Logical - mathematical models of quantitative assessment of the integral level of individual physical health based on the adaptive potential of the body

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Abstract. The paper proposes a model of the integral level of individual physical health, which allows its quantitative assessment. The logical and mathematical justification of the proposed model is presented on the basis of protective-adaptive and compensatory reactions of the body as an integral indicator of health. The results of a quantitative assessment of the integral levels of physical health of 190 practically healthy, non-sports, young people of both sexes, obtained using the developed model, are presented. The possibilities of the proposed model for ranking the subjects on 6 levels, including prenosological functional states instead of 2, are shown according to generally accepted practice, which allows a personalized, reasoned and differentiated approach to preventive measures to preserve the health of healthy people.

1 Introduction

In recent years, in the developed countries of the world, health systems have significantly intensified measures to protect the health of healthy people. Their goals are to create a system of formation, active preservation, restoration and strengthening of people's health, where one of the urgent tasks is to assess the current level of their individual health and monitor its changes. To do this, information is needed, both about the conditions of health formation and about the final result of their implementation — specific quantitative indicators characterizing the state of an individual's health. However, at present, in practical medicine, human health is considered to be the absence of disease. With traditional examinations, excluding pathology, the doctor states that the subject is healthy, while a quantitative assessment of the quality level of his health is usually not carried out. Thus, the need for a quantitative assessment of health is quite obvious, because without knowing its quantitative side, it is impossible to predict its change, to carry out reasonable preventive measures aimed at improving the health of the body at the individual level, to adjust it towards maximum health.

In the literature [1-3] there are data on numerous studies devoted to the development of methods for assessing the state of physical health. During the analysis of the available data

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on the development of health assessment scales, it was found that in them the assessment of health levels is carried out on the basis of conditional units –points with their translation into qualitative health indicators.

The variety of indicators and criteria of health, more and more urgently requires the development of generalized indicators that integrally characterize the state of health and methods for quantifying the level of health. However, the concept of "health" does not contain a quantitative measure, so it is proposed to use as such a measure, the indicators of the equations of the mathematical model of health.

2 Methods

It should be noted that the methods of mathematical modeling, which are a quantitative description of the phenomena studied in the language of mathematics, are widely used to study all kinds of body processes – they are always logically sound models using a minimum number of indicators and assumptions accepted as hypotheses about the principles and mechanisms of processes in modeling objects.

It should be noted that any logical reasoning is based on hypotheses or axioms that are accepted on faith and do not contradict existing knowledge, concepts and other scientific ideas. The main difference between scientific modeling lies not only in the ability to perform the necessary operations and actions for the actual modeling, but also in the knowledge of the "internal" mechanisms of interaction of the indicators included in the model. It can be said that scientific modeling knows not only how to model, but also why it should be done.

This "third way of knowledge" combines the advantages of both theory and experiment. On the one hand, working not with the object itself, but with its model, we can relatively quickly and without significant costs investigate its properties and behavior in any conceivable situations. On the other hand, computational experiments with object models make it possible, relying on the achievements of modern computational methods and computer technology, to study objects in detail and in depth in sufficient completeness, inaccessible to theoretical research.

As a result, it became possible to approach many medical problems on a scientific basis[4], where the problem of quantifying individual human health can be attributed.

It should be noted that currently many scientists are working on the creation and implementation of complex diagnostics and self-diagnosis of health, based on information technologies using information and methodological software complexes, including tools and author's programs of various types [4-8]. They provide an assessment of functional states, working capacity and reserve capabilities, followed by an express assessment of individual health. In the work [5] it is rightly noted that the knowledge of one's health status, the inclusion of the person himself in the process of managing his health allowed to reveal a sharp increase in his motivation to work on strengthening his health.

The development of mathematical and logical models of integral health indicators also deserves attention [9-13]. For example, in [13], the results of research on the creation of a mathematical model of the physical health of a "healthy person" by regression analysis are presented, where the physical parameters of a person act as factors, and an indicator of physical performance is used as a response. As a result, the method of multiple regression analysis of statistics was chosen to predict the physical health of a person, which allows the analysis of multifactorial statistical models. The author presents the multiple regression model in the following form:

$$Y_i = B_0 + B_1 X_1 + B_2 X_2 + ... + B_n X_n + \varepsilon ,$$

where Yi - is the response (dependent variable), B_0 - is the constant component estimate, Bi - is the i–th multiple regression coefficient, Xi - is the i-th independent variable, ε is the error; (i=0.1,..,n).

The paper defines significant parameters for forecasting models, with the help of which it is possible to quickly and effectively assess the physical health of persons aged fourteen to seventeen years.

Note that the algorithms of prenosological diagnostics discussed above based on regression models of physiological states proceed from the idea that the entire scale of transitions from one state to another can be described by a linear function. In fact, complex physiological and pathological processes of adaptation of the body to environmental conditions are unlikely to be linear. This is due to the fact that at different stages of adaptation, the interaction of the processes of homeostasis, compensation and adaptation mechanisms proper develops in different ways. The spaces in which the processes of interaction of the organism with the environment unfold are extremely heterogeneous, and therefore more specific mathematical models should be used to accurately describe them, the creation of which is an urgent task.

The analysis of the well-known models for assessing the health of the population suggests that each of them is unique in its own way, however, only qualitative levels of individual health are diagnosed (such as excellent, good, average or bad), and are not calculated for its quantitative assessment. These models fully provide the possibility of dynamic control over selected groups of healthy, practically healthy and sick people, however, they are sensitive, mainly only to qualitative changes in the state of health. Therefore, the development of more advanced mathematical models that allow a quantitative assessment of integral indicators of individual human health in a wide range of his vital activity remains an urgent task.

It is quite obvious that it is advisable to build mathematical models of health on the principles of multidimensional mathematical statistics, the use of which makes it possible to reduce a large number of health indicators to a small number of generalized quantitative assessments of the severity of this process. Adequate models are considered, in the construction of which the main informative integral indicators characterizing the levels of health are used. Such are the indicators of the levels of protective and adaptive, as well as compensatory reactions of the body to endogenous and exogenous factors of influence. They can serve as a fairly accurate and early indicator of the occurrence of premorbid conditions, quantify the state of health and the effectiveness of adaptation.

It should be noted that the subject of consideration in this article is the physical component of health, which reflects the biological essence of the category "health", consisting of its two main aspirations — to preserve the individual (survival) and to preserve the species (reproduction). It is determined by the level of growth and development of organs and the state of the functional systems of the body, its ability to adapt to the changed conditions of the external and internal environment, the harmony of physiological processes. Based on the modern definition of individual physical health, it can be represented as follows: it is a dynamic human condition, which is determined by the reserves of self-organization mechanisms (resistance to pathogenic factors and the ability to compensate for the pathological process), characterized by informational (genetic), energy and plastic support of self-organization processes (adaptation, homeostasis, reactivity, resistance, etc.) which, ultimately, is a condition for the optimal manifestation of the biological functions of the individual.

Taking into account the relevance of the quantitative assessment of the individual level of health in practical medicine, and the above-mentioned features of modeling, we have made an attempt to develop a mathematical model of the integral level of physical health of a person in his various functional states - from absolute health to painful, inclusive. It is

based on the dependence of physical health on the level of the adaptive potential of the organism - its functional reserve, necessary for both protective and adaptive processes providing homeostasis, and the necessary intensity of protective and compensatory processes aimed at self-preservation in pathology. At the same time, we have taken into account that physical health is the level of development of the functional capabilities of the organs and systems of the body, respectively, its basis is the functional reserves of the body, the normal functioning of which is provided by homeostasis and its adaptation to the effects of various endogenous and exogenous factors, that is, its adaptive ability. At the same time, the cardiovascular system, as a sensitive indicator of the adaptive reactions of the whole organism, is the first to react to all fluctuations in environmental conditions, and is a regulator of the internal environment of the body, maintaining homeostasis of its organs and systems through their adequate blood supply. Thus, the main system–forming factor for an organism as a dissipative system is adaptation – the desire to balance with the environment, whereas for individual physiological systems such a factor is homeostasis - the desire for internal balancing. Adaptation and homeostasis are two of course–resultant, organizing the functioning of individual systems and the whole organism as a whole, therefore, we consider the assessment of the adaptive capabilities of the organism as one of the important integral criteria of health.

In [1, 14-18], an overview of methods for assessing the adaptive and functional reserves of the body and assessing the level of health is considered. Despite this, the need to develop mathematical models of physical health that allow noninvasively, remotely, in a short time interval, in the mode of express diagnostics, to determine quantitative indicators of the integral level of the state of health of the organism in a wide range of its existence - "healthy-practically healthy- weakened- premorbid states- ill" [2] persists. In this aspect, it should be taken into account that a wide class of mathematical models of integral indicators (IP) can be set by an algebraic sum of products Ki x PSi , where PSi is the i-th indicator of the system, and Ki is its weighting factor. Since in the general case these products can have different signs, the problem arises of choosing the value of Ki so that the IP always changes in a given interval.

In this regard, the logic of our reasoning on the issue under consideration boils down to the following: the physical health of an anatomically formed organism is its integral indicator and is expressed by the level of its protective and adaptive reactions. Applying a systematic approach to the issue of studying the quantitative assessment of the health (LH) of the organism and taking as a basis its physiological aspects, expressed in the intensity of its protective-adaptive and compensatory reactions, and using methods of mathematical logic, we have proposed the following general models for describing the level of physical health, in a wide range of its manifestations(LFHmax) -from the maximum with optimal functioning of the body, to the minimum - with its pathological and extreme functioning:

$$LFH=LFHmax - LFHadap + LFHkom \quad (1)$$

where LFHadap – the amount of health, which is the “price” of the body's protective and adaptive reactions to disturbing factors;

LFHkom - the amount of health restored due to compensatory reactions triggered in the body during its pathological and extreme conditions;

The signs of action “ – ’ and “+ ” are associated with the peculiarities of the contribution of the specifically considered health factor to the overall integral level of health.

Note that in the case of optimal functioning of the organism, its adaptive mechanism works in a control mode, homeostasis is maintained by genetically determined mechanisms. For this state of the body, its adaptive potential is optimal (APop) and the maximum level

of physical health of the body (LFHmax) is provided, which we have accepted, in relative units, as 100%. With an increase in the intensity and duration of external and internal factors negatively affecting the body, various adaptation mechanisms with the potential of APi (with APi > APop) are triggered to maintain its homeostasis, the "price" of which is an adequate decrease in the integral level of physical health of the body (negative factor). Quantitatively, this change in health depends on the magnitude of the deviation of the individual's APi from the optimal APop and can be estimated based on the fact that what part it makes up depends on the overall width of the AP corridor of the functioning of the organism (AP =AP max - APop) taken as a percentage. In the language of mathematics, the following expression can be written for this factor:

$$((APi-APop)/(APmach - APop))x\ 100, \text{ in } \% \quad (2)$$

Earlier [16] considering that the golden proportion is a universal natural law and the highest manifestation of the structural and functional perfection of the organism, and has properties and principles-self-development, self-organization and self-regulation, as well as balance and stability, we proposed a scale of adaptive potential and functional states of the organism based on its optimization by principles and constant golden proportions. In this school with 6 grades, the state of functioning of the organism in the optimal mode has an adaptive potential, in conditional units equal to $\mathbf{F^0}$, and reaches a maximum value of $\mathbf{F^3}$, with extreme functioning. At the same time, the functional corridor of the first 2 intervals of states (physiological norm) has a width equal to $\mathbf{F^{-1}}$; the next 2 intervals (prenosological states) have a width of $\mathbf{F^0}$; and the last 2 intervals (pathological states) have a width equal to **F**, so that the ratio of the width of the subsequent intervals to the previous corresponds to the constants of the golden the proportions of **F** (here **F** = 1.618 ..., one of the constants of the golden proportion). With this in mind, formula (2) can be presented in the following form:

$$((APi-APop)/(APmax - APop))x\ 100=[\ (APi - 1)/(4{,}236- 1)\ ]\ x\ 100 \quad (3)$$

Thus, the magnitude of the decrease in physical health due to protective and adaptive processes in the body is expressed in the values of its adaptive potential, and at the same time, the greater the deterioration in health, the more adaptive potential is needed to maintain homeostasis. If the adaptive processes of vital activity underlie the interaction of the organism with the external environment, then the concept of compensation is used in relation to the body's ability to adapt to changed conditions in pathology. The fact is that in the changed conditions, with the disease there is a violation of normal functions, and compensatory and adaptive reactions occur in the body aimed at restoring impaired functions. It should be noted that compensatory adaptations are important adaptive reactions of the body to damage, expressed in the fact that organs and systems that are not directly affected by the action of a damaging agent take over the function of destroyed structures by substitutive hyperfunction or qualitative changes in function [17]. In the first case, adaptive mechanisms should work, leading to changes, the direction of which takes the individual away from the initial state, thereby restoring balance. In the second case, compensatory mechanisms are activated, which also lead to internal changes, but opposite in the direction of adaptive changes. Compensatory processes tend to return the individual to the original lost state. Thus, along with the above-mentioned protective-adaptive mechanism of homeostasis support, the body also has protective-compensatory mechanisms that are stored automatically in extreme cases of functioning, as a mechanism for self-preservation of the body's health. At the same time, the closer the functional state of the

body is to extreme, the greater the contribution of this mechanism to the preservation of the amount of health. In this regard, it can be logically argued that the contribution of this factor is inversely proportional to the difference in the adaptive potential of an individual AP_i from AP_{max}. We proposed to take its maximum share in the total amount of integral physical health at the level of 20 %. In this case, the determination of the amount of this contribution to integral health can be carried out by the formula:

$$(APi/APmax)x\ 20= (APi\ /\ 4{,}236)x\ 20,\ in\ \% \quad (4)$$

Thus, the amount of the relative integral level of physical health (RILFH) is a function of two integral reactions of the body, namely protective-adaptive (PAR) – adaptive, and protective-restorative (PCR)-compensatory reactions. Moreover, the first reduces the amount of health, and the second increases it. This functional dependence, taking into account the formula (1), (2), (3) and (4) can be written as the following equations:

$$RILFH =100- [\ (APi - 1)/(3{,}236)]x\ 100 + (APi\ /\ 4{,}236)x\ 20 + K, \quad (5)$$

K is a constant component (number), which is added to the expression of the RILFH to implement the necessary offset of the interval of its possible values (to make, for example, these values no more than 100). The value of the constant of equation K can be calculated by the formula (5), normalizing the value of the RILFH for the functioning of the organism in an optimal mode, that is, RILFH = 100 and, accordingly, APi = 1. In this case, for C, we get a negative value equal to -4.72.

Thus, our proposed model of the individual's physical health has the form:

$$RILFH =100- [\ (APi - 1)/(3{,}236)\ ]x\ 100 + (APi\ /\ 4{,}236)x\ 20 – 4{,}72,\ \% \quad (6)$$

According to this model, to quantify the relative integral level of physical health of an organism, it is necessary to determine its adaptive potential (AP). Among the whole range of methods for analyzing the adaptive potential of a person, based on the assessment of various parameters of vital activity, the most informative are those that characterize the activity of the cardiovascular system - the main indicator of all events occurring in the body. In favor of the possibility of using the indicator of the adaptive potential of the circulatory system as a measure of the functional states of the body and a quantitative assessment of the level of health, the following can be taken: The main system–forming factor for an organism as a dissipative system, as already noted, is adaptation – the desire for balance with the environment, whereas for individual physiological systems such a factor is homeostasis - the desire for internal balancing. Adaptation and homeostasis are two of course–resultant, organizing the functioning of individual systems and the whole organism as a whole. In the adaptation of the body to environmental factors, the leading role belongs to the cardiovascular system [14]. The success of both urgent and long-term adaptation to various environmental factors depends on the state of this system.

An assessment of the adaptive processes of the organism, taking into account not only functional reserves, but also the degree of tension of the regulatory mechanisms that ensure homeostasis, was proposed by R.M. Baevsky [14, 15]. Today it forms the basis of prenosological diagnostics. At the same time, the reaction of the circulatory system, as the system responsible for the adaptation of the body to a large number of various environmental factors, is considered as an indicator of the adaptive reactions of the whole organism. The proposed algorithm for calculating AP is based on indicators that are subject to mandatory measurement during dispensary examinations, namely, blood pressure, (SAP,

DAP), heart rate per minute (HR), Height (H in cm.), body weight (W in kg), Age (A). The capabilities of this algorithm follow from the physiological interpretation of its mathematical model, which is identified by the equation:

$$AP = 0{,}011HR - 0{,}014\ SAP + 0{,}008\ DAP + 0{,}014\ A + 0{,}009\ W - 0{,}009H - 0{,}27 \quad (7)$$

and characterizes the relationship between myocardial-hemodynamic (HR, SAP, DAP) and structural-metabolic (H, W) homeostases. Each of the elements of the model is influenced by environmental factors. Myocardial-hemodynamic homeostasis reacts promptly to changes in environmental conditions, ensuring an adequate change in the transport of oxygen and nutrients. Here, age, as a factor leading to a decrease in the adaptive capabilities of the body, increases the activity of myocardial-hemodynamic homeostasis as the transition from catabolic to anabolic type of metabolism.

In order to assess the sensitivity and diagnostic objectivity of our proposed model, 190 (99 male and 91 female) practically healthy young people aged 18-24 years were examined. The data obtained using formulas (7) and (6) on the number of levels of their physical health, ranked in accordance with our scale [16], are presented in the table below (Table 1).

Table 1. A quantitative assessment of the physical health of the contingent of the examined persons.

№	Function Status	Boundary indicators of adaptive potential accordingto [16]	adaptations	the amount of physical health %	health levels	The number of people surveyed, with givengiven health levels					
						total	in, % of all	Including			
								boys		and girls	
								in total	in % of the survey. boys	in total	In% of the survey. Girls
1	Optimal	1.00 - 1.309	Exl.	91.9-100	Exl.	0	-	-	-	-	-
2	Normall	1.309-1.618	well	83.8-91.9	well	3	1,6	--	-	3	3,3
3	Donoz-1	1,618-2,118	satisfactor	70,7-83,8	мedium	79	41,6	26	26,3	53	58,2
4	Donoz-2	2,118-2,618	tense	57.6-70.7	lower average	97	51.0	63	63.6	34	37.4
5	Premorb.	2,618-3,427	notsatisfac	36.5-57.6	bado	11	5.8	10	10.1	1	1.1
6	Pathologicfeatures	3,427-4,236	disruption	15,0-36,5	Very badoh	0	-	-	-	-	-
					total	190	100	99	100	91	100

As a result of a quantitative assessment of the physical health of the contingent of the examined persons, using the proposed model, the following were established:

1. Among the examined persons, persons with an excellent level (91.9-100%) of physical health were not identified;
2. Only 3 girls have a good level of physical health;
3. Of the 190 examined, 176 (92.6%) are in a prenosological functional state. At the same time, 97 (51%) of them have adaptation maintained in stress mode, with the risk of developing pathological processes requiring corrective preventive measures;
4. 11 of the examined, mostly young men, are in a pre-painful condition, who require a diagnostic examination;
5. The examined patients have no pathological condition.
6. The data presented in the table also show that in the levels of physical health of the surveyed persons, pronounced gender characteristics are observed, namely, among people with average and good health, girls are 2 times more, and among people with poor health 2 times less than boys. This phenomenon, in addition to genetic factors, in our opinion, is

associated with greater motor activity of girls, due to the features assigned to them in everyday life, according to Eastern traditions and customs.

3 Conclusion

Thus, it can be argued that our proposed model can be used for an objective quantitative assessment of the individual integral physical health of the examined and their differentiation by health levels, not in two physiological states (healthy or ill), as is now customary in practical medicine, but in 6 functional states, 4 of which cover prenosological states health of a healthy person. As a result, a personalized and differentiated approach becomes possible in planning and carrying out preventive measures to preserve the health of healthy people.

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