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L5 physics of cardiovascular system

Pressure across the blood vessel wall

The greatest pressure drop in the cardiovascular system occurs in the region of the arterioles and capillaries. The capillaries have very thin walls (~1 µm) that permit easy diffusion of O_2 and CO_2.

Laplace law

In order to understand why the capillaries do not burst we must discuss the law of Laplace, in physics, that states that the wall tension is proportional to pressure (P) times radius (r).

- The wall tension is the force in the container's walls that resists the force trying to expand it.

The walls of the capillaries of the human circulatory system are so thin as to appear transparent under a microscope, yet they withstand a pressure up to about half of the full blood pressure. LaPlace's law gives insight into how they are able to withstand such pressures: their small size implies that the wall tension for a given internal pressure is much smaller than that of the larger arteries.

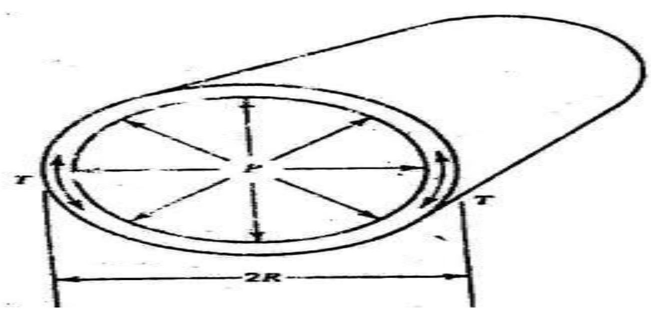
Consider a long tube of radius R carrying blood at pressure P. We can calculate the tension T in the wall.

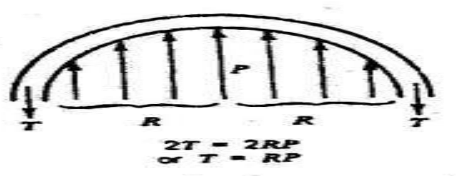
$$T = RP$$

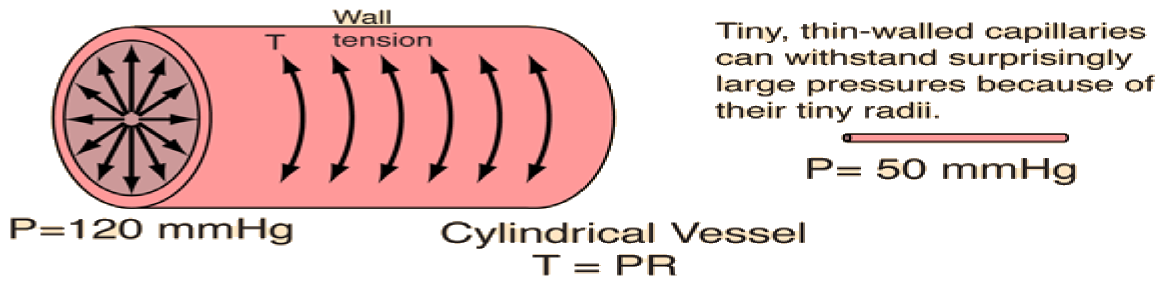
We can divide the tube in half as shown in figure. The force per unit length pushing upward is 2RP. There is a tension force T per unit length at each edge that holds the top half of the tube to bottom half. Since the wall is in equilibrium the force pushing the two halves a part is equal to the tension forces holding them to gather or

$$2T = 2RP$$

or $T = RP$ Laplace equation







For example, the tension in the wall of the aorta is about 156,000 dynes/cm while the tension in a capillary wall is only about 24 dynes/cm. For comparison, a single layer of toilet tissue can withstand a tension of about 50,000 dynes/cm before tearing. This tension is about 3000 times greater than that the capillary has to withstand.

Type of fluid

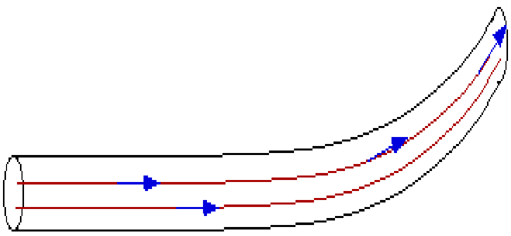
The ideal fluid (Gas and Liquid):

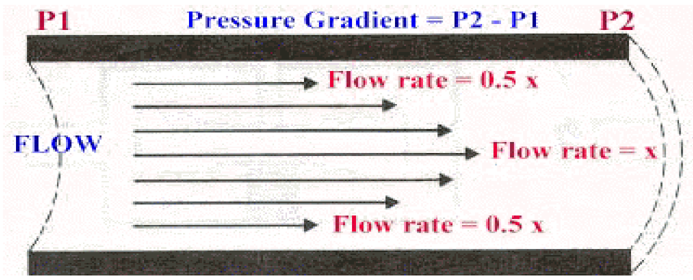
It is incompressible (the density of the fluid is constant); nonviscous (the fluid has no internal friction);Steady flow (the velocity of the fluid at each point is constant in time).

The real fluid: It is compressible; viscous and the velocity is changed.

Laminar and Turbulent Flow

Laminar Flow: "Streamline flow of a fluid in which the fluid moves in layers without fluctuations or turbulence so that successive particles passing the same point have the same velocity.



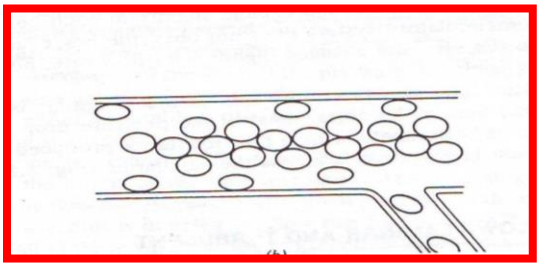


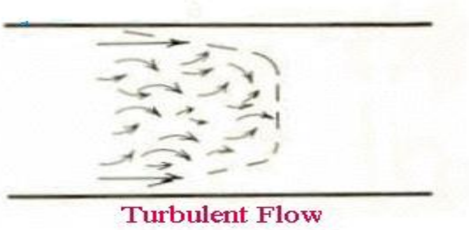
In laminar flow,

- The direction of the flow is parallel to the vessel wall and is straight.
- This type of flow is silent: it does not produce an audible noise of any kind.
- The pressure gradient establishes flow direction and interestingly the flow rate is not uniform in the cross-sectional representation (profile). $\Delta P = P_2 - P_1$
- The highest Flow is in the middle of the channel and the flow rate drops to near zero close to the tube wall.

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 move more rapidly.
- The red blood cells in an artery not distributed uniformly; there are more in the center than the edges .Erythrocytes (RBC) are round and look like coins about 7 microns wide. However, they have remarkable plasticity.





This produces two effects:

1-When blood enters a small vessel from the side of main vessel the percentage of red blood cell in that blood *(the hematocrit)* will be slightly less than that in the blood in the main vessel because of the *(skimming effect.)(* The RBC squeeze themselves through capillaries going side on, twisting, and changing shape and the flow is very slow (which is good because exchange of gases, nutrients and waste products can happen in that time-frame).

2-The plasma along the vessel walls is moving more slowly than the red blood cells, the blood in the extremities has a greater percentage of red blood cells than when it left the heart .This causes an increase in the hematocrit in the hands and feet of approximately of 10% over the hematocrit of the whole blood.

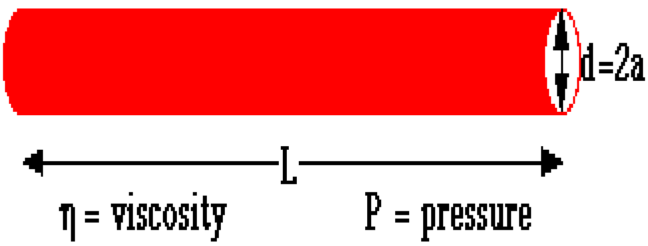
Turbulent flow

- The irregular movement of particles (chaotic) of the fluid characterizes turbulent flow.
- In turbulent flow, the direction of the flow is not parallel to the vessel wall and blood flows in different directions.
- Turbulent flow can often cause small whirlpools to form in the blood, much like the ones seen in rivers at points of obstruction.
- This type of flow makes an audible noise, which can be heard by a stethoscope.
- Obviously, flow that is turbulent causes much more resistance in the blood vessel than that laminar flow.

❖ If all blood flow were laminar, information could not be obtained from the heart with a stethoscope. The heart sounds heard with a stethoscope are caused by turbulent flow.

Blood flow refers to the movement of blood through the vessels from arteries to the capillaries and then into the veins. Moreover, usually expressed in terms of volume of blood per unit of time.(V/t)

Poiseuille's Equation: a mathematical equation describing blood flow and its relationship to known parameters.



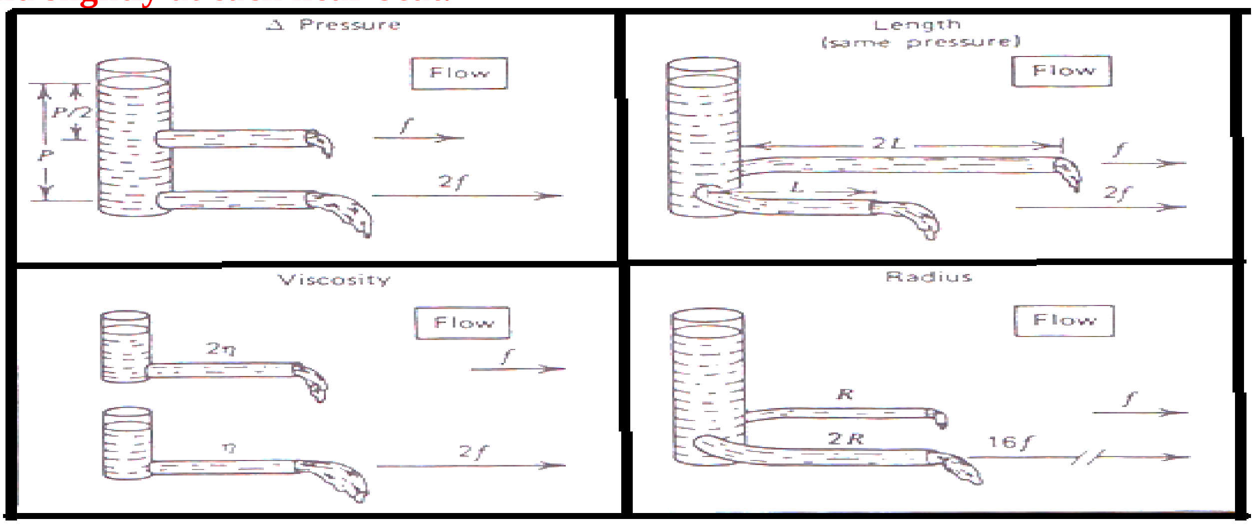
The flow rate due to Poiseuilles law:

$$Q = \frac{\pi r^4 \Delta P}{8\eta L}$$

The factors affect the blood flows in the vessel and its units of measurement:

- **Pressure difference (ΔP):** If ΔP is doubled, the flow rate also doubles. mmHg is used for measurement. [For the formula, convert to Pa (Pascals)(N/m^2) by multiplying the mmHg by 133.3.]
- **Viscosity of fluid (η).** The flow of fluid varies inversely with the viscosity of fluid, i.e. greater the viscosity, lesser the flow and vice versa. The viscosity of blood is typically 3x 10^{-4} to 4x10^{-4} . P (Poise) or Pa·s or kg·m^{-1}·s^{-1} are the units For the formula, convert P (Poise) to (Pa. s) by dividing the value by 10.
- **Radius (a),:** if the radius is doubled the flow rate increases by 2^4 or factor 16. mm (millimeters) or micrometers are appropriate dimensions, but it is most useful in the formula to use cm (centimeters).
- **Length of the vessel.** The flow is inversely proportional to the length of the vessel. Therefore , longer the length greater will be the total resistance offered. cm (centimeters) is most convenient for measurements and for the formula.

Poiseuille's law applied to rigid tubes of constant radius. Blood flow in the circulatory system does not obey the law exactly because of **major arteries have elastic walls and expand slightly at each hear beat.**



The resistance in the vascular system

It is clear that the higher the pressure exerted by the heart, the faster blood will flow. This is an example of a direct or proportional relationship between two quantities.

There is also another factor which controls the blood flow rate, it is the resistance of the blood vessels to blood flow. This resistance is simply due to the width of the vessels - it's hard to push a lot of blood through a thin tube! Thus, we have an inverse relationship between blood vessel resistance and the blood flow rate - the higher the resistance, the slower the flow rate.

- Fluids flow down pressure gradients
- Law of body flow: **Q = ΔP / R**

Q = Flow (Rate) Δ P = pressure gradient R = resistance

From Poiseuille's Equation:

$$Q = \frac{\pi r^4 \Delta P}{8\eta L} = \Delta P/R$$

$$R = 8\eta L/\ \pi r^4 \ \ \textit{measured in ohm}$$

By examining this equation, you can see that there are only three variables: viscosity, vessel length, and radius, since 8 and π are both constants. The important thing to remember is this: Two of these variables, viscosity and vessel length, will change slowly in the body. Only one of these factors, the radius, can changed rapidly by vasoconstriction and vasodilation, thus dramatically affecting resistance and flow. Further, small changes in the radius will greatly affect flow, since it raised to the fourth power in the equation.

Ohm law

Blood flow rate: **means the quantity (volume) of blood passes a given point in the circulation in a given period of time (ml/sec), (L/min)**

Q=V/t

V:volume t : time

Electrical current**: means the quantity of charge passed through a material in period of time**

I = e/t I : current e: electrical charge

I=ΔV/r ohm's law

ΔV: electrical potential difference

r: ohm's resistance

Q =ΔP/R	→	**I = ΔV/r**
Q	→	**I**
ΔP	→	**ΔV**
R	→	**r**

Series: $R_T = R_1 + R_2 + R_3$

Parallel : $= 1/R_1 + 1/R_2 + 1/R_3$

Circulatory systems have both series and parallel arrangements of blood vessels.