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ABBREVIATIONS

AV – atrioventricular
SA – sinoatrial
EMF – electromotive force
HCM – hypertrophic cardiomyopathy
TMP – transmembrane cell potential
EHA – electrical axis of the heart
HR – heart rate
IHD – Ischemc heart disease
LAD – descending coronary artery
CLC – Clerk–Levy–Cristesco
SSS – syndrome sick sinus
RBBB – right bundle branch block
LBBB – left bundle branch block
PVCs – premature ventricular contractions
LMCA – left main coronary artery system
LCA – left coronary artery
LCx – left circumflex coronary artery
RCA – right coronary artery
WPW – Wolf–Parkinson–White syndrome

PREFACE

Despite the development of costly and complex methods of research in cardiology (such as echocardiography, single photon emission computed tomography or positron emission tomography scan) the electrocardiography remains the most affordable and reliable instrumental method for the diagnosis of a number of diseases of the cardiovascular system. It is the ECG but not the MB-fraction of creatine kinase or echocardiography that dictates the need for rapid and radical thrombolytic therapy. There is no other method that would compete with the ECG in the diagnosis of arrhythmia, which is so prevalent problem in the cardiologic clinic. It should be noted that the diagnosis of hypertrophy of the heart chambers, the diagnosis of myocardial ischemia and other diseases can be confirmed only with the data of the ECG.

HISTORY OF THE METHOD

Although the electrocardiogram as a diagnostic method for heart condition in clinical medicine has been used for over 100 years, but to this day it continues to amaze its contemporaries with its new capacities. For the first time it was an English scientist Augustus D. Waller who registered electromotive force of the heart from the surface of the human body (with the help of a bulky capillary electrometer of Lippmann) in 1887, in fact, almost 100 years after the discovery of "animal electricity" by L. Galvani. However, before clinical application of this technique, it took 15 years. Lippmann capillary electrometers represented the recording of the electromotive force of the heart that was difficult to analyze. Only in 1903 William Einthoven, a Professor of physiology at the University of Leiden received a recording of the electrical currents of the heart in a clinical setting, similar to modern-day performance by means of the string galvanometer of Adler, built on the principle of the apparatus for the reception of transatlantic telegrams. W. Einthoven, the inventor of the technique gave it the name of electrocardiography, and the device that recorded the currents of the heart, was called an electrocardiograph (Fig. 1). In 1907–1908 W. Einthoven created the basics of analysis of the electrocardiogram resulting from outstanding discoveries, which today helps to understand the foundation of this unique method of study of the heart. For the contribution to physiological science of the heart and clinical cardiology W. Einthoven was awarded the Nobel Prize in 1924. This scientist developed the system of standard leads, without which there is no modern electrocardiogram.

In 1934, the American scientist F. N. Wilson using the technique of the so-called unipolar leads implemented a system of six chest leads, which greatly expanded the possibilities of using the electrocardiographic method for determining physiological characteristics of a child's heart, and to diagnose diseases of the heart muscle. In 1942, the American scientist E. Goldberger created an original system of reinforced leads from the limbs, which was also included in any standard electrocardiographic studies.

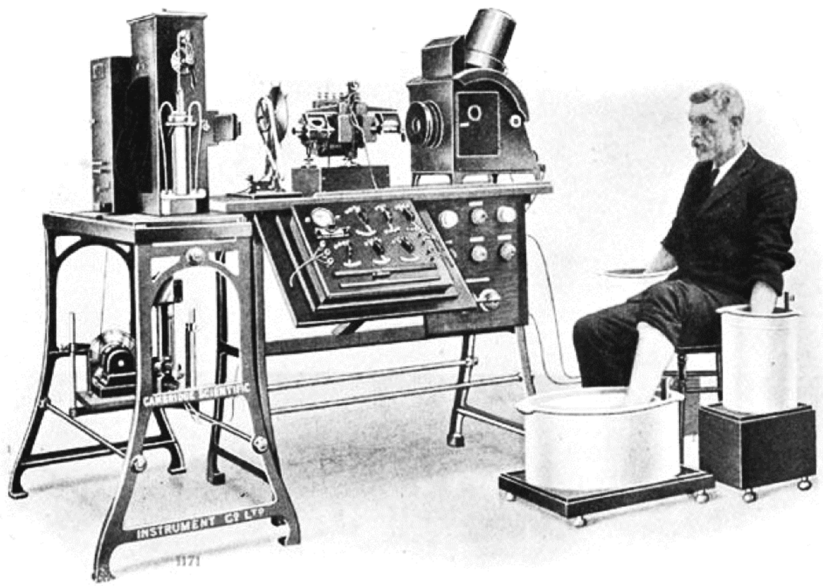

Fig. 1. String galvanometer, invented by W. Einthoven

Thus, for 70 years the standard electrocardiogram includes the recording of the electromotive force of the heart in twelve leads, six of which are the leads of the frontal plane: three standard leads according to W. Einthoven (I, II, III) and three unipolar enhanced leads from the limbs by E. Goldberger (aVR, aVL, aVF); six chest leads of the horizontal plane by F. N. Wilson (V1-V6).

Great contributions to the development of clinical electrocardiography were made by the Austrian scientist K. F. Wenckebach and the German scientist W. Mobitz.

In Russia the first work on electrocardiography was published by A. F. Samoilov, the Professor of Kazan University (1908).

ELECTROPHYSIOLOGICAL BASICS OF ELECTROCARDIOGRAPHY

The function of the heart as an organ responsible for moving blood in the human body includes:

1. Automatism – i. e. the initiation of the pulse, or the ability of the heart to spontaneous diastolic depolarization.
2. Conduction – impulse conduction to the working myocardium.
3. Excitability – ability to excitation.
4. Refractory – i. e., the impossibility of excitation under certain circumstances.
5. Contractibility – a function, which ensures blood flow in the human body.

The electrocardiogram allows us to estimate all the functions of the heart, except for the evaluation of myocardial contractility.

The heart as a tissue structure comprises:

- cells of the working myocardium, contraction of which leads to the ejection of blood from ventricles of the heart; endothelial cells, fibrous tissue;
- connective tissue cells;
- cells of the conduction system (there can be several types: R-cells, carrying out the function of automaticity; cells of Purkinje, forming fibers, which conduct impulse; transitional T-cells, which are located between R-cells and Purkinje cells) (Fig. 2);
- secretory cells, located mainly in the right atrium and produce Na-uretic peptide that is involved in the regulation of acid-base balance, and blood pressure.

In relation to the electrophysiology of the myocardial cells there are typically three alternating conditions: rest or polarization, excitation or depolarization, restoration of the resting potential or repolarization. Each of them is associated with rhythmic recharge of intra- and extracellular environment as a result of the cross-membrane migration of ions K^+, Na^+, CA^{++}, and CL^-. Being strictly regulated, it creates specific ionic basis of transmembrane potential in different phases of the evolution of electric cells (transmembrane potential is measured in millivolt – current between the outer and inner sides of the cellular membranes that are always opposite in sign charge).

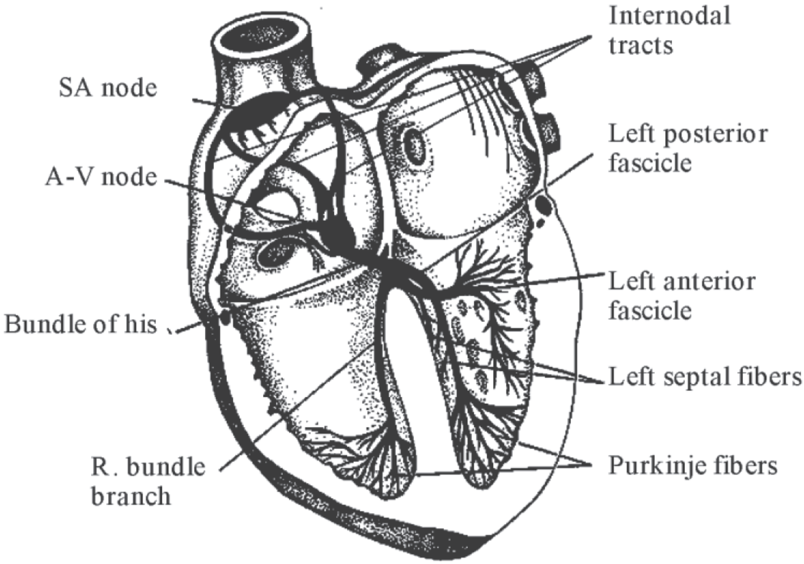

Fig. 2. Conduction system of the heart

Since in practice the recordings of the heart currents are accomplished from the surface of the body only those electrical phenomena that arise on the outside of the membranes of myocardiocytes are accessible. They interest us in the first place.

At rest all cell membranes are **polarized** so that their outer side, and therefore, the surface of single muscle fibers and myocardium on the whole are **positively** charged, i. e. the potential difference as a precondition for the appearance of current is absent.

Depolarization or activation of the cells under the influence of the electric impulse leads to the recharge of the membranes: the outer side of the excited area (cells, fibers, entire myocardium)

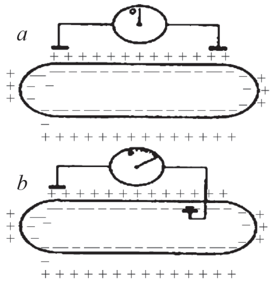

Fig. 3. Transmembrane cell potential at rest and during depolarization:
a) cell is polarized, rest state;
b) depolarization, the cell is "active"

acquires a **negative** charge (Fig. 3, *a, b*). Its appearance and rapid spread, accompanied by the neutralization of the positive charge of rest, creates a potential difference and generates an **electromotive force** (EMF) – depolarization current ("minus driving a plus in front of it"). At the end of the depolarization, the potential difference disappears, since the entire surface of the myocardium becomes **electropositive** (Fig. 4).

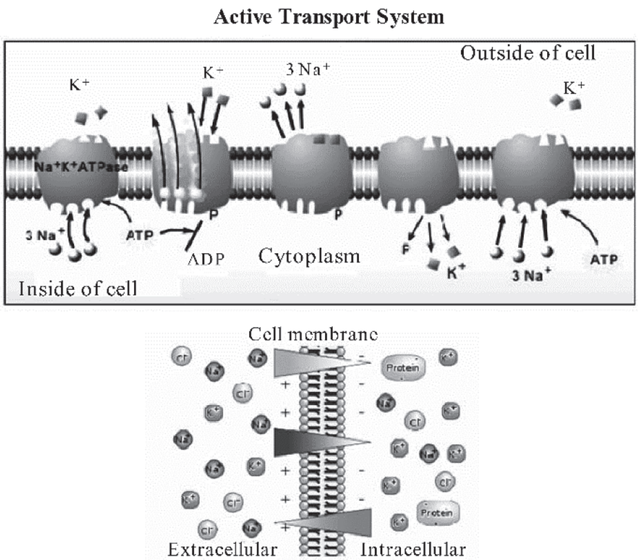

Fig. 4. The movement of ions across the cell membrane and the formation of the transmembrane potential

The essence of **repolarization** is the recovery of the initial potential (rest potential) and readiness for the next excitation, i. e. in restoring the positive charge of the external side of the cell membranes. The gradual substitution of the negative charge re-creates the EMF – this time a **current of repolarization** ("a plus driving minus in front of it").

Taking into account the laws of physics, de- and repolarization constitute typical examples of the dipole, which implies the coexistence and movement of two equal in magnitude, but opposite sign charges, located at an infinitely small distance from each other.

Under the influence of the excitation impulse countless macrodipoles of single muscle fibers – the basic sources of the EMF in the heart begin to function. Stacking, they form increasingly bigger macrodipoles of the separate fragments of the myocardium, heart chambers and eventually form a single cardiac dipole and the EMF of the heart.

Specialized, the so-called pacemaker cells (PCs) of the cardiac conduction system have the ability to generate electrical impulse. The ability to self-activation known as **automatism**, fundamentally distinguishes them from the contractile cells of the myocardium. The latter, having **excitability,** are activated only under the influence of impulses, coming from the PC.

The highest automatism is peculiar to the sinoatrial node (SA node), which suppressing lower automatic potencies of the downstream PC normally acts as a pacemaker or center of automatism of I order. Downstream PCs in the atria, atrioventricular connection (AV connection) and the ventricles act as passive conductors of excitation. In the physiological sense, they are reserve (emergency) sources of impulse formation, or centers of automatism of II and III order.

Starting in the SA node, the excitation impulse activates first the right, then the left atrium, and after a short delay in the AV connection through the system of His is transmitted to the ventricles. On their territory the interventricular septum gets depolarized first, and its parts facing the left ventricle are the first to receive a negative charge. Consequently, the excitation covers the septum from left to right. Next, the electrical impulse reaches the walls of the ventricles. Their depolarization starts at the inside of the upper subendocardial region, where there are branched terminals of the conduction system – Purkinje fibers and spreads to the epicardium (Fig. 5). Thus, the excitation of the walls of the ventricles occurs in the direction from the inside outwards.

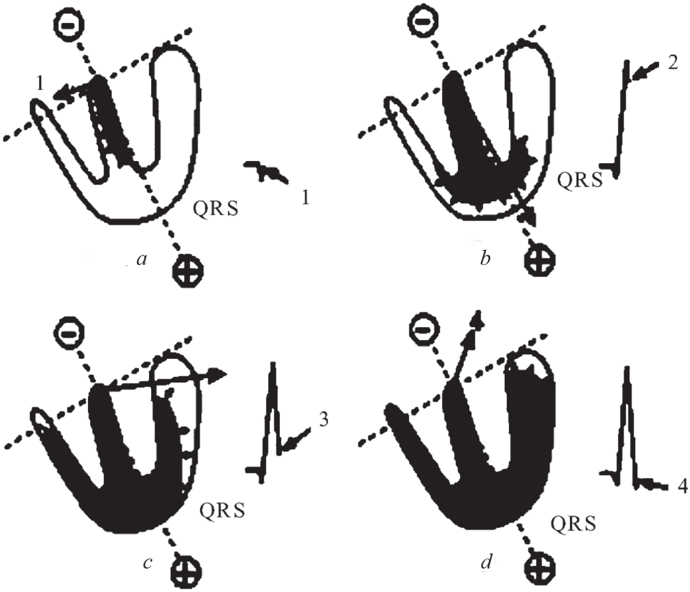

Fig. 5. Phases of depolarization of the ventricle

On the whole, there is a general trend of depolarization of the myocardium, from top to bottom and from right to left. After depolarization, the final of which is the contraction of the ventricles, the process of repolarization begins (Fig. 6).

It is clear from the above said that the EMF that occurs in the activation of the heart, is not only characterized by the quantitative value of voltage, but also a direction, i. e. it is a **vector quantity**. It is known from physics that the vector is represented by a straight