the heart such that the externally applied current depolarizes all the muscle cells at the same time, thereby returning synchronous electrical activity to the heart.

Quick Check 13.4

1. Under normal conditions, which controls the heartbeat—the SA node or the AV node? Explain why.
2. Arrange the order of the following terms so that they describe the normal path of electrical impulses through the heart: *Purkinje fibers, atrioventricular bundle, AV node, bundle branches, SA node, ventricular muscle, atrial muscle.*
3. The entry of calcium into a ventricular muscle cell helps to maintain depolarization of the membrane during the plateau phase of the action potential. Which other important function does this calcium perform?
4. Match the terms *P wave, QRS complex,* and *T wave* with the following events: ventricular depolarization, ventricular repolarization, atrial depolarization.

13.5 The Cardiac Cycle

The **cardiac cycle** includes all the events associated with the flow of blood through the heart during a single complete heartbeat. The discussion here concentrates on the following aspects of the cardiac cycle: (1) the various phases in the pumping action of the heart; (2) periods of valve opening and closure; (3) changes in atrial, ventricular, and aortic pressure, which reflect contraction and relaxation of the heart muscle; (4) changes in ventricular volume, which reflect the amount of blood entering and leaving the ventricle during each heartbeat; and (5) the two major heart sounds.

The relationships among the various aspects of the cardiac cycle are depicted in the *Wigger diagram* in **Figure 13.18**. (The pressure graphs pertain to the left heart only; the graphs for pressures in the right heart are similar, except that the peak pressures are lower.)

Phases of the Cardiac Cycle

Because the cardiac cycle involves the events of one heartbeat, a complete cycle involves both ventricular contraction and ventricular relaxation. As a result, the cycle can be divided into two major stages: **systole,** the period of ventricular contraction, and **diastole,** the period of ventricular relaxation. (Even though the atria also undergo periods of contraction and relaxation—termed *atrial systole* and *atrial diastole,* respectively—we use the terms *systole* and *diastole* to refer to ventricular events.)

We begin our examination of the cardiac cycle in the middle of diastole, a time at which the atria and ventricles are completely relaxed:

1. *Ventricular filling.* During mid-to-late diastole (phase 1 in Figure 13.18), blood returning to the heart via the systemic and pulmonary veins enters the relaxed atria and passes through the AV valves and into the ventricles under its own pressure. The return of blood from the veins to the heart, which is called **venous return,** occurs because the pressure in the veins is greater than that in the atria. During this time, the pulmonary and aortic (semilunar) valves are closed because ventricular pressure is lower than that in the aorta and pulmonary arteries.

   Late in diastole (at the end of phase 1), the atria contract, driving more blood into the ventricles. Shortly thereafter, the atria relax and systole begins. This entire phase of blood entering the ventricle is called **ventricular filling.**
2. *Isovolumetric contraction.* At the beginning of systole (phase 2), the ventricles contract, which raises the pressure within them. When ventricular pressure exceeds atrial pressure (which occurs very early in systole), the AV valves close; the semilunar valves remain closed because ventricular pressure is not yet high enough to force them open. At this point, no blood flows into or out of the ventricles because all the valves are closed. Thus, even though the ventricles are contracting, the volume of blood within them remains constant, so phase 2 is termed **isovolumetric contraction.** Phase 2 ends when the ventricular pressure is great enough to force open the semilunar valves so that blood can leave the ventricles.
3. *Ventricular ejection.* In the remainder of systole (phase 3), blood is ejected into the aorta and pulmonary arteries through the open semilunar valves, and ventricular volume falls. During the exit of blood from the ventricles, referred to as **ventricular ejection,** ventricular pressure rises to a peak and then begins to decline. When it falls below aortic pressure, the semilunar valves close, ending ejection (and systole) and marking the beginning of diastole.
4. *Isovolumetric relaxation.* At the onset of early diastole (phase 4), the ventricular myocardium is relaxing. Some blood is present in the ventricles, and it remains under pressure because it takes time for the tension in the ventricular muscle to wane. Ventricular pressure is simultaneously too low to keep the semilunar valves open and too high to allow the AV valves to open. Because all valves are closed and the volume of blood remains constant within the relaxing ventricles, phase 4 is referred to as **isovolumetric relaxation.**

   Once ventricular pressure decreases to less than atrial pressure, thereby permitting the AV valves to open again, blood enters the ventricles from the atria. This marks the beginning of phase 1, and the pump cycle begins once again.

The durations of systole and diastole are not equal. For a heart beating at the normal resting rate of 72 beats per minute (one beat every 0.8 second), most of the cardiac cycle (approximately 65%, or 0.5 second) is spent in diastole; systole lasts only about 0.3 second. This longer diastole gives the heart adequate time to fill with blood, which is essential for efficient pumping; it also gives the heart muscle more time to relax, which helps prevent fatigue.

Now that this overview of the cardiac cycle is complete, we can examine pressure and volume changes during this cycle.

Atrial and Ventricular Pressure

By convention, cardiovascular pressures (the pressure of blood in the chambers of the heart or in the vasculature) are given in millimeters of mercury (mm Hg). Atmospheric pressure is also measured in millimeters of mercury, with normal atmospheric pressure at sea