Understanding the 12-lead ECG part I

Find how the ECG translates the heart's electrical activity into a waveform and what it tells you about your patient's condition.

BY GUY GOLDICH, RN, CCRN, MSN

RESPONDING TO THE CALL bell, you find George Smythe, 67, sitting up in bed and complaining of chest discomfort. Mr. Smythe had a laparoscopic cholecystectomy earlier today. You take his vital signs and perform a chest pain assessment, which includes the onset, location, quality, intensity, duration, and any radiation of the discomfort. You ask about associated signs and symptoms and factors that aggravate or relieve the pain. Following your facility's protocol, you administer supplemental oxygen at 2 to 4 liters/minute via nasal cannula and page the physician on call, who orders stat serum cardiac biomarkers, a 12-lead electrocardiogram (ECG), and sublingual nitroglycerin.

Do you know what to look for to determine if Mr. Smythe's 12-lead ECG is abnormal? Could you recognize signs that he's having a myocardial infarction (MI)? If you can independently interpret a 12-lead ECG, you can anticipate and prepare for the emergency care your patient may need.

In this article, I'll cover the basics of 12-lead ECG interpretation, focusing on a normal ECG. Next month, I'll discuss ECG abnormalities.

What's happening in the heart

The heart's internal conduction circuit initiates each heartbeat and coordinates all parts of the heart to contract at the proper time. A normal heartbeat is initiated in the sinoatrial (SA) node, a specialized group of cells in the right atrium. The SA node depolarizes at a rate of 60 to 100 times/minute, causing the atria to contract and propel blood into the ventricles.

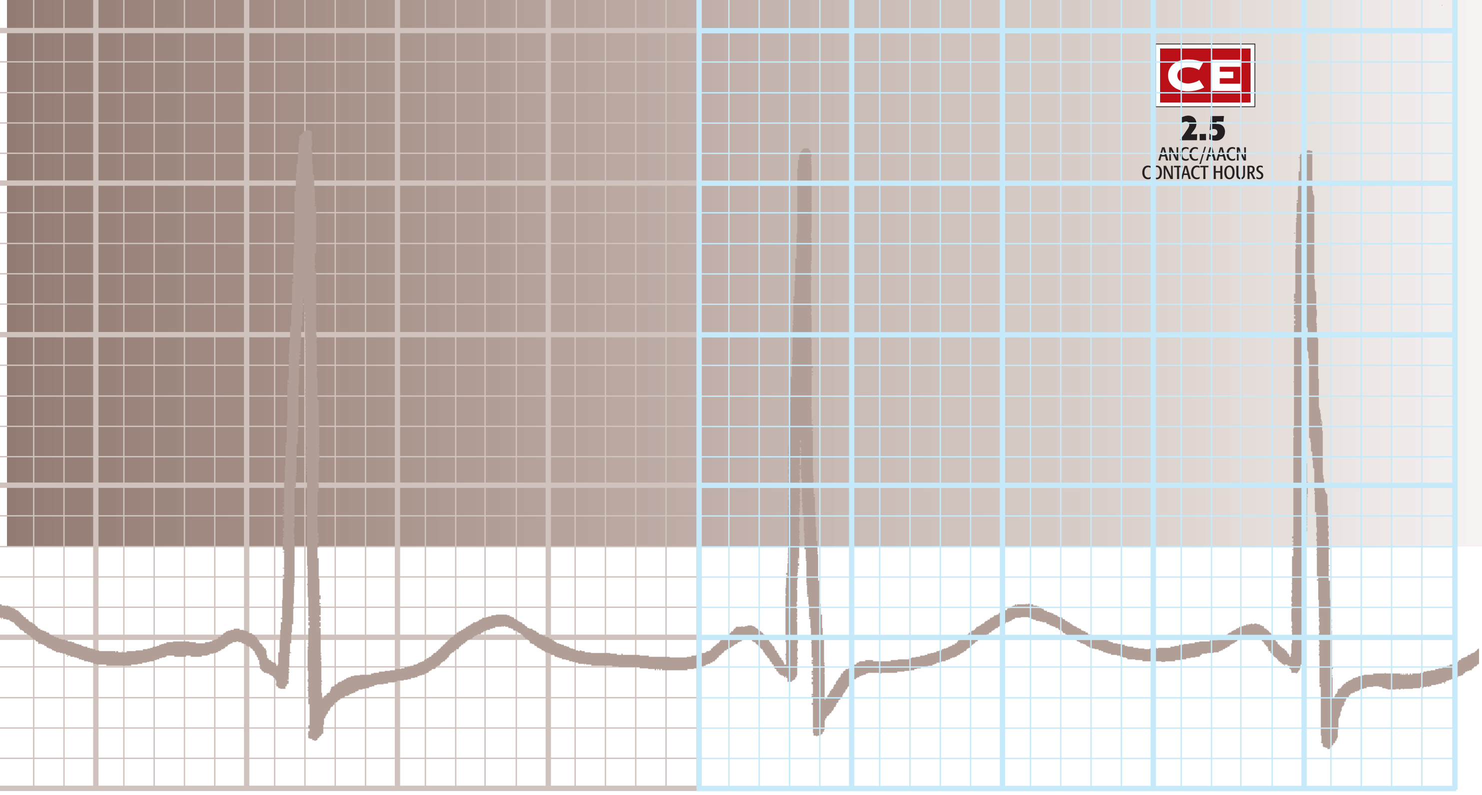
Atrial depolarization produces the first element on the ECG waveform: the *P wave*. The P wave is the first part of the cardiac cycle and appears as a small, semicircular bump (see *Tracing a normal ECG waveform*).

The wave of depolarization continues through the atria until it encounters the next important structure, the *atrioventricular (AV) node*. The AV node receives the atrial impulse and (after a brief pause to let the ventricles fill) transmits it to the ventricles via the *bundle of His*. A collection of cardiac conduction fibers, the bundle of His splits into the right and left *bundle branches*.

The bundle branches are high-speed conducting fibers that run down the intraventricular septum and transmit the cardiac impulse to the *Purkinje fibers*. These fibers form a complex network that mingles with ventricular myocardial cells. The function of the Purkinje fibers is to rapidly stimulate ventricular muscle fibers, resulting in the next major event in the cardiac cycle: *ventricular depolarization*.

Ventricular depolarization generates the *QRS complex*, the electrical equivalent of ventricular systole. (Remember that electrical activity precedes mechanical activity, and the ECG shows only electrical activity.) If you palpate a carotid or radial pulse while looking at a cardiac monitor, you should feel a pulse with each QRS complex on the monitor.

The QRS complex normally has a duration of 0.06 to 0.1 second. A duration greater than 0.12 second



usually indicates prolonged ventricular conduction caused by a bundle-branch block. The QRS complex is variable in appearance and may have a different shape (or morphology) in different patients or even look different in various ECG leads in the same patient. The QRS complex may have one, two, or three wave components, depending on the lead and your patient's condition.

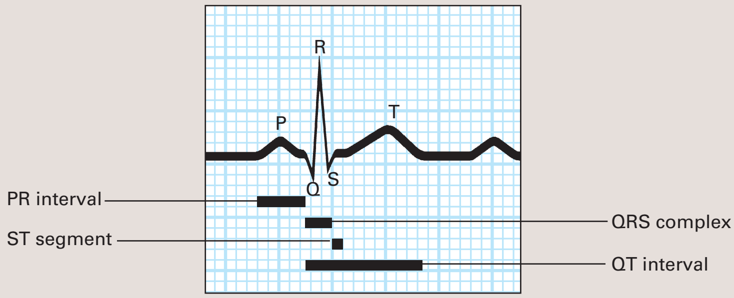
The last major wave component of the ECG is the *T wave,* which is larger than the P wave and rounded or slightly peaked. Immediately following the QRS complex, it represents ventricular repolarization or a metabolic rest period between heartbeats. During repolarization, electrolytes such as potassium, sodium, and calcium cross the cell membrane (back to their original location) to prepare the cardiac cell for the next depolarization.

Besides the three waveforms, the normal ECG cardiac cycle tracing has two important *segments,* or flat (isoelectric) parts of the tracing between the waveforms: the *PR interval* and the *ST segment*.

The PR interval is the period from the beginning of the P wave to the beginning of the QRS complex. It consists of the P wave plus the short isoelectric segment that terminates at the start of the QRS complex. The normal PR interval lasts 0.12 to 0.2 second; this represents the time from SA node depolarization to ventricular depolarization. If the PR interval is *less* than 0.12 second, then the cardiac impulse didn't follow the normal conduction pathway. If the PR interval is *longer* than 0.2 second, then a disease process may be affecting the cardiac conduction pathway, keeping it from functioning properly.

The ST segment consists of the isoelectric line between the end of the QRS complex and the beginning of the T wave. The ST segment reveals information about the heart's oxygenation status. For example, myocardial ischemia (a temporary, reversible decrease in oxygenation) often results in an ST segment below the baseline of the ECG tracing. When myocardial cells are injured (reversible physical damage from lack of oxygen), the ST segment often is elevated above the baseline. So ST-segment elevations are a key indicator of MI. I'll discuss this in detail in the next part of this series. For tips on how to use the ECG to calculate heart rates and more, see *Paper training*.

Tracing a normal ECG waveform



Catching the wave

If you examine a 12-lead ECG, you'll notice that some QRS complexes have upward deflections and others have downward deflections. Here's why.

Each ECG lead has a positive (or sensing) electrode and a negative electrode, which acts as an anchor. The positive electrode looks toward its negative electrode and senses whether electrical energy is being directed toward or away from the positive electrode.

When electrical energy is directed *toward* the positive monitoring electrode, the QRS complex has an upward deflection. When the electrical energy is directed *away* from the positive monitoring electrode, the QRS complex has a downward deflection. The more directly aligned the direction of the electrical energy with the positive electrode, the more upright the complex. If the electrical energy approaches the positive monitoring electrode at a glancing angle, the complex will still be upright, but less upright than if the energy were directly aligned with the positive electrode.

Energy arriving at a perpendicular angle to the positive electrode results in either a waveform with little deflection (isoelectric) or equal amounts of positive and negative deflection.

As the energy is directed away from the positive electrode, the QRS complex becomes progressively more negative. When energy flow is directed totally away from the positive electrode, the QRS complex is deflected directly downward.

Going with the flow: A look at vectors

All cardiac cells are electrochemical, meaning they generate electrical energy during depolarization. This electrical energy, called a *vector*, has strength (measured in millivolts) and direction (measured in degrees from an arbitrary zero point called the electrical axis). Each cardiac cell generates its own microvector. The mathematical average of these microvectors is the *mean QRS vector* or *mean vector,* which follows the conduction pathway of the heart—downward and to the left. The mean vector flows slightly to the left of the ventricular septum because the left ventricle has more and larger cardiac cells.

Generally, each person has a unique mean vector direction, which remains constant unless his cardiac status changes. For example, left ventricular hypertrophy secondary to heart failure pulls the mean vector even more sharply to the left side.[1] A person who has a mean vector in an abnormal direction is said to have an *axis deviation*. (For details, see *Axis deviation: As easy as pie (charts)*.)

Putting it all together

The mean vector is a representation of the overall electrical properties of the heart. A 12-lead ECG is the electrical record of the mean vector from 12 different monitoring sites (leads) on the surface of the body. As when you look at any object, you need to see all the angles to get a complete picture.

Looking at limb leads

The first six leads of the 12-lead ECG come from four electrodes placed on the patient's arms and legs; the right lower leg electrode is the ground electrode. The limb leads record the mean vector in the up-down and left-right direction along the body's frontal plane. Because they use separate positive and negative electrodes, they're called bipolar or standard leads.

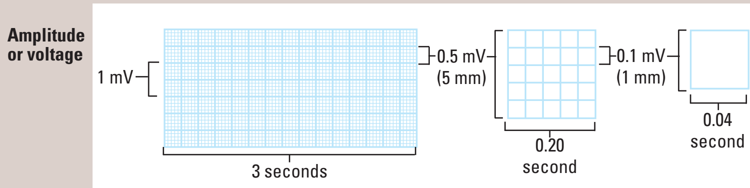
- **Lead I** has the positive electrode on the left arm and looks toward the negative electrode on the right arm for electrical energy. Because

Paper training

You can use the markings on ECG paper to calculate events within the cardiac cycle. The ECG paper is a grid of large and small blocks. On the horizontal axis, a large block is equal to 0.2 second and a small block is equal to 0.04 second. The vertical axis represents voltage or electrical energy, with each vertical millimeter (small block) being 0.1 millivolt of electrical energy. However, in practice, deflections are typically described as being in millimeters, not millivolts.

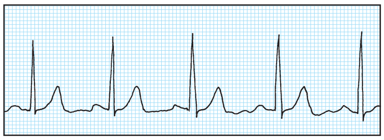
By counting the number of small squares and multiplying by 0.04, you can calculate the duration of any event in the ECG tracing. A QRS complex that's 2.5 small squares wide is 0.1 second. You also can use the ECG paper to calculate heart rates, using one of two methods. In the 6-second method, you start 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 heartbeats. Make sure you 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 and you'll have 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.



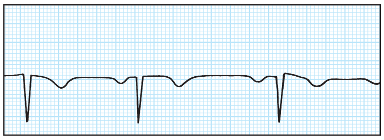
Lead I

Lead II

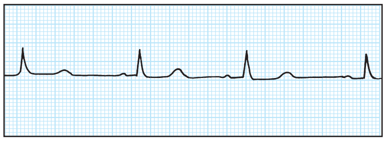


Lead III

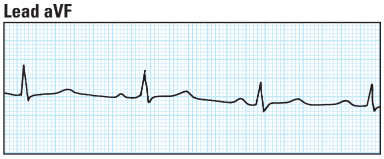
Lead aVR



Lead aVL



Lead aVF



the mean vector travels from upper right to lower left, energy flows toward the positive electrode of lead I, resulting in an upward deflection of the QRS. And because the mean vector doesn't flow directly toward lead I, but approaches it at a somewhat broad angle, the upward deflection of the QRS complex is moderate.

- In **lead II**, the positive electrode is on the left foot and the negative electrode is on the right arm. Because the mean vector flows directly at the positive lead II electrode, this lead usually has the most upright QRS complexes and the most prominent P waves of the entire 12-lead ECG. That's why lead II is a favorite monitoring lead in many intensive care and telemetry units.
- **Lead III** puts the positive electrode on the left foot and the negative one on the left arm. The mean vector flow approaches lead III downward from the right, again producing an upward QRS deflection. Because the angle is narrower than the angle between the mean vector and lead I, the lead III QRS complex is more upright than the lead I QRS complex.

The second set of limb leads are called the augmented or unipolar leads and use a single positive monitoring electrode. The negative electrode is an electrically calculated location at the center of the heart.[2]

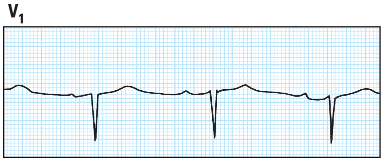
- **Lead aVR** is the only limb lead on the right side of the body. Its positive monitoring electrode is located on the right arm and looks downward and to the left. The mean vector also flows downward and to the left, directly *away* from lead aVR, resulting in a negative deflection for all waveforms. In a normal ECG, lead aVR is the only limb lead with a downwardly deflected QRS.
- **Lead aVL** positions a positive electrode on the left arm and looks to the right and *downward* toward to the center of the heart (in contrast to lead I, which looks strictly to the right). The mean vector approaches aVL at a very broad angle, producing the least upright QRS complex among the limb leads.
- **Lead aVF** has its positive monitoring lead on the left leg and looks straight up to the center of the chest. The mean vector approaches aVF at a fairly direct angle, although not as directly as lead II, so lead aVF has very upright QRS complexes with prominent P waves. Because leads II, III, and aVF all look upward at the oncoming mean vector, their waveforms share many qualities, such as highly positive QRS complexes and prominent P waves. Because these leads look upward at the bottom or inferior ventricular wall of the heart, they're known as the inferior leads.

Six chest leads weigh in

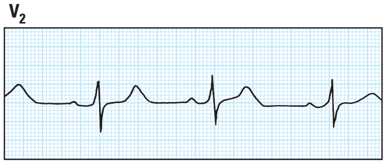
The six chest or precordial leads lie across the anterior chest and measure the mean vector in the horizontal plane.

- **Lead V_1** is located at the right sternal border, fourth intercostal space, and lies above the right ventricle and septum.
- **Lead V_2** is at the left side of the sternum, fourth intercostal space.
- **Lead V_3** is midway between leads V_2 and V_4.
- **Lead V_4** is at the midclavicular line in the fifth intercostal space.
- **Lead V_5** is at the anterior axillary line in the fifth intercostal space.
- **Lead V_6** is at the midaxillary line, fifth intercostal space, and is positioned above the lateral wall of

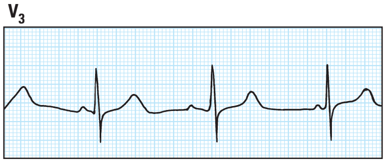
V_1



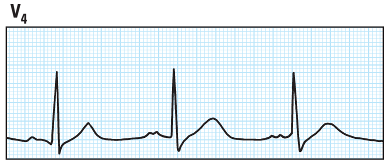
V_2



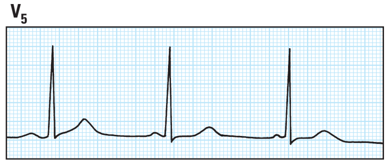
V_3



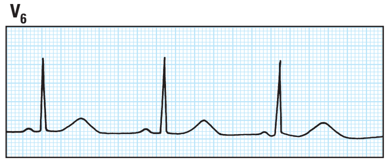
V_4



V_5



V_6

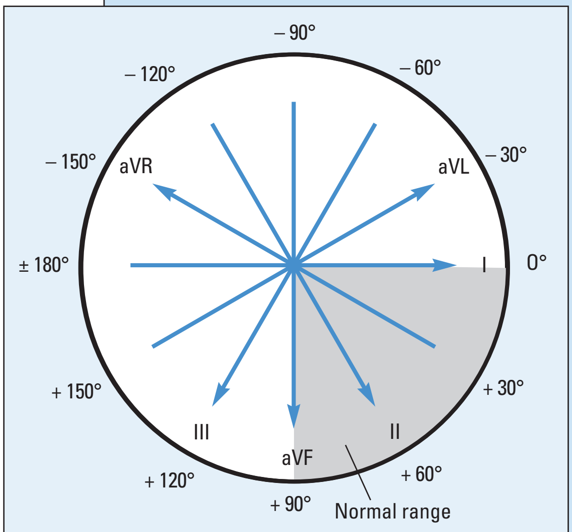


Axis deviation: As easy as pie (charts)

Combining your assessment skills with an understanding of axis deviation can give you a more detailed picture of your patient's condition. The hexaxial reference system and the quadrant method can help you 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 you clues about what's going wrong in 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.

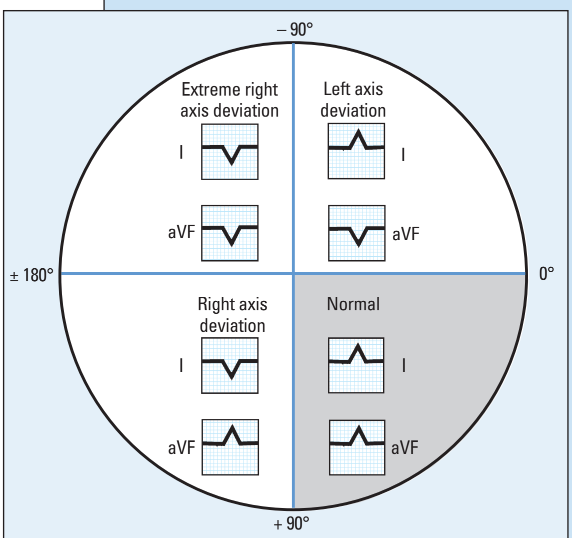
Each lead can be assigned a number of degrees, and the mean vector's direction can be given in degrees. If the mean vector is aligned directly with lead I, its axis is 0 degrees. A mean vector directed halfway between leads II and aVF has an axis of 75 degrees. (Although you can calculate your patient's electrical axis, all 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's 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're *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.



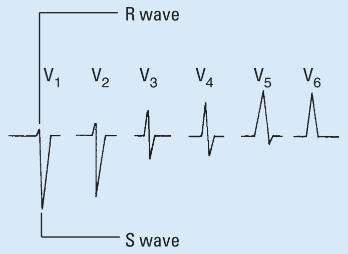
Left axis deviation occurs when lead I is upright and lead aVF is down or negative. The electrical axis is located in the upper right quadrant. The mean vector is abnormally directed to the left side of the heart. A left axis deviation can be caused by many different pathologic conditions. Some left 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 enlarged 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.

You can recognize a *right axis deviation* 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 you find an indeterminate axis deviation on your patient's ECG, 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).

R-wave ups and downs



the left ventricle.

The mean vector in the horizontal plane is influenced by the overwhelming power of the left ventricle and can be thought of as flowing toward the left side. Because the mean vector flows away from lead V_1, this lead has a downward QRS deflection; the QRS is almost totally upright in leads V_5 and V_6 because the mean vector flows directly at these leads. The QRS complex becomes progressively more upright across the chest wall from V_1 to V_6, a change known as *R-wave progression* (see *R-wave ups and downs*).[3] This is another characteristic of a normal ECG.

Putting it all together

Prepared with our new knowledge of 12-lead ECGs, let's examine Mr. Smythe's 12-lead ECG. His heart rate is normal, and you see clear P waves, QRS complexes, and T waves. The PR interval is 0.14 second, which falls within the normal range. The QRS complex should be less than 0.12 second; Mr. Smythe's QRS complexes are 0.08 second wide. The T waves are upright and normal looking. Finally, the ST segment is level with the baseline.

Mr. Smythe's limb leads are all upright with the normal exception of aVR. Lead II is the most upright and aVL is the least upright. The chest leads demonstrate downward lead V_1 and upright leads V_5 and V_6 with normal R-wave progression across the chest wall.

You conclude that Mr. Smythe has a normal 12-lead ECG, indicating no electrical abnormalities in heart function. However, he's not out of the woods yet. Some types of ischemic chest pain aren't apparent on routine ECG, so the physician may consider following up with a stress test.[4]

Mr. Smythe's normal ECG, negative cardiac enzymes, and benign patient history led the medical team to rule out a cardiac source for his discomfort. He was discharged home the next day with a prescription for pantoprazole and told to follow up with his health care provider if his chest discomfort recurs.

In this article, you've learned to recognize the features of the normal ECG. Next month, I'll examine some abnormalities of the 12-lead ECG and discuss how to assess for MIs and arrhythmias.

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Understanding the 12-lead ECG, part I

GENERAL PURPOSE To familiarize nurses with the basics of 12-lead ECG interpretation. **LEARNING OBJECTIVES** After reading the preceding article and taking this test, you should be able to: **1.** Discuss the cardiac conduction system. **2.** Describe vectors and axis deviation. **3.** Explain the 12 leads of the standard ECG.

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1. The normal heartbeat is initiated in the
a. SA node.
b. AV node.
c. bundle of His.
d. Purkinje fibers.

2. The structure that briefly delays an impulse (to let the ventricles fill) is the
a. SA node.
b. AV node.
c. bundle of His.
d. Purkinje fibers.

3. The QRS represents
a. atrial repolarization.
b. atrial depolarization.
c. ventricular depolarization.
d. ventricular repolarization.

4. Which QRS duration indicates a bundle-branch block?
a. 0.04 second
b. 0.08 second
c. 0.10 second
d. 0.14 second

5. The T wave represents
a. atrial depolarization.
b. atrial repolarization.
c. ventricular depolarization.
d. ventricular repolarization.

6. Which reveals information about the heart's oxygenation status?
a. PR interval
b. QT interval
c. ST segment
d. QRS complex

7. Electrical energy generated during depolarization is called
a. an axis.
b. a vector.
c. axis deviation.
d. the cardiac cycle.

8. Which of the following represents normal axis?
a. QRS complex positive in leads I and aVF
b. QRS complex negative in leads I and aVF
c. QRS complex positive in lead I and negative in lead aVF
d. QRS complex negative in lead I and positive in lead aVF

9. Which represents left axis deviation?
a. QRS complex positive in leads I and aVF
b. QRS complex negative in leads I and aVF
c. QRS complex positive in lead I and negative in lead aVF
d. QRS complex negative in lead I and positive in lead aVF

10. Left axis deviation can be caused by
a. pulmonary embolism.
b. right ventricular hypertrophy.
c. chronic obstructive pulmonary disease.
d. an inferior-wall MI.

11. Which of the following leads view the horizontal plane of the heart?
a. V_1 through V_6
b. I, II, III
c. aVR, aVL, aVF
d. I, II, III, aVR, aVL, aVF

12. Which chest lead is placed at the right sternal border, fourth intercostal space?
a. lead V_1
b. lead V_2
c. lead V_3
d. lead V_4

13. R-wave progression refers to the QRS complex becoming progressively more
a. positive from lead I to lead III.
b. positive from lead aVR to lead aVF.
c. positive from lead V_1 to V_6.
d. negative from lead V_1 to V_6.

14. Myocardial injury generally is represented by an ST segment that is
a. above the baseline.
b. level with the baseline.
c. below the baseline.
d. isoelectric.

15. On the horizontal axis, a small box on ECG paper is equal to
a. 0.04 second.
b. 0.1 second.
c. 0.1 millivolt.
d. 1 mm.

ENROLLMENT FORM *Nursing2006,* November, Understanding the 12-lead ECG, part I

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B. Test Answers: Darken one circle for your answer to each question.

	a	b	c	d		a	b	c	d		a	b	c	d
1.	❍	❍	❍	❍	6.	❍	❍	❍	❍	11.	❍	❍	❍	❍
2.	❍	❍	❍	❍	7.	❍	❍	❍	❍	12.	❍	❍	❍	❍
3.	❍	❍	❍	❍	8.	❍	❍	❍	❍	13.	❍	❍	❍	❍
4.	❍	❍	❍	❍	9.	❍	❍	❍	❍	14.	❍	❍	❍	❍
5.	❍	❍	❍	❍	10.	❍	❍	❍	❍	15.	❍	❍	❍	❍

C. Course Evaluation*

1. Did this CE activity's learning objectives relate to its general purpose? ❑ Yes ❑ No
2. Was the journal home study format an effective way to present the material? ❑ Yes ❑ No
3. Was the content relevant to your nursing practice? ❑ Yes ❑ No
4. How long did it take you to complete this CE activity?___ hours___minutes
5. Suggestion for future topics ____

D. Two Easy Ways to Pay:

❑ Check or money order enclosed (Payable to Lippincott Williams & Wilkins)

❑ Charge my ❑ Mastercard ❑ Visa ❑ American Express

Card # ____________________________________ Exp. date ______________

Signature ____

*In accordance with the Iowa Board of Nursing administrative rules governing grievances, a copy of your evaluation of the CE offering may be submitted directly to the Iowa Board of Nursing.

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