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A NEW METHOD FOR ESTIMATING THE MOUNTAIN CLIMATE EFFECT ON HEALTHY AND SICK PEOPLE

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Key words: mountain climate effect, mountain sickness and hypoxia, exponential approximation, lipid profile, vegetative support of activity.

Annotation. The algorithms of a new application of the well-known method of mathematical modeling (approximation of empirical data presented in the form of time series, with a specially selected exponential expression) for assessing the mountain climate effect on the level of lipoproteins and vegetative support of muscle activity are described. The possibilities of applying the new method in other areas of rehabilitation and sports medicine and, more broadly, in the physiology of adaptation are discussed.

Introduction. Mountain climate effect is used in therapy and rehabilitation of a wide range of diseases and varies both in altitude (mountain sickness) and in the level of physical activity on different altitudes (combination of mountain sickness and hypoxia) [1-3]. Modern methods of the evidence-based medicine centered around probability estimations require a long-term gathering of a big amount of empirical data with a minimal heterogeneity, which is hardly achievable for mountain climate treatment exactly due to its high variability and combinations of factors of different intensity (thin clear air, ultraviolet, physical loads, cold etc.) [4-5].

Moreover, probability and statistical methods, including calculation of linear correlation coefficients according to Pearson or Spearman, do not allow evaluating such important parameters of a therapeutic effect as, for example, the rate of achieving key characteristics of homeostasis, which is an objective counterpart of health. It is also known that approximations of time series using linear functions in the course of increasing or decreasing variable often give inadequate results, i.e. infinite increases of substance concentrations or negative pressure values in case of their linear decrease. In order to avoid such errors (i.e. “bad infinity”), researchers use methods of approximating time series of empirical data using non-linear functions. Approximations of empirical data using the exponential function are often used in the biomedical field [6]. That is the reason the purpose of this study is to review two successful applications of exponential approximation to conduct a comparative analysis of the mountain climate effect on the blood lipid profile and vegetative support of muscle activity [7-8].

Methods and organization. Empirical data on changes in the blood lipid profile and vegetative support of muscle activity was gathered during annual scientific and research expeditions "Himalayas 2009-2018" within the author project of Irina Arkhipova "Searching for lost knowledge" (c), aimed at supporting national science. Examinations of participants who were recruited in the format of Citizen Science took place before, during and after staying at the Himalayas' middle altitude (Kullu valley, Himachal Pradesh, India), at an altitude of 2000 to 3500 meters above sea level. Blood collection for identifying the standard lipid profile was taken in 16 participants of both genders in the fasted state before and after their one-week stay in the "Himalayas 2009" expedition. We also used the data of other authors of mountain climate treatment of dislipoproteinemia, as well as the data of periodical hypobaric therapy that matched the stay of participants at given altitudes.

Vegetative support of muscle activity was studied in "Himalayas 2016 and 2017" expeditions, in which participants of both genders (n=13) performed gradually increasing echocardiographic load tests before and after staying at the Himalayas' middle altitude (the same spot).

The Ethics committee of the Saint Petersburg State University (IRB00003875 – № 67, e-mail: irb@spbu.ru) approved the research. All participants signed an informed consent and answered all questions asked by the researchers.

Statistical processing and exponential approximation was performed using Fisher's methods of least square and maximum likelihood, implemented in OriginPro 2019b (c) and Derive 5.05 (c) mathematical programs.

Results and discussion. To compare the rate of antiaterogenic changes, we used following calculation algorhythm, following one of well-known usages of integral calculus [9]:

1. According to results of averaged changes of the lipid profile's numeric values before, during and after staying in various conditions of reduced barometric pressure using the least square method (LSM), we performed the exponential approximation of changes in total cholesterol and cholesterol in high and low density lipoproteins using a following expression:

$X(t) = Ce^{kt}$ (1),

where X – a number of lipids, t – time, k and C – coefficients found by using the LSM.

2. To compare the rate of changes, we noted the first variable, physical meaning of which is the rate of the aforementioned expression.

3. Then we calculated a square of a certain integral of the first variable of the expression (1) with limits of integration of 0 to 29 (according to maximum duration of staying for 30 days from four compared options – Pyatigorsk resort, Kyrgyzstan resorts, hypobaric therapy and the Himalayas expeditions):

$$\left(\int_0^{29} Cke^{kt}\, dt\right)^2$$

In order to give full information, we present a summary table (table 1) of exponential models [7]:

Table 1

Summary table of exponential models of the Ce^{kt} type for changes of the total cholesterol, cholesterol of high-density (HDL) and low-density lipoproteins (LDL) (columns 2, 4, 6) and calculated numeric values of squares of specific intervals from their first variables in time with integration limits of 0 to 29 (days) $\left(\int_0^{29} Cke^{kt}\, dt\right)^2$ (colums 3, 5, 7)

№	Total cholesterol		HDL cholesterol		LDL cholesterol	
1	2	3	4	5	6	7
1	$297.1\,e^{-0.004t}$	1285				
2	$241.1\,e^{-0.002t}$	146	$37.5\,e^{0.0045t}$	27.1	$161\,e^{-0.001t}$	24.3
3	$204.2\,e^{-0.003t}$	275	$49.4\,e^{0.003t}$	17	$142.8\,e^{-0.005t}$	344
4	$\mathbf{190.8\,e^{-0.01t}}$	**2902**	$\mathbf{34.3\,e^{0.02t}}$	**702**	$\mathbf{131.8\,e^{-0.016t}}$	**2480**

Contents of the table 1 serve as an evidence for the fact that combination of the mountain sickness, moderate physical loads and regular exposure to cold (4th row is the “Himalayas 2009” expedition) supports with the highest rate of the total cholesterol’s decrease, increase of the HDL cholesterol level and decrease of the LDL cholesterol level, which significantly exceeds changes in the lipid profile associated only with the mountain sickness (1st and 2nd rows – Pyatigorsk and Kyrgyzstan resorts) and adaptation to the hypobaric hypoxia (3rd row).

We applied the same algorhythm to evaluate vegetative support of muscle activity before and after staying at an altitude of 2000-3700 m above sea level according to results of graduated load tests on the stationary bicycle [8]:

1. Based on results of direct measurements of blood pressure and pulse performed at each stage of the load test, we calculated pointwise values of the Kerdo index using the following expression:

$$V = 1 - \frac{dBP}{HR} \quad (2),$$

where dBp – diastolic blood pressure (mm of Hg), HR – heart rate (beats/min) [10].

2. Approximation with a suitable exponential expression $V(t)=A_1-A_2\cdot e^{-kt}$ with a subsequent quantitative assessment of vegetative control of the activity produced by the organism in case of standardized load tests before and after staying at a middle altitude was carried out using the Fisher’s maximum likelihood method.

3. In order to compare vegetative control of the activity before and after the stay in middle altitude, we calculated a ratio of areas (integrals) of founded approximating exponentials on equal time intervals. Integration limits were set according to a shorter duration of the load test (in seconds), i.e. before staying at a middle altitude.

Table 2

Integral evaluation of vegetative control of the activity in the experimental group (51) when performing the standardized load test before and after staying at a middle altitude

1	2	3	4	5	6		7	6
Date	Time, s	dBP, mm of Hg	HR, beats/min	Kerdo index	Coefficients of approximating exponential of the $V(t)=A_1-A_2\cdot e^{-kt}$ equation		Integral evaluation of vegetative control before (S_1) and after (S_2) staying at a middle altitude	S_1/S_2
20.04.2017	0	60	57	-0,05			$S_1=\int_0^{384} V(t)dt \approx 146,4$	≈1,6
	85	60	94	0,36				
	187	70	112	0,38	A_1	0,46306		
	271	70	125	0,44	A_2	0,51195		
	302	70	129	0,46	k	0,01624		
	384	70	146	0,52	p	0,00155		
11.05.2017	0	80	55	-0,45			$S_2=\int_0^{384} V(t)dt \approx 128,5$	
	87	80	97	0,18				
	189	80	110	0,27	A_1	0,39181		
	270	80	120	0,33	A_2	0,84068		
	332	80	134	0,40	k	0,01388		
	404	80	142	0,44	p	0,00219		

Note: dBP – diastolic blood pressure; HR – heart rate; A_1, A_2, k – approximating exponential coefficients; p – approximation significance according to the Fisher-Snedecor criterion, S_1 и S_2 – computational integrals (areas under the curve) in equal time intervals before and after staying in the mountains

In order to give full information, we present an example of integral evaluation of successful adaptation to altitude after one-week stay at an altitude of 2000-3700 above sea (table 2 and fig. 1).

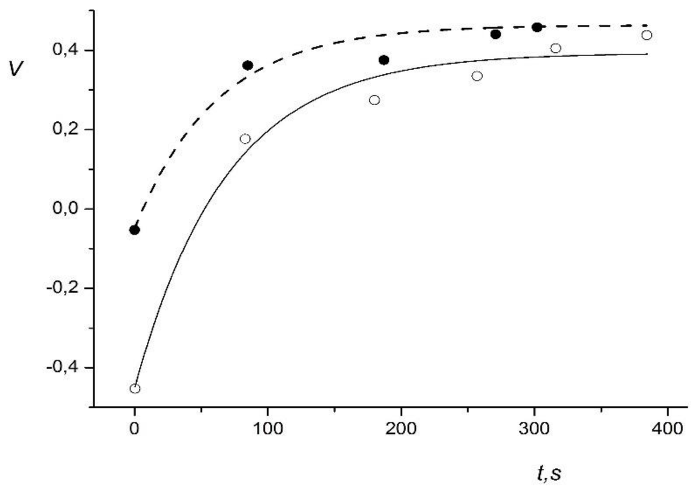

Fig. 1. Graphic interpretation of vegetative support of the activity when performing load tests by the experimental group (51) before and after staying at middle altitude

Note: X-axis – time (t) in seconds, Y-axis – the Kerdo index (V);
● initial values of the Kerdo index, revealed in case of performing the load test before staying at middle altitude;
- - - - approximating exponential before staying at middle altitude;
○ the Kerdo index values, revealed in case of performing the load test after staying at middle altitude;
——approximating exponential after staying at middle altitude.

The revealed ratio of areas – 1,6 (6th row of the table 2) shows that the vegetative support of physical activity of the experimental group after staying at an altitude shifted towards a decrease of sympathetic effects, which means that physiological value of a load (its ergotropic component) has reduced. On the fig.1 a decrease of the sympathetic tone is illustrated through the fact that the exponential that approximates pointwise assessments of the vegetative tone during standardized load test before staying at an altitude is located higher than the exponential that approximates results of the vegetative tone of the same load test after staying on the mountains. Moreover, despite the fact that in all participatns who stayed at an altitude a time of achieving the submaximum (85%) HR as a response to the load test increased, as well as the maximal oxygen consumption, the vegetative control revealed opposite tendencies in healthy people and in people with cardiovascular pathologies. Results of the integral evaluation of the exponential approximation of the load test vegetative control show that after staying at an altitude of 2000-3700 m above sea level, adaptation (an adequate vegetative support of the activity) to loads occurred only in 10 of 13 participants, whose area under the corresponding exponential reduced after returning from the altitude of 200-3700 m.

Using the new method of the integral assessment of the activity with the Kerdo index contributed to revealing this regularity of the vegetative control as a response to physical loads. Matching measurements of blood pressure and heart rate to pointwise moments of time in case of the standardized load test allowed carrying out an adequate exponential approximation with a subsequent comparison of the discovered analytical expressions of the vegetative control before and after staying at an altitude.

Conclusion. Using the exponential approximation to empirical data presented as time series allows gathering an additional physiological and/or clinically significant information, such as the speed of changes in examined characteristics or the physiological value of adaptation, which can be applied not only when evaluating the mountain climate treatment, but also in other fields of rehabilitation medicine, sports medicine and adaptation physiology.

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