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INTERPRETATION OF ECG RECORDINGS: PART 1

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A – study design, **B** – data collection, **C** – statistical analysis, **D** – interpretation of data, **E** – manuscript preparation, **F** – literature review, **G** – sourcing of funding

ABSTRACT

Background: Despite having an academic background in the medical sciences, including students in the field, many encounter issues in evaluating electrocardiogram (also known as electrocardiograph or ECG) recordings to make appropriate diagnoses. The prevalent idea among most students currently is that ECG recordings are difficult to comprehend and even more difficult to interpret. Unfortunately, it is still possible today to come across a doctor (that is not a cardiologist) who cannot correctly evaluate an ECG, despite being frequently used as a diagnostic indicator of serious health conditions. Evaluation of an ECG recording is a key cardiac assessment that is safe, inexpensive, simple, and quick to complete. Some of the many reasons that require an ECG include: health problems that are cardiologic or related to other internal organs, evaluation of the risk of cardiovascular diseases, exclusion of potential pathological changes associated with age, and goals of disease prevention. Evaluation of the test is made difficult due to a lack of understanding of the functional mechanisms of an ECG as well as how to use it properly, which can distort the interpretation of the test.

Aim of the study: This article aims to explain the basic mechanisms of how an ECG functions, the proper method of conducting the test, and will review the basics of interpreting recordings.

Material and methods: The hope is that the knowledge and information presented here will assist in laying a foundation for better understanding disease mechanisms detected using ECG imaging, and help students current and future students effectively learn about the test.

Results: This work is a proof of concept with simulations that appropriately reflect the physiological functioning of the heart that are evaluated by ECG recordings.

Conclusions: This should make it easier for students to understand the basics of conducting and interpreting ECG tests.

KEYWORDS: electrocardiogram, interpretation, lead, complex, wave

Background

Prior to beginning our review of ECG recordings, we must explain what an ECG actually is and the mechanism of its functioning. It is also important to mention the appropriate method of performing the test in order to avoid diagnostic errors.

Electrocardiogram (ECG) is a recording of electrical voltage changes in the heart muscle tissue. The electrical energy comes from every living cell in the heart muscle. Electrical voltage in a single cell is connected to changes in the speed of permeation of sodium, potassium, and calcium ions through the cell membrane. The resulting "currents" that are generated in the heart muscle are conducted by tissues to the surface of the skin where, with the aid of appropriate electrodes, they can be registered and recorded in the form of an ECG. Thanks to this test, the electrical activity of the heart can be assessed non-invasively. The obtained recording allows for the registration of

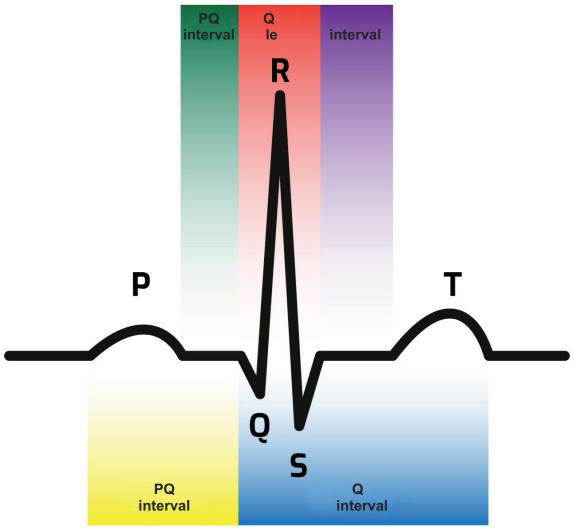

Figure 1. Diagram of waves in an ECG isoelectric line

rhythm and conduction, evaluation of the functioning of devices or implants (e.g. pacemaker), as well as evaluation of irregularities in the vascularization of the heart muscle. It can also be helpful in assessing changes in the heart muscle resulting from underlying diseases other than heart diseases [1–6].

In order to perform the test correctly, the patient must remove all clothing and accessories down to the waist (the upper half of the body) and must be placed in supine position on a couch or bed. Electrodes must be placed in the appropriate locations on the upper and lower limbs as well as the chest. The electrodes are usually covered with a special gel, which decreases the electrical resistance of the skin. The electrodes are attached to the body with the aid of rubber belts, clamps, suction cups, or affixed and then connected to the ECG with the aid of appropriately marked cables. During the ECG recording, the patient should lie motionless, not contract their muscles, and remain calm and silent. Sometimes, the person performing the test may ask the patient to inhale and keep the air in the lungs, which may bear significance in diagnostic evaluations. [1,3,7].

There are numerous components in the ECG recording that must be evaluated. In order to carry out said evaluation, we must take a closer look at what the recording itself contains. As we already know, an ECG shows a recording of the electrical activity of the heart, or more appropriately, a difference in the potential of the passing of ions through cellular membranes in the heart muscle. Thanks to the differences in "voltage" on the isoelectric line, various deviations appear, which are depicted as individual waves in the diagram below. The space between the ending of one wave and the beginning of another is known as a segment, the consolidation of Q, R, and S waves – the QRS complex, while the space between the beginning of one wave and the beginning of another is known as an interval [2–5,7–10].

Under physiological conditions, stimulation of the heart muscle is observed to go from the sinoatrial node, through the atrioventricular node, then through the bundle of His, and then to the right and left branches of the bundle [1–3,11].

In the ECG recording, we can distinguish individual leads, divided into:

– limb: I, II, III, aVR, aVL, aVF;
– precordial: V1, V2, V3, V4, V5, V6.

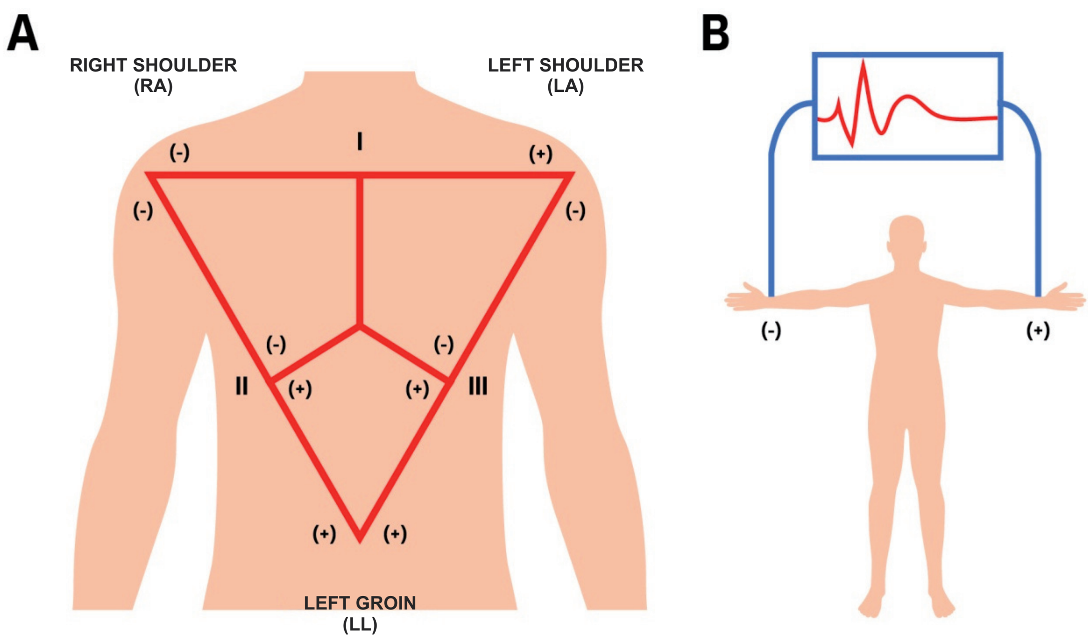

Figure 2. Einthoven Triangle

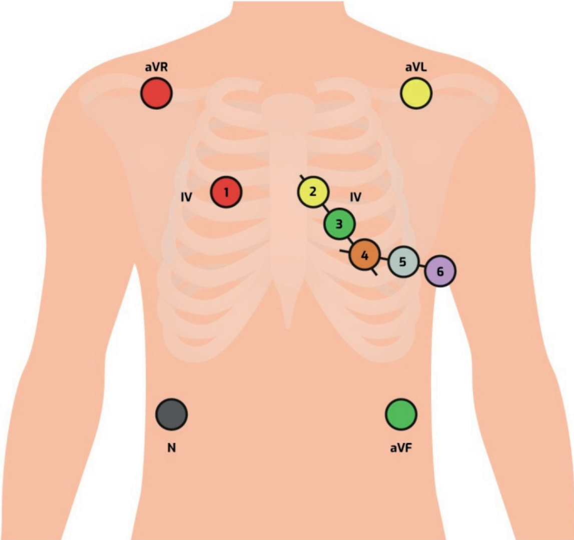

Figure 3. Diagram of 12 ECG leads

We must remember that a single isoelectric line is registered in each of the leads.

In order to understand the correct placement of each lead, we can utilize the so-called Einthoven Triangle (Figure 2), which is related to the geometrical shape of the heart muscle and the course of electrical stimulation registered by leads I, II, III [4,5,7,9,10,12].

In the case of electrodes from leads aVR, aVL, aVF and V1–V6, they are placed in accordance with the diagram (Figure 3).

We must pay particular attention to the placement of the precordial electrodes (V1–V6). The electrodes should be placed:

– V1 on right parasternal line at approx., no. 4 in the intercostal space,

– V2 on the left parasternal line at approx., no. 4 in the intercostal space,

– V3 in the direction of the left midclavicular line at approx., no. 5 in the intercostal space,

– V4 on the left midclavicular line at no. 6 in the intercostal space,

– V5 on the left anterior axillary line at no. 6 in the intercostal space,

– V6 on the left anterior axillary line at no. 6 in the intercostal space [4,5,7,9,10,12].

The technique of reading an ECG

Now that we are familiar with the placement of individual electrodes and the correct nomenclature of selected waves in an ECG test, let us move on to the technical aspects which will enable us to interpret results and later provide a diagnosis.

Firstly, we must make sure that the individual precordial and limb leads have been properly placed on the patient's body, and then exclude extrinsic deformities in the curve which can include: contamination of electrodes or their improper adhesion, interferences by variable current, respiratory movements, muscle trembling, or the patient coming in contact with metal elements of the bed during the test. Excluding these artifacts allows for reliable interpretations of the test result [2,3,9,11].

Analysis of an ECG result should be based on a detailed evaluation of the recordings created from all the leads, interpreting the precordial leads V1 to V6 as a whole. At first, after becoming familiar with the waves, the origin of the rhythm of the heart must be established, as well as the existence of possible irregularities in this area. Then we must move on to calculating the frequency of the rhythm, and then to evaluating individual ECG segments, including waves. The next step is to measure the time duration of the PQ interval, the ORS complex, and the QT interval, with the best position for this calculation being the II limb lead. Having the bipolar limb leads (I, II, III) at our disposal in the ECG, we can evaluate the electrical axis of the heart, while based on the curve of unipolar leads (aVR/aVL/aVF), we can determine the location of the heart in the chest. Based on the precordial leads (V1–V6), rotation around the long axis of the heart can be established [3,9–11,13,14].

Proper ECG components

The waves, complexes, or segments, which are components displayed on a printout from an ECG, vary according to their duration time, shape, or height, depending on the lead in which it occurs. Other important factors in the appearance of the curve are patient age, time since the patient's last meal, breathing phase, or the frequency of the heart rhythm. Let us now discuss in detail the individual accuracies of ECG waves, segments, and intervals, starting with the beginning of the recording [3].

P Wave

Generation of the P Wave corresponds to the depolarization of atria, and thus with the path of simulation from the sinoatrial node to the atrial muscles. The ascending limb of the P wave corresponds to the stimulation of the right atrium, while the descending arm with stimulation of the muscle of the left atrium [2,3].

During the course of recording of a normally functioning heart, the P wave is positive in leads V2–V6, I, II and aVF. The recording from limb lead III generally creeps up above the isoelectric line, while the aVR lead has a negative value. Looking at the ECG recording in the aVL lead, the course of the P wave will be equal to the isoelectric line, while from the V1 precordial lead, it will be positive or positive-negative (two-phase), taking into account the fact that its negative value may not exceed 0.03 mms. In the coronal plane, the angle α (the angle of the electric axis incline) of the P wave generally assumes the value of +60°. Considering normal P waves, their height should not exceed 3 mm (3 mV) in lead V1–V6 or 2.5 mm (0.25 mV) from the limb leads (I–III). The appropriate duration of the P wave is between 0.04 s to 0.11 s [9,10,14,15]. In the case of the P wave having a large positive amplitude, a negative deviation (Ta) is possible, conditioned by the occurrence of the repolarization of the atrial muscle. Generally, it is hidden among deviations of the QRS complex and has no diagnostic value.

PQ interval and segment

The PQ interval connects the P wave and the PQ segment with respect to the time it takes for the electrical impulse to pass through the sinoatrial node, to the atrial muscle, to the atrioventricular node, and then all the way to the bundle of His and its branches in the heart ventricles. Physiologically, its duration time should not exceed 0.11 to 0.20 s. An exception to this rule is tall people of a young age whose hearts work slowly, in which case the PQ interval may exceed the aforementioned maximum value. However, after physical effort, it may drop down below 0.20 s [3,9,10].

The PQ segment is a combination of the P wave and the QRS complex. Along the isoelectric line, it represents the repolarization of the atria as well as the duration of time for conduction of the stimulus between the atrioventricular node, the bundle of His, and its branches. When a person is healthy, its value should be between 0.04 to 0.1 s. However, it is dependent on any autoimmune activity in the body, which causes an increase in voltage among fibers of the sympathetic nervous system. This shortens or lengthens the PQ segment under the influence of a stimulus that affects functioning of the parasympathetic nervous system [3,9,13,14]. Based on their recorded values, we can determine the relationship between the P wave and the PQ segment in the second limb lead. This relationship is the Macruz Index, which should, for a healthy person have an average value equal to 1.2 (min. 1.0; max 1.6) [4,5,13,15].

QRS Complex

The QRS complex consists of the negative Q wave with a small deviation, positive R wave, and negative S wave. A positive R and negative S may also appear in the complex. High amplitudes (> 5mm = > 0.5 mV) are represented with capital letters, and lower voltages with lowercase letters (q, r, s). The entire QRS complex corresponds to the working stimulation of the muscle of the heart ventricles [3,9].

The size of the QRS deviation for healthy people oscillates between 15 and 20 mm. The Q wave, with a low amplitude and short duration time (≥ 0.03 s), is a physiological value in all leads. The second precordial lead (V2) is the only exception where the presence of a Q deviation is deemed to be an irregularity. During analysis of the Q deviation, we must also consider its depth. A “deep” Q deviation is one where the deviation is greater than 1/2R in the III limb lead or 1/4R in leads I, II, V5, V6. The occurrence of a “deep” Q in lead III can be caused by a high position of the diaphragm in the chest, and generally disappears during inhalation [3,9,10,13,15].

An R wave that is deemed appropriate assumes a value of 20 mm in bipolar limb leads (I, II, III) and unipolar limb leads (aVF), while in aVL, it only goes up to 11 mm. Moreover, in the precordial lead V5–V6, its value may be as high as 26 mm, while it is only up to 7 mm in V1. Physiological changes in the amplitude of the R wave in the right ventricular precordial leads are observed in newborns and children, as well as in teenagers with a vertical electrical axis of the heart [3,9,10,14,15].

The remaining components of an ECG recording include the S wave whose size should not exceed 8 mm in leads I and II, and the first precordial lead (V1) which should not exceed 25 mm [13,15].

After discussing each of the deviations of the complex, we must also mention the proper duration time which should be no greater than 0.09 s and is dependent on height, age, as well as the heart rhythm frequency of the test subject. The QRS complex can also be classified based on its voltage. When speaking of low voltage, we think of QRS deviations that are lower than 5 mm in all limb leads, or with respect to leads V1–V6, the highest QRS amplitude is lower than 10 mm [3–5,9,13,15,16].

J Point

The J point is the point that connects QRS deviations with the segment ST, which is located at the level of the isoelectric line (allowed deviations are either 1 mm higher or lower). The exception here is the “syndrome of premature ventricular repolarization”, which is characterized by a higher amplitude of the J point in leads V1–V6 (and also sometimes in I, II, III, aVL, aVR and aVF) and an elevation of the ST segment characterized by a concave or horizontal position [4,5,13,14–16].

ST Segment

The ST segment is located along the isoelectric line or between 1 mm above, or 0.5 mm below it. It connects the ending of the QRS complex with the beginning of the T wave. The duration time of the ST segment should be between 0.02 and 0.12 s. However, it is not an essential indicator in evaluation of the heart muscle [3,9,13,15,16].

Under physiological conditions, the ST segment may be located below the isoelectric line for people with a vertical position of the heart in the limb III lead (and sometimes also in II), while its elevation above the line can be observed in the right ventricular precordial leads and is dependent on the position of the J point in relation to the isoelectric line. This phenomenon most often occurs in young people who are physically active [3–5,9,10,14,15].

T Wave

A deviation that indicates entry into the final phase of contraction of the heart ventricles also indicates their repolarization. Healthy individuals have a T wave with a non-symmetrical, dome shape and direction that is consistent with the QRS complex [3,10].

The physiological T deviation is positive in the I lead. Generally, it also has a similar shape in leads II and aVF, while it varies in leads III and aVL. It always has a negative value in the unipolar limb lead aVR,. Looking at electrodes V1–V6, their recording on the left side will always be positive, while on the right side (depending on the age of the patient) it can be either positive or negative [3,9,10,13].

The normal range of the amplitude of the T wave is 2–7 mm (0.2–0.7 mV) in bipolar limb leads. Values with a lower voltage are known as flat waves, while higher values correspond to high waves. Normal T deviation in lead II should equal to ¼ of the height of the R wave or twice the height of the P wave while in the precordial leads, the voltage for is = 2–10 mm [3,9,10,13,14]. The whole repolarization process of the heart muscle lasts from 0.12 to 0.16 s in the ECG recording. However, this value is variable and is dependent on heart rhythm frequency. An increase in the speed of heart functioning conditions a shortening of the duration of the T wave [4,5,9,10,13].

QT Interval

The value of the QT interval is determined by the measurement of time connecting the period between the beginning of the depolarization of the ventricles, all the way to the end of repolarization. The time of the QT interval includes the length of the QRS complex, the ST segment, and the T wave. This value is dependent on sex, age, physical activity, speed of heart function, and autoimmune activity. This means that the time of the QT interval is shorter for children compared with adults. This comparison is also valid for QT for women and men or for people who are physically active or not [4,5,13,14].

U Wave

The U Wave is an unstable phenomenon on the isoelectric line with a positive character and a deviation of up to 3 mm in precordial leads and 2 mm in limb leads. The only exceptions are the leads V1 and aVR where it assumes a negative value. The U wave is most often present in an ECG recording for young people when the heart functions slowly [2,4, 5,9,13–15].

Interpretation of the ECG recording

Relevant information for the appropriate description of an ECG printout:

- patient age,
- sex,
- clinical picture,
- drugs taken,
- possibility to compare with previous ECG,
- possibility to see the evolution of changes in the studied ECG.

The technique for outlining an ECG description consists of the so-called "description decalogue", which should include the following elements:

- checking the accuracy of the connections of leads, the speed of the movement of paper as well as characteristics,
- description of the heart rhythm along with its frequency,
- description of the electrical axis of the heart,
- evaluation of the P waves,
- evaluation of the PQ interval,
- evaluation of QRS as far as conduction and duration time,
- evaluation of QRS as far as hypertrophy,
- evaluation of QRS as far as pathological Q or reduction of R,
- evaluation of ST segment,
- evaluation of the occurrences of rhythm irregularities,
- evaluation of the functioning of any implanted device (e.g. stimulator).

Items a through c should always be put on the ECG recording, while the remaining ones are only added if pathologies are detected.

INTERPRETATION OF A NORMAL ECG RECORDING

Patient Age: 33
Sex: M

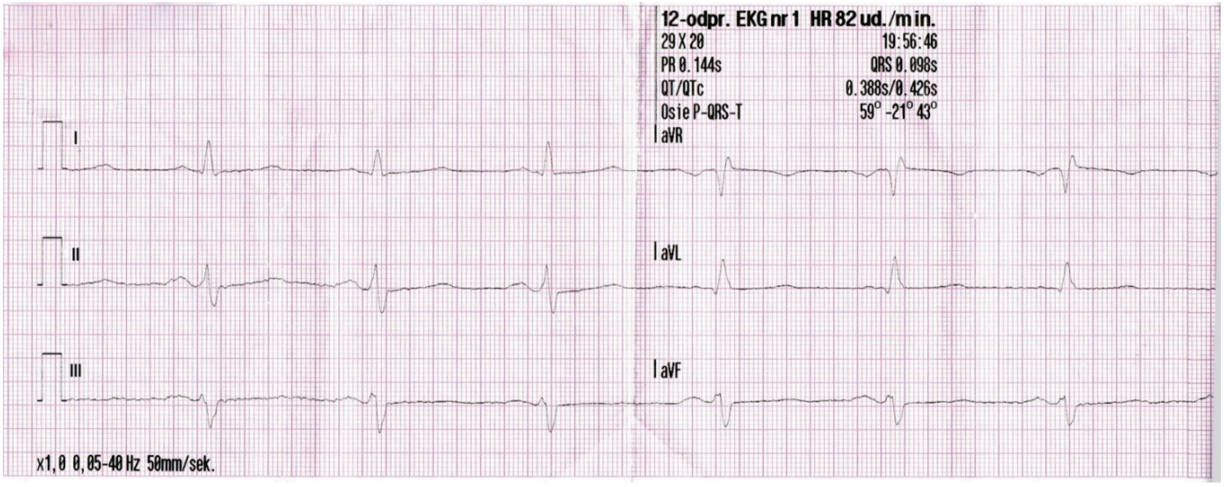

Figure 4. The first part of the normal ECG (limb electrodes)

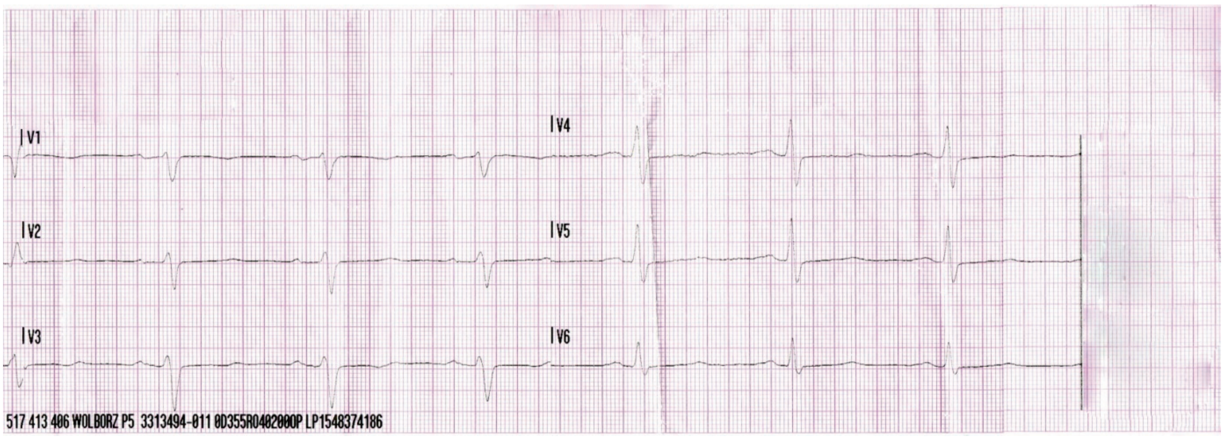

Figure 5. The second part of the normal ECG (precordial electrodes V1–V6)

DESCRIPTION

a) 25 mm/s, 10 mm/Mv,

b) regular sinus rhythm with a frequency of 75 beats/min,

c) appropriate electrical axis of the heart, without pathological changes [2,14,17–19].

In conclusion, the factors which determine the appropriate interpretation of an ECG recording, apart from knowledge and medical experience, also include remembering to properly prepare the patient for the test and the proper placement of electrodes on a patient's body. It is important for both medical students and doctors to continually improve ECG techniques.

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