The cardiovascular system

The heart as a pump

The electrical activity of the heart is designed to serve the pumping action of the heart. This is accomplished when depolarization process triggers a wave of contraction that spreads through the myocardium. In single muscle fibers, contraction starts just after depolarization and lasts until about 50 ms after repolarization is completed. The term systolic pressure refers to the peak pressure reached during systole; similarly, the diastolic pressure refers to the lowest pressure during diastole.

Mechanical events of the cardiac cycle

Late diastole

Late in diastole, the A-V valves are open and the semilunar valves are closed. Blood flows into the heart throughout diastole, filling the atria and ventricles. The rate of filling declines as the ventricles become distended and the cusps of the A-V valves drift toward the closed position. The pressure in the ventricles remains low. About 70% of the ventricular filling occurs passively during diastole.

Atrial systole

Contraction of the atria propels some additional blood into the ventricles. Contraction of the atrial muscle narrows the orifices of the superior and inferior vena cava and pulmonary veins, and the blood tend to be kept in the heart. However, there is some regurgitation of blood into the veins.

Ventricular systole

- Isovolumetric (isovolumic, isometric) ventricular contraction: At the start of ventricular systole, the A-V valves close. Ventricular muscle initially shortens relatively little, but intra-ventricular pressure rises sharply as the myocardium presses on the blood in the ventricle. This will last for about 0.05 seconds, until the pressures in the left and right ventricles exceed the pressures in the aorta (80 mm Hg) and pulmonary artery (10 mm Hg) and the aortic and pulmonary valves open. During isovolumetric contraction, the A-V valves bulge into the atria, causing a small but sharp rise in atrial pressure.

- Ventricular ejection: During this phase, aortic and pulmonary valves open. Ejection is rapid at first, slowing down as systole progresses. The intra-ventricular pressure rises to a maximum and then declines

somewhat before ventricular systole ends. Peak pressures in the left and right ventricles are about 120 and 25 mm Hg, respectively.
Late in systole, pressure in the aorta actually exceeds that in the left ventricle, but for a short period momentum keeps the blood moving forward. The A-V valves are pulled down by the contractions of the ventricular muscle, and atrial pressure drops.

- End-diastolic ventricular volume: The filling volume of a ventricle which is about 130 ml.

- Stroke volume: The amount of blood ejected by a ventricle per each contraction at rest which is about 70-90 ml.

- End-systolic ventricular volume: The volume of blood remaining in each ventricle at the end of systole which is about 50 ml.

- Ejection fraction: The percentage of the end-diastolic ventricular volume that is ejected with each stroke which is about 65%.

Early diastole

- *Protodiastole:* The period in which the ventricular muscles are fully contracted and the already falling ventricular pressures are dropping more rapidly. It lasts for about 0.04 seconds. It ends when the aortic and pulmonary valves close.

- *Isovolumetric ventricular relaxation:* The period at which ventricular pressure continues to drop rapidly after the closure of the valves. This period ends when the ventricular pressure falls below the atrial pressure and the A-V valves open, permitting the ventricles to fill. Filling is rapid at first, and then slows as the next cardiac contraction approaches. Atrial pressure continues to rise after the end of ventricular systole until the A-V valves open, and a next cardiac cycle starts.

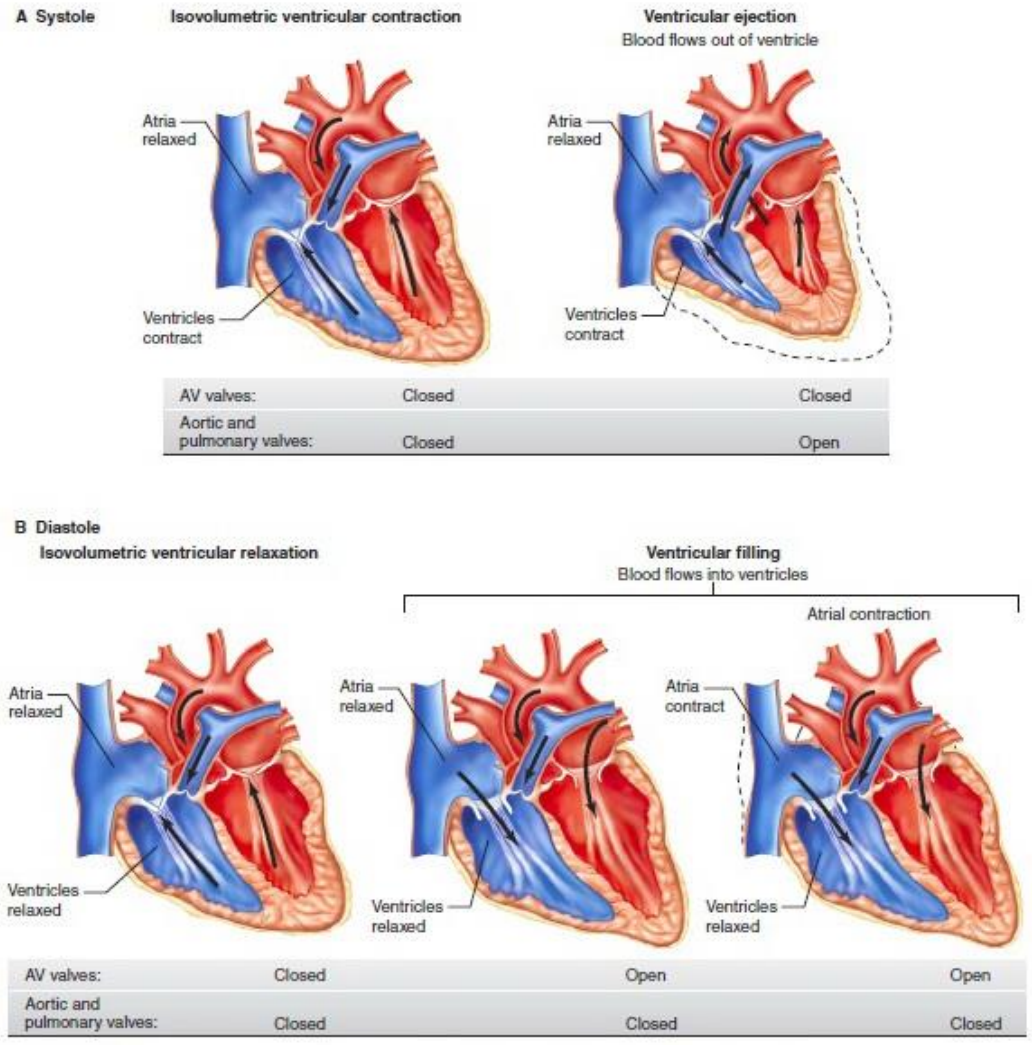

Figure (1) Cardiac cycle divided into systole and diastole

Timing

Although events on the two sides of the heart are similar, they are somewhat asynchronous. Right atrial systole precedes left atrial systole, and contraction of the right ventricle starts after that of the left. However, since pulmonary arterial pressure is lower than aortic pressure, right ventricular ejection begins before that of the left.

During expiration, the pulmonary and aortic valves close at the same time; but during inspiration, the aortic valve closes slightly before the pulmonary. When measured over a period of minutes, the outputs of the two ventricles are equal; but transient differences in output during the respiratory cycle occur in normal individuals.

Length of systole and diastole

The normal duration of the cardiac cycle in a resting adult heart with a heart rate of 75 beats per minute is about 0.8 seconds, 0.3 seconds for the systole and 0.5 seconds for the diastole. Cardiac muscle has the unique property of contracting and repolarizing faster when the heart rate is high, and the duration of systole decreases from 0.27 seconds at a heart rate of 65 to 0.16 seconds at a rate of 200 BPM.

The reduced time interval is mainly due to a decrease in the duration of systolic ejection. However, the duration of systole is much more fixed than that of diastole, and when the heart rate is increased, diastole is shortened to a much greater degree. For example, at a heart rate of 65, the duration of diastole is 0.62 seconds, whereas at a heart rate of 200, it is only 0.14 seconds. This fact has important physiologic and clinical implications, because during diastole the heart muscle rests, and most of the ventricular filling occurs here. At heart rates up to about 180, filling is adequate as long as there is sufficient venous return, and cardiac output per minute is increased by an increase in rate. However, at very high heart rates, filling may be compromised to such a degree that cardiac output per minute falls.