the horizontal periphery of the lower lung fields (i.e., Kerley B lines). As venous pressures further increase, fluid collects in the alveolar space, which early on collects preferentially in the inner two thirds of the lung fields, resulting in a characteristic butterfly appearance.

Fluoroscopy or plain films may identify abnormal calcification involving the pericardium, coronary arteries, aorta, and valves. Fluoroscopy can be instrumental in evaluating the function of mechanical prosthetic valves. Specific radiographic signs of congenital and valvular diseases are discussed in later sections.

Electrocardiography

The electrocardiogram (ECG) represents the electrical activity of the heart recorded by skin electrodes. This wave of electrical activity is represented as a sequence of deflections on the ECG (Fig. 4-2). The horizontal axis of the graph paper represents time, and at a standard paper speed of 25 mm/second, each small box (1 mm) represents 0.04 second, and each large box (5 mm) represents 0.20 second. The vertical axis represents voltage or amplitude (10 mm = 1 mV). The heart rate can be estimated by dividing the number of large boxes between complexes (i.e., R-R interval) into 300.

In the normal heart, the electrical impulse originates in the sinoatrial (SA) node and is conducted through the atria. Given that depolarization of the SA node is too weak to be detected on the surface ECG, the first, low-amplitude deflection on the surface ECG represents atrial activation and is called the *P wave.* The interval between the onset of the P wave and the next rapid deflection (QRS complex) is known as the *PR interval*. It primarily represents the time taken for the impulse to travel through the atrioventricular (AV) node. The normal PR segment ranges from 0.12 to 0.20 second. A PR interval greater than 0.20 second defines AV nodal block.

After the wave of depolarization has moved through the AV node, the ventricular myocardium is depolarized in a sequence of four phases. The interventricular septum depolarizes from left to right. This phase is followed by depolarization of the right ventricle and inferior wall of the left ventricle, then the apex and central portions of the left ventricle, and finally the base and the posterior wall of the left ventricle. Ventricular depolarization results in a high-amplitude complex on the surface ECG known as the *QRS complex*. The first downward deflection of this complex is the Q wave, the first upward deflection is the R wave, and the subsequent downward deflection is the S wave. In some individuals, a second upward deflection may occur after the S wave, and it is called *R prime* (R′). Normal duration of the QRS complex is less than 0.10 second. Complexes greater than 0.12 second are usually secondary to some form of interventricular conduction delay.

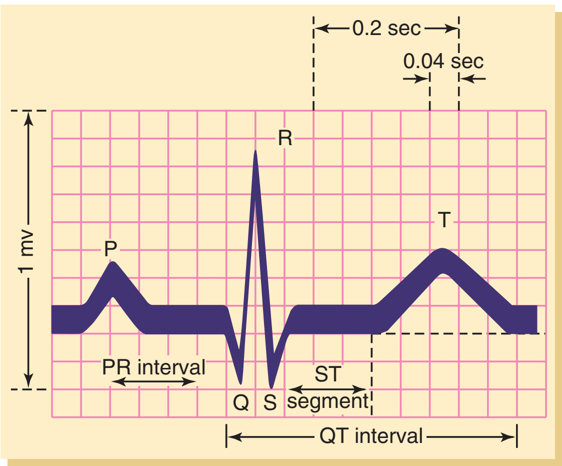

FIGURE 4-2 Normal electrocardiographic complex with labeling of waves and intervals.

The isoelectric segment after the QRS complex is the ST segment, which represents a brief period during which relatively little electrical activity occurs in the heart. The junction between the end of the QRS complex and the beginning of the ST segment is the J point. The upward deflection after the ST segment is the T wave, which represents ventricular repolarization. The QT interval, which reflects the duration and transmural gradient of ventricular depolarization and repolarization, is measured from the onset of the QRS complex to the end of the T wave. The QT interval varies with heart rate, but for rates between 60 and 100 beats/minute, the normal QT interval ranges from 0.35 to 0.44 second. For heart rates outside this range, the QT interval can be corrected (QT_c) using the following formula (all measurements in seconds):

$$QT_c = QT/\text{R-R interval}^{1/2}$$

In some individuals, the T wave may be closely followed by a U wave (0.5 mm deflection, not shown in Figure 4-2), the cause of which is unknown.

The standard ECG consists of 12 leads: six limb leads (I, II, III, aVR, aVL, and aVF) and six chest or precordial leads (V_1 to V_6) (Fig. 4-3). The electrical activity recorded in each lead represents the direction and magnitude (i.e., vector) of the electrical force as seen from that lead position. Electrical activity directed toward a particular lead is represented as an upward deflection, and an electrical impulse directed away from a particular lead is represented as a downward deflection. Although the overall direction of electrical activity can be determined for any of the waveforms previously described, the mean QRS axis is the most clinically useful and is determined by examining the six limb leads.

Figure 4-4 illustrates the axial reference system, a reconstruction of the Einthoven triangle, and the polarity of each of the six limb leads of the standard ECG. Skin electrodes are attached to both arms and legs, with the right leg serving as the ground. Leads I, II, and III are bipolar leads and represent electrical activity between two leads. Lead I represents electrical activity between the right and left arms (left arm positive), lead II between the right arm and left leg (left leg positive), and lead III between the left arm and left leg (left leg positive). Leads aVR, aVL, and aVF are designated the *augmented leads.* Using these leads, the QRS is positive or has a predominant upward deflection when the electrical forces are directed toward the right arm for aVR, left arm for aVL, and left leg for aVF. These six leads form a hexaxial frontal plane of 30-degree arc intervals. The normal QRS axis ranges from −30 to +90 degrees. An axis more negative than −30 defines left axis deviation, and an axis greater than +90 defines right axis deviation. A positive QRS complex