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Research Article

The Possibility of Using Precordial Electrical Impedance Measurements to Study the Heart Activity Phase Structure

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Abstract

The article is described about the possibility of applying the precordial electrical impedance method for analyzing the heart activity phase structure. In the course of research, it was found that for most patients with atrial fibrillation and hypertrophic cardiomyopathy on average time duration of heart activity phases are more than the "conditional norm" by 10 - 20%.

Keyword: Phase Structure; Atrium; Ventricular; Atrial Fibrillation; Hypertrophic Cardiomyopathy

Abbreviations

CVD: Cardiovascular Diseases; SCD: Sudden Heart Death; AF: Atrial Fibrillation; PATE: Thromboembolia of the Pulmonary Artery; CVS: Cardiovascular System; ECG: Electrocardiography; EF: Ejection Fraction; SV: Stroke Volume; HCM: Hypertrophic Cardiomyopathy.

Introduction

Cardiovascular diseases (CVD) are the leading cause of death worldwide. Every year more than 17 million people die from this type of disease [1].

Among all death causes occurring outside medical institutions, the proportion of Sudden Heart Death (SCD) is about 40% [2]. In this case (SCD) people die in 95% of cases either at home or on the street. Every third death occurs without witnesses. Most often, SCD is associated with Ischemic Heart Disease.

Another common death cause are various kinds of arrhythmias. They can be divided into life-threatening and non-life-threatening. The first type requires immediate intervention in the patient's condition, with the second person can live for many years without any suspicion.

The most common variant of arrhythmia is atrial fibrillation (AF). AF is non-dangerous arrhythmia. The prevalence of this arrhythmia type in the general population is about 2% [3,4]. At the same time, "silent", asymptomatic AF develops in approximately 0.4% of the total world population [5]. AF leads to a twofold increase in the mortality risk. One of the most serious complications is pulmonary artery thromboembolia (PATE), which requires immediate medical attention. Every year more than 800 thousand people die from PATE all over the world [6].

Due to the presence of asymptomatic types of cardiac abnormalities, as well as taking into account a significant increase in the likelihood of repeated life-threatening assaults (for example, strokes or heart attacks), it is necessary to investigate the state of the cardiovascular system (CVS) of each person during medical inspections and during disease development. Additional information about the patient's status may allow for more accurate selection of an individual treatment method, which will ensure a higher effectiveness [7].

The most common diagnostic method is electrocardiography (ECG), since this technique is very simple to use and has been largely studied. However, every year non-invasive visual diagnostic methods play an increasing role in diagnosis. For example, such methods are sonography, magnetic resonance diagnostic methods and others. Almost all such medical equipment is stationary and is located in medical institutions. But the main problem of CVDs is outside hospitals and clinics.

The heart activity phase structure is the generally accepted basis of all cardiac diagnosis methods. Traditionally, when analyzing cardio activity, the electrical, mechanical, and electromechanical phases of the heart work are considered. Electromechanical phases make it possible to characterize numerically the cause-and-effect in the heart activity. It is especially important to obtain the electromechanical activity phase structure in the monitor mode. This requires simultaneous non-invasive measurements of the parameters of the electrical and mechanical heart activity.

Traditional instrumental methods of heart diagnosing do not allow to simultaneously evaluate the electrical and mechanical activity of different heart parts in the monitor mode with clinically significant accuracy, which leads to an increase in the complexity of objective treatment process monitoring and the heart disease detection in the early stages. For such a task, a combination of ECG method and multichannel electrical impedance measurements is potentially suitable today. A modern understanding of the possibilities of electrical impedance measurements makes it possible to set tasks not only to determine the temporal characteristics of the heart's activity electromechanical phases, but also to evaluate the heart's compartments and structures numerical movement characteristics.

Precordial electrical impedance research methods are described in the works of

D. Timokhin, A. Tikhomirov, S. Shchukin, V. Strelkov and others [8-14]. Over the past few years the technology of non-invasive precordial rheographical measurements has received great development. To date, electrical impedance methods allow to obtain reliable information about the phase structure of the heart activities, to determine the local movement of the ventricles walls, to measure the volumetric parameters of the heart hemodynamics [8].

The main advantages of electrical impedance methods are:

- The possibility of long-term heart parameters monitoring,
- The method of precordial radial mapping [15] allows determining local movements of the ventricle's walls, which further makes it possible to calculate cardiac hemodynamics with an error of less than 15%,
- No adverse effects on the patient.

Weaknesses

- To obtain accurate absolute values of the stroke volume (SV), it is necessary to pre-tune the system based on the MRI or CT data;
- Low prevalence of methods;
- Distrust of specialists to traditional electrical impedance measurements methods

Materials and Methods

To assess of the heart electromechanical activity, it is necessary for the system to have at least one ECG channel and several electrical impedance channels. For these tasks in the Biomedical Engineering Research Institute at BMSTU (Moscow, Russia) was developed multi-channel electrical impedance system REO-32. System characteristics are presented in table 1.

Characteristic	Value
Number of precordial electrical impedance channels	30
The number of transthoracic electrical impedance channels	1
The number of ECG channels	1
Channel sampling rate	500 Hz
Maximum amplitude, ECG channel	3 mV
Bandwidth, ECG channel	0.01...137 Hz
Impedance measurement method	Tetropolar
Probe current amplitude	1 vF
Probing frequency	100 kHz
Base impedance measurement range	1...250 Ohm
Pulse impedance measurement range	-2...+2 Ohm
Bandwidth, electrical impedance channel	0.01...117 Hz

Table 1: Characteristics of multi-channel electrical impedance system REO-32.

Studies were conducted on the basis of the Sechenov University (Moscow, Russia). Patients with a clinically confirmed diagnosis were considered. The study involved 14 people. All patients were divided into 2 nosological groups: AF (5), HCM (9). The electrode systems location on the patient's body in the precordial region is shown in figure 1. The volumetric parameters of the cardiac hemodynamics were also measured using a transthoracic electrical impedance electrode system. The localization of the transthoracic channel electrodes and the calculation of SV and EF were carried out according to the method of S.I. Shchukin, V.G. Zubenko., *et al.* [16,17]. Synchronously with electrical impedance measurements an ECG channel was recorded in the aVF lead.

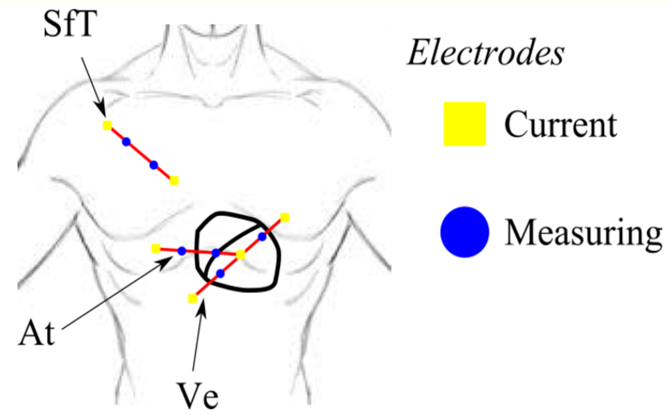

Figure 1: Electrode systems location on patients. SfT: Thoracic Channel (soft tissues); At: Atrium Channel;

Ve: Transventricular Channel.

Conditions for conducting experimental studies

- The patient was lying down,
- Room temperature: 22 to 26°C
- 2 precordial electrical impedance channels (atrial and transventricular) were used,
- 1 thoracic channel was used to account for the soft tissue blood filling,
- 1 transthoracic channel was used to calculate SV and EF,
- 1 ECG channel was used (aVF lead),
- Measurements were taken on the exhalation of the patient.

The sizes of the transventricular and atrial electrode systems were selected individually for each patient, depending on the patient's chest perimeter. The minimum size of the electrode system: 160 x 80 mm (where 160 mm is the distance between the current electrodes, 80 mm between the measuring electrodes). Maximum size of the electrode system: 260 x 130 mm. The size of the thoracic electrode system corresponded to the atrial electrode system size.

In the course of signal processing, in order to eliminate the effect of soft tissue blood filling, the data of the atrial and trans ventricular channels were recalculated taking into account the thoracic channel.

Figure 2 shows classical view of the phase structure of the heart activities, obtained on a healthy volunteer.

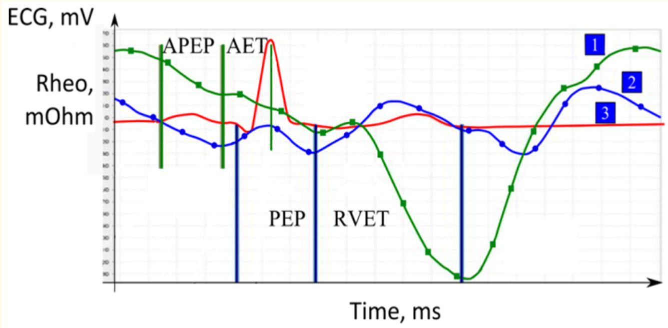

Figure 2: Phase structure of the heart compartments activities of healthy volunteers aged 22-30 years and body mass index according to A. Quetelet from 21 to 25.

APEP: The phase of the right atrium preparation for mechanical contraction; AET: The phase of mechanical atrial systole; PEP: Phase of ventricles preparation to the systole; RVET: Phase of expulsion of blood from the ventricles.

Graphs: 1 - Transventricular channel, 2 - Atrium channel, 3 - ECG.

Results and Discussion

The results of the study are presented in table 2.

In the course of the research the following main results were obtained:

1. For most patients, on average, time duration of heart activity phases is greater than the "conditional norm" by 10 - 20%,
2. In patients with AF, the longest durations of APEP (on average, APEP was 24% higher than the values obtained in healthy volunteers) and AET (more by 33%) were observed. At the same time, a low stability of the parameters from the cardiocycle to the cardiocycle during the entire study is recorded,
3. The most pronounced changes in parameters in patients with HCM are detected in the PEP period. The phase of ventricles preparation to the systole from the ventricles

Parameter	Healthy volunteers	Cardiac Patients	
		AF	HCM
The number of measurements	6	5	9
Age, years	27 ± 1	71 ± 12	44 ± 5
Body mass index according to A. Quetelet, kg/m2	23 ±2	34 ± 3	31 ± 1
The average duration of atrial preparation for systole, APEP, ms	90 ± 10	125 ± 9	102 ± 13
The average duration of atrial systole, AET, ms	100 ± 10	125 ± 13	83 ± 9
The average duration of preparation of the ventricles for systole, PEP, ms	90 ± 20	135 ± 21	137 ± 11
The average duration of ventricular systole, RVET, ms	250 ± 30	260 ± 16	265 ± 12

Table 2: The results of research conducted by the method of electrical impedance analysis of the heart activities phase structure.

exceeds the "conditional rate" by an average of 18%. At the same time, a high stability of the parameters from the cardiocycle to the cardiocycle during the whole study is recorded.

Conclusion

Our studies have shown that it is necessary to use precordial measurements in conjunction with the thoracic electrical impedance channel to conduct precordial electrical impedance measurements.

Further research and development should be aimed at improving the stability of the measurement results obtained using precordial electrical impedance mapping methods. Solving the problem of measurement stability will make it possible to achieve widespread adoption of electrical impedance technologies in the field of technical means of diagnosing human CVDs.

The developed research methods can allow the diagnosis of cardiac hemodynamics in the monitor mode, as well as be used to monitor the body's response to the medications taken.

Conflict of Interest

The authors declare that they have no conflict of interest.

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