3 CIRCULATION OF THE BLOOD

Blood is not a simple fluid; it contains cells that complicate the flow, especially when the passages become narrow. The veins and arteries are **not rigid pipes**, but are **elastic** and alter their shape in response to the forces applied by the fluid.

3.1 BLOOD PRESSURE

The contraction of the heart chambers is triggered by electrical pulses that are applied simultaneously both to the left and to the right halves of the heart.

First the atria contract, forcing the blood into the ventricles; then the ventricles contract, forcing the blood out of the heart. Because of the pumping action of the heart, blood enters the arteries in spurts or pulses.

The maximum pressure driving the blood at the peak of the pulse is called the **systolic pressure**. The lowest blood pressure between the pulses is called the **diastolic pressure**. Therefore, the average pressure of the pulsating blood at heart level is 100 torr.

We can estimate the **pressure drop** through arteries using Poiseuille's law

$$\Delta P = P_1 - P_2 = \frac{8Q\eta L}{\pi R^4}$$

The expression $P_1 - P_2$ (dyne/cm^{-2}) is the pressure drop that accompanies the flow rate Q (cm^3/sec) along a length L (cm) of the pipe with a radius R (cm).

For example, we can estimate the pressure drop per centimetre length of the aorta when the blood flow rate is 25 litre/min. The radius of the aorta is about 1 cm, and the coefficient of viscosity of blood is 4×10^{-2} (dyne.sec/cm^2).

$$\Delta P = \frac{8Q\eta L}{\pi R^4} = \frac{8 \times 25\,\frac{\text{liter}}{\text{min}} \times 4 \times 10^{-2}\,\frac{\text{dyne. sec}}{\text{cm}^2} \times 1\text{cm}}{\pi (1)^4\,\text{cm}^4} = 42.5\,\frac{\text{dyne}}{\text{cm}^2} = 3.19 \times 10^{-2}\ \text{torr}$$

which is negligible compared to the total blood pressure (100 torr).

The arterial blood pressure, which is on the average 100 torr, can support a column of blood 129 cm high.

This means that if a small tube were introduced into the artery, the blood in it would rise to a height of 129 cm (see Figure 3).

The weight of the blood must be taken into account in calculating the pressure at various locations. For example, the average pressure in the artery located in the head, 50 cm above the heart is

$$P_{head} = P_{heart} - \rho g h$$

$$\left(100 \times 133 \ \frac{\mathrm{N}}{\mathrm{m}^2}\right) - \left(1050 \frac{\mathrm{Kg}}{\mathrm{m}^3} \times 9.8 \frac{\mathrm{m}}{\mathrm{s}^2} \times 0.5\mathrm{m}\right)$$

$$(13300 - 5145) \frac{\mathrm{N}}{\mathrm{m}^2} = (100 - 38.6) \ \mathrm{torr} = 61.4 \ \mathrm{torr}$$

In the feet, 130 cm below the heart, the arterial pressure is about 200 torr.

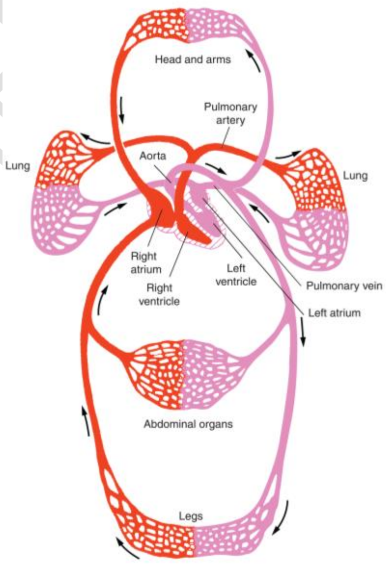

Figure 2: Routes of blood circulation.

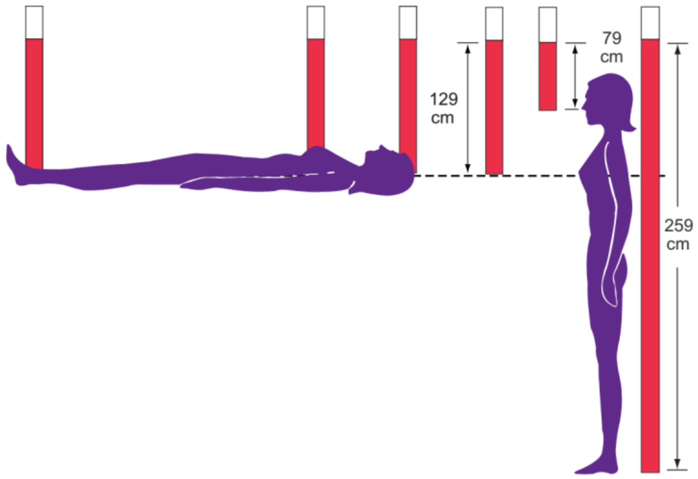

Figure 3: Blood pressure in a reclining and in an erect person.

3.2 TURBULENCE IN THE BLOOD

At rest, the rate of blood flow is about 5 liter/min and the average velocity of the blood through the aorta is 26.5 cm/sec. Through most of the circulatory system the blood flow is **laminar**. Only in the aorta does the flow occasionally, i.e. **Turbulent** flow. During the period of flow, the velocity of the blood is about three times as high as the overall average value (79.5 cm/sec).

Laminar flow is **quiet**, but turbulent flow produces **noises** due to vibrations of the various surrounding tissues, which indicate abnormalities in the circulatory system.

$$V_c = \frac{\Re \eta}{\rho D}$$

where V_c is the critical velocity of the onset of turbulence, $\Re$ is Reynold's number (2000 – 3000), η is the viscosity of the blood (0.04 sec/cm^2), ρ is the density of the blood (1.05 gm/cm^3) and D is the diameter of blood vessel.

3.3 ARTERIOSCLEROSIS AND BLOOD FLOW

In arteriosclerosis, the arterial wall becomes **thickened**, and the artery is **narrowed** by **deposits** called **plaque**. This condition may seriously impair the functioning of the circulatory system.

A 50 % narrowing (*stenosis*) of the arterial area is considered moderate. 60-70% is considered severe, and a narrowing above 80% is deemed critical.

The velocity of blood flow would increase if the blood passes through a constricted region. This would lead to a pressure drop down than the average value of the pressure.

Because of the low pressure inside the artery, the external pressure may close off the artery and block the flow of blood.

Stenosis above 80% is considered critical because at this point the blood flow usually becomes turbulent. As a result, the pressure drop in the situation presented earlier is even larger. Further, turbulent flow can damage the circulatory system because parts of the flow are directed toward the artery wall rather than parallel to it, as in laminar flow.

There is another problem associated with arterial plaque deposit. Deposits of plaque cause an increase in the mass of the arterial wall and a **decrease in its elasticity** and thus may cause further damage to the arterial wall.