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 cases 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, seysmocardiography) 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.

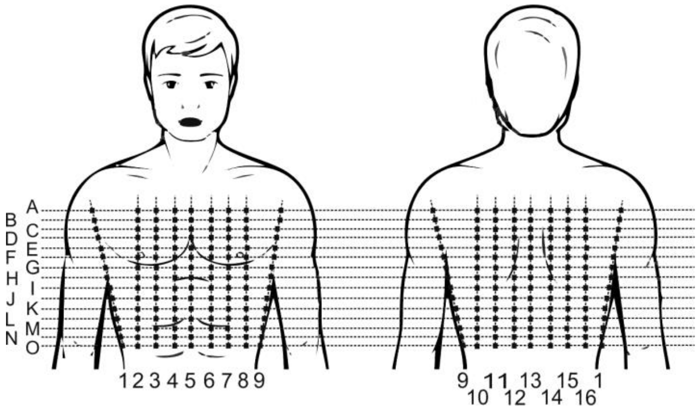

Figure 1. Layout of electrodes for surface ECG mapping, n = 240.

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.

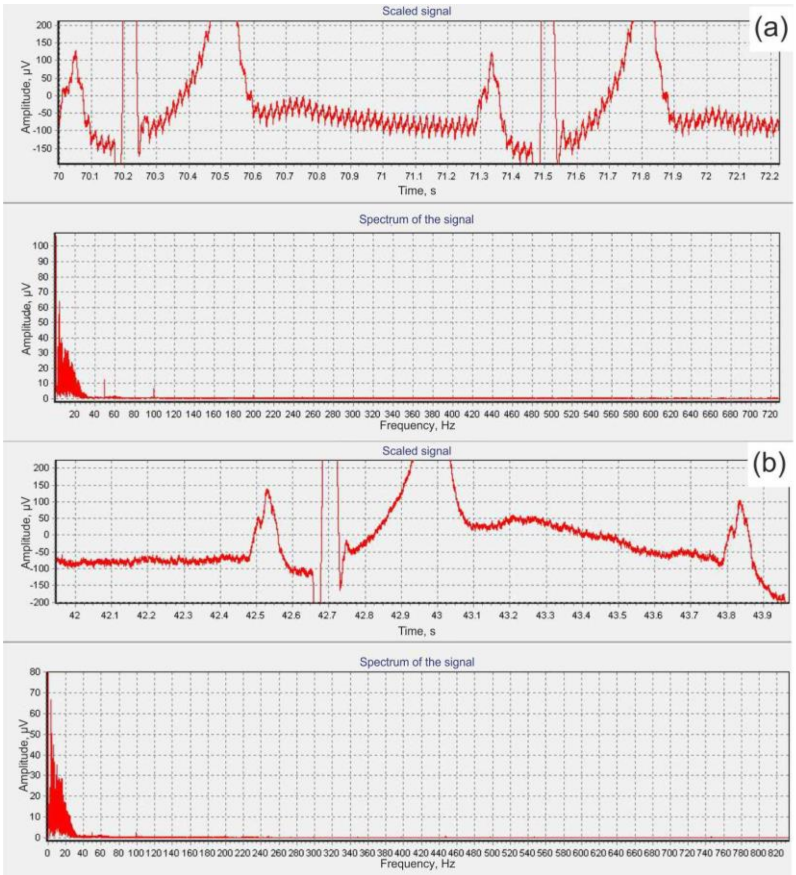

Figure 2. Results of the study of noise immunity to line interference: (a) conventional chlorine-silver electrodes by FIAB Spa (Florence, Italy), sensitivity 50 μV/div and (b) nanosensors, sensitivity 50 μV/div.

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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