1. Background of the invention of cardiometry – new fundamental science

1.1 Historical paradigm in cardiology

The principles of modern cardiology theory were laid at the time of the electrocardiograph invention by V.Eithoven in 1906 for the electrocardiogram (ECG) recording and use for diagnostics. It allowed to start the interactive investigation of the cardiac functions and to organize the data that have been obtained earlier through the rib-cutting. Since then, the ECG recording and analysis means have transformed sufficiently, but still his procedure is the main general-purpose diagnostic aids.

The data obtained through ECG made the basis of theoretical investigation of cardiovascular system functioning. The means and facilities for electrocardiographic investigation diversified: phonocardiographs, rheographs, ballistocardiographs, ultrasonic and tomographic scanners. The synchronous analysis method came into practice that allowed to check a number of signals at a time, now it is known as polycardiography method.

The newcoming data on the cardiovascular system functioning built up the level of knowledge that gave the basis for the theory of heart functioning. It was believed that the main diagnostic criteria are as follows: cardiac rhythm, the heart anatomical position in thoracic cage relative the electrical axis of heart angulation, the heart nervous system asequence and desorder. It became a common practice to create the ECG forms database.

The above-mentioned developments provided the basis for the cardiology theory. There were the electrocardiological signals that became the source of information needed for constructing the up-to-date cardiology theory.

However, the hemodynamics evaluative criteria did not exist. It was assumed that the hemodynamics is estimated by systolic and diastolic blood pressure values measured by standard indirect measuring instruments. The invention and use of tomographic scanning did not contribute to hemodynamic processes insight. The cardiological instruments standardization did not result in introduction of uniform procedure for the cardiosignals interpretation. In practice, the demonstrative medicine was used, it was based on medical assessment and statistical proof. So, the problem of the diagnoses verification was not solved. The same variations in ECG form were interpreted by specialists in different ways.

The necessity of medical treatment of pathologies expedited the development of pharmacology. The theory of metabolic processes in cordial muscles created the variety of prerequisites for invention of of new cardiological pharmaceutical drugs. However, nine times of ten they are recommended ignoring the changes in process that can be monitored only by the electrocardiosignals.

The cardiosurgeons contribute greatly to the paradigm of learning the cardiology aspects. The highly professional specialists make the unique cardiac surgery, but their contribution to the hemodynamics theory is not considerable. The cardiosurgery is based on the experience which is passed on from generation to generation. The new cardiological theories review the quantitative parameters of surgeries, that can change the situation for the worse and cause the difficulties in staff training process and the degradation of surgery quality. It's a challenge, and the problem should be solved cautiously.

The lack of the adequate mathematical model of circulatory dynamics (hemodynamics) is the major problem in theory of cardiology and that fact influenced the paradigm of knowledge in cardiology. The laminar flow regime has been assumed as a basis for explanation of the hemodynamic processes, but this point of view contradicts the actual state of matters. All diagnostic criteria that are based on the above-mentioned prerequisite have not been proved by practice. This situation provided the basis for global contradictions that do not assure the positive trend of cardiology science development.

1.2 Contradictions that prevented introducing the natural science laws in cardiology theory

The natural philosophy scientists have described two types of fluid flow: turbulent flow and laminary flow. The direction of fluid particles moving inside the hard tubes in parallel to the tube axis was taken to be an assessment criterion. There is no cross displacement of the particles. The motion of this type can exist without velocity and pressure pulsation.

The question now arises of whether the above-mentioned conditions are adequate and can exist in the real pulsatile bloodstream and pressure fluctuation conditions. The answer is “no”. The mathematicians made an attempt of describing the various boundary conditions that expedite the blood circulation in springy vessels, but they did not succeed. And what is more, it prevented from the physical science laws introduction into cardiology. Until now, no mathematical equation exited that facilitated the calculation of hemodynamic values to be used as the diagnostic criteria. Up to now we only know the indications of changes in cardiosignals that correspond to some pathologic processes. Until now, the hemodynamics concept does not exist [1].

Since the laws of physics are not applicable, the cardiology can not be regarded as natural science. Laws form the basis for the nature cognition by practice. Any phenomenon should be analized and proved to be logically true. Any variation in the shape of electrocardiography signal must be logically relevant, and proved to be true and valid, to be more specific it must correspond to the processes that caused the above variation. For this purpose we can address the axiomatics, the science that is based on the laws that enable to formulate the statements that hereafter do not require the proof and are the basis for derivation of the theorems and rules. The data analysis is based on the logic, and all the reasoning and arguments must be logical and consistent.

Now we shall address the contradictions that prevail in cardiology science. There are a lot of them. In the first place, there is a lack of uniform understanding of the cordial cycle phase structure. There is no logical justification for the absence of description of four (out of ten) main phases. There is no reasoning for the muscular activity of the isolated heart. The detectable asequence in the heart nervous system still is not treatable. At that, they can be observed in lying position and are not manifested in standing position. The nature of extrasystoles is not understood. The list may be continued, but the conclusion is as follows: up to now there is no concept of the good heart, and the norm - pathology border line is still not determined.

1.3 Systematic hemodynamics concept in cardiology

To understand adequately the level of knowledge in cardiometry (as represented in cardiometry theory) it is necessary to know the notions and concept of the systematic hemodynamics in cardiology science.

It is reasonable to understand properly the term “hemodynamics”. In “Comprehensive medical encyclopedia”, the name of the section describing the circulatory physiology has the Greek origin (“haima” reads “blood” + “dynamikos” reads “force”, “related to force”) – this branch of the medicine studies the circulatory physiology based on hydrodynamics laws that facilitate the study of the cause, conditions and blood-moving mechanisms in cardiovascular system [2]. At the same time, the term “Hemodynamics” can be understood in different ways, but in general it comes to understanding of conditions that provide the sanguimotion (in other words “blood flow”) in blood vessels. Only two parameters are available for physicians to asses the hemodynamics: arterial blood pressure and heart rate. In view of the fact, that these two criteria are not the key factors for the hemodynamics assessment since they do not characterize the sanguimotion pattern formation and support, it becomes apparent, that the cardiology science has not yet obtained the “full-blown” hemodynamics theory. Only the fragmentary theoretical evidence and individual particular cases of diagnostics are available, but they do not represent the variety of the cardiovascular system interrelations in full scope.

It is important to know and understand that the hemodynamic diagnosis should be made not merely based on the anatomical knowledge.The available data on the cardial cycle phases, metabolic processes in myocard and cardio-vascular system functioning must also be taken into account. It's only possible when the adequate mathematical model of hemodynamic processes is available, but up to the present moment it has not been invented.

1.4 Mathematical modeling in cardiology

The last decades of the previous century revealed the necessity of interdisciplinary approach to the energetic mechanisms research process and to investigation of particularities of blood circulation in the normal physiological conditions and in pathological state [3–9].

For example, [3], the efforts of the participants of this process (very important for the practical medicine) are comparable with efforts put into Tower of Babel erection complicated with the fusion of languages of the people who built it. In our particular case, we deal with the mix of the languages of mathematics, physicists, biologists, physicians. So, the main problem was to compile the defining dictionary to solve this linguistic problem.

At the same time, the classical hydromechanical and mathematical models/ methods applicability borders are defined for their application to biological systems in general and to blood circulatory system in particular. For example, the continuous medium approximation method is used in classical hydrodynamics to the extent where it is reasonable to consider only those continuous medium motion lengths that are several orders greater than the molecular track length [10]. Accordingly, it is necessary to define the scope of continuum model applicability to the blood when the blood density is considered to be a parameter of this continuum in cases when it is necessary to use a large sample volume for the blood density determination [9].

In [3–9], as well as in other scientific papers [e.g.11–14], considered are the specific simplified mathematical models aimed at improving the diagnostic, therapeutic and surgical methods of practical medicine. In particular, in [14] the mathematical model of the CVS hemodynamics is represented. In this model, the quasi-onedimensional approximation of the blood frictional flow is represented in the flowchart of the branched elastic vessels, with the cardiac performance parameters and capillary structure of tissue taken into account. In references [14] and [3–9; 11–13] and in some other publications, the quantitative modeling of CVS functions is proposed which can be of considerable practical importance because it enables to generate the quantitative criteria of normal functioning and of various pathologies.

Specifically, in [14] proposed is the simplified hydromechanical mathematical model of the blood circulatory system in terms of vascular system with various types of vessels linking the internal parts and tissues of body thus enabling their functioning. At that, conventionally four classes of elements are allocated to be used as mathematical modeling objects: heart, vessels, branch points and tissues. The zone where a number of vessels are joined is defined as a branch point. The vessels may come through the tissues that mold the organs. After passing the tissues, the blood again enters the heart via the venous low tension circulation system. At that, CVS is represented by graph, the verges of which represent the vessels and the vertices represent the heart, branch points and tissues. The mathematical aspect of the task consists in recording the mass and momentum (kinetic momentum) conservation equations and assigned law of the vessel cross-section changing on each verge of the graph based on the presumption that the vessel cross section area size linearly depends on the pressure.

At that, the additional conditions of conjugation in branch points, tissues and heart must be met. Among other factors, it is admissible to assume the feasibility of the blood particles inertial motion in the area of vessels bifurcation, when the blood velocity is described by the Hopf equation (Euler equation with the zero right side) with zero pressure gradient, which considered to be the same within the whole branching area. When modeling the vessels conjugation with the tissue it is assumed that the blood passing through the tissue is similar to the process of fluid filtration via porous medium. In this case, one should keep in mind the probability of the net blood flux changing due to blood absorption or effusion by the tissue. Based on the observation data, for the mathematical modeling of the heart-to-vessels conjugation area, the law of the blood volumetric flow rate variation with time is taken to be assigned. In the described model [14], the gravity force and force of friction are also taken into account. At that, the force of friction is taken to be proportional to flow velocity square (with the coefficient being in inverse proportion to the vessel cross-section radius), which is usually characteristic of turbulent flow regime when the Reynolds numbers are sufficiently high. Depending on the type of the task, this simulation may be of simplified form, at the expense of the a priori assigned velocity and pressure profiles.

This type of CVS descriptive modeling [14] can be very helpful (among other things, it allows the model evaluation of the functioning of important cardial nodes, e.g. heart, kidneys, etc.), but it does not allow to reveal the basic mechanisms that assure the unique energetic performance of the cardio-vascular system when it is free from pathologies. The general approach to the blood circulation modeling based on variational principles is described in [15], but the other approaches [e.g.13, 14] are based on Poiseuille law [10] (the law is applied only to laminary streamline currents).

Since the times of Leonardo da Vinci the people were interested in CVS energetic working mechanisms. Leonardo noticed and paid attention specifically to energetic efficiency of the whirling non-viscous motion that ensures the aortic valve closing at the end of the left ventricular systole. At the present time, based on color Doppler velocimetry results and based on the magnetic resonance imaging – velocimetric method, it was established that the bloodstream in the CVS great vessels [16] has a curved spiral flow. There is evidence for interrelationship of the deterioration in structurally stable system of blood flow induced by the surgical treatment and multiple postoperative complications associated with high risk of clotting [16]. In its turn, the clotting is associated with hydromagnetic instability of the destructured blood stream relative to the random turbulent perturbations that usually occur in the areas of the vascular system bifurcation and on the atherosclerotic lumps in the endothelia of vascular wall. The hydraulic-mechanical basis of the curved spiral flow formation is the same both for intensive atmospheric vortex and for the normal blood flow in CVS, ref. [17–21].

Apart from the curved spiral structure of the bloodflow, the key function is performed by the pulsed blood transfer mode of CVS that ensures the efficiency of the CVS functioning. G.M Poedinzev and O.K. Voronova were the first to notice this phenomenon [22] and to prove it based on the exact transient solution of Navier-Stokes equations (that generalize the Poiseuille law), and the theory was further developed [23, 24].

Based on the proposed algorithm [22] for the evaluation of blood volume entering the aorta in any moment of the cardial cycle (systole – diastole), in 2004 the first cardiometry instrument CARDIOCODE has been invented. This allowed to make the synchronous measuring of the electrocardiogram and rheogram phases and to obtain the quantitative parameters that define the functional status of the human cardio-vascular system.

Contrary to model represented in [14], the procedure proposed in [25] requires not barely to select arbitrary the pulse mode of the cross section area variation in blood vessel model, but also to determine it based on the solution of variational constrained extremum task. In this task, the law of the pipe radius variation in time is determined based on the minimum energy required for transfer of the assigned volume of liquid within the whole period of expansion and the subsequent contraction of the pipe radius.

Moreover, in [25] the generalized mass-conservation equation (proposed in [26]) was obtained, and the generalized model of the optimal pipeline [27] for the case of Poiseuille law replacement with its nonstationary modification [23, 25] was prposed.

The findings [25] prove the principle implications of Poedintsev – Voronova theory [22], thus defining the new trends of the quantitave cardiometry development.