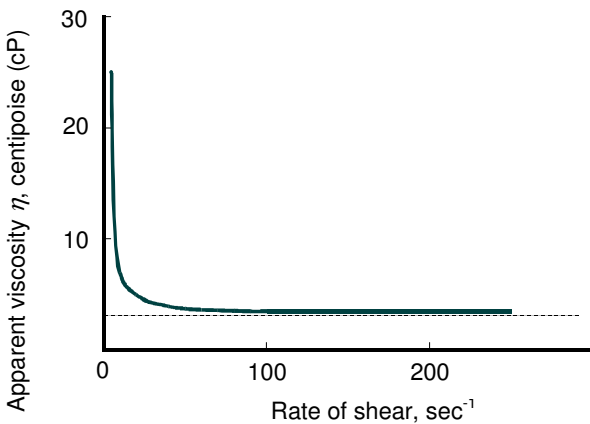


PROBLEMS:

Viscosity

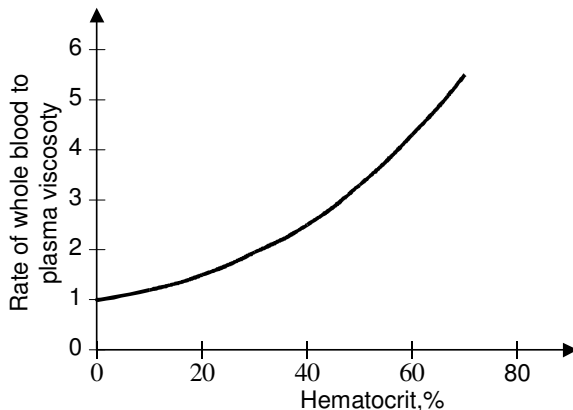
1. Concept of viscosity, units of viscosity, rate of shear, velocity flow profiles, laminar and turbulent flow, prediction of the flow type - the Reynolds number.
2. The factors which determine viscosity of blood:
 - the rate of shear,
 - a conduit diameter (Fahraeus-Lindquist effect),
 - the hematocrit,
 - consequences of uneven distribution of red blood cells in the blood stream (axial accumulation)

Blood viscosity is not constant at low rates of shear. At rates above about 100 s^{-1} blood viscosity tends



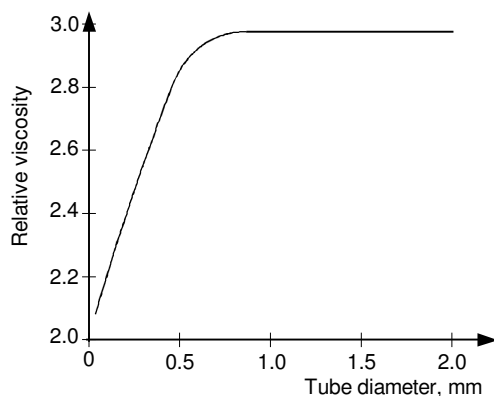
toward an asymptotic value at about 0.035 poise, but if shear rate falls below 100 s^{-1} the viscosity increases. In the normal circulation, maximal rates of shear averaged through the cardiac cycle range from 40 to 70 s^{-1} in the ascending aorta, and reach 300 through 500 s^{-1} in very small arteries.

Ratio of apparent viscosity of blood to viscosity of blood plasma increases with hematocrit. For hematocrit about 60% this relation is twice as normal.



The Fahraeus-Lindquist effect

Relative apparent viscosity of blood declines markedly in tubes of diameter less than 1 millimeter.



The laws of flow:

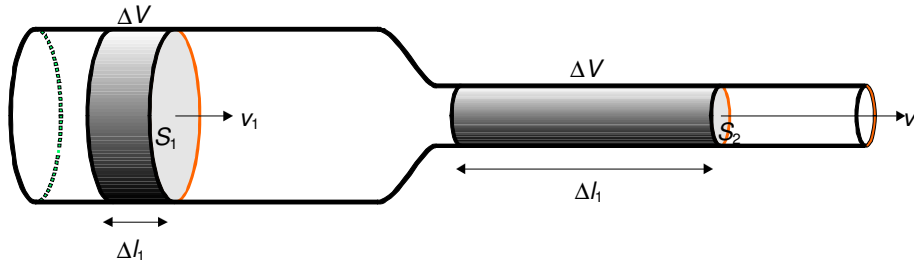
1. The law of continuity:

In the case of incompressible fluid flowing via a rigid tube the volume rate of flow Q remains constant:

$$Q = \frac{dV}{dt} = \text{const.}$$

Because $dV = Sdl$

$$\frac{dV}{dt} = \frac{Sdl}{dt} = Sv = \text{const.} \Rightarrow S_1v_1 = S_2v_2$$



2. The Hagen - Poiseuille law

The volume rate of flow through a tube depends on pressure difference between the ends of the tube Δp .

For this same pressure difference it depends on:

- viscosity of the fluid η
- the tube radius r
- the tube length l

The relation between these factors is known as Poiseuille's - Hagen law:

$$Q = \frac{dV}{dt} = \frac{\pi r^4}{8\eta l} \Delta p$$

Vascular resistance

The vascular resistance R is defined as the ratio of pressure difference between the ends of the tube Δp to the volume rate flow Q :

$$R = \frac{\Delta p}{Q}$$

and according to the Poiseuille-Hagen law may be written as:

$$R = \frac{8\eta l}{\pi r^4}$$

The unit of R used in physiology is $\frac{\text{mmHg}}{\text{milliliter}} \frac{1}{\text{second}}$ and is called "*peripheral resistance unit*" (PRU). This is a con-

ventional unit of vascular resistance equal to the resistance that produces a pressure difference of 1 mm Hg, corresponding to a blood flow of 1 mL/sec.

In the circulatory system the length of any given vessel is virtually constant, and viscosity of the blood does not vary appreciably. Thus, the major alterations in resistance are produced, physiologically or pathologically,

by virtue of variations of a radius r . The term $\frac{l}{r^4}$ is known as the geometrical factor.

Arrangement of vessels and the means of estimation of the vascular resistance of composed systems:

a) arrangement in series:

The total vascular resistance is:

$$R = R_1 + R_2 + R_3$$

b) arrangement in parallel:

The inverse of total vascular resistance R_T of parallel arrangement is calculated as sum of the inverse of the resistances of the segments:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

3. The Bernoulli law:

For non-viscous fluids the total pressure p_T of the fluid remains constant in all parts of a

$$p_{T1} = p_{T2} = p_{T3} = \text{constant}$$

The total pressure p_T , (neglecting the gravitational factor that is the hydrostatic pressure) is the sum of lateral (or static) pressure p_l and dynamic pressure p_D (where $p_D = \frac{1}{2} \rho v^2$) and can be written as:

$p_T = p_l + \frac{1}{2} \rho v^2$ (ρ stands for fluid density and v stands for velocity of fluid flow). Finally:

$$p_T = p_{l1} + \frac{1}{2} \rho v_1^2 = p_{l2} + \frac{1}{2} \rho v_2^2 = p_{l3} + \frac{1}{2} \rho v_3^2$$

Properties of vascular walls

Elasticity, stress and strain, cylindrical stress and strain,

Laplace's law

Viscoelasticity and viscoelastic models of vascular walls.

Arterial elasticity and pulse wave velocity, the Moens-Korteweg equation.

Mechanical work of the heart:

The heart as a mechanical pump.

Work, power and efficiency of the heart.

Mechanical and electrical models of circulatory system.

Sounds of the heart