Advanced features of ECG mapping

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Abstract. Cardiovascular diseases are the leading cause of death worldwide. A great number of
methods have been developed to monitor the state of the heart, each of which has its own
advantages and limitations. One of the most promising method is surface mapping. To improve
reliability and informativity of this method, researchers of Medical Engineering Laboratory of
TPU developed nanosensors with unique metrological characteristics for non-invasive
measurement of ECG signals of microvolt and nanovolt levels. The results of previous studies
showed that metrological characteristics of the developed nanosensors significantly exceed
those of conventional electrodes. Based on this, nanosensors used for surface ECG mapping
will enable qualitative improvement of data obtained and diagnostic capabilities of this
method.

1. Introduction
Cardiovascular diseases are the most common cause of death in the world among the population.
According to statistics from the World Health Organization, an estimated 17.9 million persons died
from cardiovascular diseases in 2016 [1]. Ischaemic Heart Disease (IHD) is particularly prominent
among all causes of deaths caused by cardiovascular diseases. IHD is a disease of cardiac muscle
caused by an acute or chronic imbalance between myocardial blood supply and demand. The disease is
manifested in the development of ischemic injury, necrosis and scarring in cardiac muscle. According
to statistics, about 25–30% of patients with a confirmed diagnosis of IHD die suddenly. Patients with
acute myocardial infarction are most at risk of sudden cardiac death in the first hour after the onset of
heart attack [2]. Due to this, the diagnosis of the state of the cardiovascular system is an important
component of systemic measures to reduce mortality. For this purpose, non-invasive methods are most
widely used in clinical and polyclinic practice to provide measurement data on the state of the
cardiovascular system and to allow for the possibility of repeated measurements.

To date, a great number of methods for non-invasive diagnostics have been developed. These
methods can be divided into electrographic (electrocardiography (ECG), ECG mapping, Holter
monitoring, magnetocardiography) mechanographic (apexcardiography, ballistocardiography,
seismocardiography) and visualization (X-ray image, ultrasound, radionuclide, X-ray computed
tomography, magnetic resonance imaging). The leading and most common method of instrumental
studies of heart diseases is electrocardiography that enable diagnosis of a large number of patients.
The main task of the ECG method is to record electrical potentials from the surface of the human body
and to present these data in the form convenient for perception. In addition, the method is focused on
of automatical interpretation of the results obtained using special software [3-5]. Under polyclinic and
clinical conditions, specialists mainly use 3- and 12-channel electrocardiographs to assess time and
amplitude characteristics of ECG at a certain time point and in dynamics, and such variables as
microvolt T-wave alternans (MTWA), sustained ventricular tachycardia, filtered QRS interval (fQRS),
dispersion and daily dynamics of QT interval, heart rate turbulence, baroreflex sensitivity, short
paroxysmal ventricular tachycardia, decreased heart rate variability, late ventricular potentials (LVP),
etc [6, 7]. However, the sources available provide different data on the reliability of these
indicators [8]. In addition, the use of 3- and 12-channel electrocardiographs cannot reliably localize
the site of ischemic damage to cardiac muscle.

The method of body surface mapping (BSM) has been developed to solve this problem based on
recording of multiple ECG leads from the entire surface of the chest. Multichannel systems are used to
implement the method, including up to 300 sensors for ECG recording [9, 10]. The data obtained
using this method show the nature of electrophysiological processes in the heart. The method makes it
possible to analyze electrical potentials of the heart on the chest surface at every moment of PQRST
cycle. Visualization of these potentials using special software is the instantaneous picture of the
electric field of myocardial cells. Local defects in the electrophysiological properties of cardiac muscle
can be identified in the picture presented. In addition, this picture shows local violations in the
sequences of depolarization and repolarization. Thus, the method provides the opportunity for solving
the problem of diagnosing ischemic heart disease, which is reported in many [11-18].

2. Methods and materials
Tomsk Polytechnic University in collaboration with Cardiology Research Institute (Tomsk National
Research Medical Center of the Russian Academy of Sciences), developed a nanosensor-based
hardware and software complex for recording real-time heart micropotentials without filtering and
averaging. The complex does not comprise filtering circuits in the measuring channel, which enables
recording of undistorted measurement data in a wide frequency range. Also, the hardware and
software complex includes nanosensors developed at Tomsk Polytechnic [19]. Nanosensors are highly
stable, low-noise and non-polarizable electrodes. These electrodes enabled the exclusion of filtering
units from the measuring circuit in the frequency range from 0 to 10 kHz.

Based on current experience and developments, it is proposed to create a nanosensor-based
hardware and software complex (HSC) for recording high-resolution electrocardiograms with
micropotentials in order to localize the damaged and necrotic sites in the patient’s heart by comparing
ECGs recorded using multi-channel HSC with model ECGs from the database. The database of model
ECGs will make it possible to early detect and localize ischemic sites without additional time costs per
patient under polyclinic conditions.

Figure 1 presents the proposed layout of 240 electrodes for surface ECG mapping using the multi-
channel HSC.

Previously, conventional chlorine-silver electrodes for recording ECG signals and nanosensors
developed at TPU using 3-channel HSC were compared [20]. Chlorine-silver electrodes by FIAB Spa
(Florence, Italy) were used as standard. Comparative studies were carried out under similar
environmental conditions on the same patients. The method of the study did not change. Preliminary
studies were conducted on volunteers at Cardiology Research Institute. Each volunteer signed an
informational consent in accordance with the internal regulations on hospitalization procedure at
Cardiology Research Institute (collection of information consents (order of the Chief Medical Officer
of Cardiology Research Institute #12 of 06.06.2014). All volunteers were provided with
comprehensive information on the study according to the internal regulations on hospitalization
procedure at Cardiology Research Institute. The confidentiality of data obtained was respected.
3. Results

The comparison of conventional chlorine-silver electrodes and nanosensors showed that the electrodes by FIAB Spa (Florence, Italy) exhibit lower sensitivity and no immunity to line interference (Figure 2). It should be noted that previous studies revealed negative impact of a filter, which can significantly distort cardiac micropotentials [21]. Thus, a filter used in the measuring circuit will not provide reliable results of the study of cardiac micropotentials in dynamic observations, since line interference is not stationary and changes over time.

![Figure 1. Layout of electrodes for surface ECG mapping, n = 240.](image)

![Figure 2. Results of the study of noise immunity to line interference: (a) conventional chlorine-silver electrodes by FIAB Spa (Florence, Italy), sensitivity 50 µV/div and (b) nanosensors, sensitivity 50 µV/div.](image)
4. Conclusion
The results of the study show that the developed nanosensors exhibit higher sensitivity and noise immunity to line interference, which confirm and complement the data obtained in our previous studies [20]. In addition, an ECG recorded far from the source of interference using nanosensors does not contain electromagnetic interference in the range from 0 to 10,000 Hz.

Thus, nanosensors developed at Tomsk Polytechnic University will enable qualitative improvement and increase in the reliability of data obtained using surface ECG mapping. Nanosensors employed in this method will open up new possibilities for localization of damaged and necrotic areas in the heart at the very early stages of the development of the disease.

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