

CARDIAC CYCLE

The cardiac cycle is a period from the beginning of one heart beat to the beginning of the next one. It consists of two parts:

1. Ventricular contraction called **systole**.
2. Ventricular relaxation called **diastole**.

Each part of the cardiac cycle consists of several phases characterized by either a strong pressure change with constant volume or a volume change with a relatively small change in pressure.

Systole includes:

1. **Isovolumic contraction.**
2. **Ejection.**

Diastole includes:

3. **Isovolumic relaxation.**
4. **Rapid ventricular filling.**
5. **Slow ventricular filling (diastasis).**
6. **Atrial contraction.**

The duration of the cardiac cycle is inversely proportional to the heart rate. The cardiac cycle duration increases with a decrease in the heart rate and on the other hand it shortens with increasing heart rate. At a normal heart rate of 75 beats per minute, one cardiac cycle lasts 0.8 second. Under resting conditions, systole occupies $\frac{1}{3}$ and diastole $\frac{2}{3}$ of the cardiac cycle duration. At an increasing heart rate (e.g. during an intensive muscle work), the duration of diastole decreases much more than the duration of systole.

In the following six chapters the individual phases of the cardiac cycle are described. The description contains:

- Mechanical events in the heart (the contraction on pictures is represented by a colour change of the myocardium).
- Pressure and volume changes in both the atria and the ventricles. The pressure changes in the right atrium are seen in the recording of the **venous pulse**.
- Pressure changes in the arteries – **arterial pulse**.
- Electrical activity of the heart – **electrocardiogram (ECG)**
- **Heart sounds** or **phonocardiogram**.

The teaching material contains the animation of the mechanical events in the heart during the cardiac cycle including the arterial pulse, ECG, heart sounds, venous pulse, pressure and volume changes in the right atrium and in the left ventricle.

1. Isovolumic Contraction

1.1. Heart

The ventricles contract due to the ventricular depolarization and the pressure inside the ventricles rapidly increases. Immediately after a ventricular contraction begins, the pressure in the ventricles exceeds the pressure in the atria and thus the atrioventricular valves shut. The semilunar valves are closed because the ventricular pressure is lower than that in the aorta and the pulmonary artery (fig. 1.1).

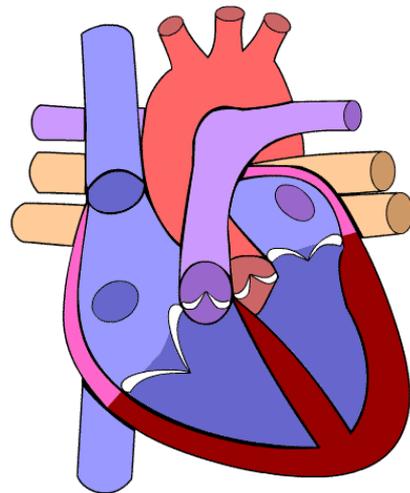


Fig. 1.1. Isovolumic contraction
The contraction is represented by a colour change of myocardium.

1.2. Pressure and volume changes

Ventricles

The ventricles contract and all valves are closed, so no blood can be ejected. The ventricular pressure rises considerably without any change in the ventricular blood volume – **isovolumic contraction** (fig. 1.2). The blood volume in the ventricles equals to the **end-diastolic volume** (circa 130 ml).

Atria

The atrioventricular valves are bulged backward into the atria because of increasing pressure in the ventricles. This event causes the **c wave** in the venous pulse (fig. 1.2).

Arteries

Pressures in arteries of both systemic and pulmonary circulations decrease constantly (fig. 1.2).

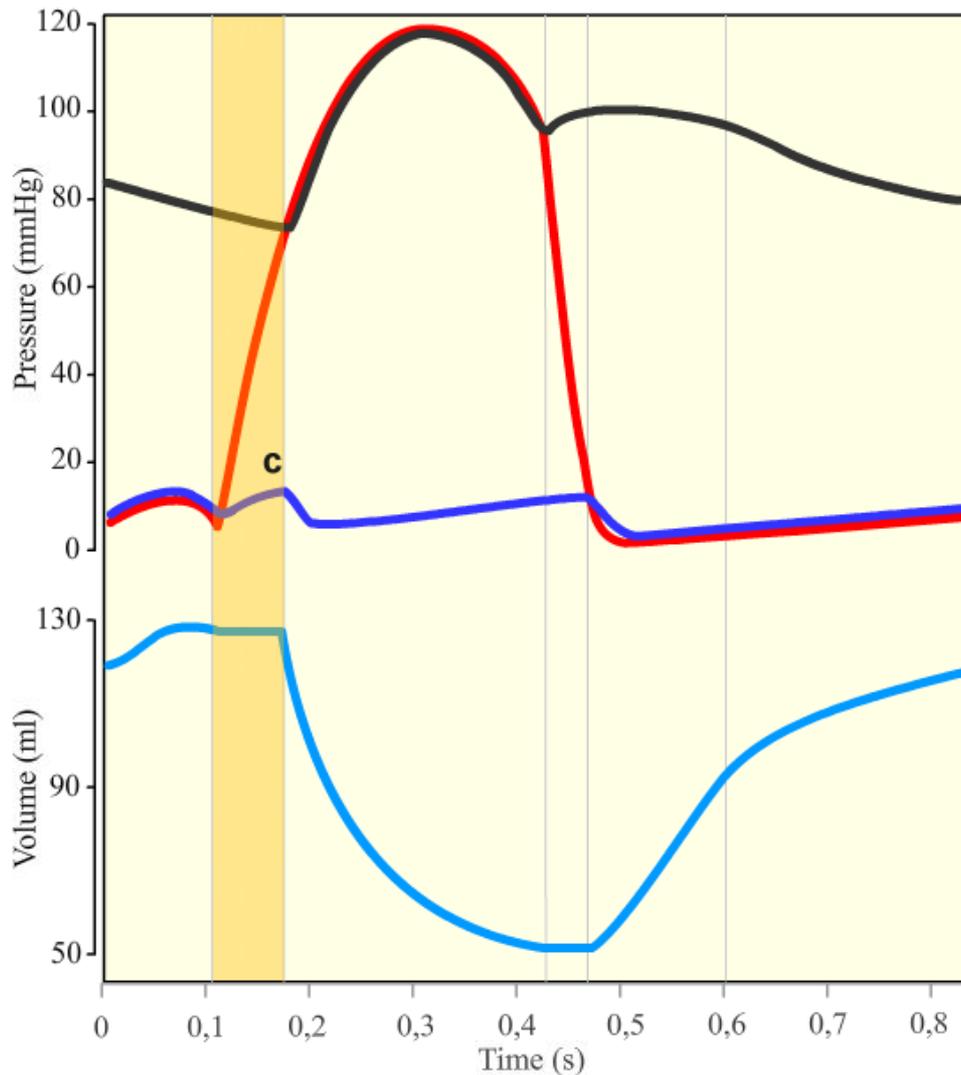


Figure 1.2. Isovolumic contraction - pressure and volume changes
Red line - pressure in the left ventricle, black - the aortic pressure, dark blue - the pressure in the right atrium, light blue - the ventricular volume.

1.3. Electrocardiogram

The depolarization spreads from the atrioventricular node to the septum and the walls of both ventricles through the bundle of His and Purkyne fibres. The ventricular depolarization causes the **QRS complex** in the ECG (fig. 1.3). At the same moment, the atria are repolarized to produce the **atrial T (Ta) wave** in the ECG. The atrial T wave is not visible on the physiological ECG because it is covered by the QRS complex.

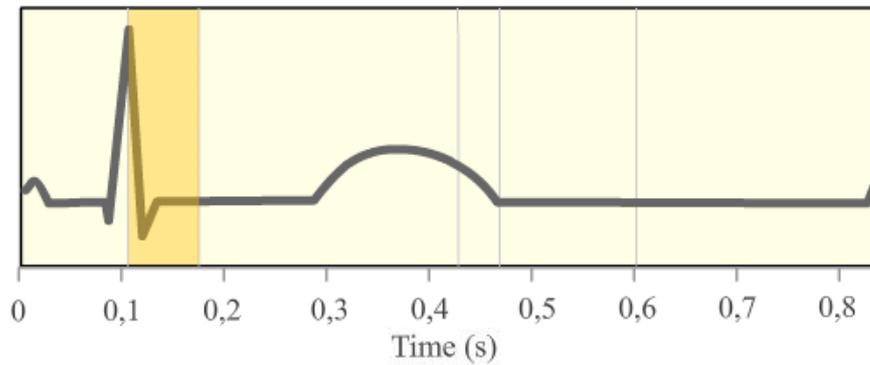


Fig. 1.3. Isovolumic contraction – ECG

1.4. Heart sounds

During the isovolumic contraction, the first heart sound appears (fig. 1.4). This sound is caused by vibrations of the atrioventricular valves, the adjacent myocardium and blood due to the closure of the atrioventricular valves.

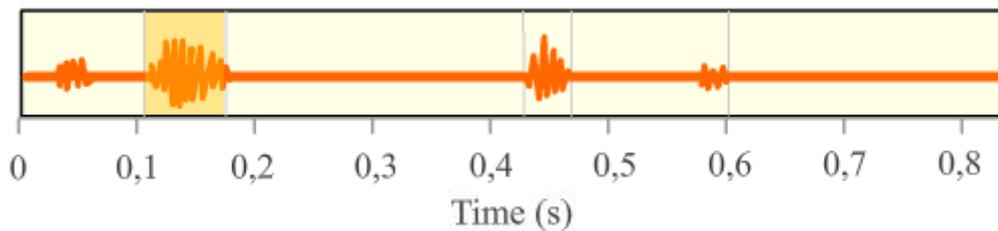


Fig. 1.4. Isovolumic contraction – heart sounds

2. Ejection

2.1. Heart

The rising left ventricular pressure exceeds the pressure in the aorta and the rising right ventricular pressure exceeds the pressure in the pulmonary artery and thus the semilunar valves open. The ventricular contraction continues and blood is ejected from the left and the right ventricles to the aorta and the pulmonary artery, respectively. The atrioventricular valves are closed (fig. 2.1).

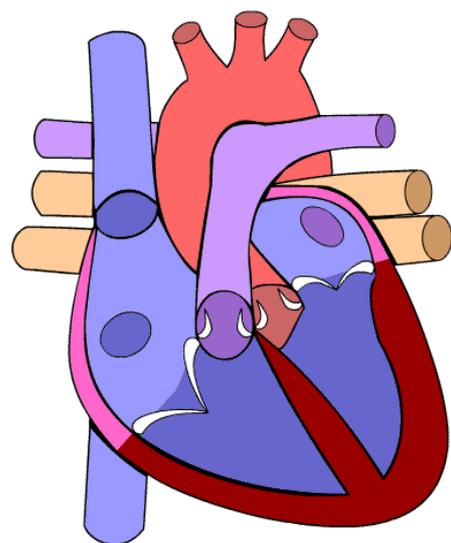


Fig. 2.1. Ejection
The contraction is represented by a colour change of myocardium.

2.2. Pressure and volume changes

Ventricles

During the first part of the ejection, the ventricular pressure rises and blood is intensively ejected to the arteries – **rapid ejection**. As the blood volume in the ventricles decreases, the ventricular pressure starts to decline in the second part of this phase (fig. 2.2). The pressure gradient between ventricles and arteries decreases and blood is ejected more slowly – **decreased** or **slow ejection**. The maximum ventricular pressure at the top of the ejection reaches 120 mmHg and 25 mmHg in the left and right ventricles, respectively. This peak value is called **systolic pressure**.

Under resting condition, about 70 ml of blood is ejected from each ventricle during ejection; this volume is called the **stroke** or **systolic volume**. About 60 ml of blood remains in each ventricle at the end of systole – the **end-systolic volume** (fig. 2.2). The ratio of the stroke volume and the end-diastolic one is called the **ejection fraction**. It is the fraction of the ventricular blood which is ejected during systole. Its physiological value is about 60 %.

Atria

As the ventricles contract they also shorten. The shortening ventricles elongate the atria and the big veins, lowering their pressure. This pressure decrease is represented by the **x wave** in the venous pulse (fig. 2.2).

Arteries

The blood pressure in the big arteries rises due to rapid ejection to reach the maximum value of 120 mmHg and 25 mmHg in the aorta and the pulmonary artery, respectively (= **systolic pressure**). During the slow ejection, the blood pressure in the systemic and pulmonary circulations starts to drop progressively (fig. 2.2).

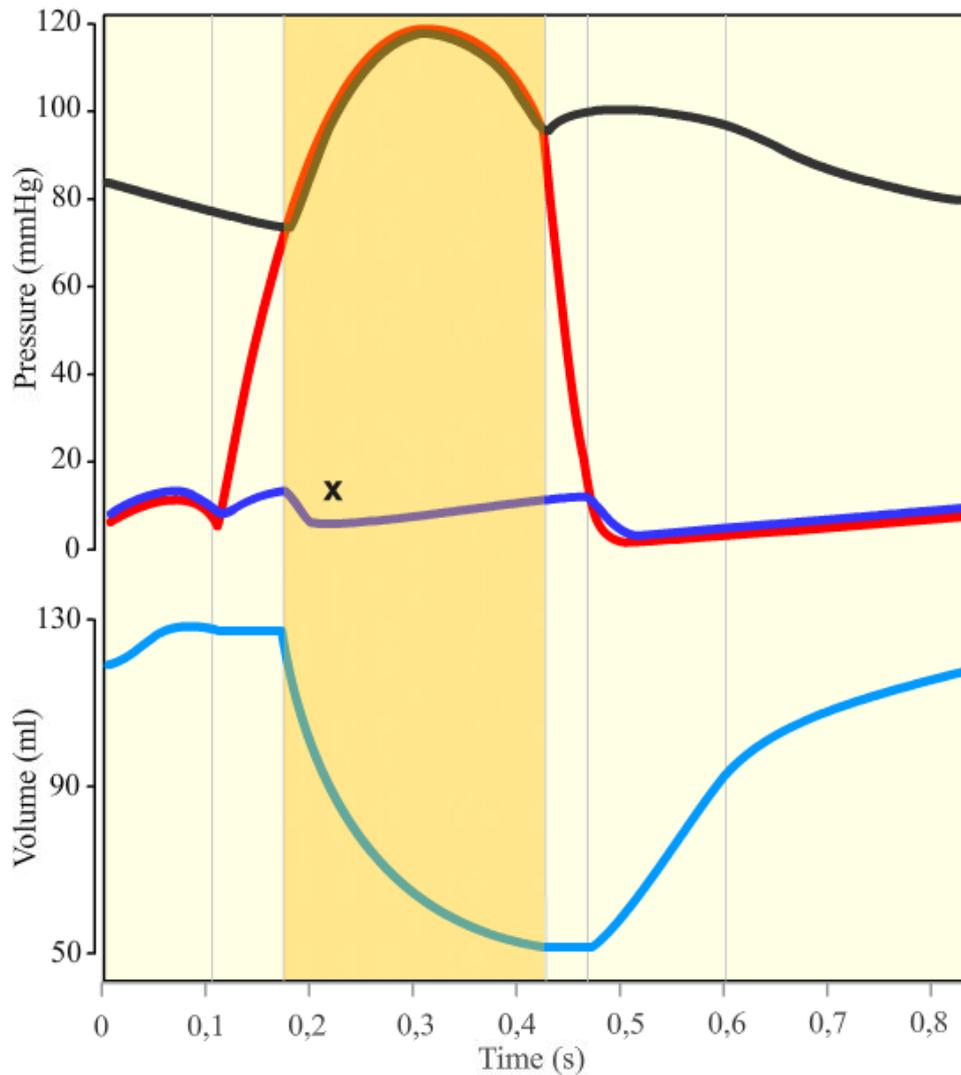


Figure 2.2. Ejection - pressure and volume changes
Red line - pressure in the left ventricle, **black** - the aortic pressure, **dark blue** - the pressure in the right atrium, **light blue** - the ventricular volume.

2.3. Electrocardiogram

The ventricles are completely depolarized at the beginning of the ejection – **segment ST** in the ECG. The **T wave** appears due to the ventricular repolarization in the second half of this phase (fig. 2.3).

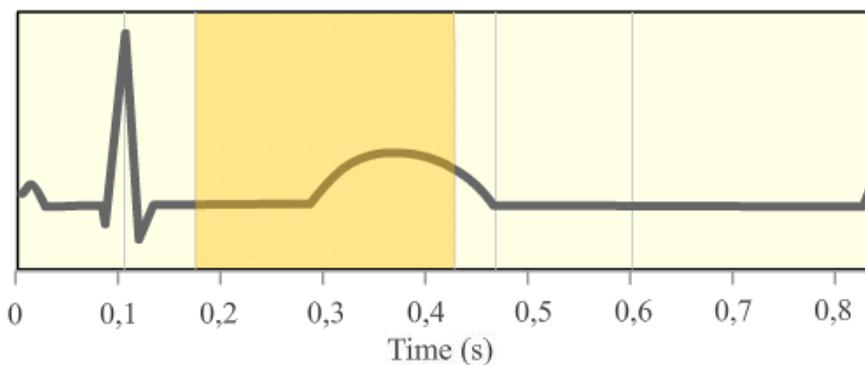


Fig 2.3. Ejection - ECG

3. Isovolumic Relaxation

3.1. Heart

At the end of systole, the ventricles relax and the ventricular pressure decreases rapidly. Due to the blood inertia, the blood flows out of the ventricles (for a short time) even when the pressure in large arteries exceeds the ventricular pressure. Immediately after the blood inertia is overcome, the elevated pressures in the aorta and the pulmonary artery push the blood back toward the ventricles to close the semilunar valves.

The atrioventricular valves are closed because the pressure in the atria is lower than the ventricular pressure (fig. 3.1).

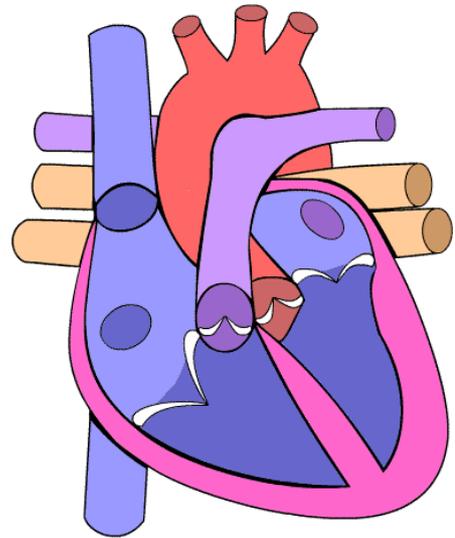


Fig. 3.1. Isovolumic relaxation

3.2. Pressure and volume changes

Ventricles

The ventricles relax without changing blood volume in ventricles – the **isovolumic relaxation**. The blood volume in each ventricle equals to the end-systolic volume (about 60 ml). The ventricular relaxation leads to a significant pressure decrease. The ventricular pressure at the end of an isovolumic relaxation is close to zero in both ventricles (fig. 3.2).

Atria

Blood flows from the veins to the atria while the atrioventricular valves are closed. The atrial pressure increases to produce the **v wave** in the venous pulse (fig. 3.2).

Arteries

The decrease in the arterial pressure is interrupted by the **dicrotic notch** that is seen in the aortic pulse. It is a momentary pressure increase caused by a short period of backward blood flow immediately before the closure of the semilunar valves (fig. 3.2).

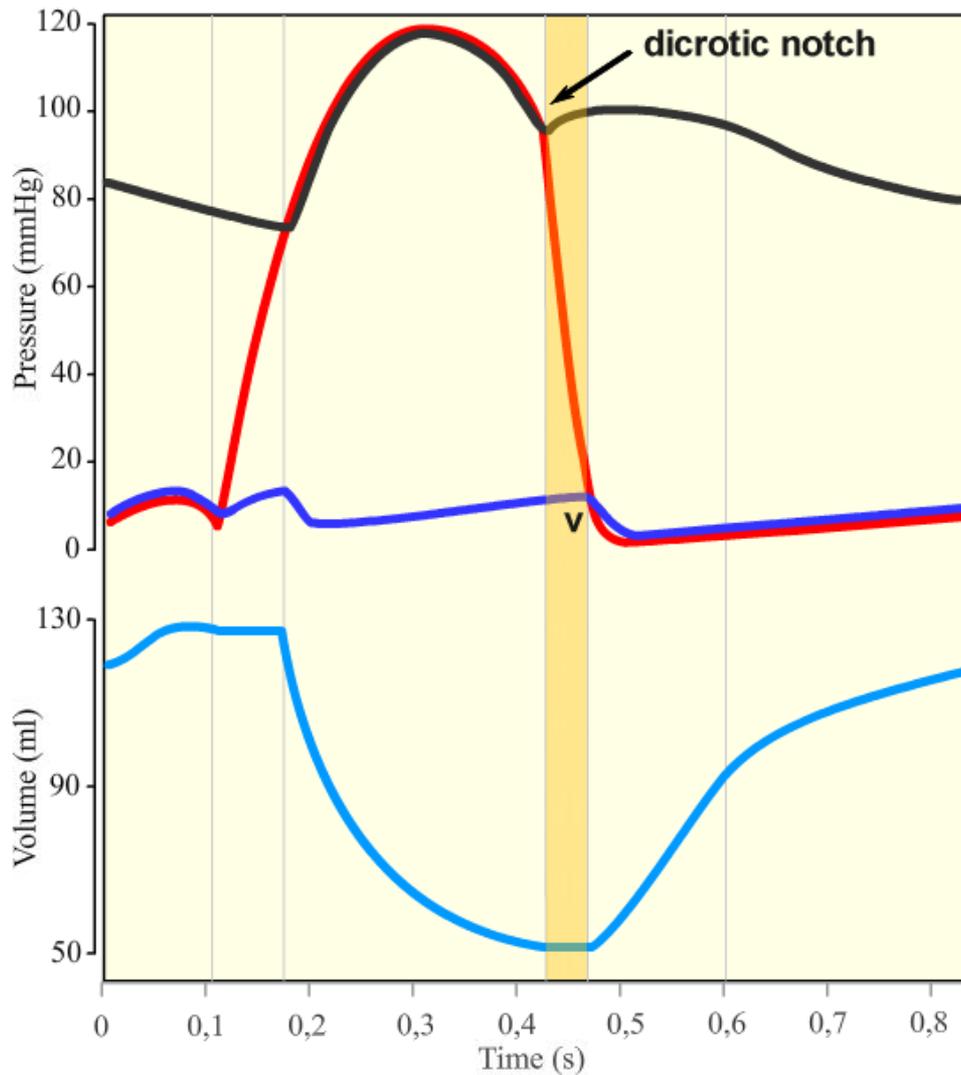


Figure 3.2. Isovolumic relaxation - pressure and volume changes
Red line - pressure in the left ventricle, **black** - the aortic pressure, **dark blue** - the pressure in the right atrium, **light blue** - the ventricular volume.

3.3. Electrocardiogram

The ventricular repolarization is being completed and the end of the T wave appears in the ECG (fig. 3.3).

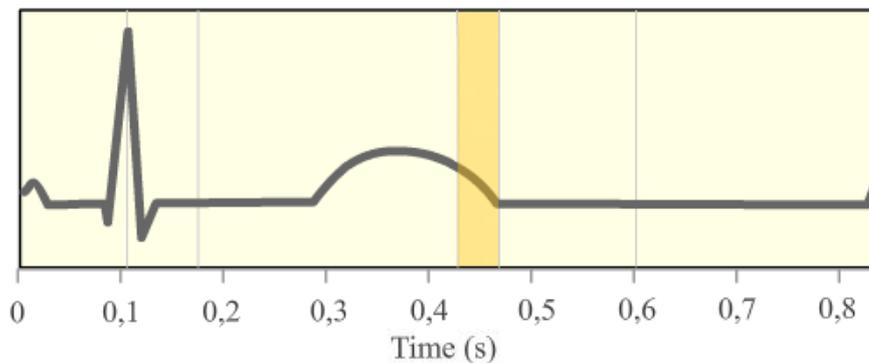


Fig. 3.3. Isovolumic relaxation - ECG

3.4. Heart sounds

During the isovolumic relaxation, the second heart sound appears (fig. 3.4). This sound is caused by vibrations of the semilunar valves, the adjacent myocardium and blood due to the closure of the semilunar valves.

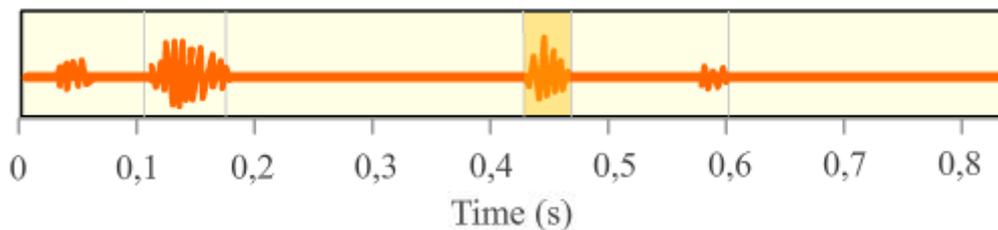


Fig. 3.4. Isovolumic relaxation – heart sounds

4. Rapid Ventricular Filling

4.1. Heart

As soon as the ventricular pressure falls below the atrial pressure, the atrioventricular valves open. Blood flows rapidly from the atria to the ventricles. The semilunar valves are closed (fig. 4.1).

4.2. Pressure and volume changes

Ventricles

The ventricles are rapidly filled with the blood cumulated in the atria before the opening of the atrioventricular valves. This phase accounts for the most of the ventricular filling. Although the ventricular volume increases, the ventricular pressure is not changed significantly due to the ventricular relaxation (fig. 4.2).

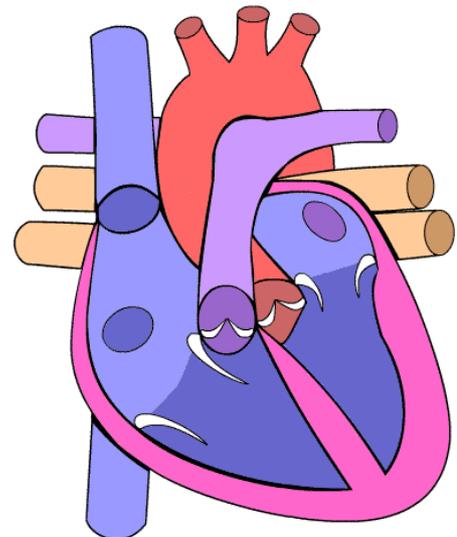


Fig. 4.1. Rapid ventricular filling

Atria

The negative **y wave** in the venous pulse is caused by the blood evacuation from the atria to the ventricles (fig. 4.2).

Arteries

After the semilunar valves close, the arterial pressure slowly decreases. Unlike the pressure in the ventricles, the pressure in the large arteries never falls to zero due to their elastic property. The minimum pressure within one cardiac cycle called **diastolic pressure** is about 80 mmHg and 8 mmHg in the systemic and the pulmonary circulations, respectively (fig. 4.2).

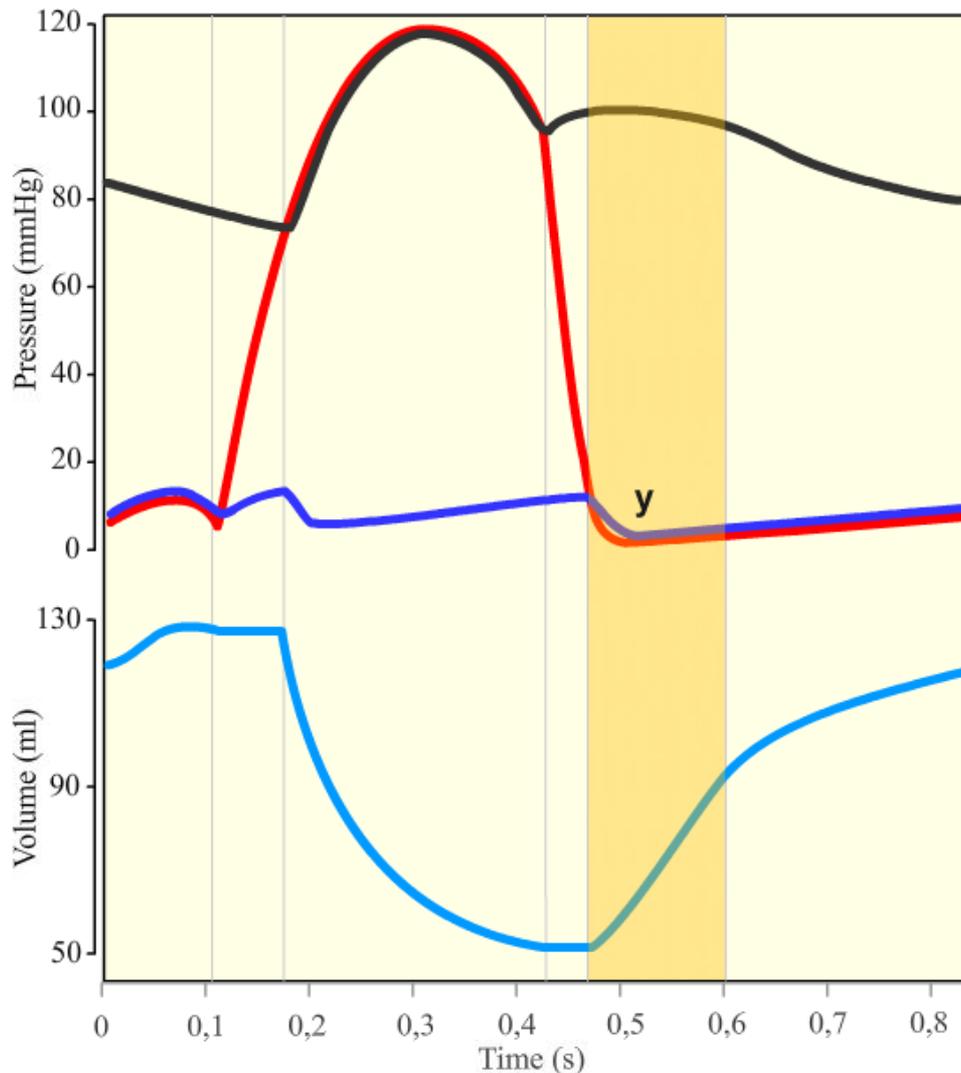


Figure 4.2. Rapid ventricular filling - pressure and volume changes

Red line - pressure in the left ventricle, **black** - the aortic pressure, **dark blue** - the pressure in the right atrium, **light blue** - the ventricular volume.

4.3. Electrocardiogram

No electrical activity is produced by cardiac cells thus the isoelectric line is present in the ECG (fig. 4.3).

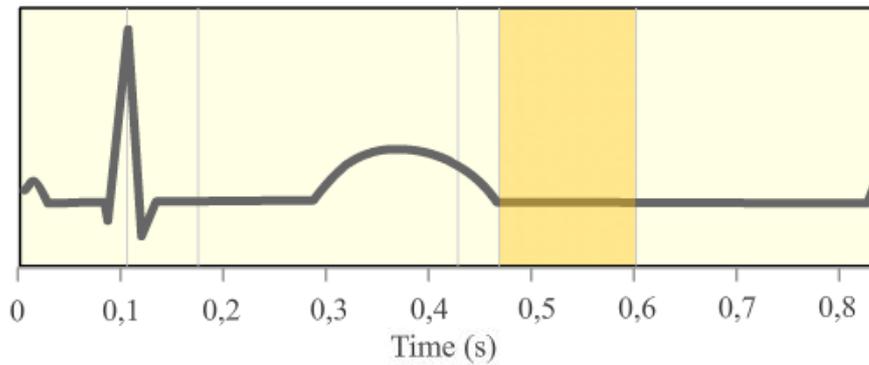


Fig. 4.3. Rapid ventricular filling - ECG

4.4. Heart sounds

The third heart sound, which occurs rarely, is probably caused by the rapid blood flow (fig. 4.4).

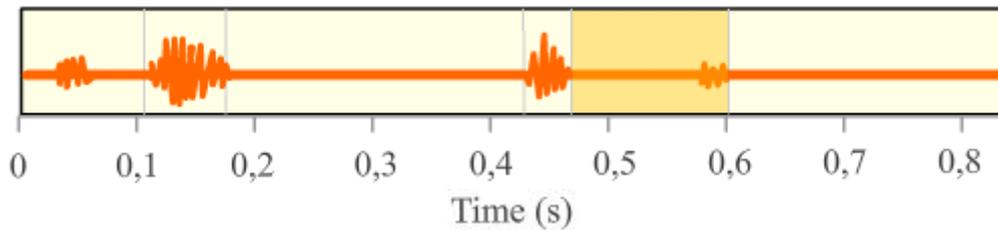


Fig. 4.4. Rapid ventricular filling – heart sounds

5. Slow Ventricular Filling

5.1. Heart

The atrioventricular valves remain open while the semilunar valves are closed.

5.2. Pressure and volume changes

Ventricles

During the middle part of a diastole a small volume of blood flows into the ventricles. This is the blood flowing from veins and passing the atria to fill the ventricles. The pressure in both ventricles is close to zero (fig. 5.1).

Arteries

The pressures in arteries of both systemic and pulmonary circulations decrease constantly (fig. 5.1).

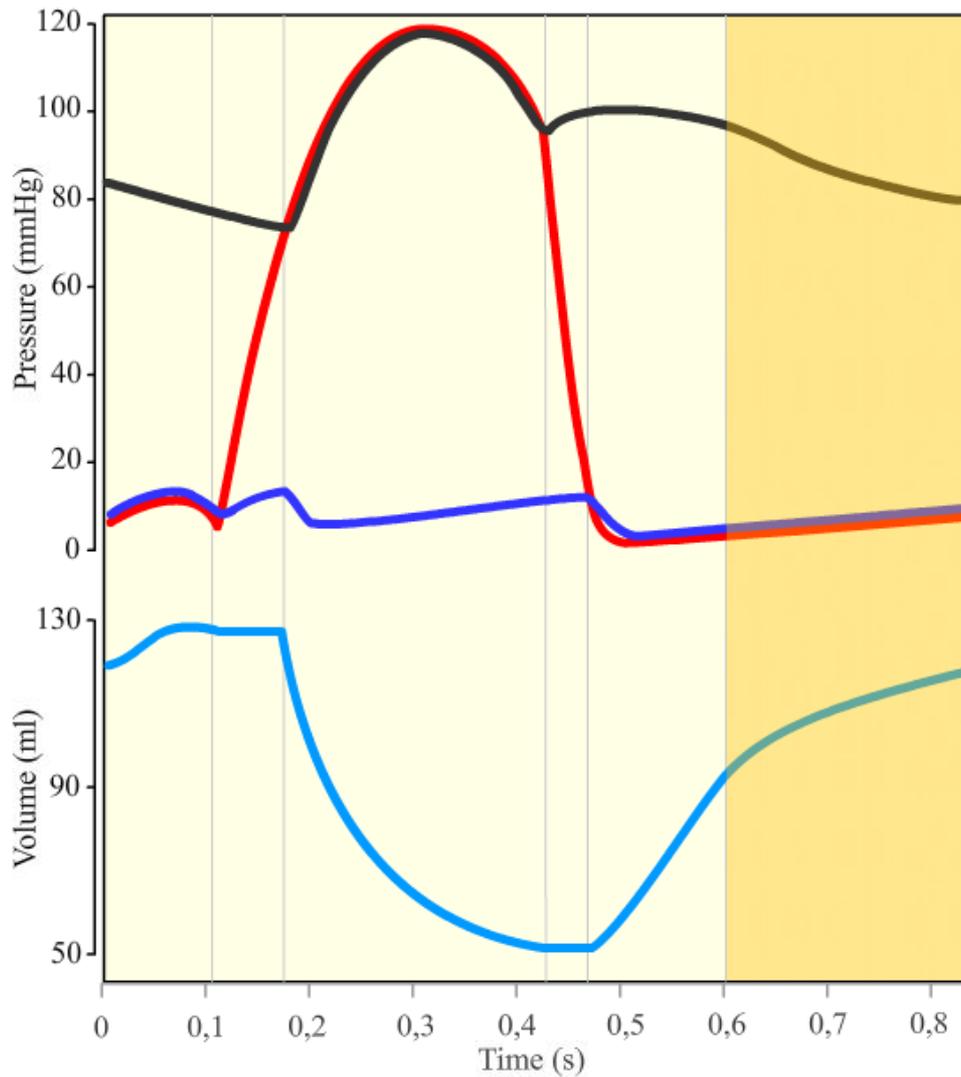


Figure 5.1. Slow ventricular filling - pressure and volume changes
Red line - pressure in the left ventricle, **black** - the aortic pressure, **dark blue** - the pressure in the right atrium, **light blue** - the ventricular volume.

5.3. Electrocardiogram

At the end of slow ventricular filling, depolarization spreads from sino-atrial node in all directions over the atria to produce the **P wave** in ECG (fig. 5.2).

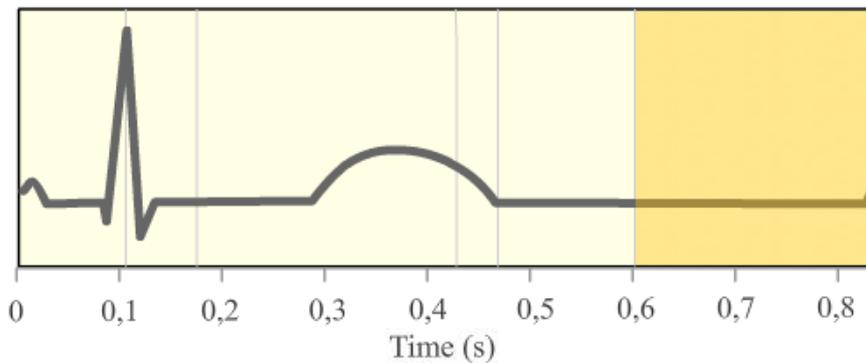


Fig. 5.2. Slow ventricular filling – ECG

6. Atrial Systole

6.1. Heart

The atrial systole is the last phase of a diastole during which the ventricular filling is completed. The atrioventricular valves are open; the semilunar valves are closed (fig. 6.1). The atria contract to eject blood into the ventricles.

6.2. Pressure and volume changes

Ventricles

About 25 % of the ventricular filling volume is ejected from the atrium to the ventricle. As the ventricular myocardium is relaxed, the ventricular pressure does not change significantly. The blood pressure in both ventricles is almost zero. At the end of the atrial systole each ventricle contains 130 ml of blood; it is so called **end-diastolic volume** (fig. 6.2).

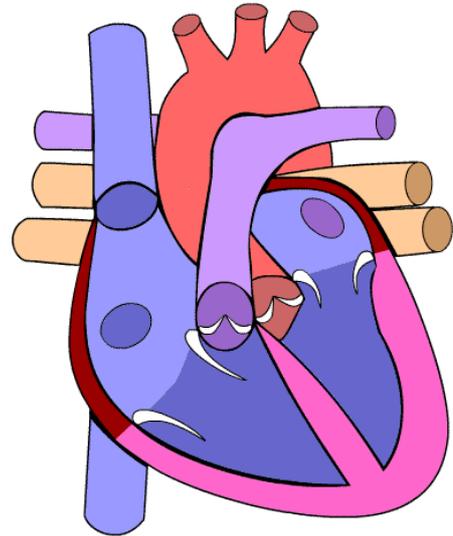


Fig. 6.1. Atrial systole
The contraction is represented by a colour change of myocardium.

Atria

The atrial contraction causes a rise in the atrial pressure which produces the **a wave** in the venous pulse (fig. 6.2).

Arteries

The pressure in arteries of both systemic and pulmonary circulations decreases constantly (fig. 6.2).

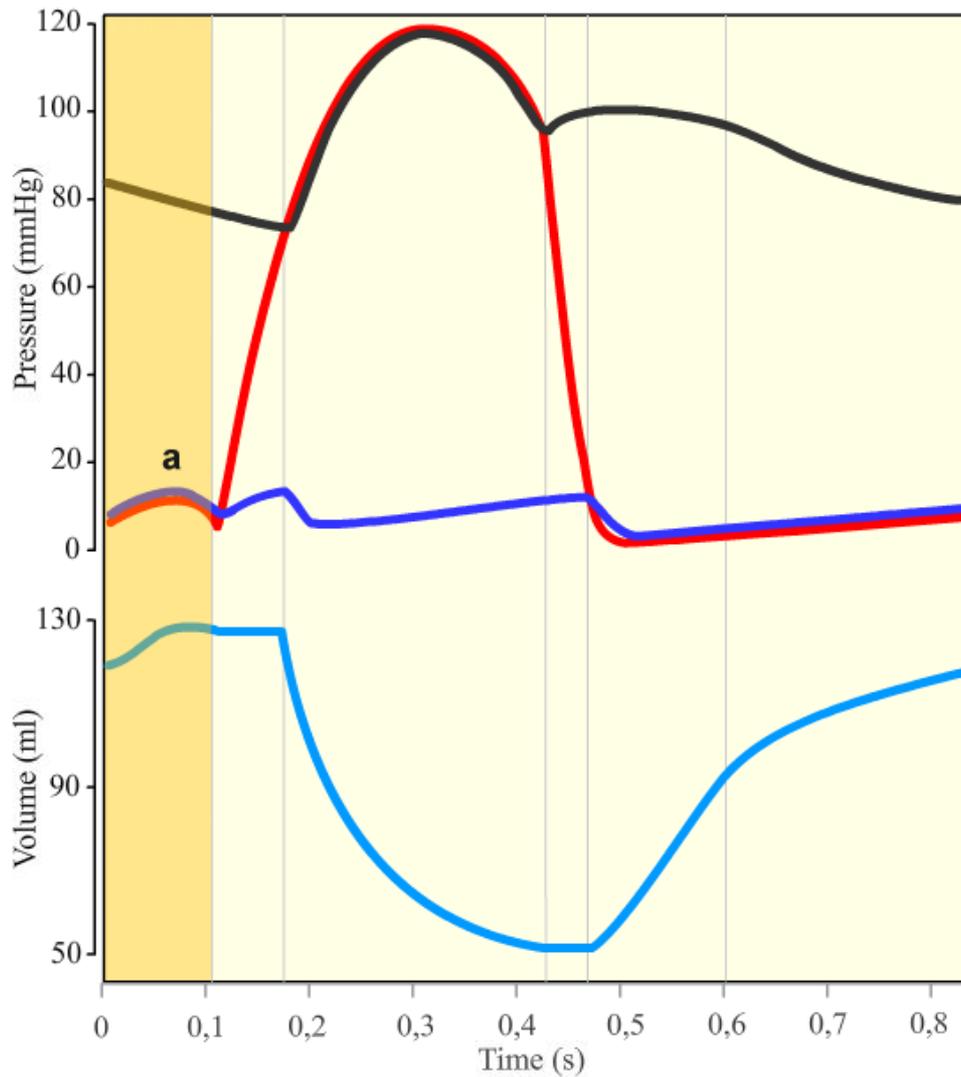


Figure 6.2. Atrial systole - pressure and volume changes

Red line - pressure in the left ventricle, **black** - the aortic pressure, **dark blue** - the pressure in the right atrium, **light blue** - the ventricular volume.

6.3. Electrocardiogram

The atrial depolarization is completed and the end of the **P wave** appears at the beginning of the atrial systole. Subsequently, the depolarization spreads from the atria to the atrioventricular node and the **PR segment** is visible in the ECG (fig. 6.3).

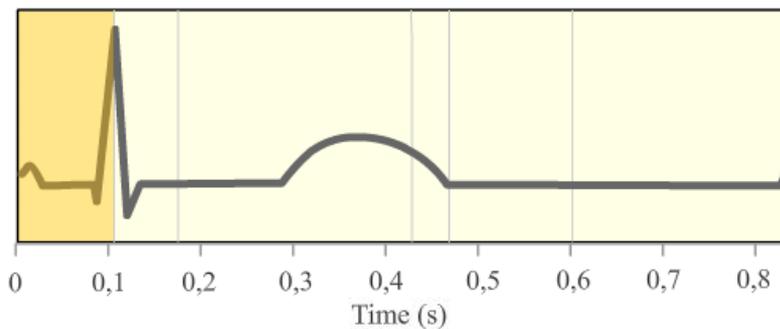


Fig. 6.3. Atrial systole - ECG

6.4. Heart sounds

The fourth heart sound is a soft sound due to an increase in the ventricular pressure following an atrial systole. It very rarely occurs in a healthy person (fig. 6.4.). Under pathological conditions this sound is present owing to an increase in intra-atrial pressure or lower compliance of the ventricle (e.g. in ventricular hypertrophy).

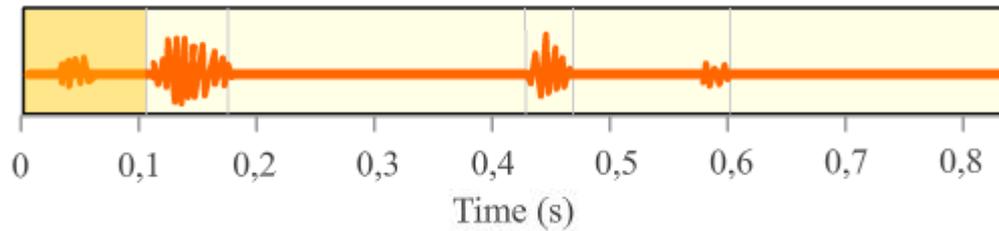


Fig. 6.4. Atrial systole – heart sounds