Resistive factors of the blood flow and energy distribution in the body

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Blood flow in human body is full of theoretical and practical controversy. There are lots of factors, which "prevents" the blood flow:

- Systolic blood flow in aorta is inertial, with the high Womersley's number.
- Blood flow in aortic arch and main pulmonary artery is circular, with the high turbulence and resistivity.
- At the arterial branching, flow separation increases flow resistivity.
- Increased blood viscosity in the venous blood.

PURPOSE of the study is to identify the reason for the formation of the resistive factors in blood flow.

BACKGROUND: Consideration of hemodynamics is essential for a comprehensive understanding of the functioning of the circulatory system. Blood flow has a pulsatile distribution in cardiovascular system [1]. Blood vessels and cells are viscoelastic, so classical hydrodynamics and fluids mechanics based on the use of classical viscometers cannot explain hemodynamics. Herewith, it is crucial to take into account a non-Newtonian features of the blood, which is best studied in rheology and not hydrodynamics [2].

To investigate blood flow, multidisciplinary study is necessary. Discussion can be made by the law of conservation, as they make it possible to predict the macroscopic behavior of a system without having to consider the microscopic details of the course of a physical process or chemical reaction. Underestimation of the circumstances, leads to the inadequate conclusions, for instance for the flow resistivity.

METHODS: Blood flow velocities were studied in the different sites of the large vessels in 35 normal adults (15 men, 20 women, age 21 - 49 years) with the use of Magnetic Resonance Angiography. Blood radiodensity (HU) was measured by the CT scanner. Blood flow pulsatility, resistivity indexes were carried out with the Duplex US.

RESULTS: Resistive and pulsatility indexes for the ascending aorta are 0.96±0.07 and 3.14±1.7, abdominal aorta 0.91±0.07 and 2.7±1.3, carotid artery 0.74±0.07 and 2.04±0.53, pulmonary trunk 0.74±0.11 and 1.49±0.37, inferior vena cava 0.32±0.21 and 0.69±0.37. Blood radiodensity (in HU) in the ascending aorta is

Blood peak systolic velocity (Vps), pulsatility (PI) and resistance indexes (RI) done by Duplex US, Womerslay's number (A) of the different vessels

Vessel	Vps (cm/sec)	Dmm	RI	PI	A
Ascendant aorta	112.8±17.9	17.5±5.5	0.96±0.07	3.14±1.7	13.2
Abdominal aorta	62.1±15.7	8.5±3.5	0.91±0.07	2.7±1.3	8.0
Pulmonary trunk	43.6±13.1	14.3±4.7	0.74±0.11	1.49±0.37	15.0
Inferior vena cava	42.9±17.1	10.5±4.5	0.32±0.21	0.69±0.37	8.8
CA	72.5±15.8	5.7±0.7	0.74±0.07	2.04±0.53	4.4
Proximal ICA	61.9±14.2	4.5±0.6	0.67±0.07	1.41±0.50	-
ACA (A1)	85.4±19.5	2.6±0.3	0.50±0.15	0.85±0.17	-
MCA (M1)	91.9±16.9	2.7±0.3	0.50±0.17	0.86 ±0.14	-

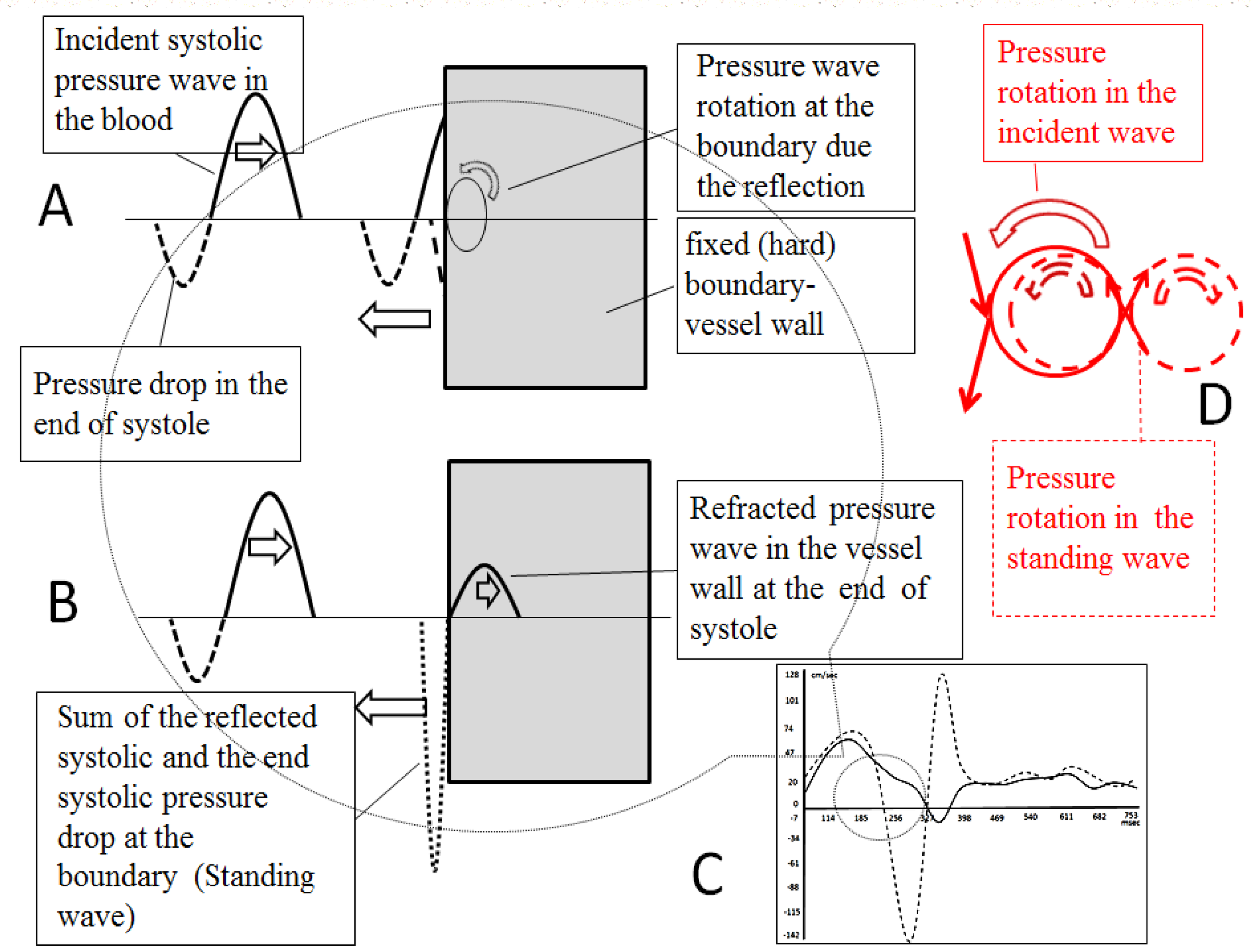
DISCUSSION:

Study of the pulsatile blood flow through the cardiovascular system in precise mathematical terms is insuperable because the blood viscosity is not constant, flow is not steady but pulsatile, vessels are elastic, multi branched conduits with the constantly changing diameter and shape [3] [4] [5].

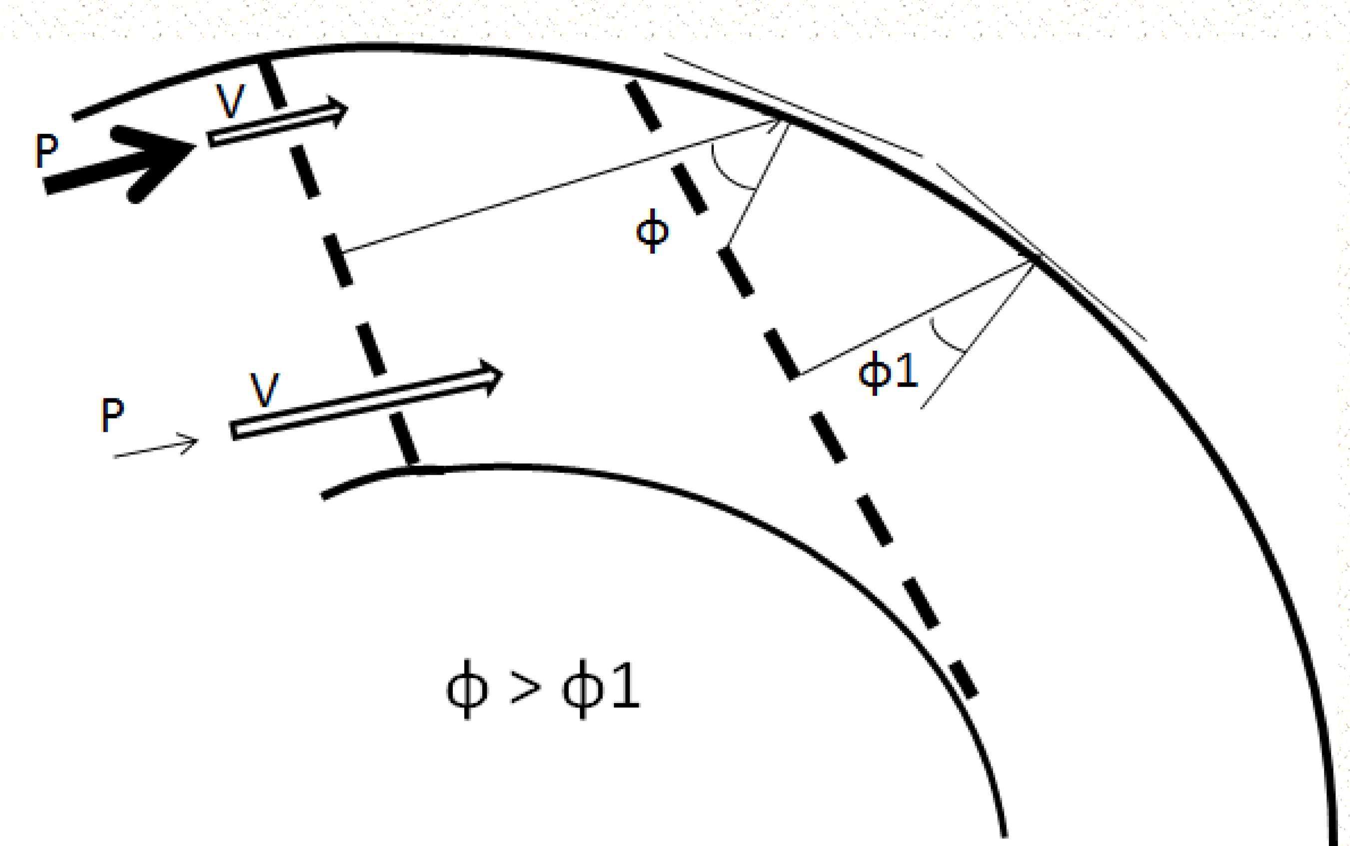
Blood flow is the subject of the energy transmission and can by study by the conservation laws. As the arterial blood flow is pulsating, it is reasonable to investigate blood motion as the momentum. Impulse is dimensionally equivalent to the momentum. Momentum can be defined as "mass in motion." In relativistic mechanics the mass of the sum is not a physical quantity, i.e. the mass of the system is generally not equal to the sum of the masses of components and includes the binding energy, which depends on the nature of motion of particles relative to each other. The momentum of an isolated system is a constant [6].

Inertial blood flow at the proximal aorta, transforms to viscous one in the capillaries. Structural changes of the blood are expressed in decrease of the Womerlay's number, dynamic viscosity and radio density. Flow turbulence, due to the anatomical specifications of the arteries, with the frequency dispersion, in the distal arterial tree changes the entropy of the blood. With this, spontaneous reactions in the capillaries across the endothelial cell membrane become more favorable. Entropy represents the physical quantity that characterizes the degree of disorder and is the metaphoric attribute of fluidity. Sum of the entropy changes in the system and surroundings determines whether a process will occur spontaneously or not. Free energy enables us to express changes, that occur at a constant temperature and pressure (the Gibbs free energy), or constant temperature and volume (the Helmholtz free energy) [7]. Diffusion of the substances across the cell membrane will give them more space in which to move, with the result that the entropy, of the system is increased. Maximum entropy is achieved when the concentration of molecules is the same on both sides of the membrane. There is a close relation between the concepts of entropy and viscosity, associated with systems of conservation laws. That is, the higher the degree of order in the microstructure, the lower the Voronoi entropy and the higher the viscosity. Entropy usually increases when a liquid or solid dissolves in a solvent.

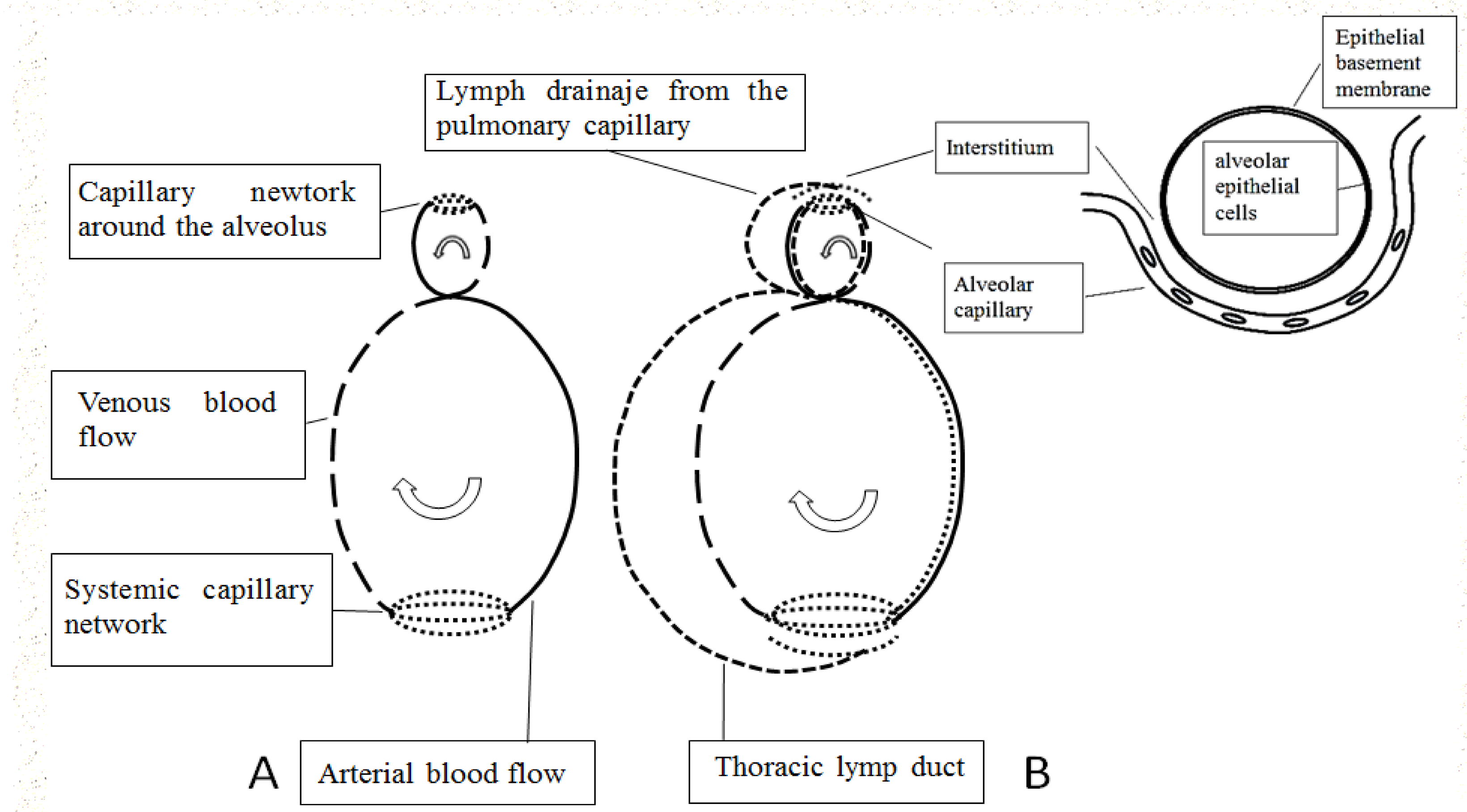
Herewith, at the arterial end of pulmonary capillaries, due to the exothermic features of the hemoglobin oxygenation, entropy of the system increases. Changes in Gibbs free energy is negative and transmembrane pro-



Magnetic resonance angiography. Flow quantification. Blood flow at the end of aortic isthmus. Near the external wall, amplitude and frequency of the flow wave oscillation in the reflected wave is higher, than that at the initial, while in the distance from the wall, oscillation frequency is the same. (A -D). At the end of systole, pressure drop is coincident with the systolic pressure wave reflection. In aorta Womerslay's number is high (inertial flow), velocity profile is flat, and flow wave lags behind the pressure wave – there is the phase delay. Due to the wave superposition, pressure at the boundary increases (B). Dashed lines - flow near the external wall (C). Refracted (transmitted) wave in the vessel wall has the same frequency, as the incidental wave. Difference in frequency of the waves, facilitate the structural disaggregation of the flowing mass, separation of the flow and shearing of the vessel wall (D).

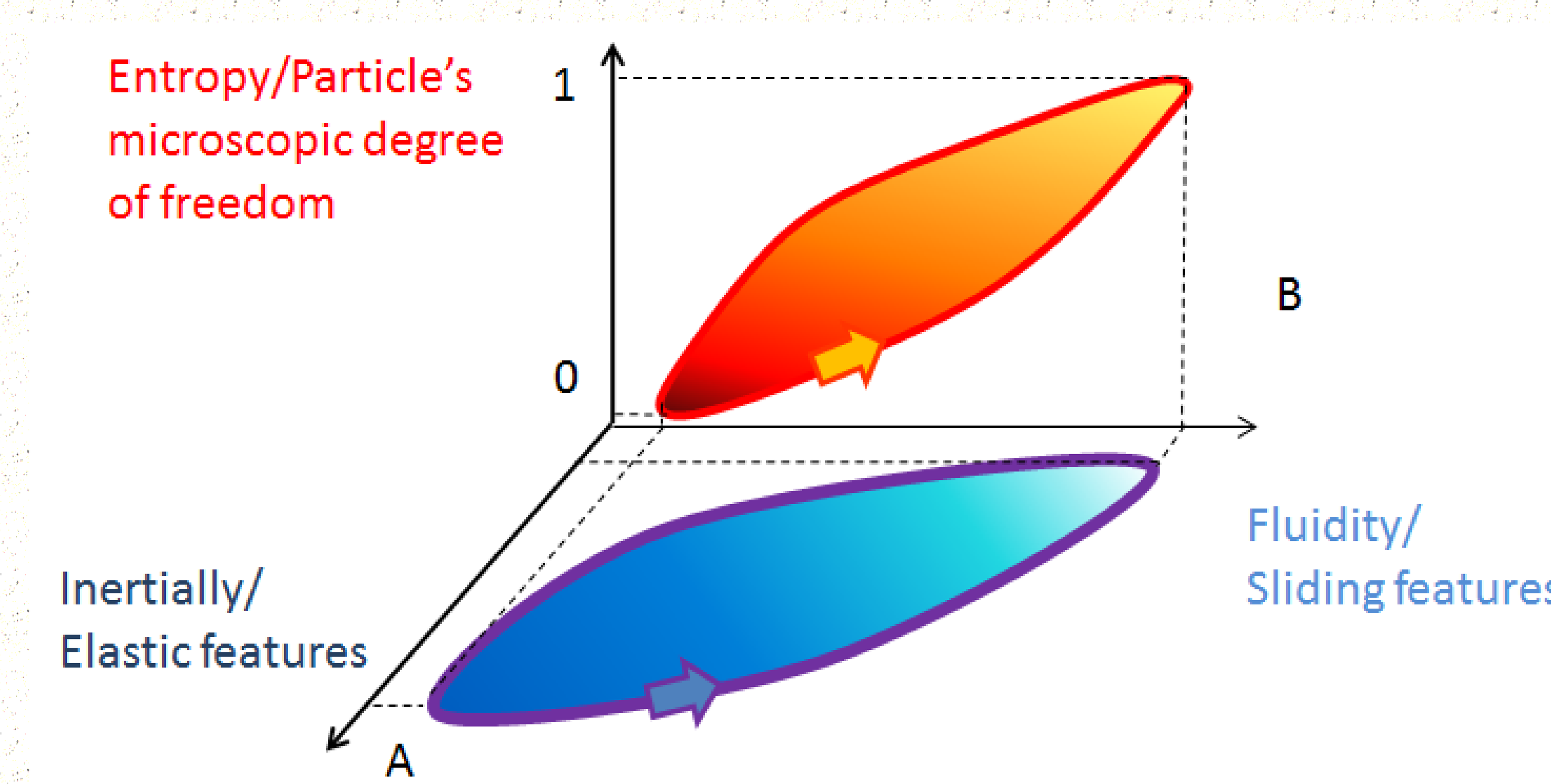


Wave vector is perpendicular to the wave front. At the external wall of the isthmus, angle of incidence (ϕ) of the wave vector decreases and the energy transmitting to the wall increases. Pressure near to the external wall is higher, than that at the internal, while flow velocity is lower. Pressure differences facilitate blood outflow in arterial branches and separation of the flow at the end of the systole.



A. Systemic and pulmonary blood circulation. B. Circulation of blood and lymph.

At the entrance of the right atrium, lymph mixes with the venous blood and after the systolic oscillation, it flows to the pulmonary circulation. From the lung alveolus, oxygen dissolves in interstitial space and is absorbed by the red blood cells in capillary network around the alveolus. Oxygen initially dissolved in the blood serum, reacts with hemoglobin to form oxygen-hemoglobin complex. Blood volume of the systemic circulation is normally 9.3 times higher than that the pulmonary circulation [1]. Pulmonary and systemic blood circulations have not the same blood flow value. They are connected in series, but the lymph flow value in the pulmonary circulation is higher than that in systemic. Herewith angular frequency of the pulmonary lymph circulation must be 9.3 times higher than that in systemic. Therefore entropy in the pulmonary capillaries increases. High Womerslay's number in pulmonary trunk, compared to inferior vena cava (table) shows, that fluidity depends not only on the solvent (lymph), but on the paramagnetic features of the erythrocytes, expressing at the



Correlation between entropy, elastic and sliding features of the blood at the flow.

Conclusion: Energy is stored in the elastic deformation of the blood cells and arterial walls, in kinetic energy of the blood flow, entropy of the system. Inertial blood flow due to the frequency dispersion in the arteries transforms into the flow with the high fluidity in arterial end of capillaries. Entropy increases, enabling spontaneous chemical reaction to proceed across the cell membrane. Process is altered in the venous blood. Changes in resistance expresses the distribution of energy in the body.

REFERENCES:

1. John E Hall. (2015) Guyton and Hall Textbook of Medical Physiology. Elsevier. 13 e.
2. Timothy W. Secomb. (2016) Hemodynamics. Comprehensive Physiology. Volume 6, Issue 2,
3. Giovanni P.Galdi, Rolf Rannacher, Anne M.Robertson, Stefan Turek. 2008. Hemodinamical flows. Modeling, Analysis, and simulation. Birkhauser.Verlag AG.
4. C. Y. Wang, J. B. Bassingthwaighte. (2014) Blood Flow in Small Curved Tubes. J Biomech Eng. 125(6).
5. Frank M. White. (2016) Fluid mechanics. Mc Graw Education.
6. David Halliday, Robert Resnick, Jeral Walker. (2011) Fundamentals of Physics. John Wiley & sons.
7. David W. Ball. (2015) Physical Chemistry. Stamford.