جامعة الملك سعود
King Saud University

MED438
KING SAUD UNIVERSITY

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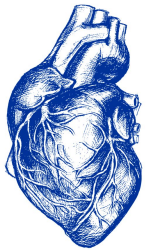
# Lecture 3 - 4
# Cardiac Cycle

- Red: important
- Black: in male / female slides
- Pink: in female slides only
- Blue: in male slides only
- Gray: extra information

Editing file



Physiology
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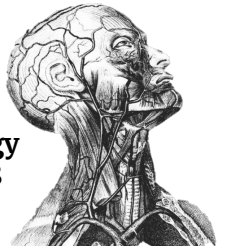


# Objectives:

- Enumerate the phases of cardiac cycle.
- Explain the effect of heart rate on duration of systole and diastole.
- Recognize the pressure, electrical, sound and volume changes during cardiac cycle.
- Correlate different phases of cardiac cycle with various in events.
- Compare and contrast left and right ventricle during the cardiac cycle.
- Describe atrial pressure waves & their relationship to cardiac cycle.
- Describe the use of the pressure-volume loop in describing the phases of the cardiac cycle.

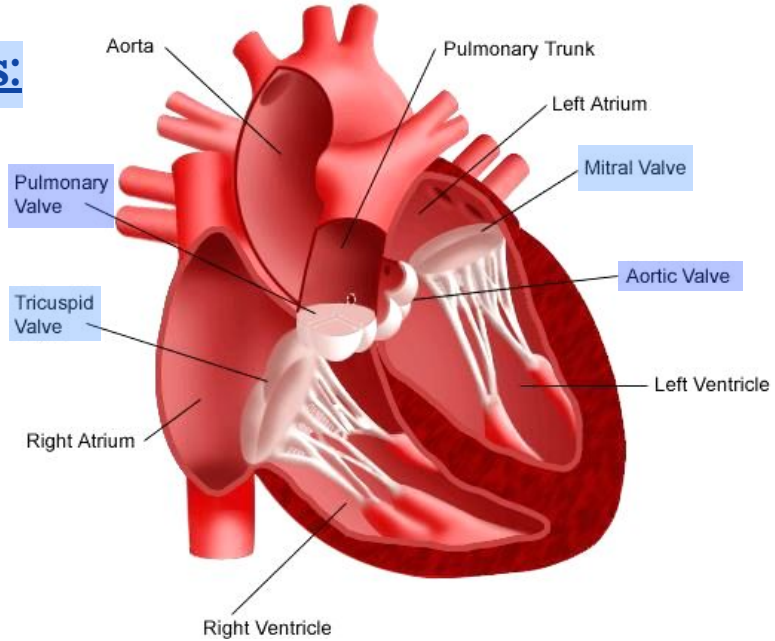
# Valves of the heart

Female slides

## Atrioventricular(AV) valves:

1- Tricuspid valves: Between the right atrium and right ventricle

2- Mitral valve: between the left atrium and left ventricle




## Semilunar valves:

1- Pulmonary valve: between the right ventricle and pulmonary artery

2- Aortic valve: between the left ventricle and aorta

- These valves open and close in response to pressure changes in the heart.
- They only allow blood to flow in ONE direction.
- Both of them can stay closed at the same time, but they CANNOT stay open simultaneously.

# Cardiac Cycle

## Definition:

The cardiac cycle is the time duration comprising all events from one heart contraction to the beginning of the next heart contraction.
Each cycle is initiated by depolarization of the SA node, followed by atrial systole (0.1 sec) → ventricular systole (0.3 sec) → diastole of whole heart (0.4 sec).

## Events:

1. Mechanical events: pressure, volume, and sound changes
2. Electrical events (ECG): action potentials

## Cardiac cycle time:

- To calculate the duration of one complete cardiac cycle:

  **Duration = 60 / HR**

- For example, if a person's HR is 75 bpm, his/her cardiac cycle duration = 60/75 = 0.8 s
- Duration is inversely proportional to the HR

# Cardiac Cycle

-Notice how when heart rate increased, Diastole was more affected than systole

-Both events occur simultaneously

The cardiac cycle has two phases:

| Atrial Events | |
|---|---|
| Systole (0.1 s) | Diastole (0.7 s) |
| **Ventricular Events** | |
| Systole (0.3 s)<br>After exercise:<br>Systole (0.14) | Diastole (0.5 s)<br>After exercise:<br>Diastole (0.16) |

**The total time for the cardiac cycle (HR = 75 bpm)**
**0.8 seconds**

Ventricular diastole is **long** for **three** important reasons:
1- Coronary blood flow
2- Ventricular filling
3- Rest

# General principles of Cardiac Cycle

1. The main function of the heart is to pump blood throughout the body through pulmonary (lungs) and systemic (whole body) circulations.
2. Contraction of the heart generates pressure change that allows blood movement
3. Blood flows from areas of high pressure to areas of low pressure
4. Events in right and left ventricles are the same, but with lower pressure gradients in the right side
5. Atrial & ventricular systole do not occur at same time, but their relaxation occurs at same time during diastole of whole heart which lasts for 0.4 sec

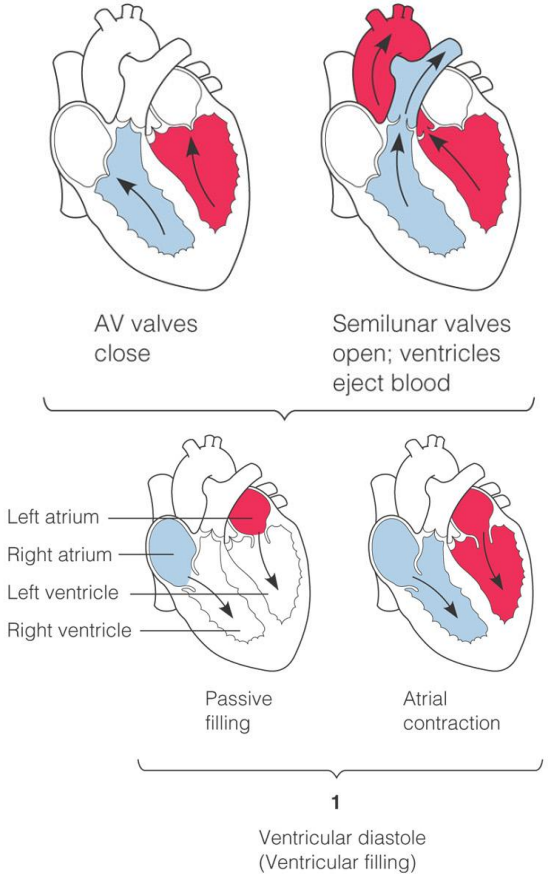
# Phases of the Cardiac Cycle

## Ventricular systole
(0.3 seconds)

1- Isovolumetric contraction
(Early systole)

2- Rapid Ejection
(Late systole)

3- Reduced Ejection
(Late systole)




## Ventricular diastole
(0.5 seconds)

4- Isovolumetric relaxation
(Early diastole)

5- Rapid filling
(Late diastole)

6- Slow filling
(Late diastole)

7- Atrial systole

# Volume Changes

| | |
|---|---|
| **ESV**<br>End-systolic volume | Volume of blood left in a ventricle at the end of systole (**40-60 ml**) |
| **EDV**<br>End-diastolic volume | Volume of blood in a ventricle at the end of diastole (**120-130 ml**) **MAX** |
| **SV**<br>Stroke volume | Volume of blood ejected by a ventricle during systole (**~70 ml**) (Per beat) |

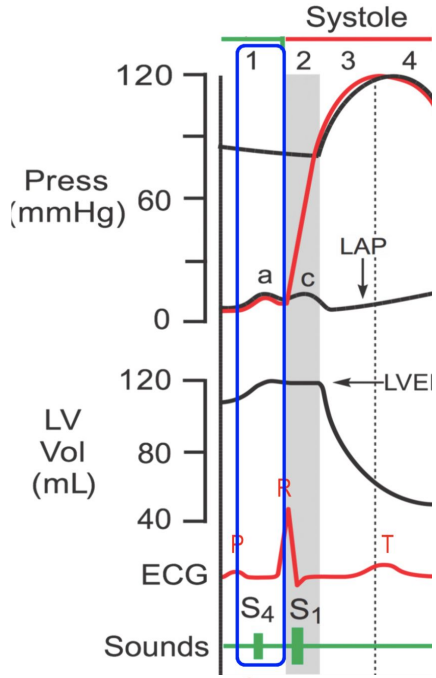
**Ejection Fraction:** the ratio of ejected blood (SV) to the blood in a ventricle right before a diastole (EDV). It is a good indicator of ventricular function.
***Normal range: 60-65%**

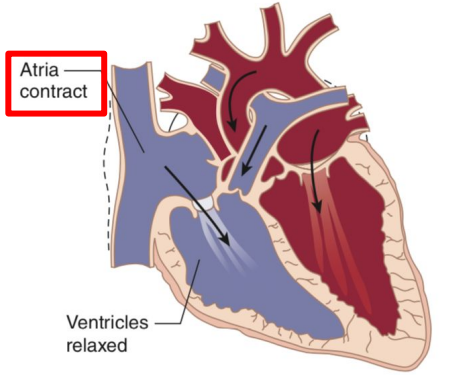
$$\underline{EF = SV / EDV \times 100}$$

SV = EDV - ESV

# Atrial Systole

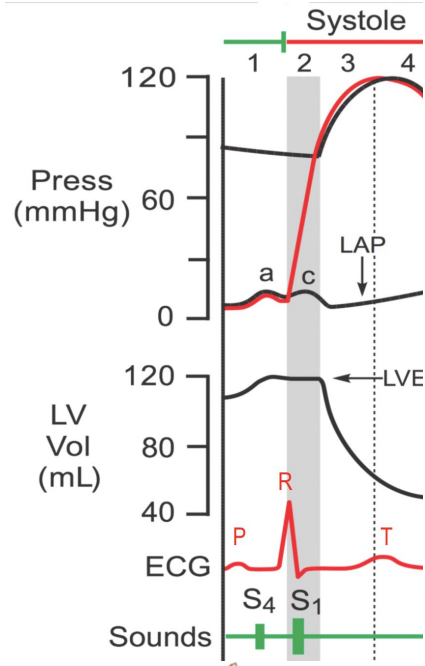
| | | | | |
|---|---|---|---|---|
| **Description** | The atria contract, pushing the last 25% of blood to the ventricles. | | | |
| **Duration** | 0.11 seconds | | | |
| **Valves** | **AV** | Open | | |
| | **Semilunar** | Closed | | |
| **Ventricular volume** | Ventricular volume rise to EDV (120-130 ml) at the end of this phase | | | |
| **Ventricular pressure** | First a slight ↑ (blood entry)<br>Then slight ↓ (ventricular dilation) | | **Atrial pressure** | First ↑ (by systole)<br>Then ↓ (blood exit) |
| **Sounds** | **4th** heart sound (S4) | | | |

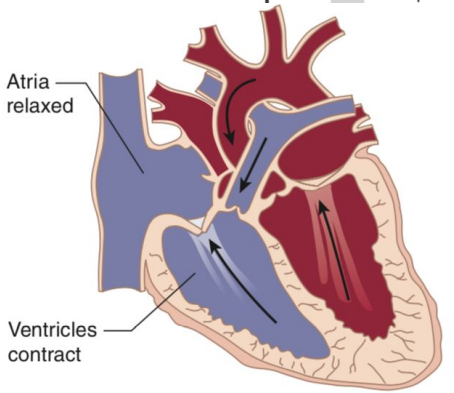


# Isovolumetric contraction (AKA Isometric contraction)

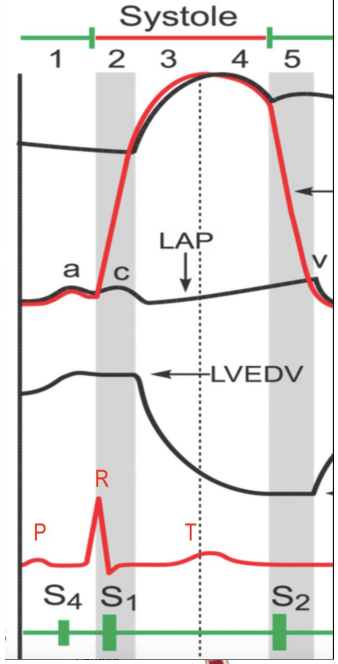
| | | | |
|---|---|---|---|
| **Description** | The ventricle builds up tension <u>without</u> changing its length to open the semilunar valves<br>It occurs at the beginning of ventricular systole | | |
| **Duration** | 0.05 seconds | | |
| **Valves** | **AV** | Closed | |
| | **Semilunar** | Closed | |
| **Ventricular volume** | Maximum EDV = 120-130 ml | | |
| **Ventricular pressure** | <u>Sudden</u> rise up to 80 mmHg which will open the aortic valve | **Atrial pressure** | ↑ Due to doming of closed A-V cusps into atria |
| **Sounds** | **1st** heart sound (S1) **(AV valve closure)** | | |

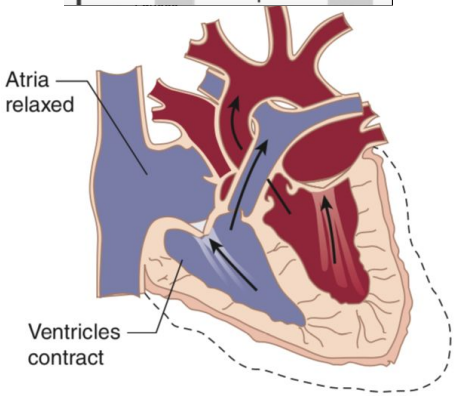


# Ejection (Rapid & Reduced)

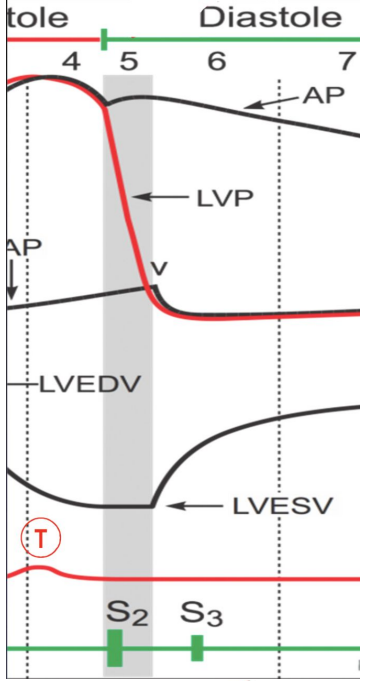
| | | | |
|---|---|---|---|
| **Description** | The ventricle shortens its wall (isotonically) ejecting blood through the aorta and pulmonary artery in two phases, marking the end of systole:<br>**Rapid (ejecting 70%) & Reduced (ejecting 30%)** | | |
| **Duration** | Rapid: 0.10 seconds<br>Reduced: 0.15 seconds | | |
| **Valves** | **AV** | Closed | |
| | **Semilunar** | Open | |
| **Ventricular volume** | Decrease to ESV = 50 ml | | |
| **Ventricular pressure** | Rapid: increase to 120 mmHg<br>Reduced: decrease | **Atrial pressure** | First ↓ because when ventricles contract, they pull the AV fibrous ring & valves down then increase. |
| **Sounds** | **None** | | |

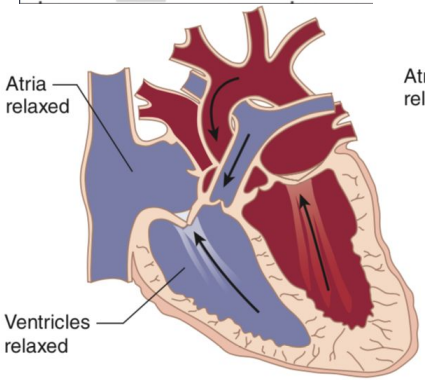


# Isovolumetric relaxation

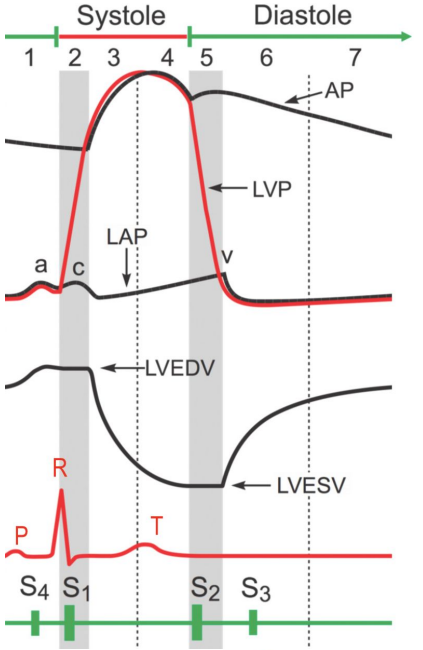
| | | | | |
|---|---|---|---|---|
| **Description** | The ventricles relax, causing a drop in pressure which leads to backflow of blood from the aorta (closing the valves) | | | |
| **Duration** | 0.06 -0.04 seconds | | | |
| **Valves** | **AV** | Closed | | |
| | **Semilunar** | Closed | | |
| **Ventricular volume** | Volume does not change ESV= 50 ml | | | |
| **Ventricular pressure** | Decreases rapidly to diastolic levels (2-10 mmHg) because the valves are closed & the relaxation is isometric | **Atrial pressure** | Increases gradually due to accumulation of venous blood | |
| **Sounds** | **2nd** heart sound (S2) **(Sudden Aortic valve closure)** | | | |

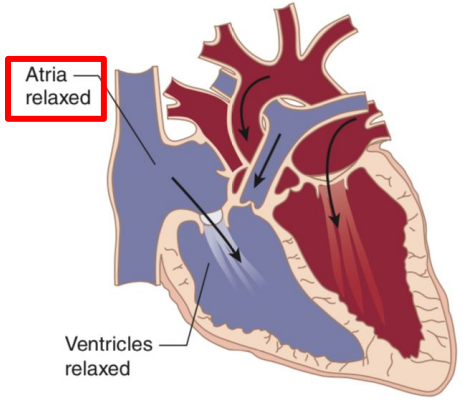


# Filling phase (Rapid & Slow)

| | | | | |
|---|---|---|---|---|
| **Description** | The AV opens, filling the ventricle in 3 phases:<br>Rapid (70%) & Slow/Diastasis (5%) & Atrial systole (25%) | | | |
| **Duration** | Rapid: 0.11 seconds | | Slow (diastasis): 0.22 seconds | |
| **Valves** | **AV** | Open | | |
| | **Semilunar** | Closed | | |
| **Ventricular volume** | Volume is increased in ventricles and decreased in atria | | | |
| **Ventricular pressure** | ↑ slightly due to increase in volume, but is still **less** than atrial pressure | | **Atrial pressure** | First sudden ↓ due to rush of blood into ventricles.<br>Then ↑ due to venous blood entry. |
| **Sounds** | **3rd** heart sound (S3) during **rapid filling** phase (rush of blood and vibrations in ventricular wall) | | | |



# Aortic pressure curve

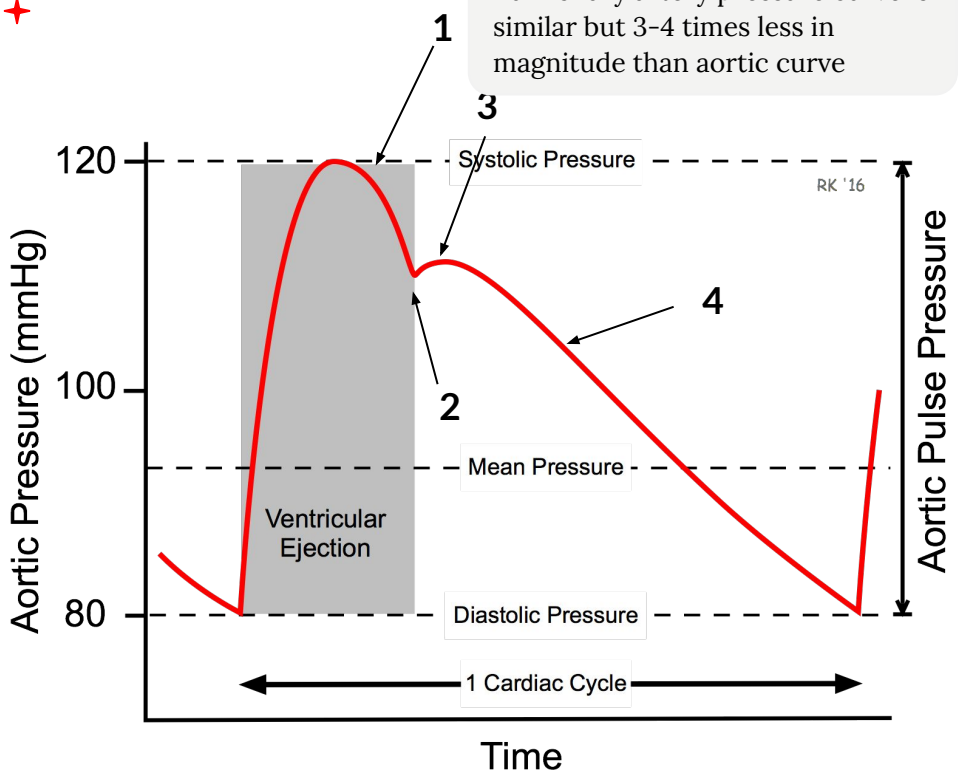
1- **Ascending phase (anacrotic limb):**

Aortic pressure increases to 120 mmHg, coincides with rapid ejection.

2- **Descending phase (catacrotic limb):** Can be split into 4 stages:

1. **Decrease in aortic pressure**
   Coincides with reduced ejection (blood entering aorta is less than blood leaving it)
2. **Dicrotic notch (incisura)**
   Sudden drop in pressure caused by closure of aortic valve at the end of ventricular systole.
3. **Dicrotic wave**
   Slight increase in aortic pressure caused by the aortic elastic recoil
4. **<u>Slow</u> aortic pressure decrease**
   Down to 80 mmhg due to continuous blood flow in systemic arteries.

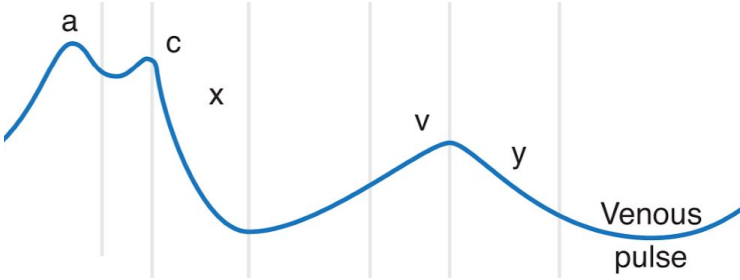
Pulmonary artery pressure curve is similar but 3-4 times less in magnitude than aortic curve

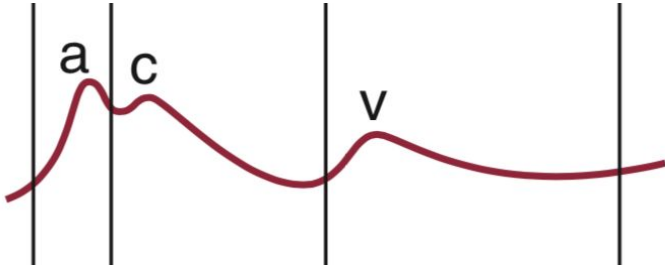



Arterial curve is similar to aortic, but **sharper.**
- **systolic peak pressure** of 110-130 mmHg.
- **diastolic pressure** of 70-85 mmHg.

# Atrial pressure waves

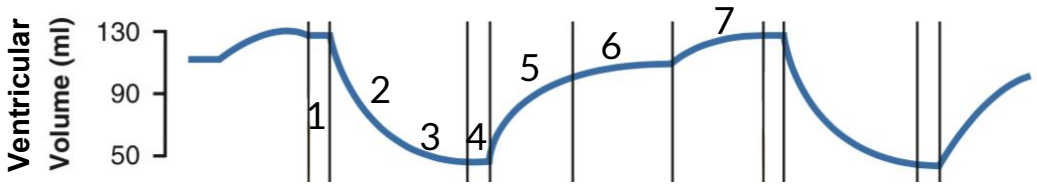
1. **“a” wave (atrial systole):**
   increase due to atrial contraction
   decrease due to blood passing into ventricles
2. **“c” wave (ventricular systole):**
   Increase due to bulging of AV valve in isometric contraction
   decrease due the downward pulling of AV valve during ventricular rapid ejection
3. **“x” descent**:
   decrease due continued pulling of AV valve during ventricular reduced ejection
4. **“v” wave (atrial diastole):**
   Increase due to venous return
   decrease due to blood entry into the ventricles during rapid filling phase
5. **“y” descent:**
   Decrease due to continued blood flow during reduced filling phase.




**In Jugular venous pulse(JVP), the same waves can be seen but are delayed**

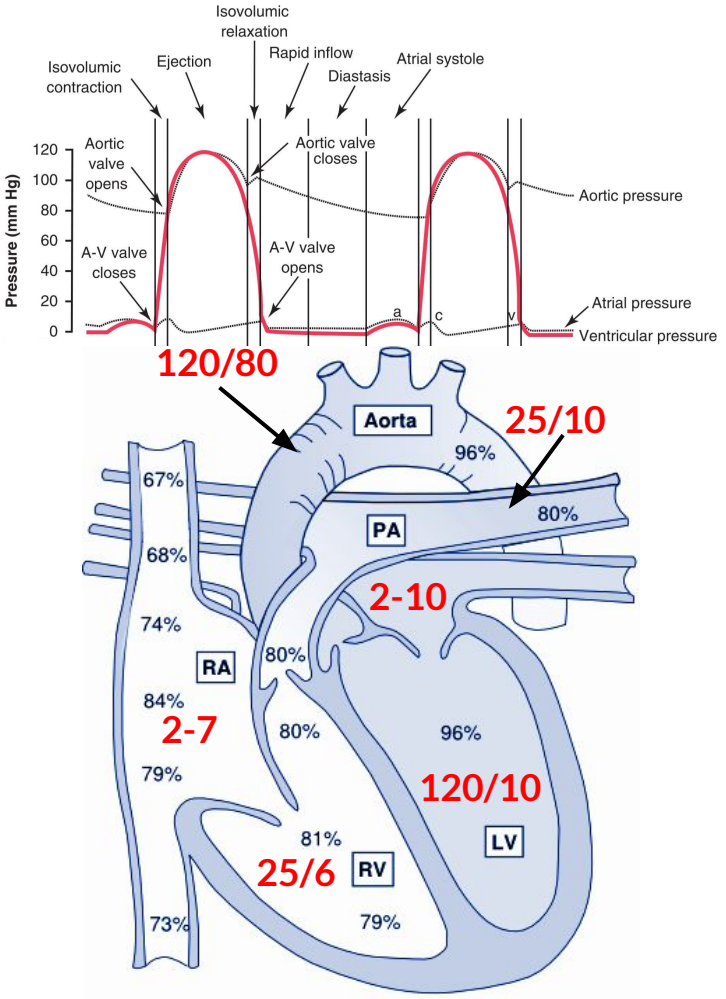
# Volume changes




| # | Phases | Ventricular Volume | Atria Volume |
|---|---|---|---|
| 1 | **Isometric Contraction** | Constant (EDV) | Increase |
| 2 | **Rapid Ejection** | Decrease rapidly | Increase |
| 3 | **Reduced Ejection** | Decrease slowly | Increase |
| 4 | **Isometric Relaxation** | Constant (ESV) | Increase |
| 5 | **Rapid Filling** | Increase rapidly | Decrease |
| 6 | **Reduced Filling** | Increase slightly | Decrease |
| 7 | **Atrial Systole** | Increase moderately | Decrease |

# Pressure changes

| # | Phases | Ventricular Pressure |
|---|---|---|
| 1 | **Isovolumetric Contraction** | Increase suddenly (80mmHg) |
| 2 | **Rapid Ejection** | Increase rapidly (120mmHg) |
| 3 | **Reduced Ejection** | Decrease slowly |
| 4 | **Isovolumetric Relaxation** | Decrease rapidly |
| 5 | **Rapid Filling** | Increase slightly |
| 6 | **Reduced Filling** | Increase gradually |
| 7 | **Atrial Systole** | Increase slightly then decrease |

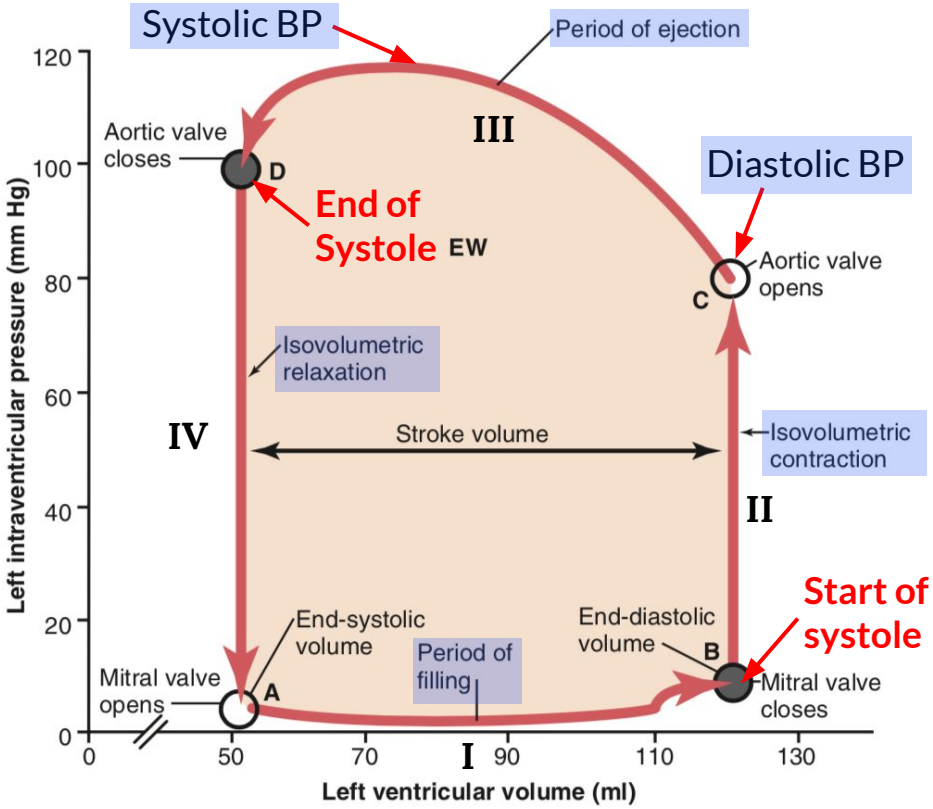



Different pressures in the chambers of the heart

# Ventricular-Pressure Volume Loop

| | |
|---|---|
| **Phase I (filling phase) (A-B)** | **Pressure:** 2-3 mmHg<br>**Volume:** rises to EDV=120 ml<br>**Valves**:<br>A- mitral valve opens<br>B- mitral valve closes |
| **Phase II (Isovolumetric contraction) (B-C)** | **Pressure:** rises to 80 mmHg<br>**Volume:** EDV, remains constant<br>**Valves:**<br>B- all closed<br>C- Aortic valve opens |
| **Phase III (Ejection phase) (C-D)** | **Pressure:** rises from 80 to 120 mmHg.<br>**Volume:** drops to ESV= 50 ml<br>**Valves:**<br>C-aortic valve stays open<br>D-Aortic valve closes |
| **Phase IV (Isovolumic relaxation) (D-A)** | **Pressure:** drops to 2-3 mmhg<br>**Volume:** ESV, remains constant<br>**Valves:**<br>D- Aortic valve stays closed<br>A- Mitral valve opens |

For further explanation Click here



# Ventricular-Pressure Volume Loop

## Importance:

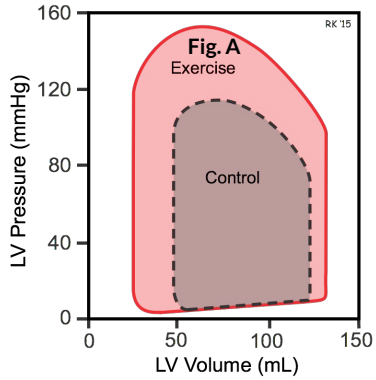
1. calculating cardiac work output.
2. "EW" represents the net external work output of the ventricle during cardiac cycle.

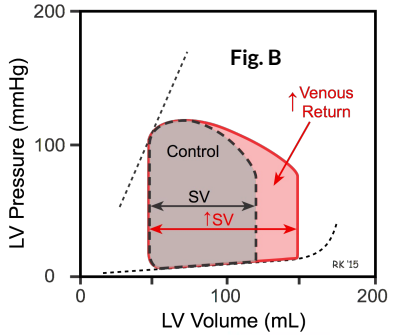
## Changes to PV loop:

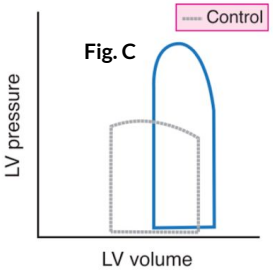
- An <u>increase</u> in **Contractility** (Figure A) as seen during **exercise**.

- An <u>Increase</u> in **preload** (Figure B) correlates with more venous return, which will increase the stroke volume, as shown by the increased width of the graph.
  - **Preload:** the degree of tension on the muscle when it begins to contract (end-diastolic pressure)

- An <u>increase</u> in **afterload** (Figure C) means there is an increase in aortic pressure and a decrease in stroke volume (high pressure, less blood gets pumped out). as shown by the increased height of the graph. This can be seen in **aortic stenosis**.
  - **Afterload:** Arterial pressure against which the ventricle exerts its contractile force.

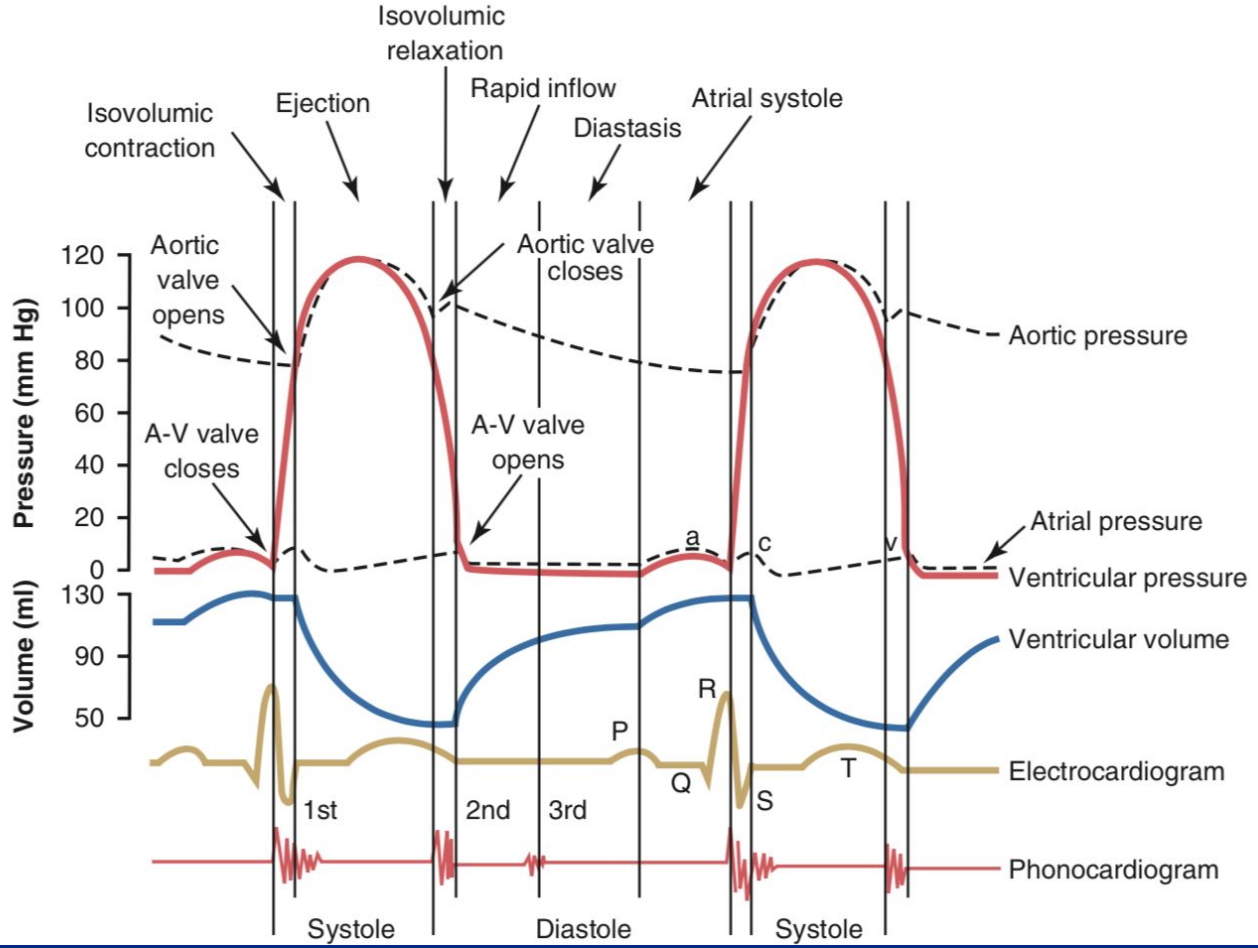



will be discussed in detail in future lectures

# Summary


Isovolumic relaxation
Isovolumic contraction
Ejection
Rapid inflow
Diastasis
Atrial systole
Aortic valve opens
Aortic valve closes
A-V valve closes
A-V valve opens
Pressure (mm Hg)
120
100
80
60
40
20
0
Volume (ml)
130
90
50
a
c
v
Aortic pressure
Atrial pressure
Ventricular pressure
Ventricular volume
R
P
Q
S
T
Electrocardiogram
1st
2nd
3rd
Phonocardiogram
Systole
Diastole
Systole

# Quiz

1. Venous return increases atrial pressure in which of the following waves?

**A.** C wave
**B.** A wave
**C.** V wave
**D.** Y wave

2. Calculate the ejection fraction if EDV is 135 ml and ESV is 65.

**A.** 52%
**B.** 48%
**C.** 65%
**D.** 55%

3. The closure of the mitral and tricuspid valves causes which of the following sounds?

**A.** S1
**B.** S2
**C.** S3
**D.** S4

4. The average diastolic pressure in the left ventricle is?

**A.** 80 mmHg
**B.** 25 mmHg
**C.** 10 mmHg
**D.** 120 mmHg

5. Which of the following valves is stimulated during the ejection phase?

**A.** Mitral valve
**B.** Aortic valve
**C.** Tricuspid
**D.** Pulmonary

SAQ:

1- Explain the effects of increased Afterload on the PV loop

Increased aortic pressure, leads to decreased stroke volume because less blood is getting pumped out. Fig c

2- Enumerate the different phases of the aortic pressure curve.



Answers: C - A - A - C - B

# Leaders

**Sedra Elsirawani** **Abdulrahman Alhawas**

# Members

- Lama AlZamil
- Arwa AlEmam
- Noura AlTurki
- Ghada AlSadhan
- Nouf AlShammari
- Nouf AlHumaidhi
- Taibah AlZaid
- Ajeed AlRashoud
- Reem AlGarni
- Raghad AlKhashan
- Leen AlMazroa
- Nouran Arnous
- Maha AlNahdi
- Badr Almuhanna
- Abdulrahman Almezaini
- Omar Aldosari
- Omar Alghadir
- Ibrahim Alshaqrawi
- Abdullah Aldawood
- Abdullah Shadid
- Meshari Alzeer
- Mohammed Alhamad
- Abdullah Alassaf
- Khalid Alkhani
- Amjad Albaroudi
- **Mohammed Alhuqbani**