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Basics of the 12-lead ECG

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Abstract: A 12-lead ECG is a noninvasive diagnostic tool that detects and records cardiac electrical activity and can identify cardiac pathology. This article discusses the electrical conduction system of the heart, the anatomy of an ECG complex, ECG lead views, and an overview of a systematic method of ECG interpretation.

Keywords: cardiology, cardiovascular disease, ECG, 12-lead

A 12-lead ECG, which depicts the heart's electrical activity, was first utilized in 1901 by Willem Einthoven.[1] His work laid the foundation for the current worldwide practice of determining cardiac abnormalities.[1] The ECG is a noninvasive diagnostic tool that detects and records cardiac electrical activity and is useful in detecting cardiac pathology.[1]

This article discusses the electrical conduction system of the heart, the anatomy of an ECG complex, ECG lead views, and an overview of a systematic method of ECG interpretation. Independently interpreting a 12-lead ECG enables nurses to anticipate and prepare for the emergency care patients may need, ultimately contributing to optimal patient care.

The electrical conduction system

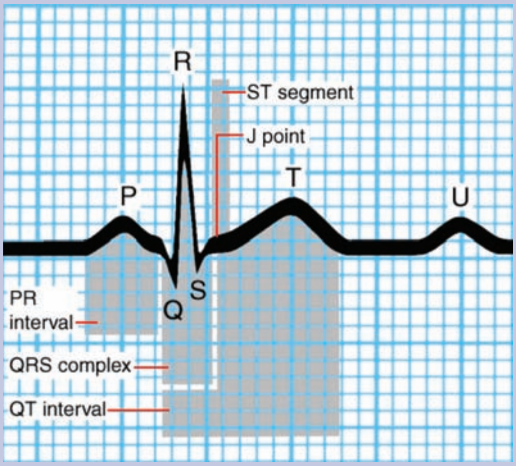
The cardiac electrical conduction system is made up of several components, including the sinoatrial (SA) node, the atrioventricular (AV) node, the atrioventricular bundle (bundle of His), and the Purkinje fibers. The initial electrical impulse is generated from the SA node, located in the upper portion of the right atrium. The SA node generates 60 to 100 beats/minute and is the heart's normal intrinsic pacemaker. As the electrical impulse leaves the SA node, it is conducted to the left atria by way of the interatrial tract (Bachmann bundle) and through the right atria via the internodal tracts, causing electrical stimulation (depolarization) and atrial contraction. Atrial contraction is the beginning of the cardiac cycle.[2,3]

The electrical impulse subsequently travels to the AV node located in the lower right atrium near the interatrial septum. The AV node can initiate conduction in the case of SA node failure. The AV node can independently generate impulses at approximately 40 to 60 beats/minute. The AV node briefly slows conduction, allowing the atria to empty blood into the ventricles.[2,3]

After AV node conduction, the impulse continues along the conduction pathway via the atrioventricular bundle (bundle of His). The bundle of His is comprised of specialized muscle cells that can conduct electrical impulses. This bundle is located along the upper portion of the interventricular septum. It then further separates into a right bundle branch and a left bundle branch. The right bundle branch remains one intact structure that conducts impulses to the right ventricle. The left bundle branch, however, further divides into the anterior and posterior fascicles. The left anterior fascicle transmits impulses to the left ventricle's upper, anterior wall; the left posterior fascicle transmits impulses to the left ventricle's lower, posterior wall.[2,3]

Corresponding bundle branches subsequently transmit the impulse to the Purkinje fibers–a weblike network of cells located in the subendocardial layer of the ventricles. The impulse from the Purkinje fibers stimulates ventricular contraction. The right ventricle pumps blood into the pulmonary artery and the left ventricle pumps blood into the aorta. The bundle of His and the Purkinje fibers can serve as a backup pacemaker at a rate of approximately 20 to 40 beats/minute. Contraction of the ventricles completes the cardiac cycle (see *Electrical conduction system of the heart*).[2,3]

ECG waveforms and components



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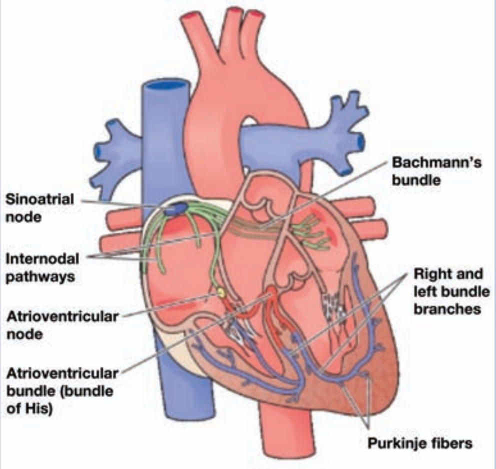
Electrical conduction system of the heart



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Anatomy of ECG waveforms

The heart must depolarize before initiating a contraction. Waves of depolarization include the P wave and the QRS complex (see *ECG waveforms and components*). The T wave represents ventricular repolarization.[4] The basic pattern for the electrical impulses begins with the P wave. The P wave represents atrial depolarization and will be depicted as a small deflection wave that is normally upright.[4]

Time intervals are an important aspect of the ECG (see *Normal durations*). The time from the beginning of the P wave to the beginning of the deflection of the next wave, the QRS complex, is known as the PR interval. The QRS complex is composed of three wave deflections: the Q wave, the R wave, and the S wave. The QRS interval starts at the beginning of the Q wave and ends at the point where the S wave terminates. Although the term QRS complex is used, not every QRS complex contains all three waves. If the initial deflection is negative, it is termed a Q wave. The Q wave should be small; Q waves represent depolarization of the interventricular

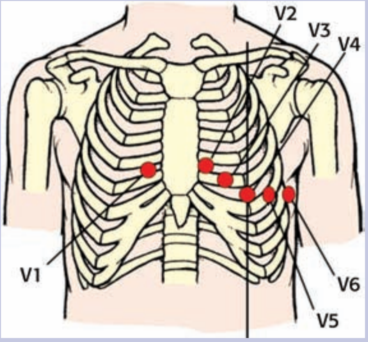
Normal durations[1,4,5]

Component	Representation	Normal duration
P wave	Atrial depolarization	0.10 second or less
PR interval	Time from the onset of atrial depolarization to the onset of ventricular depolarization	0.12 to 0.20 second
QRS complex	Depolarization of the right and left ventricles	0.08 to 0.10 second

septum. The first positive deflection of the QRS complex is called the R wave. The R wave is the largest of the waves; it corresponds with the depolarization of a large portion of the ventricles. The negative deflection following the R wave is the S wave. The S wave represents the depolarization of the ventricles at the base of the heart. The QRS interval ends where the S wave returns to the baseline, known as the J point.[4]

The ST segment follows the QRS complex and represents the point between ventricular depolarization and repolarization. The ST segment is the flat line between the QRS complex and the T wave. Normally, the ST segment is positioned at the baseline or the isoelectric line. The T wave represents ventricular repolarization. The QT interval represents the time between the onset of ventricular depolarization and the end of ventricular repolarization measured from the beginning of the Q wave to the end of the T wave. The U wave, which is not always seen, represents late ventricular repolarization. Atrial repolarization cannot be seen on the ECG because it occurs during the QRS complex and is hidden within the larger electrical impulse.[4]

Chest leads



V1 – Fourth intercostal space to the right of the sternum; **V2** – Fourth intercostal space to the left of the sternum; **V3** – Midway between V2 and V4; **V4** – Fifth intercostal space at the midclavicular line; **V5** – Anterior axillary line at the level of V4, or halfway between V4 and V6 if the anterior axillary line is unclear; **V6** – Midaxillary line at the level of V4.

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ECG graph paper

The PQRST sequence is recorded on special graph paper consisting of horizontal and vertical lines (see *ECG graph paper*). The horizontal lines measure the duration (width) of the waveform in seconds. Each small square measured horizontally represents 0.04 second. The vertical lines measure the amplitude or voltage (the height or depth of a wave or complex) in millimeters (mm). Each small square represents 1 mm in height or depth.

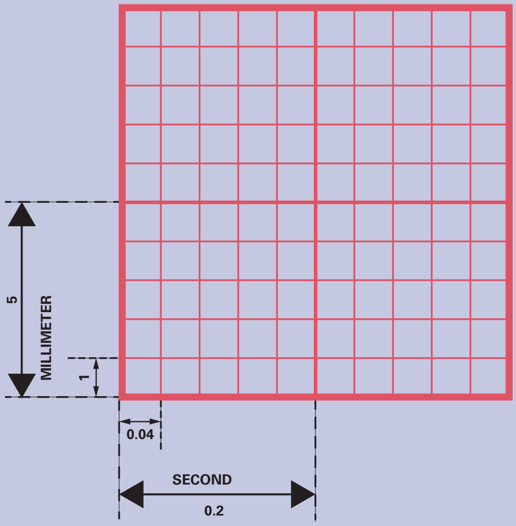
ECG lead views

Ten recording electrodes (leads) are used to obtain a 12-lead ECG. Six electrodes are placed on the chest (precordial leads) and four on the extremities (limb leads); electrical activity is subsequently monitored on both horizontal and frontal planes.[5] The chest leads depict electrical activity on the horizontal plane and the extremity leads depict activity on the frontal plane. Proper positioning of electrodes is imperative to achieve an accurate depiction of electrical activity and subsequent correct interpretation.

Chest leads are labeled V1 through V6 (V stands for "voltage"). Leads V1 through V4 view cardiac activity from the anterior surface. V1 and V2 view the electrical activity of the interventricular septum and right ventricle. The interventricular septum is the cardiac tissue wall separating the left and right ventricles.[6] V3 and V4 view activity from the anterior wall of the left ventricle; V5 and V6 measure activity from the lower anterolateral wall of the left ventricle (see *Chest leads*).[7]

The extremity leads are I, II, III, aVR, aVL, and aVF.[8] These leads view electrical activity on the fron-

ECG graph paper



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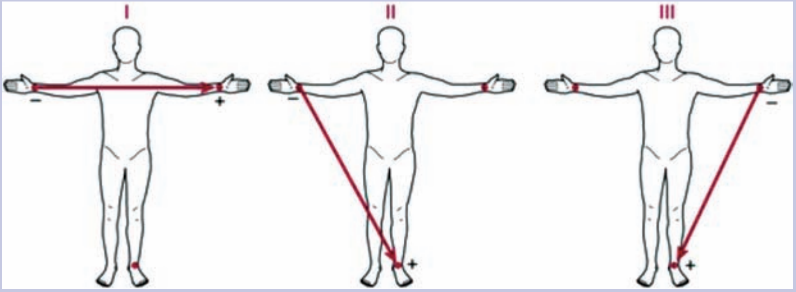
tal plane[5] and have either a negative or positive pole.[8] The right lower extremity electrode is a ground lead that cancels out noise from the system. Extremity leads are placed accordingly: aVR (augmented voltage right upper extremity), aVL (augmented voltage left upper extremity), and aVF (augmented voltage left lower extremity). The electrical conduction traveling between extremity leads I, II, and III, and aVR, aVL, and aVF generates the depiction of Einthoven's Triangle (see *Einthoven's triangle*). In Einthoven's triangle, lead I records the difference between the right arm and the left arm, lead II between the right arm and left leg, and lead III between the left arm and left leg.[9]

Leads I, aVL, and aVR view activity from the upper lateral wall of the left ventricle.[5] Leads II, III, and aVF view activity from the inferior wall of the left ventricle.

Einthoven's triangle



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Basics of ECG interpretation

A systematic approach to interpreting an ECG is essential.

ECGs should be analyzed by using the following process: Rate, Rhythm, Intervals, P Wave, QRS Complex, ST segment-T wave, Axis, and Overall interpretation.

- **Rate:** Is the rate normal, between 60 and 100? Rates less than 60 beats/minute are bradycardic and greater than 100 beats/minute are tachycardic (see *Calculating heart rate*).
- **Rhythm:** Is the rhythm regular, irregular, or irregularly irregular? Is there a constant distance between the same waves, such as from one R wave to the next R wave?
- **Intervals:** Are the intervals normal? What is the PR interval? Is the PR interval constant? What is the QRS interval (duration)?
- **P wave:** Are P waves present? Is there a P wave before every QRS complex? Are P waves normal in shape and size?
- **QRS complex:** Is there a QRS complex after every P wave? Are there pathologic Q waves present? Is the QRS complex narrow or wide?
- **ST segment and T wave:** Is the ST segment isoelectric, elevated, or depressed? Is the T wave upright with an amplitude of less than 5 mm?
- **Axis:** Is there left or right axis deviation (see *Axis deviation*).
- **Interpretation:** What is the overall impression based on the above information?

Normal sinus rhythm

A normal sinus rhythm (NSR) has a P wave before every QRS complex and a QRS complex after every P wave. P waves are upright in leads I and II. The heart rate should be between 60 and 100 beats/minute.[4] A normal PR interval is 0.12 second to 0.20 second and is reflected as 3 to 5 small squares counted from the start of a P wave to the start of the QRS complex. The normal QRS width (duration) is 0.08 second to 0.10 second, measured as 2 to 2-1/2 small squares.[4,5] The ST segment should normally be level with the baseline (the isoelectric line).[4] Deviation from the baseline, such as ST-segment elevation, may indicate abnormalities such as myocardial infarction. Conversely, ST-segment depression may indicate myocardial ischemia. Normal T waves are rounded and slightly asymmetrical, and positive in all leads except aVR and V1 with an

Calculating heart rate[4,10]

The ECG paper can be used to calculate heart rates using one of two methods. In the *6-second method*, start by looking for the markings (usually short vertical lines) at the top of the rhythm strip or ECG paper. These markings divide the ECG paper into 3-second intervals. Count the number of QRS complexes contained in two intervals (6 seconds) and multiply by 10. This method works for both regular and irregular heart rhythms. In the *division method*, count the number of small squares between any two QRS complexes. Make sure to use the same part in both QRS complexes—usually the peak of the complex works the best. Divide 1,500 by the number of small squares to get the heart rate in beats per minute. This method is accurate only with regular heart rates because irregular heart rhythms have a varying number of small squares between any two QRS complexes.

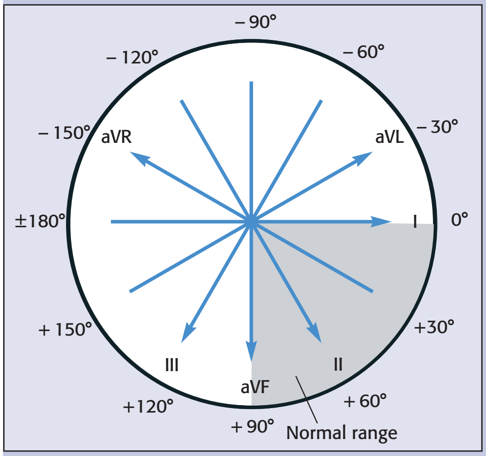
In a regular rhythm, the rate is assessed by counting the number of large squares from the end of one QRS complex to the beginning of the next. Then, divide 300 by the number of large squares to determine the rate. Five large squares equal 60 beats/minute, 4 large squares equal 75 beats/minute, 3 large squares equal 100 beats/minute, and 2 large squares equal 150 beats/minute.[4]

Axis deviation

Combining assessment skills with an understanding of axis deviation can provide a more detailed picture of a patient's condition. The hexaxial reference system and the quadrant method can help visualize problems with cardiac conduction.

Hexaxial reference system

The normal QRS complex (or vector) represents the average electrical signal that the heart generates during depolarization. Within the heart, the mean vector generally flows from upper right to lower left. The exact direction of that flow (called the electrical axis) can be used as an assessment tool in the 12-lead ECG because an abnormal axis can give clues about the heart's electrical system.



To measure the electrical axis, imagine all six limb leads displayed simultaneously around a central point in a circle, which represents the heart (see the illustration at left). In this hexaxial system, the leads divide the circle into equal 30-degree segments.

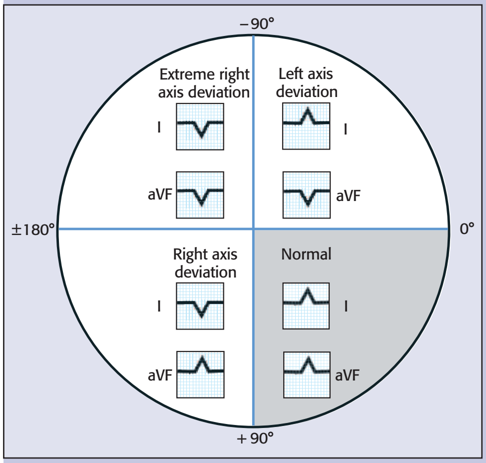
Each lead can be assigned a number of degrees, and the mean vector's direction can be given in degrees. If the mean vector is aligned directly with lead I, its axis is 0 degrees. A mean vector directed halfway between leads II and aVF has an axis of 75 degrees. (Modern 12-lead ECG machines provide this information automatically.)

The normal electrical axis of the heart falls between -30 and +90 degrees. Although this is a wide range, it is a numeric equivalent of the concept that the electrical conduction of the normal heart is right to left and top to bottom.

A left axis deviation occurs when the electrical axis of the heart is between -30 and -90 degrees. *A right axis deviation* occurs when the electrical axis is in the +90-to-+180-degree range. A mean vector having an electrical axis within the range of -90 to -180 degrees is called an *indeterminate axis* or *extreme right axis deviation*.

Quadrant method

To approximate axis deviation using the quadrant method, divide the circle (which represents the patient's heart) into four quadrants (see the illustration below). You need only two ECG leads to make this assessment. Examine leads I and aVF. If lead I is upright, then the vector is flowing right to left. If lead aVF is upright, the vector is directed top to bottom. If they are *both* upright, the electrical axis must fall into the lower left or normal quadrant. This quadrant roughly matches the criteria for *normal electrical axis*, indicating a normal direction of electrical conduction.



Left axis deviation occurs when lead I is upright and lead aVF is down or negative. The electrical axis is located in the upper right quadrant. The mean vector is abnormally directed to the left side of the heart. A left axis deviation can be caused by many different pathologic conditions. Some left bundle-branch blocks will produce a left axis deviation because the cardiac vector flows abnormally from the right side of the heart to the left. Because the mean vector is not conducted by infarcted tissue and flows away from it, an inferior-wall myocardial infarction will produce a left axis deviation (due to a negative QRS in lead aVF). Many patients with pacemakers have a left axis deviation because the pacemaker leads are on the right side of the heart.

Finally, some structural body changes will produce a left axis deviation. In advanced pregnancy, the gravid uterus may occupy so much space in the abdomen that the elevated diaphragm pushes the heart to a more horizontal or leftward-lying position, producing a left axis deviation. Similarly, short and squat or morbidly obese patients may have a left axis deviation because of the heart's position in the chest.

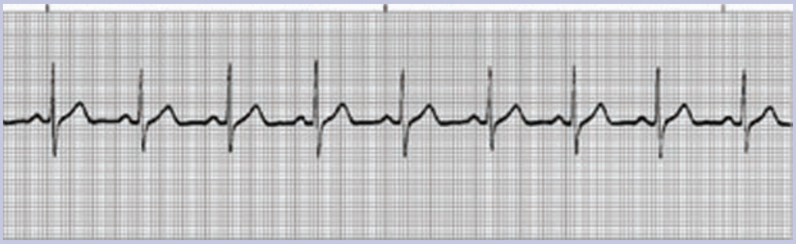
A *right axis deviation* can be identified when lead I is negative and lead aVF is upright. The mean vector is abnormally directed to the right side of the heart. Causes of right axis deviation include chronic obstructive pulmonary disease and right ventricular hypertrophy. In both instances, enlargement of the right cardiac chambers pulls the mean vector to the right side. A right bundle-branch block causes the mean vector to flow from left to right, resulting in right axis deviation. Children and tall, thin adults may have a normal right axis deviation if the heart hangs down in a more vertical position.

If both leads I and aVF are negative, then the axis deviation is termed *indeterminate axis* or *extreme right axis deviation*. The mean vector is directed upward and to the right. If an indeterminate axis deviation is present, check the leads; incorrect ECG lead placement is a common cause of this finding. Other causes are some types of pacemakers, abnormal cardiac rhythms such as ventricular tachycardia, congenital heart disease, or dextrocardia (heart positioned on the right side of the chest).

amplitude less than 5 mm (see *Normal sinus rhythm*).

Normal sinus rhythm

Rhythm: Regular
Rate: 79 beats/minute
P waves: Sinus
PR interval: 0.16 to 0.18 second
QRS complex: 0.06 to 0.08 second.



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Conclusion

ECG interpretation requires practice and begins with an understanding of basic cardiac physiology. Nurses must ensure proper lead placement and use a systematic approach to review the ECG. Appropriate interpretation of the ECG allows for timely intervention when indicated, resulting in optimal patient care. ■

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