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Structural Topological Analysis of Cardiac Conduction System

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In this paper the method of structural-topological analysis of cardiac conduction system based on wavelet analysis of electrocardio signal reflecting conductive network of heart topology has been considered.

Keywords: electrocardiography, wavelet analysis.

Структурно-топологический анализ проводящей системы сердца

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В данной статье рассмотрен метод структурно-топологического анализа проводящей системы сердца на основе вейвлет-анализа электрокардиосигнала, отражающего проводящую систему топологии сердца.

Ключевые слова: электрокардиография, вейвлет-анализ.

The presence of dynamic chaos and $1/f^{\beta}$-fluctuations in the data physiology suggests fractal function and fluctuations, determined by the topology of biosystems. Scale-invariant biological structures and processes are closely related to physiological manifestations. Fractal topology of His system, conducting electrical signals from the atria to the ventricles was thoroughly studied. The nervous system is observed in the fractal structure on a macroscopic level, particularly in the neural structures, and in individual neurons structures (Fig. 1).

Adequate models of the processes occurring in the cardiac conductive system are very important for the diagnosis of cardiovascular diseases. In the currently existing models the basic property inherent

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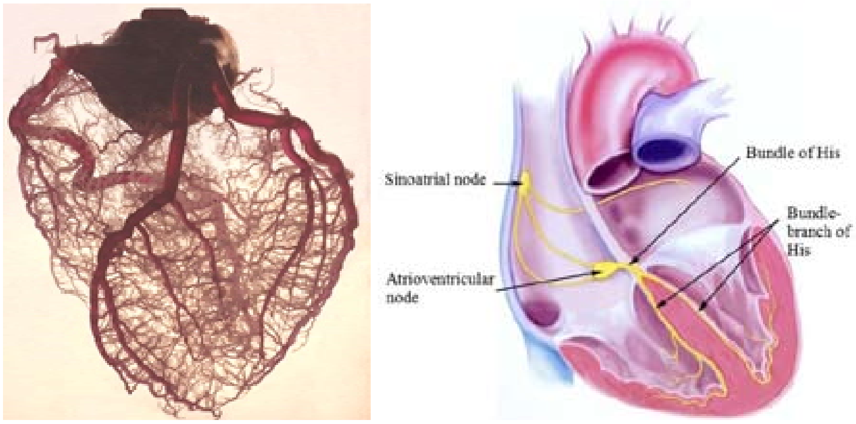

Fig. 1. Fractal structure of the vascular and cardiac conductive system

in nervous tissue – distribution of soliton excitation through the conductive network, branching with a definite scaling is not exhibited. Excitation of conductive network in the form of single waves (solitons) over conductive network are extended from the heart pacemaker. The fluctuations in each fragment occur when the sectional branches network changes. The sum of these fluctuation generates the signal spectrum. The conductive network branches with scaling close to the "golden section" according to the law of Fibonacci. This explains electrocardio signal spectrum characteristics as 1/f, which corresponds to the network topology. The general model of dynamic processes in living organisms – branching structure "communication systems" explains the formation of the spectral characteristics of the processes in them.

Thus, to diagnose the state of the cardiovascular system we can use the information contained in the distribution network topology, and the spectra electrocardiosignal (ECS). Signal coming from electrode reflects the state of heart conductive system. The turbulence occurs when the excitation wave propagation along the nerve and vascular bed determines the spectral characteristics of the signals.

Normally, the electrical pulse is generated in the sinoatrial node (SA) (Fig. 1), located at the confluence of the right atrium of the superior vena cava. Wave depolarization spreads quickly over the right and left atrium, reaching the atrioventricular (AV) node, where it is significantly delayed. Then pulse spreads rapidly over the bundle of His and runs along the right and left bundles of His branch. They branch out into Purkinje fibers, aloneg which the pulse diverges to myocardial fibers, causing their contraction.

Real ECS consists of three waves *P, QRS* and *T* varying amplitude (Fig. 2*a*), and its range form $1/f^{\beta}$. Corresponding conductive network topology of heart is shown in Fig. 2*b*.

ECS contains spatio-temporal information about the work of the heart conductive system. Wavelet transformations reveal analyzed process structure as pictures of local extrema surfaces lines, as well as somopodobie of this structure. This helps to identify cardiovascular disease at an early stage.

Most adequate representation of the ECS spectrum is wavelet transformation which is presented in Fig. 3.

Wavelet diagrams (Fig. 4) consistently reflect all the excitation propagation phases through the conducting network, which allows linking the presence or lack of excitement in all network fragments.

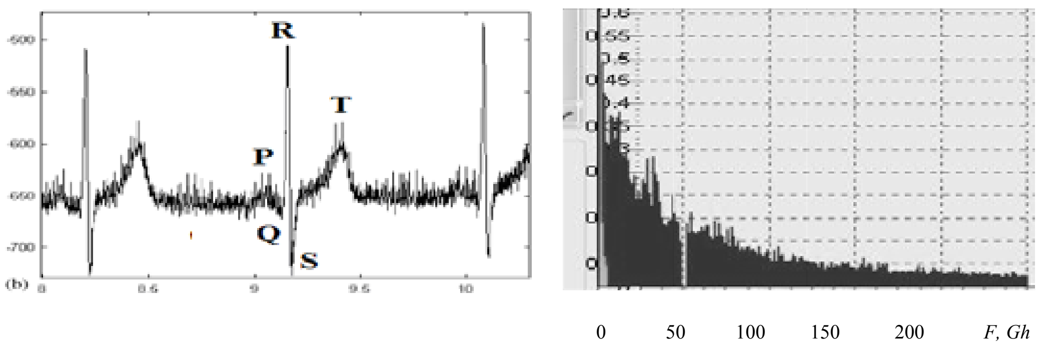

Fig. 2. Image signals: a – real ECS; b – spectrum

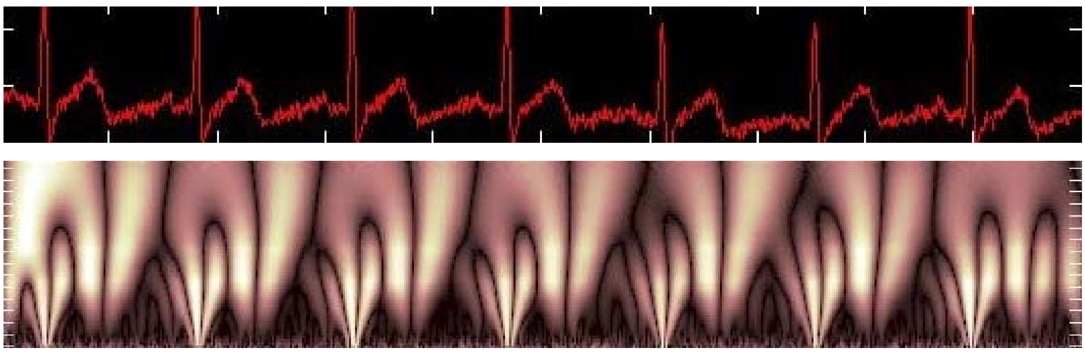

Fig. 3. ECS and its wavelet transform

Thus the wavelet representation of the ECG signal can be used as a tool for the detection of various cardiovascular diseases, such as “myocardial infarction”, “His bundle branch block”, etc. Using these wavelet data we can watch the whole process of the signal generation and its path from the pacemaker to the heart branching conductive network in real time.

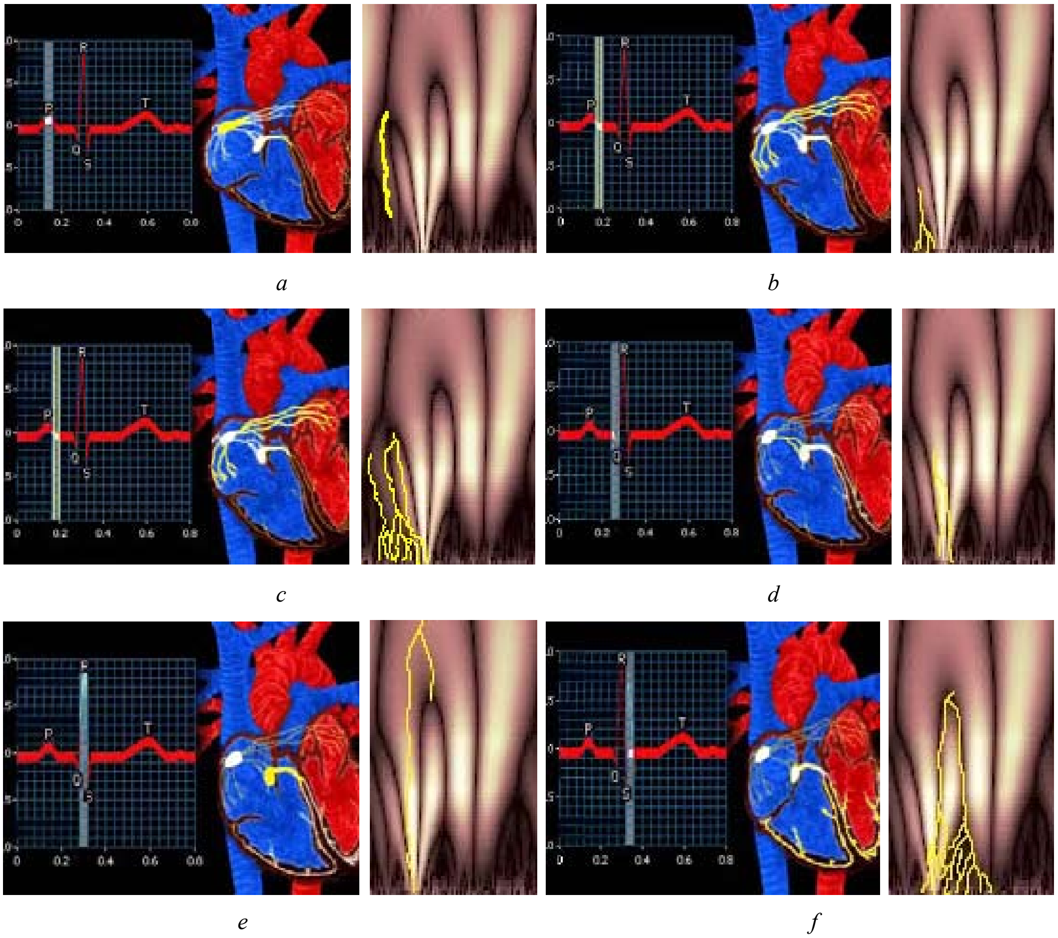

Fig. 4. Wavelet chart: *a* – Getting Started pacemaker; *b*, *c* – P-wave; *d*, *e*, *f* – QRS complex. Yellow shows the passage of excitation fragments of heart distribution network

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