Review Article ISSN 2639-8486

Cardiology & Vascular Research

Topological Analysis of The ECG Signal for The Primary Diagnosis of The Functional State of The Cardiovascular System

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Received: 24 May 2020; **Accepted:** 30 June 2020

Citation: Abdullaev N.T., Ahmadova Kh.R. Topological Analysis of The ECG Signal for The Primary Diagnosis of The Functional State of The Cardiovascular System. Cardiol Vasc Res. 2020; 4(3): 1-3.

ABSTRACT

Informative parameters of the electrocardiological signal are considered - the shape and length of the signal for the possibility of differential diagnosis of the functional state of the cardiovascular system. The values of these parameters for the normal and a number of pathological conditions of the cardiovascular system are calculated. The possibility of a graphical interpretation of the results is shown.

Keywords

Diagnostics, Electrocardiography, Waveform, Signal length, Database, Classification.

Introduction

Electrical instability of the heart is considered as a state that has a multifactorial nature. Therefore, for its reliable prognosis, a comprehensive analysis of all possible causes and triggering factors is required, including the balance of autonomic regulation (analysis of the R-R distribution), the nature of ectopia during prolonged monitoring, fluctuations in heart intervals, etc. Modern electrocardiographic systems have wide diagnostic capabilities; therefore, it is important to know and use their undoubtedly high research potential in wide clinical practice.

Some biomedical signals, including electrocardiographic (ECG), have a fairly simple form (P-, T-waves and QRS complex). Easily identifiable ECG signs can change under the influence of external factors and pathological processes within the body. Thus, it can be noted that the analysis of waveforms can be quite informative in the diagnosis of diseases. There is a connection between the forms of biomedical signals with the characteristics of physiological and pathological phenomena that generate these signals.

Analysis of ECG parameters

To analyze the forms of biomedical signals, taking into account the non-stationary nature of these signals, at the first stage, it is necessary to carry out segmentation with a duration of several seconds for an ECG (taking into account the duration of ECG removal equal to 60 seconds). For proper segmentation, in order to avoid ambiguity in determining the boundaries of a segment, it is necessary to include P, QRS, and T waves of each cycle in each segment. Then, for the obtained segments, three parameters are calculated [1], based on the concept of dispersion as a measure of signal activity:

- activity, which is simply the variance σx2 of the signal segment x (t);

- mobility MX, which is calculated as the square root of the ratio of the activity of the first derivative of the signal to the activity of the original signal

where x` - means the first derivative of x;

-form coefficient (complexity), defined as the ratio of mobility from the first derivative of the signal to the mobility of the signal

where x``, means the second derivative of the signal.

Given that the FC calculation is based on the determination of the first and second derivatives of the signal and their variances, this measure is sensitive to noise.

Other parameters are possible that characterize the complexity of the waveforms. For example, such parameters can be based on the results of nonlinear dynamics on the correlation dimension and on the dimension of the embedding of time-varying dynamical systems.

The complexity of the sinusoidal signal is single, other waveforms have a complexity value that increases in accordance with the degree of presence of changes in them.

Ectopic complexes associated with abnormal pathways of the propagation of the corresponding excitation pulses usually have a significantly different form of the QRS complex than normal. As a rule, ectopic complexes have complex waveforms. The shape factor parameter is an indicator characterizing the concept of the complexity of the waveform, which increases with increasing complexity. Therefore, it can be argued that the parameter of the shape factor can be used for differential diagnosis between normal and pathological conditions of the cardiovascular system.

For the purpose of differential diagnosis of the state of the cardiovascular system, the values of the waveform coefficients for the normal state and a number of the most common pathologies of the heart were determined: ventricular fibrillation, ventricular tachycardia, atrial fibrillation [2].

A computational experiment was carried out taking into account the experimental values of the physiological signal database physionet.org [3]. ECG recordings from the MIT-BIH Arrhythmia Database have the record name, the number of signal channels (2), the sampling frequency (360Hz) and the total number of signal samples in each channel (650,000). In addition, the following lines give the name of the file in which the signal is contained, the format for packing the signal reports, the signal scale (the number of quantization levels per 1 mV, the resolution of the analog-to-digital conversion, the level of the zero line of the sampled signal, etc.).

For each of the pathologies, the values of heart rate variability (R-R intervals) were used for 20 experiments for the II standard lead. Given that the value of the R-R intervals in the norm is 0.72-0.80 sec, a comparison was made of heart rate variability for these diseases:

- for gastric fibrillation

t_{R-R} = 0.012-0.944 sec;

- for ventricular tachycardia

t_{R-R} = 0.02-0.536 sec;

- for atrial fibrillation

t_{R-R} = 0.031-0.946 sec.

With an experiment duration of 60 seconds, the number of segments was selected 6 (10 seconds per segment).

In addition to the parameter of heart rate variability for the diagnosis, it is necessary to determine the waveform of the QRS complex and a quantitative assessment of the difference in forms under normal and pathological conditions. After detecting the QRS complex according to well-known algorithms [4,5], the shape coefficient is calculated using the above expressions. For the normal state of the cardiovascular system, the shape coefficient is in the range of FC = 1.5 ÷ 2.0; for the considered pathological conditions, the range of changes in FC = 2.0 ÷ 3.0.

For the calculated values of tR-R and FC, it is possible to construct a graph of the space of vectors of these signs corresponding to the ECG [1].

The value of CF depends on the shape of each QRS complex of the ECG, which can vary for different leads of the experiment.

Since the form of the ECG depends on the lead system used, it may be necessary to obtain a set of signs for many leads, up to 12 generally accepted leads used in clinical practice.

For a sufficiently accurate diagnosis of the state of the cardiovascular system in practice, additional parameters are required to the above two signs. Such parameters may be the signal length [1], which differs from the concept of signal duration. The signal duration is the period of time during which the signal exists, i.e., has non-zero values (neglecting the periods it has inside the signal duration, when the signal can turn out to be zero). For example, for an ECG signal, such an area is an isoline on the electrocardiogram. The concept of signal length is associated with the distribution of signal energy over its duration. The signal length depends on both the amplitude and phase spectrum of the signal.

The signal length is determined by the formula [6]:

where T is the experiment period and w (t) is a non-decreasing positive weighting function w (0). The value of w (t) depends on the specific application and on the required characteristics of the signal length. Obviously, the signal reports with increasing distance from the origin (t = 0) have increasing weights w (t).

The signal x (t) can be observed as the distribution of the amplitude of a variable along the time axis, the square of this signal x2(t) can be interpolated as the instantaneous energy of the process generating the signal. Given that the total energy of the signal is determined by the expression

The function $x^2(t)$ at $0 \leq t \leq T$ (usually the ECG measurement period is 60 seconds) can be considered as the distribution of energy or function dense until the result.

Signals with an increased phase delay will have energy distributed over a longer period, and will have higher signal lengths, which is associated with increased weights w (t).

For the indicated states of the cardiovascular system, the dependences tR-R = f (SL) were constructed. It should be noted that on the graph, the signal lengths for the normal state and pathological complexes significantly overlap in the range SL = 28–35. In this case, it is rather difficult to make a differential assessment of the state of the cardiovascular system. However, when calculating the signal length, taking into account its phase spectrum, higher SL values of pathological conditions are noted than similar values for the normal state of the cardiovascular system.

Results

Thus, in this case, it becomes possible to classify the conditions of the cardiovascular system.

The considered approach for differential diagnosis of the functional state of cardiovascular system can be used for initial assessment.

In practice, usually the indicated image classification systems require more complex approaches based on additional features. A complete diagnosis of the patient's condition requires taking into account many other factors and types of clinical information, as well as a highly qualified cardiologist.

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