Formation of descriptors for medical risk classifiers based on the current-voltage characteristics of biologically active points

A V Miroshnikov 1, A V Kiselev 1, O V Shatalova 1 and Sofiya Kadyrova 1

1 Southwest State University, 94, st. 50 years of October, Kursk, 305040, Russia

E-mail: Shatolg@mail.ru

Abstract. Diagnosis of many diseases can be achieved using the electrical response of bioactive points on patient’s body. Predictions are made by analyzing the electrical response of patients’ biologically active points. To analyze the impact on the organ, values of the current strength in the organ were measured and the changes of the passive electrical properties on selected bioactive locations on the body. The research goal is to develop a classification neural network model to predict post-surgery complication risk for prostate surgery. The obtained current-voltage characteristics is used as input in the classification artificial neural network model that predicts two classes. The dataset involves medical information of 120 patients diagnosed with prostate disease. Descriptors are composed of the analysis of five current-voltage characteristics. Neural network classifiers prediction shows a high capacity to predict critical conditions. The developed model is valuable because it can be used in beepers for prenosological diagnosis of infectious diseases. The 3 BAP models using I – Taiyuang, IX – Daling, and V – Shenmen configuration produced the highest accuracy. The accuracy of the classifier ranged from 80% to 82%.

1. Introduction

In this work, we use the effect of rotation of the current-voltage characteristic in the BAP. This is more accurate than BAP alone because the changes in the electrical conductivity in the BAP are not fixed from some nominal value, it is not known how they were received, but with respect to the resistance of an individual patient. The functional state of a person is determined by the intensity of this rotation. The rotation of the current-voltage characteristic is a decrease in the electrical resistance in the BAP due to the action of a probing (test) current on it.

Today, several researchers investigate the monitoring of the pearson's functional state (FS) which depends on various exogenous and endogenous factors. It is possible to monitor a health status using various wearable devices - beepers that can not only store but also analyze data about the FS of a particular patient. The most universal and most affordable means of obtaining information about the current state of the body include the energy characteristics of biologically active points (BAPs) [1, 2].

For diagnosing many diseases, the parameters of the body tissue composition of certain areas are of great interest as they have a significant impact on their electrical characteristics. Studies of electrical conductivity in anomalous areas - BAPs are of a particular influence. However, electrical conductivity of a biomaterial in BAPs is influenced by many changing factors, so it is advisable to use statistical methods to measure these parameters [3]. Thus, one of the disadvantages of BAP energy indicators is their high sensitivity to changes of uncontrolled exogenous and endogenous factors and, as a result, a
high dynamic range of background values of these indicators. Therefore, the main direction to improve the methods of FS control based on BAPs energy indicators is using relative values.

We normalize original signal of absolute values of the measured parameter. Normalization is conducted based on statistical indicators or selected scales (for example, by maximum deviation). However, in the case of BAPs, the use of such normalization schemes is impossible due to the dependence of statistical data not only on the state of the exogenous and endogenous environment, but also on the features of the individual’s body type.

2. Methods
We applied normalization approach based on the control of dynamics of BAP energy characteristics in the process of periodic controlled BAP exposure to an exogenous factor. One of the ways to analyze the diagnostic value of the electrical conductivity of BAPs is to study its current-voltage characteristic, followed by obtaining characteristic points whose coordinates can be used to obtain descriptors for classifying models. To determine these characteristic points, a model of a BAP current-voltage characteristic is required. Bipolar current pulses with an amplitude varying from zero to the limit value determined by pain and heat thresholds were used to construct the BAP current-voltage characteristic (CVC) [4].

A current-voltage characteristic model can be constructed either based on the phenomenological approach on the basis of a mathematical or homeostatic model of the description of the experimentally obtained data about the object of the study, either on the basis of the heuristic approach when constructing the model expert’s knowledge (observations) on the functioning of the object under study is used. Thus, it is possible to construct two types of parametric models in which descriptors are used as parameters – independent variables, and data obtained experimentally characterizing the properties of the biomaterial under certain conditions are used as dependent variables. Taking into account the fact that the nature of the data obtained as a result of experimental studies depends on rather a small group of factors (latent variables), a successful model construction will significantly simplify the solution of the problem of constructing a classifying model.

A specific feature of BAP current-voltage characteristic is the mismatch of the characteristics of the first and second pass. Moreover, the characteristic of the second pass always lies above the characteristic of the first pass regardless of whether the first pass begins with + Umax or with - Umax. If the process of exposure to bipolar current pulses is considered in dynamics, then it is possible to observe the rotation of the current-voltage characteristics counterclockwise, which characterizes their motion towards approaching the ordinate axis. This motion effect is shown in Figure 1.

**Figure 1.** BAP current-voltage characteristics under cyclic effect of current of different polarities
The green branch of the current-voltage characteristic corresponds to the voltage change on the biomaterial from $-U_{\text{max}}$ to $+U_{\text{max}}$ (the first pass), and the red branch - from $+U_{\text{max}}$ to $-U_{\text{max}}$ (the second pass). Therefore, such current-voltage characteristic is called a two-pass characteristic.

The definition of descriptors intended for classifying the functional state of a person is carried out by obtaining a continuum of reversible BAP CVCs [5, 6, 7, 8]. Descriptors are formed from pairs of vectors, each pair of vectors corresponds to an informative abscissa, examples of which are presented in Figure 2. The number of informative abscesses and their coordinates are selected empirically.

![Figure 2](image)

**Figure 2.** Visualization of the process of determining the points of CVC to form a space of informative features

Figure 2 shows the points of CVC that form a space of informative features: $a_i$ are the coordinates of the abscissa axis of the positive part of the ascending and descending branches of CVC corresponding to the ordinate $I_2$, $b_j$ are the coordinates of the abscissa axis of the positive part of the ascending and descending branches of CVC, corresponding to the ordinate $I_2$.

The components of the vectors correspond to the points of CVCs lying on the informative abscissa in such a way that the first vector corresponds to points of intersection of the abscissa with the ascending branches of the current-voltage characteristics, and the second one - with the descending branches of the current-voltage characteristics. The components of the vector are defined as follows:

$$
\Delta R_i = \left(\frac{R_{i+1} - R_i}{R_i}\right) \cdot 100
$$

$$
\Delta R_j = \left(\frac{R_{j+1} - R_j}{R_j}\right) \cdot 100
$$

where $i=0...n$, $j=0...n$, $n$ is the number of digitized points on one CVC, $\Delta R_i$ is the resistance of the positive part of the ascending and descending branches of CVC corresponding to ordinate $I_1$, $\Delta R_j$ is the resistance of the positive part of the ascending and descending branches of CVC corresponding to the ordinate $I_2$.

3. Results

An automated system (AS) consisting of a data acquisition device (DAD) connected to a personal computer (PC); an interface device (ID) and appropriate software, was used to experimentally obtain
the current-voltage characteristics of a BAP. The E20-10 L-Card was used as a DAD. In all modes, an experimental setup is used as an ID, its flowchart is provided in Figure 3.

Figure 3. ID flowchart for the automated system for a BAP conductivity study.

Current measurement in the biological object is performed using a current resistor R5, an instrumentation amplifier (IA), and an analog-to-digital converter (ADC) which is a part of the DAD. R5 resistance rating at a given maximum current through the biomaterial determines the gain of the IA. If the maximum current through the bio-object is 50 µa, and R5=1 kOhm, then at the dynamic range at the ADC input ±3 V, IA gain will be 60. The analysis of this diagram (Figure 3) shows that as the duration of exposure to bipolar pulses on the biomaterial increases, the resistance of the biomaterial decreases, which leads to the saturation of the IA.

In order to verify the proposed models of the formation of descriptors, the quality indicators of the classification of neural network classifiers of the risk of surgical treatment were studied. The problem of predicting the risk of complications from surgery of benign prostatic hyperplasia was considered as a diagnostic problem. Each patient after hospitalization was subjected to full laboratory and clinical tests. Then descriptors were determined for each patient according to the proposed method. After obtaining a database of learning samples, informative features were interpreted by neural network classifiers to determine medical risk. During diagnostics, five complete I–V characteristic cycles were taken from each BAP for information abscissas I1 = 20 mA and I2 = -20 mA. The values of descriptors were found by formulas (1), (2).

For each patient, the current-voltage characteristics of BAP of three meridians were obtained: heart meridian - C 7, lung meridian - P9, and pericardial meridian - MS7 [7, 8, 9]. For the synthesis of classifiers, a space of informative features was formed. For predicting complications in the prostate surgery in case one BAP is used, the feature space will comprise 9 components, and for 3 BAPs – 27 components.

Based on the studies of 120 patients, among which 62 patients were successfully operated (Class C1), 30 had various complications after surgery (Class C2), 28 patients required additional treatment (Class C3), a training set including learning and check samples for three selected classes was formed.
The efficiency of the proposed method was analyzed by means of studying and comparing the indicators of medical risk prediction with models with different numbers of agents at the lower level (with a different number of analyzed BAPs). Software "Neurowork" developed at the Department of Biomedical Engineering of SWSU performed in MATLAB environment was used for the implementation of neural network models of classifiers [10, 11, 12].

The following parameters were used as estimate indicators of the quality of diagnostic decision rules: diagnostic sensitivity (DS), diagnostic specificity (DSp), diagnostic efficiency of the decision rule (DE), prognostic significance (PS) of positive results (PR+), and prognostic significance of negative results (NR-) [13]. Table 1 provides the results of the classifier operation for determining post-surgery risks, using point I - Taiyuan as a BAP.

**Table 1.** Data of check tests of the intelligent system for determining post-surgery risks in diagnostics with a single BAP

| Class | Patients under study | Positive | Negative | Total | DS=71%, DSp=78%, DE=75%, PS+=78%, ПЗ=73% |
|-------|----------------------|----------|----------|-------|------------------------------------------|
| C1    | n_{ref} (C1)         | 45       | 17       | 62    |                                          |
|       | n_{ref0} (C2+C3)     | 13       | 45       | 58    |                                          |
|       | Total                | 58       | 62       | 120   |                                          |

| Class  | Patients under study | Positive | Negative | Total | DS=60%, DSp=88%, DE=81%, PS+=62%, ПЗ=87% |
|--------|----------------------|----------|----------|-------|------------------------------------------|
| C2     | n_{ref} (C2)         | 18       | 12       | 30    |                                          |
|        | n_{ref0} (C1+C3)     | 11       | 79       | 90    |                                          |
|        | Total                | 29       | 91       | 120   |                                          |

| Class  | Patients under study | Positive | Negative | Total | DS=82%, DSp=89%, DE=88%, PS+=70%, ПЗ=94% |
|--------|----------------------|----------|----------|-------|------------------------------------------|
| C3     | n_{ref} (C3)         | 23       | 5        | 28    |                                          |
|        | n_{ref0} (C1+C2)     | 10       | 82       | 92    |                                          |
|        | Total                | 33       | 87       | 120   |                                          |

The maximum diagnostic sensitivity of the model in the check sample was 84%, diagnostic specificity - 93%, diagnostic efficiency - 90%, and the inclusion of one additional BAP in the process increases the quality of classification, on average, by 6%.

4. Conclusion
The diagnostic characteristics of the intelligent system make it possible to recommend the presented technical and algorithmic solutions for practical use in the diagnosis of urological diseases. In the future, it is possible to use mobile wearable devices based on monitoring the state of BAP for prenosological diagnosis of infectious diseases.

5. Acknowledgments
The reported study was funded by RFBR, project number 20-38-90063.
References

[1] Mohammed A A, Filist S A and Shatalova O V 2013 Modelling of the impedance of biomaterials in the environment of MATLAB Series Control, computer engineering, information science. Medical instruments engineering 4 73-78

[2] Filist S A, Aleksenko V A and Kabus Kassim 2010 Hybrid information technologies for express diagnostics of infectious diseases based on multifrequency analysis of passive properties of biological tissues Proceedings of southwest state university. Series Control, computer engineering, information science. Medical instruments engineering 8(109) 12-17

[3] Popechitelev E P and Filist S A 2011 Methods and models for identification of biomaterials based on multifrequency impedance analysis Proceedings of southwest state university. Series Control, computer engineering, information science. Medical instruments engineering 1 74-80

[4] Filist S A, Shatalova O V and Bogdanov A S 2014 Bioimpedance models at the nonlinear volt-ampere characteristic and reversible breakdown of the dielectric component of the biomaterial. Bulletin of Siberian Medicine 4 (13) 129-135

[5] Shatalova O V, Burmaka A A and Korovin E N 2018 Impedance models in anomalous electrical conduction zones forming by in-vivo experiments for intelligent systems of socially important diseases diagnostic International Russian Automation Conference (RusAutoCon) 1-4

[6] Shatalova O V 2019 Iterative multiparameter bioimpedance model in in vivo experiments Proceedings of southwest state university. Series Control, computer engineering, information science. Medical instruments engineering 9 1(30) 26-38

[7] Kassim K D A, Klyuchikov I A, Shatalova O V and Ya Z D 2012 Parametric bioimpedance models for identifying the functional state of a living system Biomedicine radioengineering 4 50-56

[8] Filist S A, Kuzmin A A and Kuzmina M N 2014 Biotechnical system for controlling the impedance of biomaterials in in vivo experiments Biomedicine radioengineering 9 38-42

[9] Shatalova O V, Surzhikova S E and Bogdanov A S 2014 The use of the automated system for the study of volt-ampere characteristics of bioactive points. Biomedical Radioelectronics 9 43-46

[10] Korenevskiy N A, Filist S A, Shatalova O V, Kassim K D A and Rudenko V V 2013 Diagnostic systems on the basis of the analysis the volt-ampere of characteristics of bioactive points. Biotechnosphere. 5 (29) 33-38

[11] Kiselyov A V, Savinov D Yu, Filist S A, Shatalova O V and Zhilin V V 2018 Virtual flows in hybrid decision modules of classification of complex-structured data. Caspian journal: Management and high technologies. 2 (42) 137-149.

[12] Filist S A, Shatalova O V and Efremov M A 2014 Hybrid neural network with macro layers for medical applications Neurocomputers: development, application 6 35-69

[13] Kiselev A V, Petrova T V, Degtyarev S V, Rybochkin A F, Filist S A, Shatalova O V and Mishustin V N 2018 Neural network modules with virtual flows for classifying and predicting the functional state of complex systems Proceedings of southwest state university. Series Control, computer engineering, information science. Medical instruments engineering 4(79) 123-134