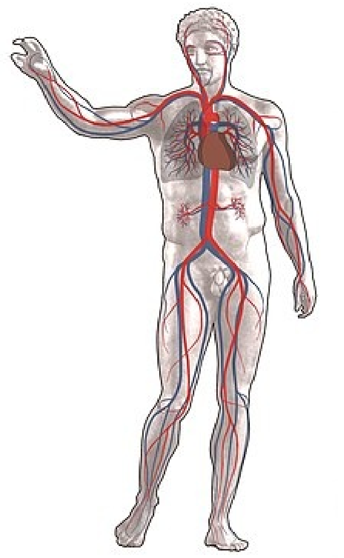
Bloodstream

The flow and flow of blood in a riverbed, which is studied by biomechanics, is called biorheology (you can also use **hemodynamics**, which translates as "blood movement and balance caused by external forces"). It describes blood circulation based on physical principles including their peculiarities in the human organism, the flow of blood in the circulatory system, the pressures of the blood in different parts of the body and under different circumstances, the action of the heart as a pump, vessels as tubes carrying blood and also studies the regulation of these phenomena. The purpose of the riverbed is to enable the circulation of blood and thus to ensure the **transport** and **exchange** of substances with the environment.



The circulatory system of the human body

Components of the Circulatory System

The circulatory system consists of 3 main parts:

Heart

Muscular pump, which with its movements induces **kinetic energy** and thus the movement of blood in the **vascular bed'**. It pumps oxygenated blood to the body system and deoxygenated blood to the lungs. There are a total of 4 pumps in the human heart: **left and right atrium & left and right ventricle**. The right atrium is the upper cavity of the right side of the heart. The blood that returns to the right atrium is deoxygenated and then travels to the right ventricle. There it is pumped by the pulmonary artery into the lungs (systole), where it is oxygenated and exchanges carbon dioxide with the environment. Newly oxygenated blood then flows from the lungs into the left atrium (diastole), then into the powerful left ventricle, which pumps blood through the aorta into the body system. The cardiac cycle of systole & diastole described in this way lasts approx. 0.75 s. The mechanism of heart contractions is called the "valve plane mechanism" - during systole, the valve plane decreases and thus the stroke volume of the next systole is absorbed. The ventricles fill with blood from the atria until the ``atrial blood pressure is greater than the ventricles - *then the semilunar valves open and the blood is pushed out of the heart further into the bloodstream.*

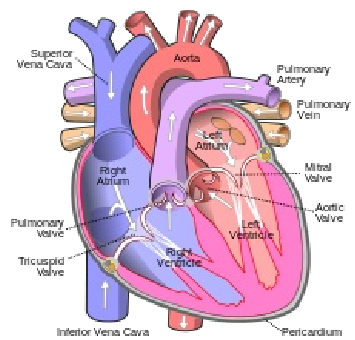


Diagram of the human heart

The mechanical ejection work of the heart is equal to 1/10 of the total mechanical energy of the heart, the rest of the energy is for maintaining the tone (tension) of the heart muscle. Changes in pressure and blood flow through the heart compartments and vessels are caused by the contraction of the individual heart chambers. The heart is made up of the cardiac muscle *myocardium*. The rhythmic beating of the heart is performed by the transduction system. The strongest part of the myocardium is located in the left ventricle of the heart, where oxygenated blood is expelled into the large blood system. Myocardial efficiency is about 30%. Volumetric work is more efficient than pressure work, i.e. the return of blood through veins will use energy better than peripheral resistance. Heart muscle is made up of '*myocardiocytes*, connective tissue, capillaries, and intercellular fluid. The composition of this complex arrangement of the myocardium forms the pressure gradients of the vessel walls. It is an important determining factor of the patency of the coronary vessels and the microcirculation of the heart wall. The relationship between the length and tension of the heart muscle is determined by Laplace's and Starling's laws - when blood is expelled in systole, the tension of individual muscle fibers "decreases" even without a change in pressure, which is caused by a decrease in the radius of the ventricles and an increase in the wall of the ventricles.

From a physical point of view, the heart performs pressure-volume work, where W stands for work, p for pressure and V for volume.

$$W = p \cdot V$$

Pulse volume

The amount of blood ejected by one cardiac systole into the aorta. The volume of expelled blood is not constant, it changes with e.g. physical activity or pathological conditions. However, the average value of the volume of expelled blood is reported to be around 70-90 ml.[1]

Vessels

The human vascular bed is closed and consists of two main circuits:

- **Small Cardiac Circulation**, blood circulates between heart and lungs - has low pressure & resistance

- **Great Cardiac Circulation**, blood circulates between heart and body - has high pressure & resistance


Vascular system

The vascular system consists of:

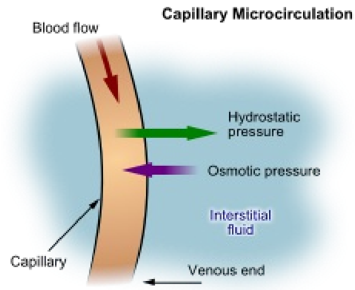
Arteries

highly elastic arteries carrying blood away from the heart; are the main site of resistance to blood flow

Arteries (flexible vessels) have very strong, flexible vessel walls, which allow them to receive the stroke volume expelled by the heart. In systole, the vessel expands, in diastole it contracts. This pressure wave is palpable as a pulse. Arterial pressure mechanics is referred to as the *elastic effect*, which enables easy blood circulation without increased heart involvement. Arteriole (resistance vessel) – a smaller artery that has dense muscle innervated by adrenaline (contracts vessels) and cholinergic fibers (dilates vessels). The system of arterioles causes changes in the total volume of the arterial bed and also changes the arterial pressure, which enables the controlled distribution of blood according to the needs of the organism.

Capillaries

– small, thin-walled blood vessels; they filter blood between tissues



Microcirculation in the capillary

The total surface area of capillaries in humans is approx. 1000 m^2, blood flows slowly in them, the capillary walls are lined with endothelium, which molecules smaller than proteins easily pass through. The following events take place in the capillaries:

- Diffusion – capillaries allow the passage of water and soluble substances through the pores of the capillary membrane
- Permeation - passage of large molecules - proteins through large pores
- Filtration – given by the relationship between hydrostatic and colloidal osmotic pressure

$V = K * (p_k - \pi_k + \pi_{iF} - p_{iF})$

V – volume, K – filtration coefficient, p_k – blood pressure, p_{iF} – the pressure of the interstitial fluid, π_k – colloidal osmotic pressure of blood , π_{iF} – colloid osmotic pressure of the interstitial fluid.

Veins

Thin-walled veins carrying blood to the heart; prevent the backflow of blood thanks to the valves on their walls

Veins (capacity vessels) are less elastic and have less muscle, which is characterized by an overall smaller volume of blood. The flow of blood back to the heart is more passive and is caused by the muscular work of the lower limbs, the valves, and the negative pressure in the pleural cavity. The venous system is low pressure.

Coronary Circulation

Circulation bloodsupplies the myocardium. Blood flow in the coronary circulation differs from the rest of the blood circulation - the volume of blood that flows through the coronary circulation per minute is approximately 240 ml. **The coronary reserve** is up to five times the increased coronary blood volume during exercise.

Blood

Blood is a body fluid composed of **liquid plasma'** and **cells'** (red blood cells, white blood cells, platelets). Plasma, which comprises 55% of blood fluid, is mostly water (92% of its volume) and contains substances such as proteins, glucose, mineral ions, hormones, carbon dioxide, and blood cells. Blood makes up about 7% of a person's weight with a density of approximately 1060 kg/m^3, which is very close to the density of water (1000 kg/m^3). The chemical composition of blood changes depending on the passage through the bloodstream. Its viscosity is about 4.5 times greater than that of water. It behaves like a non-Newtonian or non-linearly viscous fluid.

Blood flow

The cause of the blood flow is the pressure differences between the arterial and venous parts of the system, which are created by the activity of the heart. We distinguish two types of blood flow:

- laminar (straight-line - at lower speed)
- turbulent (eddy - when the current accelerates)

Laminar flow

Laminar flow is an unsteady flow of a real liquid whose particles move in mutually parallel layers without mixing with each other. In the tube (vessel) it has a small velocity that rises slowly from the edge to the center of the tube, where it is greatest. Laminar flow is maintained up to the so-called critical speed when it changes to turbulent flow. The probability of the transition from laminar to turbulent flow is influenced by the diameter of the tube (vessel), viscosity, and density of the liquid in addition to the flow speed. The elasticity of the vascular walls increases its stability.

Turbulent flow

In turbulent flow of a real liquid, turbulence occurs - changes in the speed, density, and pressure of the flowing liquid. Turbulence can be caused by the branching of vessels or the inhomogeneity of their walls. The transition from laminar to turbulent flow is characterized by the Reynolds numbers. The probability of turbulence depends directly proportionally on the density of the liquid ρ, the diameter of the considered tube R, the speed of the current v and inversely proportionally on the dynamic viscosity η.

$$Re = \frac{\rho \cdot R \cdot v}{\eta}$$

Under certain pathological circumstances, especially when the viscosity of the blood is reduced, the speed increases in the narrowed places of the aorta, and this creates a turbulent flow. This should not happen to a healthy person. Accurate determination of turbulent areas in blood circulation is of extremely high clinical importance. It manifests itself as a murmur.

Blood Flow Rate

There is internal friction between the blood molecules, which causes the inhomogeneity of the flow velocity vector field. When a vessel is cut longitudinally, the velocity field forms a parabola. The flow rate at a distance from the center of the vessel is given by:

$$v_r = v_m + (1 - \frac{r^2}{R^2})$$

where vm is the maximum flow velocity at the center of the tube. At the vessel wall, the velocity is zero. For this reason (and also because of the elasticity of blood vessels), the Bernoulli equation does not apply exactly either, according to which the sum of potential pressure energy, kinetic energy, and positional energy at each point of the fluid is constant during the flow of a unit volume of an ideal fluid:

$$\frac{1}{2}\rho v^2 + h\rho g + P = const.$$

The laws of physics are usually only approximately applicable to non-Newtonian fluids.

Blood Flow

Blood flow is a quantity defined by the product of the cross-section (lumen) of the vessel and the linear velocity of the flow through the given cross-section. If a liquid (blood) flows steadily through a system of closed tubes (vessels) of unequal diameter, the continuity law applies. The equation expresses that if the flow remains constant, its speed is then inversely proportional to the cross-section of the vascular bed.

$$Q_v = S \cdot v = const.$$

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