DOI 10.1007/s10527-018-9784-1
*Biomedical Engineering, Vol. 52, No. 1, May, 2018, pp. 68-71. Translated from Meditsinskaya Tekhnika, Vol. 52, No. 1, Jan.-Feb., 2018, pp. 50-53.
Original article submitted June 26, 2017.*

Prognosis of Recurrent Myocardial Infarction Based on Shortliffe Fuzzy Models Using the Electrical Characteristics of Biologically Active Points

N. A. Korenevskiy[1]*, S. P. Seregin[1], V. A. Ivanov[2], A. I. Kolesnik[3], G. V. Siplivy[3], K. F. Makkonen[4], V. V. Dmitrieva[5], D. I. Kicha[6], and D. A. Zubarev[1]

This report discusses the employment of the electrical characteristics of biologically active points (BAP) in the meridian of the heart to solve the task of prognosticating recurrence of myocardial infarctions during the rehabilitation period using fuzzy decision rules. Employment of only the electrical characteristics of informative BAP was found to provide a reliability level of greater than 0.85 in decision-making, with a significant uncertainty zone. If additional features characterizing long-term psychoemotional tension – lipid peroxidation and antioxidant activity – are included, the reliability of prognoses of recurrence of myocardial infarction during remission reaches 0.95.

Introduction

Studies by researchers of different scientific schools have shown that reflex diagnosis may provide an approach to the prognostication and early diagnosis of diseases, including diseases of the heart and cardiovascular system; these are based on measurement of the electrical properties of biologically active points (BAP) [1-5]. One advantage of reflex diagnosis methods is that the responses of biologically active points to changes in the internal structures of the body occur before clinical symptoms of disease are manifest. This provides for the detection and treatment of diseases at their earliest stages of development and, sometimes, their prevention by application of prophylactic measures. The medical-technical and time costs of organizing investigations are significantly lower than those of conventional approaches [2, 6].

In tasks in which the information value of BAP is insufficient for the accuracy required, this can be obtained using various signs used in conventional medicine aggregated into a final decision rule using hybrid fuzzy models, the general theory of whose construction has been laid out in [3, 7, 8].

The total cost of achieving the necessary prognostic and diagnostic accuracy is generally lower than when standard study methods are used.

Methods

One of the most important tasks in constructing decision-making models is that of selecting informative properties, particularly informative BAP.

The procedure of selecting informative BAP will be more effective if the characteristics of the production of information on the state of the body's internal structures at these points are considered. These characteristics include the production of large amounts of information at one point (multiple diagnoses, symptoms, syndromes); cyclic changes in the energy status of BAP during the day even in conditions of normal energy balance along meridians; the large volume of data required for analysis if the

[1] Southwest State University, Kursk, Russia; E-mail: kstu-bmi@yandex.ru
[2] Kursk State University, Kursk, Russia.
[3] Kursk State Medical University, Kursk, Russia.
[4] Belgorod State University, Belgorod, Russia.
[5] National Research Nuclear University MEPhI, Moscow, Russia.
[6] Peoples' Friendship University of Russia, Moscow, Russia.
* To whom correspondence should be addressed.

pathology is not already known [1-3]. These properties of the information available at a BAP hinder the procedure of selecting the informative points in studies using conventional methods of information theory and image recognition theory.

Considering the characteristics of the presentation of information on the state of the human body at biologically active points, reports [2, 3] propose methods and algorithms for finding combinations of BAP whose analysis confirms the situation being studied (the diagnosis) and rejects "interfering" situations "displayed" at BAP on the basis of reference data but not present in the subject. These combinations are termed diagnostically significant points (DSP) [2], 3].

Specially conducted studies on the prognostication and early and differential diagnosis of diseases of the cardiovascular system, gastrointestinal tract, nervous system, musculoskeletal system, respiratory system, and others have shown that the use of DSP in combination with other informative properties allows decision rules providing high classification quality to be developed [2, 3].

Considering the recommendations in [2, 5], the energy characteristics of BAP were taken as their electrical resistance measured using a 1-kHz alternating current at a current intensity of no greater than 10 μA [2, 5]. These studies showed that interval assessment of resistance $\Delta R_{j,k}$ giving the upper and lower boundaries of resistance for interval k for point j and the relative deviations of ongoing values of the resistance of BAP R_j from nominal values are highly informative.

Experience in solving a variety of prognostication and diagnostic tasks using information on the energy status of BAP has shown that the properties measured are incomplete and unclear in relation to the tasks being addressed. In these conditions, following recommendations in [3, 7, 8] led to determination of a fuzzy logic for decision-making and, in particular, the authors' development of a method of constructing sets of hybrid fuzzy decision rules.

In this study, working with the recommendations in [3, 8], the prognostication task was evaluated as a classification task with two classes: 1) the subject is not going to fall ill in the next T years (class ω_0); 2) the subject will fall ill in the next T years (class ω_l).

For selection of informative biologically active points and other informative parameters, highly qualified experts worked on those which, when recorded, increased confidence in the validity of the test hypothesis (disease, ω_l). In these conditions, according to recommendations in [3, 4, 9], the starting formula for calculating the confidence coefficient (CC) of decision-making in relation to hypothesis ω_l should be the Shortliffe cumulative iterative formula:

$$CC_{\omega l}(i + 1) = CC_{\omega l}(i) + CC^*_{\omega l}(x_{i+l})[1 - CC_{\omega l}(i)], \quad (1)$$

where $CC_{\omega l}(i)$ is the coefficient of confidence in hypothesis ω_l with the condition that verification of the hypothesis has already involved i informative properties; $CC^*_{\omega l}(x_{i+l})$ is the coefficient of confidence in diagnosis (prognosis) ω_l using only one property x_{i+l}; $CC_{\omega l}(1) = CC^*_{\omega l}(x_1)$.

In a number of applications, including the task addressed in the present study, the coefficient of confidence can conveniently be calculated using the membership function $\mu_{\omega l}(x_{i+l})$ for the class ω_l calculated for the starting variable (x_{i+l}) [2-4].

The prognostic confidence in the values of the interval assessments (ranges of resistances) $\Delta R_{j,k}$ (where j is the number of the BAP and k is the number of the range ΔR_j) is the basis forming the diagnostic assessment and is calculated by transformation of Eq. (1) into

$$CC_{\omega l}(j + 1) = CC_{\omega l}(j) + CC^*_{\omega l}(\Delta R_{j+l,k})[1 - CC_{\omega l}(j)], \quad (2)$$

The technical means for recording BAP resistance consisted of a computer device exchanging data with the PC via Bluetooth. The device operates in two modes: search mode using sound, light, and graphical recording of BAP and measuring mode at a frequency of 1 kHz at a current of 5 μA.

A version of the technical implementation of the device is described in [6].

Results

At the first stage of the study, an atlas of meridians described in [1] was used to select a list of BAP related to diseases of the cardiovascular system, from which, on the basis of recommendations in [1, 5], BAP associated with the cardiac meridian (C1-C9) were used to determine the risk of developing myocardial infarction (MI). The sympathetic heart meridian V15 and ear points AP19, AP21, AP60, AP100, AP105, and AO115 were excluded because of low informativeness and the inconvenience of measuring their characteristics.

A total of 40 patients with MI were observed. Observations of changes in patients' status were made over the period of a year. The study groups included people with increases in the energy characteristics of the major points of the heart meridian. The energy characteristics of BAP were monitored monthly. People showing at least a small increase in the resistance of the major BAP

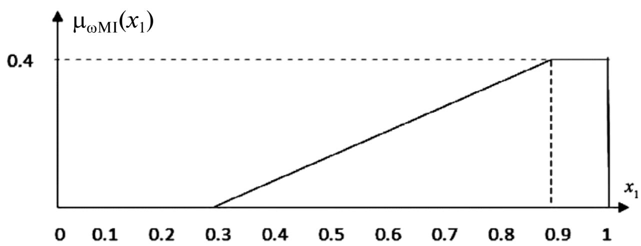

Fig. 1. Plot of ω_{MI} membership function for the basic variable x_1.

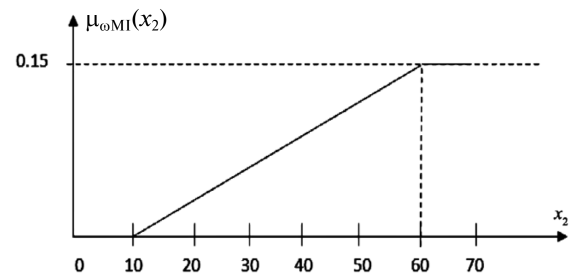

Fig. 2. Plot of ω_{MI} membership function for the basic variable x_2.

(more than 10% of nominal) without therapeutic or healthcare measures were assigned to the class of patients with high risk of onset and development of recurrent MI. At the end of the one-year observation period, 94% of subjects showed the initial clinical signs of deterioration in the activity of the cardiovascular system [4].

At the second stage of the study, the Kullback measure of informativeness was determined with a system of graduated features, as described in [2, 5].

Kullback analysis of informativeness allowed selection of six BAP for decision rule (2) from the overall list: C4, C6, C7, C8, and C9 (point numbers as described in [1]).

Our statistical studies showed that the system of graduations described in [5] worked adequately for identifying cardiac and cardiovascular system pathology. In the tasks of prognosticating MI, as demonstrated by the corresponding statistical studies, this graduation was very rough, not providing the required quality of decision-making.

Considering this, the gradation system was modified as follows: >500 kΩ – 0; 400-500 kΩ – 1; 300-399 kΩ – 2; 200-299 kΩ – 3; 100-199 kΩ – 4; 90-99 kΩ – 5; 80-89 kΩ – 6; 70-79 kΩ – 7; 60-69 kΩ – 8; 50-59 kΩ – 9; 40-49 kΩ – 10; <40 kΩ – 11.

The unevenness in the graduated scale is due to different information values in relation to the classification of the states under study.

Data from one year of studying patients with acute myocardial infarction undergoing rehabilitation in medical institutions in Kursk were used to construct a table of coefficients of confidence (CC_{jr}) for each of the BAP recorded (j is the number of the BAP and r is the number of the gradation) (Table 1). The table is based on distribution histograms of gradations of features in terms of the class ω_{MI}. In constructing the table, the recommendations in [2, 3] were taken into account.

These coefficients determine the prognostic ability of each BAP electrical resistance gradation in relation to the possible occurrence of the target class of diseases.

The overall confidence that a recurrence of MI will occur is determined by Eq. (2). Analysis of the data presented in Table 1 shows that a drop in BAP resistance to below 60 kΩ provides a reliable ($CC_{MI} > 0.92$) prognosis of the occurrence of recurrent myocardial infarction.

For the range 60-90 kΩ, there is a zone of indeterminacy in decision-making which could be significantly decreased by using additional informative features.

In the present study, the following were selected at the expert level: the level of long-term psychoemotional tension – x_1, antioxidant activity – x_2, and lipid peroxidation – x_3.

The level of long-term psychoemotional tension was determined as described in [2, 3]. Properties x_2 and x_3

TABLE 1. Prognostic Table for the ω_{MI} Class

BAP	Resistance ranges, kΩ											
	>500	400-500	300-399	200-299	100-299	90-99	80-89	70-79	60-69	50-59	40-49	<40
C*9	0	0	0	0	0	0.2	0.4	0.5	0.6	0.7	0.9	0.95
C*7	0	0	0	0	0.1	0.3	0.5	0.6	0.7	0.8	0.9	0.95
C8	0	0	0	0	0	0	0	0.2	0.3	0.5	0.8	0.95
C4	0	0	0	0.1	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2
C6	0	0	0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3

* BAP forming groups of features excluding all "interfering" situations (DSP BAP).

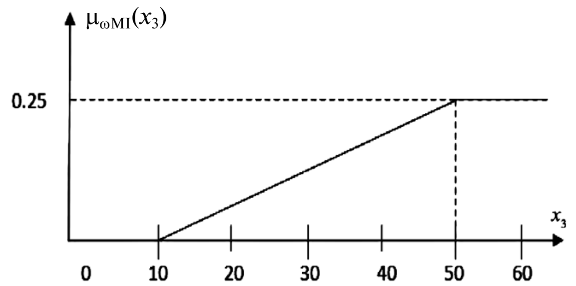

Fig. 3. Plot of ω_{MI} membership function for the basic variable x_3.

were measured by conventional laboratory analytical methods.

Using the recommendations described in [2-4], membership functions $\mu\omega_{MI}(x_j)$ were constructed to relate x_1, x_2, and x_3 to the class of "high risk of developing myocardial infarction (ω_{MI}) during remission." A plot of the membership function $\mu_{\omega MI}(x_2)$ is shown in Fig. 1.

Features x_2 and x_3 were determined, as recommended in [4], by

$$x_2 = \frac{x_A^H - x_A^T}{x_A^H} \cdot 100\%; \; x_3 = \frac{x_P^H - x_P^T}{x_P^H} \cdot 100\%,$$

where x_P^H and x_A^H are lipid peroxidation and antioxidant activity measured in a representative group of healthy subjects, and $x_P^T = x_{19}$ and $x_A^T = x_{20}$ are lipid peroxidation and antioxidant activity in the test patient.

Plots of the corresponding membership functions are shown in Figs. 2 and 3.

The final confidence that the subject will develop myocardial infarction is determined by Eq. (1), in which

$CC_{\omega MI}(1) = CC_{\omega l}$, determined by Eq. (2);
$CC^*_{\omega MI}(2) = \mu_{\omega MI}(x_1)$;
$CC^*_{\omega MI}(3) = \mu_{\omega MI}(x_2)$;
$CC_{\omega MI}(4) = \mu_{\omega MI}(x_3)$.

Results from mathematical modeling and statistical calculations for representative control cohorts showed that use of all four components gave a level of confidence in the correct prognosis of the occurrence of myocardial infarction during remission of 0.95.

REFERENCES

1. Luvsan, G., Tradition and Current Aspects of Eastern Reflex Therapy [in Russian], Nauka, Moscow (1986).
2. Korenevskiy, N. A., Krupchatnikov, R. A., and Al'-Kasasbekh, R. T., Theoretical Grounds for the Biophysics of Acupuncture with Applications to Medicine, Psychology, and Ecology Based on Fuzzy Network Models. A Monograph [in Russian], TNT, Staryi Oskol (2013).
3. Korenevskiy, N. A., Shutkin, A. N., Gorbatenko, S. A., and Serebrovskii, V. I., Assessment and Control of the State of Health in Students Based on Hybrid intelligent Technologies. A Monograph [in Russian], TNT, Staryi Oskol (2016).
4. Seregin, S. P., Vorob'eva, O. M., and Korenevskaya, S. N., Mathematical Models for the Prognostication and Prophylaxis of Recurrent Myocardial Infarction during the Rehabilitation Period. A Monograph [in Russian], N. A. Korenevskiy (scientific editor), Southwest State University, Kursk (2015).
5. Portnov, F. P., Electropuncture Reflex Therapy [in Russian], Zinante, Riga (1980).
6. Korenevskiy, N. A., Mukhataev, Yu. B., Startsev, E. A., and Lazurina, L. P., "A multichannel analyzer of the meridional structures of the body based on AFE analog interfaces," Med. Tekh., No. 6, 28-31 (2016).
7. Korenevskiy, N. A., "The use of fuzzy decision-making logic for medical expert systems," Med. Tekh., No. 1, 33-35 (2015).
8. Korenevskiy, N. A., "A method for constructing heterogeneous fuzzy rules for the analysis and control of the state of biotechnical systems," Med. Priborostr., No. 2, 99-103 (2013).