

The Electrocardiograph

3

Learning Outcomes

- 3.1 Explain the three types of leads and how each is recorded.
- 3.2 Identify the functions of common ECG machines.
- 3.3 Explain how each ECG machine control is used.
- 3.4 Recognize common electrodes.
- 3.5 Describe the ECG graph paper.
- 3.6 Calculate heart rates using an ECG tracing.

Key Terms

artifact	millimeter (mm)
augmented leads	millivolt (mV)
bipolar lead	multichannel recorder
bradycardia	output display
Einthoven's triangle	precordial lead
electrodes	serial ECG comparison
gain	signal processing
hertz (Hz)	speed control
input	tachycardia
leads	unipolar lead
limb lead	

3.1 Producing the ECG Waveform

In this chapter, you will learn about the electrocardiograph and the equipment needed to perform an ECG and record the ECG waveform. You will discover how the 12-lead system works and how to read the measurements on the ECG graph paper. Learning the equipment and lead system thoroughly and correctly will prepare you to record your first ECG.

The electrical impulse that is produced by the heart's conduction system is measured with the ECG machine. The ECG machine interprets the impulse and produces the ECG waveform. The waveform indicates how the heart is functioning electrically.

A single heart rhythm tracing views the heart from one angle. Because the heart is three-dimensional, it is necessary to view the electrical impulse from different sides to obtain a complete assessment of the heart's electrical activity. A 12-lead ECG provides a complete picture, not of the heart's structure, but of its electrical activity. It records the heart's

electrical activity from 12 different angles, as you might look at a sculpture from several different points of view. The 12 views provide information about how the electrical impulses travel through various parts of the heart.

A 12-lead ECG is actually recorded using only 10 lead wires, which, when attached to the chest and the limbs, provide the 12 different views for the 12-lead tracing. Six of these leads attach to the chest electrodes, and the other four leads attach to the electrodes on the arms and legs or shoulders and lower abdomen. **Electrodes** are small sensors placed on the skin to detect the electrical activity from the heart, and **leads** are small cables that conduct the electrical impulse from the electrodes to the ECG machine. The lead wires are identified by color and are labeled with letters to match the correct position on the patient's body (Table 3-1 and Figure 3-1).

The term *lead* also refers to the view on the ECG tracing as well as the physical location where the electrode is placed on the patient. For example, lead V2 refers to the labeled cable, the second intercostal space at the right

electrodes Small sensors placed on the skin to detect the electrical activity from the heart.

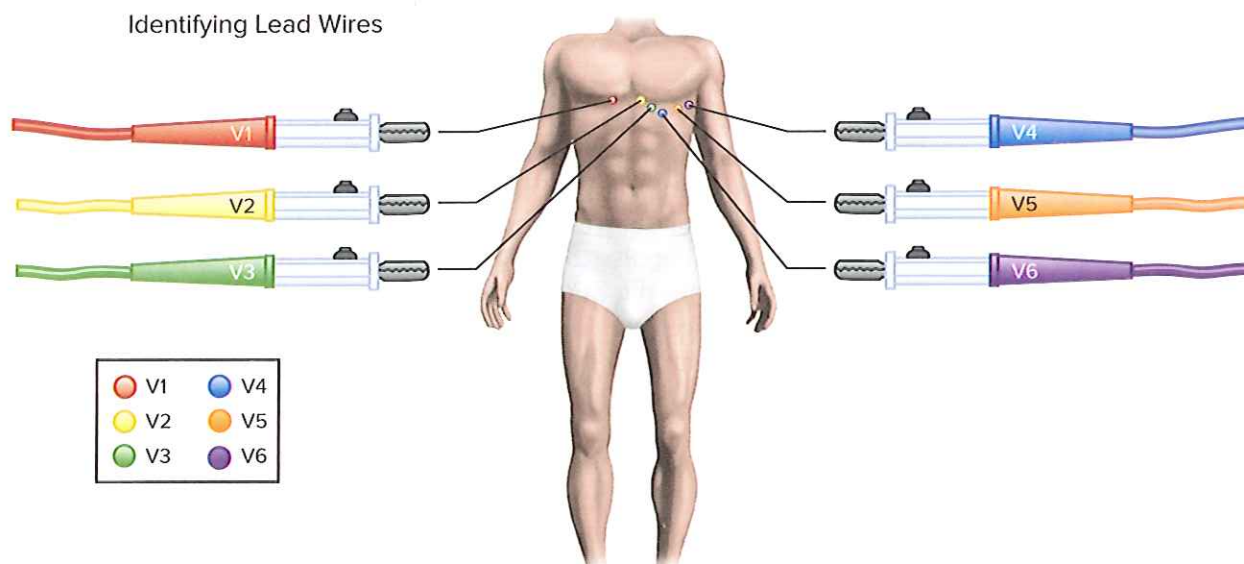
leads Covered wires that conduct the electrical impulse from the electrodes to the ECG machine.

TABLE 3-1 Lead Identification

Identifying Letters	Lead Wire Placement	Designated Color
RA	Right arm	White
LA	Left arm	Black
RL	Right leg	Green
LL	Left leg	Red
V1 to V6	Chest leads	V1 - Red V2 - Yellow V3 - Green V4 - Blue V5 - Orange V6 - Purple*

*V1 to V6 lead colors may vary.

Figure 3-1 When attaching the lead wires, check carefully for the correct color- and letter-coded wire.



sternal margin, and the V2 tracing on the printed ECG. Context is the clue to dealing with terms like these that have different meanings.

The 10 lead wires produce 12 different circuits consisting of one or more wires from the electrodes to the electrocardiograph. The 12 circuits produce 12 different tracings or views of the heart. The 12 leads include three different lead types: three standard limb leads, three augmented leads, and six chest leads. Table 3-2 identifies each of the 12 views and the specific electrodes that provide them.

Think It Through



Check the Lead Wires

Each of the lead wires is coded by color and letter. If you place the lead wires incorrectly, the ECG will not record at all or it will record the waveforms improperly. Always check and double-check the lead wires before you begin the tracing. An ECG recording produced with the lead wires attached incorrectly is not acceptable and will have to be repeated.

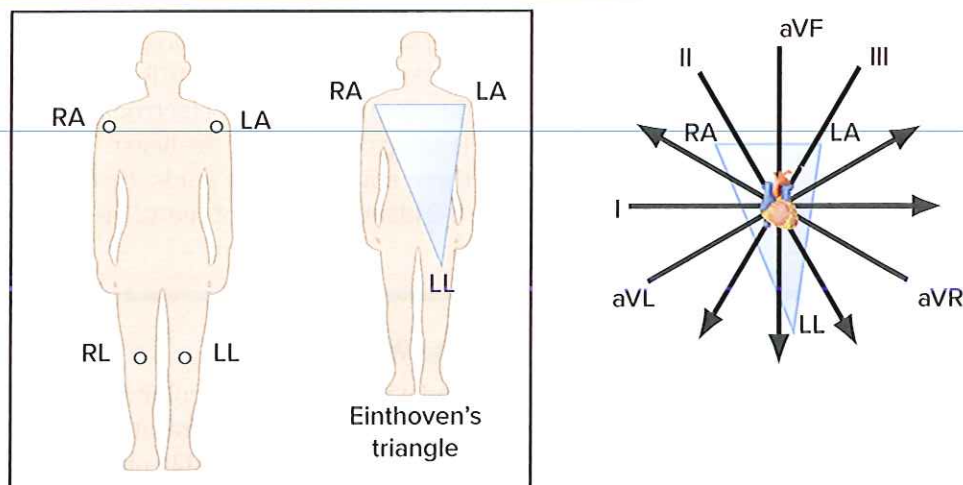
If you attempt to record an ECG and no tracing appears, what should you do?

TABLE 3-2 The 12 Views Provided by a 12-Lead ECG

Lead	Location of Electrode(s)	Surface of Heart Viewed	Type of Lead
Standard Leads			
Lead I	Right arm and left arm	Lateral	Bipolar
Lead II	Right arm and left leg	Inferior	Bipolar
Lead III	Left arm and left leg	Inferior	Bipolar
Augmented Leads			
aVR	Right arm	None – reference for dextrocardia and right ventricular hypertrophy (see the chapter <i>Performing an ECG</i>)	Unipolar
aVL	Left arm	Lateral	Unipolar
aVF	Left leg	Inferior	Unipolar
Chest Leads			
V1	Right sternum, 4 th intercostal	Septum	Unipolar
V2	Left sternum, 4 th intercostal	Septum	Unipolar
V3	Midway between V2 and V4	Anterior	Unipolar
V4	Midclavicular line, 5 th intercostal space	Anterior	Unipolar
V5	In line with V4 at anterior axillary line	Lateral	Unipolar
V6	In line with V4 and V5 at mid-axillary line	Lateral	Unipolar

Note: The right leg lead is not referenced in the 12-lead ECG. The right leg is always the ground in a traditional ECG.

Figure 3-2 A. Einthoven's triangle helps you understand the reference points for the 12-lead ECG. B. The black arrows indicate the direct and reverse views of each lead in this illustration.



Einthoven's triangle A triangle formed by three of the limb electrodes—the left arm, the right arm, and the left leg; it is used as a reference for the first six leads of the 12-lead ECG.

To understand the circuits for the first six leads, you can refer to the Einthoven triangle. Einthoven is the scientist credited with developing the first ECG machine. The **Einthoven's triangle** is formed by three of the limb electrodes: those on the right arm (RA), the left arm (LA), and the left leg (LL). The location not used becomes the ground or reference electrode, which is the right leg (RL) (Figure 3-2).

The electrical current created by the heart is measured between the positive and negative electrodes placed on the body. If no current is flowing, the waveform is flat, or isoelectric. If the current moves toward the positive electrode, the ECG waveform will be positive (above the isoelectric baseline). If the current moves away from the positive electrode/toward the negative electrode, the ECG waveform will be negative (downward, below the isoelectric baseline).

Standard Limb Leads

The first three leads are known as standard or **limb leads**. They are also known as **bipolar leads** because they measure the flow of electrical current in both directions at the same time. These first three leads are called lead I, lead II, and lead III. In the Einthoven triangle, leads I, II, and III are positioned at the same distance from the heart's electrical activity. Lead I records the tracing from the right arm (–) to the left arm (+); lead II records the tracing from the right arm (–) to the left leg (+); and lead III records the electrical activity from the left arm (–) to the left leg (+) (Figure 3-3). All three leads produce positive deflections.

Augmented Leads

The next three leads are known as **augmented leads**. The voltage is very low in the augmented leads because of the angle of measurement; therefore, the ECG waveform will be very small. The ECG machine must increase (augment) the size of the waveforms for these leads to be readable on the ECG tracing. They are also known as **unipolar leads** because they measure toward one electrode on the body. They are called aVR, aVL, and aVF. The R, L, and F refer to the direction in which the lead is measuring: R is right arm, L is left arm, and F is foot (left leg/foot) (Figure 3-4). Lead aVR records electrical activity from the heart to the right arm. Lead aVL records electrical activity from the heart to the left arm. Lead aVF records electrical activity from the heart to the left leg.

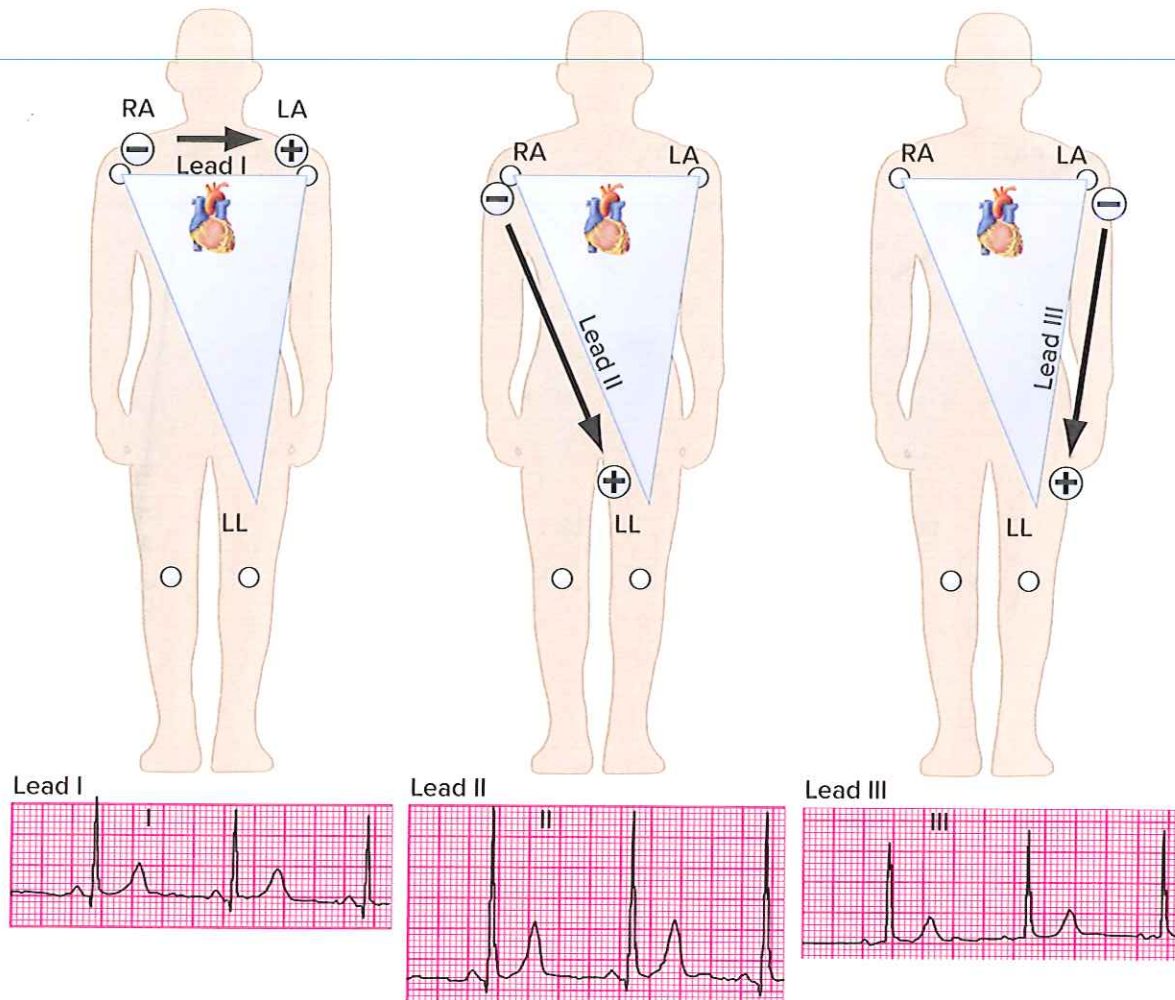
limb lead An ECG lead placed on an arm or a leg.

bipolar lead A type of ECG lead that measures the flow of electrical current in both directions at the same time.

augmented leads Normally small ECG lead tracings that are increased in size by the ECG machine in order to be interpreted.

unipolar lead A type of ECG lead that measures the flow of electrical current in one direction only.

Figure 3-3 Leads I, II, and III are standard limb leads and are recorded from these reference points on the Einthoven triangle, producing a positive deflection.



Lead aVR is usually a negative deflection. If it does not produce a negative deflection, you might have the electrodes placed in the wrong location or the limb lead wires reversed. To ensure accuracy of electrode and lead wire placement, check the aVR tracing produced when recording the 12-lead ECG; if it is not a negative deflection, verify the placement of the electrodes and lead wires to correct it.

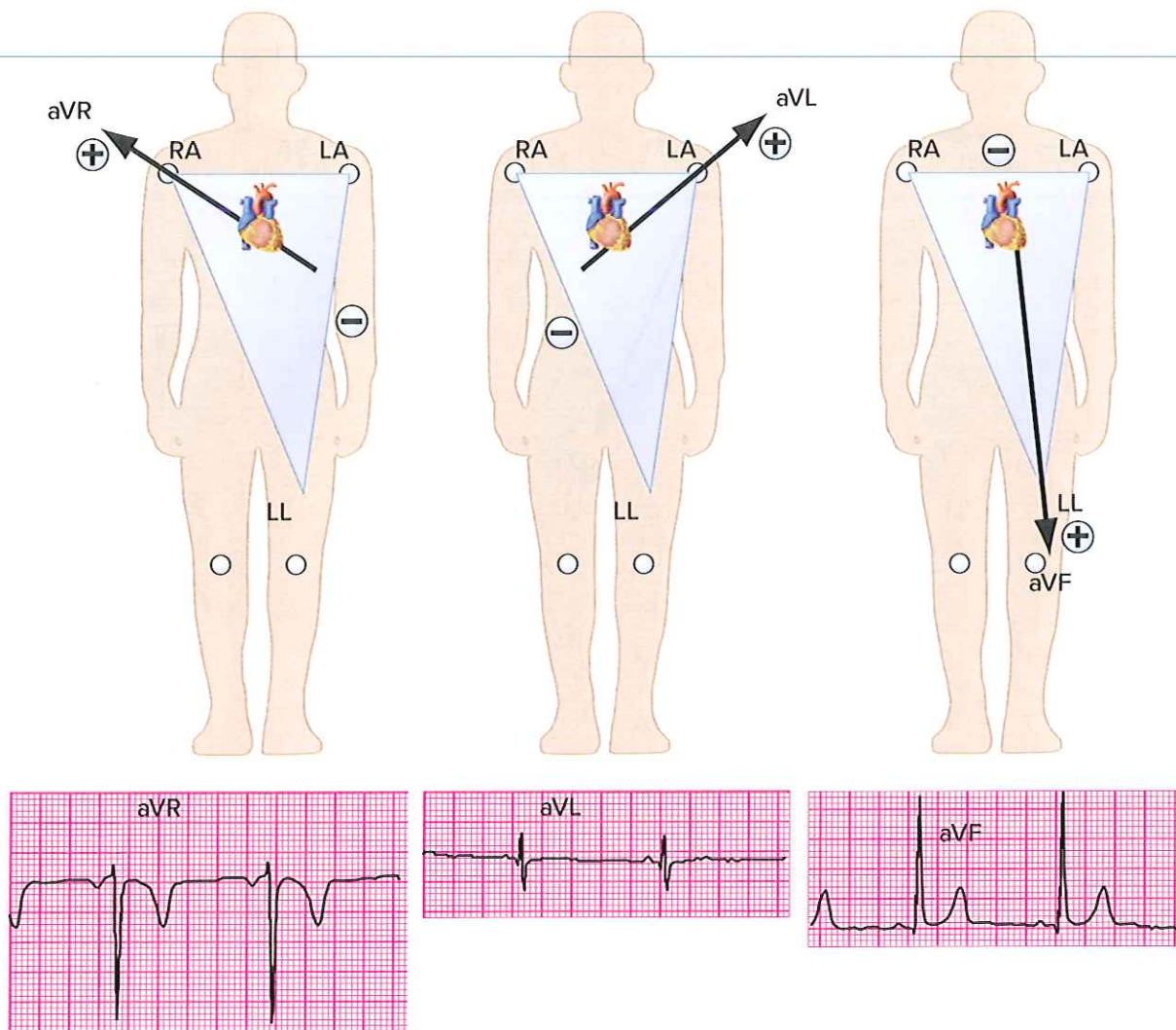
Chest Leads

precordial lead A type of lead placed on the chest in front of the heart; known as a V lead.

The last six leads are the chest leads. Also known as **precordial leads**, these leads are located in front of (*pre*) the heart (*cor*). The chest leads are unipolar because they are measured in one direction only. They are placed on specific sites on the chest. Each of the chest leads begins with the letter V and is numbered from V1 to V6. These leads record activity between six points on the chest and within the heart. You can view the placements in Figure 3-5. The procedure for placing electrodes is discussed in the chapter *Performing an ECG*.

The 12-lead ECG tracings can be interpreted separately or in conjunction with each other. When an ECG is being recorded, each of the 12 leads must be identified on the tracing. Older machines required that the ECG tracing strip be coded with identifying marks manually. Most machines in use today identify

Figure 3-4 The augmented leads aVR, aVL, and aVF are recorded from midway between two points on the Einthoven triangle. Because of the lead reference points, their tracings are normally small but are augmented (enlarged) by the ECG machine.



each lead tracing automatically. Each lead tracing looks slightly different and presents a different picture of the heart. This allows the physician to determine damage or problems in specific areas of the heart (Figure 3-6).

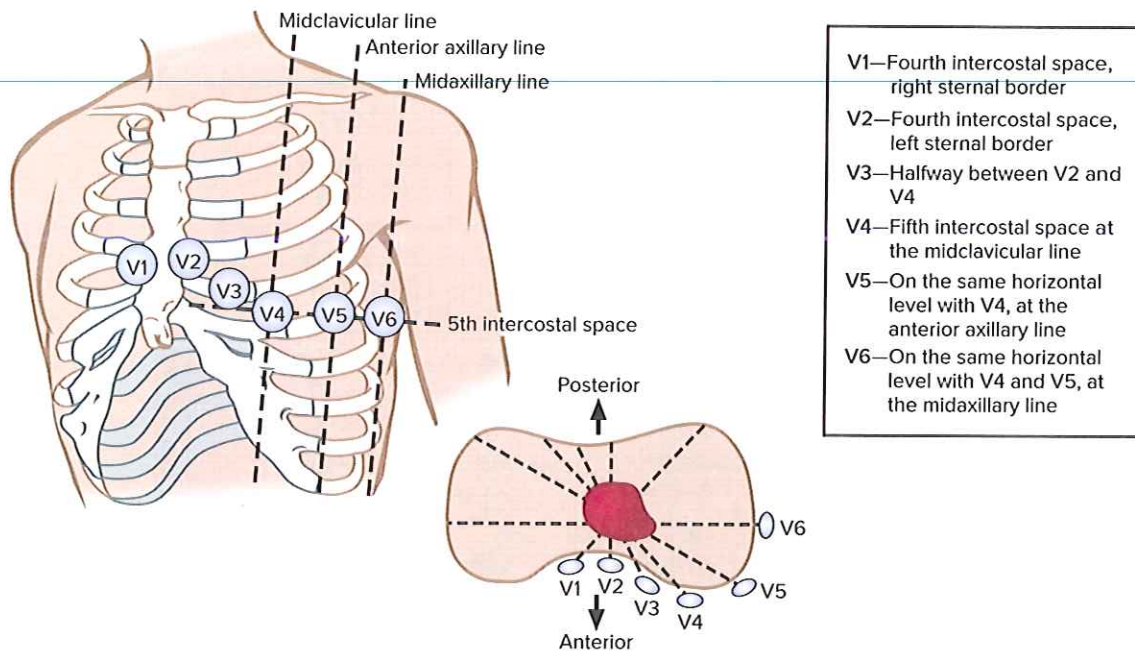
Checkpoint Questions (LO 3.1)

1. What test is done to view the heart at 12 different angles?

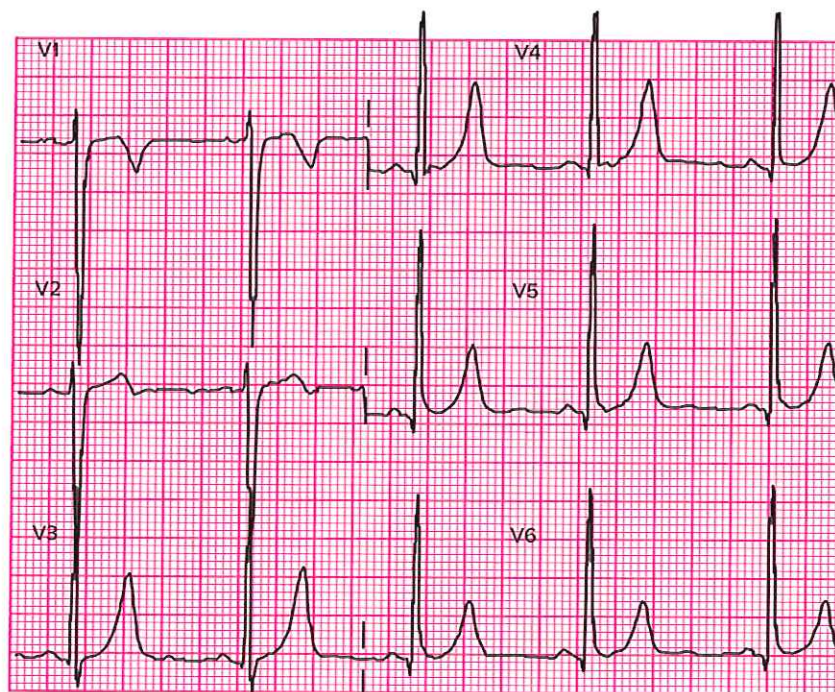
2. How many lead wires are used to obtain a 12-lead ECG tracing?

3. Name the three augmented leads.

Figure 3-5 Front and cross sectional views of chest lead placement.



- V1—Fourth intercostal space, right sternal border
- V2—Fourth intercostal space, left sternal border
- V3—Halfway between V2 and V4
- V4—Fifth intercostal space at the midclavicular line
- V5—On the same horizontal level with V4, at the anterior axillary line
- V6—On the same horizontal level with V4 and V5, at the midaxillary line



3.2 ECG Machines

multichannel recorder An ECG machine that monitors all 12 leads but records three leads at a time and switches leads automatically, recording each of the four sets of three leads.

Machines used today to measure an ECG weigh less than 10 pounds; some are as small as a credit card. All ECG machines vary slightly, but most have the same basic parts. The typical ECG machine sits on a small cart that can be pushed to the person requiring the ECG. You should become familiar with the type of machine you will be using by reading the manufacturer's instructions.

The **multichannel recorder** may be a three- or six-channel ECG machine that monitors all 12 leads but records leads in groups of three or six

Figure 3-6 A 12-lead ECG produced on a multichannel ECG machine. Each lead is identified on the printout. Note that each lead tracing (I, II, III, aVR, aVL, aVF, and V1 to V6) looks different.

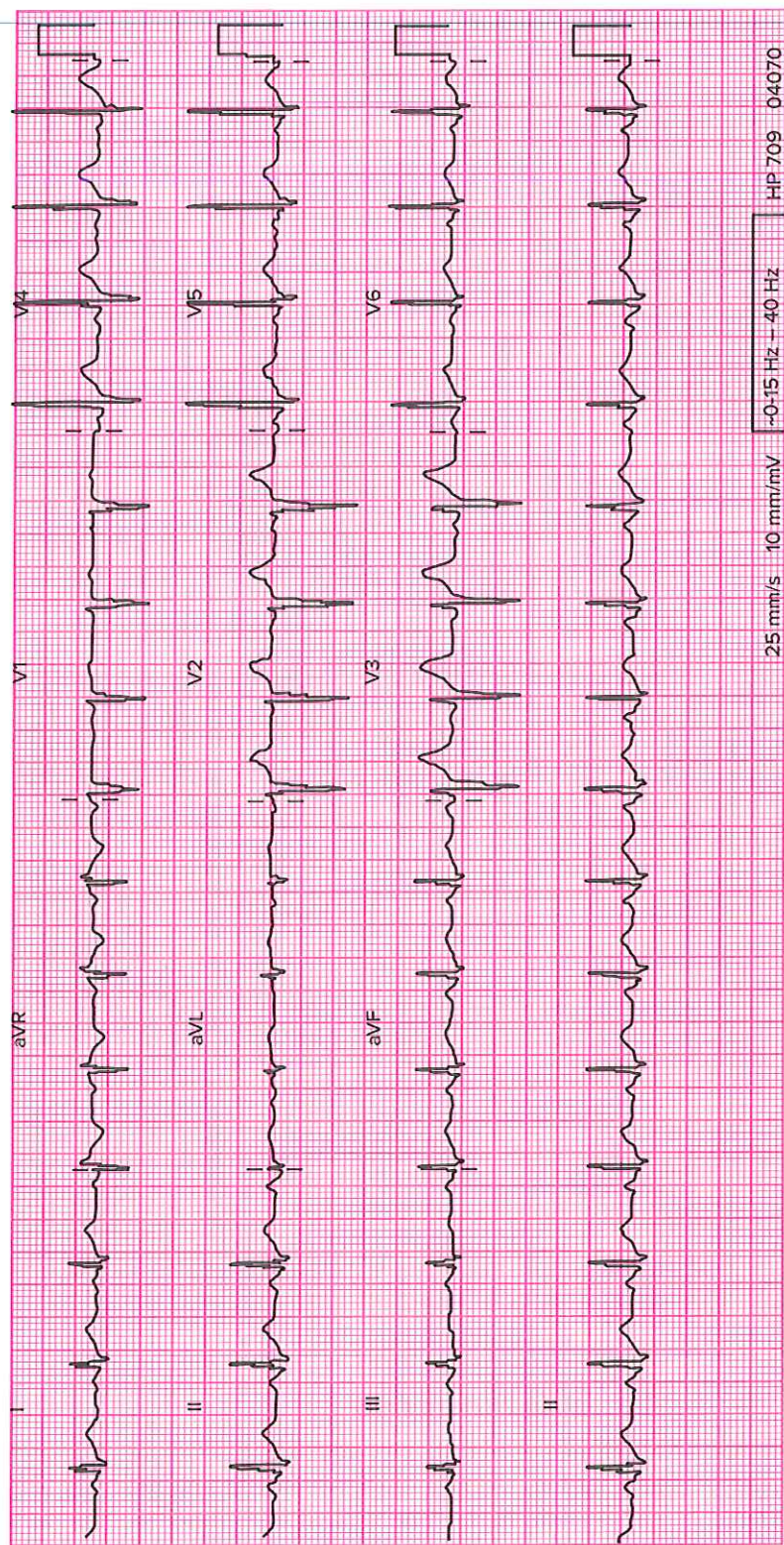


Figure 3-7 A multichannel ECG machine records three, four, or six leads at a time on a large sheet of ECG graph paper.

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Stock Photo



input Data entered into an ECG machine, usually through electrodes on the skin surface.

signal processing The process within the ECG machine that amplifies the electrical impulse and converts it to a mechanical action on the output display.

output display The part of the ECG machine that displays the tracing for the electrical activity of the heart, usually in an electronic or printed form on a 12-lead ECG machine.

at a time (Figure 3-7). It produces a full page showing all 12-lead tracings. The actual recording time for this machine is approximately 10 seconds. Some multichannel ECG machines can record up to six lead tracings at one time. In most cases, electronic copies of 12-lead tracings and interpretations are stored and transmitted electronically via telecommunications.

Functions

The electrocardiograph has three basic functions: input, signal processing, and output display. Sensors in the ECG machine serve as receiving devices for the electrical activity of the heart. Electrodes placed on the patient's skin direct the impulses to the ECG instrument, providing the **input** for the ECG machine.

Signal processing occurs inside the ECG machine. It amplifies the electrical impulse and converts it into a form that can be shown on the display. A complex collection of transistors, resistors, and circuitry amplifies and prepares the signal for transfer to the output display.

The **output display** is the result of the ECG tracing. The output is typically on a computer or other electronic screen. The output can also appear on

a dedicated LED screen, which is frequently found on a cardiac monitor or a defibrillator.

ECG machines perform other functions as well, including computerized measurement and analysis, storage, and communication. Computerized measurement and analysis provide a machine interpretation of the ECG tracing. This interpretation is not meant to replace the physician's interpretation. However, the computer interpretation can distinguish between a normal and abnormal recording quickly and may provide a second opinion. All computerized interpretations should be manually confirmed by a physician.

Some ECG machines store ECG results, which then can be recalled and printed later. ECG machines are also equipped to transmit results over the telephone, fax, or Internet.

Advancing Technologies

ECG machines have undergone many advances over the past 30 years. They have gone from single-channel to three lead machines, to our current 12-lead machines and wireless technology (Figure 3-8). The 12-lead ECG machines 30 years ago seem primitive compared to modern equipment.

Modern ECG machines are becoming much smaller and more portable than in the past. In fact, one recent innovation in ECG technology is the development of small ECG devices that connect to a computer or tablet using a USB connection. These devices can instantly convert the computer or tablet to a digital ECG system.

Advances are also being made in the area of digital technology. Many ECG machines are now able to not only acquire and store the tracings but also transmit a digital image of the 12-lead for storage in a central location.

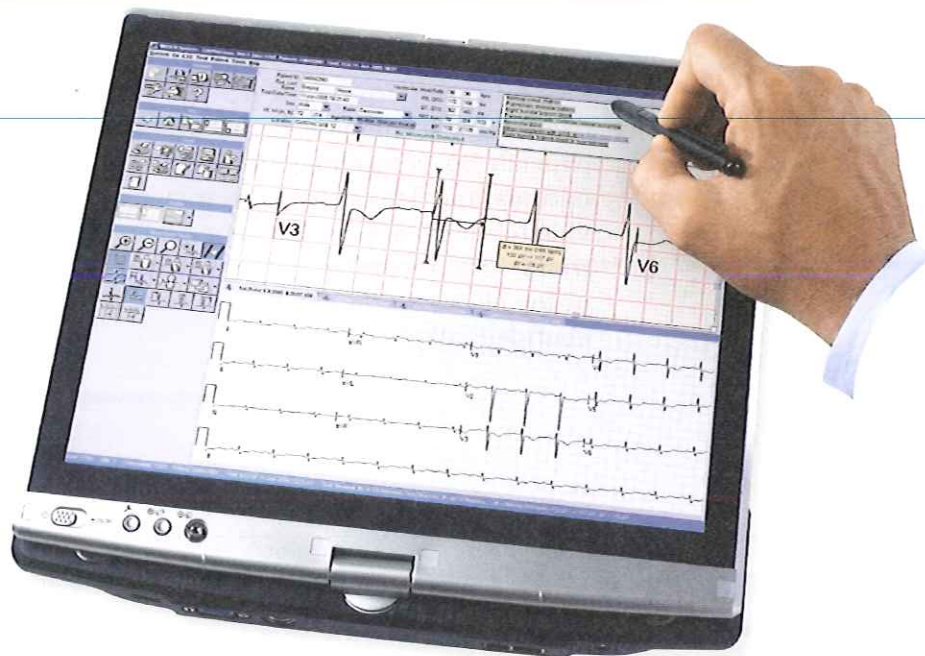
Figure 3-8 The MAC 5500 resting ECG analysis system can analyze, transmit, store, and retrieve ECG information quickly and easily.

Courtesy of GE Healthcare Systems



Figure 3-9 The electronically stored ECG retrieved by the MUSE Cardiology Information System by GE Healthcare looks just like the printed record.

Courtesy of GE Healthcare Systems



Many facilities use an ECG management system to track, store, and organize patient ECGs. This is particularly beneficial when patients are seen in hospitals other than the one where the 12-lead ECG was obtained. Access to this vital information is much more readily available than at any time in the past.

One such digital storage system is the MUSE Cardiology Information System developed by GE Healthcare (Figure 3-9). This system is able to integrate, manage, and streamline the flow of cardiac information, such as resting 12-lead ECG, exercise stress ECG, and Holter devices. This system provides faster data delivery, distribution of information, and analysis. The MUSE digital storage system allows the provider easy access to patient information. Devices like this make the healthcare system more efficient due to their ability to communicate between the hospital information system, electronic health records, and the ECG devices themselves.

This system allows you to retrieve the current ECG and older ECGs for **serial ECG comparison**. The retrieved 12-lead on the computer screen looks just like the printed record (Figure 3-9). The screen has a simple toolbar to make accessing common features quick and clear. These features help with viewing and printing the ECG. The ability to view serial ECGs is important for detecting subtle changes that may indicate myocardial abnormalities (such as ischemia, injury, or infarction).

MUSE and similar ECG management systems manufactured by Philips, Schiller, Mortara, and other companies support the progressive paperless electronic health record initiative. Computer advances in medicine improve efficiency, billing accuracy, and time from test to diagnosis, and they reduce personnel demands. Ultimately, the use of MUSE and electronic health records improves the speed and quality of medical care, where quick access to critical cardiac information is essential to patient care. Every second can count in reducing the long-term damage that can result from heart trauma. As technology advances, it is essential to stay current with any equipment you will be using.

serial ECG comparison

Multiple and frequent ECG tracings recorded at intervals based upon the patient's condition and compared to identify changes.



Protecting ECG Records

Two primary purposes of HIPAA are to improve the efficiency and effectiveness of healthcare delivery and protect and enhance the rights of patients by controlling the inappropriate use or disclosure of patient information. Transmitting, retrieving, and storing the ECG tracing provide for quick access and improved delivery of care to patients. The electronic ECG recording is part of the patient record and just like the rest of the electronic health record must be password protected and handled confidentially.

Checkpoint Questions (LO 3.2)

1. A multichannel ECG monitors all 12 leads but usually records how many leads at one time?

2. What are the three basic functions of an ECG?

3.3 ECG Controls

The three most important controls on the electrocardiograph include the speed, gain, and artifact filter.

Speed

speed control A control on the ECG machine that regulates how fast or slow the paper runs during the tracing.

millimeter (mm) A unit of measurement to indicate time on the ECG tracing. Time is measured on the horizontal axis.

The **speed control** regulates how fast or slow the paper or data runs during the ECG procedure. Paper speed is measured in **millimeters (mm)**. Each small box on the ECG grid paper is a 1 × 1 mm square. The most commonly used paper speed is 25 millimeters per second (25 mm/sec). In some cases, you may want to increase the speed to 50 mm/sec, which is twice as fast. You would do this if the patient has an unusually rapid heart rate so that the complexes are spread over a greater distance on the graph paper. It may also be done if the ECG waveform parts are too close together. Increasing the speed would allow the waveform to be analyzed more easily because they would appear wider.

Some ECG machines allow you to reduce the speed to 5 mm/sec or 10 mm/sec in order to analyze the ECG recording more carefully. Changing the speed of the recorder is usually done at the request or preference of the physician. Remember, if you change the speed to anything other than the standard 25 mm/sec, you must note this on the tracing and, if possible, notify the healthcare provider who will interpret the tracing.

Think It Through



Changing the ECG Tracing Speed

When the patient's heart rate is very fast, it is difficult to read the ECG tracing because the waveform parts are close together. Set the speed control at 50 mm/sec to widen the complexes so the ECG can be interpreted more easily. *Circle or note the speed setting and, when possible, verbally tell the healthcare provider who will be interpreting the results about the change in speed.* This notification is essential to avoid misinterpretation of the ECG; for example, a normal ECG set to double speed can sometimes look like an abnormal rhythm known as a heart block.



This ECG tracing was produced at a speed of 50 mm/sec. What should you do?

gain A control on the ECG machine that increases or decreases the size of the deflections on the ECG tracing.

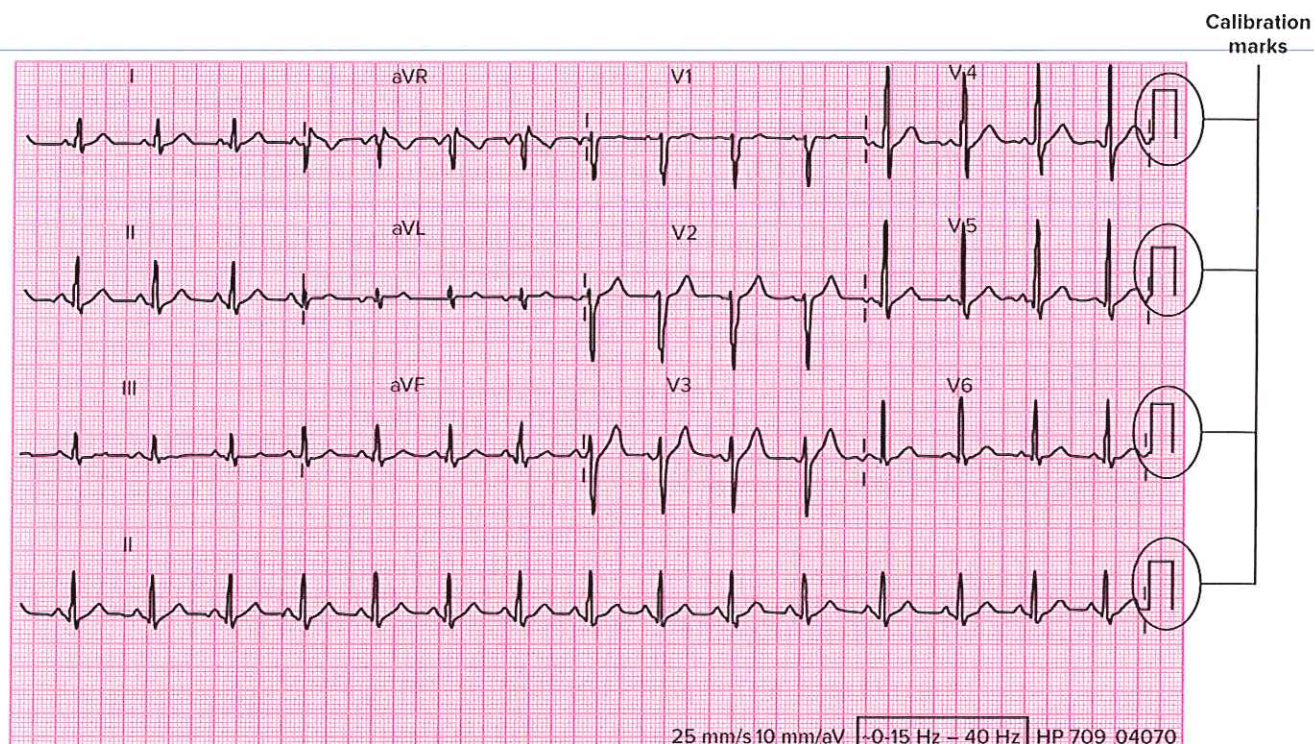
millivolt (mV) A unit of measurement to indicate voltage on the ECG tracing. Voltage is measured on the vertical axis.

Gain

The **gain** (also known as *sensitivity*) control regulates the output or height of the ECG waveform. Voltage on an ECG tracing is measured in **millivolts (mV)**. This is represented vertically (up and down) on the tracing. The normal setting is 10 mm/mV (millivolts are the units of measurement used to indicate voltage on the ECG tracing). A waveform that is 10 mm tall would be equal to 1 mV of electrical activity. By setting the gain to 20 mm/mV, you can double the height of the waveform; by setting the gain to 5 mm/mV, you reduce the height of the waveform by half. Some machines will let you change the gain, depending on which lead you are tracing. The gain control may use settings of 1/2, 1, or 2 to change the amplitude (height) of each wave. Because the tracing size can vary between leads, setting the gain will allow the ECG waveform to be readable for any lead tracing. If you change the gain setting during any lead tracing, you must record this change on the ECG report. Digital machines standardize the wave output height automatically.

Calibration marks are placed at either the beginning or the end of a 12-lead ECG tracing (Figure 3-10). These open-ended rectangular shapes are used as a reference to compare with the cardiac complexes to determine the amount of electricity (voltage) being generated in the atria and ventricles of the heart during each cardiac complex. This is similar to an old-fashioned map on which a certain measurement, such as 1 inch, is equal to a certain number of miles.

Figure 3-10 The calibration mark on the ECG tracing must be verified to ensure accuracy. The first rectangular waveform on the ECG tracing is indicating the standardization of the machine for the recorded ECG.



Communicate & Connect



Know Your ECG Machine

Become familiar with the ECG machine you will be using before performing an ECG. Your uncertainty could cause anxiety or nervousness in the patient who is having the ECG performed.

hertz (Hz) A unit of frequency measured in cycles (or events) per second.

artifact Unwanted marks on the ECG tracing caused by activity other than the heart's electrical activity.

Artifact Filter

The ECG machine you are using may have an artifact filter selection. The usual setting is between 40 and 150 **hertz (Hz)** (a unit of frequency that indicates cycles or events per second). Forty Hz is normally used to reduce **artifact** or abnormal marks on the ECG tracing due to muscle tremor and slight patient movement. The chapter *Performing an ECG* discusses artifact in more detail.

Remember that the artifact filter will correct only the printed output. If the computer performs interpretation, it will interpret the results from the actual nonfiltered information from the patient, not what is printed or viewed on the screen. This could cause the computer to misinterpret the rhythm. That is why it is essential that a physician confirm the interpretation of all ECGs. Some filtering of artifact will prohibit the view of pacemaker spikes. Pacemaker spikes are unique markings on an ECG that indicate a patient has an

Figure 3-11 A. The patient data can be entered and the ECG tracing viewed on the LCD display. B. Some machines include a bar code scanner to identify the patient and to automatically enter the patient information onto the tracing.

A. ©Dr. P. Marazzi/SPL/Science Source, B. ©Lillian Mundt.



A.



B.

artificial pacemaker. It is important to know how to modify the filter to allow for pacemaker spikes to be seen.

LCD Display

There are various other controls on the ECG machine that allow you to enter information. For example, you can enter data about the patient to be included on the printout along with the ECG results. These data can also be entered electronically using a scanner on the patient's identification band (Figure 3-11). This information is entered into the LCD (liquid crystal diode) display. This is the area of the machine where you can view the patient information you have entered. It is also where information from the ECG's computer is displayed. For example, some machines can detect if the arm leads or chest leads are reversed and display this information in the LCD panel.

Heart Rate Limits

If the ECG machine has computer interpretation, it may allow you to set the heart rate limits. In other words, at the direction of the licensed practitioner, you can set the heart rate that the machine will interpret as too slow—**bradycardia**—or too fast—**tachycardia**. If the heart rate is above or below the number set, the machine will indicate this by sounding an alarm and marking on the tracing.

Lead Selector

Most 12-lead ECG machines record each of the leads automatically. However, a lead selector can be used to run each lead individually in case one or more leads need to be repeated.

sinus bradycardia A slow heart rate, usually less than 60 beats per minute.

sinus tachycardia A fast heart rate, usually greater than 100 beats per minute

Think It Through



Changing the Gain

When the deflections on the ECG tracing are too short or too tall, you will need to correct the gain. Be certain the machine is standardized correctly, and then adjust the gain control, if necessary.

If you are recording an ECG and the deflections or spikes of the tracing are not large enough, what should you do?

Checkpoint Questions (LO 3.3)

1. What are some reasons that you may change the speed of the ECG tracing?

2. Name the major controls of the ECG machine.

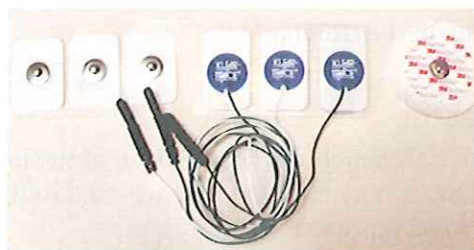
3.4 Electrodes

Electrodes are sensors that are placed on a person's skin to pick up the electrical activity of the heart and conduct it to the ECG machine. Electrodes come in a variety of types and are disposable.

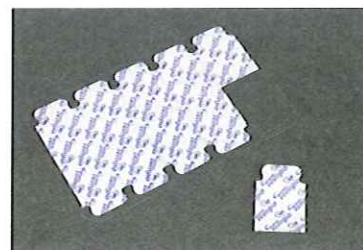
Disposable electrodes are used because they reduce the possibility of cross-contamination and can be simply removed and discarded for easier cleanup (Figure 3-12). The self-adhesive types stick easily to the patient's body. The gel is already applied so the electrodes will properly conduct the electrical impulses.

Figure 3-12 A. Disposable electrodes come in various shapes and sizes. Electrolyte gel or paste is not necessary because it is already contained on these electrodes. B. Standard resting tab electrodes are inexpensive, disposable, and easy to use for a routine ECG.

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A.



B.

Each disposable electrode is normally used for only one ECG. The only exception occurs when a second ECG is performed on the same patient immediately after the first and the electrodes have not been disturbed. For example, if you are transferring a patient from an outpatient facility to a hospital, you should leave the electrodes in place for the emergency medical personnel. They will be recording one or more ECGs on the way to the hospital. However, if the electrodes stay on the patient's skin any longer than two sequential readings, the gel will dry out, resulting in inaccurate ECG tracings.

For hospitalized patients, longer-lasting silver electrodes are available. These electrodes are used for patients who require multiple and frequent ECGs (serial ECGs). When serial ECGs are required, it is important to ensure the same lead placement for each. A slight change often causes a change in the tracing. The silver electrodes are kept on the patient and checked daily.

Electrodes can be a problem for patients. The gel can react with the skin, causing itching and irritation. With some patients, the adhesive will stick more making it painful for the electrodes to be removed right after the ECG. Additionally, sometimes the patient is accidentally sent home with electrodes in place that dry out and can cause irritation and are painful to remove.

No matter what type of electrodes are used, they must be handled and stored correctly. If a package contains more electrodes than needed, the remaining electrodes must be kept in a sealed plastic bag so the gel will not dry out. Always check the expiration date on the package before use. Make sure the electrode gel has not dried out on any electrode. Even new electrodes should be checked before placement. Additionally, you should never mix two different types of electrodes. This could cause an inaccurate tracing, which could result in incorrect treatment for the patient.



Checkpoint Question (LO 3.4)

1. Which type of electrode is used when monitoring a patient who will be having serial ECGs done?

3.5 ECG Graph Paper

The ECG machine records an image of the heart's electrical activity onto a graph on the screen or paper. This image is the ECG waveform, or a series of waves and complexes recorded from the activity in the heart. The graph provides increments to measure the electrical activity produced on the tracing. Understanding the ECG graph intervals and what they represent is essential to reading the ECG.

The two most commonly used types of graph paper are standard grid and dot matrix (Figure 3-13). Both are heat- and pressure-sensitive. Because the paper is pressure-sensitive, you should handle it carefully to avoid marking it. Marks on the paper could make the tracing difficult to read or cause the tracing to be read inaccurately. In addition, certain substances, such as alcohol, plastic, sunlight, and X-ray film, can erase the tracing. Once the ECG is completed, it should be stored away from these substances. Some companies offer recording paper that requires no special handling or storage. This paper guarantees that the tracing will last for up to 50 years.

Figure 3-13 Choose the right size and type of graph paper for the ECG machine you will be using.

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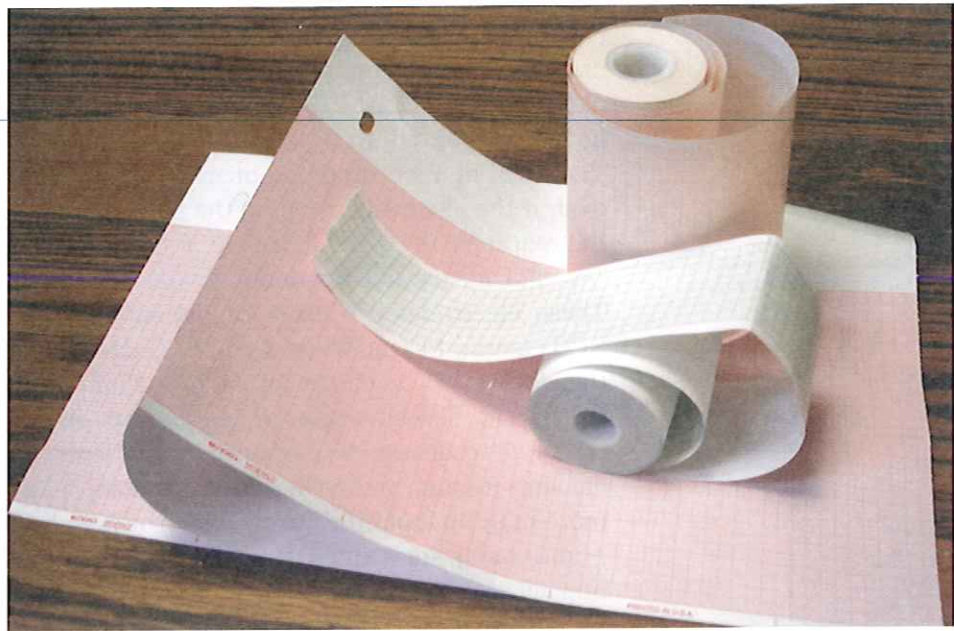


Figure 3-14 Comparison of ECG graph paper: dot matrix paper (A) requires less ink, is easier to read, and produces sharper photocopies, whereas standard grid paper (B) is slightly less expensive.

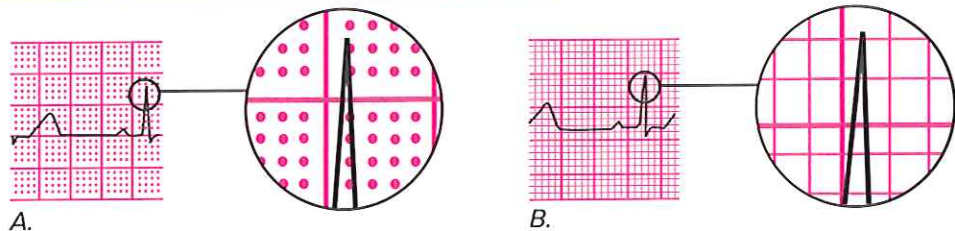
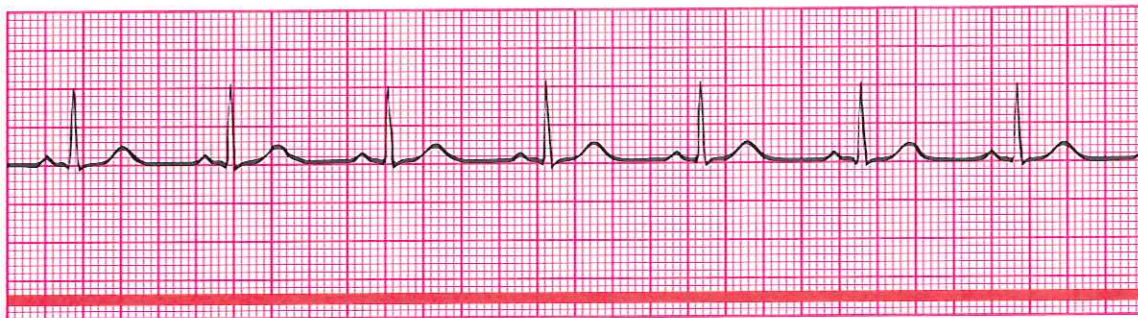


Figure 3-15 While performing an ECG, a thick red line at the bottom of the graph paper indicates that the paper needs to be changed.



Dot matrix paper has some advantages over standard grid paper. Dot matrix reports require less ink, are easier to read, and produce sharper photocopies, yet dot matrix paper is much less commonly used. One advantage of standard grid paper is that it is slightly less expensive (Figure 3-14).

Prior to performing an ECG, make sure the machine has enough paper to record the results. Each machine has a paper loading procedure that you should become familiar with. Many of the machines warn you when the paper is nearly gone by making a red mark across the bottom of the tracing (Figure 3-15). Read the manufacturer's directions for specific instructions on how to change the ECG machine paper. Keep a supply of paper on the ECG cart in case you run out of paper in the patient's room or examination room.

Think It Through



Handle the ECG Report with Care

Handle and store the ECG report with care. It can be damaged easily; and if damaged, it cannot be interpreted by the physician.

The physician places a stack of charts on top of an ECG report you just placed on his desk. What should you do?

Measurements

The ECG graph paper consists of precisely spaced horizontal and vertical lines. The horizontal increments represent time, measured in seconds. The vertical increments represent voltage, indicated in millivolts (mV). At the standard paper speed of 25 mm/sec, the paper grid can be translated into specific numerical values. One mm (small) horizontal line corresponds to 0.04 seconds. Large grid boxes are formed that measure 5 mm and represent 0.2 seconds. Each second is marked by 5 large horizontal boxes. For standardized tracings, the smallest vertical box on the graph paper is 1 mm high and represents 0.1 mV. Thus, ten small vertical boxes represents 10 mm or 1 mV. When the standardization is set to half standard then 5 mm equals 1 mV (Figure 3-16). The paper speed and the standardization may be changed based upon the patient and the heart rhythm. A calibration mark should always be verified on the left-hand side of the ECG before printing. Paper speed and voltage are usually found on the ECG tracing.

Law & Ethics



Maintaining Patient Records

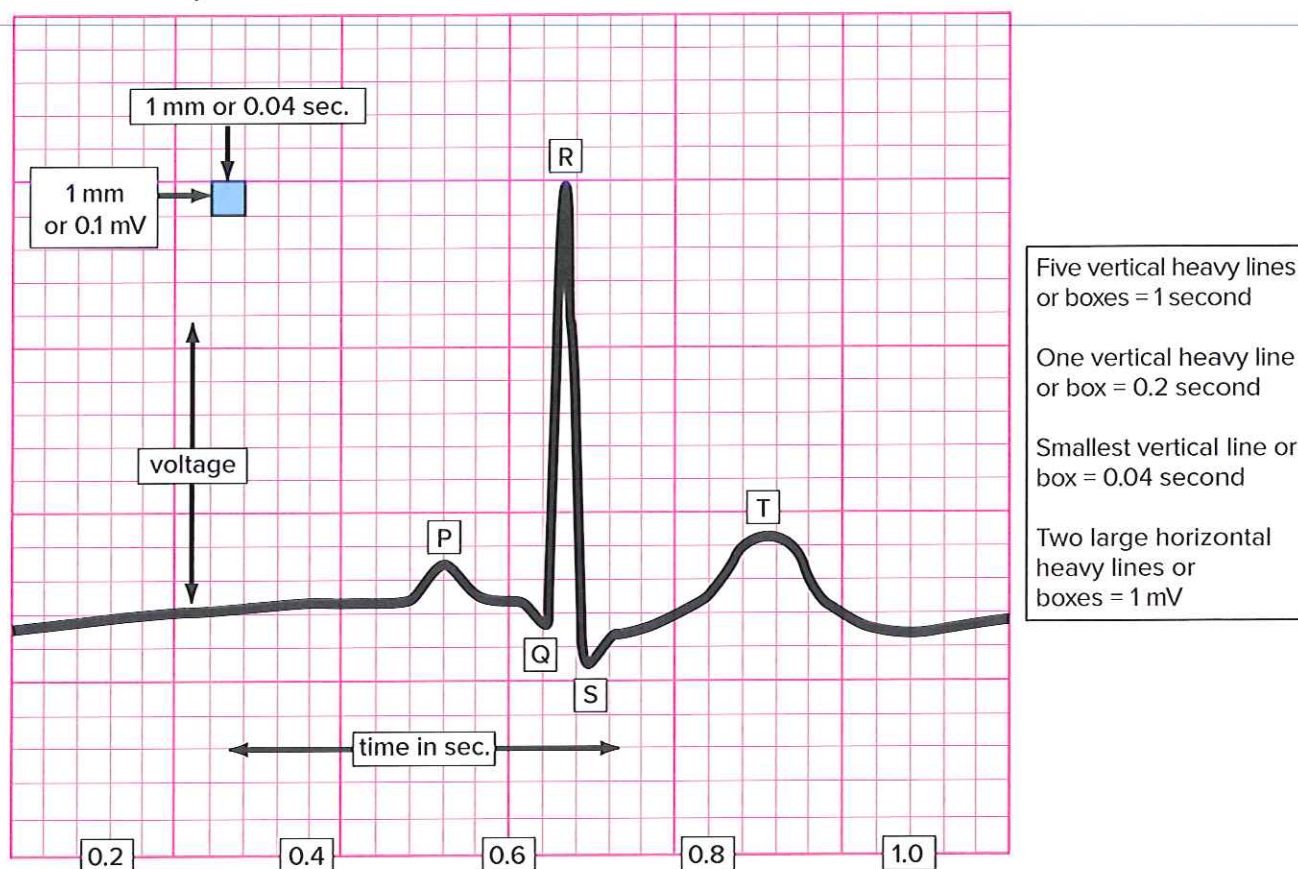
Handling the ECG paper and report correctly is essential because the ECG report is part of a patient's medical records and must be maintained for at least seven years.

Checkpoint Questions (LO 3.5)

1. When the paper speed is 25 mm/sec, how many small boxes represent 1 second?

2. When the paper speed is 25 mm/sec, how many seconds does one small box represent?

Figure 3-16 The ECG paper allows measurement of both time and voltage. Note that each small box is either 0.1 mV in voltage or 0.04 second in time. Measurement from the smallest vertical line to the next = 0.04 second. Measurement from one vertical heavy line to the next = 0.20 second.



3.6 Calculating Heart Rate

A quick look at the ECG tracing can give you an idea of the heart rate. The more space between the QRS complexes, the slower the heart rate. The less space between the QRS complexes, the faster the heart rate. A more accurate approximation can be done using a variety of methods:

1. The 300 method: useful for approximation of heart rate when the rhythm is regular
2. The 1500 method: the most accurate for use with regular rhythms
3. The 6-second method: is the only method to use for irregular rhythms, but it can also be used for regular rhythms; it provides an approximation of the heart rate only

The 300 Method

The 300 method (large box) method is based upon the fact that when you are running the ECG at 25 mm/sec (five large boxes/sec), there are 300 large boxes in a 1-minute strip. To calculate the heart rate, you need to first determine the number of complete large boxes between two R waves on the ECG tracing and divide this number into 300. This method may also be called the R to R method. For example, if there were five complete large boxes between the R waves, the heart rate would be 300 divided by 5, which equals 60 beats per minute. Table 3-3 provides the approximate heart rates based on this

TABLE 3-3 Calculating Heart Rates by the 300 (R-R) Method

Large Boxes between Two R Waves	Heart Rate Calculation	Heart Rate per Minute
1	$300 \div 1$	300
2	$300 \div 2$	150
3	$300 \div 3$	100
4	$300 \div 4$	75
5	$300 \div 5$	60
6	$300 \div 6$	50

Figure 3-17 To estimate the heart rate with the R-R method, count the number of complete large boxes between two R waves and divide into 300. In this figure there are five full boxes between the R waves for an estimated rate of 60.

The first small box is not included in the calculation. Count large boxes only.



method of calculation. Figure 3-17 illustrates the process for calculating heart rates using the R-R wave method. This technique is the least accurate method because incomplete boxes are not counted or included in the calculation.

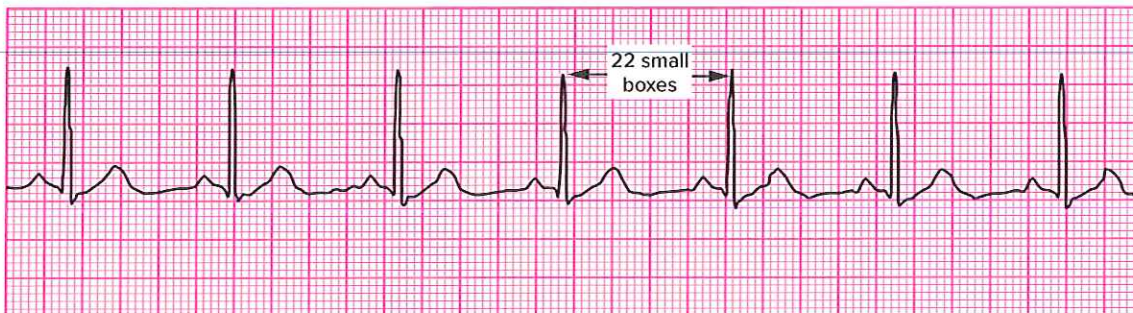
The 1500 Method

The most accurate method for determining the rate of a regular rhythm is the 1500 (small box) method, named such because in a 1-minute interval there are 1,500 small squares. To use this method, count the number of small squares between two consecutive R waves and then divide that number into 1,500. For example, if you count 25 small squares between two R waves, you will divide that into 1,500 ($1,500 \div 25 = 60$). The heart rate would be 60 beats per minute (Figure 3-18). *This technique allows you to measure to a minimum distance of 0.5 mm (one-half small box).* Because the calculation is based on the number of small squares, it has by far the smallest margin for heart rate error. *Note:* When using the 1500 technique, round to the nearest whole number. Round down if the fractional beat is less than 0.5, or round up if it is 0.5 or more. For example, $86.4 = 86$ and $76.7 = 77$.

The 6-Second Method

The third method is called the *6-second method*. This is the only method that can be used to approximate irregular heart rhythms. First, identify a 6-second section of the tracing. The ECG paper is usually marked at predetermined

Figure 3-18 Using the 1500 method, count the number of small boxes between two R waves and divide into 1,500. In this example, there are 38 small boxes. $1,500 \div 38 = 39.47$, which rounds down to 39 beats per minute.



time intervals. It may be marked at 1, 3, or 6-second intervals depending upon the manufacturer. These marks may be found at the top or bottom of the strip. Second, count the number of complete complexes seen in one 6-second interval. Each cardiac complex must include the P, QRS, and T waves. The complex should not be counted unless it is complete. Third, multiply the number of complexes by 10 to determine the estimated heart rate (Figure 3-19 and “Troubleshooting—Counting the Heart Rate”).

Think It Through



Counting the Heart Rate

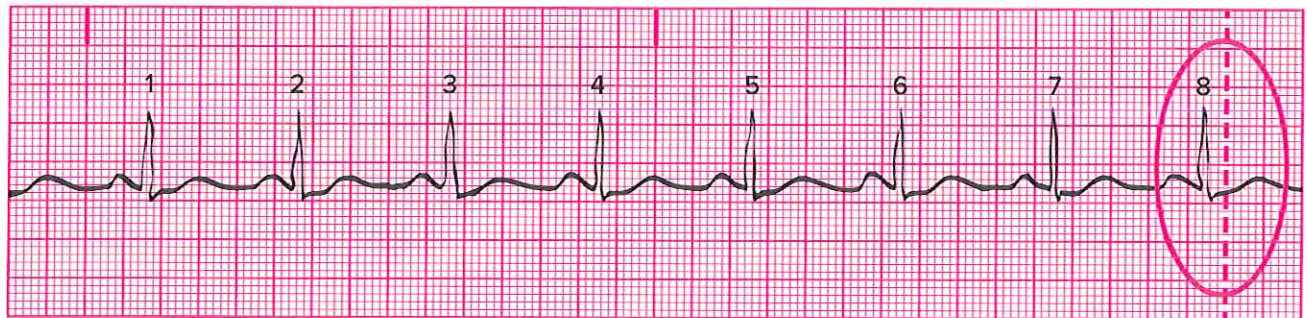
When calculating the heart rate by counting the complexes in a 6-second interval, count the complete complexes only. If there is a portion of a complex at each end of the 6-second section you are using, find another section on the tracing to view. Never count incomplete complexes; this will make your results inaccurate.



Multiply the number of complete complexes by 10

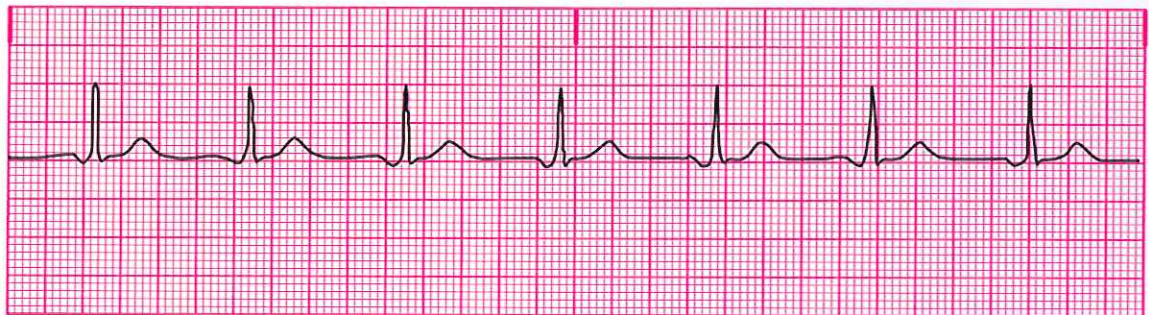
Count the number of complete complexes in the above 6-second interval then calculate the heart rate using all three methods: 6-second, R-R, and 1500.

Figure 3-19 To estimate the heart rate with the 6-second method, locate a 6-second section of the ECG rhythm strip (each small black line or heavy red mark at the top of the strip indicates 15 boxes or three seconds), count the number of complete complexes in this section, then multiply the number of complexes by 10. In this figure, eight complete complexes equal an estimated heart rate of 70. Complex number 8 cannot be counted because it is not completely within the 6-second strip.

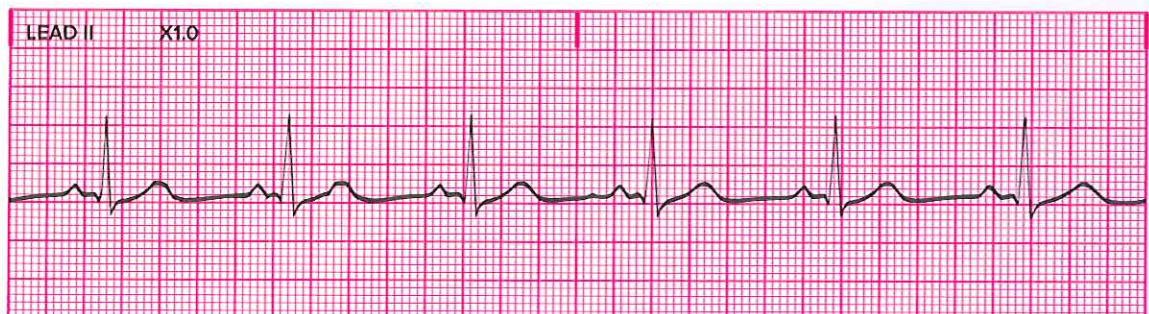


Checkpoint Questions (LO 3.6)

1. Calculate the heart rate for this ECG strip using the 1500 method.



2. Estimate the heart rate for this ECG strip using the 1500 method.



Chapter Summary

Learning Outcomes	Summary	Pages
3.1 Explain the three types of leads and how each is recorded.	Three types of leads are used to produce the ECG: limb, augmented, and chest leads. Limb leads are bipolar, meaning they measure electricity in two directions. Augmented leads are unipolar because they measure toward one electrode on the body. Chest leads record activity between six points on the chest and within the heart.	59–65
3.2 Identify the functions of common ECG machines.	The ECG machine has three basic functions: input, signal processing, and output display.	65–70
3.3 Explain how each ECG machine control is used.	The controls for the ECG machine include the speed, gain, artifact filter, LCD display, heart rate limits, standardization, and the lead selector.	70–74
3.4 Recognize common electrodes.	Various types of disposable electrodes are used, depending on the equipment and type of ECG being recorded.	74–75
3.5 Describe the ECG graph paper.	ECG graph paper has boxes that are 5 mm by 5 mm and are divided into smaller boxes that measure 1 mm by 1 mm. Each small box indicates 0.04 second in time horizontally and 0.1 mV in voltage vertically.	75–78
3.6 Calculate heart rates using an ECG tracing.	There are three common ways to calculate the heart rate, including the R-R (300) method, the 1500 method, and the 6-second method.	78–81

Chapter Review

Matching I

Match the lead names on the left with their lead types on the right. (LO 3.1)

- | | |
|--------------------|--------------------|
| _____ 1. V1 | a. limb lead |
| _____ 2. aVR | b. augmented lead |
| _____ 3. lead I | c. precordial lead |
| _____ 4. lead II | |
| _____ 5. aVL | |
| _____ 6. V3 | |
| _____ 7. V4 | |
| _____ 8. V6 | |
| _____ 9. aVF | |
| _____ 10. lead III | |
| _____ 11. V2 | |
| _____ 12. V5 | |

Matching II

Match the ECG terms on the left with their definitions on the right.

- | | |
|--------------------------------------|--|
| _____ 13. single-channel (LO 3.2) | a. disposable sensor that detects the electrical activity of the heart |
| _____ 14. speed (LO 3.3) | b. changes the height (size) of the ECG tracing |
| _____ 15. input (LO 3.3) | c. data that are entered into an ECG machine |
| _____ 16. gain (LO 3.3) | d. indicates paper speed on the ECG tracing |
| _____ 17. lead (LO 3.1) | e. conductor wire attached to the ECG machine |
| _____ 18. multichannel (LO 3.2) | f. ability to record more than one lead tracing at a time |
| _____ 19. mV (LO 3.5) | g. indicates voltage on the ECG tracing |
| _____ 20. mm/sec (LO 3.5) | h. displays the tracing for the electrical activity of the heart |
| _____ 21. signal processing (LO 3.2) | i. amplifies the electrical impulse and converts to mechanical action |
| _____ 22. electrode (LO 3.4) | j. records one lead tracing at a time |
| _____ 23. output display (LO 3.3) | k. controls how fast the machine records during an ECG tracing |

Multiple Choice

Circle the correct answer.

24. ECG machines have three basic functions. They are (LO 3.2)
- a. input, signal processing, and output display.
 - b. input, standardization, and output display.
 - c. multichannel, single-channel, and signal processing.
 - d. standardization, input display, and output display.
25. To perform an ECG with accuracy, the best source to obtain specific information about the machine is (LO 3.2)
- a. the policy and procedure manual.
 - b. the manufacturer's directions.
 - c. your supervisor.
 - d. your textbook.
26. The most commonly used electrodes are _____ and are used _____. (LO 3.4)
- a. disposable, more than once
 - b. reusable, more than once
 - c. disposable, once
 - d. reusable, once
27. "Bipolar leads" means that (LO 3.1)
- a. one electrode is placed on the chest and the machine arbitrarily places one behind the person.
 - b. both positive and negative electrodes are placed on the patient's body.
 - c. Einthoven's triangle is not used.
 - d. one of the leg limbs is used while the machine augments the rhythm.
28. What is the purpose of the LCD display? (LO 3.3)
- a. To allow entry and display of patient information
 - b. To show the results of the ECG
 - c. To sound alarms and errors
 - d. To assist the patient to understand the procedure
29. The term *multichannel ECG* indicates that (LO 3.2)
- a. you enter all the data into the machine prior to running a tracing.
 - b. three or more leads are recorded at one time.
 - c. all 12 leads are monitored.
 - d. all of the answers are correct.
30. What is the standard paper speed for an ECG machine? (LO 3.3)
- a. 25 mm/sec
 - b. 50 mm/sec
 - c. 0.25 mm/sec
 - d. 0.50 mm/sec
31. Which of the following is *not* a type of lead? (LO 3.1)
- a. Limb
 - b. Augmented
 - c. Input
 - d. Precordial

32. An artifact filter helps obtain a clear ECG tracing by (LO 3.3)
- maintaining artifact or abnormal marks on the ECG tracing.
 - reducing noncardiac marks on the tracing.
 - always recognizing that the patient has a pacemaker.
 - all of the answers are correct.
33. Computerized interpretation (LO 3.3)
- can be used for actual diagnostic interpretation.
 - never has to be validated by a physician.
 - must always be validated by a physician.
 - none of the answers are correct.
34. The horizontal reading on the ECG paper represents _____, and the vertical readings represent _____. (LO 3.5)
- voltage, time
 - time, height
 - time, voltage
 - voltage, millivolts
35. Which lead tracing must be augmented by the ECG machine to be able to analyze the different ECG waveforms? (LO 3.1)
- Lead I
 - Lead II
 - Lead V6
 - Lead aVF
36. Einthoven's triangle is formed by using which of the following placement sites? (LO 3.1)
- Right arm, left arm, left leg
 - Right arm, left leg, right leg
 - Right arm, middle of chest, left leg
 - None of the answers are correct

Matching III

Match the line sizes on the left with their times on the tracings at 25 mm/sec paper speed on the right.
Note: A heavy line or box is equal to five small boxes. (LO 3.5)

- | | |
|--|----------------|
| _____ 37. five heavy lines or boxes | a. 1 second |
| _____ 38. one vertical heavy line or large box | b. 0.04 second |
| _____ 39. one vertical light line or small box | c. 0.2 second |

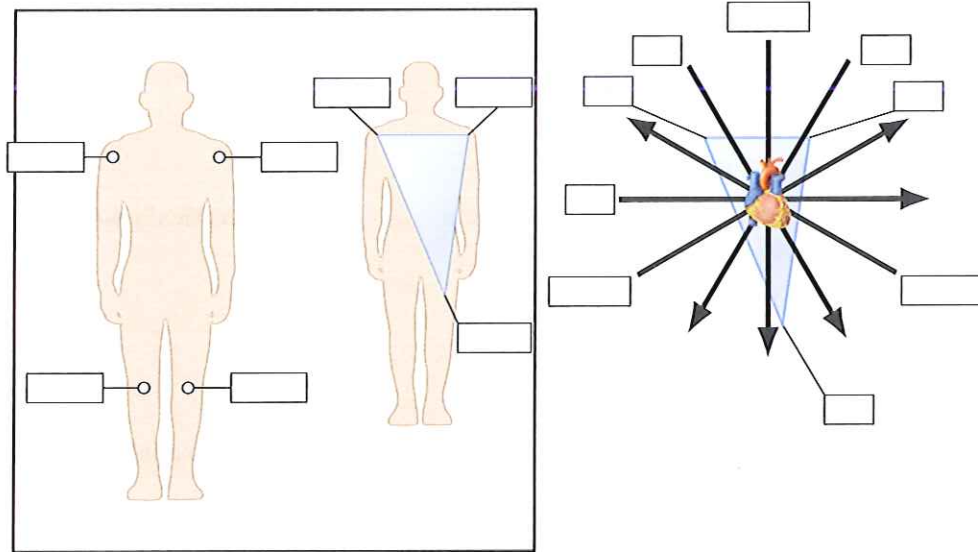
Matching IV

Match the lead wires on the left with the most common colors on the right. (LO 3.1)

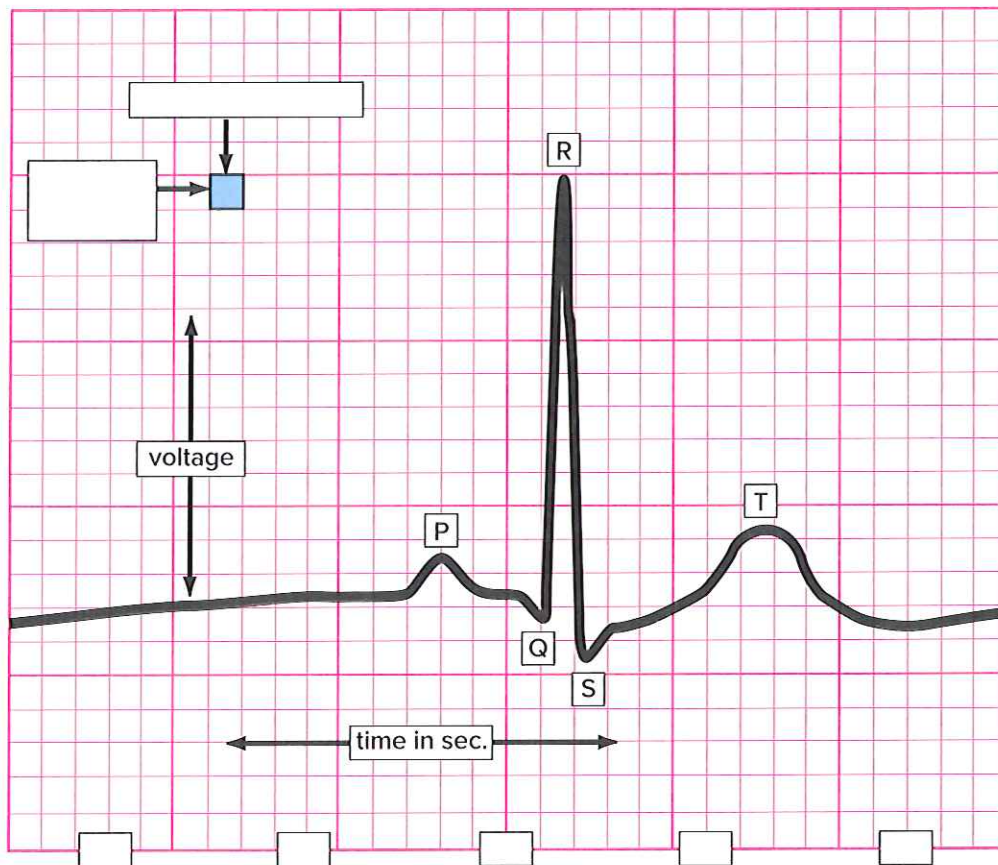
- | | |
|--------------------------|----------|
| _____ 40. left leg (LL) | a. green |
| _____ 41. right arm (RA) | b. white |
| _____ 42. right leg (RL) | c. black |
| _____ 43. left arm (LA) | d. red |

Label the Parts

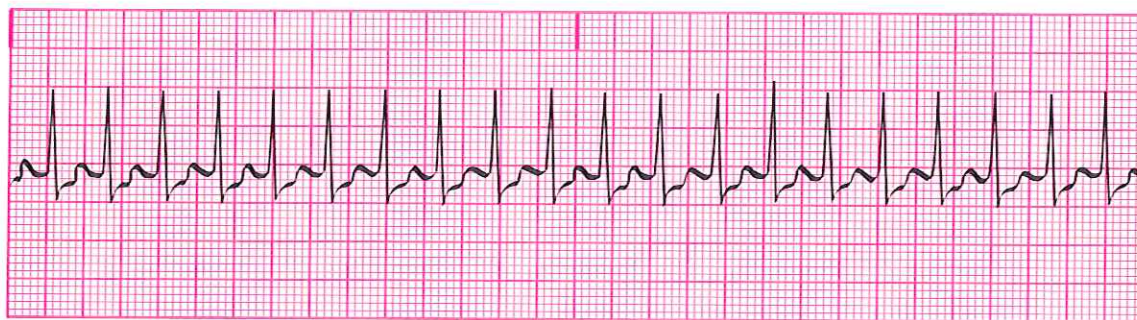
44. Label the lead tracings that produce the Einthoven triangle by writing the identifying letters in the appropriate boxes. (LO 3.1)



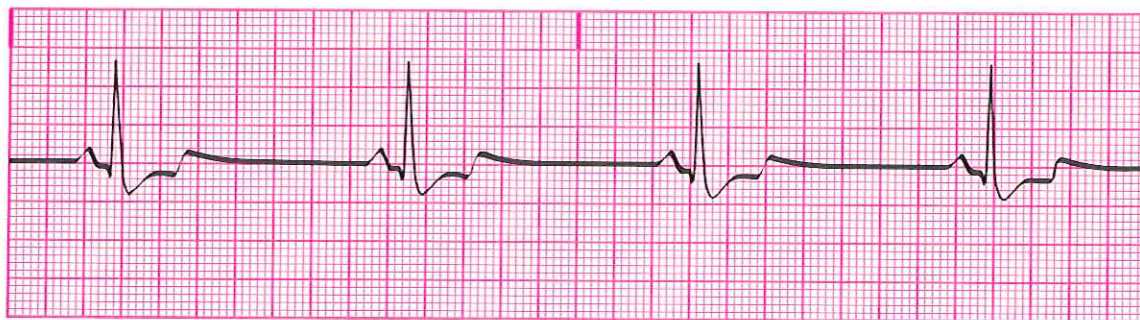
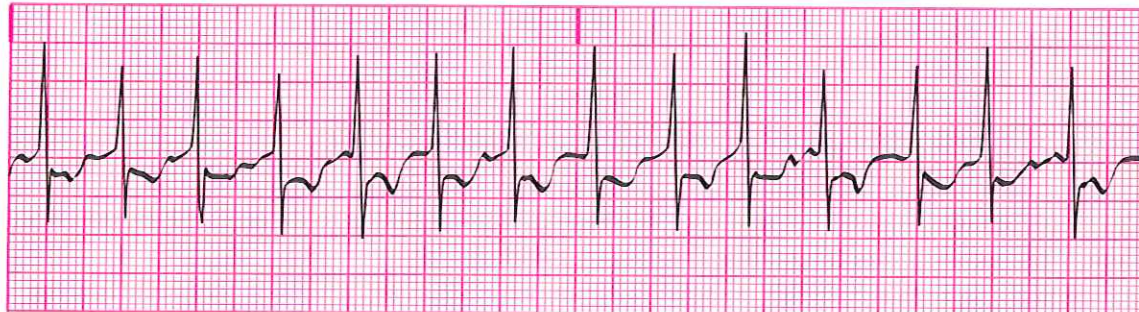
45. Label the measurements by writing them in the appropriate boxes. (LO 3.5)



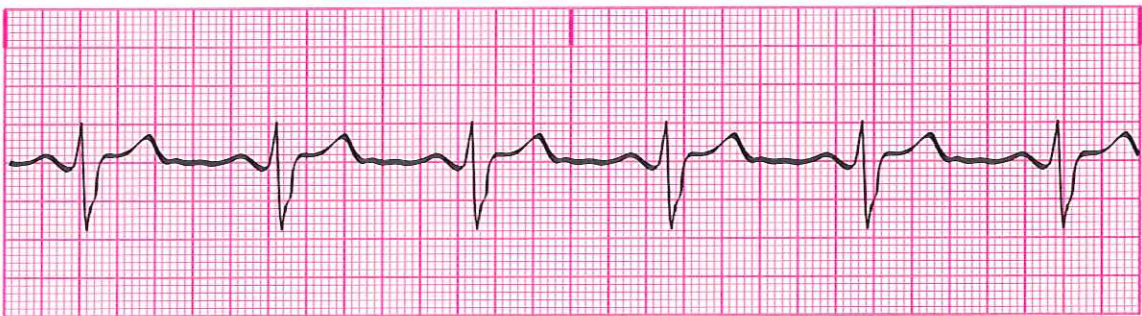
46–47. Estimate the heart rate using the R-R wave method. (LO 3.6)



48–49. Estimate the heart rate using the 6-second method. (LO 3.6)



50–51. Determine the heart rate using the 1500 method. (LO 3.6)



Critical Thinking Application *What Should You Do?*

Read the following situations, and use your critical thinking skills to determine how you would handle each. Write your answer in detail in the space provided.

52. When you start to perform an ECG on a patient, you notice a red line along the bottom of the ECG paper. What should you do? (LO 3.5)

53. When preparing to do an ECG, you find an open package of disposable electrodes on top of the ECG cart. Would you use these electrodes? Why or why not? (LO 3.4)

54. You are preparing to attach the electrodes and lead wires for a 12-lead ECG. You are unable to read the letters on each of the lead wires. You place the electrodes and lead wires, but when you run the tracing it looks like a bunch of scratches. What do you think the problem is and how would you solve it? (LO 3.1)

55. When performing a 12-lead ECG, you notice that the tracing line is very thick and hard to view. In addition, one of the leads is not recording. What would you do? (LO 3.3)
-
-



connect Now that you have completed the material in the textbook, go to Connect and complete any chapter activities you have not yet done.