Ministry of Health of Ukraine
Kharkiv National Medical University

ELECTROCARDIOGRAPHIC METHOD OF CARDIAC FUNCTION EXAMINATION. TECHNIQUE OF ECG REGISTRATION AND READING

Methodical instructions for students

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Recording ECG. Development of electrocardiography is connected with the name of a Dutch physiologist Einthoven, who was the first in 1903 to record biocurrents of the heart by a string galvanometer. He developed some theoretical and practical principles of electrocardiography.

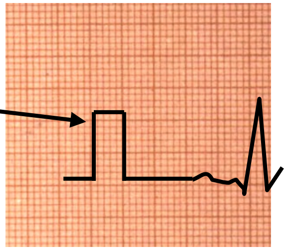
A modern **electrocardiograph** is actually a voltage-measuring instrument. It includes the following parts:

1. The sensitive elements, electrodes, which are attached to the body of the patient to pick up the potential differences that arise during excitation of the heart muscle, and lead wires;
2. Amplifiers, which amplify the minutest voltage of electromotive force (1 – 2 mV) to the level that can be recorded;
3. A galvanometer to measure the voltage;
4. A recording instrument, including a traction mechanism and a time marker;
5. A power unit.

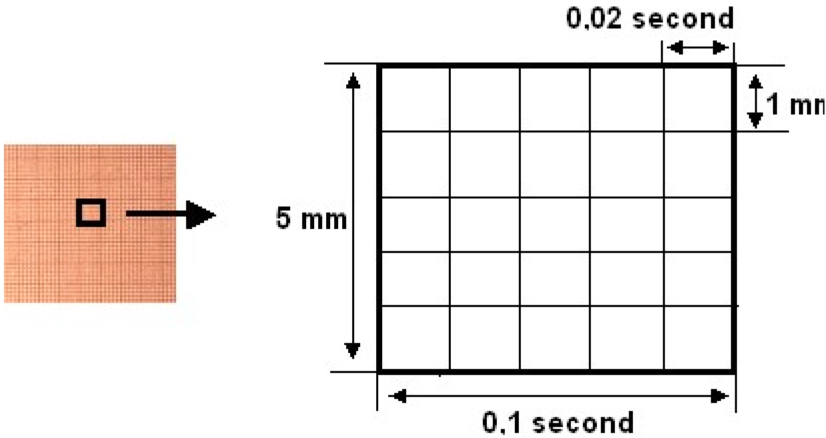
Operating principle. Fluctuations in the potential difference that arise during the excitation of the heart muscle are sensed by the electrodes attached to the patient's body and transmitted to the apparatus. The input voltage is extremely low, and it is therefore amplified 600 – 700 times. Since the magnitude and direction of the electromotive force incessantly change during the cardiac cycle, the galvanometer pointer shows variations in the voltage a recording device draws a curve on a moving paper to show graphically these fluctuations. The recording principle differs with various instruments. Electrocardiographs are popular in which the fluctuations are recorded on a moving paper during the measurement. These are ink-writing instruments, which draw curves on paper. There are electrocardiographs in which special heart-sensitive paper is used. Dark paper is coated with heart-sensitive layers of paraffin and chalk; a hot stylus, which removes paraffin from the colored supporting paper, does the record.

Whichever instrument is used, the sensitivity of the galvanometer is so selected that the voltage of 1 mV causes 1-cm deviation of the recording device. The sensitivity and amplification of the apparatus should be checked before recording electrocardiograms. To that end, a standardization voltage of 1 mV should be used, and this caused a 1-cm deviation of the stylus.

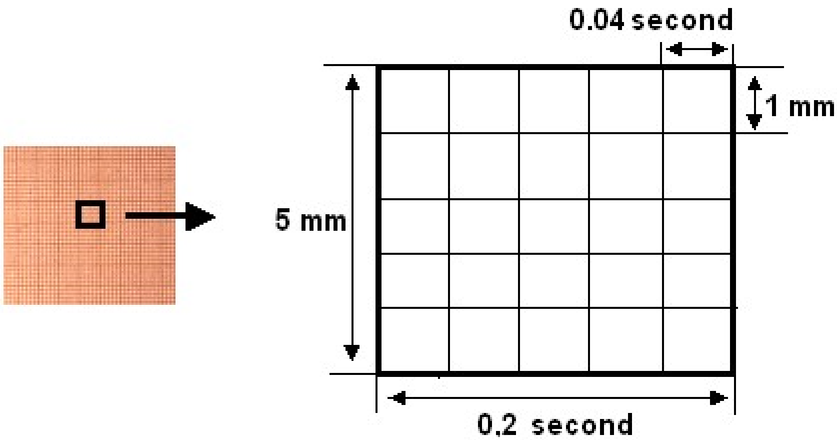
A normal one-millivolt curve
looks like a square wave.
The height of the vertical lines is 1 cm.



The tape may move at various speeds, from 25 to 100 mm/s, but the speed of 50 mm/s is usually preferred. Once the speed of the tape is known, it is easy to calculate the duration of the separate elements of the ECG. Waves amplitude is measured in mm, duration – in seconds.



ECG paper. The paper graduated in millimeters is used to record ECG. If an ECG is recorded at a speed of 50 mm/s, one small block represents 0.02 second on the horizontal line and 1 mm on the vertical line. Since a large block is five small blocks wide and five high, each large block represents 0.1 second (horizontal) and 5 mm (vertical).



If an ECG is recorded at a speed of 25 mm/s, one small block represents 0.04 second on the horizontal line and 1 mm on the vertical line. A large block represents 0.2 second (horizontal) and 5 mm (vertical).

The ECG leads

To record a routine ECG, 12 leads are used in clinical practice: 3 standard bipolar limb leads, 3 augmented unipolar limb leads, 6 chest leads.

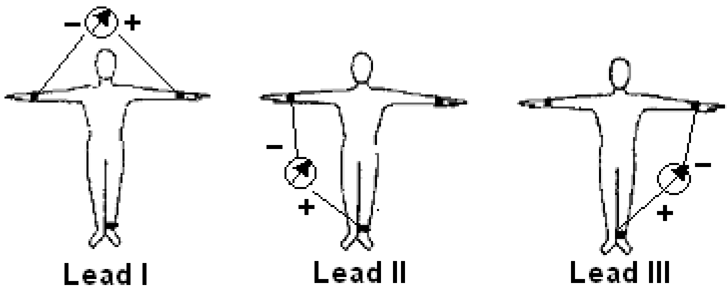
Standard Bipolar Limb Leads

Standard leads proposed by Einthoven in 1913 y., record potential difference between two points of the body. The electrodes are placed on the right arm, the left arm, the left leg, and the fourth electrode on the right leg is connected with the earth wire.

Lead I is obtained by connecting the right arm (-) and left arm (+) electrodes.

Lead II is obtained by connecting the right arm (-) and left leg (+) electrodes.

Lead III is obtained by connecting the left arm (-) and left leg (+) electrodes.



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arks (+) and (-) indicate electrode connection to the positive or negative galvanometer pole (Fig. 4.50).

Fig. 4.50. Electrode placement in the standard leads technique.

Augmented Unipolar Limb Leads

Goldberger proposed augmented unipolar leads in 1942 year. Before Goldberger proposition unipolar limb leads by Wilson were taken with the exploring electrode connected to the designated extremity (right arm, left arm, left leg) and the indifferent electrode (central terminal) connected to all three limbs, including the extremity being explored. It was observed that the final deflections obtained with the Wilson central terminal system in the limb leads were generally of very low voltage, making interpretation difficult. Coldberger modified or “augmented Wilson’s extremity lead, increasing the amplitude of the deflections by 50%. He proposed to exclude from the electrode connection the electrode of the extremity being explored. The letter “a” is used to designate the augmented lead. Three augmented unipolar leads are distinguished (Fig. 4.51):

aVR: augmented unipolar right arm (+) lead, the central (-) terminal is connection of the right arm and left leg electrodes;

aVL: augmented unipolar left arm (+) lead, the central (-) terminal is connection of right arm and left leg electrodes;

aVF: augmented unipolar left leg (+) lead, the central terminal is connection of right arm and left arm electrodes.

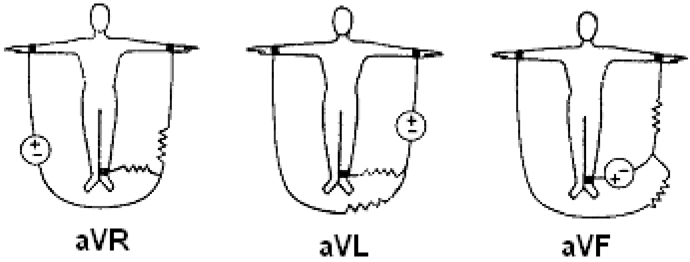


Fig. 4.51. Electrode placement in the augmented leads technique.

Unipolar Chest Leads

Wilson proposed unipolar chest leads in 1934 year, are designated by the single capital letter V followed by a subscript numeral that represents the location of the active electrode on the precordium. The negative Wilson electrode is formed by connection of right arm, left arm, left leg electrodes.

In the 1938 the American and British Heart Associations appointed committees to standardize the nomenclature of precordial leads. The positions of the chest leads selected are (Fig. 4.52):

V_1: fourth intercostal space, right sternal border

V_2: fourth intercostal space, left sternal border

V_3: midway between V_2 and V_4 on a line jointing these two points

V_4: interspace in which apex is located (fifth or sixth); midclavicular line

V_5: anterior left axillary line; on the same level with V_4

V_6: left midaxillary line; on the same level with V_4 and V_5

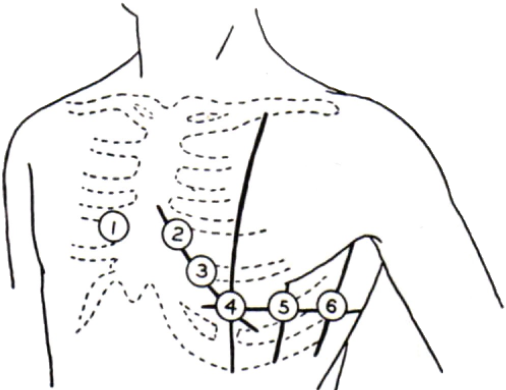
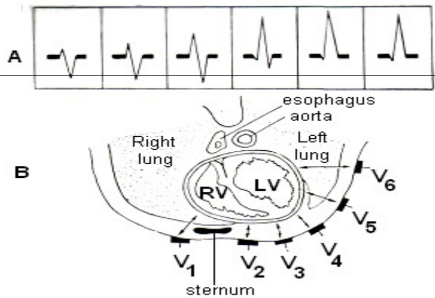


Fig. 4.52. Electrode placement in chest leads technique.

The most important leads to remember in relation to the anatomy of the heart are:

Left leads	*Right leads*
Lead I	Lead III
Lead II confirms alterations in lead I or lead III, therefore:	
Leads I, II	Leads III, II
aVL	aVF, aVR
V_4, V_5, V_6	V_1, V_2



V_3 – transition zone between right and left sides of the heart

Fig. 4.53. A, the QRS changes commonly seen in leads V_1 to V_6 in a normal subject. **B,** cross-section of the heart in the thoracic cage. Note the relation of chest electrodes to the anatomy of the heart.

Basic ECG Principles

Einthoven Triangle. The Einthoven equilateral triangle concept supposes that the left arm, right arm, and left leg form the apexes of an equilateral triangle, while the heart, an electrical point, is assumed to be the center of the triangle. At any given moment of the cardiac cycle, the electromotive forces generated by the heart may be projected to the sides of the triangle. The sides of the triangle are the analogous to the three standard limb leads and are called lead axes (Fig.4.54).

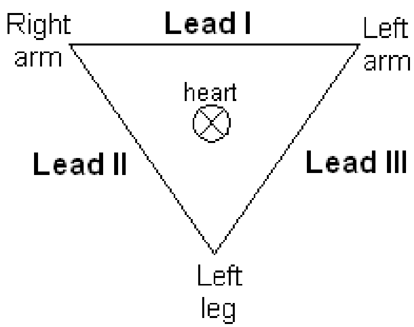


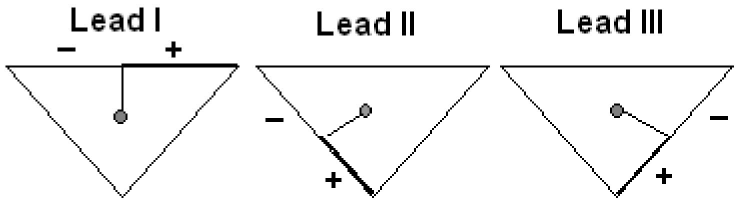
Fig. 4.54. The equilateral triangle of Einthoven, formed by leads I, II, and III.

The three standard leads have been arbitrarily established so that in lead I the right arm is negative and the left arm is positive, in lead II the right arm is negative and the left leg is positive, and in lead III the left arm is negative and the left leg is positive. These polarities are transported onto the Einthoven triangle.

The perpendicular from the center of the triangle divides each lead axis into two parts – positive turned to the positive limb and negative turned to the negative limb.

A single vector, called cardiac vector, which has magnitude, direction, and sense, represents depolarization and repolarization.

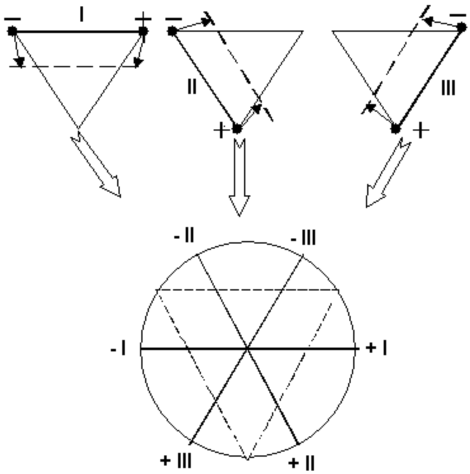
A vector projections that fall on the positive half of a lead axis appear as a positive deflections on that lead in the ECG, and on the negative half – as a negative deflection.



A vector force parallel to a given lead axis will project a large deflection in that lead; a vector perpendicular to a lead axis will project a small or biphasic complex in that lead (Fig. 4.55).

Fig. 4.55. Polarity of standard leads axes.

Triaxial and Hexaxial Frontal Plane Lead Reference System



When three sides of the triangle (leads I, II, and III) are transported so that their centers are superimposed on one another, the triaxial reference system described by Bayley is formed (Fig. 4.56).

Fig. 4.56. The triaxial reference system of Bayley, produced by transposing the three sides of the triangle (leads I, II, and III) to a common central point.

The hexaxial reference system is produced by adding the augmented unipolar limb lead axes to the triaxial system (Fig. 4.57).

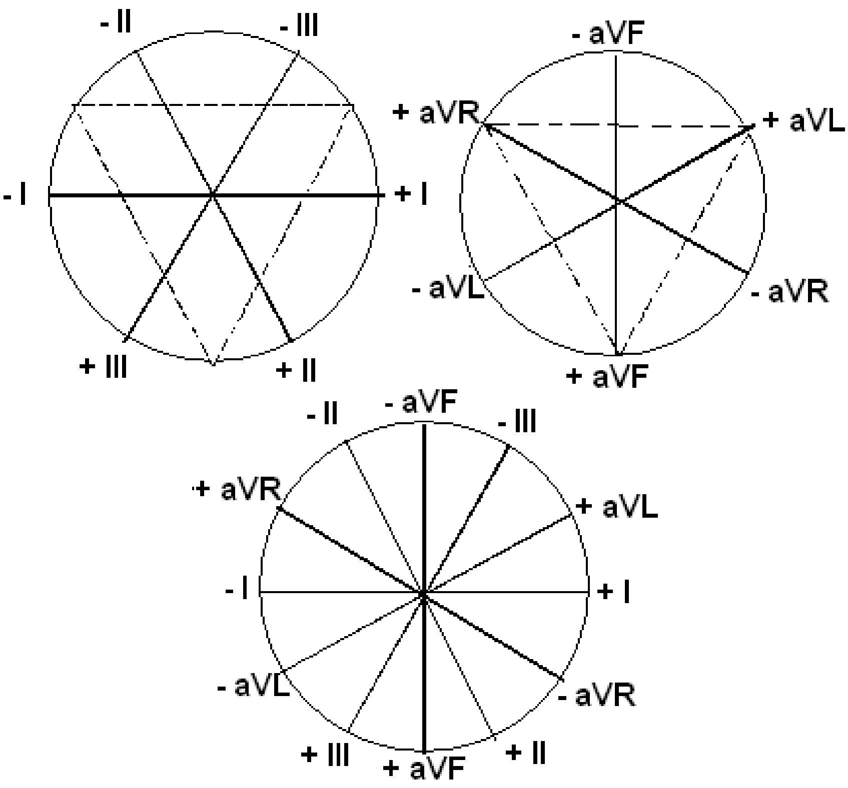


Fig. 4.57. The hexaxial reference system, produced by adding the augmented unipolar limb lead axes to the triaxial system.

The Electrical Axis of the Heart

The electrical axis of the heart coincides with its anatomical axis, and lies through the interventricular septum.

Einthoven's triangle and hexaxial reference system are useful for determining the electrical axis of the heart.

The basic principle is that an electrical force parallel to a given lead axis will record its largest deflection in that ECG lead; an electrical force perpendicular to a lead axis will record a small complex in that ECG lead.

If the cardiac vector is directed toward the positive pole of lead axis the deflections are positive in a given lead; if the cardiac vector is directed toward the negative pole of lead axis the deflections are negative in a given lead.

The electrical axis of the heart is determined by the shape of ventricular complexes in standard leads.

The relation between the electrical axis and the magnitude of the QRS complexes in standard leads is described by Einthoven triangle. The magnitude and direction of the electromotive force are designated by the A – B arrow.

If vertical lines are drawn from the ends of this arrow to the sides of the triangle, the difference of potentials recorded in each lead can be obtained.

In the normal position of the heart the direction of electrical axis is downward and leftward, therefore the highest R wave will be recorded in the lead II, the lowest – in the lead III (Fig. 4.58).

Values of R wave amplitude in normal position of the electrical axis can be shown as follows: $R_{II} > R_{I} > R_{III}$, or it can be calculated that amplitude of the R wave in lead II is equal to the algebraic sum of R in leads I and III: $R_{II} = R_{I} + R_{III}$.

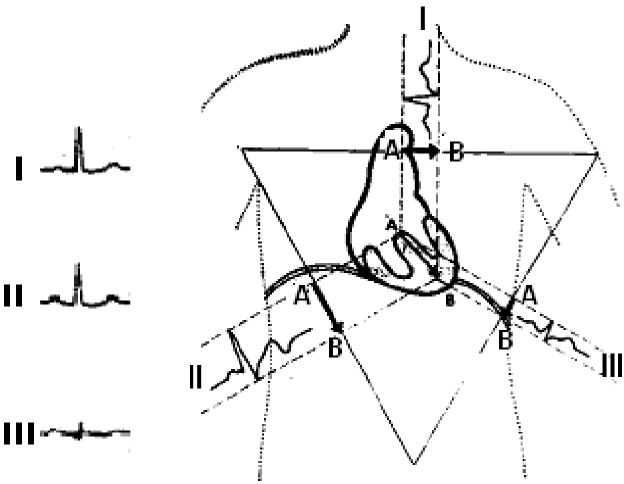


Fig. 4.58. Normal position of the heart electrical axis.

The direction of electrical axis of the heart changes depends on the position of the heart in the thoracic cage.

In high diaphragm level (hypersthenic persons) the heart assumes horizontal position (so-called "lying heart"), and electrical axis of the heart deviates to the left or horizontal become more parallel to the lead I. (Fig. 4.59).

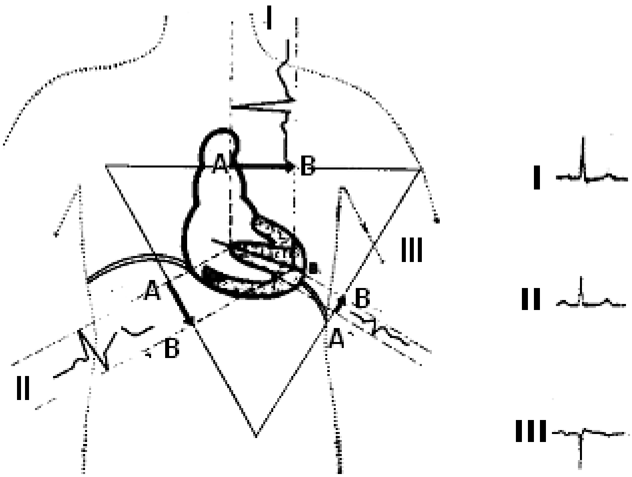


Fig. 4.59. Horizontal position of the heart electrical axis.

Therefore, the highest R wave in horizontal position of the heart is recorded in the lead I: $R_I > R_{II} > R_{III}$.

In low diaphragm level (asthenic subjects) the position of the heart is vertical (so-called “drop heart”), and electrical axis of the heart deviates to the right or vertical, that is, more parallel to the lead III (Fig. 4.60).

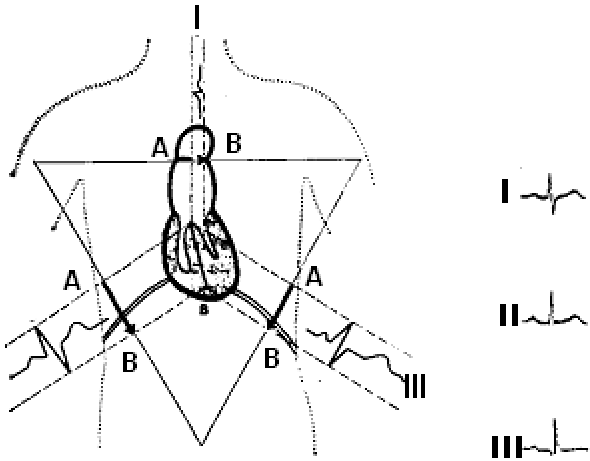
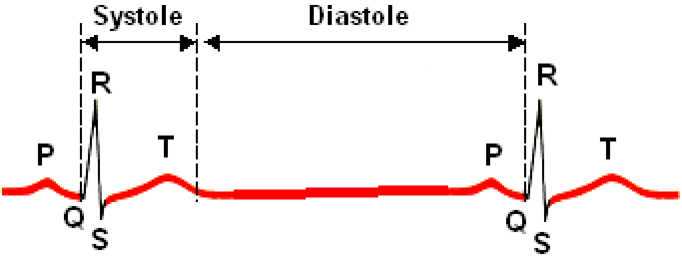


Fig. 4.60. Vertical position of the heart electrical axis.
The highest R wave is therefore recorded in lead III: $R_{III} > R_{II} > R_{I}$



The Electrocardiogram. The electrocardiogram is simply a graphic representation of the electrical forces produced by the heart (Fig. 4.61).

Fig. 4.61. Normal electrocardiogram: sinus rhythm.

Electrical activation of the heart is initiated by the SA node; however, this does not cause an electrical deflection on the surface ECG.

P wave

The P wave is the first upward deflection and is the graphic representation of the electrical activation of the atria. As impulse at first cause excitation of the right atrium and than the left atrium, the ascending portion of P wave reflects depolarization of the right atrium, and descending portion reflects depolarization of the left atrium (Fig. 4.62).

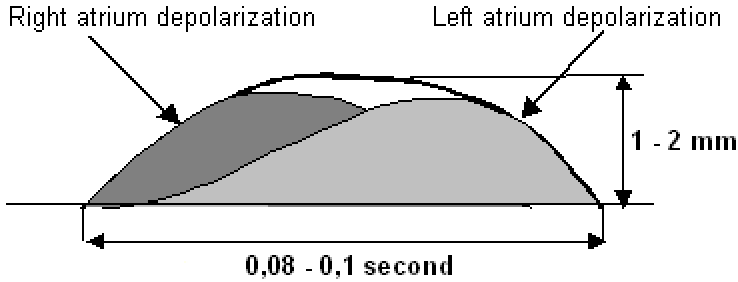


Fig. 4.62. The normal P wave formation.

1. The normal P wave duration is 0.08 – 0.10 second, amplitude - 1-2 mm.
2. The normal P wave is upright in the I, II, aVF, V_2 – V_6 leads.
3. P wave may be upright, two-phased in III, aVL, V_1 leads, and sometimes even inverted in the III and aVL leads.
4. P wave is always inverted in the aVR lead.

P – Q (or R) interval measured from the beginning of the P wave to the onset of the Q (or R) wave includes activation in atria, the AV node, the His' bundle, bundle branches, and the Purkinje network. The normal P – Q duration is 0.12 – 0.2 second. The P – Q segment, measured from the end of the P wave to the onset of the Q wave, represents mostly the delay in activation as the impulse passes through the AV node and His' bundle (Fig. 4.63).

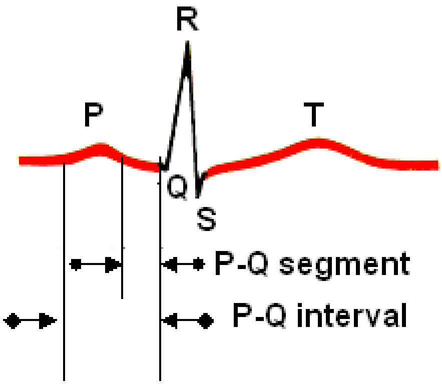


Fig. 4.63. The P – Q segment and P – Q interval.

Ventricular complex QRST

Q wave represents depolarization of the interventricular septum.

1. The normal Q wave amplitude in all leads except aVR is not more than ¼ of the R wave amplitude, and its duration is 0.03 second.
2. The normal Q wave is inverted in I, II, III, aVL, aVF, V_4 – V_6 leads.

3. Q wave may be deep and wide in the aVR lead, or even QS complex may register.

R wave represents the process of depolarization of the ventricles.

1. The normal R wave amplitude is 5-15 mm
2. The normal R wave is recorded in all standard and augmented limb leads. In the aVR lead R wave may be low or even absent.
3. In the chest leads R wave amplitude increases from V_1 to V_4, and than slightly decreases in V_5 and V_6 leads.
4. $R_{V1,V2}$ reflects activation of the interventricular septum, and R wave in V_4, V_5, V_6 leads activation of the right and left ventricles.

S wave formation on the ECG reflects depolarization of the basal parts of interventricular septum of right and left ventricles.

1. The normal S wave is inverted, its amplitude in the different electrocardiographic lead is within the large ranges, not exceed 20 mm (2.5 mm on the average).
2. In the limb lids S wave amplitude is low, except aVR lead, in the normal position of the heart in the chest.
3. In the chest leads S wave amplitude decreases from V_1, V_2 to V_4, and in V_5, V_6 leads S wave amplitude is very low or S wave may be even absent.
4. Equal S wave and R wave amplitude in the chest leads are usually in the V_3 (“transition zone”) or (rarer) between V_2 and V_3 or V_3 and V_4.

The QRS interval, measured from the beginning of the Q wave to the end of the S wave, represents the process of depolarization of the ventricles. The normal duration of the QRS interval is 0.06 – 0.1 sec., this time corresponds to the intraventricular conduction (Fig. 4.64).

The ST segment represents the period when all parts of the ventricles are in the depolarized state. The ST segment duration depends on the heart rate (Fig. 4.64).

T wave represents repolarization of both ventricles. The normal T wave is asymmetric: the gradual ascent converts into a rounded summit, which is followed by abrupt descent.

1. The normal T wave duration is 0.12 – 0.16 second, amplitude – 2.5 – 6 mm.
2. The normal T wave is always upright in I, II, aVF, V_2 – V_6, T_I > T_{III}, and T_{V6} > T_{V1} leads.
3. T wave may be upright, two-phased or inverted in III, aVL and V_1 leads.
4. The normal T wave is always inverted in aVR lead.

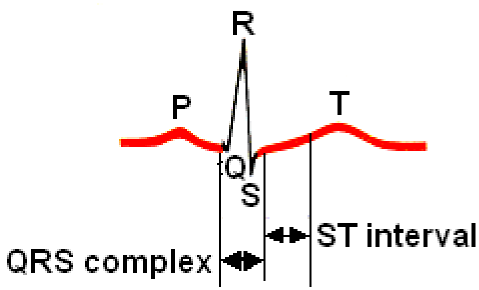
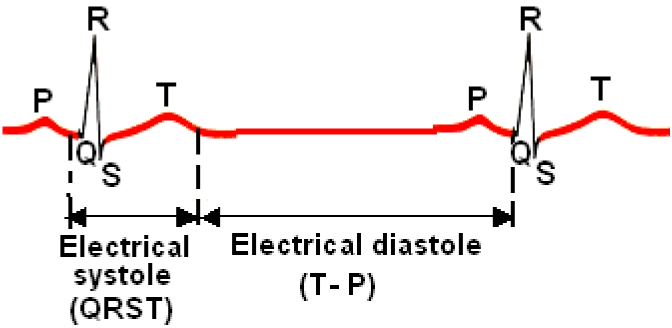


Fig 4. 64. Ventricular complex QRS and ST segment on the normal ECG.

Q – T interval (QRST complex), measured from the beginning of the Q (or R) wave to the end of the T wave, represents electrical ventricular systole. Its duration depends on the cardiac rate. The Q – T interval in women is longer than in man. For example, at the rate of 60 – 80 beats per minute, Q – T duration is 0.32 – 0.37 second in men, and 0.35 – 0.4 in women (Fig. 4.5).



T – P interval, measured from the end of the T wave to the beginning of the P wave, represents electrical diastole of the heart. Its duration depends on the heart rate (Fig. 4.65).

Fig. 4.65. Electrical systole and diastole on the normal ECG.

In each cardiac cycle there are two electrical processes: depolarization and repolarization. Depolarization is an electrochemical phenomenon that occurs rapidly. Repolarization is an electrochemical phenomenon of energy restoration that occurs more slowly. Therefore, QRS complex (ventricular depolarization) is of short duration, but the T wave (ventricular repolarization) is of long duration (Fig. 4.66).

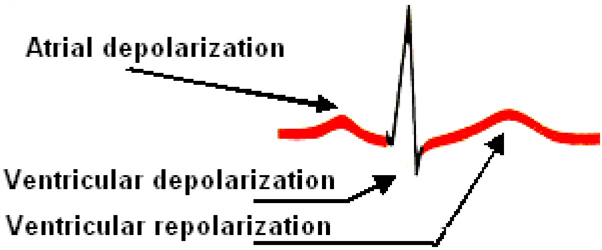


Fig. 4.66. The depolarization and repolarization portions on the normal ECG.

Interpretation of the ECG

1. *Determination of the Cardiac Rhythm Regularity.* The R-R intervals in regular rhythm should be equal. Its fluctuation normally does not exceed 0.1 second. Greater variations in the R-R intervals duration indicate irregular cardiac rhythm.
2. Calculation of the Heart Rate. In regular cardiac rhythm the heart rate is determined by formula: HR = $\frac{60}{R-R}$; where 60 is a number

of seconds in minute, R-R – duration of the R-R intervals in seconds.

3. Measurement of the ECG Amplitude. The R waves amplitude are measured in standard leads. If the amplitude of the highest R wave does not exceed 5 mm, or the sum of the R waves amplitude in the three standard leads is less than 15 mm the ECG voltage is considered decreased.
4. Determination of the Cardiac Rhythm Pacemaker Site. The normal sinus rhythm is characterized by upright P wave in lead I, II, aVF following by QRS complex. The P waves configuration is equal in each lead.
5. Estimation of the Conductivity._The P wave duration indicates time of atria activation, the P – Q interval and the QRS complex duration – ventricular activation. Increased duration of these waves and intervals indicates slowed impulse conduction in corresponding part of the cardiac conduction system.
6. Determination of the Electrical Axis of the Heart.
7. Measurement of the duration and amplitude of the ECG waves and intervals.
8. ECG conclusion. In the ECG conclusion it is necessary to note following:

a) The cardiac rhythm pacemaker (sinus or nonsinus rhythm);
b) Regularity of the cardiac rhythm (regular or irregular);
c) The heart rate;
d) Position of the electrical axis of the heart;
e) Presence of the four ECG syndromes: arrhythmias, abnormalities of conductivity, atrial and ventricular hypertrophy, myocardial damage (ischemia, injury, necrosis, scar).

Electrocardiographic method of cardiac function examination.

1. When the ECG rhythm is called regular?

A. R-R interval differ by more than 10%;

B. R-R interval differ by no more than 0.1 s;

C. R-R interval differ by more than 0.1 s;

D. R-R interval differ by more than 0, 2 s;

E. R-R interval differ by no more than 10%

2. Which P wave is of sinus origin?

A. P wave is before each QRS, singles in shape and size, positive;

B. P wave is before each QRS, varies in amplitude;

C. P wave is hidden in complex QRS;

D. P wave is negative before each QRS;

E, P wave is not proceed each QRS;

3. Which standard ECG lead is normally has the highest voltage?

A. I;

B. II;

C. III;

D. III at the height of expiration;

E. II at height of inspiration.

4. What is the value of the angle alpha of the ECG in humans normosthenic type constitution?

A. 0 - 30

B. 31 - 70

C. 71 - 90

D. 91 - 180

E. 0 - (- 180)

5. In which lead T wave normally always negative?

A. I standard;

B. II standard;
C. III standard;
D. AVR;
E. AVF.
6. Which interval is called the electrical systole of the heart?
A. P-Q;
B. QRS;
C. Q-T;
D. R-R;
E. P-P.
7. What does the increase in systolic performance?
A. Functional weakness infarction;
V. Tachycardia;
S. Polytopic rhythm;
D. Intracardiac conduction disorders;
E. Myocardial hypertrophy.
8. Where V4 chest electrode is located?
A. Right sterna border in 1V intercostal spaces;
B. Left sterna border in 1V intercostal spaces;
C. On the left anterior axillary line;
D. At the apex of the heart;
E. On the posterior left axillary line.
9. What is a sinus rhythm?
A. P wave is positive before each complex QRS, duration of R-R ranges, P-Q interval ranges from 0.25 to 0, 35 sec; within 0,15-0,45 sec;
B. P wave is before each QRS, not uniform amplitude and shape;
C. P wave before each complex QRS, duration of R-R ranges to 0.10 sec;
D. P wave before each QRS complex is negative;
10. What does the high voltage ECG mean?
A. Functional weakness infarction;
B. tachycardia;

C. polytopic rhythm;
D. inflammatory changes in the myocardium;
E. myocardial hypertrophy.
11. What does lowering voltage ECG mean?
A. electrical axis of the heart deviation;
B. tachycardia;
C. polytopic rhythm;
D. inflammatory and sclerotic changes in the myocardium;
E. myocardial hypertrophy
12. Electrical axis of the heart deviation to the left:
A. The highest R wave in lead I, the deepest S wave in lead III;
B. The highest R wave in lead III, the deepest S wave in lead I;
C. The highest R wave in lead I;
D. The highest R wave in lead II;
E. The highest R wave in lead III;
13. Potential of which wall mainly registers III standard leads?
A. Right atrium
B. Right ventricular
S. Ventricular septum
D. The anterior wall of the left ventricle
E. Posterior wall of the left ventricle
14. ECG signs of the right atrium hypertrophy?
A. Negative P wave in lead I
B. Negative T wave in lead II
C. Two pointed P wave in lead I
D. Pointed P wave in lead III
E. Two pointed P wave in lead II
15. ECG signs of the left atrium hypertrophy?
A. Negative P wave in lead I
B. Increased amplitude of T wave in lead I
C. Two pointed P wave in lead I

D. Pointed P in lead II
E. Two pointed P wave in lead II
16. ECG signs of right ventricular hypertrophy?
A. P wave duration > 0.11-0.12 sec
B. $\angle\alpha >+90^0$, R_{III}/S_{I}.
S. Syndrome $TV_1> TV_6$.
D. Syndrome $TV_1 <TV_6$
E. In leads III, aVF dominated "P-pulmonale" wave.
17. ECG signs of left ventricular hypertrophy?
A. P wave duration > 0.11-0.12 sec
B. $\angle\alpha >+90^0$, R_{III}/S_{I}.
S. Syndrome $TV_1> TV_6$.
D. Syndrome $TV_1 <TV_6$
E. In leads III, aVF dominated "P-pulmonale" wave.
18. ECG signs of left ventricular hypertrophy?
A. Index Makruza = 1
B. $\angle\alpha >+90^0$, R_{III}/S_{I}.
C. Increasing the amplitude of S wave in leads I, aVL, V5-V6.
D. Syndrome $TV_1 <TV_6$
E. Increased R wave amplitude in leads I, aVL; Rv5-6> Rv4; Rv4 <Rv6.
19. ECG signs of right ventricular hypertrophy?
A. Index Makruza> 1
B. $\angle\alpha > -30^0$
C. Increasing the amplitude of S wave in leads I, aVL, V5-V6.
D. Syndrome Tv1> Tv6
E. Increased R wave amplitude in leads I, aVL; Rv5-6> Rv4; Rv4 <Rv6

Standards of answers: 1V. 2A. 3B. 5D 6C 4B. 7A 9C 8d. 10E. 12A 11D 13E. 14D. 15C. 16B. 17C. 18E. 19C.

Methodical instructions

ELECTROCARDIOGRAPHIC METHOD OF CARDIAC FUNCTION EXAMINATION. TECHNIQUE OF ECG REGISTRATION AND READING

Methodical instructions for students

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