Estimation system of cardiovascular circulatory system state based on 24h heart rate

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Abstract – the goal of this research was to develop the methods and tools for the analysis of cardiovascular circulatory system states, early prediction of the probability of sudden cardiac arrest, as well as analysis of various cardiac arrhythmias based on the dynamics of the 24-hours heart rate. Using «k-means" method based on MacQueen algorithm, the automated classification of heart rate fragments was made. The most informative procedure was referring specific observation to the functional pattern and the diagnosis within it. The software for processing and analyzing output of 24h HR and generating diagnostic conclusion about existing pathologies of the circulatory system and the status of the regulatory reserves of the human body was developed.

Key words – 24h heart rate, blood circulation, cluster analysis, coordinate plane of stochastic homeostasis, entropy, fractal dimension, Kolmogorov complexity, regulatory reserves, variability, variance analysis.

I. Introduction

The main motivation of this research is that according to the statistics of Ministry of Health of Ukraine in 2012 the main reasons of the mortality in Ukraine were cardio-vascular diseases. More the 60% of it is sudden cardiac arrest.

The main goal of the research is increasing the informativeness of heart rate (HR) monitoring data for prediction of cardiac pathologies.

The most suitable way for monitoring such states is Holter monitoring methods. This method allows obtaining the heart rate values at least for 24 hours.

The physiological background of this research based on physiological characteristics of the heart rate, especially which are not considered in the commercial software and supplying with it.

For investigate such tasks the methods derived from nonlinear dynamics have been successfully applied.

II. Materials and methods

This study has investigated the nonlinear characteristics of heart rate complexity and variability in patients with ischemic heart dilatation with circulatory deficiency, paroxysmal tachycardia, idiopathic hypertrophic subaortic stenosis with circulatory deficiency and normal HR dynamics. The time series were divided into sub-sequences with 1000 RR duration and processed for each interval during day and night time and transition periods.

The logistic map, fractal dimension, approximate entropy, Kolmogorov algorithmic complexity and flicker-noise parameters were calculated for each interval of 1000 RR points [1 - 6].

III. Results

It was demonstrated that patients, in the early postoperative period, as well as healthy people with the value of 24h heart rate characterized by the minimum variability of values during sleep or rest have lower regulatory reserves with high probability.

In the investigation, the set of quantitative nonlinear indicators of HR dynamics with some common characteristics was elaborated. It allows performing a versatile assessment of the 24h HR changes.

A method of estimating the complexity of the HR oscillations was modified using the indicators such as approximation entropy, fractal dimension and evaluation of the Kolmogorov's algorithmic complexity, which are different from the index of flicker noise parameter β. It was shown, that they can be used in the coordinate plane "Variability-Complexity" [6].

A method for estimating the Kolmogorov's algorithmic complexity was developed [4, 5]. It enables to include heart rhythm disorders of various types in the analysis, including sections of the rigid rhythm and atrial fibrillation, and make a thorough physiological analysis as well as improve the efficiency of both diagnosis and of antiarrhythmic therapy.

Using multivariate dispersion analysis (MANOVA), the need for methods of automated segments classification of heart rate to overcome the low specificity sequence of RR-intervals in general was justified. It was found that such factor as a stage of observation is not sufficiently specific for diagnosis. It was established that the values of the indicators for each of the diagnoses at different states of observations are virtually unchanged. That is, the oscillations of heart rate are highly diverse, requiring identification of heart rhythm intervals similar to each other.

The analysis of behavior of the selected heart rate indices in the coordinate plane "Variability-Complexity" showed that the data are averaged and become practically unsuitable for diagnosis at a long-term observation. In addition, we have shown that the stage does not affect the complexity of the HR oscillations, but it affects the variability, while the HR indices correspond to appropriate diagnosis. This was the reason for the application of the automatic classification for the formation of groups of homogeneous observations for further analysis.

Using «*k*-means" method based on MacQueen algorithm [7], the automated classification of HR fragments was made. The most informative procedure was referring specific observation to the functional pattern and the diagnosis within it.

The mechanism of learning and relearning of the algorithm to recognize the different pathological

conditions was developed. On the coordinate plane "Variability – Complexity", the information content of changes of the analyzed set of indicators within each cluster was shown to be much greater compared to a general HR sequence. The obtaining corresponds between the certain observation and functional pattern along with diagnosis within it was the most informative. This has revealed a variety of HR response in the form of manifestation of certain pathology. As a result, it was formed six functional patterns HR in the form of spherical clusters. Each cluster contains a set of features corresponding to each of the studied diagnoses, namely ischemic heart dilatation with circulatory deficiency, paroxysmal tachycardia, idiopathic hypertrophic subaortic stenosis with circulatory deficiency and normal HR dynamics. This allowed to identify different types of heart rate reactions as a manifestation of some pathologies.

On the coordinate plane "Variability – Complexity", the information content of changes of the analyzed set of indicators within each cluster was shown to be much greater compared to a RR-interval sequence in general.

Within each cluster, the indicators significantly varied in dependence on the values of variability and complexity of behavior or both of them. The content of information of each indicator, which corresponds to a specific diagnosis, was also different. This confirms the benefits of integrated application of indicators, which, in general, provide a good accuracy of the diagnosis.

A visualization of time definition of formation of 24h HR pathological fragments in the form of a pie chart was proposed. It provides useful information about the selection of methods for correction of pathologies. These diagrams can clearly identify periods of degradation or improving the dynamic characteristics of HR and evaluate the results of the drug effects, if such treatment has taken place.

The software for processing and analyzing output of 24h HR and generating diagnostic conclusion about existing pathologies of the circulatory system and the status of the regulatory reserves of the human body was developed.

The system allows uploading files of heart rate with the RR-intervals data to process both the output signal, as a sequence of RR-intervals, and the difference series or the series constructed on the basis of the coefficients of the logistic map equation. Processing can take place both for the entire time series and selected fragments. The system allows processing of signal by means of mathematical methods in the time (computing statistical characteristics, developing histogram of distribution of cardio intervals) and frequency domain (fast Fourier transform, the construction of the power density spectrum), nonlinear dynamics methods (calculation of the Approximate Entropy, flicker noise, fractal dimension and Kolmogorov algorithmic complexity with the ability to view dictionary of regularities and their localization within the observation period).

Additionally, the system allows to save the data of each type of analysis in a single file of table format, to classify the data according to the obtained patterns, to obtain diagnostic information about the pathology of human circulatory system based on the theory of stochastic homeostasis. Graphic method of visualization of diagnostic information, implemented in the program, is the construction of Poincaré plots and daily power spectrum.

Also, in the system, a visualization of functional patterns of normal and pathological states of the circulatory system in the form of the dial, which shows the daily (active state) and night (sleep) periods of the day, realized. States corresponding to functional patterns are displayed on the dial by the color spectrogram for each hour of the observation period.

Conclusion

Clinical studies using the elaborated computer-aided diagnostic system showed a high predictive value of the developed methods for identifying patients with various stages of hypertension. Diagnostic sensitivity rate was 89%, specificity rate - 87%.

References

[1] Niels Wessel, Udo Meyerfeldt, Christine Ziehmann [et al.], “Statistical Versus Individual Forecasting Of Life-Threatening Cardiac Arrhythmias”, in Proceedings of the 6-th Experimental Chaos Conference “EXPERIMENTAL CHAOS”: 22-26 July 2001, Potsdam (Germany), Vol. 622. — P. 110-115.

[2] Pincus SM., “Approximate entropy as a measure of system complexity”, in Proceedings of the National Academy of Sciences of the U.S.A. (1991): 2297-2301.

[3] Pincus SM, Goldberger AL., “Physiological time-series analysis: what does regularity quantify?” — Am J. Physiol. 266 : H1643-1656, 1994.

[4] O. Kyselova, Ie. Nastenko, M. Gerasymchuk, “Heart rate complexity definition using Kolmogorov algorithmic complexity method” — Eastern-European Journal of Enterprise Technologies, vol. 1/10 (49). — pp. 11-14, 2011.

[5] O.G. Kyselova, Ie.A. Nastenko, O.K. Nosovec, M.V. Gerasymchuk, “Sposib ocinky dobovogo sercevogo rytmu” [Method of estimating the 24 hours heart rate], UA Patent 66436, January 10, 2012.

[6] Usupov R.M., Polonnikov R.I., Telemedicina – novie informacionnie tehnologii na poroge XXI veka [Telemedicine – new information technologies on the threshold of the XXI century]. Sankt-Peterburg, 1998.

[7] J. McQueen, "Some methods for classification and analysis of multivariate observations", in Proceedings of the 5th Berkeley Symposium of Mathematics, statistics and probability. — pp. 281-296, 1967.