كلية الاسراء الجامعة
قسم هندسة تقنيات الاجهزة الطبية

Physics of the cardiovascular system

The cardiovascular system or the vascular system is the system that **permits** blood to circulate and transport nutrients, oxygen, carbon dioxide, hormones, and blood cells to provide (nourishment and help in fighting diseases, stabilize temperature and pH, and maintain homeostasis).

The circulatory system comprises two separate systems:

- The cardiovascular system, which distributes blood, it contains the blood, heart, and blood vessels.
- The lymphatic system, which circulates lymph, it contains lymph, lymph nodes, and lymph vessels.

The parts of the cardiovascular system include the heart, which is the organ that pumps the blood, and a network of blood vessels contains:

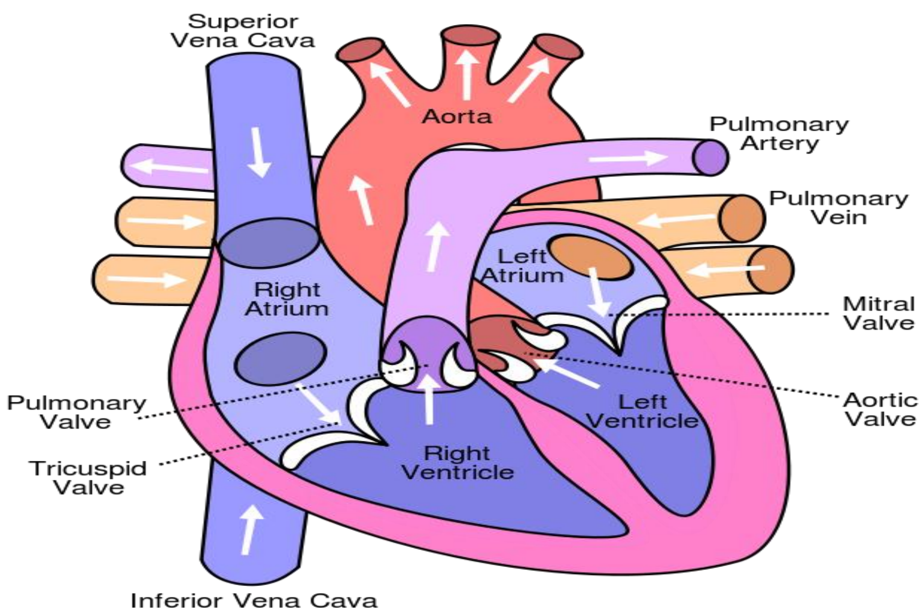
- Arteries: The blood vessels that take blood away from the heart
- Veins: Blood vessels that return blood to the heart
- Capillaries: Very small vessels that lie between the arteries and veins

The portal vein carries blood from parts of the digestive system to the liver before reaching the heart.

The heart is a muscular pump with four chambers inside: the right and left atria and the right and left ventricles. Those four chambers allow the heart to pump blood through the following two circulatory pathways:

- **Systemic circulation:** Takes oxygen-rich blood to the tissues and organs of the body
- **Pulmonary circulation**: Takes oxygen-depleted blood to the lungs and oxygen-rich blood back to the heart again

Here's the pathway taken by the blood while it's in systemic circulation, delivering oxygen-rich blood throughout the body:



#a number of problems can be classified as **cardiovascular disease**. The problems can occur after a person has developed **atherosclerosis**, also known as "hardening of the arteries," which results in decreased blood flow because the blood vessels are plugged. It occurs when fat, cholesterol, and calcium build up within the walls of the arteries. These build-ups, called plaques, can block the arteries and reduce the flexibility of the arterial walls**. Atherosclerosis** is common in older people, especially in those who have high blood pressure, are diabetic, have high cholesterol, eat too much saturated fat, drink too much alcohol, smoke, don't get enough exercise, and are overweight or obese. Blood clots can also form in the diseased vessels and stop blood flow completely, depriving tissues of oxygen.

Heart attacks (myocardial infarcts) occur when blood flow to some part of the heart is blocked, causing damage to part of the heart. **Arrhythmia** is a problem with the heart rhythm; the heart may beat too slowly, too fast, or irregularly.

Cardiovascular disease can affect the brain as well. **Ischemic strokes** happen when a blood vessel in the brain is blocked. **Hemorrhagic strokes** occur when a blood vessel in the brain breaks open. Either type of stroke can result in damage to a part of the brain. #

Work Done By the Heart

In a typical adult each contraction of the heart muscles forces about 80ml (about one-third of a cup) of blood through the lungs from the right ventricle and a similar volume to the systemic circulation from the left ventricle.

The pressure in two pumps of the heart is not the same. In the pulmonary system the pressure is quite low because of low resistance. The maximum pressure (systole), typically about 25mmHg, is about one-fifth of that in the systemic circulation. In order to circulate the blood through the much larger systemic network the left side of the heart must produce pressures that are typically about

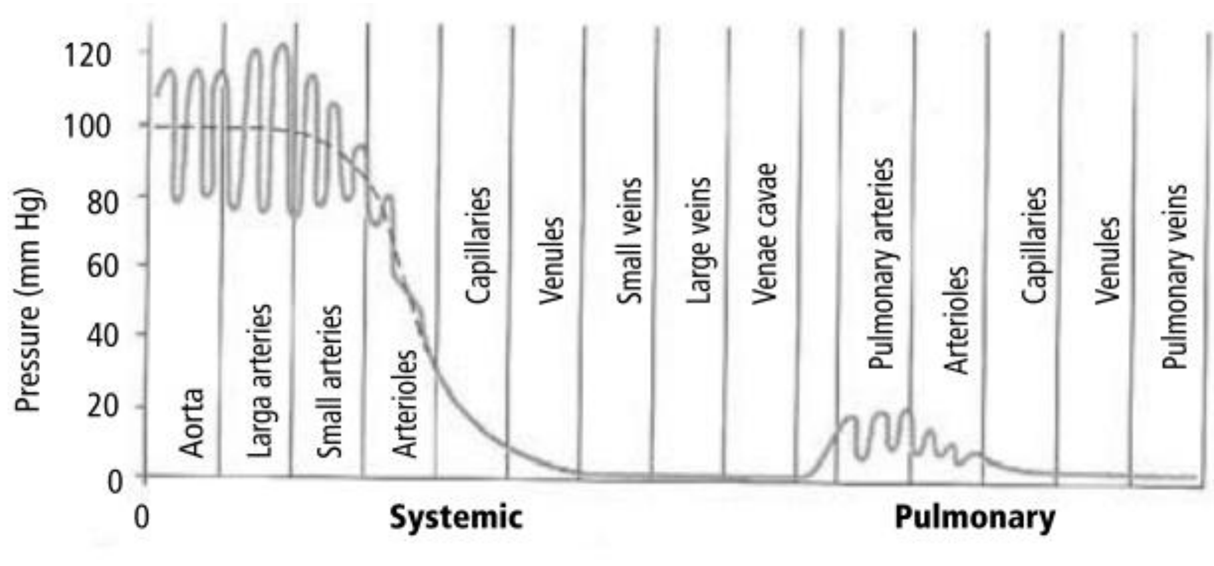
120mmHg at the peak (systole) of each cardiac cycle. During the resting phase (diastole) of the cardiac cycle the pressure is typically about 80mmHg.

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

$$\mathbf{W=P\Delta V.}$$

We can estimate the physical work done by the heart by multiplying its average pressure by the volume of blood that is pumped.

- Actually the pumping action takes place in less than one-third of the cardiac



Normal Blood Pressure in different parts of Circulatory System - HourlyBook.com

cycle and the heart muscle rests for over two-thirds of the cycle.

Example (1): The heart rate of a person is 72 pulse/min; calculate the action time and the resting time of heart muscle.

72pulse/1min = 72 pulse/60sec

= 1pulse/0.833sec

1pulse = 1/3contraction + 2/3 relaxation

0.833x1/3 = 0.277sec (the time of contraction)

0.833x2/3 = 0.555sec (the time of relaxation)

Example(2): Person has a systolic pressure 150mmHg, diastolic pressure 100mmHg, heart rate 90/min. Calculate the work done and the efficiency of the lower left half of the heart if the energy consume is 6 Watt.

Work done = $P\Delta V$

P average = (systolic +diastolic)/2

P average = (150+100)/2

P average = 125 mmHg

1 mmHg = 1330 dyne/cm2

125 mmHg = 166250 dyne/cm2

ΔV = 80ml/beat × (90beats/min)/(60sec/min)

ΔV = 120 cm3/sec

$\boldsymbol{W = P\Delta V}$

Work = 166250 dyne/cm2 × 120 cm3/sec

Work = 19950000 dyne. Cm/sec

1 erg = 1 dyne. cm

Work = 19950000 erg/sec

1 erg = 10-7 Joule

Work = 1.995 Joule/sec

Efficiency = (Work done/Energy consume) x 100%

Efficiency = (1.995/6) × 100% = 33.25 %

Blood pressure and its measurement

One of the most common clinical measurements is of blood pressure. During ventricular systole, the heart pushes blood n to the arteries and the pressure reaches a maximum value which is called **systolic pressure**. When the ventricle relaxes between beats, blood presser falls to a minimum value **called diastolic pressure**. These two pressures are expressed in millimeters of mercury (mm Hg), because the original device that measured blood pressure contains a column of mercury.

The instrument that is commonly used is a **sphygmomanometer,** it consist of a pressure cuff, gage, on the upper arm and a stethoscope placed over the brachial artery at the elbow.

Procedure

1. Applying the cuff around the arm above the elbow for about four fingers and ensures that the cuff is empty of air.

2. Open the mercury pool and put the stethoscope over the brachial artery distal the cuff.

3. Close the valve of the bulb and inflate the cuff by the squeezing the bulb of several time until the pressure lifts to the 200mmHg, this pressure closes the brachial artery so that no blood flows pass the cuff (figure2b) and no sound can be heard through the stethoscope at this point.

4. Gradually and slowly deflate the cuff by opening the valve of the bulb with the thumb and forefinger of the same hand and notice that the mercury column begins to fall and the blood beings to flow into the forearm and the sound can be heard, so that the number pointed by the sphygmomanometer at the first hearing is the systolic pressure (figure2 c)

5. Continue hearing the sound and notice the sound become louder and starts to disappear gradually as the cuff deflated and the level of the mercury decline

Until the sound disappear completely. The number pointed by the sphygmomanometer at which the sound disappeared represents the diastolic pressure (figure2 d).

Blood pressure measurements are recorded as systolic/diastolic. If systolic pressure is 120 mmHg and diastolic pressure is 80 mmHg, it will be recorded as 120/80 mmHg and we read as 120 over 80.

Reference ranges:

Newborn 90/70 mmHg

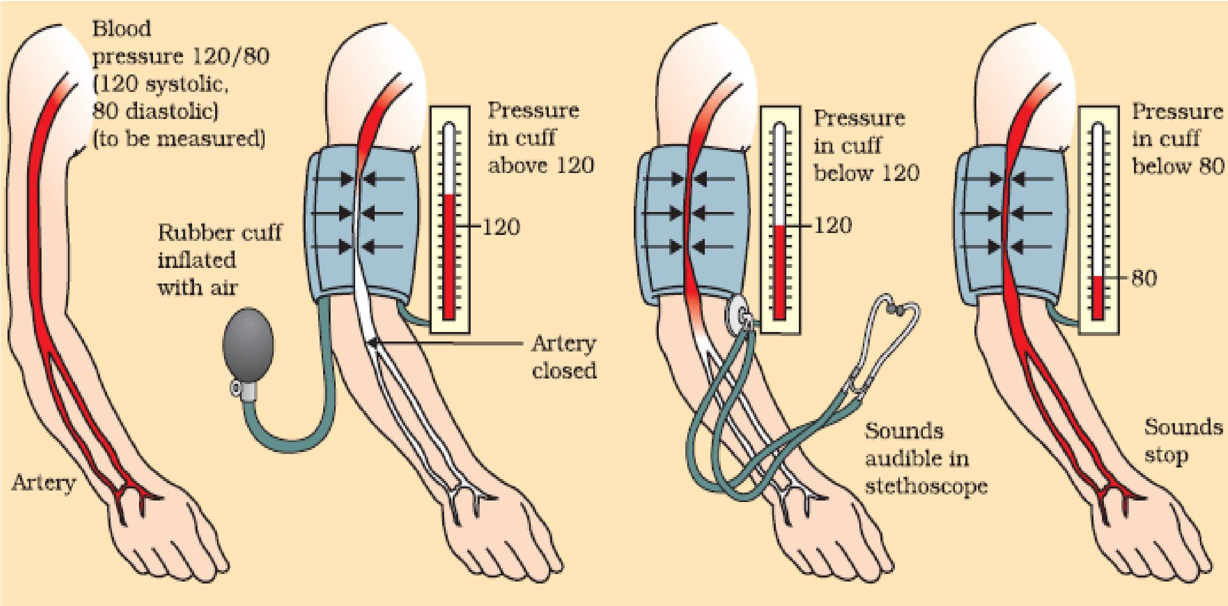
Juvenile 120/80 mmHg

Adults 130/90 mmHg

Old 150/120 mmHg #

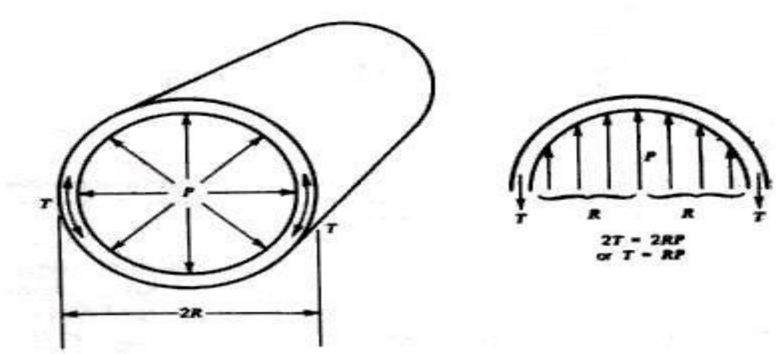
Factor affect blood pressure

1- Cardiac output
2- Blood volume
3- Flexibility of the artery wall
4- Artery diameter
5- Blood viscosity



Pressure across the blood vessel

The greatest pressure drop in the cardiovascular system occurs in the region of the ***arterioles and capillaries***. 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 a tube is related to the radius of the tube **and** the pressure inside the tube.



For a long tube of radius R with blood 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

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

$$(T=RP).$$

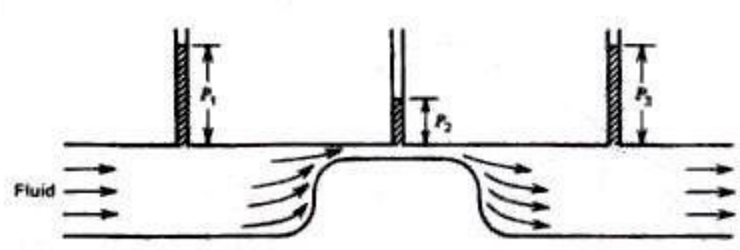
Bernoulli's principle applied to the cardiovascular system

Whenever there is a rapid flow of a fluid such as air or water, the pressure is reduced at the edge of the rapidly moving fluid.

Bernoulli's principle is based on the law of **conservation of 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 **KE** due to the motion. This kinetic energy can be expressed as energy per unit volume such as ergs per cubic centimeter.

If fluid is flowing through the frictionless tube, the velocity increases in the narrow section and the increased kinetic energy **KE** of the fluid is obtained by a reduction of the potential energy **PE** of the pressure in the tube.

As the velocity reduces again on the far side of the restriction the kinetic energy is converted back into potential energy and the pressure increases again as indicated on the manometers.



*Notice that the blood velocity is related in an inverse way to the total cross-sectional area of the vessels carrying the blood.

. The viscosity of blood is typically **3×10^{-3}** to **4×10^{-3} Pas depends** on the percentage of red blood cells in the blood (the hematocrit). As the hematocrit increases, the viscosity increases, decreasing the flow rate.

Blood flow-laminar and turbulent

Laminar: is a streamline flow which is present in most blood vessels.

Turbulent: is the flowing of blood rapidly fast. In the heart valves ,for example .

In laminar flow the blood that is 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 rapidly at the center of the vessel

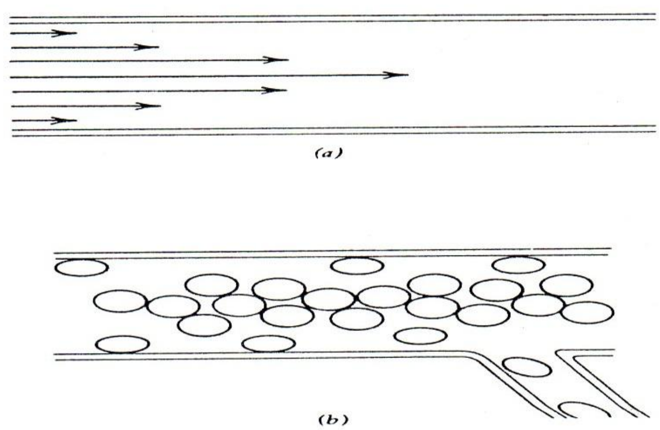
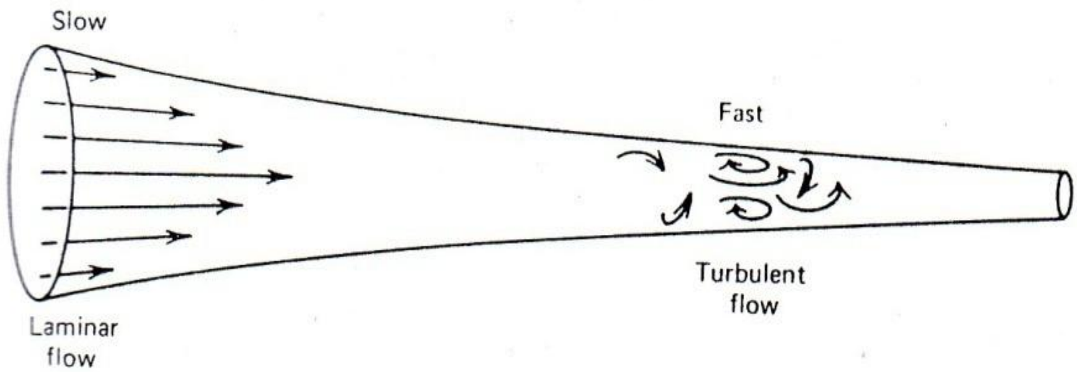


Figure 2 : Blood flow in vessels (a) In the laminar flow in most of the vessels there is a greater velocity at the center as indicated by the longer arrow . (b) The distribution of red blood cells is not uniform they are more dense at the center so the blood that flows into small arteries has smaller percentage of red blood cells that the blood in the main artery .

CRITICAL VELOCITY

If you gradually increase the velocity of a fluid flowing in a tube by reducing the radius of the tube, it will reach a critical velocity Vc. when laminar flow changes into turbulent flow as shown in figure below. The critical velocity will be lower if there is restriction or obstructions in the tube



Reynold' s found that the critical velocity is proportional to the viscosity of the fluid and is inversely proportional to the density of the fluid and radius R of the tube .

$$V_c = K\eta / \rho R$$

Where K is constant and is called Reynold's number. K = 1000 for many fluids including blood, R is the radius, ρ is the density of the fluid

VISCOSITY

Blood viscosity is the thickness and stickiness of blood. It is a direct measure of the ability of blood to flow through the vessels. It is also a key screening test that measures how much friction the blood causes against the vessels, how hard the heart has to work to pump blood, and how much oxygen is delivered to organs and tissues. Importantly, high blood viscosity is easily modifiable with safe lifestyle-based interventions

Viscosity: is the ratio of the stress to velocity gradient.

Viscosity = stress/velocity gradient (Pas)

$$\text{Viscosity} = \frac{\text{pressure (Pa)}}{\text{Velocity gradient [(m/sec)/m]}}$$

Velocity gradient = velocity /Δ L