Ministry of Health of Ukraine
Ukrainian Medical Stomatological Academy

It is approved
on meeting of department of
medical informatics, medical and biological physics
27 August 2020
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Methodical instructions
for students' self-preparation work at preparation for a practical lesson
at home and at the classroom

Subject matter	**Medical and biological physics**
The unit	1. Fundamentals of higher mathematics and biological physics
Theme of lecture:	**Bases of a blood circulation. Heart work analysis. Methods of arterial tension measurement.**
Year	1
Faculty	Medical
Speciality	Medicine

Poltava - 2020

The topic significance.

A number of biophysical processes and phenomena in a human organism have the hydrodynamics as a physical basis. One of most important of such processes is a hemodynamics – a motion of blood in vessels. The cardiovascular system is main in maintenance of normal vital activity of an organism, and its infringement, for example, infringements of a circulation, is the reason of many diseases.

Specific targets.

To find out the mechanism of operation of cardiovascular system.

To know concept a laminar and a turbulent flow, the basic hydrodynamical equation, dependence of a blood motion velocity on a cross-sectional area of vessels, and also quantities of a blood pressure in different departments of vascular system.

Basic knowledge, experience, skills necessary for studying the topic in connection with other subjects:

Previous (providing disciplines)	Obtainable skills
1. Physics 2. Anatomy	Constitution of cardiovascular system Role of heart in realization of a circulation. Constitution and principle of activity of the heart pumpe. Constitution and principle of work of a manometer. Concepts: pressure, mechanical work, velocity, mass, volume, density, viscosity. Units of quantities.

Materials for the before-class self-preparation work.

List of main term, parameters, characteristics, which student have to learn at preparation to class:

Term	Definition
hemodynamics	section of a biomechanics in which are considered a question of a blood motion in a vascular system of an live organism
systolic pressure	Blood pressure in aorta redundant above atmospheric pressure on pressure peak
diastolic pressure	Minimal walue of blood pressure in aorta during pulse wave cycle (during of a heart relaxation)
pulse wave	The wave of a supertension of a blood is promptly spread along an arterial part of vascular system
laminar stream	Fluid stream, in which momentary velocity vector of every particle of fluid is coincide with vector of stream; In which momentary velocity stream vector in every points don't change with time
Turbulent stream	Stream with eddies (swirls)

Theoretical questions to class:

1. Structure of the blood circulation system.
2. Main equation of hydrodynamics.
3. The laminar and turbulence flow; Reynolds number.
4. Basic characteristics of blood dynamics in the blood circulation system. Explain how and why blood flow velocity in the blood circulation system change.
5. The equation of continuous flow.
6. Dependence of blood velocity on cross-sectional area of vessels.
7. Changes of the mean of blood pressure in the blood circulation system.
8. Definition of liquid viscosity.
9. Formulate the Newton's formula and explain it.
10. The definition Newtonian and non-Newtonian liquids.
11. Methods of the blood viscosity measurement.
12. Change of pressure and velocity in blood system.
13. Steady flow of a fluid. Lines of a current and tubes of a current. A continuity equation of a stream. The linear and volumetric velocity of a fluid.
14. Energy of a fluid stream. A Bernoulli's equation. Allocation of pressure of a fluid at fluxion on tubes of variable and constant cross-section.
15. The basic dynamical equations of a fluid. Laminar and a turbulent flow of a fluid. Fluxion of a viscous fluid on a cylindrical tube. Equation of Poisellier. A water resistance (hydraulic resistance).
16. An internal friction in an real fluid. The formula of Newton for force of an internal friction.
17. A coefficient of viscosity of a fluid (absolute and relative values).
18. What is the velocity gradient? Mesurement unities for it?
19. Ideal and real fluids. The Newtonian and non-Newtonian fluids. Viscosity of blood and its dependence on requirements of fluxion on vessels.
20. What are parameters, which depends on viscosity of blood ?
21. How are bound among themselves volumetric and linear velocity of fluxion of a fluid?

Practical work executed in class: Measuring of Blood Pressure.

Blood pressure measuring in a blood vessel is possible by introducing a hollow needle connected to a manometer with the aid of a rubber pipe into the vessel.

In surgery the direct measuring of blood pressure in the cardiac region is carried out with the aid of a catheter, that is, by introducing of a thin polyethylene probe, which has a minute electric manometer at its end, via one of the bigger vessels.

In clinic an indirect, bloodless way of taking blood pressure is used (*according to Korotkoff*). The physical idea of this method is based on an approximate equality of pressures in the cuff and in the soft tissues, and on the possibility of registering the audio signals accompanying the vibration of the vessel walls during turbulent flow of blood through the vessels. Let us consider the physical foundation of this method on an example of taking the blood pressure in the brachial artery.

Auscultatory method.

Arterial blood pressure is measured by a sphygmomanometer (tonometer). This consists of:

1. A rubber bag surrounded by a cuff.
2. A manometer (usually a mechanical gauge, sometime electronic, rarely a mercury column).
3. An inflating bulb to elevate the pressure.
4. A deflating valve.

The subject lies down with both arms resting comfortably at his sides. Or the subject sit easily close the table and put his (her) arm on the table.

A hollow rubber sphygmomanometer cuff is wrapped around the patient's arm so that it is at heart level. The air bag inside the cuff should overlay the anterior portion of the arm about an inch above the antecubital fossa (the interior angle of elbow). The cuff should be wrapped snugly about the arm.

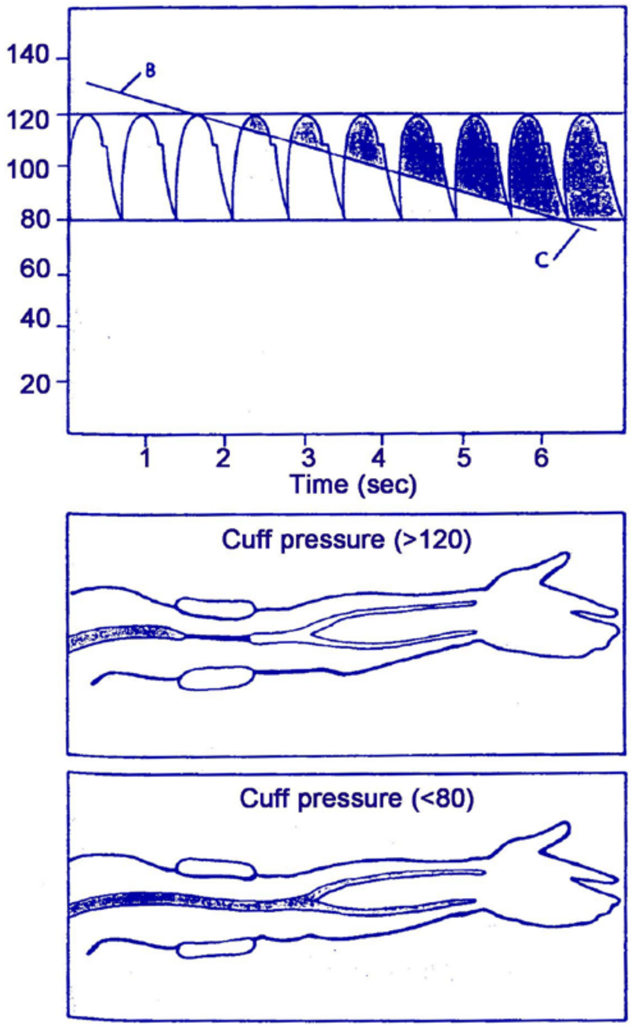

Fig.1.Arterial pressure measurement principle.

When the air is pumped into the cuff the soft tissues of the arm compress. Then, with the aid of the same pipe the air is let out, and the air pressure in the cuff is measured using a manometer. As the air is pumped in, the cuff compresses the brachial artery and stops the blood flow. By letting the air out, we decrease the pressure in the cuff and in the soft tissues the cuff is in contact with.

Apply the stethoscope bell lightly against the skin in the antecubital fossa over the brachial artery. Elevate the pressure in the cuff 20 mm Hg higher than the pressure at which the radial pulse reappeared. There will be no sounds heard if the cuff pressure is higher than the systolic blood pressure because no blood will flow through the artery beyond the cuff. Then the cuff is slowly deflated, turbulent blood flow appears beneath the cuff at stethoscope level in time moments when blood pressure is more than cuff pressure. The first heard sound is a sharp weak thud, which becomes louder, next it gradually becomes muffled and later disappears.

As soon as the pressure in the cuff equals the systolic pressure, blood pushes through the compressed artery. Turbulence flow is created and distinctive tones can be heard, which are referred to as the initial. It is this turbulent flow that produces Korotkoff's sounds. They are due to the vibration of the artery walls caused by the portions of blood pushing through the compressed part of the vessel only during the heart systole moments (moments of maximum pressure). Pulse in the radial artery appears. The manometer readings at the first pulse beat show the *maximum,* or *systole pressure.*

The cuff pressure further decreasing, additional noises add to the tones. These noises are due to the turbulent blood flow through the compressed part of the artery. Further on the noises go down and only tones can be heard in the stethoscope. These tones quickly go down and no more sound can be heard. These take place at a complete decompression of the artery by the cuff and at resuming the normal laminar blood flow. The readings of the manometer at the moment of a sharp decrease of tones correspond to the *minimum,* or *diastolic pressure.* Laminar flow is silent. Thus when the cuff is deflated completely, no sounds are heard at the antecubital fossa.

Systolic pressure approximately equals to 120 millimeters of mercury (16 kPa). During the diastole (the phase of the heart relaxation) the expanded blood vessels contract and their potential energy transforms to kinetic energy of the blood flow. The diastolic pressure is approximately 80 millimeters of mercury or 11 kPa.

Sources or error in blood pressure measurement – faulty technique

1. Improper positioning of the extremity. Whether the subject is sitting, standing, or supine, the position of the artery in which the blood pressure is measured must be at the level of the heart. However, it is not necessary that the sphygmomanometer be at the level of the heart.

2. Improper deflation of the compression cuff. The pressure in the cuff should be lowered at about 2 mm Hg per heartbeat. At rates slower than this venous congestion will develop and the diastolic reading will be erroneously high. If the cuff is deflated too quickly the manometer may fall 5 or 10 mm Hg between successive Korotkoff sounds, resulting in erroneously low readings.

3. Recording the first blood pressure. Spasm of the artery upon initial compression and the anxiety and apprehension of the subject can cause the first blood pressure reading to be erroneously high. After the cuff has been applied, wait a few minutes before recording the blood pressure. Make several measurements. Generally the third value recorded is the most basal.

***The content of the topic*.**

The hemodynamics terms section of a biomechanics in which are considered a question of a blood motion in a vascular system of an live organism. From the physical point of view human and animal blood system is the composite closed system of the series and paralleled elastic tubes of different diameter and length (an aorta, arterias, arterioles, capillars, venules and veins).

An exceptional role of the blood-circulation system in the human body requires an investigation into the biophysical aspects of this system functioning. Movement of the blood through blood vessels is a complicated process from the point of view of biophysics, and it will be approached by first considering a more simple process of water flow through pipes. Thus, let us consider the basic concepts and formulae of hydrodynamics, first.

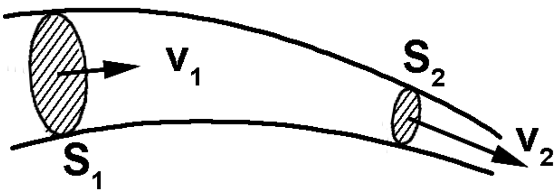

Fig.2. Flow in tube with changeable cross-section.

Biorheology is a field of biophysics, studying deformations and fluidity of the blood.

The *equation of continuous flow* – that applies for a real liquid as well. It can be put down like this (fig.1):

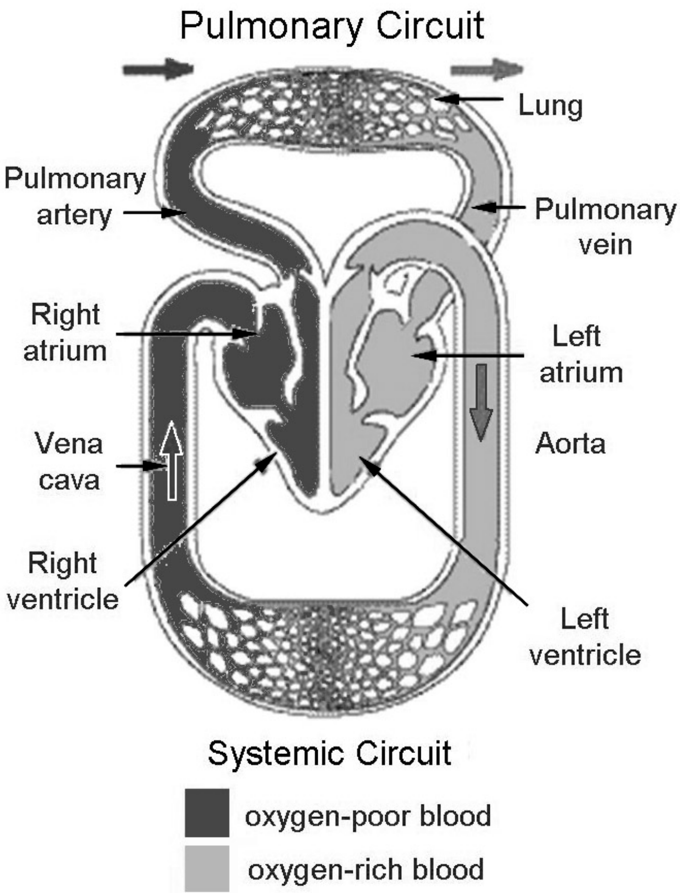

Fig.3. Cardiovascular system.

$$\frac{\Delta V}{t} = vS = const \quad \text{or} \quad \frac{v_1}{v_2} = \frac{S_2}{S_1},$$

where ΔV is the volume velocity of liquid flow, that is, the volume of liquid passing through the cross-section of a pipe per unit time, m^3s^{-1}; S is the area of the flow cross-section (in case of the water flow through the pipe it is the pipe cross-section), m^2; v is the mean velocity of the liquid for a section, $m \cdot s^{-1}$.

This equation is a corollary to the law of conservation of mass for a non-compressible liquid.

Liquid flow pattern is very important in hydrodynamics. There exist *laminar and turbulence flow*.

In *laminar flow* the liquid layers slide relative to each other, retaining their continuity, without mixing together, diffusion being neglected. *Current line* (current-flow line, streamline, thread of current, thread) – there are set of synonyms defined imaginary lines coinsided with velocities of particles in fluid stream. Such kind of flow can be observed at comparatively low relative speed of adjacent layers, that is, at velocity gradient low values.

At high relative velocities of layer movement the friction forces are high enough to create eddies at the layer boundaries. These eddies cause layers discontinuity and their mixing. Such kind of liquid flow is referred to as *turbulent flow.*

Vessels walls are elastic. Veins have elastic properties due to which the blood goes on these vessels as any fluid on elastic tubes. Velocity of a blood motion on vessels of an organism is small, therefore the its stream can be accepted as *laminar.*

Basic characteristics of blood dynamics in the blood circulation system.

Considering specific problems of hemodynamics let us first find out how the mean *velocity of blood flow* (v_{mean}) changes in the blood circulation system.

The blood goes in vascular system due to energy which is transmitted it by a cardiac work. On a fig. 3 the schematic sketch of a major circle of a circulation is represented. From a left ventricle the blood transfers into an aorta, from there in an arteries, arterioles and capillars. Further capillars embody in venules, which transform to veins. Fine and major veins form system of superior and inferior cava veins, which delivers a blood in a dextral auricle.

At transition from an aorta up to capillars the general cross-sectional area of vessels is incremented. Though diameter of each capillar is equaled 4–10 nanometers, but their quantity reaches 100-160 billion in a human body, that is why an all capillars cross-sectional area more the cross-sectional area of all arterias in 600-800 times.

Further capillars are agglomerated in fine veins, then in major and thus the general cross-sectional area of the veins decreases also a major circle of a circulation comes to an end to two cava veins which enter a dextral auricle.

So, at contraction of a cardiac muscle *(systole)* the blood is pushed out from heart into an aorta and in arterias branching off from it. Due to an elastance of walls of major arterias, they enlarge and take more blood during a systole, than it flows off to periphery. It also creates *a systolic pressure,* i.e. redundant above atmospheric pressure, which in norm on the average makes 120 mm Hg or 16 kPa.

The wave of a supertension of a blood is promptly spread along an arterial part of vascular system and invokes walls oscillations further. This pressure wave is termed as *pulse wave*, which velocity of propagation depends on elastic properties and density of vascular walls and has the order of 6-8 km/s.

During of a heart relaxation *(diastole)* walls of an aorta and arterias are contracted to an initial state, forcing blood in the following fields of vascular system. Thereof the motion of a blood

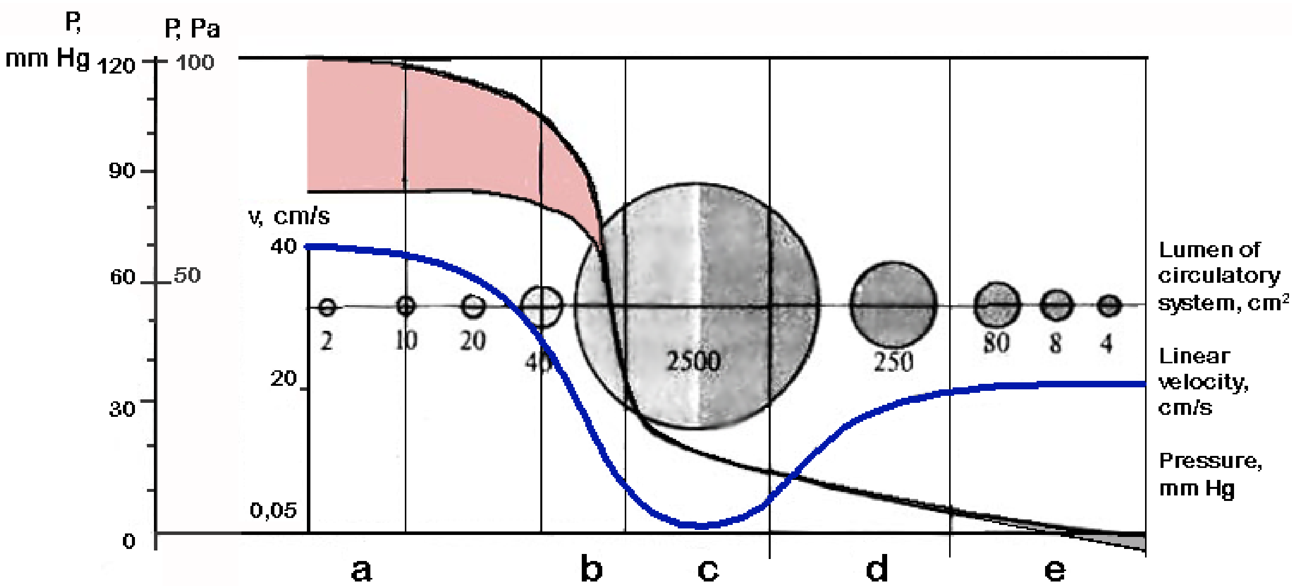

Fig.4. Pressure, blood linear velocity and lumen of circulatory system changes. Fluctuations of pressure in arteries (pulse) and in big veins (under the respiration influence) are shown by wide line. in greater circulation system. a – aorta and large arteries, b – small arteries and arterioles, c – capillaries, d – veins, e – vena cava.

has continuous character with velocity in major vessels about 0,3–0,5 m/s. Pressure of a blood is reduced up to 60–70 mm Hg or 11 kPa *(diastolic pressure).*

According to the basic hydrodynamical equation it is known, that velocity of a fluid motion in a tube with variable cross-section is inversely proportional to cross-sectional area. So, velocity of a blood motion on different sections of a major circulation circle is different. In arterias it is 0,5 km / s, in arterioles – 10-30 sm / s, in capillars – it is no more 0,5 mm / s. In veins velocity of a blood increases and in caval veins it comes nearer to velocity of a blood in an aorta.

Resistance to fluid flow the is more, then diameter of tubes on which the fluid streams is less. Velocity of a blood is even more in arterioles. The internal friction is very major here and a lot of energy is spent for it overcoming. Here there is a sharp slope of a blood pressure up to 10-30 mm Hg.

In capillars the blood is received under inappreciable pressure. This pressure prolongs to decrease in veins (fig. 4). The pressure decreases up to null in major veins near heart, and it becomes smaller then atmospheric on some mm Hg during an inspiration. The blood thus goes under suction action of a thorax at an inspiration.

Self-control material

A. Questions and statements to be answered:

1. Structure of the blood circulation system.
2. The equation of continuous flow.
3. The laminar flow; the turbulence flow; Reynolds number.
4. How and why blood flow velocity in the blood circulation system changes.
5. How and why the mean blood pressure in the blood circulation system changes.
6. What is the arterial blood pressure?
7. Changes of blood pressure in different parts of the circulation system.

8. What functions are carried out with arterial pressure in an organism?
9. List the factors determining arterial pressure.
10. How pressure varies with the age? Why?
11. Due to what mechanisms the systolic volume at trained and unexercised people raises?
12. What is emboly?
13. Venous diseases (atherosclerosis) and character of them influence on blood stream.

B. Tasks

1. If diameter of tube (in which liquid flows) decreases in 3 time, that …
   A. liquid flows in 3 time quickly
   B. liquid flows in 3 time slowly
   C. liquid flows in 9 time quickly
   D. liquid flows in 9 time slowly
2. For determining of internal friction force of liquid it is nesessary to know …
   A. tube length
   B. pressure differense between ends of tube
   C. tube diameter
   D. liquid viscosity
   E. rate gradient
3. Newtonian liquid is
   A. liquid with viscosity dependent on concentration
   B. liquid with relative viscosity less than 1
   C. liquid with viscosity dependent on nature, temperature and conditions of flow
   D. incompressible liquid
   E. liquid with viscosity dependent on nature and temperature

4. If cross-section of horizontal tube with current liquid decrease, than dynamic pressure…
   A. decrease
   B. increase
   C. stay constant

5. If cross-section of horizontal tube with current liquid increase that static pressure …
   A. decrease
   B. increase
   C. stay constant

6. Viscosity of fluids:
   1) Decreases with an increase of temperature and does not depend on pressure;
   2) Decreases with an increase of temperature and it increases with grows of pressure;
   3) It increases with grows of pressure and does not depend on temperature;
   4) It increases with an increase of temperature and decreases with grows of pressure;
   5) It increases with an increase of temperature and pressures.

7. Fluxion of a fluid is termed as turbulent, at which:
   1) hydrodynamic pressure has stationary values on all volume of a stream;
   2) Layers of a fluid slide one concerning another, not being immixed;
   3) All particles of fluid have a stationary value velocity;
   4) There is an intensive intermixing between layers of a fluid;
   5) The lateral view of time-average velocities has the parabolic shape.

8. Viscosity of blood:
   1) In fine vessels it is more, than in major;
   2) In fine vessels it is less, than in major;
   3) It is constant in all departments of vascular system.

9. In what vessels the probability of originating of a turbulent stream is more?

1) In major;
2) In small;
3) Originating a turbulence does not depend on diameter of vessels.

10. Fluxion of blood on vessels is:
    1) Always laminar;
    2) Always turbulent;
    3) Preferentially laminar and only in some cases turbulent;
    4) Preferentially turbulent and only in some cases laminar.
11. In what department of vascular system the linear velocity of a blood stream is minimal:
    1) In an aorta;
    2) In arteries;
    3) In arterioles;
    4) In capillars;
    5) In veins.
12. In what department of vascular system there is the greatest water resistance:
    1) In an aorta;
    2) In arteries;
    3) In arterioles;
    4) In capillars;
    5) In veins.
13. As pulse wave term periodic oscillations:
    1) Velocities of distribution of particles in a stream of blood;
    2) The linear velocity of a blood stream ;
    3) Volumetric velocity of a blood stream ;
    4) Static pressure;
    5) A blood pressure.

Literature recommended

Main sources.

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