Background. Endoscopes with a rigid relay optical system have several advantages over flexible endoscopes and therefore are widely used in medicine. The problem remains the predisposition of these endoscopes to the destruction of that part of the optical system, which is assembled from rigid rod glass lenses. The cause of the damage can be small (up to one degree) bends of the metal tube in the process of using the endoscope. Failure of the optical part of the endoscope during surgery can have serious negative consequences for the patient. **Objective.** The aim of the article is to improve the optical relay part of a rigid endoscope, aimed at a significant reduction of its destruction due to the bends of the tube. **Methods.** To eliminate the damage, the relay part of the optical system is proposed to be assembled from short rod lenses with spherical ends, which allow for flexible articulation of these lenses. It is proposed to place a special heat-resistant immersion in the gaps between the spherical ends of the lenses, which ensures the passage of light from one lens to another with virtually no loss of luminous flux. It is shown that the proposed improvement allows to bend the tube at an angle of up to 10 degrees without breakage of rod lenses, which is unprecedented for rigid endoscopes. It is confirmed that the introduction of an additional aberration compensator of two meniscus lenses located between one pair of adjacent rod lenses into the optical system provides high image quality across the entire field of view, superior to the image quality of the prototype. At the same time, the distribution of relative illumination in the image plane formed by the improved optical system remains almost unchanged. **Results.** Providing greater flexibility of the rigid endoscope increases its competitive ability. Further improvement of the optical system of rigid endoscopes will create the conditions for the introduction of new minimally invasive surgical techniques that will simplify, reduce the cost and make endosurgical procedures minimally traumatic.

Keywords: rigid endoscope; rod lenses; endoscope flexibility.

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RANKING THE FUNCTIONAL STATES OF A GROUP OF INDIVIDUALS BY THE ACTIVITY INDICATORS OF REGULATORY SYSTEMS EVALUATED USING ELECTROCARDIOGRAPHY DATA

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A principle and procedures for ranking a group of persons according to the functional state of their body in accordance with the value of the indicators of the activity of regulatory mechanisms are proposed. Indicators are calculated by five-minute electrocardiogram records. Contradictory situations are not excluded, when the condition is better by some indicators and worse by others. The goal of the work is to improve the hardware and software of diagnostic systems in terms of decision support software for comparative assessments of functional states for a group of individuals.

The work was performed using the traditional approach to assess the functional states of the human body using the same set of indicators as in the assessment of the integral complex indicator AIRS.

Developments of the principle and procedures for ranking the group of persons disclosed in the work are presented in this amount for the first time. The ranking of a specific group of individuals is given as a test check of the proposed software procedures.

Keywords: *functional state of human body; activity indicators of regulatory systems; hardware and software means of evaluation; ranking procedures of group of individuals.*

Introduction

The quality and reserves of human health are largely determined by the state of regulation in the body, its power and quality, degree of development [1]. Therefore, in the research in applied physiology and preventive medicine, in clinical practice [2-4], assessing the general condition of the human body becomes increasingly common. This condition is obtained according to the functional state of regulatory system based on the study of heart rate variability according to electrocardiography data and with the calculation of a certain number of relevant activity indicators.

Such indicators are widely used in special areas of medicine, including space, military, sports, and disaster medicine, as well as in related fields. They are used to assess the effectiveness of therapeutic, preventive and health measures, conducting various functional tests. In assessing the current functional state of the human operator (air traffic controller, pilot, driver of a vehicle, etc.) activity indicators are used in order to determine his readiness for professional activity, competitive selection of applicants by their health, studies of the effects of stress, preventive examinations of population contingents, determining occupational aptitude and professional selection, etc. [1-5].

These indicators are convenient for such a diverse application, since they are not specific to distinct diseases and express only the general current state of the body, its resource and regulatory capabilities as a whole and the regulation in a person is one in health and disease [1]. The role of regulatory systems in the human body is such that under their influence are all organs and systems and their functioning, their activity depends on the intensity of regulatory influences. Different levels of intensity of regulation (normal, insufficient or excessive) correspond to the respective intensity of the work of organs and systems, the quality of the realization of their functions. Therefore, the general condition of the body can be judged by the activity of its regulatory mechanisms [1-4]. Regulatory systems activity indicators objectively reflect the general tone of the body's vital activity, regulation of organs and systems by mechanisms of different levels. These indicators show regulation's consistency, balance of such management, adaptive capabilities of regulation to form adequate responses to constant changes in external and internal conditions of life [1-2, 6-7].

The widespread use of these indicators is associated with their nonspecificity in relation to specific diseases, with independence from their presence or absence, as well as with the possibility of using the assessment of the overall health of a person for different purposes. The other advantages of indicators include the ability to reveal the functional state of the human body as a whole with the characteristic of functional activity and adaptive capabilities of its regulatory mechanisms in ensuring the coordinated management of various organs and systems, with the disclosure of their interaction consistency [1-3].

These indicators objectively express the current functional state of the body at the time of the survey. Over time, their values may change, reflecting a change in the level of vital functions of the organism in the existing set of conditions.

The widespread use of the method of assessing the functional states of the human body is supported by the availability of verified practical medical and biological bases for understanding the content, meaning and interpretation of these indicators.

This method describes the complex expression by these indicators of the level of control over the functioning of the most important life support systems of the human body. The possibilities of obtaining with their help a versatile objective medical assessment of current conditions, as well as opportunities and reserves of regulatory mechanisms of the human body are of the advantages of the method. Followed by the noninvasive and technological simplicity of survey, the existence and availability of relatively cheap hardware-software means, the presence and confirmed practice, effectiveness of test techniques and results interpretation, detailed and applied technology [1-3].

The task of evaluation of the functional states of the human body using the activity indicators of regulatory systems is presented in the practice of conducting examinations in a rich variety. Utilizing the same indicators for different research purposes, for different methods of their implementation, for different conditions of the human body's vital activity is typical [1-3, 8-12] in the process of conducting examinations (Fig. 1).

The diversity of practical applications with the use of these indicators in studies of the state of human health consists in the possibility to be used for one person and for a group of people. They are used in the cases of irrespective and comparative assessments of functional states. They are suitable for research in statics for the assessment of current conditions and in the dynamics when tracking their changes. The same indicators are considered both when monitoring human states and when managing them. Research in both normal conditions of life and in the manifestation of difficult conditions is possible. It can be weightlessness, low oxygen content in the air, high (low) ambient temperature, high level of acoustic noise, the effect of vibrations of certain spectra and others. Such factors may reflect abnormal conditions that are associated with the professional activity of a person [1-3]. Studies in standard rest conditions are widespread [13], as well as studies of the body's reactions to test stimuli, especially with the targeted study of different regulatory mechanisms [1-3].

Each of these cases has its own specifics and certain features in the technology of conducting examinations and interpreting the obtained results. The variety of practiced schemes for assessing the capabilities and reserves of the human body indicates one of the main difficulties in conducting research. It consists in the need to standardize the boundaries of the values of activity indicators, the limits of their change under various effects [1]. They must be indicated for each tension level of regulatory mechanisms. The acknowledging for these boundaries is necessary when calculating and interpreting results. For different groups of people with different categories of age, gender and other features, these boundaries are generally different.

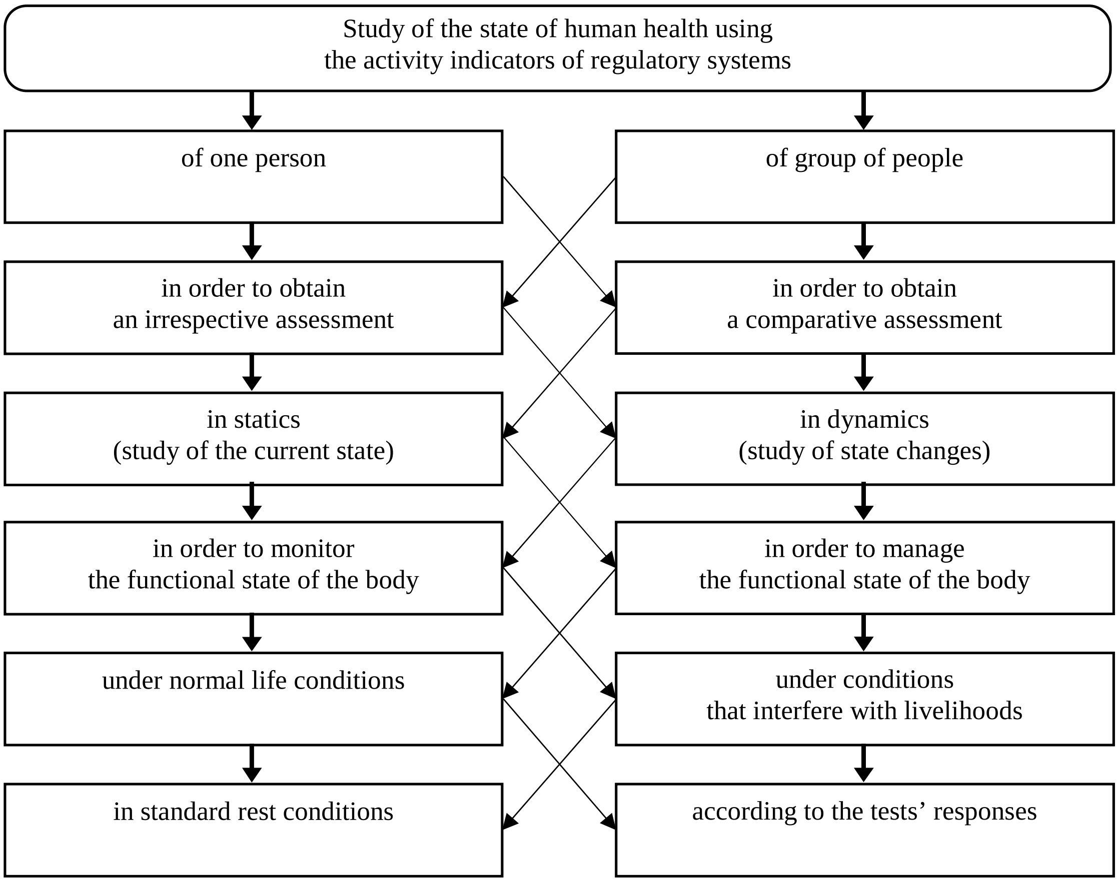

Fig. 1. Classification scheme of research options for the state of the human body using the activity indicators of its regulatory systems according to ECG data

This paper focuses on the comparative assessment of conditions for a group of individuals according to a survey in rest. Such ranking task is the most problematic in a competitive situation, when it should be linear, unambiguous, objective, justified, and carried out automatically. The usage of traditional estimates in the number of marks, as in the calculation of the integral indicator AIRS (Activity Indicator of Regulatory System) [2], can level out significant initial differences that are found on the initial scales of absolute values of indicators. The objectivity of comparative assessments is getting blurred. Even small groups can have several applicants with the same number of marks and at the same time require a unique fair linear arrangement of applicants by rank. The complexes (vectors) of indicators are necessary to use in their original numerical expression. For them, however, the notion of "more-less" is not defined. A special ranking principle and the development of appropriate procedures and software tools for data analysis are necessary to develop, which is the subject of this work.

In general, the development of linear ranking procedures for a group of individuals according to the functional state of their body with the calculation of the activity indicators of regulatory systems according to electrocardiography data is relevant and this relevance is associated with the presence of the specified competitive tasks that require for their solution corresponding software. Moreover, there are some unresolved issues about the decision-making on rankings simultaneously using sets of indicators, including conflicting situations. This relevance is also supported by the presence of several favorable circumstances for resolving such issues.

The justification of the ranking principle, the development of the implementing procedures is discussed in the second part of the paper. The third part reveals the meaning and results of the test in the MATLAB environment of the proposed ranking procedure using real indicators of the activity of the regulatory systems of the human body, which were obtained during the processing of five-minute electrocardiogram fragments. The main results and the appropriate directions for their use and development are presented in the general conclusions. In the first part of the work, in order to coordinate the development of ranking procedures with the general scheme for assessing the functional states of the human body for a group of individuals and ensuring the possibility of embedding these procedures in the specified scheme, the meaning and characteristics of the activity indicators of regulatory systems are analyzed. As well as analyzed a generalized algorithm for their assessment using different methods and approach to the interpretation of the results.

The usage of the activity indicators of regulatory systems in assessing the functional state of the human body according to electrocardiography data

One of the main goals of this section is to consider common survey methods and form a generalized algorithm for assessing the functional state of a group of individuals according to the indicators of the activity of regulatory systems. Such algorithm is being taken as the basis for expanding its functionality. Its structure will include the developed procedures for ranking a group of individuals by the level of regulatory mechanisms possibilities. The features of the indicators of activity, their evaluation, analysis and interpretation are also considered. And which follow the meaning of the desired ranking and the approach to its implementation.

The assessments of the current functional states of the human body in many methods are based on the position that heart is an indicator of the adaptation reactions of the whole organism, which are traced in the electrocardiogram [2]. It is an affordable, convenient process, which manifests the results of joint work of regulatory mechanisms of different levels. According to these results, while using the activity indicators, the quality of the regulation system can be assessed, along with its current state, regulatory capabilities and body reserves [1-2]. The assessment of the general functional state of the human body, its health using activity indicators are characterized by adequacy, simplicity, accessibility, efficiency, non-invasive examination, transparency of biomedical interpretation [1-2].

The primary data for assessing the activity of regulatory systems in this paper are the recommended for research [1-3] five-minute electrocardiogram (ECG) records at rest, lying the back at a sampling frequency of 1000 Hz and above, and the accuracy of measured RR intervals within the limits of ±1 ms.

During ECG analysis, the changes in heart rate (HR) from cycle to cycle are often assumed to be the result of multi-contour hierarchical non-linear control by regulatory systems, which can be characterized numerically as indicators of their activity. Therefore, precisely the heart rate contains the information about the state of regulation, its quality, including the communication with the outside world. The method for this regulation evaluation is called the technology of heart rate variability (HRV). HRV means the variation in the duration of RR intervals [1-3]. The “scatter functions” of RR interval durations contain basic information about the state of the systems that regulate the heart rhythm [1-3].

The main object of research in this technology is usually heart rate variability. At first, it is processed in the time domain as a cardiointervalogram for the initial variable series of the duration of RR-intervals. Then this variability is investigated in the frequency domain by the spectral components of the heart rate changes in the spectrograms. Probabilistic distributions of possible values of the duration of cardiointervals in the analyzed records are also investigated. At each such stage of the HRV analysis, it is described by whole sets, or groups of quantitative parameters, diversifying the management of the heart rhythm by the complex of the body’s regulatory mechanisms [5, 14]. These parameters are used to calculate standardized indicators of the activity of regulatory systems, including generalized, integrated indicators.

A block diagram of a generalized algorithm for assessing the functional states of a group of individuals using indicators of the activity of regulatory systems can be presented in this form on Fig. 2. After preliminary processing of 5-minute ECG records and obtaining a sequence of the durations of normal RR-intervals (block 1), one forms a cardiointervalogram (block 2) (Fig. 3), which bears the modulation of the considered RR durations. The latter expresses the work of different regulatory mechanisms that manifest themselves in different frequency domains (Fig. 4). To obtain the spectral characteristics of heart rate variability, the variable range of RR-intervals is pre-interpolated, thus providing a transition from a non-equidistant grid of time to equal-discrete for direct Fourier transform with obtaining the desired spectrogram (block 3). Block 4 generates histograms of the probability distributions of the values of RR-intervals in the electrocardiogram (Fig. 5).

In accordance with the form of the obtained characteristics, the required complex of individual indicators of the activity of the body’s regulatory systems is calculated for each tested group member (block 5). Calculations are carried out according to generally accepted definitions and corresponding formulas. Data processing for different applicants can be done in parallel, independently of each other.

If during the assessment and comparison of the functional states of the human body, a complex, integral indicator AIRS is used, then using the obtained values of individual indicators for each applicant, the corresponding calculation of the integral indicator is made (block 6). In accordance with the accepted classification [2] of the states of the human body, we determine a class of the functional state of the organism to which the applicant's body is assigned in each case by the AIRS value (block 7). This condition is attributed to the clinical and physiological interpretation characteristic of this class (block 8). Block 9 of the generalized algorithm provides a comparative assessment of the functional states of the participants in the tested group of people, which is assumed in the general case.

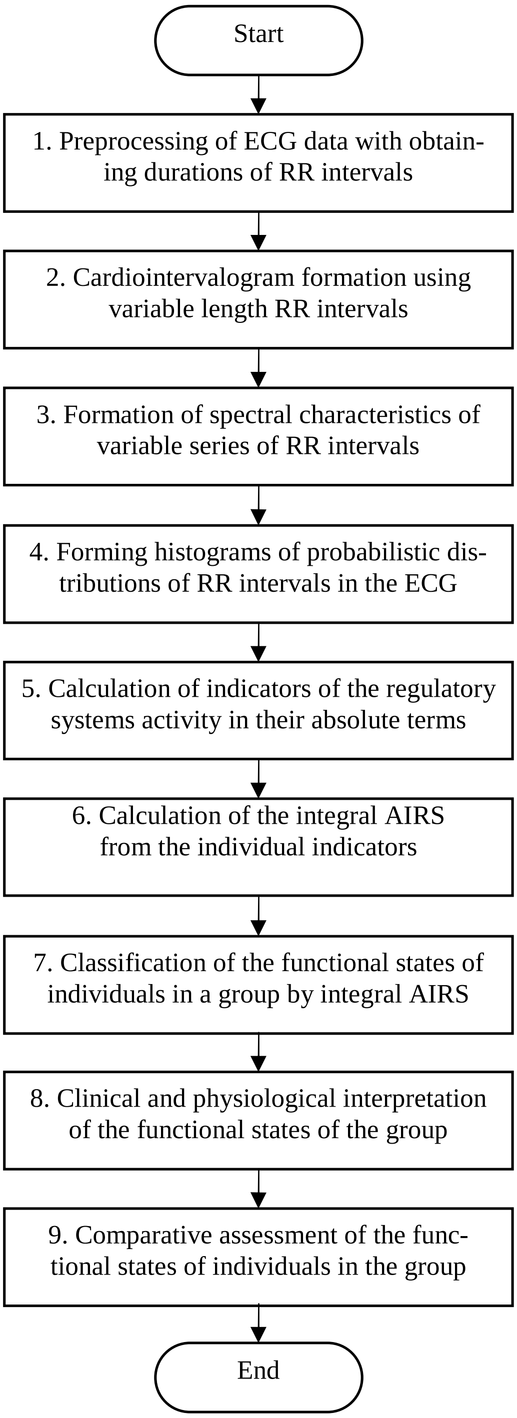

Fig. 2. A block diagram of a generalized algorithm for assessing the functional states of a group of individuals using indicators of the activity of regulatory systems

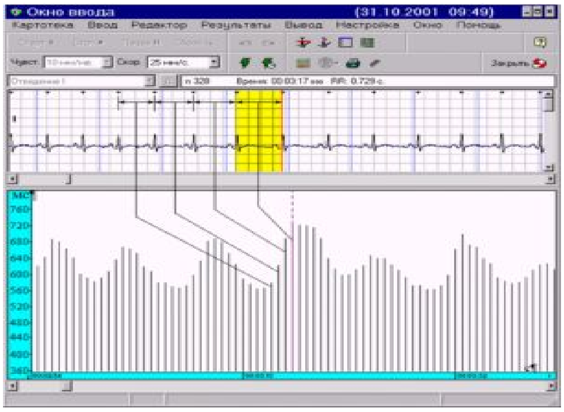

Fig. 3. The procedure for forming the intervalogram [2]

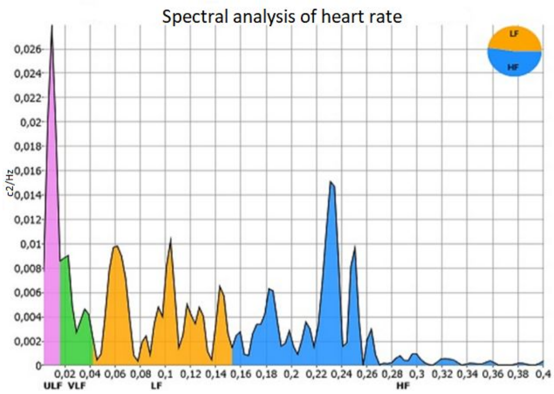

Fig. 4. Spectrogram and its informative subranges [2]

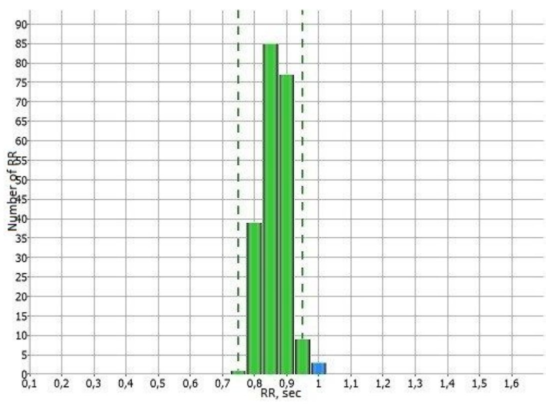

Fig. 5. Histogram of the probability distribution of the values of RR-intervals [2]

Used in the practice of research, the complexes of indicators of the regulatory mechanisms activity of the human body express different aspects of the functional state of the regulatory mechanisms [2]. In particular, to calculate the integral AIRS, reflecting the overall functional state of the regulatory system of the human body, a set of activity indicators is considered (Fig. 6). They express the total regulation effect (A), automatism function (B), vegetative homeostasis (C), stability of regulation (D), activity of subcortical nerve cents (E). Generally accepted [2] that the assessment of the state of the body's regulatory system obtained in this case is systemic and adequate.

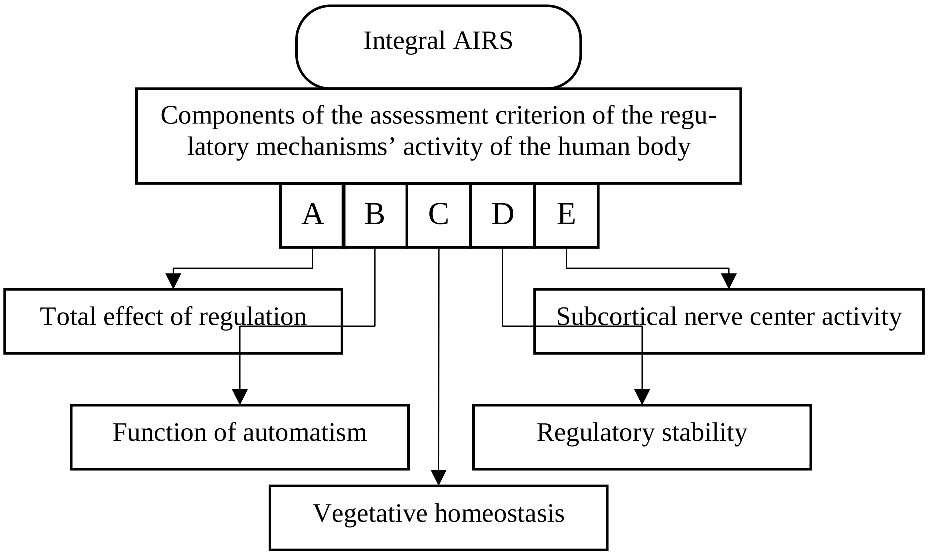

Fig. 6. Biomedical meaning of the components in the composition of AIRS

The peculiarity of the procedure for calculating the AIRS is that all individual indicators in their complex are considered to be equal in disclosing the state of the organism and equally important for ensuring its normal functioning. Indeed, the indicator AIRS is formed as the sum (with equal, single weights) of estimates (by module) of individual particular indicators of the state of the heart rhythm regulation system [5]: AIRS = | A | + | B | + | C | + | D | + | E |.

The composing factors are taken into account in the cumulative result by charging up a certain number of points. The points are awarded on the absolute values of the indicators for each participant (Fig. 7) on a typical scale of the level of dysfunctions [5].

Dysfunctions for each indicator and in general are considered in two versions, insufficiency (hypo) or excessive level (hyper) of regulatory activity. The sign in the number of points reflects the direction of departure of the indicator value from the norm.

Charged points by their meaning are, therefore, penalties. The transition from absolute values of indicators to the number of points is associated with the need for joint consideration of heterogeneous, incommensurate factors. Due to this transition, the resulting effect of regulation is assessed by summing up the manifestations of various factors in their general expression.

AIRS turns out to be a general assessment of the resulting quality of activity management of the organs and systems of the human body from its regulatory system. Moreover, in the practice of research, the normative systems for classifying the states of an organism according to the values of AIRS are used on an integer scale from 0 to 10 with the introduction of a five-level gradation of states [5].

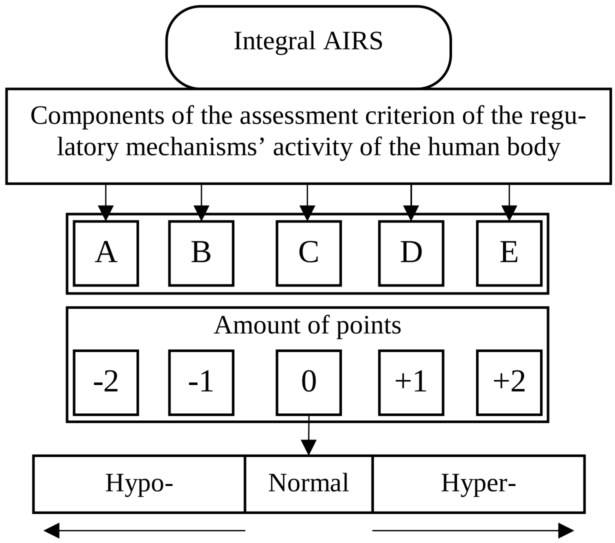

Fig. 7. Typical scale of points for functional states of the human body

With such gradation, the values of AIRS = 0...2 correspond to the functional state of the body with *optimal* state of its regulatory systems necessary to maintain active equilibrium in conditions of changes in the external and internal environment. AIRS values = 2...4 indicate *moderate* tension of regulatory systems, in which the body needs additional functional reserves for adaptation to environmental conditions. The case of AIRS = 4...6 is *pronounced* tension of regulatory systems. AIRS = 6...8 is *overstrain* of regulatory systems, *lack of protective and adaptive mechanisms*, their inability to ensure an adequate response of the body to the influence of environmental factors. AIRS = 8...10 is *exhaustion* (astenisation) of regulatory systems [2].

AIRS, as well as its individual components, is not specific to particular diseases, therefore its use finds a wide range of practical applications. It is possible to focus on the composition of the factors considered in the preparation of a set of indicators of the activity of regulatory mechanisms for an adequate, in a certain sense, comprehensive and diverse assessment of the state of the regulatory system of the organism as a whole.

An example of the results of assessing the functional state of the body of a particular group of 32 people according to 5-minute ECG recordings with the calculation of the indicators of the activity of regulatory systems and the integral AIRS is shown in Table 1.

Table 1. The results of the assessment of the functional state of the body of a group of individuals using indicators of the activity of regulatory systems and the calculation of the integral AIRS. Rounded to four meaningful digits in decimal fraction columns.

PN	Math	MxDMn	IN	CV	HF, %	N1	N2	N3	N4	N5	AIRS	SDNN	AMo	LF, %	VLF, %
1	919.0	450	24.69	9.599	34.34	0	-1	-2	-2	-1	6	88.22	20	38.52	13.80
2	566.5	380	90.11	10.19	25.21	2	-2	0	-2	0	6	57.73	37 ⅔	40.24	11.44
3	649.5	207	169.7	5.452	25.75	2	1	0	0	0	3	35.41	45 ⅔	50.30	13.05
4	710.2	502	26.56	13.99	36.18	1	-2	-1	-2	-1	7	99.35	20	27.14	12.67
5	565.6	445	96.63	12.02	33.79	2	-2	0	-2	-1	7	67.97	43	28.77	11.12
6	730.8	360	71.94	9.066	22.02	1	-1	0	-2	0	4	66.25	33 ⅔	38.11	7.800
7	590.4	256	224.9	8.114	23.35	2	1	1	-2	0	6	47.90	63 ⅓	38.35	17.38
8	688.0	485	33.79	14.69	27.12	1	-2	-1	-2	0	6	101.1	19 ⅔	29.85	18.77
9	758.8	249	101.7	7.045	35.70	1	1	0	-2	-1	5	53.46	38	43.62	13.32
10	761.1	448	35.49	11.90	29.86	1	-1	-1	-2	0	5	90.55	20 ⅔	30.53	21.59
11	792.3	393	40.41	11.77	19.85	1	-1	-1	-2	1	6	93.25	27	41.43	18.20
12	638.5	84	836.6	2.237	21.59	2	0	2	2	0	6	14.28	84 ⅓	49.30	18.74
13	680.7	546	29.65	14.52	28.70	1	-2	-1	-2	0	6	98.81	22 ⅔	37.30	11.43
14	834.2	293	93.86	5.684	40.29	0	1	0	0	-2	3	47.41	44	31.46	12.74
15	560.9	158	304.9	5.127	34.16	2	0	1	0	-1	4	28.75	53	37.48	16.34
16	760.9	381	42.65	12.11	25.08	1	-1	-1	-2	0	5	92.15	26	29.01	16.63
17	696.0	793	28.37	11.22	42.34	1	-2	-1	-2	-2	8	78.07	27	33.84	10.91
18	659.1	281	96.88	9.645	24.48	2	1	0	-2	0	5	63.57	32 ⅔	36.62	16.94
19	567.6	300	174.7	6.244	37.68	2	-1	0	-2	-1	6	35.44	57 ⅔	42.16	8.598
20	1074	1135	6.461	15.88	53.86	-1	-2	-2	-2	-2	9	170.6	14 ⅔	26.09	8.622
21	664.3	683	32.80	13.47	38.76	1	-2	-1	-2	-1	7	89.48	29 ⅓	31.50	12.66
22	664.3	688	32.80	13.47	38.76	1	-2	-1	-2	-1	7	89.48	29 ⅓	31.50	12.66
23	617.5	353	80.26	9.874	47.54	2	-1	0	-2	-2	7	60.97	34	28.97	10.62
24	527.2	576	72.34	12.82	17.51	2	-2	0	-2	1	7	67.60	41 ⅔	41.17	22.99
25	710.7	282	73.45	8.710	25.50	1	1	0	-2	0	4	61.90	29	37.62	26.64
26	790.5	276	90.18	7.233	25.44	1	1	0	-2	0	4	57.17	37 ⅓	48.96	16.36
27	790.9	359	92.85	6.073	42.56	1	-1	0	-2	-2	6	48.03	50	43.12	8.405
28	1043	599	13.41	13.71	24.01	-1	-1	-2	-2	0	6	143.2	17 ⅔	35.65	14.79
29	587.3	224	204.3	5.438	21.82	2	1	1	0	0	4	31.94	50 ⅓	50.20	12.28
30	734.7	353	70.82	7.943	52.04	1	-1	0	-2	-2	6	58.36	35	29.68	7.496
31	579.6	551	95.69	7.750	58.05	2	-2	0	-2	-2	8	44.92	58	31.23	6.294
32	679.0	366	67.96	8.476	48.74	1	-1	0	-2	-2	6	57.55	32 ⅓	28.44	9.361

In Table 1, the 6th, 15th, and 16th data columns express the total weights of the spectral components of the duration variability of the normal RR intervals in percent in the frequency subbands HF, LF, and VLF. Estimates of activity indicators in points are given in columns 7-11. The value of AIRS is in the 12th column.

The results show that the linear ranking of the functional states of the human body in a group of individuals using the AIRS is not provided. The same number of AIRS points is repeated for several persons, although there are significant differences in the initial values of the individual indicators, which contributed to the differentiation of individuals by rank, but are erased when moving to the scoring.

In general, and considering the details, the insertion point of the procedure for ranking a group of persons according to the functional state of the body's regulatory system in the considered algorithm can be the output of the block for forming absolute values of activity indicators. Particularly, before they are converted into points, before leveling the differences important in ranking for the values of indicators in different persons. In the generalized algorithm, this point is the output of block 5. The initial data for the ranking will be the sets of values of the activity indicators for calculating AIRS. The approach, principle and procedures for ranking a group of individuals will be built with a detailed account of the noted features of the indicator sets.

The principle and procedures for ranking a group of persons in the scheme for assessing the functional states of their body according to the indicators of regulatory systems activity

The principle and procedures of ranking are considered for the competitive task of the functional states of the body in a group of individuals, in which each applicant must receive a different rank. The choice of the ranking principle here is decisive in the development of this procedure.

This principle is adequate to such task, if the ranking is systematic and the comparison of states is diverse. Fair decisions are required; the worst indicator for a state of higher rank cannot be worse than the worst indicator of any state of a lower rank. Decisions must be objective. They should be formed in automatic mode without taking into account subjective assessments. Conflict-free ranking decisions are required. There should not be unresolved situations, for example, since in some indicators the state is better, and in others – worse. The approach to decisions must be based on evidence. Rank decisions must be confirmed by irrefutable quantitative indicators.

The key issue in such a case becomes ensuring the unambiguous fair decisions about ranks when using sets of indicators that have a number of features. For their analysis, indicators for calculating AIRS were taken during the examination at rest. Let us consider a summary of the data in Table 2, conditionally assuming them to be normative for the boundaries of the values of indicators in different states for a certain category of persons examined.

Table 2. An example of a characteristic of a set of activity indicators of human regulatory systems for calculating AIRS of various functional states of the body.

A	**Total effect of regulation**	***M, sec***		
+2	Severe tachycardia	< 0,66		
+ 1	Moderate tachycardia	[0,67...0,80]		
0	Normocardia	[0,81...1,00]		
-1	Moderate bradycardia	[1,01...1,20]		
-2	Severe bradycardia	> 1,20		
B	**The function of automatism**	***SD, sec***	***D/M***	***CV, %***
+2	Stable rhythm	< 0,02	< 0,10	< 2,00
+ 1	Severe sinus arrhythmia	>0,10	> 0,30	> 8,00
0	Moderate sinus arrhythmia		[0,11…0,30]	
-1	Moderate automatism disturbance		> 0,45	
-2	Severe automatism disturbance	> 0,11	> 0,60	> 8,00
C	**Vegetative homeostasis**	***D, sec***	***AMo, %***	***SI, c.u.***
+2	Severe sympathetic nervous system (SNS) overload	< 0,06	> 80	> 500
+ 1	Moderate SNS overload	< 0,15	> 50	> 200
0	Vegetative homeostasis retained	[0,15…0,30]	[30…50]	[30…50]
-1	Moderate parasympathetic nervous system (PNS) overload	> 0,30	< 30	< 50
-2	Severe PSNS overload	> 0,50	< 15	< 25
D	**Regulatory stability**		***CV, %***	
+2	Dysregulation		< 3,00	
0	Stable regulation		[3,01...6,00]	
-2	Dysregulation		> 6,00	
E	**Subcortical nerve center (SNC) activity**	***S_2/S, %***	***S_1/S, %***	***S_b/S, %***
+2	Pronounced gain	> 70	> 25	< 5
+ 1	Moderate gain	> 60		< 20
0	Normal activity of SNC	[40…60]		[20…30]
-1	Moderate decrease	< 40		> 30
-2	Pronounced decrease	< 20		> 40

Such features are essential for ranking states by a complex of similar indicators. They have generally accepted definitions. The order of their evaluation according to ECG data is regulated. Interpretation of indicators is standard, but they are heterogeneous in meaning. They have, in general, different dimensions and continuous scales.

These scales and their subranges are different for the norm and dysfunctions of different nature and level that depend on a contingent of individuals.The values of the indicators are used as criteria for ascertaining the norm and dysfunctions.

The regulation is expressed excessively or weakened. There are two types of indicators, dysfunctions can grow with the growth of their values or vice versa. The breakdown of the range of indicator values is similar. The norm interval is in the center and the following intervals are of different sizes. It is bigger for dysfunctions of a greater or lesser degree. Therefore, the indicators cannot be directly combined into a single numerical indicator. After the normative conversion to an integer number of points (0, 1, 2), they express the rate or level of dysfunctions. Numeric values are supplied with a sign ("+" for the values of "hyper-" and "–" for "hypo-"). By their meaning, in all cases the points awarded are penalties.

These features express the conditions in which the ranking principle should be chosen. As a first step in the formation of this principle, an agreement on which ranking result will be considered appropriate is required. Let the best functional state be assigned a higher rank, the worst states will be given the last places in the list. The ranking will be considered correct if the worst indicator of the state of a higher rank is not worse than the worst indicator of any state of a lower rank. The worst indicator of the applicant will be called a key indicator.

Then the applicant with the worst key indicator can be assigned the lowest rank and the other applicants can be dealt with the same way. This is rational, since the worst indicator limits the level of the functional state of the organism as a whole. In particular, if a "breakdown" of a normal state occurs according to one indicator, then the state as a whole cannot be considered normal. Similarly, when detecting various dysfunctions.

Thus, it was advisable to adopt the principle, the main points of which are reflected in Fig. 8. In order to ensure the commensurability of the indicators, which are different in meaning, let us pass in a special way to their relative values in percentages.

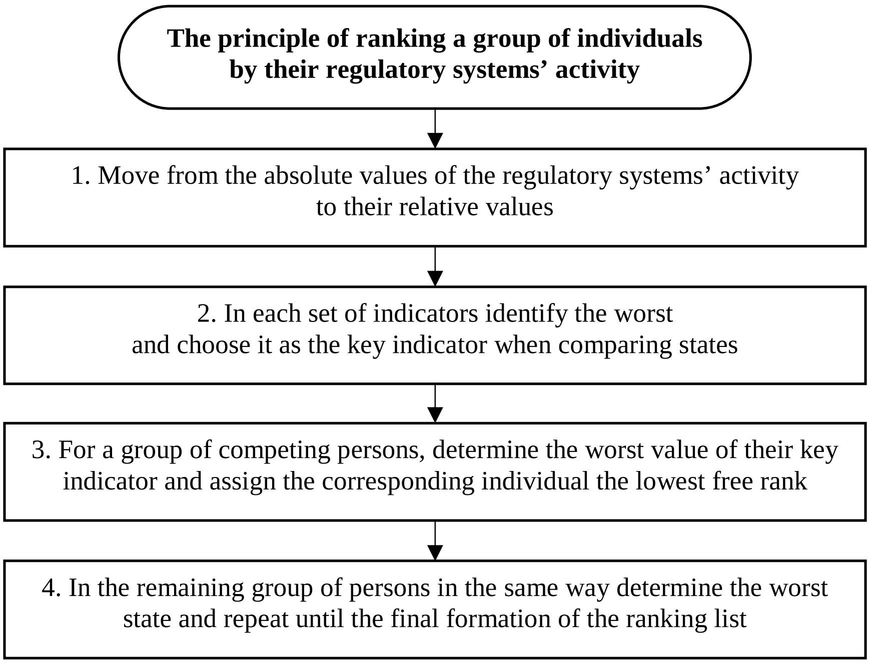

Fig. 8. The main setup of the principle of ranking a group of persons in terms of the regulatory systems activity

The ranking list is formed from the bottom up and the validity of decisions about ranks is maintained. For each person the type of key indicator and the value in percent are determined, which makes all decisions justified. The relative values of the indicators are given a meaning similar to the penalty points when calculating AIRS (Fig. 9).

The greater the departure of the indicator value from the norm, the greater is its relative value. The growth of this indicator value reflects a deterioration of the condition and this can be traced continuously along the entire scale. Full possible departure is taken as 100%. The central point of the norm interval is considered as zero.

There are two worst relative values: +100% and –100% (in the direction of excessive or insufficient regulation). Within the limits of ±100% departures, five subranges are usually being distinguished: norms and two for each (left and right) dysfunction of two levels. On the total range of 200%, lets allocate equally 40% for each subrange, as when charging the integer points for calculating AIRS. The subrange of the norm is divided by the center point in half. As a result, we obtain a piecewise linear characteristic of recalculating absolute values of the indicator into relative values. Two examples of recalculation are shown on the Fig. 9.

For indicators of the second type (higher value means lower activity), the right and left parts of the graph are swapped, and the formulas are adjusted. The proposed procedure for ranking a group of individuals by a complex of heterogeneous indicators of the regulatory systems activity is implemented in the MATLAB environment.

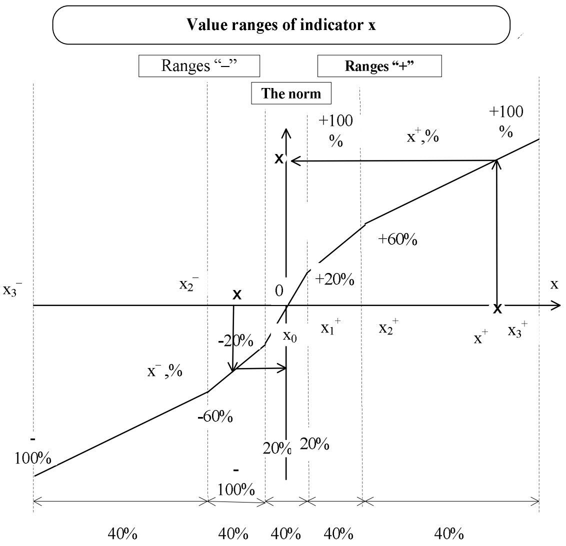

Fig. 9. Piecewise linear characteristic for recalculating the absolute values of the activity index into relative values

Test verification of the ranking procedures of a group of persons according to the functional state of the human body using the activity indicators of regulatory systems

The purpose of the study is to verify the correctness of the implementation of the developed ranking principle and its viability. The processing of complexes of indicators from Table 1 is considered, obtained for a group of persons according to the ECG at rest. The choice of key indicators is shown in Table 3. The results of the ranking with their justification are disclosed in Table 4. For example, the participant at number 4 of the original list occupies the 23rd rank position, its key indicator is SDNN (70.67%). The indicators of all participants of a higher rank is lower (better) than of number 4. All the rest have more (worse) relative indicator values. The analysis of such data shows a positive test result.

A flowchart of the ranking procedure as a whole and a summary of the formulas are presented in Fig. 10.

For the implementation of the procedure, regulatory data on the subrange boundaries of the contingent indicator values of the tested persons and the results of the evaluation of their indicators are required. The ranking will be done automatically.

Similar tables for the subrange boundaries and recalculation characteristics can be obtained (considering the surveyed contingent) for the deviations of the indicators arising from different tests. The ranking procedure remains the same.

Conclusions

1. The principle of a fair linear conflict-free ranking of functional states of the human body for a group of individuals according to the values of sets of activity indicators of regulatory mechanisms, calculated according to data in five-minute ECG records, has been developed.

The ranking decision of the current state of each participant is confirmed by an irrefutable numerical indicator.

2. The validity of the development is confirmed by a test check on real data from a survey of a group of individuals.

The developed software procedures can be used in the problems of improving the hardware and software of systems for assessing the functional states of the human body according to the activity of the regulatory systems.

Conducted studies show the feasibility of further in-depth study of such procedures for their implementation in practice.

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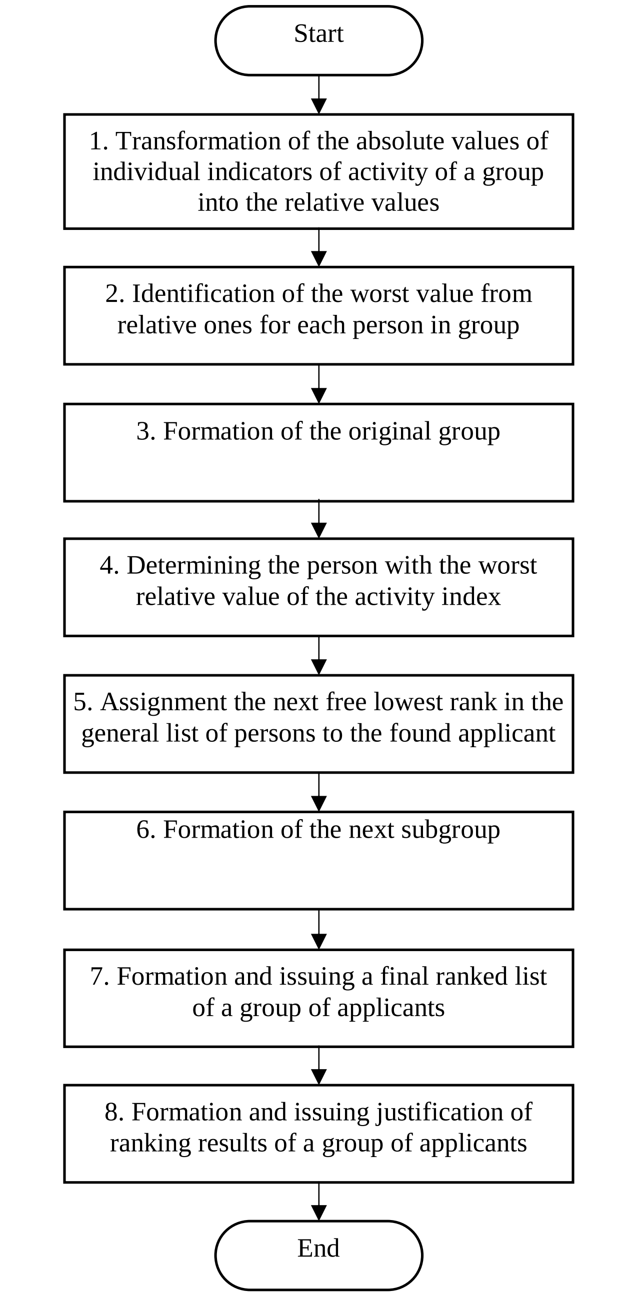

Formula Summary

For the center point:

$$x_0,\% = 0\%;\quad x_0 = \left(x_1^+ - x_1^-\right)/2.$$

For the right part of the characteristic:

$$x_1^+,\% = +20\%;\quad x_2^+,\% = +60\%;\quad x_3^+,\% = +100\%;$$

$$x_0 < x^+ \le x_1^+ \Rightarrow x^+,\% = x_0,\% + \frac{x^+ - x_0}{x_1^+ - x_0}\cdot 20\%;$$

$$x_1^+ < x^+ \le x_2^+ \Rightarrow x^+,\% = x_1^+,\% + \frac{x^+ - x_1^+}{x_2^+ - x_1^+}\cdot 40\%$$

$$x_2^+ < x^+ \le x_3^+ \Rightarrow x^+,\% = x_2^+,\% + \frac{x^+ - x_2^+}{x_3^+ - x_2^+}\cdot 40\%$$

For the left part of the characteristic:

$$x_1^-,\% = -20\%;\quad x_2^-,\% = -60\%;\quad x_3^-,\% = -100\%;$$

$$x_1^- \le x^- < x_0 \Rightarrow x^-,\% = x_0,\% - \frac{x^- - x_0}{x_1^- - x_0}\cdot 20\%;$$

$$x_2^- \le x^- < x_3^- \Rightarrow x^-,\% = x_2^-,\% - \frac{x^- - x_2^-}{x_3^- - x_2^-}\cdot 40\%;$$

$$x_2^- \le x^- < x_3^- \Rightarrow x^-,\% = x_2^-,\% - \frac{x^- - x_2^-}{x_3^- - x_2^-}\cdot 40\%$$

Fig. 10. A flowchart and summary of formulas for the procedure for ranking a group of individuals by a set of heterogeneous indicators of the body’s regulatory systems activity

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УДК 004.67, 611.839

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РАНЖУВАННЯ ФУНКЦІОНАЛЬНИХ СТАНІВ ОРГАНІЗМУ ГРУПИ ОСІБ ЗА ПОКАЗНИКАМИ АКТИВНОСТІ РЕГУЛЯТОРНИХ СИСТЕМ, ЩО ОЦІНЮЮТЬСЯ ЗА ДАНИМИ ЕЛЕКТРОКАРДІОГРАФІЇ

Об'єктом досліджень є технології оцінки функціональних станів організму людини за даними електрокардіографії з використанням показників активності регуляторних систем його організму. Предметом розробок є принцип і процедури ранжування групи осіб за функціональним станом їх організму відповідно до значень показників активності регуляторних механізмів. Показники обчислюються по п'ятихвилинних записах електрокардіограм. Рішення щодо ранжування приймаються одночасно за комплексом різнорідних показників. Не виключаються суперечливі ситуації, коли за одними показниками стан є кращим, за іншими – гіршим. Метою роботи є вдосконалення апаратно-програмного забезпечення діагностичних систем в частині програмних процедур підтримки прийняття рішень щодо порівняльних оцінок функціональних станів людини для групи осіб.
Робота виконана в межах традиційного підходу до оцінки функціональних станів організму людини з використанням того ж складу показників, як і при оцінці інтегрального комплексного показника ПАРС, який використовується в практиці для різнобічної адекватної оцінки станів організму людини в цілому. Процедура ранжування групи осіб розглядається як доповнення до загальної схеми оцінки станів здоров'я людини.
Розробки принципу і процедур ранжування групи осіб, які розкриті в роботі, представлені вперше в такому обсязі. Ранжування конкретної групи осіб наводиться як тестова перевірка запропонованих програмних процедур. Зміст досліджень, підхід до ранжування за показниками активності регуляторних механізмів організму людини розкриваються для обговорення отриманих результатів з метою уточнення пріоритетів і акцентів в подальших розробках з розвитку запропонованого підходу.
Ключові слова: функціональний стан організму людини; показники активності регуляторних систем; апаратно-програмні засоби оцінки; процедури ранжування групи осіб.

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РАНЖИРОВАНИЕ ФУНКЦИОНАЛЬНЫХ СОСТОЯНИЙ ОРГАНИЗМА ГРУППЫ ЛИЦ ПО ПОКАЗАТЕЛЯМ АКТИВНОСТИ РЕГУЛЯТОРНЫХ СИСТЕМ, ОЦЕНИВАЕМЫМ ПО ДАННЫМ ЭЛЕКТРОКАРДИОГРАФИИ

Предлагаются принцип и процедуры ранжирования группы лиц по функциональному состоянию их организма в соответствии со значениями показателей активности регуляторных механизмов. Показатели вычисляются по пятиминутным записям электрокардиограмм. Не исключаются противоречивые ситуации, когда по одним показателям состояние лучше, по другим – хуже. Цель работы – совершенствование аппаратно-программного обеспечения диагностических систем в части программных процедур поддержки принятия решений по сравнительным оценкам функциональных состояний человека для группы лиц.
Работа выполнена в рамках традиционного подхода к оценке функциональных состояний организма человека с использованием того же состава показателей, как и при оценке интегрального комплексного показателя ПАРС.

Разработки принципа и процедур ранжирования группы лиц, раскрытые в работе, представлены в таком объеме впервые. Ранжирование конкретной группы лиц приводится как тестовая проверка предложенных программных процедур.
Ключевые слова: функциональное состояние организма человека; показатели активности регуляторных систем; аппаратно-программные средства оценки; процедуры ранжирования группы лиц.

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ПІДВИЩЕННЯ ІНФОРМАТИВНОСТІ ТЕРМОГРАФІЧНИХ ЗОБРАЖЕНЬ В МЕДИЧНІЙ ПРАКТИЦІ

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В сучасній медицині термографія комплексно застосовується з іншими видами променевої діагностики. Точність діагностування залежить від температурної чутливості термографа та якості термографічного зображення, яке досягається, в тому числі, за рахунок вдосконалення програмного забезпечення. Над вдосконаленням програмного забезпечення працюють практично всі фахівці, які розробляють та використовують в своїй роботі термографічну діагностику. В роботі використовувався вітчизняний охолоджуваний матричний термограф з базовою тестовою програмою для тепловізійної системи "Thermo Visio".

В даній роботі розглядаються питання підвищення якості та розширення можливостей інтерпретації термографічних зображень, які включають: зниження впливу шумів, впливу пошкоджених пікселів, можливість виділення ділянок на термографічних зображеннях з мінімальною та максимальною температурою, отримання осцилографічних розподілів температури в заданих ділянках в реальних значеннях температур, визначення площі патологічної зони, отримання тривимірного зображення та розподіл/у температури по всій поверхні досліджуваного об'єкту.

Розроблено спосіб визначення площі ураженої ділянки та отримання тривимірного зображення з можливістю вимірювати температуру по всій поверхні досліджуваного об'єкту, що значно розширює діагностичні можливості термографічних зображень. Робота з вдосконалення програмного забезпечення буде направлена на подальше підвищення інформативності термографічних зображень. При виконанні термографічних досліджень біологічного об'єкту виникає потреба у визначенні площі ураженої ділянки, що має особливе значення під час операційних втручань.

Впровадження результатів проведеної роботи дозволило підвищити рівень інформативності та якість термографічних зображень.

***Ключові слова**: термограф; діагностика; програмне забезпечення; шуми; термозріз.*

Вступ

Тепловізійна діагностика за останні десятиріччя широко використовується в медичній практиці. Можуть бути застосовані тепловізори 2-х типів: з охолоджувальною та неохолоджувальною матрицею. Тепловізори з неохолоджувальною матрицею мобільні, дозволяють вимірювати температуру в зоні інтересу з точністю до 0,1ºС. В тепловізорах з охолоджувальною матрицею (охолодження рідким азотом) точність вимірювання температури складає (0,07-0,001)ºС, що дозволяє діагностувати захворювання на початкових стадіях. Підвищити інформативність та якість зображення також можливо за рахунок вдосконалення програмного забезпечення. В роботах [1-8] викладені деякі результати наукових досліджень по вирішенню цих задач. Незважаючи на отримані досягнення продовжується робота над подальшим удосконаленням програмного забезпечення. В даний час розробники сучасної тепловізійної апаратури