Department of Electronic & Telecommunication Engineering
University of Moratuwa

# BM2102 - Modelling and Analysis of Physiological Systems

## Assignment 02
## Simulation of cardiac physiology

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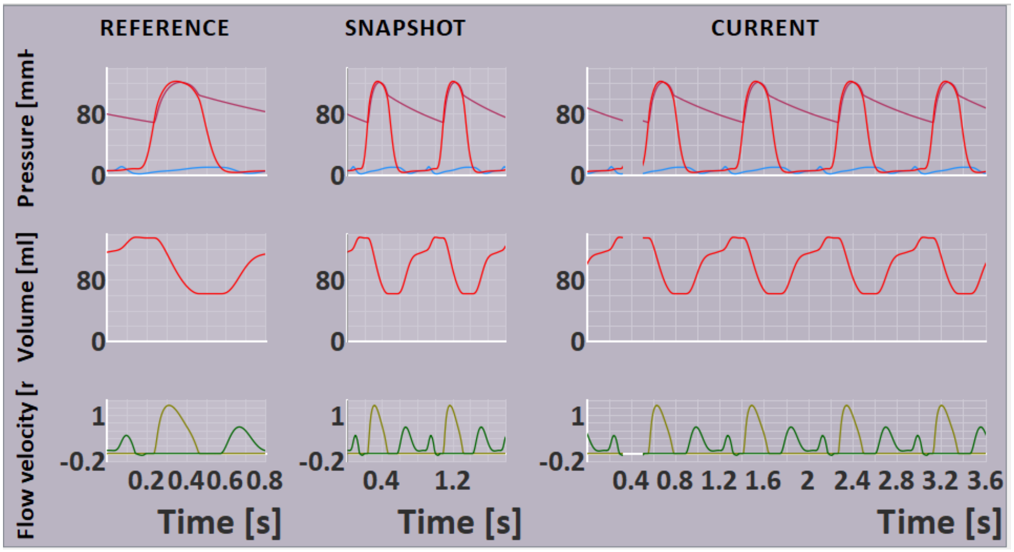
# Contents

# 1 Cardiac cycle and Wiggers diagram

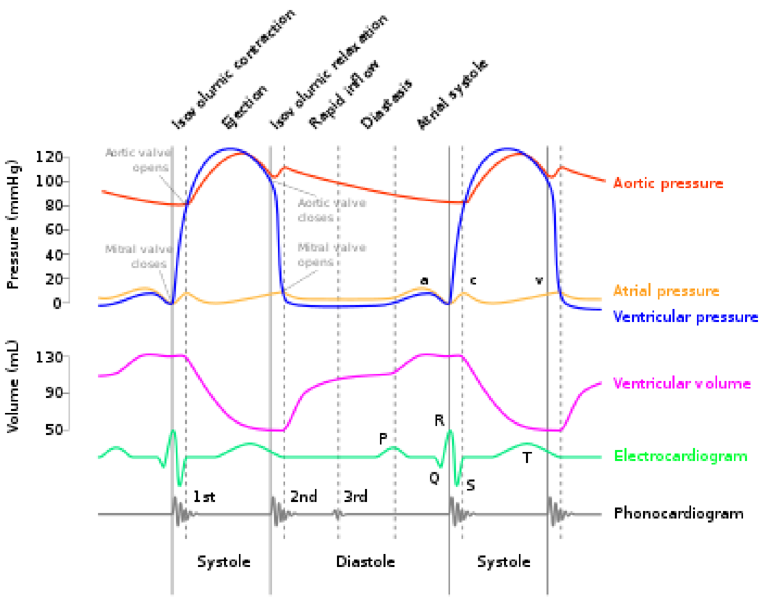
## Simulation window at normal conditions




Physiological Parameters modeled in the above graph

1. Left ventricular pressure
2. Left atrial pressure
3. Aortic pressure
4. Left ventricular volume
5. Blood Flow Rate of Aortic valve
6. Blood Flow Rate of Mitral valve

## Wiggers Diagram



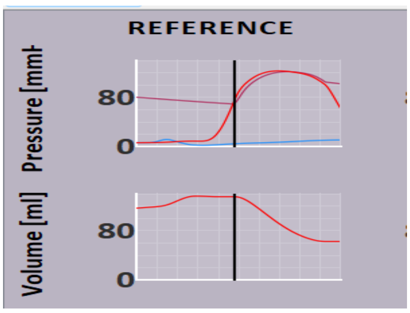
1. **Isovolumic Contraction (Systole):**
   When the ventricles start contracting this phase occurs and it marks the starting point of systole. Ventricular contraction, and closure of the atrioventricular valves (mitral and tricuspid) happens in this stage and no blood is ejected yet since all valves are closed.
2. **Ejection (Systole):**
   In this phase blood is ejected from the ventricles into the aorta and pulmonary artery. Opening of the aortic and pulmonary valves happens during this time and rapid rise in pressure in the ventricles leads to blood ejection.
3. **Isovolumic Relaxation (Diastole):**
   This is the phase where the ventricles relax, but the semilunar valves are still closed. This marks the initial phase of diastole . Ventricular relaxation, and closure of the aortic and pulmonary valves happen during this phase. No blood transformation to or from the ventricles.
4. **Rapid Inflow (Diastole):**
   Blood flows rapidly from the atria to the ventricles. Opening of the mitral and tricuspid valves happens in this phase.Ventricles passively fill with blood from the atria.
5. **Diastasis (Diastole):**
   This is a period of slower filling, in this phase The ventricles continue to fill with blood at a slower rate. Pressure in the heart chambers remains relatively constant.
6. **Atrial Systole (Diastole):**
   Atrial contraction contributes a final push of blood into the ventricles The remaining blood is pushed into the ventricles.

# 2 Normal Sinus Rhythm

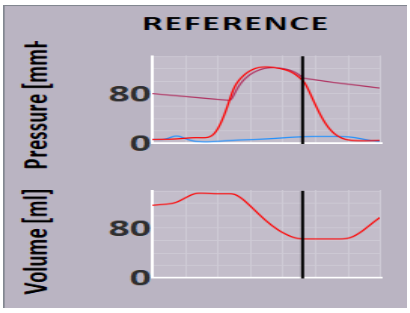
## 2.1 Aortic valve opening and closing

The aortic valve opens when the left ventricle contracts and pumps blood to the aorta. This can be seen in the graph as a sudden increase in the aortic pressure and this corresponds to the decrease in the left ventricle volume

The aortic valve closes when the pressure in the aorta exceeds the pressure in the left ventricle. This can be seen in the graph as a sudden decrease in the aortic pressure and this corresponds to the increase in the left ventricle volume




(a) Time when Aortic valve opens

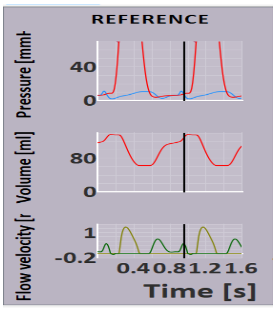



(b) Time when Aortic valve closes

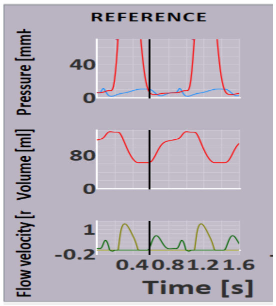
### 2.2 Mitral valve opening and closing

Mitral valve opens when the left ventricle relaxes and fills with blood from the left atrium at this time pressure in the left atrium exceeds the pressure in the left ventricular. This can be seen as a sudden increase in the left ventricular volume. In the pressure diagram this corresponds to a decrease in the left ventricular pressure.

Closing of the mitral valve occurs when the pressure in the left ventricle exceeds the pressure in the left atrium. This can be seen as a sudden decrease in the left ventricular volume. IN the pressure diagram this corresponds to a decrease in the left atrial pressure.

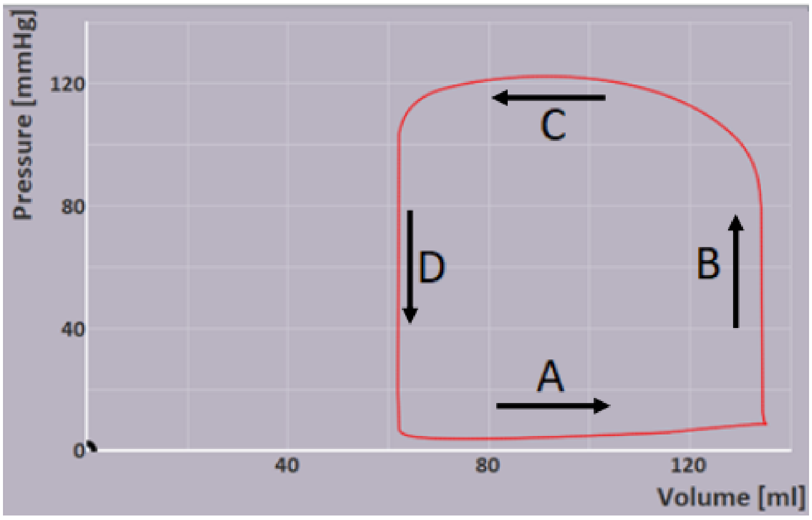



(a) Time when Mitral valve opens




(b) Time when Mitral valve closes

### 2.3 Pressure-volume relation

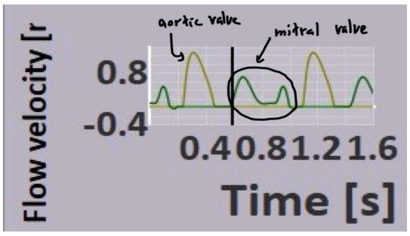



1. A - mitral closing (Filling)
2. B - aortic opening (Isovolumic Contraction)
3. C - mitral opening (Ejection)
4. D - aortic closing (Isovolumic Relaxation)

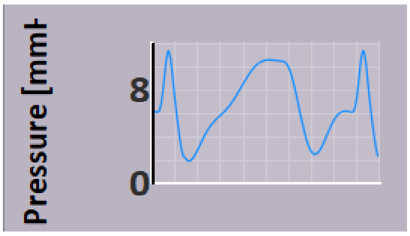
### 2.4 Flow velocity patterns in the aortic and mitral valves

**Aortic Valve:** The aortic valve is located between the left ventricle and the aorta. Blood flows from the left ventricle into the aorta during ventricular ejection (systole). Here The flow velocity pattern typically exhibits a single hump because blood is ejected from the left ventricle into the aorta in a relatively rapid and continuous manner.

**Mitral Valve:** The mitral valve is situated between the left atrium and the left ventricle. It allows blood to flow from the left atrium into the left ventricle during ventricular filling(diastole). The flow velocity pattern often exhibits two humps.The first hump corresponds to the early rapid filling phase (rapid inflow) when blood flows into the left ventricle due to the pressure difference between the atrium and the ventricle. The second hump occurs during atrial systole when the atrium contracts, providing an additional push of blood into the ventricle.



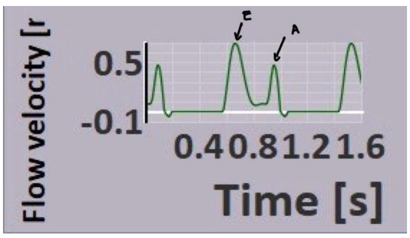

### 2.5 Atrial pressure curve



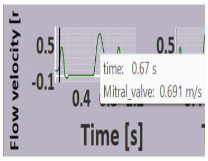

The fast increase in atrial pressure occurs during atrial systole. Atrial contraction leads to a rapid increase in pressure within the atria pushing blood into the ventricles. The sharp rise in atrial pressure corresponds to the P-wave on the ECG. The P-wave represents atrial depolarization, which precedes atrial contraction.

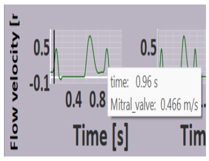
The slow increase in atrial pressure is associated with the passive filling of the atria during ventricular diastole. blood from the veins flows passively into the atria. This slow filling results in a gradual increase in atrial pressure. This occurs during the period between the P-wave and the subsequent QRS complex on the ECG.

### 2.6 Mitral blood flow velocity



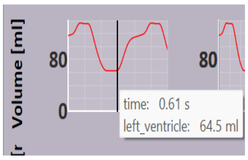
### 2.7 E/A-ratio

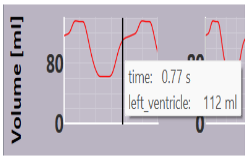


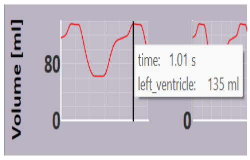




$E/A = 0.691/0.466 = 1.4828$

### Q. i)




Due to active filling= 135ml-112ml=23ml

Due to passive filling= 112ml-64.5ml=47.5ml

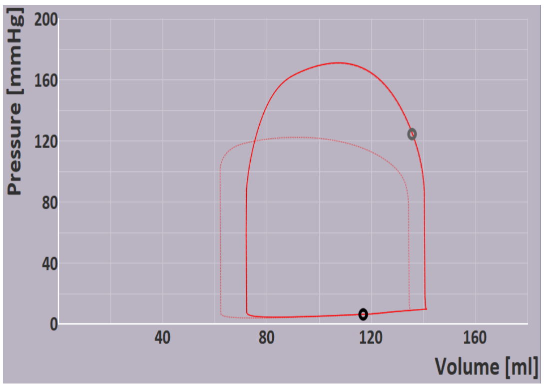
## 3 Aortic Valve Stenosis

### 3.1 Preload and Afterload

**Preload:** This is the amount of stretch that the cardiac muscle fibers experience before they contract. It is determined by the total blood volume remaining in the ventricles before pumps out. It means before systole.

**Afterload:** This is the force that the heart must overcome to eject blood from the ventricles. It is the pressure produced by the heart to eject blood during systole.

### 3.2 Maximal left ventricular pressure



So we can identify the maximum left ventricular pressure that occurs at 80% stenosis. It is equal to 170 mmHg according to the below table.

| Percentage of stenosis(%) | Peak flow velocity through aortic valve(m/s) | peak pressure at left ventricle(mmHg) |
|---|---|---|
| normal | 1.25 | 122 |
| 5 | 1.3 | 122 |
| 10 | 1.38 | 123 |
| 15 | 1.46 | 124 |
| 20 | 1.49 | 124 |
| 25 | 1.62 | 124 |
| 30 | 1.72 | 126 |
| 35 | 1.84 | 126 |
| 50 | 2.28 | 129 |
| 60 | 2.69 | 138 |
| 70 | 3.14 | 148 |
| 80 | 4.16 | 170 |

Table 1: pressure values at each stenosis percentage

### 3.3 Affect of the aortic valve stenosis to the preload and the afterload

**Preload of the Left Ventricle:**

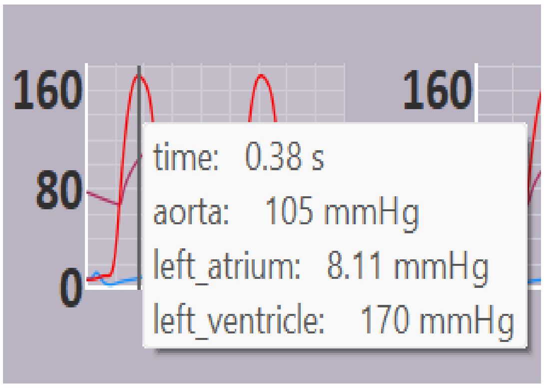
In aortic stenosis, the narrowed valve impedes the efficient ejection of blood into the aorta. This leads to a buildup of blood in the left ventricle during diastole, increasing preload

**Afterload of the Left Ventricle:**

In aortic stenosis, the narrowed valve increases resistance to blood flow, creating a higher afterload for the left ventricle. The ventricle has to generate greater pressure to push blood through the stenotic valve and into the aorta.

**Impact on Cardiac Output:** Cardiac output is the volume of blood that the heart pumps per minute. In aortic valve stenosis, cardiac output can decrease as the condition progresses. The left ventricle faces increasing resistance, and it may struggle to maintain an adequate stroke volume. Eventually, the compensatory mechanisms may be overwhelmed, and cardiac output can decrease.

### 3.4 Pressure drop across the stenotic aortic valve



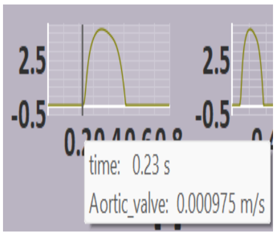

The maximum left ventricular pressure is equal to 170 mmHg.
Aortic valve pressure is 105 mmHg at that time.
Pressure drop = 170 mmHg - 105mmHg = **65 mmHg**

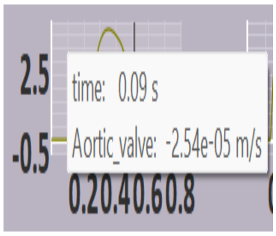
According to bernoulli's equation, drop accross the valve as below.

Maximum Flow Velocity = 4.2ms1
Pressure Drop = 4  $(4.22^2)$=70.56mmHg

above we have got 65 mmHg as the pressure drop across the aortic valve. Here we got approximately 70.56 mmHg.

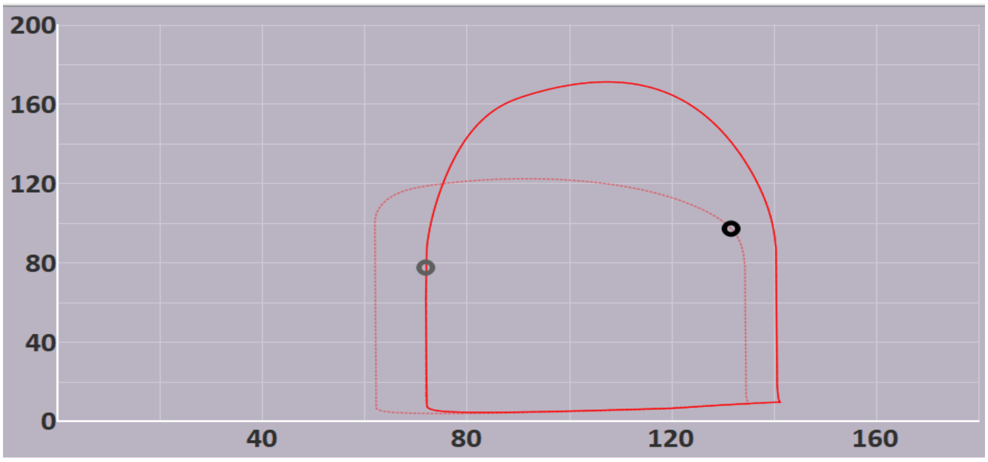
### 3.5 Duration of ejection.




The duration of ejection across the aortic valve is 0.23 s - 0.09 s = 0.14s

### 3.6 External pump work generated by the left ventricle




Number of squares in normal graph= 20
Number of squares in second graph= 24
Increase of the external pump work= 4*20*20 mlmmHg = 1600 mlmmHg

### 3.7 Left ventricle adaptation

Myocardial hypertrophy involves an increase in the size of individual cardiac muscle cells. The heart undergoes hypertrophy to increase muscle mass and wall thickness. This adaptation helps the left ventricle generate greater force during contraction

Improved Contractility: The hypertrophied myocardium allows the left ventricle to generate higher contractile force, helping it overcome the increased resistance

Increased Stiffness: Over time, hypertrophied myocardium may become stiffer This stiffness can contribute to increased afterload as the ventricle faces greater resistance during diastole.