THE DYNAMIC INTERRELATIONS OF THREE ECG SIGNAL PARAMETERS

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Abstract

The rapid development of counting techniques and technology make it possible to collect increasing amounts of information and perform modern data analysis. The complexity of the problems often stimulates the use of innovative mathematical techniques that are able to capture accurately processes that occur at multiple scales in time and space. The purpose was to present the analytical method for the analysis of dynamic interrelations of ECG, cointegrating data to matrixes by each cardio - cycle. The dynamic interrelations were compared between healthy persons and persons with MI, during coronary angiography. The results showed that a short and quick reciprocity of the signals could be observed using matrix analysis. The values of dynamic interrelations were significant higher (p<0.05) in healthy persons. The new algorithm required just three signal points for the evaluation of dynamic interrelations – it was practical to use in monitoring systems for real time analysis.

1. INTRODUCTION

Recently, the rapid development of counting techniques and technology make it possible to collect increasing amounts of information and perform modern data analysis. New problems of processing of signals and their inherent information emerge that are particularly acute in areas where signal sources are very complex. One of the most actual and complex information storage and signal processing areas is human physiology [1]. Basically, the majority of complex adaptive systems were defined as complex as well as the signals characterizing these systems. The processing of these signals in terms of complex systems provides the possibilities to perceive the system components and dynamic interrelations [2], [3]. Currently, timely diagnosis of cardiovascular diseases is one of the most important problems not only in medical but also in social terms. The basic cardiovascular research, widely used in clinical practice is an ECG recording. The new electronic technologies allowed automatically to record the characteristic points of ECG signal during each cardio-cycle time, and to use them for examining of the different dynamic processes on different time scales. Moreover, it provided a selection of combinations of the parameters that reflected best different processes occurring in the heart and the detailed analysis of the level of these processes. However, the fragmental, disintegrated methods that are used in the modern analysis systems of ECG parameters still lack a unifying methodology and processing techniques of holistic signals and information that allow to combine and synthesize information into cardiac organically integrated whole. Small and fast changes occurring may have significant consequences.

In view of these problems, the aim of the study is to analyse the ECG signals using the complex system theory approach based on integral analysis, which embraces holism of the systems analysed, as well as interrelations of their components. So the main aim of this paper was to present the analytical method for the analysis of dynamic interrelations of three ECG parameters.

2. THEORETICAL BACKGROUND

The classical methods for data set interrelation – the correlation analysis, the crosscorrelation analysis, the coherence analysis require big sets of data. Their results are generalized. The complex system adapts to different conditions, the relations between its elements (complex system consists of at least three elements) are shifting. So the main was to present the new analytical method for the analysis of dynamic interrelations of three signals, which require only three points of each signal.

Suppose we have three synchronous signals $(x_n; n = 0,1,2,...)$, $(y_n; n = 0,1,2,...)$ and $(z_n; n = 0,1,2,...)$, the follwing elements x_n, y_n and z_n are determined. For the cointegration of three signals to series of third order matrixes can be constructed as follows:

$$A_n = \begin{pmatrix} a_{11}^{(n)} & a_{12}^{(n)} & a_{13}^{(n)} \\ a_{21}^{(n)} & a_{22}^{(n)} & a_{23}^{(n)} \\ a_{31}^{(n)} & a_{32}^{(n)} & a_{33}^{(n)} \end{pmatrix},$$

here $a_{11}^{(n)} = x_n$, $a_{12}^{(n)} = x_{n+1} - y_{n+1}$, $a_{13}^{(n)} = x_{n+1} - z_{n+1}$, $a_{21}^{(n)} = y_{n-1} - x_{n-1}$, $a_{22}^{(n)} = y_n$, $a_{23}^{(n)} = y_{n+1} - z_{n+1}$, $a_{31}^{(n)} = z_{n-1} - x_{n-1}$, $a_{32}^{(n)} = z_{n-1} - y_{n-1}$, $a_{33}^{(n)} = z_n$.

The invariants of matrix A_n:

$$\begin{aligned} &Inv_1(A_n) := a_{11}^{(n)} + a_{22}^{(n)} + a_{33}^{(n)}; \\ &Inv_2(A_n) := a_{22}^{(n)} \cdot a_{33}^{(n)} + a_{11}^{(n)} \cdot a_{22}^{(n)} + \\ &+ a_{11}^{(n)} \cdot a_{33}^{(n)} - a_{13}^{(n)} \cdot a_{31}^{(n)} - a_{21}^{(n)} \cdot a_{12}^{(n)} - a_{32}^{(n)} \cdot a_{23}^{(n)}; \\ &Inv_3 A_n = \det A_n. \end{aligned}$$

If $Inv_1 A_n = a,\ Inv_2 A_n = b,\ Inv_3 A_n = c,$ then the symmetry coeficients can be defined:

$$\begin{aligned} &\rho_{23} = \mathrm{dsk}_2(A_n) = a^2 - 3b; \\ &\rho_{12} = \left(a - \sqrt{a^2 - 3 \cdot b}\right)^2 \cdot \left(a + \sqrt{a^2 - 3 \cdot b}\right) - 27c; \\ &\rho_{13} = \left(a + \sqrt{a^2 - 3 \cdot b}\right)^2 \cdot \left(a - \sqrt{a^2 - 3 \cdot b}\right) - 27c. \end{aligned}$$

The large discriminant of matrix A_n:

$\mathrm{dsk}_1 A_n = \rho_{12} \cdot \rho_{13}$.

According to these expressions, hypothesis can be formulated: if discriminants of matrixes become close to zero, then numeric time series become similar, i.e., their interrelation is high [4].

Interrelations of the signal series can be labeled as „$\circ$“. According to the previous expressions, the value of interrelations can be defined as follows:

$$\varepsilon(x_n \circ y_n \circ z_n) = \frac{1}{l \cdot dsk_1 A_n},$$

here *l* – real number, ε – the value of interrelations.

Assuming that *l=1*, dynamic interrelationhip of each cardio-cycle was calculated for ECG parameters.

3. MATERIALS AND METHODS

For the synchronous registered ECG parameters series the matrix analysis was applied. The automated ECG analysis system "Kaunas – Load W01", developed at the Institute of Cardiology was used [5]. From ECG signals some parameters during every cardio – cycle were calculated: RR interval in ms (*RR*), JT interval duration in ms (*DJT*), R wave amplitude in μV (*AR*), QRS complex duration in ms (*DQRS*) and T wave amplitude in μV (*AT*).

Data of ECG parameters series of 30 persons were analyzed. All persons were divided into three groups: healthy persons (N=10, 40-60 years old, average age 43.16±1.17), 2 groups of patients with acute myocardial infarction (one group patients of 30-60 years old, N=9, average age 42.44±3.91; another group - patients of 60-90 years old, N=11, average age 72.55±3.78). For all patients the coronary angiography was performed and occlusion of at least of the one coronary artery was diagnosed. For all of them percutanies transluminal coronary angioplasty reconstructing TIMI3 flow in damaged artery was successfully performed [6], [7].

For the analysis of different complexity levels of the heart [8] some triad were selected:

$RR \circ DJT \circ AR$ for the system level,

$RR \circ DJT \circ DQRS$ for the subsystem (heart regulation) level and $RR \circ DJT \circ AT$ for the subsystem (heart metabolism) level. For the correct interrelations analysis and comparison all the data were normalized to interval [0; 1] as follows:

$$x = \frac{x_0 - x_{\min}}{x_{\max} - x_{\min}},$$

here x_0 - the original value, x – normalized value $x_{\min}$ and $x_{\max}$ minimal and maximal physiological value [4].

4. RESULTS AND DISCUSSION

It was hypothesized, that if a person was healthy, the values of ECG parameter interrelations were high, if ischemic heart disease was diagnosed – values were low. All mentioned dynamic interrelations for each person were calculated and analyzed individually. The examples of initial ECG parameters and their dynamic interrelations before, during and after coronary angiography of patient with acute myocardial infarction are given in the Figure 1 and Figure 2.

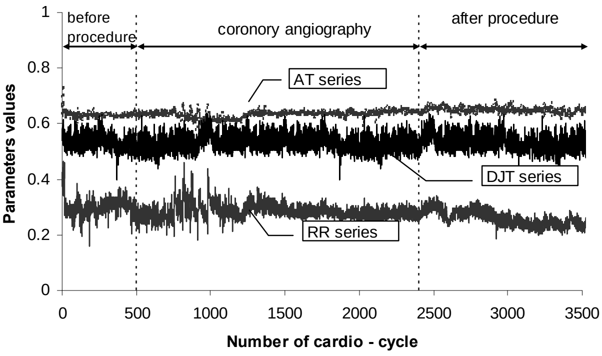

Fig. 1. An example of one investigation, initial ECG parameters RR, DJT and AT sequences

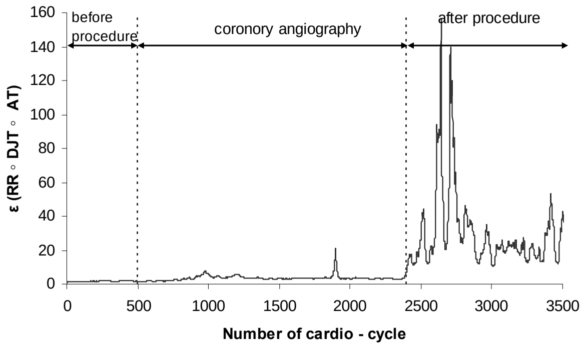

Fig. 2. An example of dynamic interrelations of one investigative ECG parameters RR, DJT and AT

For the results comparison the average value of was calculated. Non – parametric Man – Whitney – U test for the independent samples was applied. For the comparison of results before and after coronary angiography for ischemic patients non – parametric Wilcoxon test for two related samples was applied. The significance level 95 % was selected. The dynamic interrelations after coronary angiography were significant ($p<0.05$) higher for both groups. The comparison between groups is given in Figure. 3.

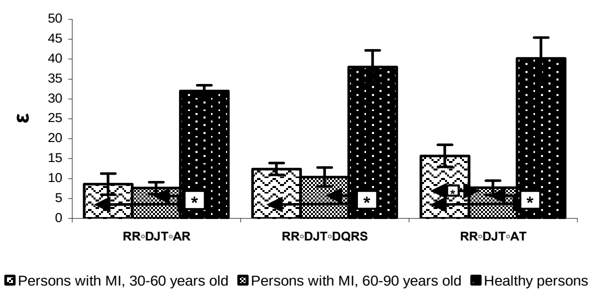

Fig. 3. Comparison of different ECG parameters dynamical interrelations average values for between different groups (* - the difference is statistically significant, $p<0.05$)

It was estimated that the values of dynamic interrelations of ECG signal parameters were significant higher ($p<0.05$) in healthy persons and better physical state (younger group). But in both situations the initial data didn't differ ($p<0.05$).

Non-invasive diagnosis of ischemic heart disease (IHD) is the main objective of cardiologists. However at rest accuracy of usual ECG, using only common, widely used diagnostic parameters is only about 45%. It increases using stress test [9], but also in this case accuracy and specificity is too low. If to take human body as a complex system [1], [10], important features of its complex function is assessment of dynamic interrelations between investigative parameters. There is still unknown the form of changes of any ECG parameters, during coronary artery revascularization procedures, when there is changing ischemic situation in the heart [11]. In this work it was hypothesized, that if person is healthy, ECG parameters interrelations values are high, if an ischemic heart disease is diagnosed – values are low [4]. The results confirm the hypothesis and illustrate, that dynamic interrelations are more informative for clinical practice than initial ECG parameters series [4],[10].

5. CONCLUSIONS

The results showed that a short and quick reciprocity of the signals could be observed using matrix analysis. Moreover, the new algorithm required just three signal points for the evaluation of dynamic relations – it was practical to use in monitoring systems for real time analysis.

It was observed, that dynamic interrelations are different to each person and it is better to analyze them individually.

All results should be tested with more data from ECG signals, registered for different age, gender and functional state persons.

6. ACKNOWLEDGMENTS

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References

[1] Quarteroni, L. Fornaggia, A. Veneziani, *Complex Systems in Biomedicine,* Springer, Milan, 2006.

[2] G. Kersulyte, Z. Navickas, A. Vainoras, L. Gargasas, G. Jarusevicius, "Analysis of Cardiosignals Cohesion based on Hankel Matrix", *Electronics and Electrical Engineering,* Vol. 8(88), Technology, Kaunas, 2008, pp. 55-58.

[3] J. West Bruce, *Where Medicine Went Wrong. Rediscovering the Path to Complexity. Studies of Nonlinear Phenomena in Life Science,* World Scientific, 2006.

[4] K. Berškienė, A. Vainoras, A. Lukoševičius, Z. Navickas, L. Bikulčienė, "The analysis of the interactions of nonlinear physiological systems", *Biomedical engineering: Proceedings of International Conference*, Technologija, Kaunas, 2008, pp. 38-41.

[5] Vainoras, L. Gargasas, R. Jurkonienė, V. Jurkonis, G. Jaruševičius, K. Berškienė, Z. Navickas, "Analysis of Electric Cardiac Signals – Methods and Application Results", *Electronics and Electrical Engineering*, Vol. 5(85), Technology, Kaunas, 2008, pp. 81-84.

[6] M. C. De Bruyne, A. W. Hoes, J. A. Kors, A. Hofman, J. H. Van Bemmel, D. E. Grobbe, "QTc dispersion predicts cardiac mortality in the elderly. The Rotterdam Study", *Circulation*, Vol. 97, 1998, pp.467 - 472.

[7] R. Yilmaz, R. Demirbag, M. Gur, "The Association of QT Dispersion and QT Dispersion Ratio with Extent and Severity of Coronary Artery Disease", *Annals of Noninvasive Electrocardiology*, Vol. 11, 2006, pp. 43 - 51.

[8] B. Y. Yaneer, *Complexity Rising: From Human Beings to Human Civilization, a Complexity Profile,* EOLSS Publishers, Oxford, 2002.

[9] Vainoras, L. Gargasas, G. Jarusevicius, "The bicycle ergometry and the possibility of complex evaluation", *Lithuanian Journal of Cardiology*, Vol. 6(4), Kaunas, 1999, pp. 760-763.

[10] W. T. Myers,Anatomy trains. – Edinburgh, Churchill Livingstone, 2001. - 281 P.

[11] H. V. Huikuri, T. H. Mäkikallio, J. Perkiömäki, "Measurement of Heart Rate Variability by Methods Based on Nonlinear Dynamics", *Journal of Electrocardiology*, Vol. 36, 2003, pp. 95–99