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MODELING RISK EVOLUTION OF DIGESTIVE TRACT FUNCTIONAL VIOLATIONS WHEN EXPOSED TO CHEMICAL ENVIRONMENTAL FACTORS

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Modern methods of health risk assessment are based on the representation of individual and public health as a dynamic process of "evolution", which describes a continuous course of negative (and positive) changes in the condition of the body. The article presents a conceptual diagram of multilevel health risk evolution modeling under the influence of environmental factors. The main aspects associated with the simulation of digestive processes in the "meso level" are considered. Some results of solving the problem of the flow in the digestive tract antroduodenal area taken into account tract motility. Further development ways of the model are outlines – account of biochemical reactions, secretory and absorptive functions tract. The proposed approach will enable not only to predict the risk of digestive system functional disorders, but also take into account basic physiological processes, mechanisms of income, distribution, excretion of chemicals.

Key words: *mathematical modeling, functional disorders, digestive system, peristaltic transport, chemical hazards.*

Development of methods for assessing the health risk associated with the impact of physical, chemical, biological and other living environment factors assumes the use of the up-to-date scientific and methodical approaches combining the adjacent fields of knowledge such as medicine, physiology, biology, biomechanics and mathematics. One of the most prospective approaches to the forecast and assess the contributions of factors to the health disorders as well as to establish the cause-and-effect relations is the use of the mathematical simulation methods which have a number of advantages: saving of material and time resources, possibility to implement in the numerical experiment of impacts hazardous for the life and health of human, possibility to study the impact of separate factors or their different combinations. One of the main directions of studies which actively use the methods of simulation is associated with the problems of management in relation to the occupational diseases [5]. The combined action of different factors requires the solutions of the multidimensional health risk assessment task with involvement of the results of theoretical studies associated with description of mechanisms for the accumulation of damages in the body with the course of time. As of now, there is the wide spectrum of similar theories which both consider the natural processes of the accumulation of violations (theories of ageing) [1, 16] and take into account the impact of the living environment factors [4, 6, 19]. The modern health risk assessment methods are based on the presentation of the health of individual and population in the form of dynamic process ("evolution") describing the continuous course of negative (and positive) changes in the condition of body from some initial level.

Within the evolution simulation approaches a set of authors develop the multilevel model for the accumulation of disorders in the functions of organs and systems of human body [3] – as the basic model used during the health risk analysis and assessment. The feasibility of the multilevel models development is stipulated by the complexity of the studied objects, wide spectrum of spatial and time scales of physiological processes. The principal scheme for the interaction of the levels of model at the in-depth risk analysis performance is shown in fig. 1.

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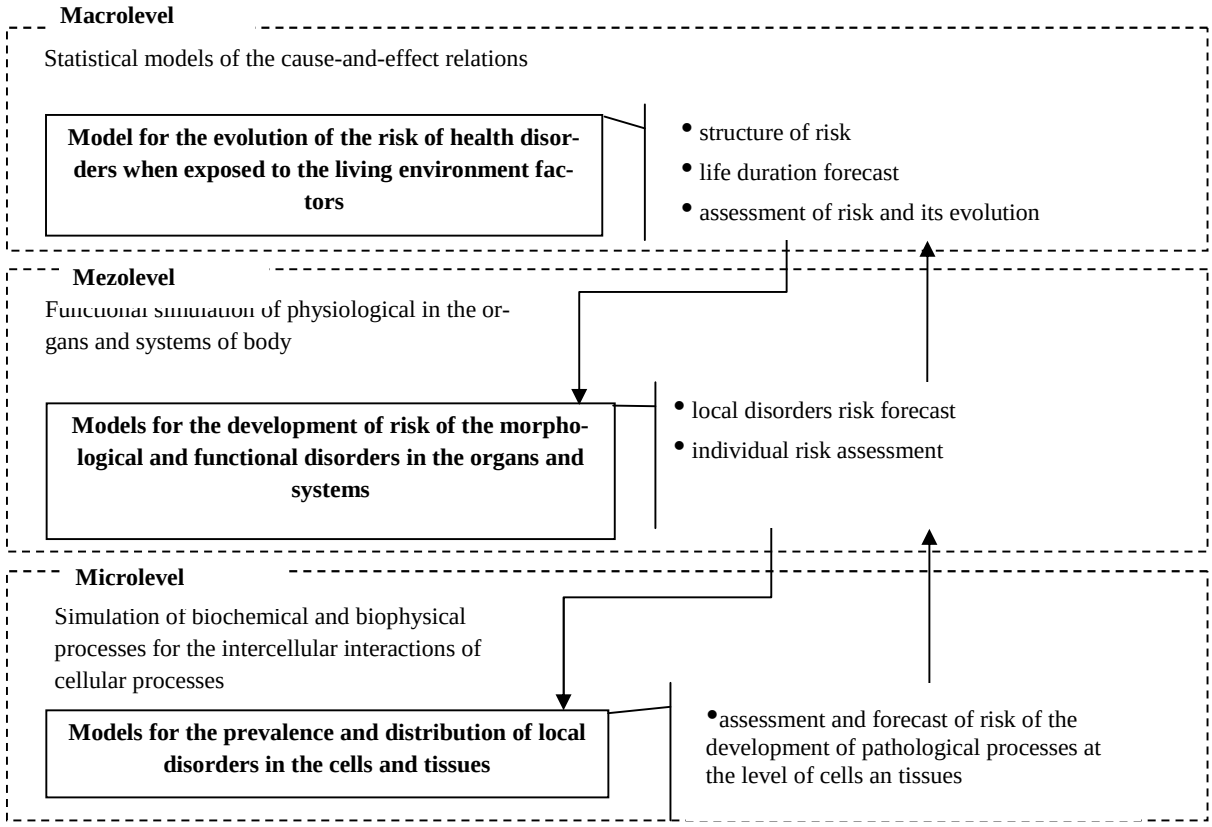

Fig. 1. Principal diagram of the risk assessment and forecast and its evolution based on the multilevel simulation

According to the specific character of the solved tasks the mathematical apparatus of models at the large-scale levels varies from the usual differential equations to the balanced equations of the continuum mechanics – preservation of mass, impulse and energy. One of the most important tasks is the coordination of models under the time scales because the seconds and minutes are used as a rule to describe the physiological processes in the human body, and the model for the evolution of risk of disorders in the organs at the "macrolevel" assumes the calculation at the medium and long-term scales of exposure (hours, days, months, yeara). When considering the mechanisms of local damages caused by the irritating impact of chemical substances on the wall of gastrointestinal tract or respiratory tracts it is necessary to calculate the local risk evolution taking into account the time scales of the corresponding "mezolevel" model.

The simulation for the accumulation of health disorders at the macrolevel is aimed at the obtainment of models reflecting the population regularities for the impact of the living environment factors on the population. Based on the obtained evolution dependences of the macrolevel it is necessary to perform the assessment and forecasting for the accumulation of risk of violation in the functions of the organs and system of body when exposed to the chemical, physical and biological factors, s well as the lifestyle, developed the approaches on assessing the additional cases of morbidity and mortality associated with the impact of the living environment factors as well as the approaches on assessing the contributions of the separate factors to the risk structure [2]. The results of the health risk simulation at the macrolevel are the initial data for simulating the processes of the development of risk of health disorders at the mezolevel the purpose of which is in the clarification of the conditions of formation and location of the morphofunctional damages of separate organs. The development of such models is performed based on the functional simulation of physiological processes occurring in the body under the negative impact of the living environment factors. At this stage we developed the structure, main notions and definitions of the mathematical model at the "macrolevel", the models of "mezolevel" of the digestive, respiratory [10], cardiovascular, immune and endocrine systems [11]. The locations of disorders inside the separate organs and critical links of physiological processes are the results of the risk calculation at the mezolevel. The forecast of the local risks implementation to the real pathological process combined with the damage of tissues of the organs and

cellular structures is performed based on the models of intercellular interactions – the models of microlevel. At this stage the microlevel of model is represented conceptually; the main attention of authors is paid to the development of the mathematical realtions of the macro and mezolevels.

Due to the complexity and diversity of the tasks of multilevel evolution simulation this article considers in detail only the fragment of the one of models of "mezolevel" – task of current at the antroduodenal area of the gastrointestinal tract [9] which waa actively developed because it was necessary to take into account the peroral intake of chemical substances to the human body.

Kinetic cameral models widely used to assess the concentrations of substances in the blood, digestive and other systems of the human body [8] does not allow for tracing the spatial characteristics of processes, because in general they are based on the system of typical differential equaitons with time variable. In this relation it is fasible to assess the peroral intake of chemical substances using the methods of continuum mechanics (hydrodynamics) with application of differential equations in the partial derivatives dscribing the spatial-temporal regularities [17, 20]. The physiology is one of the advantages of this approach – possibility to simulate the main digestion processes, including the absorption and secretion (diffusion processes), motility of the walls of tract, grinding and dissolution of food, and biochemical reactions in the cavity of gastrointestinal tract.

The model of "mezolevel" of digestion in the cavity of gastrointestinal tract combines the modern concepts of digestive processes in the separate sections of tract with addition of the organs and systems of human body and taking into account the factors of impact (fig. 2).

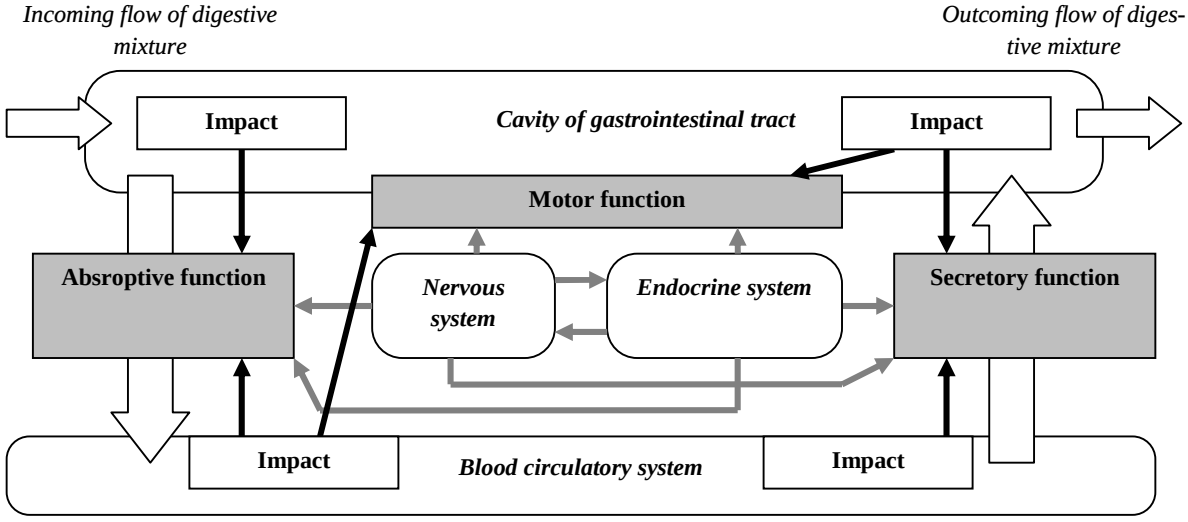

Fig. 2. Functions of digestive system

The digestive process implementation is ensured by the performance of three physiological functions – secretory, motor and absorptive for the conversion of complex nutrients to the simplier which can be consumed by the human body. The management of digestive processes is performed by the nervous and endocrine systems. The provided scheme, depending on the considered section of gastrointestinal tract, is filled with the certain substance and detailed by the additional strucutural elements. It is possible to distinguish two groups of the living environment factors affecting the digestive system: first – the chemical substances influencing through the blood circulatory system, second – the substances influencing from the cavity of gastrointestinal tract (GIT). The chemical substances taken to the blood circulatory system during the absorption through GIT wall are distributed in the body and have the damaging impact on the other organs and systems.

The stomach "mezolevel" model provides the movement of multiphase mixture (suspension) [7, 18] in the hannel of complex form with movable borders. The first phase is a liquid with the chemical substances dissolved at the molecular level, the second phase – the solid food particles. The size of particles of the second phase at the beginning of the digestive process is determined using the Rozin-Rammler equation [13] and depends on the functional condition of dentition and the number of chewing cycles. Для The algorithm of reconstruction based on the results of individual ultrasound

examinations is developed to build the evolving three-dimensional form of the athroduodenal area of the gastrointestinal tract.. In few minutes after the taking of food the involution waves start to distribute in the antral segment of stomach – the reduction of areas (bands) of the circular layer of muscles along the whole circumference of stomach. The relaxation of muscles occurs after the reduction of the circular muscles area and the involution wave goes to the other area (fig. 3).

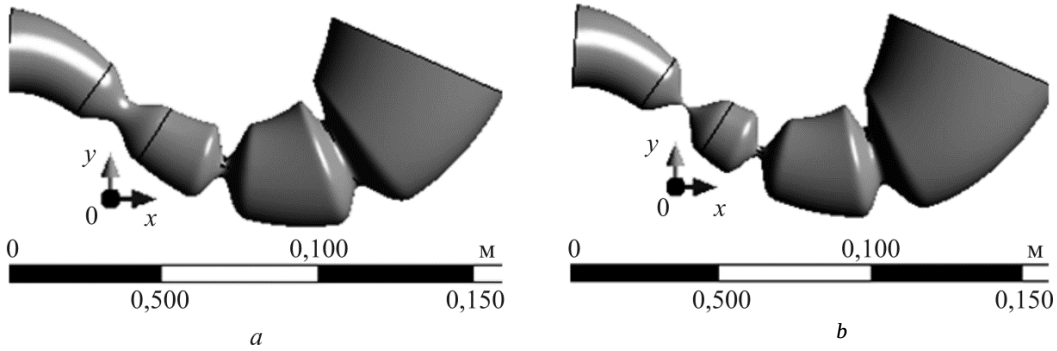

Fig. 3. The position of waves in the antral segment at the opened (a) and closed (b) pyloric sphincter

To set the involution wave characteristics in the antral segment and motion of pyloric sphincter we developed the algorithm for determining the changes in the position of the computational grid nodes. The dynamic re-building of computational grid is performed using the Dynamic Mesh tools in the Fluent equation solver which automatically calculates the position of internal nodes according to the set configuration of threshold elements at each moment of time [12].

The calculation of flow is performed in the Fluent equation solver taking into account the changes in the omputational grid configuration during the peristaltic wave simulation (speed $2.2 \cdot 10^{-3}$ m/s, period 18 s) and the pyloric hole motion. At the closed pyloric sphincter the single-phase flow character correlates with the known literature data [15] and the results of three-dimensional simulation without taking into account the evacuation to the intestinal tract [14, 21]. We observed the flow zone formation with speed of up to 0.031 m/s directed opposite to the peristaltic waves distribution speed and the area of circulating flows between the peaks of neighboring waves. When the pyloric hole is opened, the content of stomach is evacuated to the intestinal tract with the speed of up to 0.016 m/s, the speed of flow in the antral segment is decreased to 0.019 m/s (fig. 4).

The presence of functional disorders in the stomach motion results in the significant decrease of the speed of flow (at the set conditions – by one order) and weak mixing of the content of stomach. When simulating the flow of two-phase medium the particles of the second phase due to higher density deposit rapidly nearby the convex wall of stomach and the separation of phases is performed. The circulation of the second phase particles occurs at the passing of peristaltic wave long the convex wall of stomach, and the evacuation of particles at the set parameters is not observed.

Quite limited number of the three-dimensional models of flow in the gastrointestinal tract as of now provides the wide field for the conduction of further studies – analysis of the flow of multiphase mixture with different number of phases with different viscosity and density. In addition, it is possible to vary the size of food particles, taking into account the processes of dissolution, biochemical reactions, and study the impact of the body position on the flow of multiphase mixture. The certain difficulties during the development of this direction can be caused by the limited base of experimental studies for the identification of more comples models.

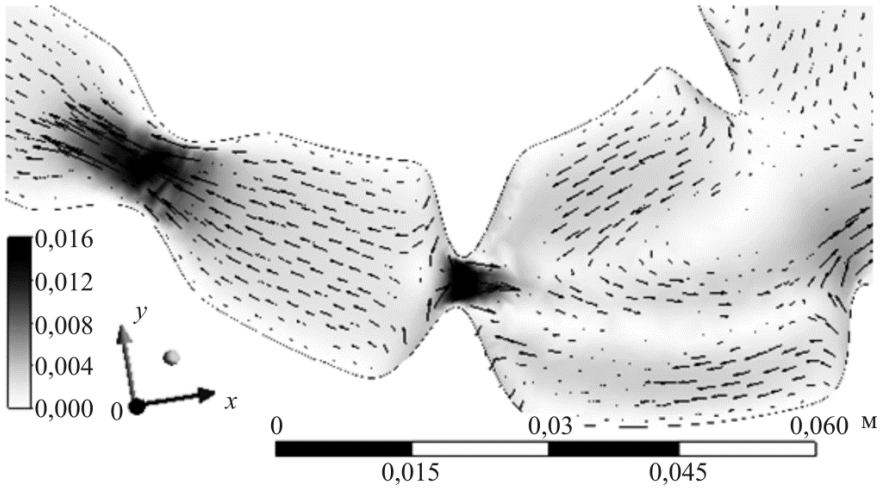

Fig. 4. The field of speeds in the atroduodenal segement of tract at the opened pyloric sphincter, m/s

Therefore, the developed approaches within the multilevel model for the evolution of the risk of functional disorders will allow for not only the forecasting of risk but also for taking into account the main physiological processes, mechanisms of intake, distribution and excretion of chemical substances. It should be noted that the complete prognostic force in relation to the risk of disorders will be obtained by the multilevel model only after the achievement of the correspondent degree of development of all the sub-models and relationships between them. In future, it planned to account in the model the vermicular motion of duodenum as well as the interaction of the hydrochloric acid produced in the stomach and sodium bicarbonate emitted to the duodenum with pancreatic juice. The possible use of such sub-model is in determining the hyperacidity areas and detecting the mechanisms of their formation. One of the priority tasks is the accounting in the model of the absorption of chemical substances to the blood circulatory system because the determination of the concentration of substances in the cavity of gastrointestinal tract and blood is necessary to forecast the risk of the functional disorders in the organs and systems of human at the "macrolevel" at the peroral intake of chemical substances with food and drinking water.

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