Doctor.021

no. 8

CVS PHYSIOLOGY

Writer: Layan Al-Zoubi

Corrector: Toleen Haddad

Doctor: Yanal Shafagof

Mechanical cardiac physiology

- The function of the heart is to eject blood; it ejects 5L/m at rest, 10L/m during mild exercise, 15L/m during moderate exercise and 20L/m during severe exercise.

Cardiac cycle

- Cardiac cycle refers to all events associated with blood flow through the heart: Systole- contraction of heart muscle and Diastole- relaxation of heart muscle.
- When talking about the cardiac cycle, we're referring to the:

Systole	Diastole
• 0.3 seconds • 3 phases • ejection part of the cycle	• 0.5 seconds • 4 phases • refilling part

So, the cardiac cycle has 7 phases in total.

- These phases work the same in both sides of the heart, but you'll find a difference in numbers.

  Let's talk about the left side of the heart:
- During diastole, the pressure in the left atrium is 5 mmHg and in the left ventricle is 0 mmHg which means that the mitral valve is open (blood moves from the chamber of higher pressure to the one of lower pressure), but the aortic valve is closed since the pressure in the aorta is 80 mmHg.
- During systole, the pressure in the left ventricle becomes 6 mmHg. This pressure is enough to close the mitral valve but inadequate to open the aortic valve.
- The end diastolic volume in the left ventricle is 120 ml.
  - End diastolic volume (pre-systolic volume) is the volume of blood at the end of the diastolic phase.
- At beginning of the systole, the mitral valve is closed, and the contraction starts, but the pressure in the ventricle (6-80mmHg) still

hasn't exceeded the one in the aorta so the aortic valve remains closed as well; this phase is called the isovolumic contraction phase and it lasts 0.05 sec.

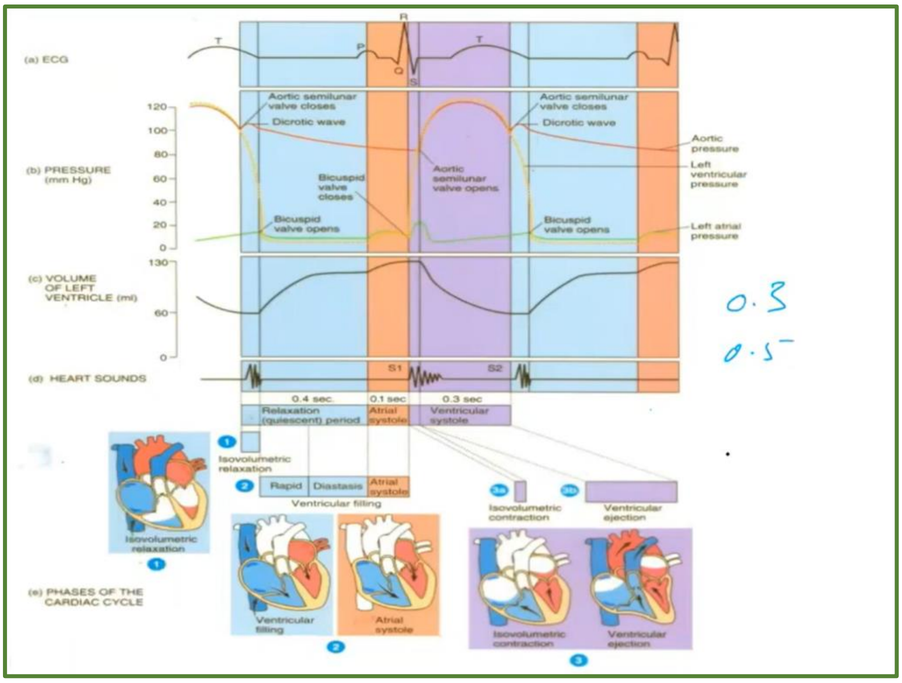
- The ventricle is a closed chamber during this phase (nothing comes in or goes out); so, when it contracts the volume of the chamber decreases and accordingly the pressure increases (P*V = constant).
    - **Further clarification**: Isovolumic = the volume of blood inside the ventricle is constant, but that doesn't mean that the volume of the ventricular chamber is constant, it gets smaller upon contraction and thus increases the pressure just for a brief period (0.01 sec) before the valve opens and the ejection occurs. Otherwise, PV wouldn't equal a constant if only the pressure increased, and the volume of the chamber remained constant! Makes sense now?

- After the isovolumic phase, the aortic valve opens allowing blood to be ejected into the aorta.
- The ejection of blood causes the pressure in the aorta to increase.
    - The pressure equals the force divided by the area (P= F/A); the force comes mainly from the blood volume in the aorta. The aorta has two ends: the blood enters from the ventricle and leaves to the periphery.

<u>But this is not what normally happens in our bodies.</u>

- When the blood is ejected out of the ventricle, the aortic pressure increases that it becomes -theoretically- higher than the ventricular pressure which puts more load on the ventricle (to increase its force of contraction), but because the aortic wall is highly elastic (its wall is composed of elastic fibers rather than smooth muscle cells) which allows it to increase its area whenever blood comes in thus preventing the pressure from reaching 180mmHg instead of 120 mmHg.

- The pressure in the aorta during diastole is 80 mmHg and during systole is 120 mmHg.
- The mean pressure doesn't equal 80+120/2 because the diastole (0.5 sec) takes more time than systole (0.3 sec); we calculate it as 2/3 diastolic pressure+ 1/3 systolic pressure.
  - This is how we calculate the mean pressure at rest, in the case of tachycardia for instance, the mean pressure becomes closer to the systolic pressure.
- The pulse pressure equals the systolic pressure – the diastolic pressure.
  - Normally and at rest, PP equals 40mmHg. However, when there is no elasticity (arteriosclerosis for example), it becomes 100 mmHg.



- Notice how they're representing the heart sounds, the volume, the pressure and the ECG in the figure.
- When the mitral valve closes, we hear a sound and we call it S1.

- Diastole or systole always refer to the ventricular relaxation or contraction, respectively. However, when talking about the atrial contraction or relaxation we say atrial systole/diastole.
- Now study the following thoroughly in parallel to the figure above, during diastole the pressure in the atrium is 5mmHg, when depolarization happens it increases to 8mmHg, the pressure in the ventricle is always less, and when the atrium squeezes blood into the ventricle, the ventricle's pressure certainly increases, this gives a wave called A wave (atrial contraction). The P wave should precede the A wave though because excitation comes before contraction, and they are coupled to each other. Along the QRS wave, the contraction of ventricle happens as well. When the pressure in the ventricle reaches 80mmHg, the semilunar valves open. Pressure in ventricle> atrium; therefore, mitral valve closes.
  Now, in case we're asked about the order of events in the exam:

1. **QRS**
2. **Closure of the AV valve**
3. **S1 (which is the first sound called lubb caused by the closure of AV valve)**

- The phase between the closure of the AV valve and the opening of the semilunar valve is called isovolumic contraction where the ventricle carries 120ml. Contraction occurs but volume is constant.
- Now, lets consider the A wave in relation to right atrium; if we increase the pressure in the RA, the pressure in the SVC will simultaneously increase as there is no valve between them, as well as in the neck jugular veins. So, in case you measure the pressure in the neck jugular veins, you will get this wave.
- We previously said that the end **diastolic** volume is 120/130 ml; the ventricle ejects about 70 ml which we call '**stroke volume**' and it

keeps around 60 ml- the remaining amount of blood 'End **systolic** volume'.

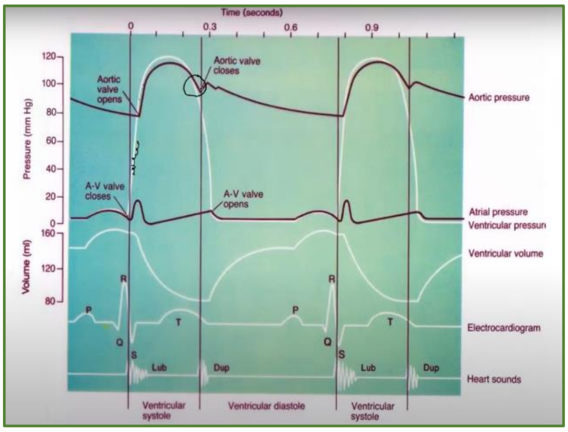
- From the previous points, we can calculate the ejection fraction, which is the amount of blood that your heart pumps each time it beats. Ejection fraction is measured as a percentage of the total amount of blood in your heart that is pumped out with each heartbeat. So, for the previous numbers the EF = (70/130) × 100% = 54%
- Normal values of EF are 50% or higher.
- EF (ejection fraction) can be used as a tool to classify different stages of heart failure; it is also relevant in surgical scenarios→ if the EF is low, anaesthesia carries a severe risk to the patient.
- To calculate the ejection fraction, we use the following formula:

$$E_f = \frac{SV}{EDV} = \frac{EDV - ESV}{EDV}$$

Where,
E_f = Ejection fraction
SV = Stroke volume
EDV = End-diastolic volume
ESV = End-systolic volume.

- When the ventricular contraction begins, the AV valve will be pushed towards the atrium - the presence of papillary muscles prevents the complete eversion of the valve and the backflow of blood- and makes the atrium smaller thus increasing the pressure inside giving us the 'C' wave. 'C' is due to the bulging of cusps in the atrium or the contraction of ventricles.
- After the 'C' wave, there is an ascending line that occurs during venous return and then we get another wave called the 'V' wave. When this pressure reaches a point where it is higher than the ventricular pressure, the AV valve opens. As the atrium empties its content into the ventricle, the pressure in it declines.
- If someone has mitral stenosis, the atrium becomes overloaded as it exerts more force, and the 'A' wave will be more elevated than normal- becomes kind of as shown in green.

- If HR =100, end diastolic volume = 180 ml, end systolic vol. = 20 ml, what is the ejection fraction?
  - Ejection fraction= 160/180%=~ 90%.
- If the End diastolic volume = 125 ml, end systolic volume = 55 ml, ejection volume (stroke volume) = 70 ml then what is the ejection fraction?
  - Ejection fraction = 70ml/125ml = 56% (normally 60%)
- The opening of the valves doesn’t result in any sound, only the closure does.
- As we previously said, the ventricular pressure must remain higher than the aortic pressure for the blood to flow, but in the last systolic phase, the aortic pressure becomes slightly higher and unexpectedly the blood flow doesn’t stop; this is referred to the momentum of blood.



- The white lines in this figure represent everything related to the ventricles, notice how the pressure in the ventricle remains higher than in the aorta until we reach near the time of aortic valve closure, it becomes lower.
- The pressure in the ventricle is less than the aortic pressure so the aortic valve is closed, the ventricle’s pressure is also greater than that of the atria therefore, the AV valve is also closed. This phase is called the isovolumic relaxation phase. Look at the ventricular volume graph, the volume is almost constant for a while after systole.
- When ventricular pressure becomes lower than the atrial, the AV valves open and this is silent.
- Between S1 and S2 (aortic valve closure), we have ventricular systole. But, between S2 and S1 there is ventricular diastole.
- To conclude all what has been said before:
  - Atrial systole 0.1 second
  - Atrial diastole 0.7 second

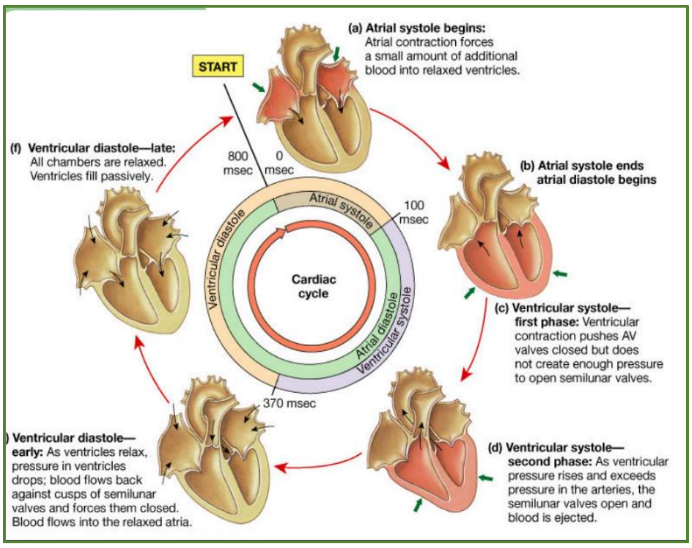
- Ventricular systole 0.3 second
  - Isovolumic contraction 0.01 seconds
  - Rapid ejection period
  - Slow ejection period
- Ventricular diastole 0.5 seconds
  - Isovolumic relaxation 0.02 seconds
  - Rapid filling
  - Slow filling (Diastasis)
  - Atrial contraction

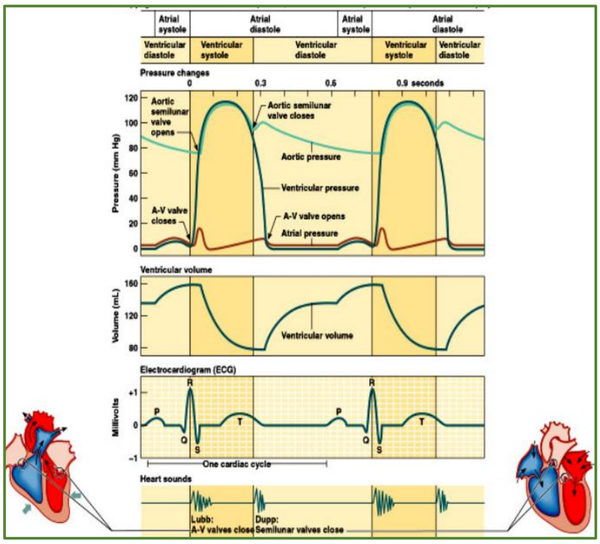
- End diastolic volume (EDV) – End systolic volume (ESV) = Stroke volume (SV)
- SV X heart rate (HR) = cardiac output (CO)
- Ejection fraction = SV/EDV
- Inotropic vs. Chronotropic
- Autonomic control of cardiac cycle (pump)
- Changes during Cardiac cycle:
  - Volume changes: End-diastolic volume, End-systolic volume, Stroke volume and Cardiac output.
  - Aortic pressure: Diastolic pressure ~80 mmHg, Systolic pressure ~ 120 mmHg, most of systole ventricular pressure higher than aortic.
  - Ventricular pressure: Diastolic ~ 0, systolic Lt. ~120, Rt. ~ 25 mmHg.
  - Atrial pressure: A wave =atrial systole, C wave= ventricular contraction (AV closure), V wave= ventricular diastole (Av opening).
  - Heart sounds: S1 = turbulence of blood around closed AV valves, S2 = turbulence of blood around closed semilunar valves.
- Phases of the Cardiac Cycle:
  - Ventricular filling – mid-to-late diastole.
    - Heart blood pressure is low as blood enters atria and flows into ventricles.
    - AV valves are open, then atrial systole occurs.
  - Ventricular systole.
    - Atria relax.
    - Rising ventricular pressure results in closing of AV valves.

- Isovolumic contraction phase.
- Ventricular ejection phase opens semilunar valves.

○ Isovolumic relaxation – early diastole.
  - Ventricles relax.
  - Backflow of blood in aorta and pulmonary trunk closes semilunar valves.

○ Dicrotic notch – brief rise in aortic pressure caused by backflow of blood rebounding off semilunar valves.





➢ Heart Sounds (lubb-dupp) are associated with closing of heart valves.

➢ Auscultation – listening to heart sound via stethoscope.

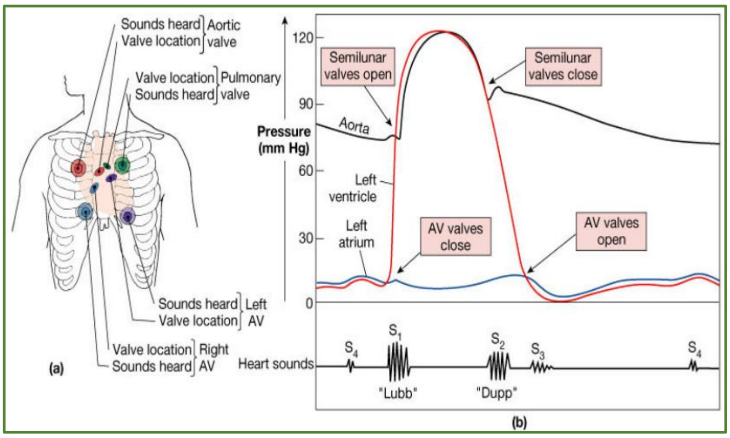
➢ Four heart sounds:

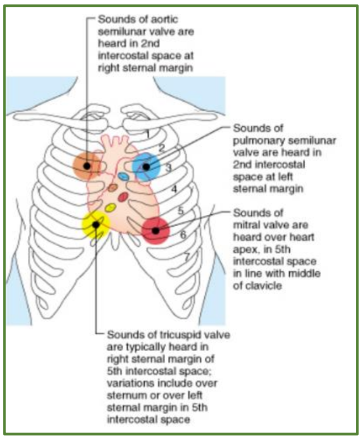
○ S1 – "lubb" caused by the closing of the AV valves.

○ S2 – "dupp" caused by the closing of the semilunar valves.

○ S3 – a faint sound associated with blood flowing into the ventricles.

○ S4 – another faint sound associated with atrial contraction.





- Valvular Function
  - To prevent back-flow.
  - Chordae tendineae are attached to A-V valves.
  - Papillary muscle, attached to chordae tendineae, contract during systole and help prevent back-flow.
  - Because of smaller opening, velocity through aortic and pulmonary valves exceed that through the A-V valves.
- Ventricular Pressure and Volume Curves
  - During the latter part of the ejection phase how can blood still leave the ventricle if pressure is higher in the aorta? Momentum of blood flow
  - Total energy of blood = $P + mV^2/2$ = pressure + kinetic energy
  - Total energy of blood leaving ventricle is greater than in aorta.

اللهم كن مع أهلنا في فلسطين وسوريا، اللهم ارحم ضعفهم وقلة حيلتهم... اللهم أصلحنا وأصلح بنا الأمة وأعِنّا على نصرتك.

V4

1- Page 3: further clarification about isovolumic contraction
2- Page 5: highlighted text
3- A few slides added at the end.