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Blood Motion: Turbulent or Laminar?

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ABSTRACT

Introduction: The issue on the mode of blood motion in the bloodstream, where the arterial and venous flow is significantly different, has been of greater concern recently. However, the conclusions are largely based on the analysis of the geometric orientation in the wall of arteries of smooth muscle elements.

The **aim** of our study was to examine the characteristics of the prominent configuration of cardial cavities and arterial vessels.

Methods and Material: The material for study were specimens of human heart, rabbit aorta and arterial microvessels of rat salivary glands, examined by injection and corrosive methods, scanning and transmission electron microscopy.

Results. Specific attachments are to be involved to transform the laminar flow of blood into the turbulent one. We hypothesize that appendages in the atria and muscular trabeculae of heart in the ventricles with particular orientation to the bloodstream from the atria into the aorta and pulmonary trunk should be assigned to such attachments. The longitudinal axes of the auricles are at the right angle to the axial blood flow from the atria to the ventricles. Compound relief of the right auricle is caused by the pectineal muscles and compound relief of the left auricle by the coral-like processes. Vortex flow is formed due to configuration of such relief in auricular systole, which is superimposed on the main bloodstream from the atria to the ventricles, making it turbulent. Ventricles of the heart, due to contractive activity of muscular trabeculae are the place of origination of vortex motion of blood in the initial parts of pulmonary and systemic circulations.

Muscular trabeculae in the left ventricle have right-handed helical path with large slope of turns from the apex of the heart to its base, whereas in the right ventricle they are of left-handed flabelliform orientation from the cardiac apex to cardiac base.

Such position suggests that the turbulence of blood flow, originating in the cardial cavities, is dictated by the need for even mixing of blood corpuscles while moving on the arteries. We believe that consumed energy could be enough for overcoming a resistance in the main arteries, in the wall of which there is a lack of active contraction elements.

Intimal relief of the rabbit aorta is representad by the distinctly pronounced folds, longitudinally oriented on the steep spiral. They acquire especially steep (whirlpool or vortex) nature in the area of the opening into the intercostal arteries, which, as it is well known, in contrast to the aorta, are assigned into the arteries of the mixed type. Minor arterial microvessels (metarterioles-like type) have similar internal relief of the wall, which must extrude into the inner lumen of nuclear zones of endothelial cells. But the motion of blood in the arterial microvessels will greatly depend on the wave myogenic activity of smooth myocytes in their wall. Specific orientation of smooth muscle elements in the arterial microvessels is directed onto the formation of turbulent blood flow, contributing to its better mixing and ten-time increase in the intensity of metabolic processes.

Conclusion: The findings show that the conditions of hemodynamics in the great blood vessels suppose turbulent motion of blood that emerges in the cardial cavities, which is necessary for even mixing of blood corpuscles and their orderly distribution in homogeneous erythrocytic mass that would have been impossible in conditions of laminar motion of blood.

Keywords: auricles, ventricle, arteries, turbulent blood motion.

Introduction. The issue on the mode of blood motion in the bloodstream, where the arterial and venous flow is significantly different, has been of greater concern recently. The significant number of morphological and physiological

indicators show that the laminar motion of blood prevails in the venous flow, whereas in the arterial flow it becomes turbulent, requiring not only additional expenditure of energy, but also a particular configuration of arterial vessels [1, 2]. It is noteworthy that such approach is not new; it has been theoretically grounded by the findings of examination of the blood vessels at the end of the last century, made by V.V. Kupriyanov [3] and A.N. Pshenichnyi [4].

However, the conclusions have been largely based on the analysis of the geometric orientation in the wall of arteries (relative to its longitudinal axis) of smooth muscular elements.

Purpose. The paper was aimed at the study of characteristic features of the topographic configuration of cardiac cavities and arterial vessels.

Object and Methods. The material for study were specimens of human heart, rabbit aorta and arterial microvessels of rat salivary glands, examined by the injection and corrosive methods, scanning and transmission electron microscopy.

Results and Discussion. The analyzed plastic casts of cardiac cavities shows that longitudinal axis of both right and left auricles are at the (90°) right angle to the axial blood flow from the atria to the ventricles that should be considered as a special adaptation which leads to formation of vortex flows during auricular systole, superimposed on the main bloodstream from the atria to the ventricles, making it turbulent. (Fig.1). We hypothesize that the sphere of the right auricle should be seen more extensively, assigning to it those parts of the right atrium wall which has pectineal trabeculae on the inner surface, oriented across the long axis of the auricle. Therefore, currently, we stick to the same opinion according to which the area of the right auricle, due to presence of pectineal muscles and deep furrows between them is a special adaptation which leads to formation of vortex flows during auricular systole, superimposed on the main bloodstream from the atria to the ventricles, making it turbulent. The topography of the left auricle is determined by the coral-like processes and furrows between them.

At the first sight the topography of ventricular cavities may seem to be irregular. In fact, it is presented by deeply pitted orbicular surface, negatively

displaying the configuration of muscular trabeculae, in which their right-side motion with big slope of turns from the apex to the base of the heart is viewed. The most revealing difference has the topography of the inner surface of the left ventricle. It is obvious that this anatomical feature (spiral or helical orientation of muscular trabeculae) is determined by the function. We hypothesize that due to this fact the blood motion in the left ventricle in systole should acquire a nature of circular vortex that leads to increased turbulence in the aorta. Consequently, the ventricular cavities, due to the special configuration and contractile activity of muscular trabeculae, are the place of origination of the blood vortex motion in the primary parts of the pulmonary and systemic circulation. It should be taken in consideration that the movement of fluids in turbulent mode requires more energy than when in laminar one as it is expended not only to overcome the forces of internal friction between the layers, but also in the process of mixing, evoking in the fluid additional shear stresses, leading to the fact that its particles, while mixing, move on the most bizarre, constantly changing pathways.

Such position suggests that the turbulence of blood flow, originating in the cardiac cavities, is dictated by the need for even mixing of blood corpuscles while moving on the arteries. We believe that the expended energy could be enough for overcoming a resistance in the main arteries, in the wall of which there is a lack of active contraction elements. As it well known, such vessel is the aorta.

In the context of the issue under consideration it would be useful to figure out what topography has the inner surface of the aorta wall. Judging from the publications, which consider the issue of hemodynamics peculiarity in the main blood vessels and the behavior of the corpuscles in the blood flow on them, the morphological aspect of the problem has not been taken into account by the authors. The papers, studying the rheology of blood, *a priori* consider it to be smooth. Probably, at that time the authors had no concrete visual data, in connection with which they proceeded from the idea that the inner surface of the main arteries is smooth. In fact, this view is erroneous. In support of this we can refer to the findings, contained in the “Atlas of Cells, Tissues and Organs Scanning

Electron Microscopy”, edited by O.V. Volkova, V.A. Shahlamov and A.A. Mironov [5], as well as in the theses of E.V. Vlasova [6], accomplished at the Department of Human Anatomy at “Ukrainian Medical Stomatological Academy”, supervised by Professor Yu.P. Kostilenko, presenting the high-quality scans illustrating that the intimal topography of the rabbit aorta is represented by the distinctly pronounced folds, longitudinally oriented on the steep spiral (Fig. 2). They acquire especially steep (whirlpool or vortex) nature in the area of the opening into the intercostal arteries, which, as it is well known, in contrast to the aorta, are assigned to the arteries of the mixed type. The morphological evidences leave no doubt that the arterial blood flow possesses a structure to sustain physiologically required swirling movement of blood, which, according to our data, enables an equal distribution in mass flow of erythrocytes of another (fewer) corpuscles. In addition to this, it has been found that the minor arterial microvessels (metarterioles-like type) have similar internal topography of the wall, too, due to bulging of nucleate zones of endothelial cells into the inner lumen (Fig. 3). But the motion of blood in the arterial microvessels greatly depends on the wave myogenic activity of smooth myocytes in their wall. According to A.N. Phenichniy, a specific orientation of smooth muscle elements in the arterial microvessels is directed onto the formation of turbulent blood flow, contributing to its better mixing and ten-time increase in the intensity of metabolic processes.

Conclusions.

1. Specific adaptations are required to transform the laminar flow of blood into the turbulent one. We hypothesize that the auricles in the atria and muscular trabeculae in the ventricles with particular orientation to the bloodstream from the atria into the aorta and pulmonary trunk should be assigned to such adaptations.
2. The auricles have a compound internal configuration due to presence of pectineal muscles in the right auricle and coral-like processes in the left auricle. Their longitudinal axes are at the right angle to the axial blood flow from the atria to the ventricles. From this perspective, the auricles should be seen as a specific hydrodynamic device capable of altering the mode of blood motion in the cavities

of the atria.

3. The ventricles, due to special configuration of the topography and contractile activity of muscular trabeculae are the place of origination of the blood vortex motion in the primary parts of the pulmonary and systemic circulation. Muscular trabeculae in the left ventricle have the right-handed helical path with large slope of turns from the apex of the heart to its base, whereas in the right ventricle they are of left-handed flabelliform orientation from the cardiac apex to cardiac base.

4. The findings show that the conditions of hemodynamics in the great blood vessels suppose the turbulent blood motion that originates in the cardiac cavities, which is necessary for even mixing of blood corpuscles and their ordered distribution in homogeneous erythrocytic mass that would have been impossible in conditions of laminar blood motion.

The perspectives of further research will encompass the analysis of features of the intimal topography of the normal carotid arteries and brachiocephalic trunk.

The research has been carried out within the research scientific work, entitled “Study of the typical and abnormal behavior of viscera structural organization”, State registration number: 0106U003236, 2016-2020 year, Oleg O. Sherstyuk.

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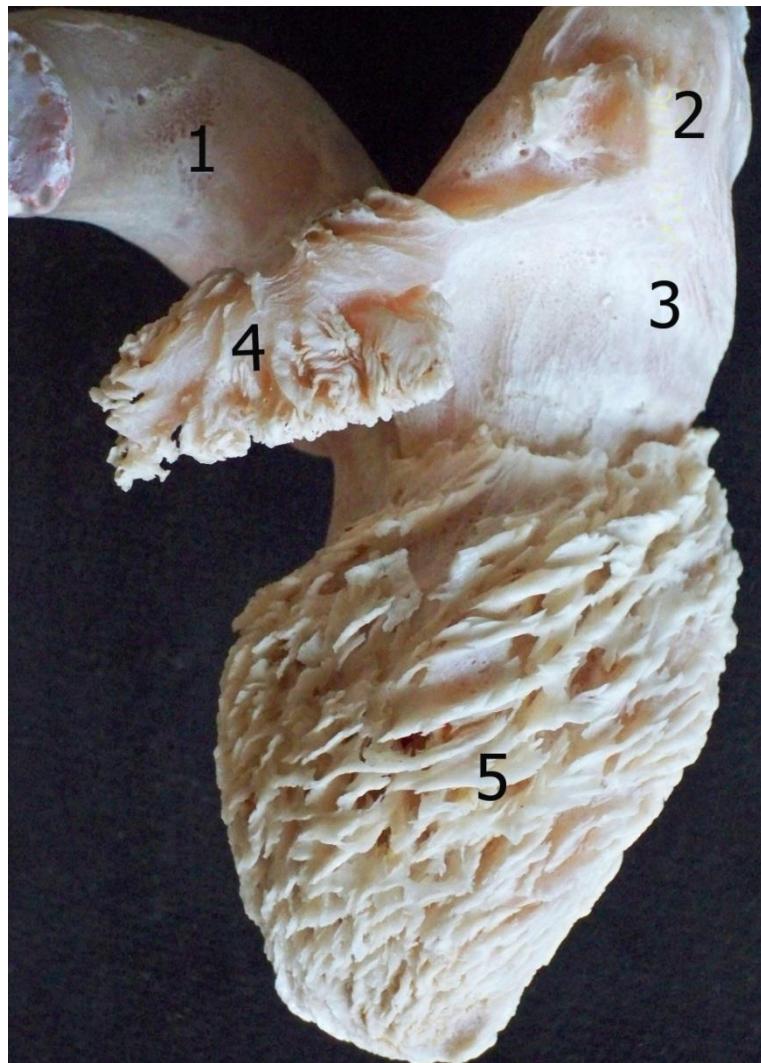


Fig. 1. Internal topography of human left heart.

Plastic cast: 1 – aorta; 2 – superior (sine) part of the left atrium; 3 – inferior (infundibular) part of the left atrium; 4 – left auricle; 5 – left ventricle.

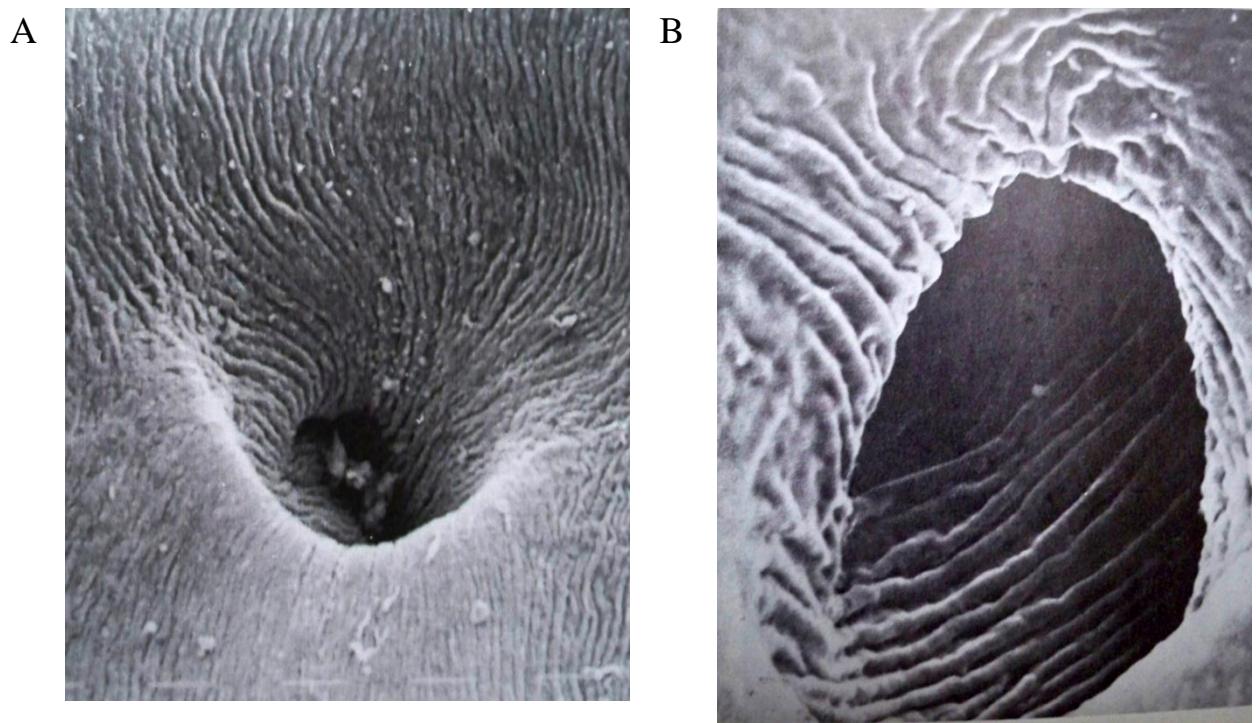


Fig. 2. Intimal topography of rabbit aorta in the area of the opening into the intercostal artery. Scanning images. A – E.V. Vlasova's specimen; B – A.A. Mironov's specimen.

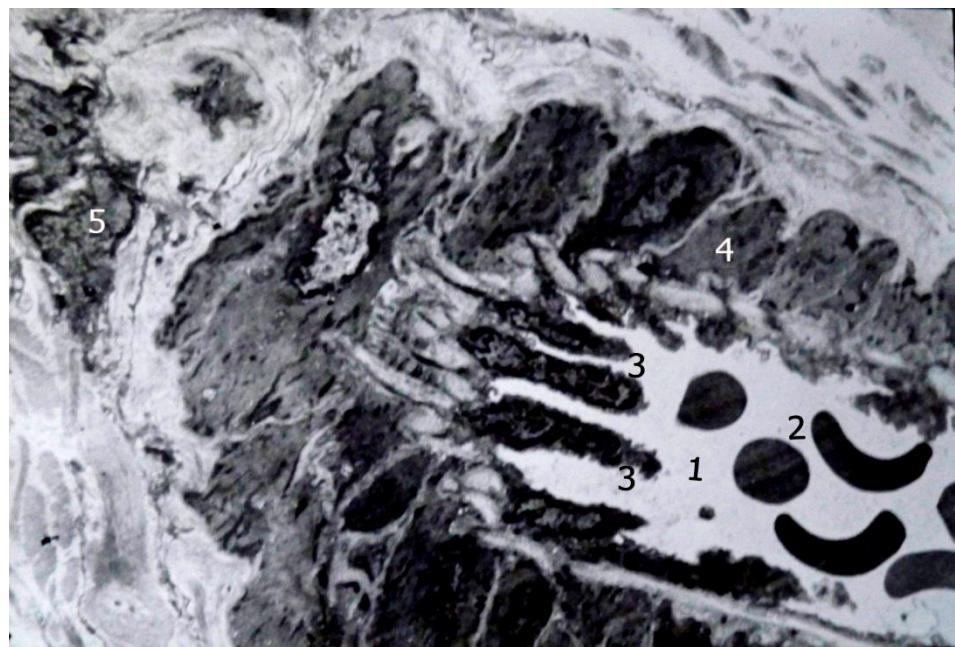


Fig. 3. Terminal artery (metarteriole) of rat minor salivary glands. Y.P.Kostilenko's electron diffraction pattern: 1 – inner lumen; 2 – red blood cells; 3 – bulged nucleate zones of endothelial cells; 4 – smooth muscle cells; 5 – perivascular fibroblasts.