the wall . (Fig 8.9 b)

There for the force per unit length pushing upward is 2RP. And there is tension for T per unit

Length at each edge .

$2T = 2RP$. $T = RP$.

And for avery small radius the tension is also very small .

Table 8.1 gives some typical pressure and tension in the blood vessels .

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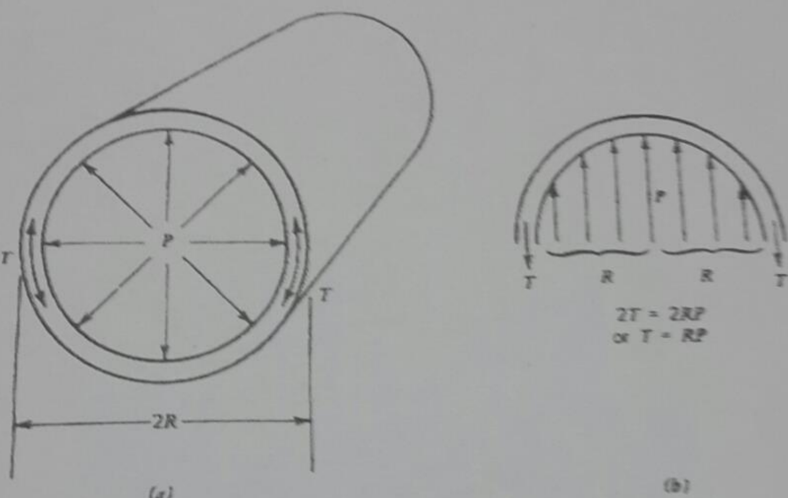


Figure 8.9. For a long tube of radius *R* with blood at pressure P (a), we can calculate the tension in the walls (*b*). The tension is very small for very small vessels, and thus their thin walls do not break.

Table 8.1. Typical Pressures and Tensions in Blood Vessels

	Mean Pressure		Radius	Tension
	(mm Hg)	(dynes/cm^2)	(cm)	(dynes/cm)
Aorta	100	1.3×10^5	1.2	156,000
Typical artery	90	1.2×10^5	0.5	60,000
Small capillary	30	4×10^4	6×10^{-4}	24
Small vein	15	2×10^4	2×10^{-2}	400
Vena cava	10	1.3×10^4	1.5	20,000

Bernoulli's principle applied to the cardiovascular system

Bernoulli's principle is based on the law of conservation of energy.pressure in fluid is a form of potential energy (PE) since it has the ability to perform useful work in Moring fluid there is kinetic energy (KE) due to the motion

- The pressure is reduced at the edge of the rapidly moving fluid .(Fig 8.10)
- If fluid is flowing through the frictionless to be shown in fig 8.10 the velocity increases in the narrow section and increased kinetic energy (KE) of fluid is obtained by a reduction of the potential energy of the pressure in the tube . As the velocity reduce again on the for side of the restriction the KE is converted back into potential energy and the pressure increases again and to calculate the average KE per unit volume of 1g (1 cm^3) .
- Blood when leaves the heart with average velocity about 30 cm/sec .

$KE = \frac{1}{2} m v^2$

$\therefore KE = \frac{1}{2} \times 1 \times (30^2) = 450$ erg or 450 $ergs/cm^3 \cong$ a potential energy of 450 $dynes/cm^3$

Pressure of 1 mm Hg corresponds to 1330 $dyne/cm^2$

$\therefore$ the potential energy amount to less that 0.4 mm Hg at rest

And at heavy exercise the velocity of the blood being pumped by heart may be five time its average value during rest $\therefore$ the pressure be lower .

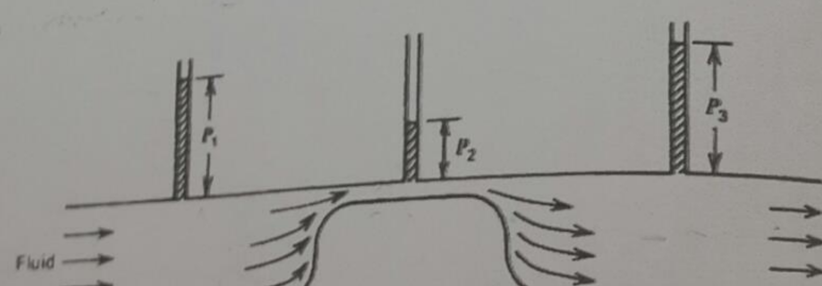


Figure 8.10. As the velocity of the fluid increases in the narrow section of the tube, part of the potential energy (pressure) is converted into kinetic energy so there is a lower pressure P_2 in this section. P_2 is less than P_1 and P_3

How fast dose your blood flow

The blood velocity is related in an inverse way to the total cross-sectional area of the vessels carring blood .

.The velocity equals the flow rate divided by the cross-sectional area.

THE average velocity in the aorta is about 30 cm/sec.that in a capillary is only about 1 mm/sec.

It is in the capillary that the exchange of o2 and co2 takes place , and this low velocity allows time for diffusion of the gases to occur.

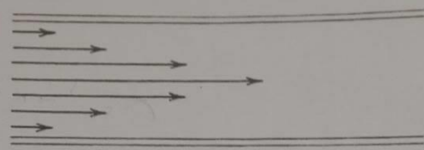
8.8 blood flow-LAMINAR and TURBULENT

- in laminar flow the blood that is in contact with the walls of the blood vessel is essentially stationary , the layer of blood next to the outside layer is moving slowly . and successive layers more rapidly just as the water in the middle of a quiet stream moves more rapidly than the water along the banks (fig 8.14 a) . this behavior has an effect on the distribution of red blood cells in the circulatory system . (Fig 8.14b)

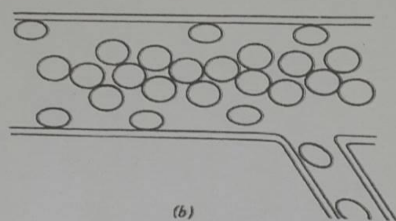
- If gradually increase the velocity of a fluid flowing in a tube by reducing the radius of the tube , it will a critical velocity V_c when laminar flow change into turbulent flow (fig 8.15)this critical velocity is proportional to the viscosity of the fluid and is inversely proportional to the density ρ of the fluid and the radius of the tube

$\therefore V_c = \frac{K.\eta}{\rho R}$ K = constant of proportionality is called Reynolds's number

- The velocity in the aorta ranges from 0 to 0.5 m/sec and thus the flow is turbulent during part of the systole during heavy exercise the amount blood pumped by heart may increase four or five times and the critical velocity will be exceeded for a longer period of time ... the heart sound of a person doing heavy exercise are different from those of a person as rest .



(a)



(b)

Figure 8.14. Blood flow in the vessels. (*a*) In the laminar flow in most of the vessel there is a greater velocity at the center as indicated by the longer arrow. (*b*) Th distribution of red blood cells is not uniform; they are more dense at the center s the blood that flows into small arteries has a smaller percentage of red blood cell than the blood in the main artery.

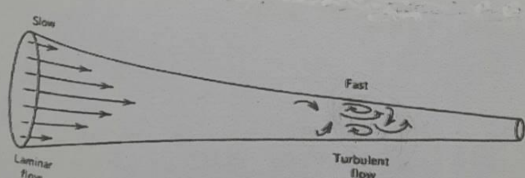


Figure 8.15. If fluid is flowing in a long tapering tube, the velocity will gradually increase to the point where it exceeds the critical velocity V_C, producing turbulent flow.

8.10 the physics of some cardiovascular dieses

1. aneurysm is a weakening in the wall of an artery resulting in an increase in its diameter , the increased diameter increases the tension in the wall proportionately and if in braine a type of cerebra vascular (CVA) accident

2. more common vessel problem is the for motion of sclerotic plaques on the walls of an artery . the plaques can cause turbulent flow and produce a noticeable murmur . the narrowing of the artery will cause an increase in the blood velocity in that region with decrease in wall pressure because of the Bernoulli effect . the plaque may dislodge and travel with the blood until it lodges is smaller artery . this blockage will shut off the blood supply to the affected part , if it is in the brain it will produce a stroke , another type of cerebra vascular

3. aneurisms and plaques causes

Embarrassment is varicose veins ... in leg and the standard treatment for varicose veins is surgical removal of the offending vessels . there are usually adequate parallel veins to carry the blood back to the heart .

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