One of the most valuable diagnostic tools available, an electrocardiogram (ECG) records the heart’s electrical activity as waveforms. By interpreting these waveforms accurately, you can identify rhythm disturbances, conduction abnormalities, and electrolyte imbalances. An ECG aids in diagnosing and monitoring such conditions as acute coronary syndromes and pericarditis.

To interpret an ECG correctly, you must first recognize its key components. Next, you need to analyze them separately. Then you can put your findings together to reach a conclusion about the heart’s electrical activity. This chapter explains that analytic process, beginning with some fundamental information about electrocardiography.

The heart’s electrical activity produces currents that radiate through the surrounding tissue to the skin. When electrodes are attached to the skin, they sense those electrical currents and transmit them to the electrocardiograph. This electrical activity is transformed into waveforms that represent the heart’s depolarization–repolarization cycle.

Myocardial depolarization occurs when a wave of stimulation passes through the heart and causes the heart muscle to contract. Repolarization is the relaxation phase. An ECG shows the precise sequence of electrical events occurring in the cardiac cells throughout that process and identifies rhythm disturbances and conduction abnormalities.

**Leads and planes**

Because the electrical currents from the heart radiate to the skin in many directions, electrodes are placed at different locations to obtain a total picture of the heart’s electrical activity. The ECG can then record information from different perspectives, which are called leads and planes.

**Leads**

A lead provides a view of the heart’s electrical activity between two points, or poles. Each lead consists of one positive and one negative pole. Between the two poles lies an imaginary line representing the lead’s axis, a term that refers to the direction of the current moving through the heart. Because each lead measures the heart’s electrical potential from different directions, each generates its own characteristic tracing. (See Current direction and waveform deflection.)

The direction in which the electric current flows determines how the waveforms appear on the ECG tracing. When the current flows along the axis toward the positive pole of the electrode, the waveform deflects upward and is called a *positive deflection*. When the current flows away from the positive pole, the waveform deflects downward, below the baseline, and is called a *negative deflection*. When the current flows perpendicular to the axis, the wave may go in both directions or may be unusually small. When electrical activity is absent or too small to measure, the waveform is a straight line, also called an *isoelectric deflection*.

**Planes**

A plane is a cross section of the heart, which provides a different view of the heart’s electrical activity. In the frontal plane—a vertical cut through the middle of the heart from top to bottom—electrical activity is viewed from right and left. The six limb leads are viewed from the frontal plane.

In the horizontal plane—a transverse cut through the middle of the heart dividing it into upper and lower por-
tions—electrical activity can be viewed moving anteriorly and posteriorly. The six precordial leads are viewed from the horizontal plane.

**Types of ECG recordings**

The two main types of ECG recordings are the 12-lead ECG and the rhythm strip. Both types give valuable information about the heart’s electrical activity.

- **12-lead ECG**

A 12-lead ECG records information from 12 different views of the heart and provides a complete picture of electrical activity. These 12 views are obtained by placing electrodes on the patient’s limbs and chest. The limb leads and the chest, or precordial, leads reflect information from the different planes of the heart.

Different leads provide different information. The six limb leads—I, II, III, augmented vector right (aVR), augmented vector left (aVL), and augmented vector foot (aVF)—provide information about the heart’s frontal plane. Leads I, II, and III require a negative and positive electrode for monitoring, which makes these leads bipolar. The augmented leads—aVR, aVL, and aVF—are unipolar, meaning they need only a positive electrode.

The six precordial, or V, leads—V1, V2, V3, V4, V5, and V6—provide information about the heart’s horizontal plane. Like the augmented leads, the precordial leads are unipolar, requiring only a positive electrode. The negative pole of these leads, which is in the center of the heart, is calculated with the ECG.

- **Rhythm strip**

A rhythm strip provides continuous information about the heart’s electrical activity from one or more leads simultaneously. Commonly monitored leads include lead II, V1, and V6. A rhythm strip is used to monitor cardiac status. Chest electrodes pick up the heart’s electrical activity for display on the monitor. The monitor also displays heart rate and other measurements and can print out strips of cardiac rhythms.

**ECG monitoring systems**

The type of ECG monitoring system used—hardwire monitoring or telemetry—depends on the patient’s clinical status. With hardwire monitoring, the electrodes are connected directly to the cardiac monitor. Most hardwire monitors are mounted permanently on a shelf or wall near the patient’s bed. Some monitors are mounted on an I.V. pole for portability, and some include a defibrillator.

The monitor provides a continuous cardiac rhythm display and transmits the ECG tracing to a console at the nurses’ station. Both the monitor and the console have

---

**Current direction and waveform deflection**

This illustration shows possible directions of electrical current and the corresponding waveform deflections. The direction of the electrical current through the heart determines the upward or downward deflection of an electrocardiogram waveform.

As current travels toward the negative pole, the waveform deflects mostly downward.

When current flows perpendicular to the lead, the waveform may be small or go in both directions (biphasic).

As current travels toward the positive pole, the waveform deflects mostly upward.
alarms and can print rhythm strips to show ectopic beats, for example, or other arrhythmias. Hardwire monitors also have the ability to track pulse oximetry, blood pressure, hemodynamic measurements, and other parameters through various attachments to the patient.

Hardwire monitoring is generally used in critical care units and emergency departments because it permits continuous observation of one or more patients from more than one area in the unit. However, this type of monitoring does have disadvantages, including limited mobility because the patient is tethered to a monitor.

With telemetry monitoring, the patient carries a small, battery-powered transmitter that sends electrical signals to another location, where the signals are displayed on a monitor screen. This type of ECG monitoring frees the patient from cumbersome wires and cables and protects him from the electrical leakage and accidental shock occasionally associated with hardwire monitoring.

Telemetry monitoring still requires skin electrodes to be placed on the patient’s chest. Each electrode is connected by a thin wire to a small transmitter box carried in a pocket or pouch. Telemetry monitoring is especially useful for detecting arrhythmias that occur at rest or during sleep, exercise, or stressful situations. Most systems, however, can monitor only heart rate and rhythm.

Electrode placement

Electrode placement is different for each lead, and different leads provide different views of the heart. A lead may be chosen to highlight a particular part of the ECG complex or the electrical events of a specific area of the heart.

Although leads II, V1, and V6 are among the most commonly used leads for continuous monitoring, lead placement is varied according to the patient’s clinical status. If your monitoring system has the capability, you may also monitor the patient in more than one lead. (See Dual-lead monitoring.)

■ Standard limb leads

All standard limb leads or bipolar limb leads have a third electrode, known as the ground, which is placed on the chest to prevent electrical interference from appearing on the ECG recording.

Lead I provides a view of the heart that shows current moving from right to left. Because current flows from negative to positive, the positive electrode for this lead is placed on the left arm or on the left side of the chest; the negative electrode is placed on the right arm. Lead I produces a positive deflection on ECG tracings.

Lead II is commonly used for routine monitoring. The positive electrode is placed on the patient’s left leg and the negative electrode on the right arm. For continuous monitoring, place the electrodes on the patient’s torso for convenience, with the positive electrode below the lowest palpable rib at the left midclavicular line and the negative electrode below the right clavicle. The current travels down and to the left in this lead. Lead II tends to produce a positive, high-voltage deflection, resulting in tall P, R, and T waves.

Lead III usually produces a positive deflection on the ECG. The positive electrode is placed on the left leg and the negative electrode on the left arm.

The axes of the three bipolar limb leads—I, II, and III—form a triangle around the heart and provide a frontal plane view of the heart. (See Einthoven’s triangle, page 16.)

■ Augmented unipolar leads

Leads aVR, aVL, and aVF are called augmented leads because the ECG enhances the small waveforms that would normally appear from these unipolar leads.

In lead aVR, the positive electrode is placed on the right arm and produces a negative deflection on the ECG because the heart’s electrical activity moves away from the lead. In lead aVL, the positive electrode is on the left arm and usually produces a positive deflection on the ECG. In lead aVF, the positive electrode is on the left leg and produces a positive deflection on the ECG. These three limb leads also provide a view of the heart’s frontal plane.

■ Precordial unipolar leads

The six unipolar precordial leads are placed in sequence across the chest and provide a view of the heart’s horizontal plane (see Precordial views, page 16):

- The precordial lead V1 electrode is placed on the right side of the sternum at the fourth intercostal rib space.
- Lead V2 is placed to the left of the sternum at the fourth intercostal space.
- Lead V3 goes between V2 and V4 at the fifth intercostal space. Leads V1, V2, and V3 are biphasic, with positive and negative deflections on the ECG.
- Lead V4 is placed at the fifth intercostal space at the midaxillary line and produces a positive deflection on the ECG.
- Lead V5 is placed at the fifth intercostal space at the anterior to the axillary line. Lead V5 produces a positive deflection on the ECG.
- Lead V6, the last of the precordial leads, is placed at the fifth intercostal space at the midaxillary line. Lead V6 produces a positive deflection on the ECG.
These precordial leads are useful in monitoring ventricular arrhythmias, ST-segment changes, and bundle-branch blocks.

Modified chest leads

The modification of the chest lead occurs because a negative electrode is placed on the left side of the chest, rather than having the center of the heart function as the negative lead. MCL1 is created by placing the negative electrode on the left upper chest, the positive electrode on the right side of the heart, and the ground electrode usually on the right upper chest. The MCL1 lead most closely approximates the ECG pattern produced by the chest lead V1.

When the positive electrode is on the right side of the heart and the electrical current travels toward the left ventricle, the waveform has a negative deflection. As a result, ectopic, or abnormal, beats deflect in a positive direction.

Choose MCL1 to assess QRS-complex arrhythmias as a bipolar substitute for V1. You can use this lead to monitor premature ventricular beats and to distinguish different types of tachycardia, such as ventricular and supraventricular tachycardia. MCL1 can also be used to assess bundle-branch defects and P-wave changes.
MCL₆ is an alternative to MCL₁ and most closely approximates the ECG pattern produced by the chest lead V₆. Like MCL₁, it monitors ventricular conduction changes. The positive lead in MCL₆ is placed at the midaxillary line of the left fifth intercostal space, the negative electrode below the left shoulder, and the ground below the right shoulder.

Application of electrodes

Before attaching electrodes to your patient, make sure he knows you’re monitoring his heart rate and rhythm, not controlling them. Tell him not to become upset if he hears an alarm during the procedure; it probably just means a leadwire has come loose.

Explain the electrode placement procedure to the patient, provide privacy, and wash your hands. Expose the patient’s chest, and select electrode sites for the chosen lead. Choose sites over soft tissues or close to bone, not over bony prominences, thick muscles, or skin folds. Those areas can produce ECG artifact—waveforms not produced by the heart’s electrical activity.

Skin preparation

Wash the patient’s chest with soap and water, and then dry it thoroughly. Use a special rough patch on the back of the electrode, a dry washcloth, or a gauze pad to briskly rub each site until the skin reddens. Be sure not to damage or break the skin. Brisk scrubbing helps to remove dead skin cells and improves electrical contact.

Hair may interfere with electrical contact; therefore, it may be necessary to clip areas with dense hair. Dry the areas if you moistened them. If the patient has oily skin,

Precordial views

These illustrations show the different views of the heart obtained from each precordial (chest) lead.
clean each site with an alcohol pad and allow it to air-dry. This process ensures proper adhesion and prevents alcohol from becoming trapped beneath the electrode, which can irritate the skin and cause skin breakdown.

Application of electrode pads

To apply the electrodes, remove the backing and make sure each pregelled electrode is still moist. If an electrode has become dry, discard it and select another. A dry electrode decreases electrical contact and interferes with waveforms.

Apply one electrode to each prepared site using this method:

- Press one side of the electrode against the patient's skin, pull gently, and then press the opposite side of the electrode against the skin.
- Using two fingers, press the adhesive edge around the outside of the electrode to the patient's chest. This fixes the gel and stabilizes the electrode.
- Repeat this procedure for each electrode.
- Every 24 hours or according to your facility's policy and procedure, remove the electrodes, assess the patient's skin, and replace the old electrodes with new ones.

Attaching leadwires

A three- or five-leadwire system may be used for bedside monitoring. (See Leadwire systems, page 18.) You'll need to attach leadwires and the cable connections to the monitor. Then attach leadwires to the electrodes. Leadwires may clip on or, more commonly, snap on. If you're using the snap-on type, attach the electrode to the leadwire before applying it to the patient's chest. You can even do this step ahead of time if you know when the patient will arrive, to prevent patient discomfort and disturbances of the contact between the electrode and the skin. When you use a clip-on leadwire, apply it after the electrode has been secured to the patient's skin. That way, applying the clip won't interfere with the electrode's contact with the skin.

Cardiac monitoring

After the electrodes are properly positioned, the monitor is on, and the necessary cables are attached, observe the screen. You should see the patient's ECG waveform. Although most monitoring systems allow you to make adjustments by touching the screen, some require you to manipulate knobs and buttons. If the waveform appears too large or too small, change the size by adjusting the gain control. If the waveform appears too high or too low on the screen, adjust the position dial.

Verify that the monitor detects each heartbeat by comparing the patient's apical rate with the rate displayed on the monitor. Set the upper and lower limits of the heart rate according to your facility's policy and the patient's condition. Heart rate alarms are generally set 10 to 20 beats/minute higher or lower than the patient's heart rate.

Monitors with arrhythmia detection generate a rhythm strip automatically whenever the alarm goes off. You can obtain other views of your patient's cardiac rhythm by selecting different leads. You can select leads with the lead selector button or switch.

To get a printout of the patient's cardiac rhythm, press the record control on the monitor on the control console. The ECG strip will be printed at the central console. Some systems print the rhythm from a recorder box on the monitor itself.

Most monitors can input the patient's name, date, and time as a permanent record; however, if the monitor you're using can't do this, label the rhythm strip with the patient's name, date, time, and rhythm interpretation. Add appropriate clinical information to the ECG strip, such as any medication administered, presence of chest pain, or patient activity at the time of the recording. Be sure to place the rhythm strip in the appropriate section of the patient's medical record.

Troubleshooting monitor problems

For optimal cardiac monitoring, you need to recognize problems that can interfere with obtaining a reliable ECG recording and performing an accurate rhythm strip interpretation. (See Common monitor problems, pages 19 and 20.) Causes of interference include artifact from patient movement and poorly placed or poorly functioning equipment.

Artifact, also called waveform interference, may be seen with excessive movement (somatic tremor). It causes the baseline of the ECG to appear wavy, bumpy, or tremulous. Dry electrodes may also cause this problem because of poor contact.

Electrical interference, also called AC interference or 60-cycle interference, is caused by electrical power leakage. It may also result from interference from other room equipment or improperly grounded equipment. As a result, the lost current pulses at a rate of 60 cycles/second. This interference appears on the ECG as a baseline that's thick and unreadable.

A wandering baseline undulates, meaning that all waveforms are present but the baseline isn't stationary.
Leadwire systems

The illustrations below show the correct electrode positions for some of the leads you’ll use most often—the five-leadwire, three-leadwire, and telemetry systems. The abbreviations used are RA for the right arm, LA for the left arm, RL for the right leg, LL for the left leg, C for the chest, and G for the ground.

Electrode positions

In the three- and five-leadwire systems, electrode positions for one lead may be identical to those for another lead. When that happens, change the lead selector switch to the setting that corresponds to the lead you want. In some cases, you’ll need to reposition the electrodes.

Telemetry

In a telemetry monitoring system, you can create the same leads as the other systems with just two electrodes and a ground wire.

Five-leadwire system

<table>
<thead>
<tr>
<th>Lead I</th>
<th>Lead II</th>
<th>Lead III</th>
<th>Lead MCL₁</th>
<th>Lead MCL₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>RA</td>
<td>RA</td>
<td>RA</td>
<td>RA</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>RL</td>
<td>RL</td>
<td>RL</td>
<td>RL</td>
<td>RL</td>
</tr>
<tr>
<td>LL</td>
<td>LL</td>
<td>LL</td>
<td>LL</td>
<td>LL</td>
</tr>
</tbody>
</table>

Three-leadwire system

<table>
<thead>
<tr>
<th>Lead I</th>
<th>Lead II</th>
<th>Lead III</th>
<th>Lead MCL₁</th>
<th>Lead MCL₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>RA</td>
<td>RA</td>
<td>RA</td>
<td>RA</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>LL</td>
<td>LL</td>
<td>LL</td>
<td>LL</td>
<td>LL</td>
</tr>
</tbody>
</table>

Telemetry system

<table>
<thead>
<tr>
<th>Lead I</th>
<th>Lead II</th>
<th>Lead III</th>
<th>Lead MCL₁</th>
<th>Lead MCL₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Movement of the chest wall during respiration, poor electrode placement, or poor electrode contact usually causes this problem.

Faulty equipment, such as broken leadwires and cables, can also cause monitoring problems. Excessively
Common monitor problems
These illustrations present the most commonly encountered monitor problems, including the way to identify them, their possible causes, and interventions.

<table>
<thead>
<tr>
<th>Waveform</th>
<th>Possible causes</th>
<th>Interventions</th>
</tr>
</thead>
</table>
| Artifact (waveform interference)  | - Patient experiencing seizures, chills, or anxiety                          | - If the patient is having a seizure, notify the physician and intervene as ordered.  
- Dirty or corroded connections   | - Replace dirty or corroded wires.                                          | - Keep the patient warm and encourage him to relax.                           |
|                                  | - Improper electrode application                                               | - Check the electrodes, and reapply them if needed. Clean the patient’s skin well, because skin oils and dead skin cells inhibit conduction. |
|                                  | - Dry electrode gel                                                            | - Check the electrode gel. If the gel is dry, apply new electrodes.          |
|                                  | - Short circuit in leadwires or cable                                          | - Replace broken equipment.                                                  |
|                                  | - Electrical interference from other equipment in the room                     | - Make sure all electrical equipment is attached to a common ground. Check all three-pronged plugs to ensure that no prong is loose. Notify the biomedical department. |
|                                  | - Static electricity interference from inadequate room humidity               | - Regulate room humidity to 40%, if possible.                                |
| False high-rate alarm            | - Gain setting too high, particularly with MCL₁ setting                      | - Assess the patient for signs and symptoms of hyperkalemia.                 |
|                                  | - HIGH alarm limit set too low or low alarm limit set too high                | - Set alarm limits according to the patient’s heart rate.                     |
|                                  |                                                                                | - Reset gain.                                                                |
| Weak signals                     | - Improper electrode application                                               | - Reapply the electrodes.                                                    |
|                                  | - QRS complex too small to register                                            | - Reset gain so that the height of the complex is greater than 1 mV.        |
|                                  | - Wire or cable failure                                                        | - Try monitoring the patient on another lead.                               |

(continued)
worn equipment can cause improper grounding, putting the patient at risk for accidental shock.

Be aware that some types of artifact resemble arrhythmias and that the monitor will interpret them as such. For example, the monitor may sense a small movement, such as the patient brushing his teeth, as a potentially lethal ventricular tachycardia. So, remember to treat the patient, not the monitor. The more familiar you become with your unit’s monitoring system—and with your patient—the more quickly you can recognize and interpret monitor problems and act appropriately.

The ECG grid

Waveforms produced by the heart’s electrical current are recorded on graphed ECG paper by a heated stylus. ECG paper consists of horizontal and vertical lines forming a grid. A piece of ECG paper is called an ECG strip or tracing. (See Understanding the ECG grid.)

The horizontal axis of the ECG strip represents time. Each small block equals 0.04 second, and five small blocks form a large block, which equals 0.2 second. This time increment is determined by multiplying 0.04 second (for one small block) by five, the number of small blocks that make up a large block. Five large blocks equal 1 second \((5 \times 0.2)\). When measuring or calculating a patient’s heart rate, a 6-second strip consisting of 30 large blocks is usually used.

The ECG strip’s vertical axis measures amplitude in millimeters (mm) or electrical voltage in millivolts (mV). Each small block represents 1 mm or 0.1 mV; each large block, 5 mm or 0.5 mV. To determine the amplitude of a wave, segment, or interval, count the number of small...
blocks from the baseline to the highest or lowest point of the wave, segment, or interval.

**ECG waveform components**

An ECG complex represents the heart's electrical activity (depolarization-repolarization cycle) occurring in one cardiac cycle. The ECG tracing consists of three basic waveforms: the P wave, the QRS complex, and the T wave. These units of electrical activity can be further broken down into these segments and intervals: the PR interval, the ST segment, and the QT interval.

In addition, a U wave may sometimes be present. The J point marks the end of the QRS complex and the beginning of the ST segment. (See *Identifying ECG waveform components*.)

The upward and downward movement of the ECG machine's stylus, which forms the various waves, reflects the directional flow of the heart's electrical impulse. When the electrodes are placed correctly, an upward deflection is positive and a downward deflection is negative. Between each cardiac cycle, when the heart's electrical activity is absent, the stylus on the ECG recorder re-

---

**Understanding the ECG grid**

This electrocardiogram (ECG) grid shows the horizontal axis and vertical axis and their respective measurement values.

![ECG Grid Diagram](image-url)

---

**Identifying ECG waveform components**

This illustration shows the components of a normal electrocardiogram (ECG) waveform.

![ECG Components Diagram](image-url)
turns to the baseline or isoelectric line and records a straight line.

■ **P wave**

The P wave is the first component of a normal ECG waveform. It represents atrial depolarization or conduction of an electrical impulse through the atria. When evaluating a P wave, look closely at its characteristics, especially its location, configuration, and deflection. A normal P wave has the following characteristics:

- **Location**: precedes the QRS complex
- **Amplitude**: 2 to 3 mm high
- **Duration**: 0.06 to 0.12 second
- **Configuration**: usually rounded and smooth
- **Deflection**: positive or upright in leads I, II, aVF, and V2 to V6; usually positive but may vary in leads III and aVL; negative or inverted in lead aVR; biphasic or variable in lead V1

If the deflection and configuration of a P wave are normal—for example, if the P wave is upright in lead II and is rounded and smooth—and if the P wave precedes each QRS complex, you can assume that this electrical impulse originated in the sinoatrial (SA) node. The atria start to contract partway through the P wave, but you won’t see this on the ECG. Remember, the ECG records only electrical activity, not mechanical activity or contraction.

Peaked, notched, or enlarged P waves may represent atrial hypertrophy or enlargement associated with chronic obstructive pulmonary disease, pulmonary emboli, valvular disease, or heart failure. Inverted P waves may signify retrograde or reverse conduction from the atrioventricular (AV) junction toward the atria. Whenever an upright sinus P wave becomes inverted, consider retrograde conduction and reverse conduction as possible conditions.

Varying P waves indicate that the impulse may be coming from different sites, as with a wandering pacemaker rhythm, irritable atrial tissue, or damage near the SA node. Absent P waves may signify impulse initiation by tissue other than the SA node, as with a junctional or atrial fibrillation rhythm. When a P wave doesn’t precede the QRS complex, heart block may be present.

■ **PR interval**

The PR interval tracks the atrial impulse from the atria through the AV node, bundle of His, and right and left bundle branches. When evaluating a PR interval, look particularly at its duration. Changes in the PR interval indicate an altered impulse formation or a conduction delay, as seen in AV block. A normal PR interval has the following characteristics (amplitude, configuration, and deflection aren’t measured):

- **Location**: from the beginning of the P wave to the beginning of the QRS complex
- **Duration**: 0.12 to 0.20 second
- **Short PR intervals** (less than 0.12 second) indicate that the impulse originated somewhere other than the SA node. This variation is associated with junctional arrhythmias and preexcitation syndromes. Prolonged PR intervals (greater than 0.20 second) may represent a conduction delay through the atria or AV junction resulting from digoxin toxicity or heart block—slowing related to ischemia or conduction tissue disease.

■ **QRS complex**

The QRS complex follows the P wave and represents depolarization of the ventricles, or impulse conduction. Immediately after the ventricles depolarize, as represented by the QRS complex, they contract. That contraction ejects blood from the ventricles and pumps it through the arteries, creating a pulse.

Whenever you’re monitoring cardiac rhythm, remember that the waveform you see represents only the heart’s electrical activity. It doesn’t guarantee a mechanical contraction of the heart and a subsequent pulse. The contraction could be weak, as happens with premature ventricular contractions, or absent, as happens with pulseless electrical activity. So, before you treat what the rhythm strip shows, check the patient.

Pay special attention to the duration and configuration when evaluating a QRS complex. A normal complex has the following characteristics:

- **Location**: follows the PR interval
- **Amplitude**: 5 to 30 mm high, but differs for each lead used
- **Duration**: 0.06 to 0.10 second or half of the PR interval (Duration is measured from the beginning of the Q wave to the end of the S wave or from the beginning of the R wave if the Q wave is absent.)
QRS waveform variety

These illustrations show the various configurations of QRS complexes. When documenting the QRS complex, use uppercase letters to indicate a wave with a normal or high amplitude (greater than 5 mm) and lowercase letters to indicate one with a low amplitude (less than 5 mm).

- **Configuration**: consists of the Q wave (the first negative deflection, or deflection below the baseline, after the P wave), the R wave (the first positive deflection after the Q wave), and the S wave (the first negative deflection after the R wave) (You may not always see all three waves. It may also look different in each lead.) (See QRS waveform variety.)

- **Deflection**: positive (with most of the complex above the baseline) in leads I, II, III, aV₁, aV₅, and V₄ to V₆; negative in leads aV₂ and V₁ to V₂; biphasic in lead V₃

Remember that the QRS complex represents intraventricular conduction time. That's why identifying and correctly interpreting it is so crucial. If no P wave appears before the QRS complex, then the impulse may have originated in the ventricles, indicating a ventricular arrhythmia.

Deep, wide Q waves may represent a myocardial infarction. In this case, the Q wave amplitude (depth) is greater than or equal to 25% of the height of the succeeding R wave, or the duration of the Q wave is 0.04 second or more. A notched R wave may signify a bundle-branch block. A widened QRS complex (greater than 0.12 second) may signify a ventricular conduction delay. A missing QRS complex may indicate AV block or ventricular standstill.

- **ST segment**

The ST segment represents the end of ventricular conduction or depolarization and the beginning of ventricular recovery or repolarization. The point that marks the end of the QRS complex and the beginning of the ST segment is known as the **J point**.

Pay special attention to the deflection of an ST segment. A normal ST segment has the following characteristics (amplitude, duration, and configuration aren’t observed):

- **Location**: extends from the S wave to the beginning of the T wave
- **Deflection**: usually isoelectric or on the baseline (neither positive nor negative); may vary from –0.5 to +1 mm in some precordial leads

A change in the ST segment may indicate myocardial injury or ischemia. An ST segment may become either elevated or depressed. (See Changes in the ST segment, page 24.)

- **T wave**

The peak of the T wave represents the relative refractory period of repolarization or ventricular recovery. When evaluating a T wave, look at the amplitude, configuration, and deflection.

Normal T waves have the following characteristics (duration isn’t measured):

- **Location**: follows the ST segment
- **Amplitude**: 0.5 mm in leads I, II, and III and up to 10 mm in the precordial leads
- **Configuration**: typically rounded and smooth
Changes in the ST segment

Closely monitoring the ST segment on a patient’s electrocardiogram can help you detect myocardial ischemia or injury before infarction develops.

**ST-segment depression**

An ST segment is considered depressed when it’s 0.5 mm or more below the baseline. A depressed ST segment may indicate myocardial ischemia or digoxin toxicity.

**ST-segment elevation**

An ST segment is considered elevated when it’s 1 mm or more above the baseline. An elevated ST segment may indicate myocardial injury.

- Deflection: usually positive or upright in leads I, II, and V2 to V6; inverted in lead aVR; variable in leads III and V1

  The T wave’s peak represents the relative refractory period of ventricular repolarization, a period during which cells are especially vulnerable to extra stimuli. Bumps in a T wave may indicate that a P wave is hidden in it. If a P wave is hidden, atrial depolarization has occurred, the impulse having originated at a site above the ventricles.

  Tall, peaked, or “tented” T waves may indicate myocardial injury or electrolyte imbalances such as hyperkalemia. Inverted T waves in leads I, II, aVL, aVF, or V2 through V6 may represent myocardial ischemia. Heavily notched or pointed T waves in an adult may indicate pericarditis.

**QT interval**

The QT interval measures the time needed for ventricular depolarization and repolarization. The length of the QT interval varies according to heart rate. The faster the heart rate, the shorter the QT interval. When checking the QT interval, look closely at the duration.

A normal QT interval has the following characteristics (amplitude, configuration, and deflection aren’t observed):

- Location: extends from the beginning of the QRS complex to the end of the T wave
- Duration: varies according to age, gender, and heart rate; usually lasts from 0.36 to 0.44 second; shouldn’t be greater than half the distance between the two consecutive R waves (called the R-R interval) when the rhythm is regular

  The QT interval measures the time needed for ventricular depolarization and repolarization. Prolonged QT intervals indicate that ventricular repolarization time is slowed, meaning that the relative refractory, or vulnerable, period of the cardiac cycle is longer.

  This variation is also associated with certain medications, such as class I antiarrhythmics. Prolonged QT syndrome is a congenital conduction-system defect present in certain families. Short QT intervals may result from digoxin toxicity or electrolyte imbalances such as hypercalcemia.

**U wave**

The U wave represents repolarization of the His-Purkinje system or ventricular conduction fibers. It usually isn’t present on a rhythm strip. The configuration is the most important characteristic of the U wave.

When present, a U wave has the following characteristics (amplitude and duration aren’t measured):

- Location: follows the T wave
- Configuration: typically rounded
- Deflection: upright

  The U wave may not appear on an ECG. A prominent U wave may result from hypercalcemia, hypokalemia, or digoxin toxicity.
The 8-step method

Analyzing a rhythm strip is a skill developed through practice. You can use several methods, as long as you’re consistent. Rhythm strip analysis requires a sequential and systematic approach such as the eight steps outlined here.

■ Step 1: Determine rhythm

To evaluate the heart’s atrial and ventricular rhythms, use either the paper-and-pencil method or the caliper method. (See Methods of measuring rhythm.)

For atrial rhythm, measure the P-P intervals—that is, the intervals between consecutive P waves. These intervals should occur regularly, with only small variations associated with respirations. Then compare the P-P intervals in several cycles. Consistently similar P-P intervals indicate regular atrial rhythm; dissimilar P-P intervals indicate irregular atrial rhythm.

To determine the ventricular rhythm, measure the intervals between two consecutive R waves in the QRS complexes. If an R wave isn’t present, use either the Q wave or the S wave of consecutive QRS complexes. The R-R intervals should occur regularly. Then compare R-R intervals in several cycles. As with atrial rhythms, consistently similar R-R intervals mean a regular ventric-

Methods of measuring rhythm

You can use either of the following methods to determine atrial or ventricular rhythm.

Paper-and-pencil method

Place the electrocardiogram (ECG) strip on a flat surface.
Position the straight edge of a piece of paper along the strip’s baseline.
Move the paper up slightly so the straight edge is near the peak of the R wave.
With a pencil, mark the paper at the R waves of two consecutive QRS complexes, as shown below. This distance is the R-R interval.
Move the paper across the strip lining up the two marks with succeeding R-R intervals. If the distance for each R-R interval is the same, the ventricular rhythm is regular. If the distance varies, the rhythm is irregular.
Using the same method, measure the distance between P waves (the P-P interval) to determine whether the atrial rhythm is regular or irregular.

Caliper method

With the ECG on a flat surface, place one point of the calipers on the peak of the first R wave of two consecutive QRS complexes.
Adjust the caliper legs so the other point is on the peak of the next R wave, as shown below. This distance is the R-R interval.
Pivot the first point of the calipers toward the third R wave, and note whether it falls on the peak of that wave.
Check succeeding R-R intervals in the same way. If they’re all the same, the ventricular rhythm is regular. If they vary, the rhythm is irregular.
Using the same method, measure the P-P intervals to determine whether the atrial rhythm is regular or irregular.
ular rhythm; dissimilar R-R intervals point to an irregular ventricular rhythm.

After completing your measurements, ask yourself:
- Is the rhythm regular or irregular? Consider a rhythm with only slight variations, up to 0.04 second, to be regular.
- If the rhythm is irregular, is it slightly irregular or markedly so? Does the irregularity occur in a pattern (a regularly irregular pattern)?

**Step 2: Calculate rate**

You can use one of three methods to determine atrial and ventricular heart rates from an ECG waveform. Although these methods can provide accurate information, you shouldn't rely solely on them when assessing your patient. Keep in mind that the ECG waveform represents electrical, not mechanical, activity. Therefore, although an ECG can show you that ventricular depolarization has occurred, it doesn't mean that ventricular contraction has occurred. To determine this, you must assess the patient's pulse. So remember, always check a pulse to correlate it with the heart rate on the ECG.

- Times-10 method: The first method that's the simplest, quickest, and most common way to calculate rate is the times-10 method, especially if the rhythm is irregular. ECG paper is marked in increments of 3 seconds, or 15 large boxes. To calculate the atrial rate, obtain a 6-second strip, count the number of P waves on it, and multiply by 10. Ten 6-second strips equal 1 minute. Calculate ventricular rate the same way, using the R waves.

- 1,500 method: If the heart rhythm is regular, use the second method—the 1,500 method, so named because 1,500 small squares equal 1 minute. Count the number of small squares between identical points on two consecutive P waves, and then divide 1,500 by that number to get the atrial rate. To obtain the ventricular rate, use the same method with two consecutive R waves.

- Sequence method: The third method of estimating heart rate is the sequence method, which requires memorizing a sequence of numbers. For atrial rate, find a P wave that peaks on a heavy black line and assign the following numbers to the next six heavy black lines: 300, 150, 100, 75, 60, and 50. Then find the next P wave peak and estimate the atrial rate, based on the number assigned to the nearest heavy black line. Estimate the ventricular rate the same way, using the R wave. (See Calculating heart rate.)

### Calculating heart rate

This table can help make the sequencing method of determining heart rate more precise. After counting the number of boxes between the R waves, use this table to find the rate.

For example, if you count 20 small blocks, or 4 large blocks, the rate would be 75 beats/minute. To calculate the atrial rate, use the same method with P waves instead of R waves.

#### Rapid estimation

This rapid-rate calculation is also called the countdown method. Using the number of large boxes between R waves or P waves as a guide, you can rapidly estimate ventricular or atrial rates by memorizing the sequence “300, 150, 100, 75, 60, 50.”

<table>
<thead>
<tr>
<th>Number of small blocks</th>
<th>Heart rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 (1 large block)</td>
<td>300</td>
</tr>
<tr>
<td>6</td>
<td>250</td>
</tr>
<tr>
<td>7</td>
<td>214</td>
</tr>
<tr>
<td>8</td>
<td>188</td>
</tr>
<tr>
<td>9</td>
<td>167</td>
</tr>
<tr>
<td>10 (2 large blocks)</td>
<td>150</td>
</tr>
<tr>
<td>11</td>
<td>136</td>
</tr>
<tr>
<td>12</td>
<td>125</td>
</tr>
<tr>
<td>13</td>
<td>115</td>
</tr>
<tr>
<td>14</td>
<td>107</td>
</tr>
<tr>
<td>15 (3 large blocks)</td>
<td>100</td>
</tr>
<tr>
<td>16</td>
<td>94</td>
</tr>
<tr>
<td>17</td>
<td>88</td>
</tr>
<tr>
<td>18</td>
<td>83</td>
</tr>
<tr>
<td>19</td>
<td>79</td>
</tr>
<tr>
<td>20 (4 large blocks)</td>
<td>75</td>
</tr>
<tr>
<td>21</td>
<td>71</td>
</tr>
<tr>
<td>22</td>
<td>68</td>
</tr>
<tr>
<td>23</td>
<td>65</td>
</tr>
<tr>
<td>24</td>
<td>63</td>
</tr>
<tr>
<td>25 (5 large blocks)</td>
<td>60</td>
</tr>
<tr>
<td>26</td>
<td>58</td>
</tr>
<tr>
<td>27</td>
<td>56</td>
</tr>
<tr>
<td>28</td>
<td>54</td>
</tr>
<tr>
<td>29</td>
<td>52</td>
</tr>
<tr>
<td>30 (6 large blocks)</td>
<td>50</td>
</tr>
<tr>
<td>31</td>
<td>48</td>
</tr>
<tr>
<td>32</td>
<td>47</td>
</tr>
<tr>
<td>33</td>
<td>45</td>
</tr>
<tr>
<td>34</td>
<td>44</td>
</tr>
<tr>
<td>35 (7 large blocks)</td>
<td>43</td>
</tr>
<tr>
<td>36</td>
<td>42</td>
</tr>
<tr>
<td>37</td>
<td>41</td>
</tr>
<tr>
<td>38</td>
<td>39</td>
</tr>
<tr>
<td>39</td>
<td>38</td>
</tr>
<tr>
<td>40 (8 large blocks)</td>
<td>37</td>
</tr>
</tbody>
</table>
Step 3: Evaluate the P wave

When examining a rhythm strip for P waves, ask yourself:
- Are P waves present?
- Do the P waves have a normal configuration?
- Do all the P waves have a similar size and shape?
- Is there one P wave for every QRS complex?

Step 4: Calculate the PR interval

To measure the PR interval, count the small squares between the start of the P wave and the start of the QRS complex; then multiply the number of squares by 0.04 second. After performing this calculation, ask yourself:
- Does the duration of the PR interval fall within normal limits, 0.12 to 0.20 second (or 3 to 5 small squares)?
- Is the PR interval constant?

Step 5: Evaluate the QRS complex

When determining QRS-complex duration, make sure you measure straight across from the end of the PR interval to the end of the S wave, not just to the peak. Remember, the QRS complex has no horizontal components. To calculate duration, count the number of small squares between the beginning and end of the QRS complex and multiply this number by 0.04 second. Then ask yourself:
- Does the duration of the QRS complex fall within normal limits, 0.06 to 0.10 second?
- Are all QRS complexes the same size and shape? (If not, measure each one and describe them individually.)
- Does a QRS complex appear after every P wave?

Step 6: Evaluate the T wave

Examine the T waves on the ECG strip. Then ask yourself:
- Are T waves present?
- Do all of the T waves have a normal shape?
- Could a P wave be hidden in a T wave?
- Do all T waves have a normal amplitude?
- Do the T waves have the same deflection as the QRS complexes?

Step 7: Calculate the duration of the QT interval

To determine the duration of the QT interval, count the number of small squares between the beginning of the QRS complex and the end of the T wave, where the T wave returns to the baseline. Multiply this number by 0.04 second. Ask yourself:
- Does the duration of the QT interval fall within normal limits, 0.36 to 0.44 second?

Step 8: Evaluate other components

Note the presence of ectopic beats or other abnormalities such as aberrant conduction. Also, check the ST segment for abnormalities, and look for the presence of a U wave.

Now, interpret your findings by classifying the rhythm strip according to one or all of the following.
- Origin of the rhythm: for example, sinus node, atria, AV node, or ventricles
- Rate: normal (60 to 100 beats/minute), bradycardia (fewer than 60 beats/minute), or tachycardia (greater than 100 beats/minute)
- Rhythm interpretation: normal or abnormal—for example, flutter, fibrillation, heart block, escape rhythm, or other arrhythmias
Normal sinus rhythm

Before you can recognize an arrhythmia, you first need to be able to recognize a normal cardiac rhythm. The term arrhythmia literally means an absence of rhythm. The more accurate term dysrhythmia means an abnormality in rhythm. These terms, however, are typically used interchangeably.

Normal sinus rhythm (NSR) occurs when an impulse starts in the sinus node and progresses to the ventricles through a normal conduction pathway—from the sinus node to the atria and AV node, through the bundle of His, to the bundle branches, and on to the Purkinje fibers. No premature or aberrant contractions are present. NSR is the standard against which all other rhythms are compared. (See Identifying normal sinus rhythm.)

The ECG characteristics of NSR include:
- **Rhythm**—atrial and ventricular rhythms regular
- **Rate**—atrial and ventricular rates 60 to 100 beats/minute, the SA node’s normal firing rate
- **P wave**—normally shaped (round and smooth) and upright in lead II; all P waves similar in size and shape; one P wave for every QRS complex
- **PR interval**—within normal limits (0.12 to 0.20 second)
- **QRS complex**—within normal limits (0.06 to 0.10 second)
- **T wave**—normally shaped; upright and rounded in lead II
- **QT interval**—within normal limits (0.36 to 0.44 second)
- **Other**—no ectopic or aberrant beats.

### Identifying normal sinus rhythm

<table>
<thead>
<tr>
<th><strong>Rhythm</strong></th>
<th><strong>PR interval</strong></th>
<th><strong>QT interval</strong></th>
<th><strong>Other</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial regular</td>
<td>Within normal limits (0.12 to 0.20 second)</td>
<td>Within normal limits (0.36 to 0.44 second)</td>
<td>No ectopic or aberrant beats</td>
</tr>
<tr>
<td>Ventricular regular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 to 100 beats/minute (sinoatrial node’s normal firing rate)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>P wave</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal shape (round and smooth)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upright in lead II</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One for every QRS complex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All similar in size and shape</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Normal sinus rhythm

Use the 8-step method to interpret the following rhythm strip. Place your answers on the blank lines. See the answer key below.

Rhythm: Atrial and ventricular rhythms regular
Rate: Atrial and ventricular rates normal; 78 beats/minute
P wave: Normal; precedes each QRS complex; all P waves similar in size and shape
PR interval: Normal; 0.12 second
QRS complex: 0.08 second
T wave: Upright
QT interval: Normal; 0.44 second
Other: No ectopic or aberrantly conducted impulses
ECG basics

PRACTICE STRIPS

PRACTICE 2-1

Rhythm: _______________________
Rate: _______________________
P wave: _______________________
PR interval: _______________________
QRS complex: _______________________
T wave: _______________________
QT interval: _______________________
Other: _______________________
Interpretation: _______________________

PRACTICE 2-2

Rhythm: _______________________
Rate: _______________________
P wave: _______________________
PR interval: _______________________
QRS complex: _______________________
T wave: _______________________
QT interval: _______________________
Other: _______________________
Interpretation: _______________________

PRACTICE 2-3

Rhythm: _______________________
Rate: _______________________
P wave: _______________________
PR interval: _______________________
QRS complex: _______________________
T wave: _______________________
QT interval: _______________________
Other: _______________________
Interpretation: _______________________
**PRACTICE STRIP ANSWERS**

**PRACTICE 2-1**
- Rhythm: Regular
- Rate: 94 beats/minute
- P wave: Normal
- PR interval: 0.16 second
- QRS complex: 0.12 second
- T wave: Normal
- QT interval: 0.34 second
- Other: None
- Interpretation: NSR

**PRACTICE 2-2**
- Rhythm: Regular
- Rate: 100 beats/minute
- P wave: Normal
- PR interval: 0.16 second
- QRS complex: 0.12 second
- T wave: Normal
- QT interval: 0.34 second
- Other: None
- Interpretation: NSR

**PRACTICE 2-3**
- Rhythm: Regular
- Rate: 88 beats/minute
- P wave: Normal
- PR interval: 0.18 second
- QRS complex: 0.08 second
- T wave: Normal
- QT interval: 0.36 second
- Other: None
- Interpretation: NSR