The cardiovascular system

Arterial pulse

The blood forced into the aorta during systole not only moves the blood in the vessels forward but also sets up a pressure wave that travels along the arteries. The pressure wave expands the arterial walls as it travels, and the expansion is palpable as the "pulse".

The rate at which the wave travels, is about 4 m/s in the aorta, 8 m/s in the large arteries, and 16 m/s in the small arteries of young adults. Consequently, the pulse is felt in the radial artery at the wrist about 0.1 second after the peak of systolic ejection into the aorta. With advancing age, the arteries become more rigid, and the pulse wave moves faster.

The pulse is weak "thready" in shock. It is strong when stroke volume is large; for example during exercise. When the pulse pressure is high, the pulse waves may be large enough to be felt or even heard by the individual "palpitation or pounding heart". When the aortic valve is incompetent (aortic insufficiency), the pulse is particularly strong, and the force of systolic ejection maybe sufficient to make the head nod with each heartbeat. The pulse in aortic insufficiency is called "collapsing or water-hammer pulse".

The "dicrotic notch", a secondary upstroke in the descending part of the pulse wave caused by vibrations set up when the aortic valve snaps shut, is visible if the pressure wave is recorded but is not palpable at the wrist. The pulmonary artery pressure curve also has a dicrotic notch produced by the closure of the pulmonary valves.

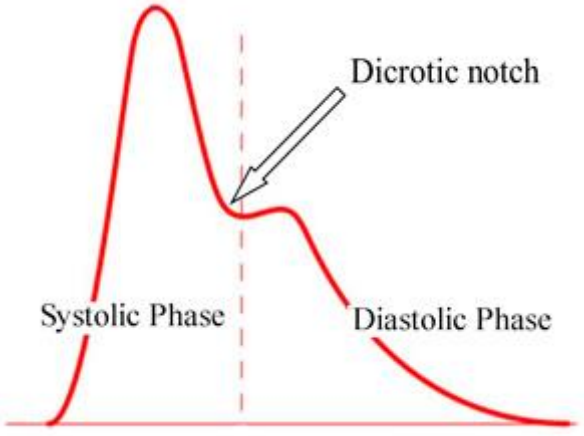

Figure (1) Normal arterial pulse wave form, showing the dicrotic notch

Atrial pressure changes and the jugular pulse

Atrial pressure rises during atrial systole and continues to rise during isovolumetric ventricular contraction when the A-V valves bulge into the atria. When the A-V valves are pulled down by the contracting ventricular muscle, pressure falls rapidly and then rises as blood flows into the atria until the A-V valves open early in diastole. The return of the A-V valves to their relaxed position also contributes to this pressure rise by reducing atrial capacity. The atrial pressure changes are transmitted to the great veins, producing three characteristic waves in the record of jugular pressure:

The a wave: It is due to atrial systole. As mentioned previously, some blood regurgitates into the great veins when the atria contract. In addition, venous inflow stops, and the resultant rise in venous pressure contributes to the a wave.

The c wave: It is due to the rise in atrial pressure produced by the bulging of the tricuspid valve into the atria during isovolumetric ventricular contraction.

The v wave: It is due to the rise in atrial pressure with passive atrial filling before the tricuspid valve opens during diastole.

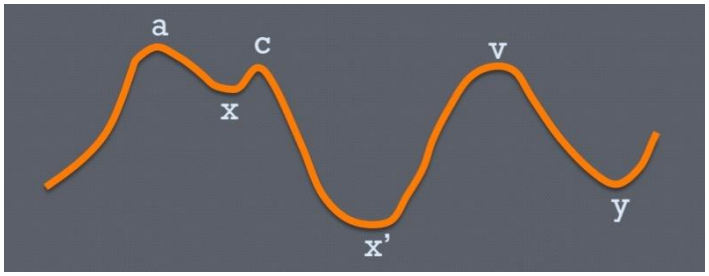

Figure (2) Jugular venous pressure (JVP) waveform

Heart sounds

When listening to a normal heart with a stethoscope, one hears a sound usually described as "lub, dub, lub, dub". The "lub" is associated with closure of the A-V valves at the beginning of systole, and the "dub" is associated with closure of the semilunar valves at the end of systole. The "lub" sound is called the first heart sound, and the "dub" is called the second heart sound. Two other sounds may be present, and all will be described as follows:

First heart sound

It is a low, slightly prolonged sound, caused by vibrations set up by the sudden closure of the A-V valves at the start of ventricular systole. It has a duration of about 0.15 seconds and a frequency of 25-45 Hz.

Second heart sound

It is a shorter, high-pitched sound**,** caused by vibrations associated with closure of the semilunar valves just after the end of ventricular systole. It lasts about 0.12 seconds, with a frequency of 50 Hz. The interval between aortic and pulmonary valve closure during inspiration is frequently long enough for the second sound to be reduplicated (physiologic splitting of the second sound). Splitting also occurs in various diseases.

Third heart sound

It is a soft, low-pitched sound, heard about one third of the way through diastole in many normal young individuals. It coincides with the period of rapid ventricular filling and is probably due to vibrations set up by the inrush of blood. When present, it has a duration of 0.1 seconds.

Fourth heart sound

It can sometimes be heard immediately before the first sound when atrial pressure is high or the ventricle is stiff in conditions such as ventricular hypertrophy. It is due to atrial contraction and is rarely heard in normal adults.

Murmurs

Murmurs, or bruits, are abnormal sounds heard in various parts of the vascular system. Blood flow is laminar, non-turbulent, and silent up to a critical velocity; above this velocity (such as beyond an obstruction), blood flow is turbulent and creates sounds. Blood flow speeds up when an artery or a heart valve is narrowed.

The major -but not only- cause of cardiac murmurs is disease of the heart valves. When the orifice of a valve is narrowed (stenosis), blood flow through it is accelerated and turbulent. When a valve is incompetent, blood flows through it backward (regurgitation or insufficiency), again through a narrow orifice that accelerates flow.

The timing (systolic or diastolic) of a murmur due to any particular valve can be predicted from a knowledge of the mechanical events of the cardiac cycle. Murmurs due to disease of a particular valve can generally be heard well when the stethoscope is directly over the valve. Most murmurs can be heard only with the aid of the stethoscope, but this high-pitched musical diastolic murmur is sometimes audible to the unaided ear several feet from the patient.

Table (1) Cardiac murmurs and their timings

Valve	Abnormality	Timing of Murmur
Aortic or pulmonary	Stenosis	Systolic
	Insufficiency	Diastolic
Mitral or tricuspid	Stenosis	Diastolic
	Insufficiency	Systolic