DEPARTMENT OF ELECTRONIC AND TELECOMMUNICATION ENGINEERING

UNIVERSITY OF MORATUWA

BM2101 - Modelling and Analysis of Physiological Systems

Assignment on analysis of cardiac physiology

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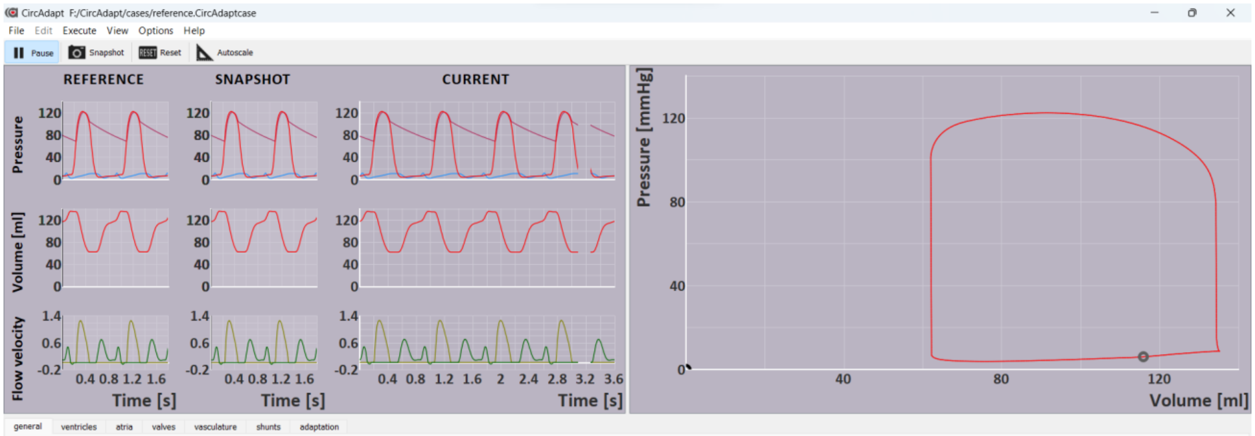
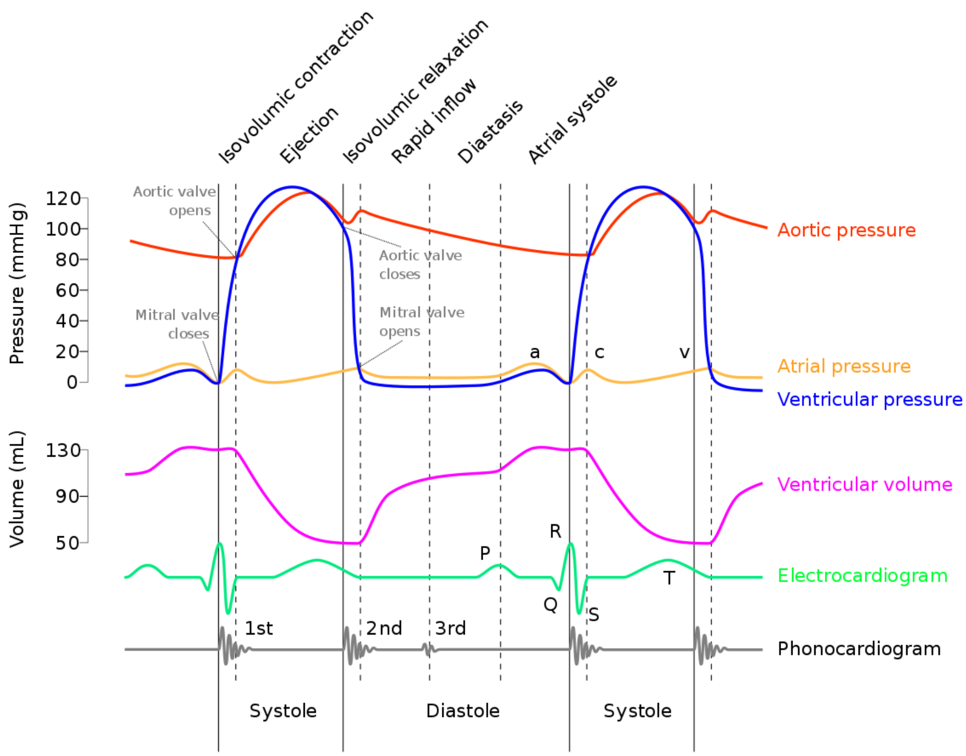
July 31, 2023

1.



Wiggers diagram



Diastole: AV valves open (semilunar valves are closed) and the ventricles fill with blood from the atria.

Systole: AV valves close (semilunar valves open) and ventricles push blood into the aorta or pulmonary artery.

Ventricular volume and pressure curve

The ventricular volume curve goes down at the start of systole because the blood is pumped out to the rest of the body.

Phase 1 Systole: isovolumic contraction phase in which both valves are closed. None of the blood is being pushed out yet so that pressure in the ventricles begins to rise.

Phase 2 Systole: Rapid ejection in which the pressure in the ventricle becomes greater than the aortic pressure, the aortic valve opens, and you have a rapid ejection of blood into the aorta.

Phase 3 Systole: Reduced ejection phase in which the pressure in the ventricles falls below that of the aorta.

Eventually, ventricular pressure becomes low enough that the aortic valve closes and this begins diastole.

The curve slowly rises up again, which is diastole, because the ventricles are filled with blood from the atria.

Phase 1 Diastole: isovolumic relaxation phase in which both valves are again closed and there is no change in ventricular volume but the pressure decreases enough to a point where it falls below the atrial diastolic pressure and the AV valve opens.

Phase 2 Diastole: Rapid filling is when the ventricular pressure falls below the atrial pressure, the blood rushes into the ventricle.

Phase 3 Diastole: Reduced filling is when the ventricles continue to fill with blood but at a reduced rate as the ventricle starts filling up.

Left atrial pressure curve

This graph shows the change in pressure in the left atrium during the cardiac cycle. The pressure increases during diastole and decreases during systole.

"A" wave represents atrial systole which contributes about 10ml of blood to the ventricular volume in ventricular diastole.

"C" wave comes after the QRS wave, created because the ventricles are pumping blood into the aorta and also contracting which compresses the atria.

"V" wave: atria that are filling up with incoming blood from the pulmonary veins.

Aortic pressure curve

Once the ventricular pressure increases above the aortic pressure and the aortic valves opens, the ventricles pump the blood into the aorta.

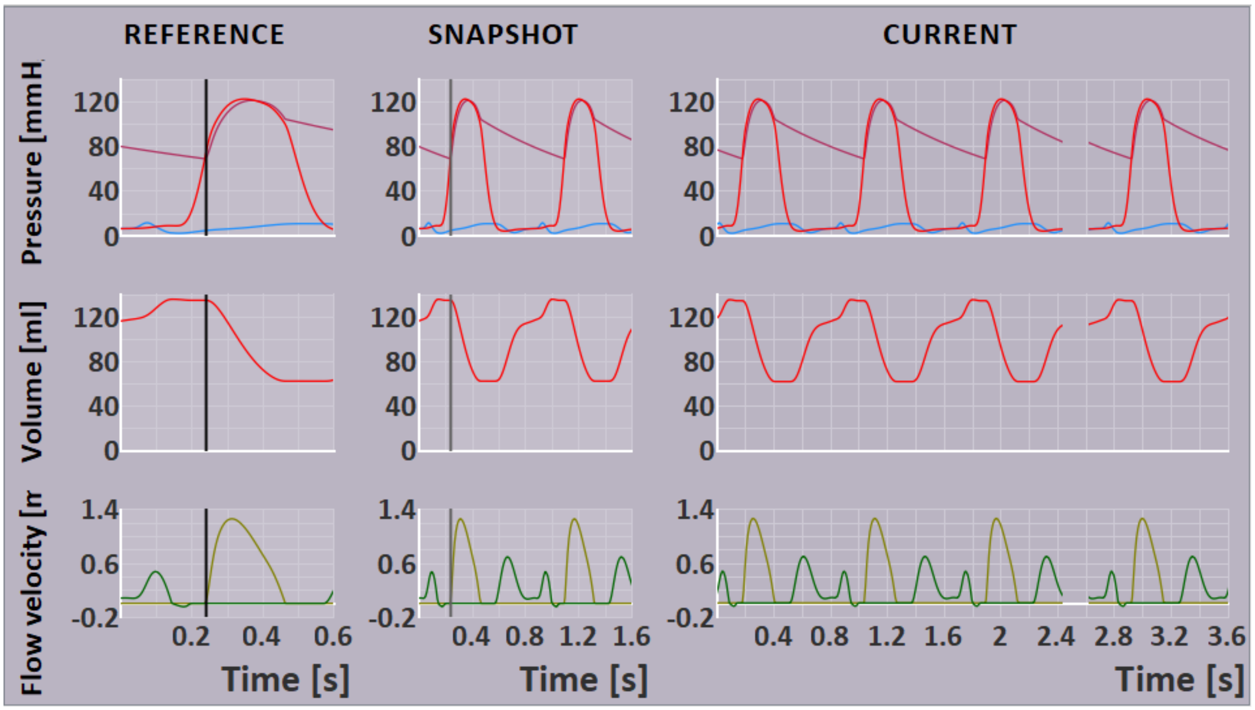
Initially, the aortic pressure in the rapid ejection phase is below the ventricles and then the pressure rises above the ventricular pressure.

The aortic valves eventually close from decreasing ventricular pressure, starting diastole.

Dicrotic notch or incisura is caused by a slight backflow of aortic blood that fills the cusps of the aortic valves as it closes at the end of ventricular systole.

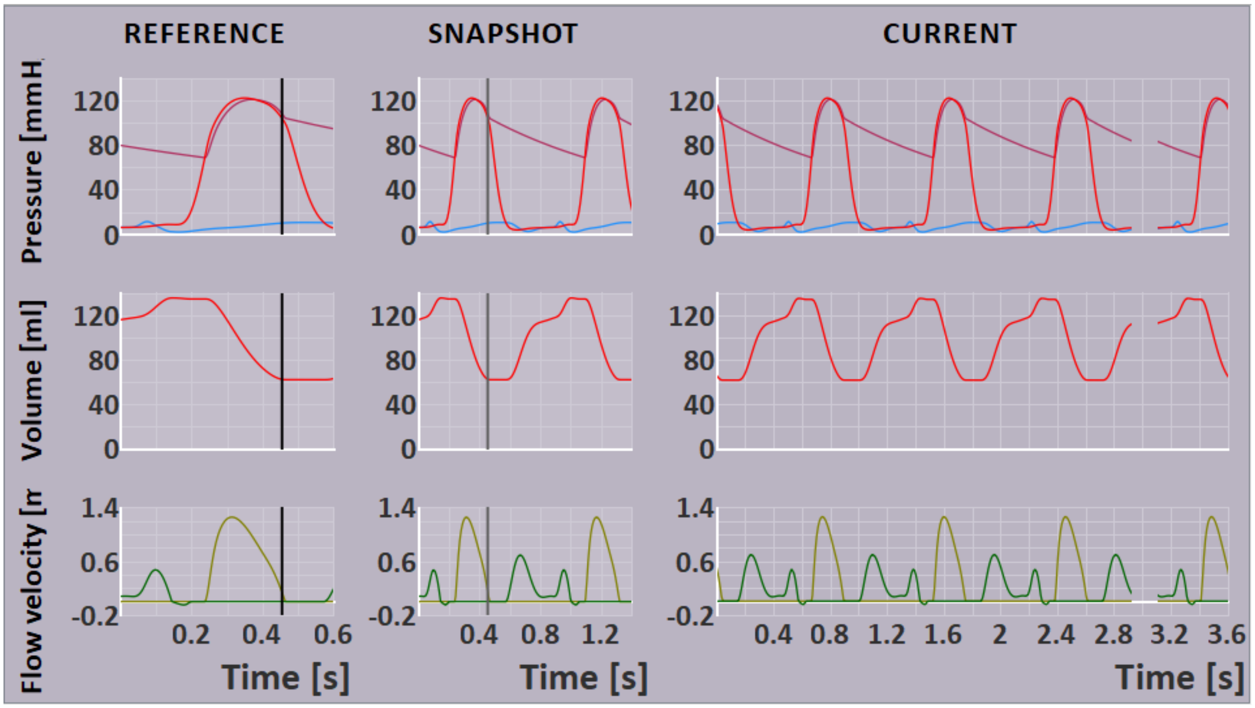
a. **Aortic valve opening**

The aortic valve opens when the pressure in the left ventricle exceeds the pressure in the aorta. This can be seen in the graphs as a sudden increase in the aortic pressure, which coincides with a decrease in the left ventricular pressure. The opening of the aortic valve also corresponds to a decrease in the left ventricular volume.



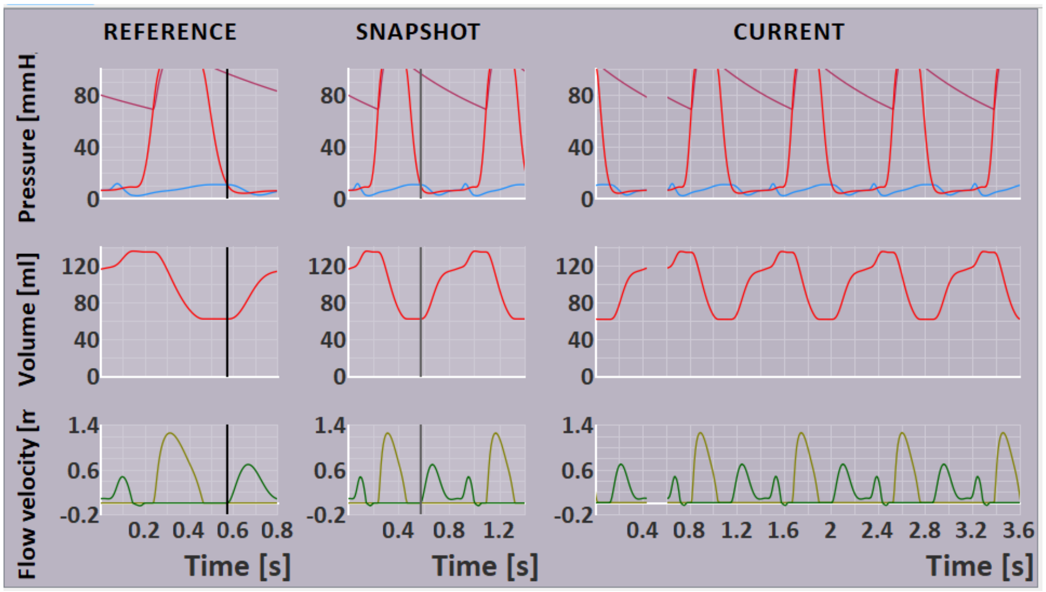
Aortic valve closing

The aortic valve closes when the pressure in the aorta exceeds the pressure in the left ventricle. This can be seen in the graphs as a sudden decrease in the aortic pressure, which coincides with an increase in the left ventricular pressure. The closing of the aortic valve also corresponds to an increase in the left ventricular volume.



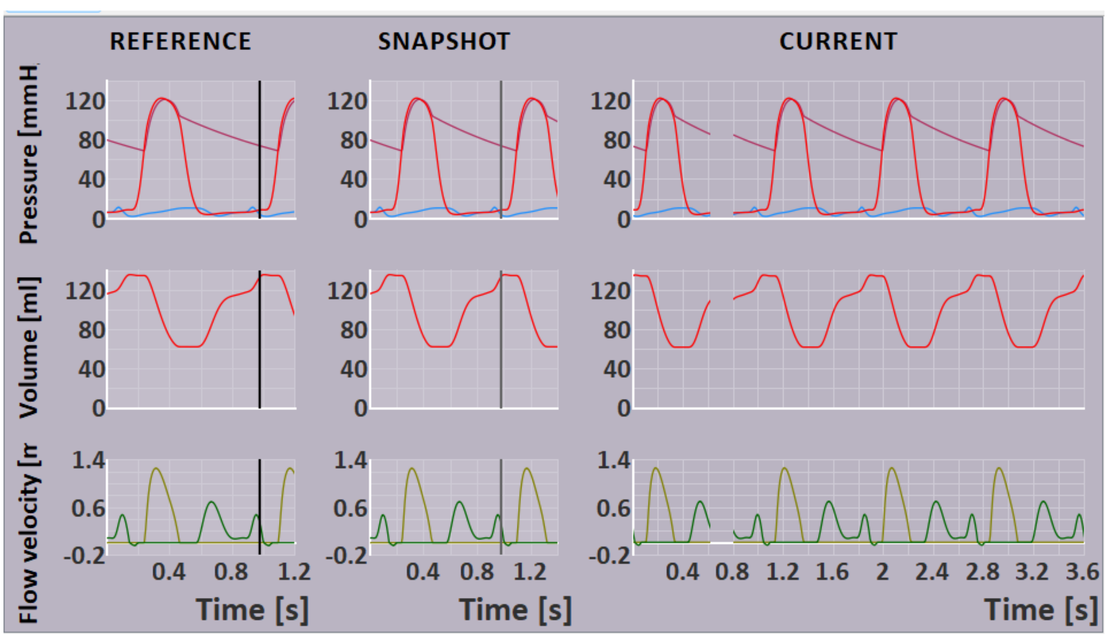
b. Mitral valve opening

The mitral valve opens when the pressure in the left atrium exceeds the pressure in the left ventricle. This can be seen in the graphs as a sudden increase in the left ventricular volume, which coincides with a decrease in the left atrial pressure. The opening of the mitral valve also corresponds to a decrease in the left ventricular pressure.



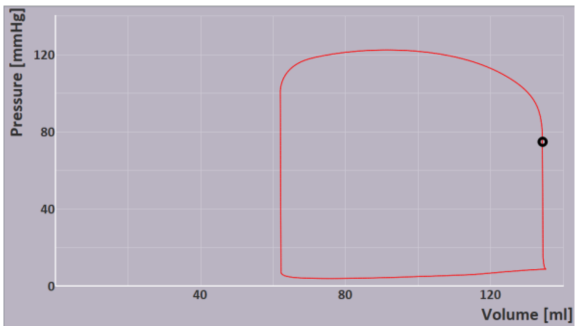
Mitral valve closing

The mitral valve closes when the pressure in the left ventricle exceeds the pressure in the left atrium. This can be seen in the graphs as a sudden decrease in the left ventricular volume, which coincides with an increase in the left atrial pressure. The closing of the mitral valve also corresponds to an increase in the left ventricular pressure.

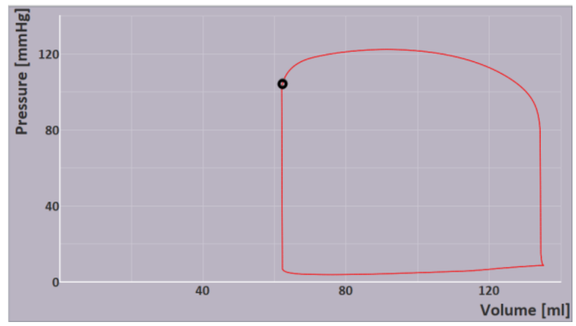


c.

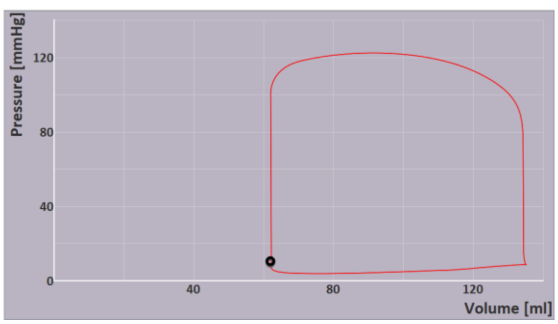
Aortic valve opening



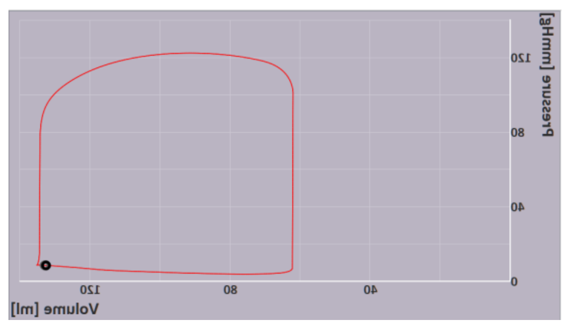
Aortic valve closing



Mitral valve opening



Mitral valve closing



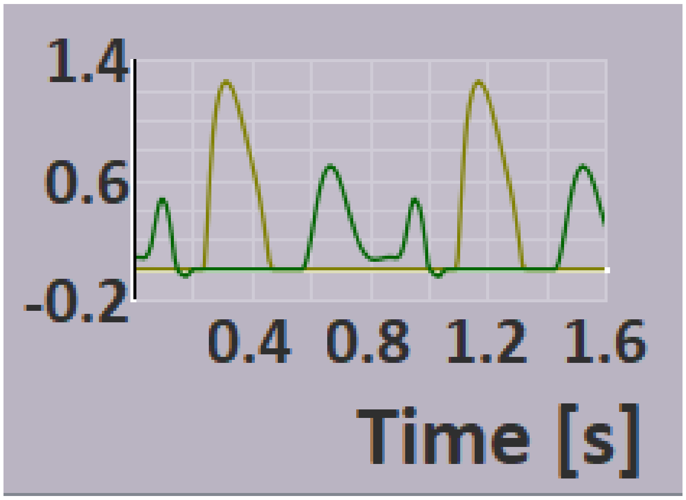
d. A – Filling

B – Isovolumic contraction

C – Ejection

D – Isovolumic relaxation

e.

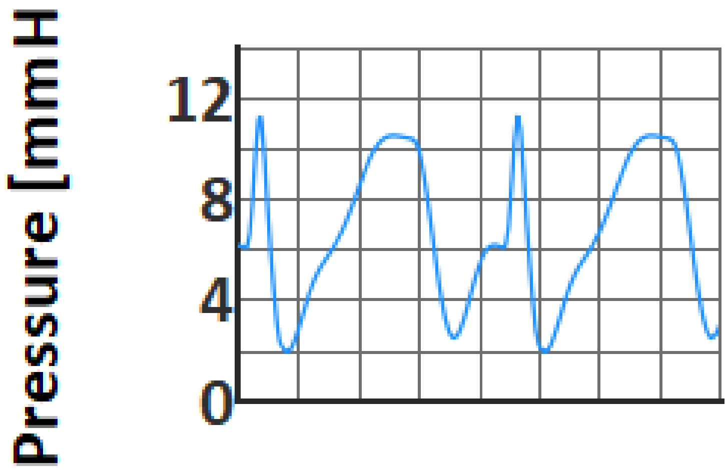


The aortic valve opens when the pressure in the left ventricle exceeds the pressure in the aorta. This causes the leaflets of the aortic valve to open and blood to flow from the left ventricle into the aorta. The flow of blood through the aortic valve is relatively smooth and continuous, which is why the flow velocity pattern has only one hump.

The mitral valve opens when the pressure in the left atrium exceeds the pressure in the left ventricle. This causes the leaflets of the mitral valve to open and blood to flow from the left atrium into the left ventricle. The flow of blood through the mitral valve is not as smooth as the flow of blood through the aortic valve, because the mitral valve has two leaflets that can flutter or vibrate. This causes the flow velocity pattern to have two humps.

The first hump in the flow velocity pattern of the mitral valve corresponds to the initial opening of the mitral valve and the rapid inflow of blood into the left ventricle. The second hump corresponds to the closing of the mitral valve and the slower outflow of blood from the left atrium into the left ventricle.

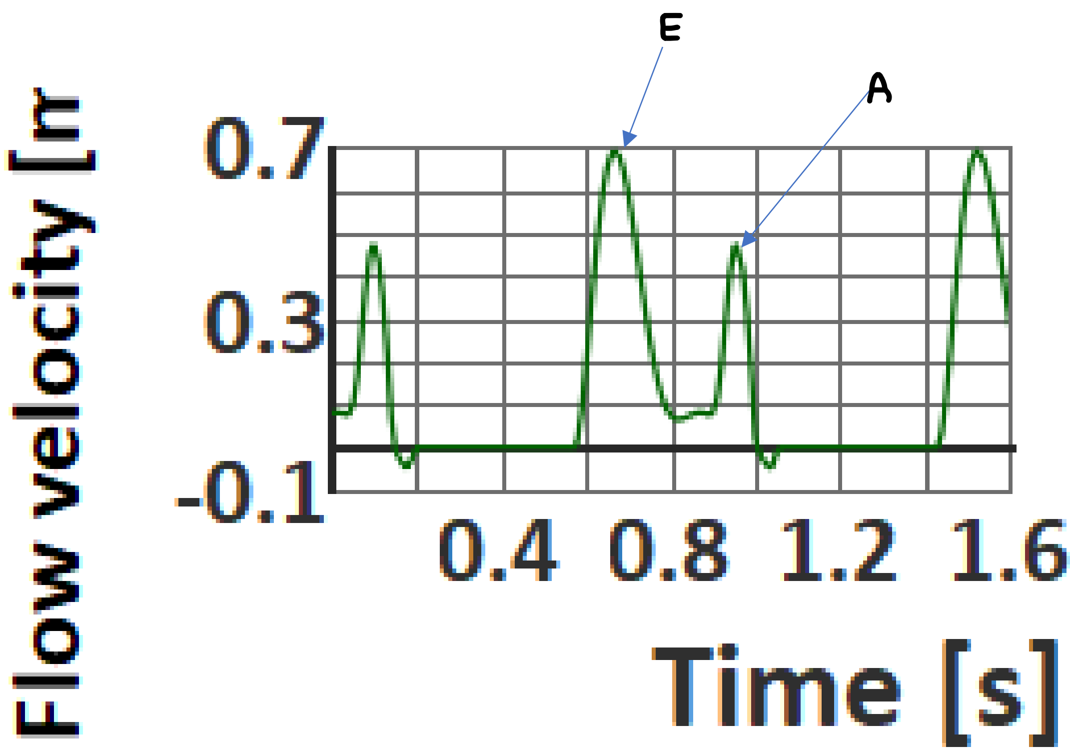
f.



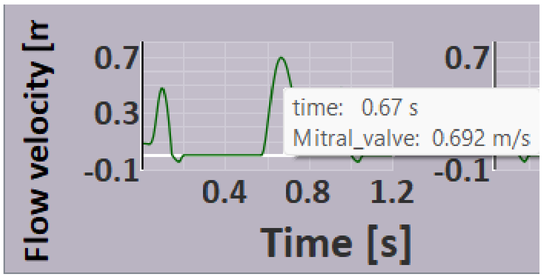
The two atrial pressure rises during a single cardiac cycle are caused by the atrial contraction and the v wave.

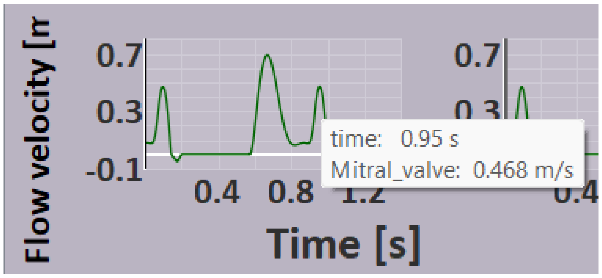
- Atrial contraction: The atrial contraction is a brief period of time when the atria contracts and pump blood into the ventricles. This causes a sharp rise in atrial pressure, which can be seen in the graph as the **a wave** (In the wiggers diagram). The **a wave** corresponds to the P wave on the ECG.
- V wave: The v wave is a slower rise in atrial pressure that occurs as blood continues to flow into the atria from the vena cava. This is caused by the bulging of the atrioventricular valves into the atria during ventricular systole. The v wave does not correspond to any specific ECG waveform.

g.



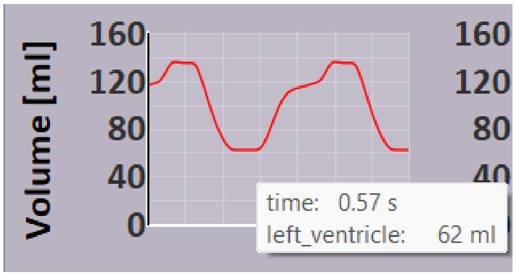
h.

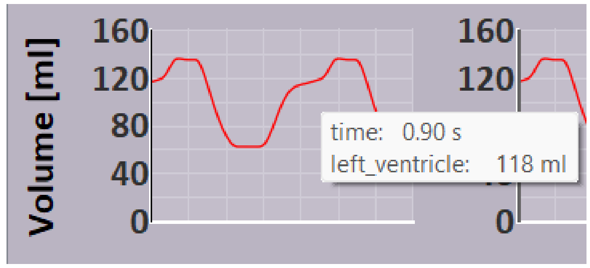


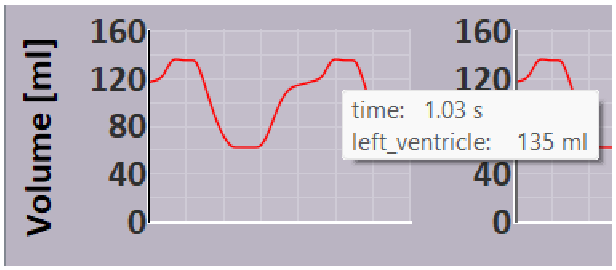


$$\frac{E}{A} = \frac{0.692}{0.468} = 1.4786$$

i.







Due to passive filling = 118ml – 62ml = 56ml
Due to active filling = 135ml – 118ml = 17ml

j. Opening area of a valve (Cross section)

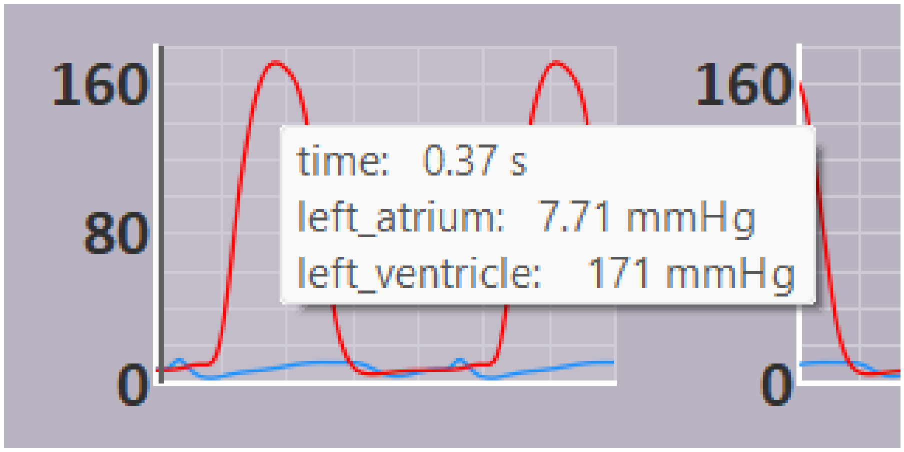
2.

a.

- **Preload:** Preload is the amount of stretch that the cardiac muscle fibers experience before they contract. It is determined by the amount of blood that fills the ventricles before they contract. A higher preload means that the cardiac muscle fibers will be stretched more, which will lead to a stronger contraction.
- **Afterload:** Afterload is the force that the heart must overcome in order to eject blood from the ventricles. It is determined by the resistance of the blood vessels

that the blood must flow through. A higher afterload means that the heart will have to work harder to pump blood out of the ventricles.

b.



As the severity of aortic stenosis (AS) increases, the left ventricle must work harder to pump blood through the narrowed aortic valve. This results in increased left ventricular pressure during systole. Additionally, blood flow through the narrowed valve accelerates to compensate for the obstruction and maintain adequate cardiac output, resulting in increased flow velocity across the aortic valve.

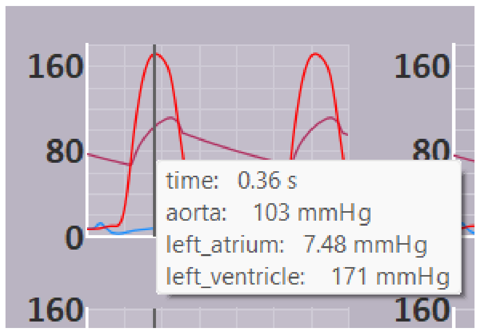
The pressure-volume loop, which represents the left ventricular pressure and volume during one cardiac cycle, shifts to the right and upward with increasing AS severity. This results in an increased area under the curve, indicating greater left ventricular work and myocardial energy expenditure needed to overcome the stenosis and effectively eject blood.

c. **Preload:** The preload of the left ventricle is the amount of blood that fills the ventricle before it contracts. In aortic valve stenosis, the preload of the left ventricle typically increases slightly. This is because the increased afterload of the left ventricle causes the ventricle to contract more forcefully, which increases the amount of blood that can be pumped into the ventricle during diastole.

Afterload: The afterload of the left ventricle is the force that the left ventricle must overcome in order to eject blood from the heart. In aortic valve stenosis, the afterload of the left ventricle increases significantly. This is because the narrowed aortic valve creates an obstruction to blood flow, which increases the resistance that the left ventricle must overcome.

Cardiac output: Cardiac output is the volume of blood that the heart pumps per minute. In aortic valve stenosis, cardiac output can decrease. This is because the increased afterload of the left ventricle makes it more difficult for the left ventricle to eject blood from the heart, which can lead to a decrease in the amount of blood that is pumped out of the heart each minute.

d.



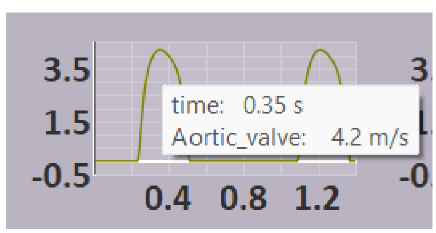
Maximum left ventricle pressure = 171mmHg

Aorta pressure when maximum ventricle pressure occurs = 103mmHg

Pressure drop across stenotic aortic valve = 171mmHg – 103mmHg

= **68mmHg**

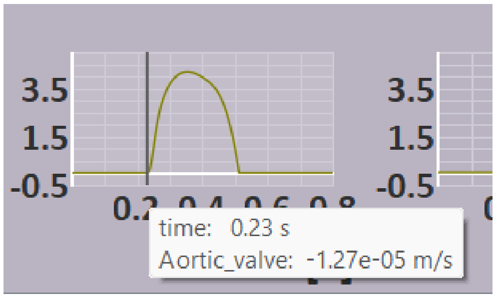
e.

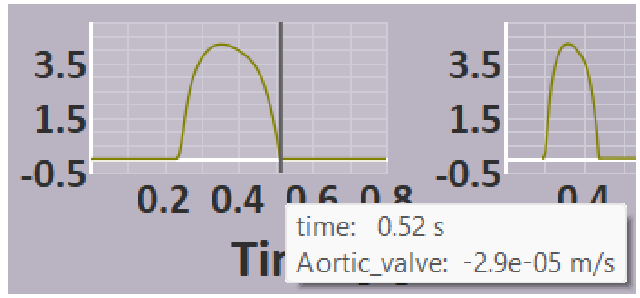


$$\Delta P \approx 4v^2$$
$$\Delta P \approx 4 \times 4.2^2$$
$$\Delta P \approx 70.56mmHg$$

Answers are nearly equal.

f. .

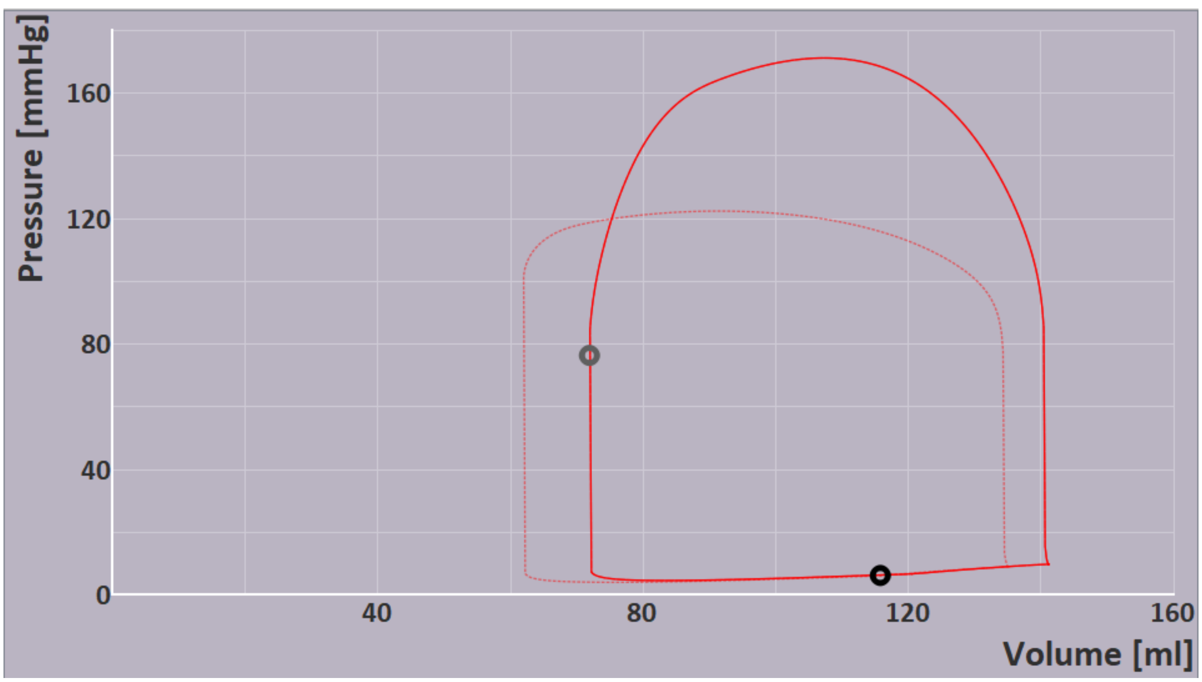




Duration of ejection $= 0.52\text{ms} - 0.23\text{ms}$

$= 0.29\text{ms}$

g.



Number of squares before 80% AS ≈ 20

Number of squares after 80% AS ≈ 24

Increase ≈ 4 squares

≈ 4×20×20

≈ **1600mlmmHg**

h. Hypertrophy: The heart muscle cells will become larger and thicker. This will allow the heart to generate more force and overcome the increased afterload.

Increased contractility: The heart muscle cells will become more contractile. This will allow the heart to eject more blood with each contraction.

Increased compliance: The heart muscle will become more compliant. This will allow the heart to stretch more easily, which will help to maintain a normal preload.

The effect of this adaptation on afterload is that it will increase the left ventricular wall tension. This is because the increased muscle mass and contractility will cause the left ventricle to generate more force. The increased wall tension will further increase the afterload.