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Analysis of Electrocardiological Predictors for Differential Diagnosis Cardio-Vascular Diseases

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Annotation

Signs of pathological changes in the electrocardiogram, which can be used to judge the functional state of the cardiovascular system, are studied as predictors of heart disease. The possibilities of using such predictors as an elongated form of the QRS complex, the intervals between the peak complex and the final value of the T wave, spatial QRS - T, ventricular gradient and other angles were analyzed. Consequently, the number of prognostic predictors includes indicators of the period of depolarization and repolarization of the heart muscle, as well as integral and calculated indices. From the integral indicators of the periods of polarization, the ventricular gradient and angular indicators of the electrocardiogram should be taken into account. A new group of predictors of cardiovascular disease can be investigated by heart rate intervals, which is a chaotic process. This analysis is based on the search for a predictor of cardiac output (R-wave) above a certain fixed amplitude threshold. As a result of this analysis, it becomes possible to determine four new informative features. For differential diagnostics of the functional state of the cardiovascular system, these signs can be used as input parameters of an artificial neural network.

Keywords: cardiovascular system, diagnostics, disease predictors, informative signs, integral indicators, chaotic process.

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Any violation of the rhythm of the heart or damage to the heart muscle can change the electrical activity of the heart, depending on what changes are taking place and the shape of the electrocardiogram (ECG). For effective automatic detection and classification of ECG, we need a reliable method of detection of arrhythmia symptoms. The main problems in the classification of ECG are:

- lack of standardized ECG standardization;
- variability of the characteristic ECG;
- individuality of the ECG scheme;
- lack of optimal ECG classification rules;
- variability of the ECG form of patients.

Automated ECG classification is a complex task, as the morphological and temporal characteristics of ECG signals have significant differences in different and physical conditions [1].

Efficiency and specificity are assessed by the use of quantitative parameters. Standard symptoms, as a rule, are given in **Table 1**, which shows a typical feature of a normal ECG signal with a heart rate of 60 beats per minute in an adult patient [2].

Classification and identification of types of arrhythmias is necessary in identifying the abnormality present in the patient's ECG signal. The choice of indicators that are promising for early recognition of pathological changes in the myocardium are called predictors of cardiovascular diseases. Such predictors at an early stage of diagnosis are the signs extracted from specific details of the ECG signal [2]. **Table 2** shows the different types of arrhythmias and their features in the ECG signal.

Sign	Normal value	Change threshold
Waves P	110 ms	±20 ms
Interval PQ/PR	160 ms	±40 ms
QRS duration	100 ms	±20 ms
Interval QT	400 ms	±40 ms
Amplitude P	0,115 mV	±0,05 mV
Amplitude QRS	1,5 mV	±0,5 mV
Amplitude ST	0 mV	±0,1 mV
Amplitude T	0,3 mV	±0,2 mV

Table-1

Sign	Arrhythmia type
Interval RR longer	Bradycardia
RR interval is shorter	Tachycardia
Long interval PR	Atrioventricular block I degree
Segment ST promoted	Myocardial infarction
Segment ST short (missing)	Hypercalcemia
Wide QRS- complex	Premature ventricular collapse
Lack of waves P	Atrial fibrillation, idioventricular rhythm
Flipped over waves T	Coronary ischemia
Long interval QT	Nocturnal hypoglycemia
P waves are larger than the QRS complex	Atrioventricular block 2 and 3 degrees
Tall or T-wave	Hyperkalemia

Table-2

Of course, such an approach to diagnosing diseases of the cardiovascular system is very preliminary, and, therefore, new predictors of heart disease and their use in routine medical practice are needed to be included in automatic ECG analysis programs. These indicators include the extended duration of the QRS complex, the spatial angle of the QRS-T, the Tr-Te (Tpeak-Tend), QT and QTc intervals, the ventricular gradient, and others [3]. Making these ECG readings available for general medical practice, means increasing the detection of people at high risk for adverse cardiovascular events and sudden cardiac death.

The predictively significant ECG indicators of the electrical activity of the heart include indicators of the periods of depolarization and repolarization, as well as indicators that include both these processes, integral and calculated indices.

The indicator of changes in the depolarization process is the expansion of the QRS complex. Studies show that QRS ≥ 120 ms is a predictor of a sudden cardiac death with a relative risk of 1.7 and a predictor of arithmetic events with a relative risk of 2.2 [4].

Repolarization is analyzed by intervals, angles and amplitude indicators of the T period on the ECG. The extended interval Tpeak-Tend is measured from the apex of the Tpeak to the end of the T wave (Tend) and characterizes the state of the final phase of repolarization of the ventricular myocardium. This indicator is recommended for predicting ventricular tachyarrhythmias and cardiovascular death [5].

The Tpeak-Tend interval > 89ms is included in the sick electrical risk assessment system. In the elderly population, the interval should be the increased spatial angle θ(Tpeak I │ Tend). Angle θ is the angle between the Tpeak vector and the reference T vectors, which normally characterizes the degree of deviation of the maximum depolarization vector from its normal position. The most dangerous predictors were θ (TpeakTend)> 42^0 and the T amplitude in lead aVR> 100 μV [6], they have an increased risk of coronary heart disease by more than 2 times. These rates and repolarization are considered independent, isolated predictors of mortality.

The increased spatial angle θ(Tinit|Tterm) is the angle between the starting and ending vectors of the repolarization period. It rises to the temple of death when θ(Tinit|Tterm)> 30^0 [6]. This angle reflects the increased divergence of the spatial initial and final vectors of repolarization and, therefore, is directly related to the change in the shape of the T loop.

Indicators of changes in ST-T, the final part of ventricular repolarization, in contrast to angular and integral ECG indicators, have been studied quite well and are available to the doctor for analysis.

T-wave inversion in lead aVR, AVL, V1 and V6 is associated with ischemic heart disease and is fatal. Depending on the gender, age and baseline of the patient, the relative risk can range from 1.6 to 3.2. This is confirmed by clinical [7] studies.

Among the ECG indicators, called predicates of cardiovascular diseases, an extended QT interval has been widely studied, which includes processes, depolarization and repolarization of the ventricles. QT-interval is measured here first of the Q wave to the end of the T wave, in ms. A prolonged QT interval is associated with an increased risk of ventricular arrhythmias, and syncope is fatal. Values>450ms are considered to be the criteria for an extended QT interval [8].

In contrast to a prolonged QT interval, very short QT intervals are generally not associated with adverse outcomes.

The situation with the indicator called QT variance is also not entirely clear. QT dispersion is the difference between the maximum and minimum values of the duration of the QT interval in the 12 ECG leads. And given the lack of clarity with the electrophysiological meaning of this indicator and the presence of a correlation with other ECG predictors of adverse events, there is no need for further study [9].

Relative indicators obtained by dividing different time intervals or amplitudes into each other are considered quite promising, but also in their electrophysiological meaning and according to the studies obtained.

For example, the ratio of electrical systole to the duration of QT/QRS depolarization makes it possible to differentiate the contribution of depolarization and repolarization [10]. With the primary lengthening of depolarization, the QT/QRS value decreases, with the lengthening of repolarization, it increases. Thus, an increase in the QT/QRS ratio is associated with a predisposition of ventricular tachycardia, a precursor to ventricular fibrillation. High values of the ratio of the end part of ventricular repolarization as an electric systole TreakTend/QT are observed in patients with a threat of life on dangerous arrhythmias.

The strongest predictor of death from coronary heart disease is the ratio of the amplitude of the initial and maximum vectors T: ToV / TpV. Of the integral indices of depolarization, the ventricular gradient and angular ECG indices should be emphasized [11]. The ventricular gradient is calculated as the sum of the areas of the QRS complex and the T wave. The ventricular gradient characterizes the degree of electrical heterogeneity in different parts of the myocardium, which allows us to expect a high predictive value from the ventricular gradient. This concept has not yet received widespread implementation in clinical practice.

Of the angular prognostic indicators of the ECG, the following can be distinguished:

a) Increased spatial angle θ (QRS|STT), which is an indicator of changes in the simultaneous processes of ventricular depolarization and repolarization, characterizing the divergence of their vectors in space. This angle is called the indicator of high risk of mortality from cardiovascular disease. For example, θ(QRS|STT) ≥1000 is associated with more than two-fold death, while θ(QRS|STT) are among the selected markers of arrhythmias [4, 12]. An increased QRS-T has a higher risk score than all other traditional factors;

b) The frontal angle QRS - T is calculated from the frontal axes QRST - T, as the absolute value of the difference between the axes of these factors. To the frontal angle, QRS-T is an important predictor of overall mortality, with a wide variability of the norm depending on age and sex. The purpose of risk assessment is this indicator is an affordable clinical substitute for its spatial analogue [12];

c) The electric axis of the vector T (spatial or frontal). Deviation from the normal position of the electric axis of the T vector often leads to a change in the value of the QRS-T angle. Therefore, most of the disc death associated with the QRS-T angle may be due to changes in this indicator [13]. When analyzing the spatial angle QRS-T, there is a problem of choosing the method of its calculation. To the corner can be calculated from the orthogonal system XYZ leads or orthogonal leads previously synthesized from orthogonal leads. Regardless of the used system of orthogonal leads, the calculation can be carried out between the maximum and, integral vectors, vectors of areas or Eigen planes of spatial QRS and T loops. Which of the calculation methods is the most predictively informative indicator has not been sufficiently researched.

Thus, the analysis of the prognostic capabilities of ECG indicators shows that the electrocardiogram can be included in the computer analysis programs in the following informative predictors of adverse outcome, which are absent in general medical practice.

Necessary indicators:

- ventricular gradient
- spatial and frontal angles θ(QRS|STT), electric axes of the corresponding vectors QRS and T.

The spatial angle QRS-T and the ventricular gradient are important complementary measures.

Desired indicators:

- spatial and frontal angles θ(Tpeak|Tref), θ (Tinit|Tterm);
- QT intervals in addition to the usual available intervals;
- the ratio of the durations of the intervals QT/QRS, TpTe/QT and TpTr/QTc;
- the ratio of the amplitudes of the initial and maximum vectors ToV/TpV, plus the characteristics of the vectors To and Tr.

The noted ECG indicators will be very useful in making a final diagnostic conclusion.

Recently, methods have been developed to study certain transitions in a series of heartbeat intervals. It was found that the dynamics of many physiological processes, including heart rate, is chaotic and can be described from the standpoint of the theory of nonlinear deterministic systems [14, 15, 16]. The basis of the classical approach to predicting outliers of a random process, which consists in exceeding a certain fixed threshold Q, is the search for a predictor of such a selection, i.e., the characteristic behavior of a random process at times immediately preceding the occurrence of an outlier.

Consider the predictor Xn, k of the outlier Xn> Q of the random process Xn, expected at time n, consisting of k reports of the random process, preceding the selection Xn, k = Xn-k, Xn-k+1, Xn-1. The first approach is to analyze only those sequences by activity k, which were followed by outliers, using available realizations of the random process. In this approach, the key value is the posterior probability P(Xn,k | Xn>Q). The main disadvantage of this transition is the small amount of information used, since it does not analyze other fragments of the available realizations of the random process, except for those immediately preceding the outliers. This prevents the use of information in sequences that are obviously atypical as predictors.

An alternative approach is to analyze all sequences Xn,k=Xn-k, Xn-k+1, Xn-1 with duration k over all available implementations of a random process (sliding window) and estimate the conditional probability P (Xn>Q | Xn-k) of a given threshold Q at time n immediately following the sequence Yn,k.

This approach is more effective in relation to a wide class of random processes with short-term and long-term dependence [17]. In this case, the simplest option for constructing a decision-making algorithm is to choose the most probable predictor Xn,k. With further analysis in real time, the deviation from it of the received sequences of reports of the process with duration k is calculated with the assignment of one or another deviation metric. In this case, the criteria for making a decision about waiting for an outburst at the next moment of time is the distance value below a certain threshold value. This approach is very effective when working with simple systems, where the function P(Xn>Q|Xn,k) has one pronounced extremum, which is a global maximum. However, when working with complex self-regulating systems, which include physiological systems, one cannot exclude the possibility of the appearance of more complex dependences P(Xn>Q|Xn,k), including those with several extrema comparable in magnitude. In this case, the choice of the most probable predictor is ineffective, and for the analysis it is necessary to store a complete database of predictors Xn,k and the corresponding probabilities of choice, obtained from the available implementations of the random process used to train the algorithm. In this case, the criterion for making a decision about the expected outburst at the next moment in time is the increase in the probability P(Xn>Q|Xn,k) of some predetermined threshold Qp.

The choice of the optimal value of Qp in the general case is based on minimization of alternative losses from corrected decisions made during forecasting, depending on the a priori specified values of losses in case of a false alarm and when a surge is missed.

The above approach makes it possible to take into account only the short-term dynamics of the process, in particular, to the reports preceding the release. When analyzing physiological signals, slow regulation loops and forming long-term dependence play an important role in the formation of anomalies, including outliers. In this regard, it seems appropriate to use additional information about the nature of long-term dependence [18, 19].

From the analysis, the set of records (extreme events {Xi}(i=1, 2, ... L)) rhythmogram and statistics of repeated intervals (return intervals) between records {ri}(i=1, 2, ... LQ), exceeding, informative signs can be extracted for the diagnosis of a patient's heart disease.

These are the following informative signs:

1. Fractal characteristics of many records;
2. Unconditional and conditional probability density function of the lengths of repeated intervals; conditional repeat period;
3. Conditional repeat period;
4. Autocorrelation function of repeated intervals.

The described informative signs can be used to diagnose various diseases of cardiovascular systems on the basis of ECG signals [20, 21]. For the purpose of differential diagnosis and classification of diseases of the cardiovascular system, artificial neural networks should be used, having trained them according to the indicated informative signs.

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