CVS
PHYSIOLOGY

Modified NO: 9

كتابة: أحمد مطارنة و ميس قشّوع

تدقيق: ميس العتيق

الدكتور: د فاطمة الريالات

Cardiovascular Physiology

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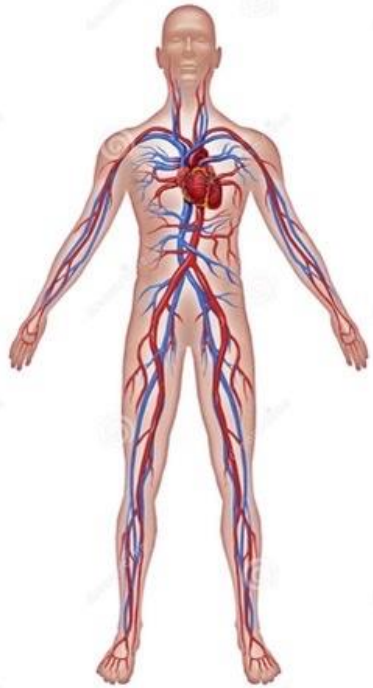

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- Slides
- Doctor
- Additional info
- Important

The undrlined text = what doctor mentioned from slides

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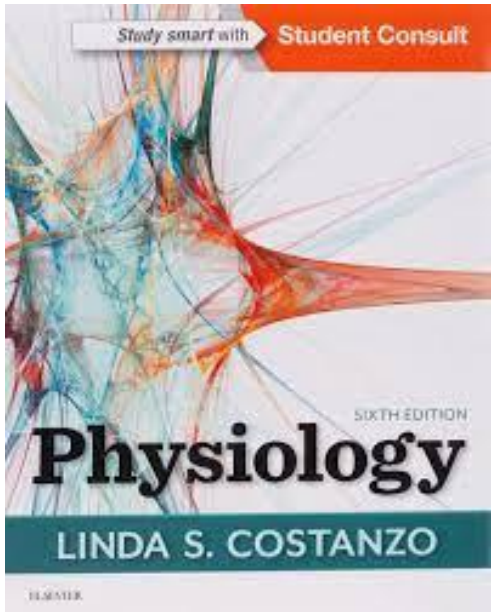
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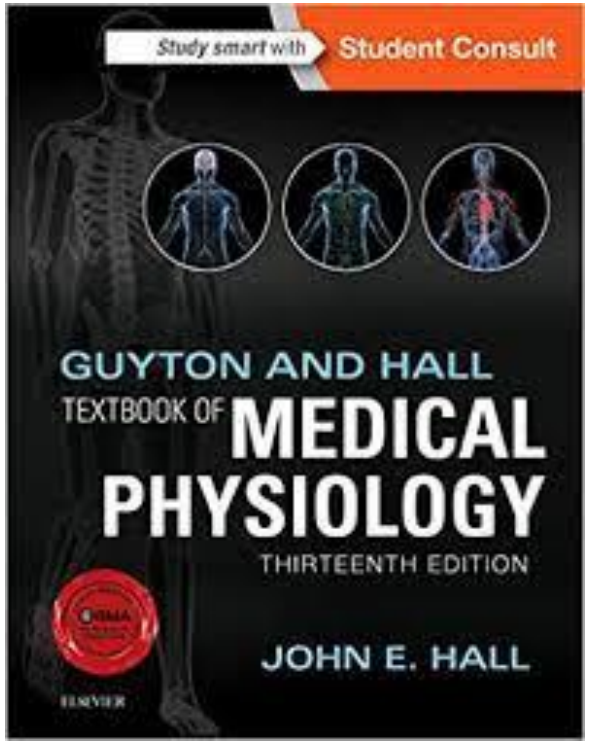
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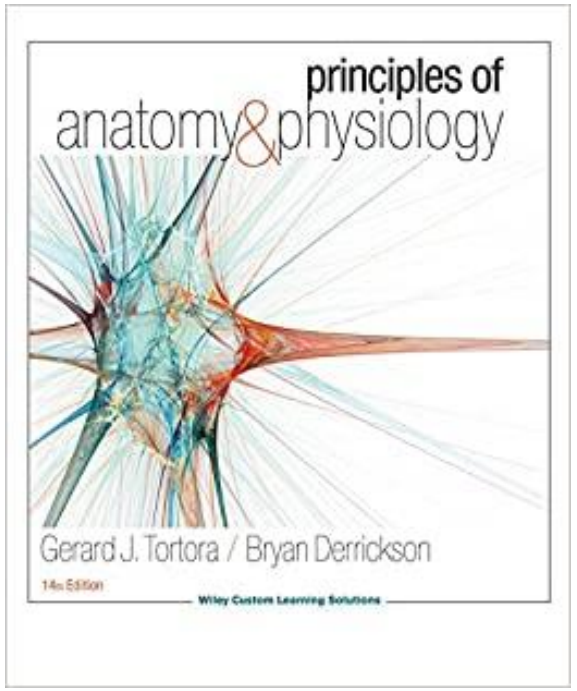
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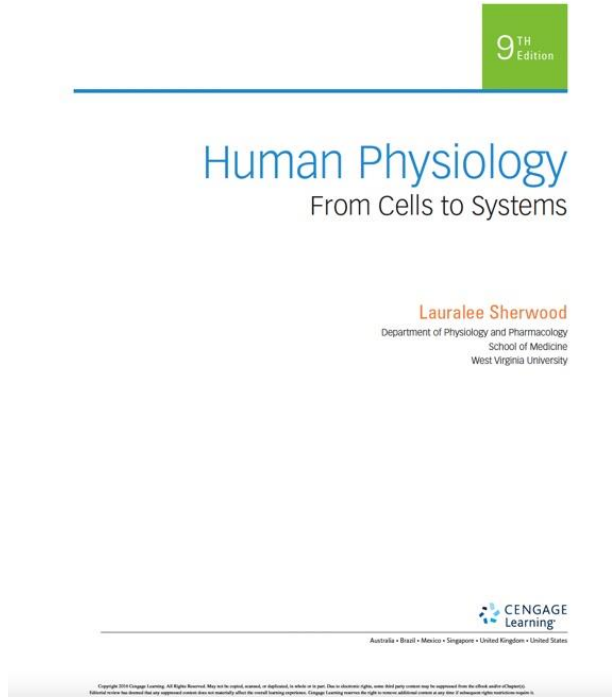
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Cardiac cycle

We talked about the electrical function of the heart, now we will talk about the translation of the electrical to mechanical function.

- Depolarization will lead to excitation contraction coupling.
- In repolarization the muscle will return to relaxation state.
- The heart consists of two pumps, we will talk about the left pump (what we talk about the left pump is also applicable to the right pump except the pressure differences).
- The pressure in the pulmonary circulation is less than in systemic circulation.
- Blood flow is one way; caused by the pressure differences between different compartment.
- No pressure difference no blood flow.
- In the cardiac cycle:
- The relaxation is called → diastole (relaxation and blood filling)
- The contraction called → systole (contraction and blood ejection)
- Normally, The atrial diastole and ventricular diastole may happen at the same time, however, it's impossible for the atrial systole and ventricular systole to happen at the same time.

Cardiac cycle basics of mechanical events

- Blood flow from area of higher pressure to lower pressure.
- Heart valves prevent backflow of blood.
- Times in which all valves (AV and aortic) are closed are called isovolumic (no blood flow so no change in volume) contraction or relaxation, but there will be changes in pressure.
- Electrical changes (depolarization and repolarization) precede mechanical changes (contraction and relaxation).

Cardiac cycle basics

- Graphs represent left side of the heart only.
- Same principles are applied to right side of the heart, except with lower pressures.

- There is continuous flow of blood from the venous side to the atria (no valves). Help in refilling the atria quickly

Cardiac cycle basics

- The cardiac cycle consists of alternate periods of systole (contraction and emptying) and diastole (relaxation and filling).
- Contraction results from the spread of excitation across the heart, whereas relaxation follows the subsequent repolarization of the cardiac muscle.
- The atria and ventricles go through separate cycles of systole and diastole.

Cardiac cycle basics

- Cardiac cycle is the reciprocal to the heart rate.
- If heart rate increases, cardiac cycle shortens.

(Diastolic phase will be more affected than the systolic.)

- Diastolic phase will be shortened mainly

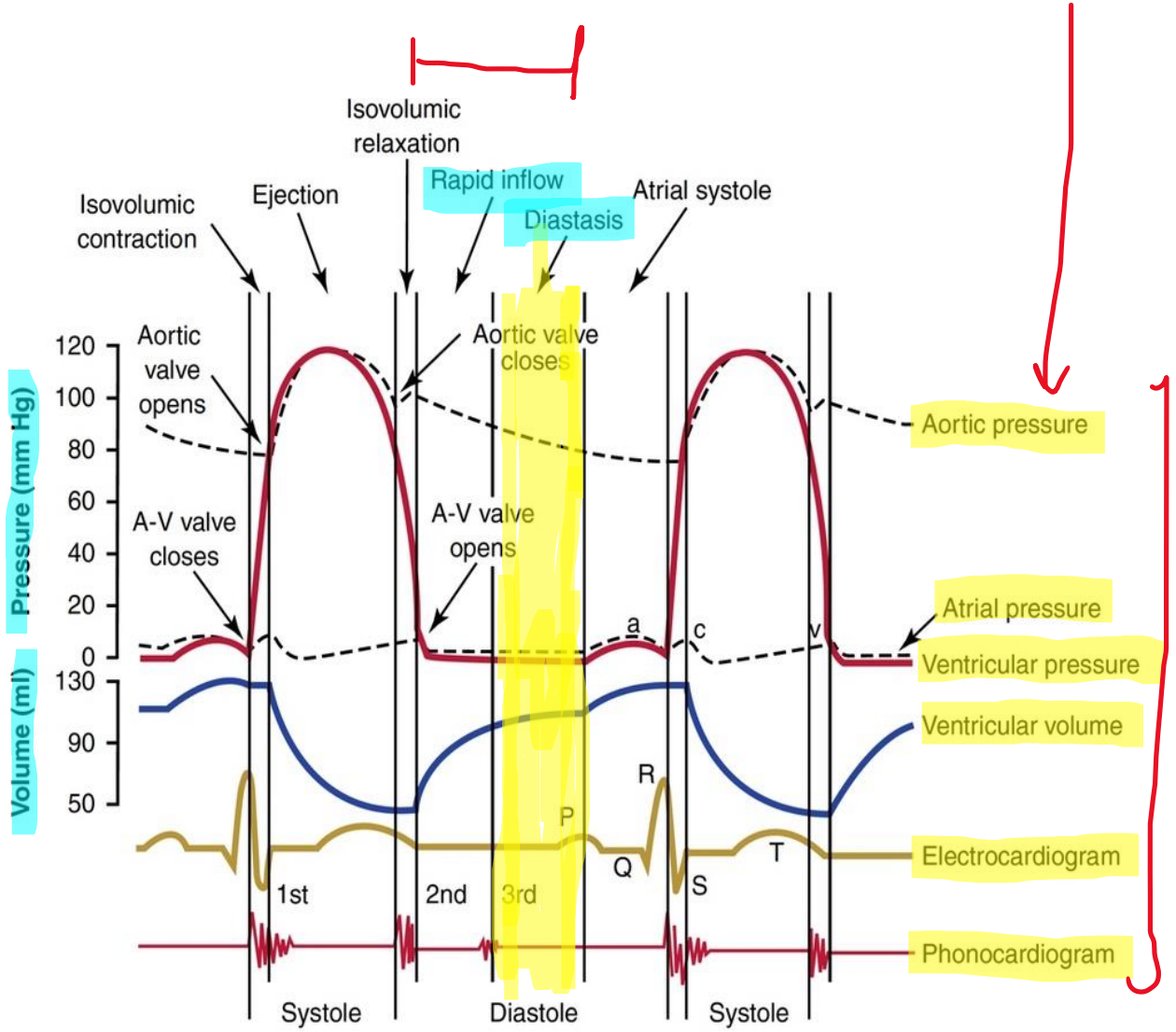
1.Mid ventricular diastole

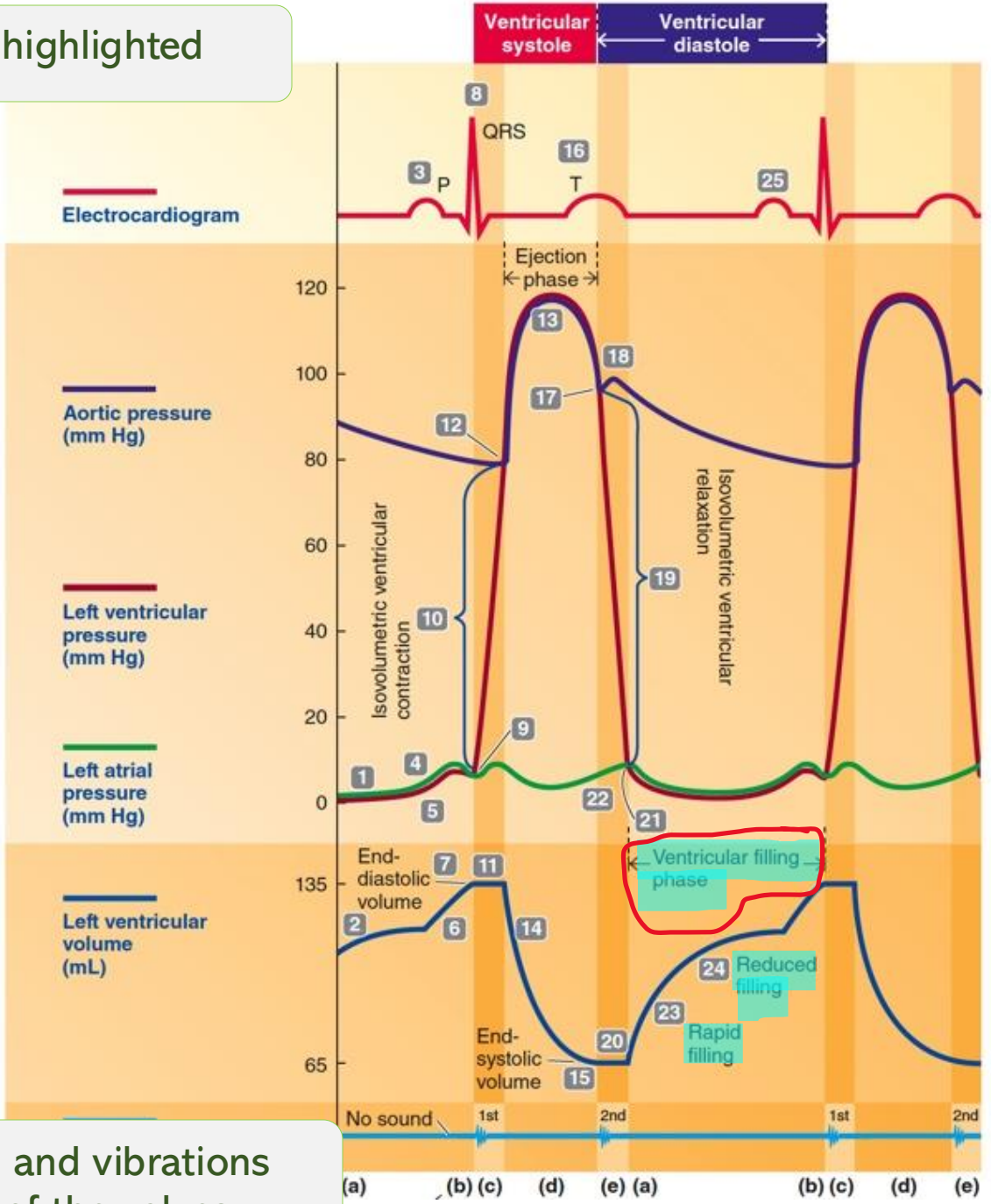
- ECG: T-P segment.
- Atrium and ventricle are relaxing (diastole).
- Pressure in both chambers is low.
- Because of the continuous blood flow from the veins into the atrium, atrial pressure slightly exceeds ventricular pressure. Therefore, AV valve (mitral) is open, and blood flows from the atrium to the ventricle (passive filling).
  - Passive → no contraction in the atria
- Ventricular volume slowly rises (diastasis or reduced ventricular filling).
  - The fast-filling phase, is another separate phase before the diastasis phase that we are talking about in this slide pay attention😉
- Long phase, affected by increased heart rate the most. (If heart rate increases, cardiac cycle shortens.)

There are two graphs in the next slides that's are the same (from different sources), with minor differences (don't pay attention to it)

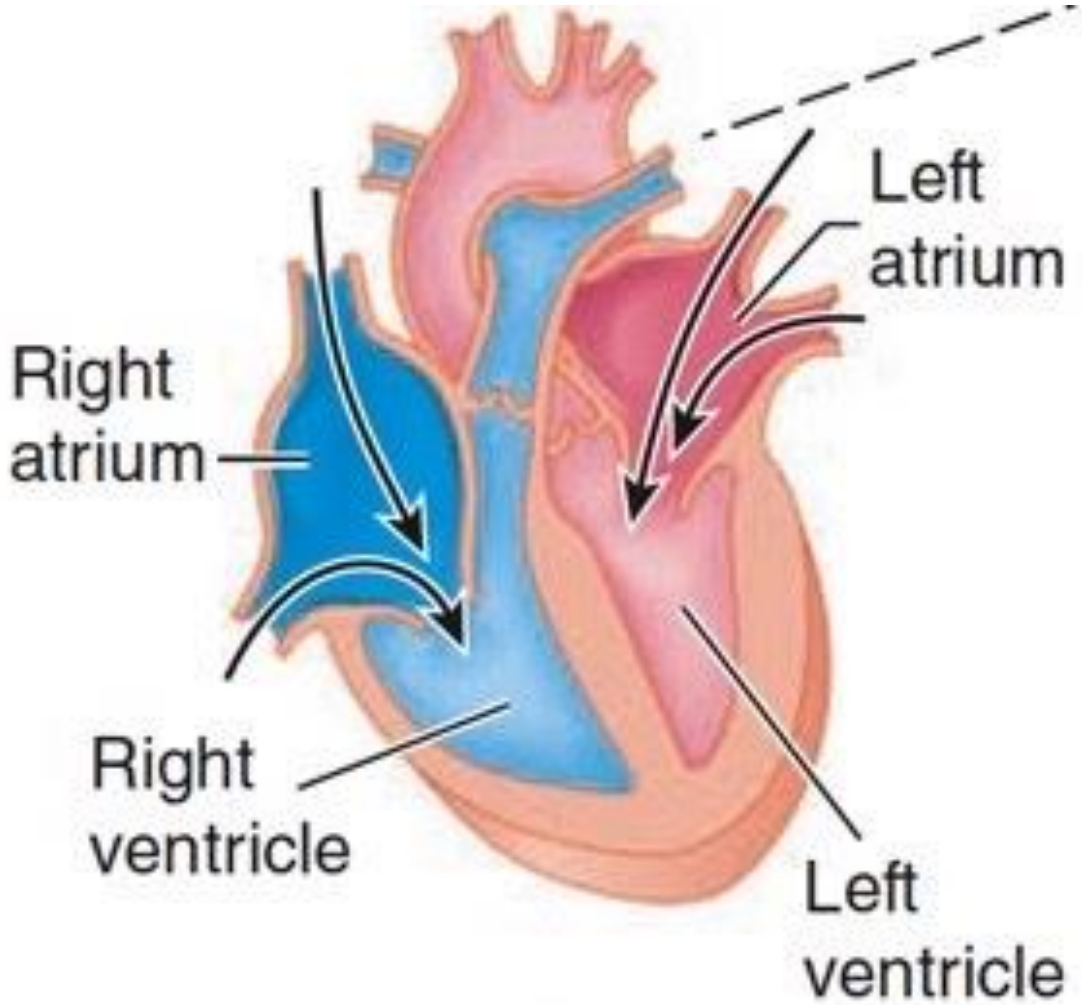
T-P segment

Pay attention to changes in the highlighted





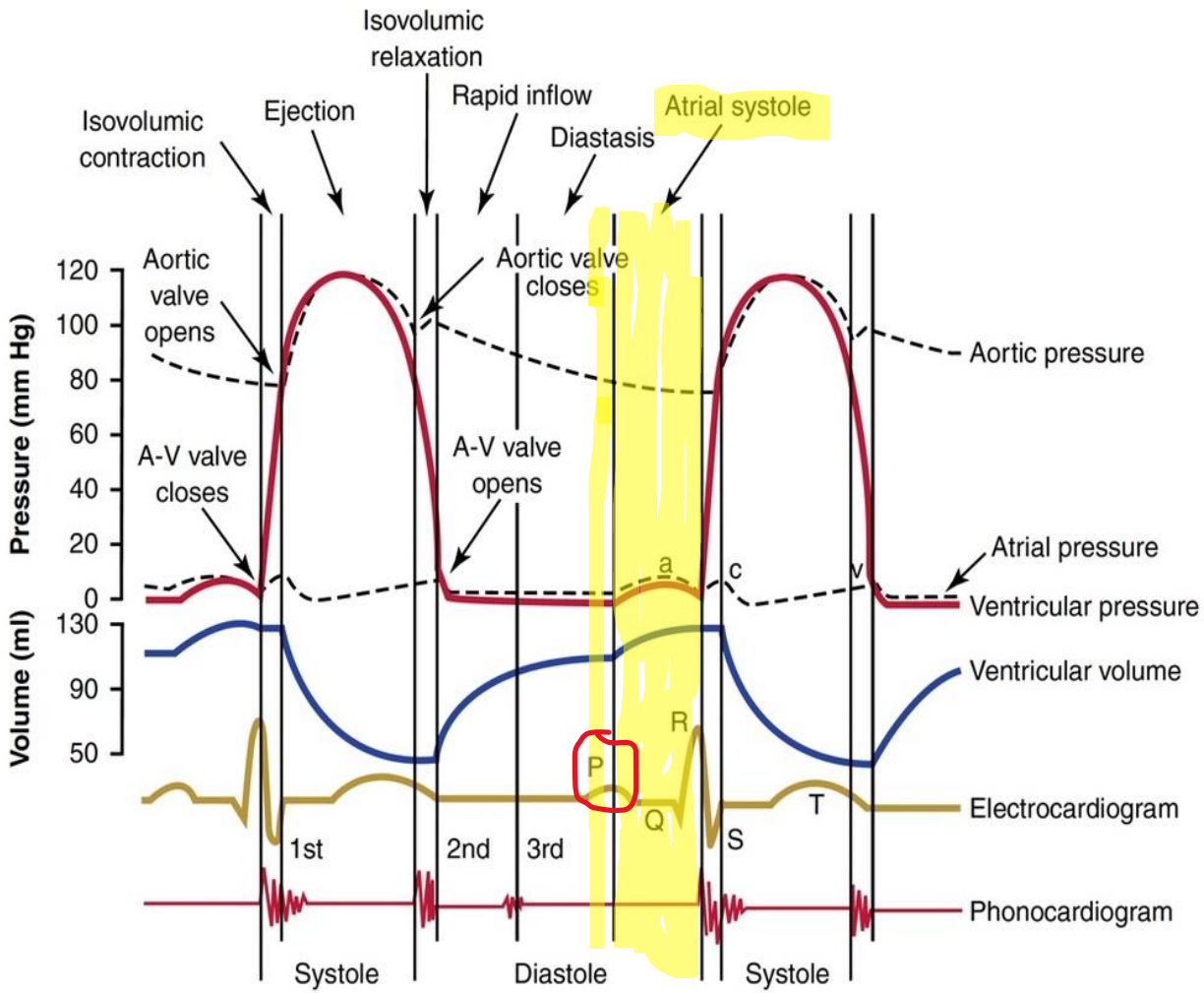
phonocardiogram (PCG) is a graphical representation of the sounds and vibrations produced by the heart during its activity. Heard during the closure of the valves



(a) Passive filling during ventricular and atrial diastole

2.Atrial systole

- ECG: P wave.(atrial depolarization)
- SA node initiates a new cycle, atrial depolarization leads to atrial contraction.
- Atrial pressure increases, blood is pumped from atrium to the ventricle. (active filling)
- Pressure in the ventricle starts to increase (because of increased blood volume) but still below the atrium (because of the contraction its increase more than the ventricles), therefore, AV valve is still open.
- The flow here is slow
- Ventricles are still in diastole phase (relaxed)


Isovolumic relaxation
Ejection
Rapid inflow
Isovolumic contraction
Diastasis
Atrial systole
Aortic valve opens
Aortic valve closes
A-V valve closes
A-V valve opens
Pressure (mm Hg)
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Volume (ml)
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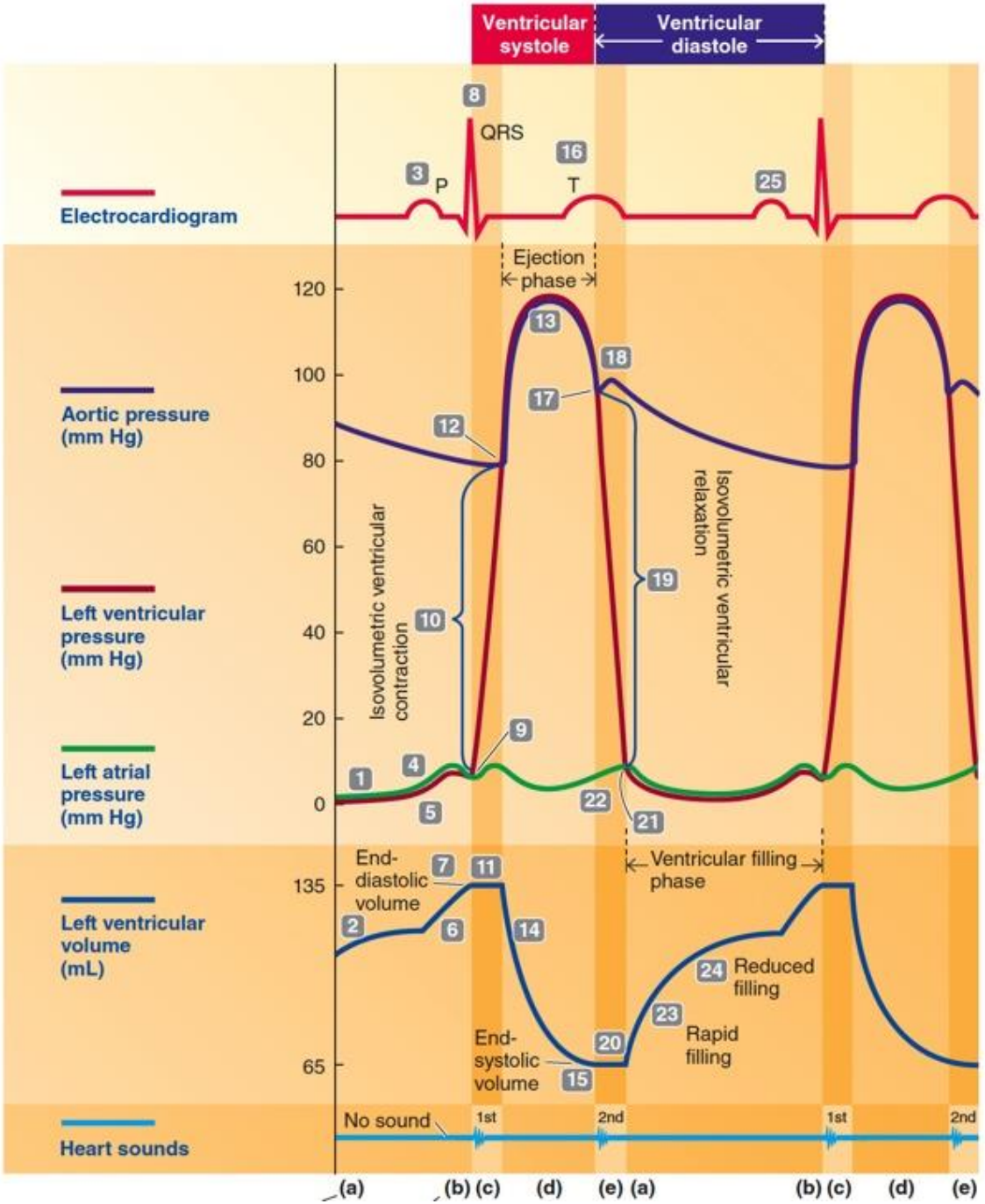
Diastole
Systole


Ventricular systole
Ventricular diastole
Electrocardiogram
QRS
P
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Ejection phase
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Left ventricular pressure (mm Hg)
Isovolumetric ventricular contraction
Isovolumetric ventricular relaxation
Left atrial pressure (mm Hg)
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Left ventricular volume (mL)
End-diastolic volume
Ventricular filling phase
End-systolic volume
Reduced filling
Rapid filling
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Heart sounds
No sound
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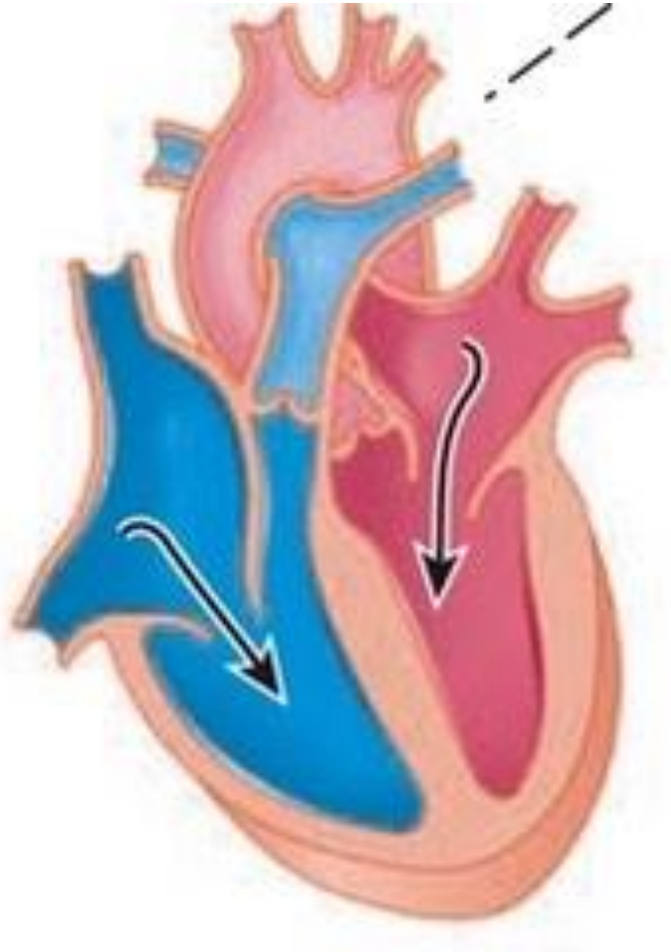
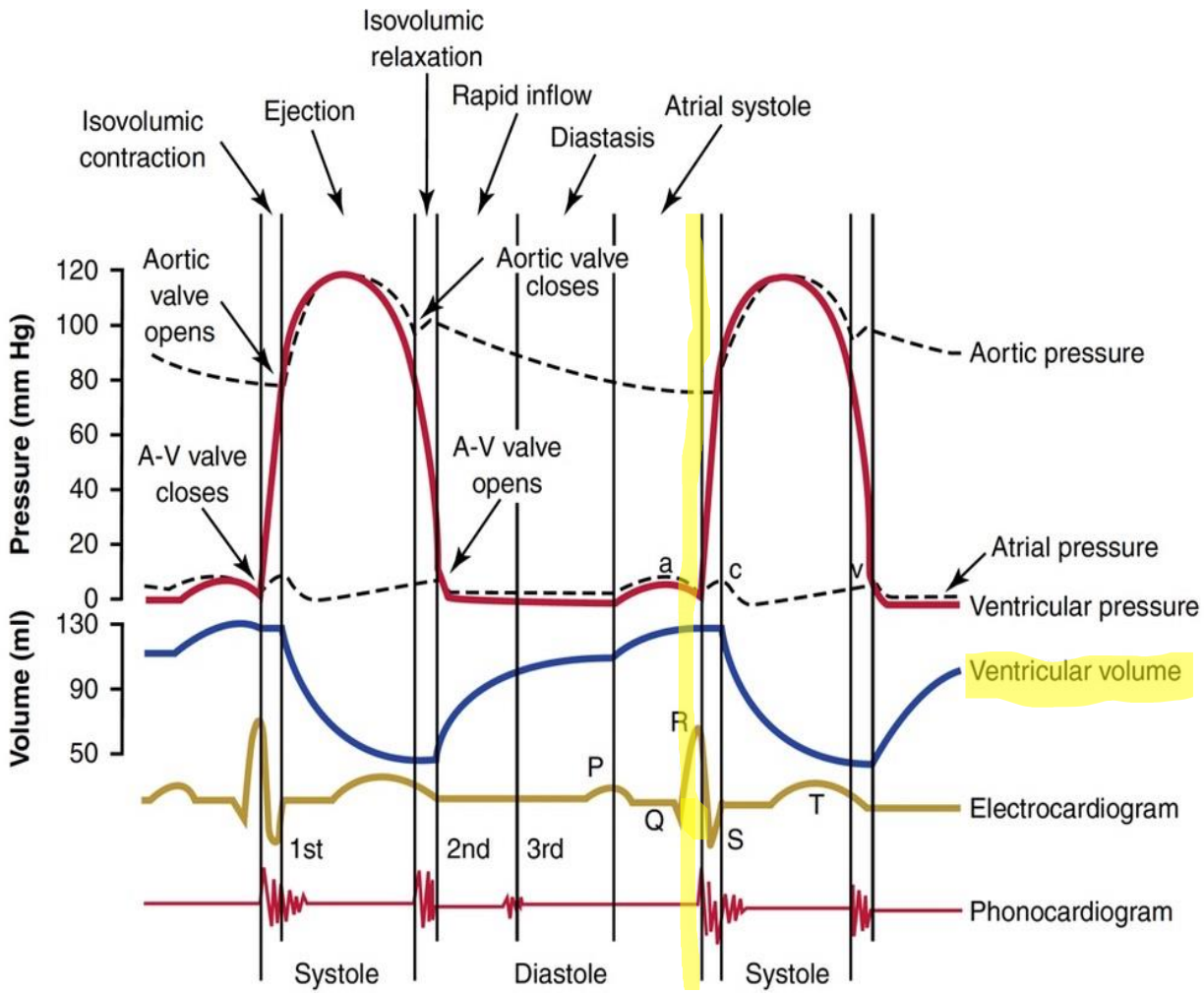


(b) Atrial contraction

3.End of ventricular diastole

- Ventricular diastole ends at the onset of ventricular contraction.
- By this time, atrial contraction and ventricular filling are completed.
- The volume of blood in the ventricle at the end of diastole is known as the end-diastolic volume (EDV), which averages about 135 mL.
- No more blood is added to the ventricle during this cycle.
- Therefore, the end-diastolic volume is the maximum amount of blood that the ventricle contains during this cycle.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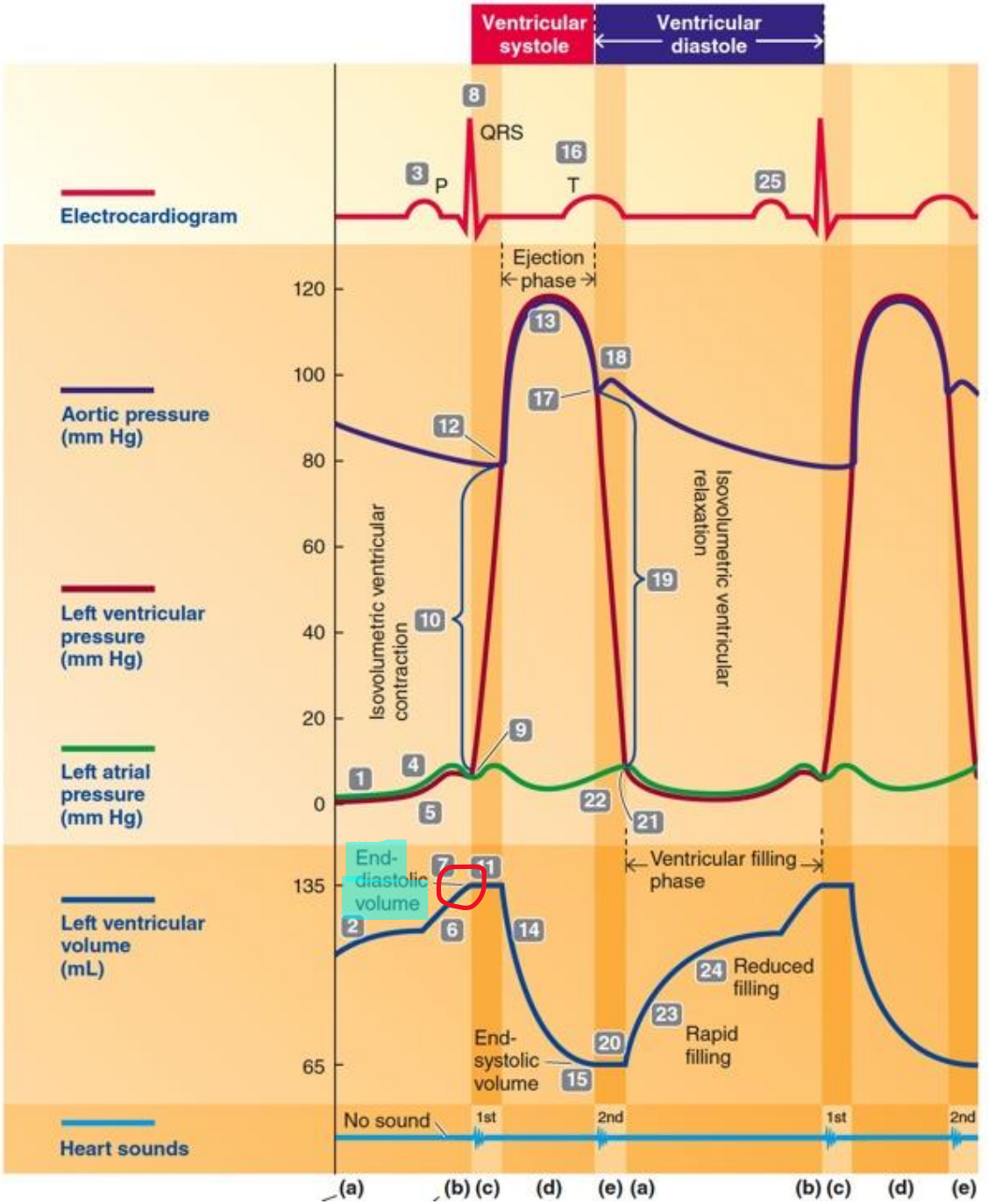
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Ventricular filling phase
Left ventricular volume (mL)
135
65
End-systolic volume
Reduced filling
Rapid filling
Heart sounds
No sound
1st
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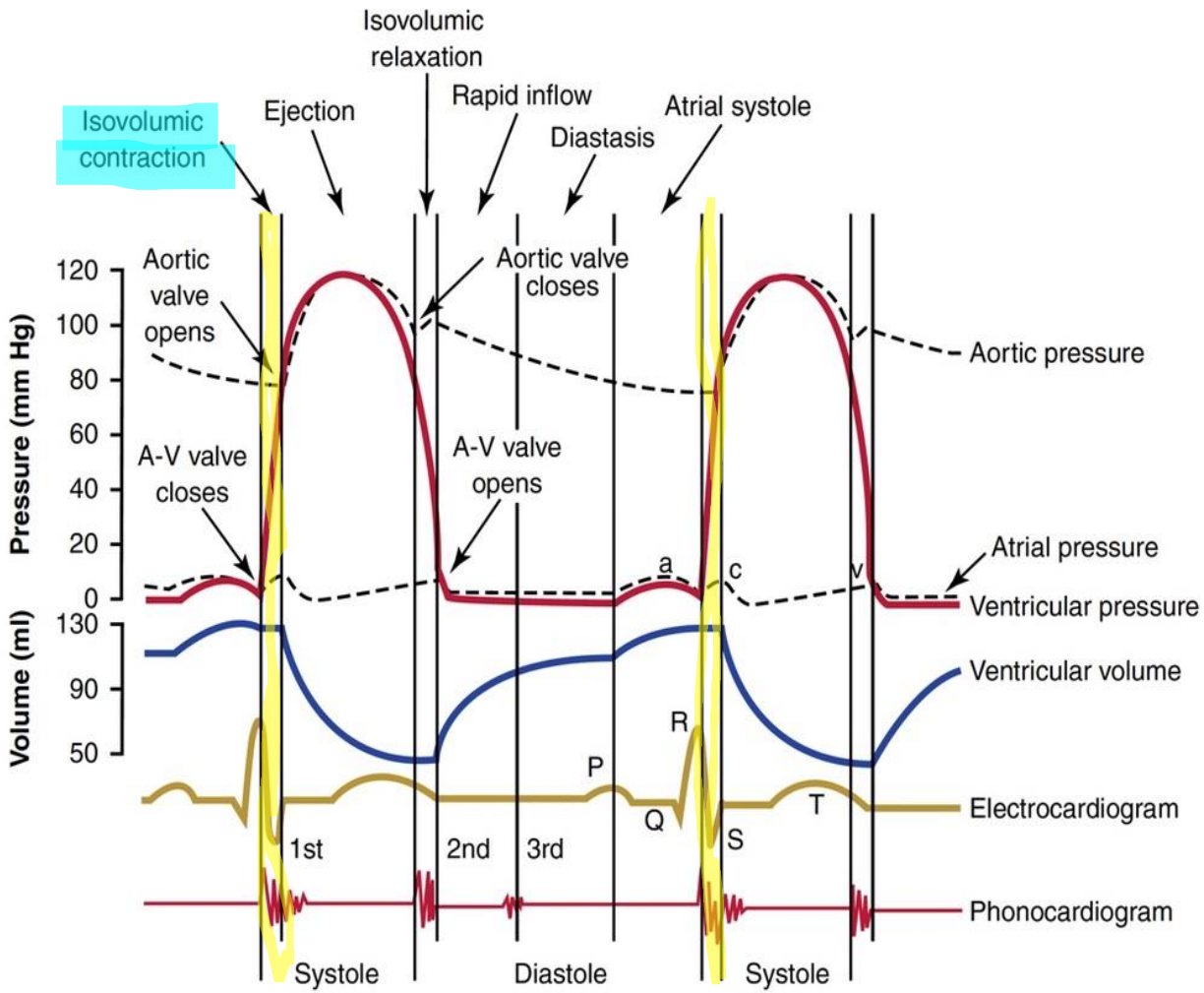
4.Onset of ventricular systole (atrial diastole)

- After atrial excitation, the impulse travels through the AV node and specialized conduction system to excite the ventricle. Simultaneously, the atria are contracting.
- By the time ventricular activation is complete, atrial contraction is already over.
- QRS complex begins slightly before the onset of ventricular systole.
- The ventricular pressure curve sharply increases shortly after the QRS complex, signaling the onset of ventricular systole.
- As ventricular contraction begins, ventricular pressure immediately exceeds atrial pressure.
- These two events happen together contributing to closure of AV valve:
    1. QRS → ventricular depolarization → contraction → increase the pressure sharply
    2. Atrial repolarization → atrial relaxation → decrease in atrial pressure
- This backward pressure differential forces the AV valve closed.
- AV valve closure is primarily a passive process caused by pressure changes during the cardiac cycle.
- Papillary muscles and chordae tendineae play a supportive role in ensuring proper valve function and preventing prolapse(bulging of a heart valve leaflet back into the atrium) during ventricular systole.

Isovolumic ventricular contraction

- All valves are closed.
- Ventricular pressure higher than atrial pressure → AV valve closed
- Ventricular pressure lower than aortic pressure → aortic valve closed
- The closure of the AV valve will cause vibration, heard using the stethoscope, and translated to sound wave (named **S1)** appear in phonocardiogram.
- S1 represents the beginning of ventricular systole or the end of atrial systole (AV valve is closed)
- No blood flow, so isovolumic.
- Isometric contraction.
- Isometric contraction refers to a type of muscle contraction in which the muscle generates force without changing its length. This occurs when the muscle exerts tension but does not shorten or lengthen
- Usually muscles start with isometric contraction, build tension, then change to isotonic contraction (Muscle changes length while generating force)
- Ventricular pressure continues to increase (the muscle is contracting with no change in volume the pressure will increase rapidly) to exceed aortic pressure.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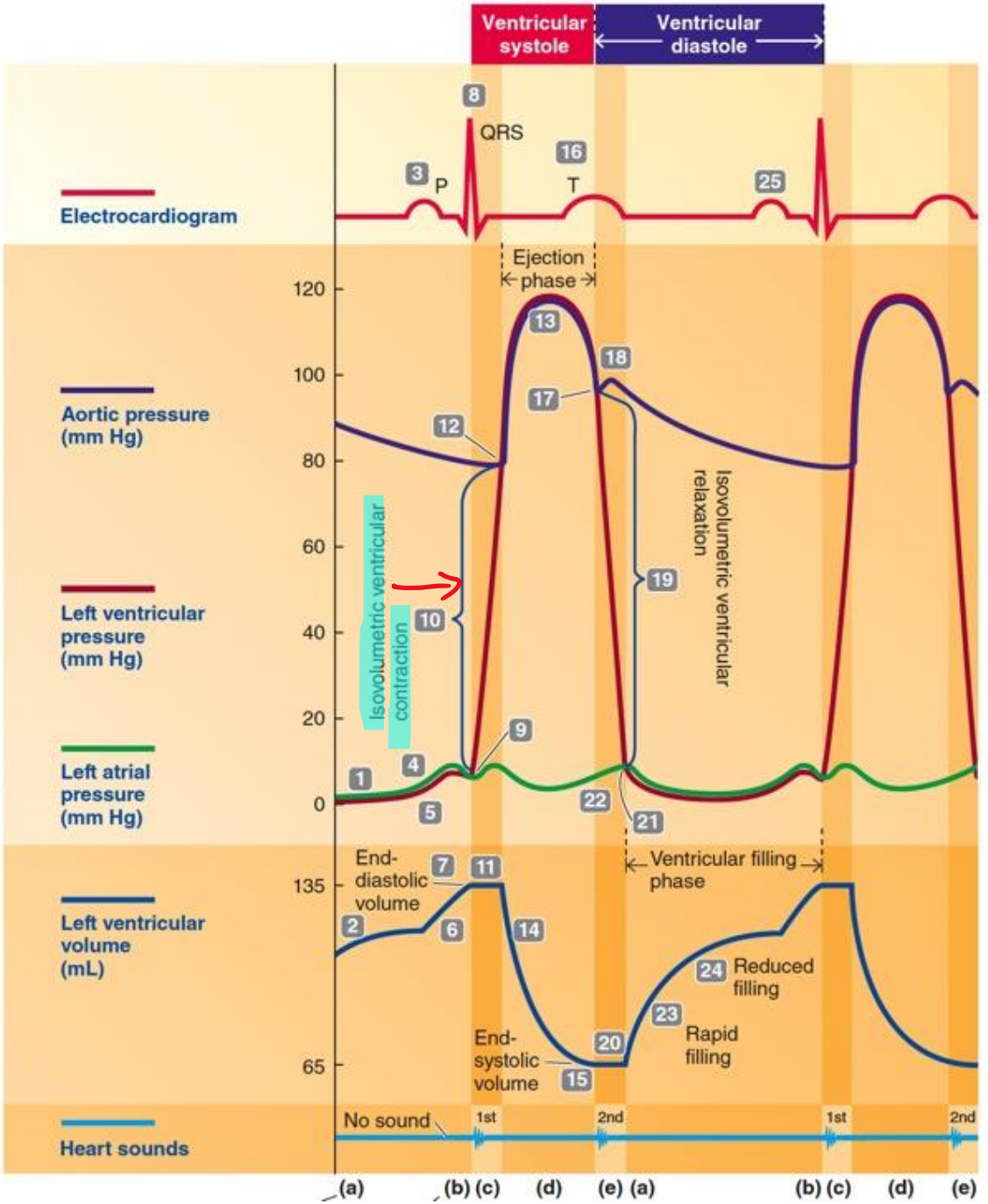
Ventricular systole
Ventricular diastole
Electrocardiogram
Aortic pressure (mm Hg)
Left ventricular pressure (mm Hg)
Left atrial pressure (mm Hg)
Left ventricular volume (mL)
Heart sounds
QRS
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Isovolumetric ventricular relaxation
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Ventricular filling phase
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Rapid filling
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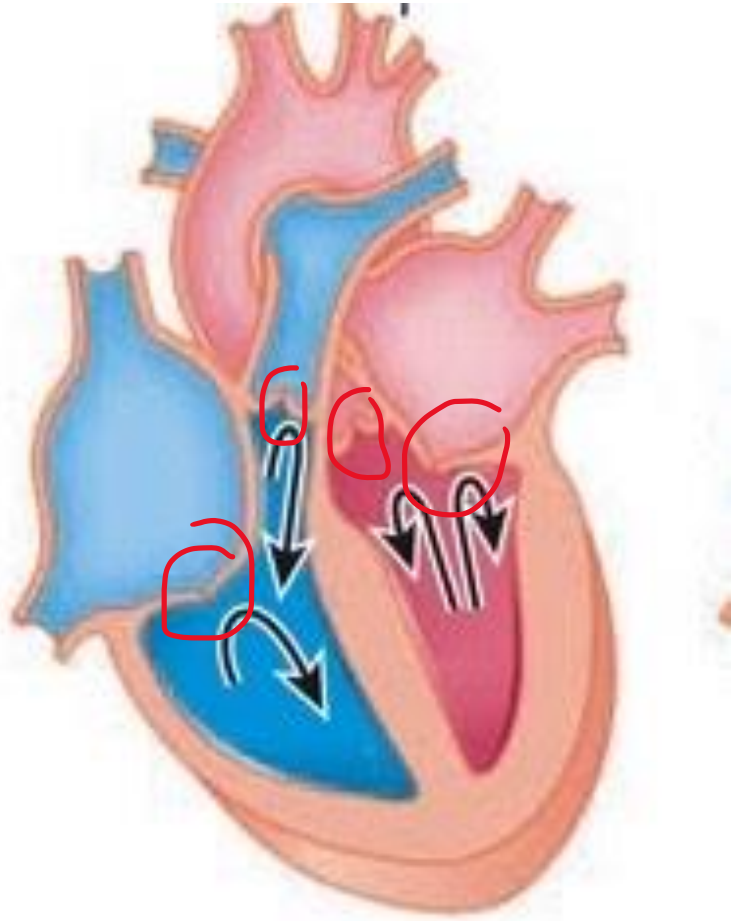
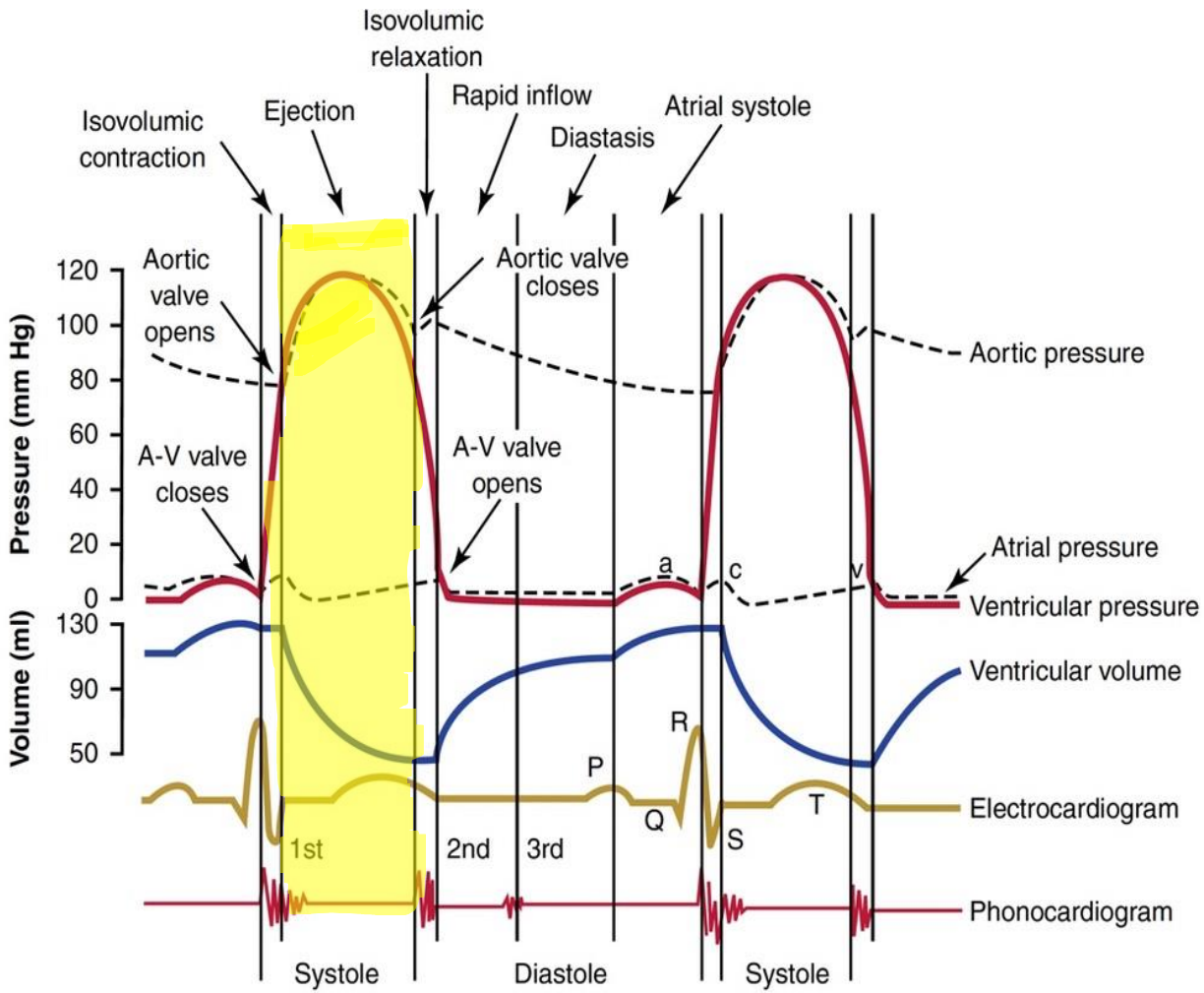


(c) Isovolumetric ventricular contraction

All valves closed

5.Ventricular ejection

- When ventricular pressure exceeds aortic pressure, the aortic valve is forced open and ejection of blood begins.
- The amount of blood pumped out of each ventricle with each contraction is called the stroke volume (SV).
- Most of the stroke volume is ejected during rapid ventricular ejection, dramatically decreasing ventricular volume. Concomitantly, aortic pressure increases as a result of the large volume of blood that is suddenly added to the aorta.
- During reduced ventricular ejection, the ventricles begin to repolarize, which is marked by the beginning of the T wave on the ECG.
- Ventricular pressure falls because the ventricles are no longer contracting.
- Because the aortic valve is still open, blood continues to be ejected from the left ventricle into the aorta, at a reduced rate; ventricular volume also continues to fall, but at a reduced rate.


Isovolumic relaxation
Ejection
Rapid inflow
Atrial systole
Isovolumic contraction
Diastasis
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A-V valve closes
A-V valve opens
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Ventricular volume
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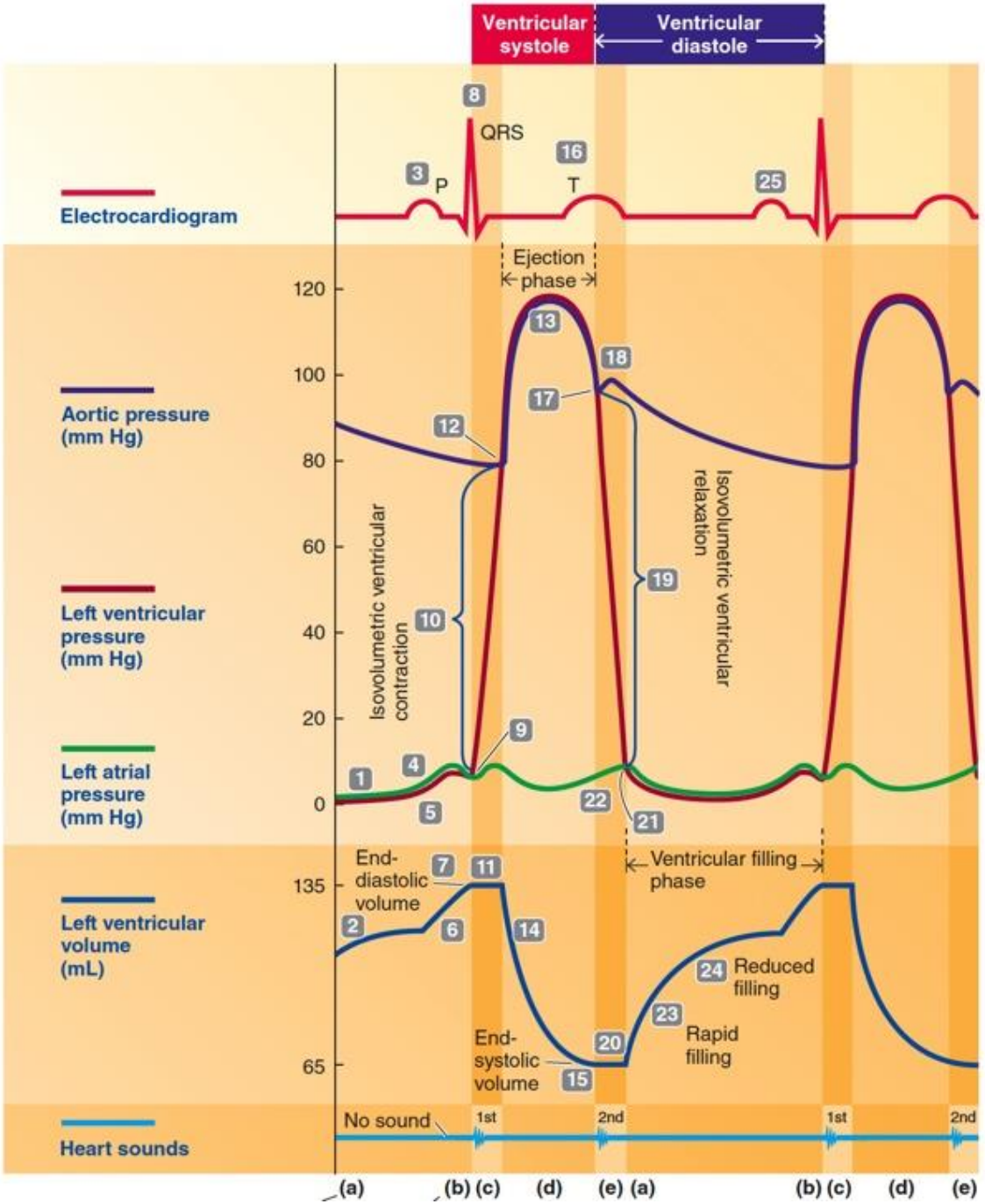
Ventricular systole
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Electrocardiogram
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Left ventricular pressure (mm Hg)
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Left ventricular volume (mL)
Heart sounds
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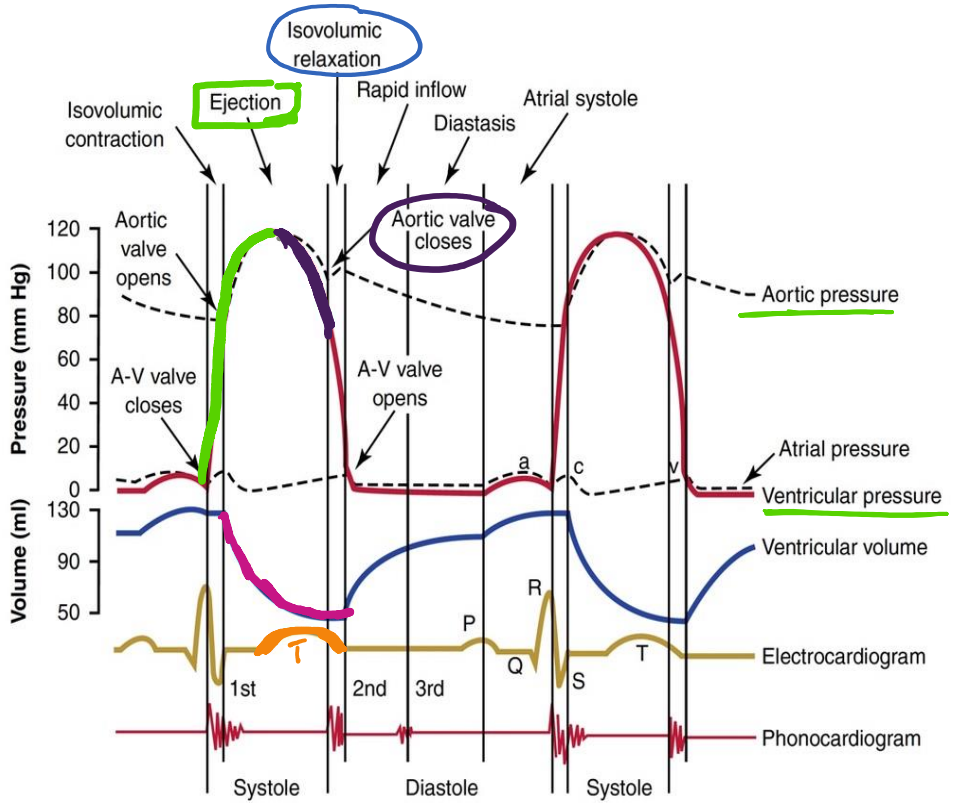


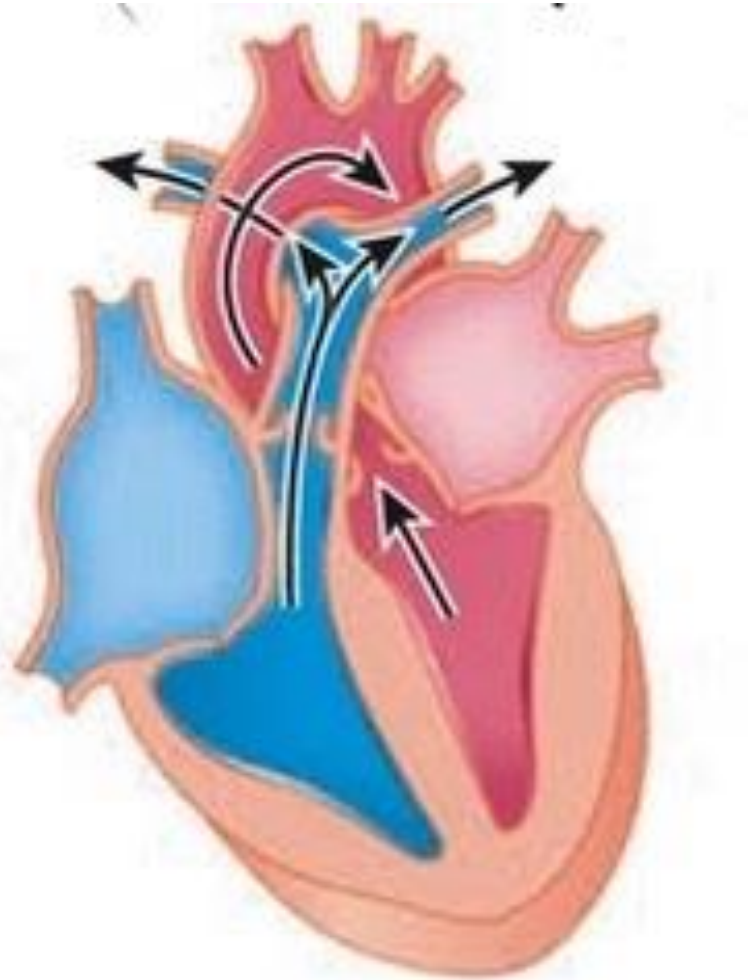
- S1 represents the beginning of ventricular systole (AV valve is closed) , while S2 represents the end of ventricular systole (Aortic valve is closed).

- The ventricular pressure increases rapidly until it exceeds the aortic pressure. At this point, the aortic valve opens, and blood **ejection** begins. No sound is heard during this phase because the valve is opened.

- The ejection of blood initially starts rapidly and then slows down, similar to the pattern of ventricular filling, which starts quickly and then slows. During the rapid ejection phase, the blood volume in the ventricles decreases.

- At the same time the T wave occurs, indicating ventricular repolarization, which signifies relaxation and the filling.

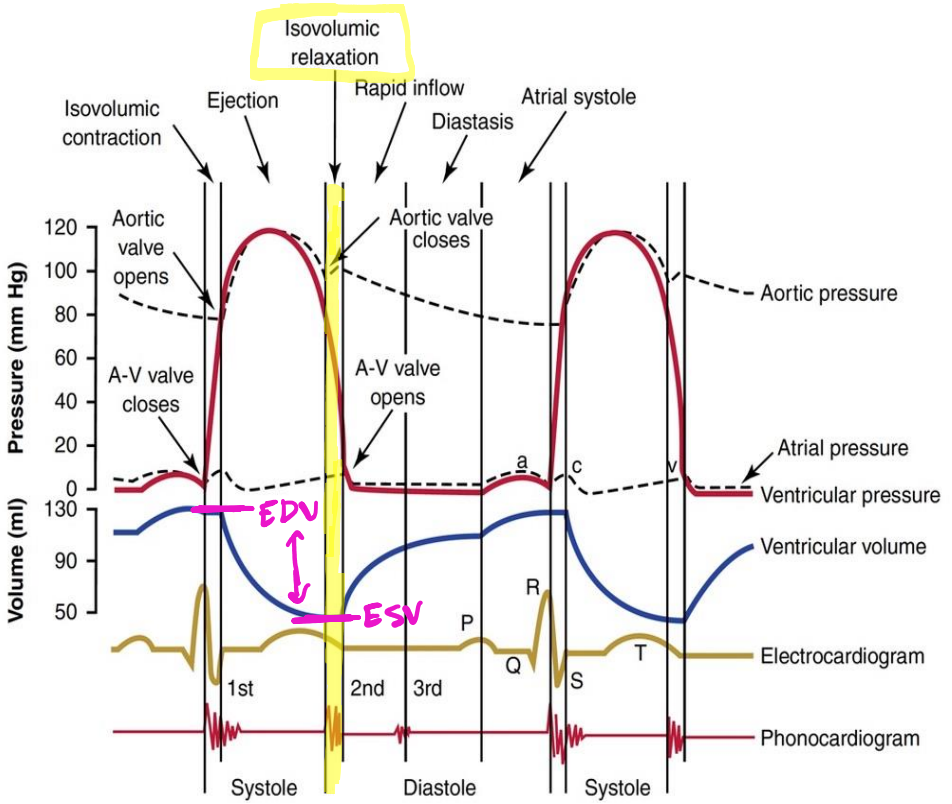
- As the ventricular pressure drops below the aortic pressure, the aortic valve closes, producing the second heart sound (S2).



(d) Ventricular ejection

Isovolumic (isometric) ventricular relaxation

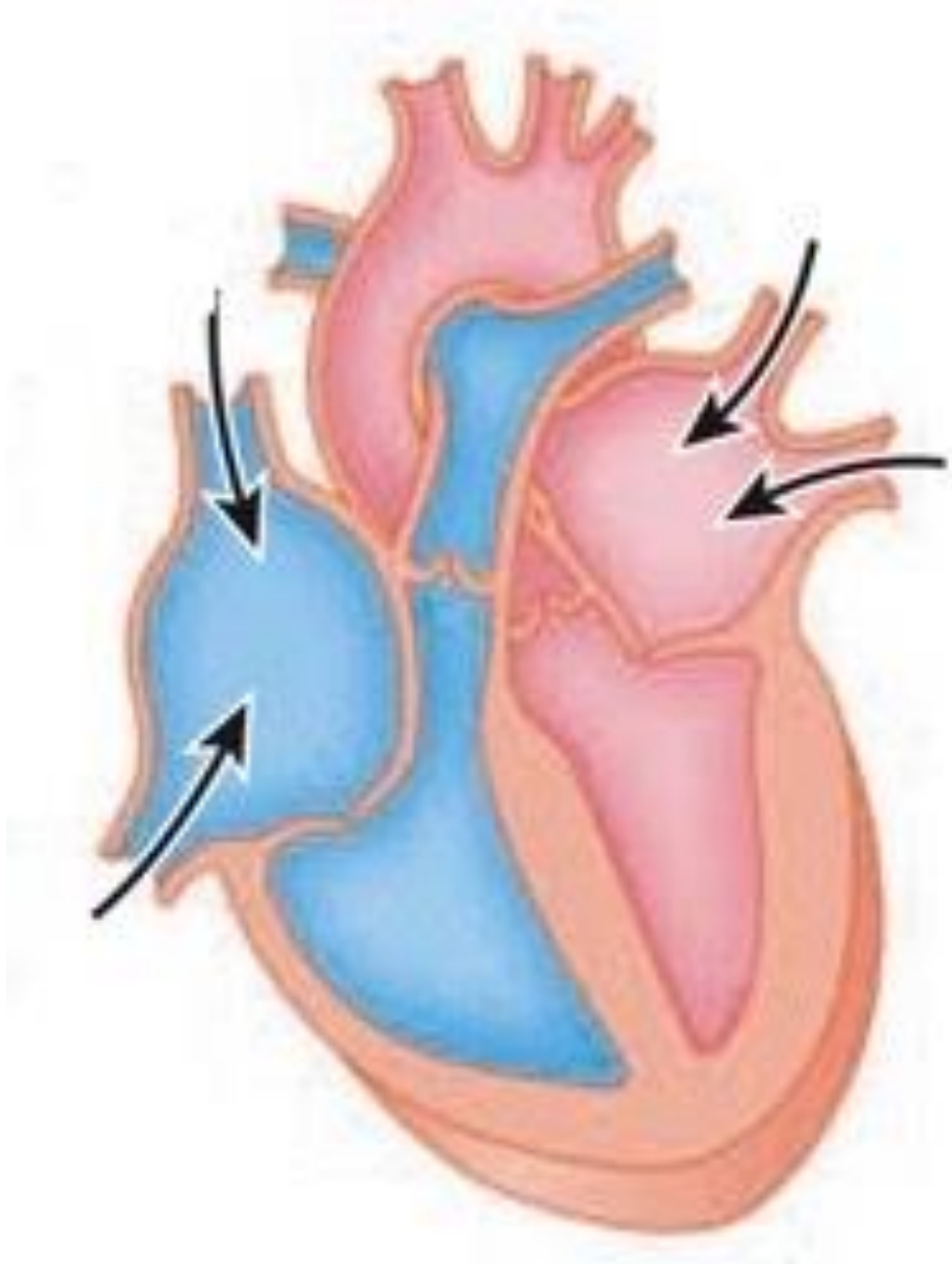
- All valves are closed.
- No blood flow.
- The muscle fiber length and chamber volume remain constant.
- the ventricle continues to relax and the pressure steadily falls.



- During this phase which represents the end of systole, all valves are closed, and ventricular pressure decreases until it falls below atrial pressure.
- Note that the ventricular volume remains constant (here about 50 mL) , indicating that the ventricle does not completely empty during contraction or ejection. This remaining blood volume is called the end-systolic volume (ESV).

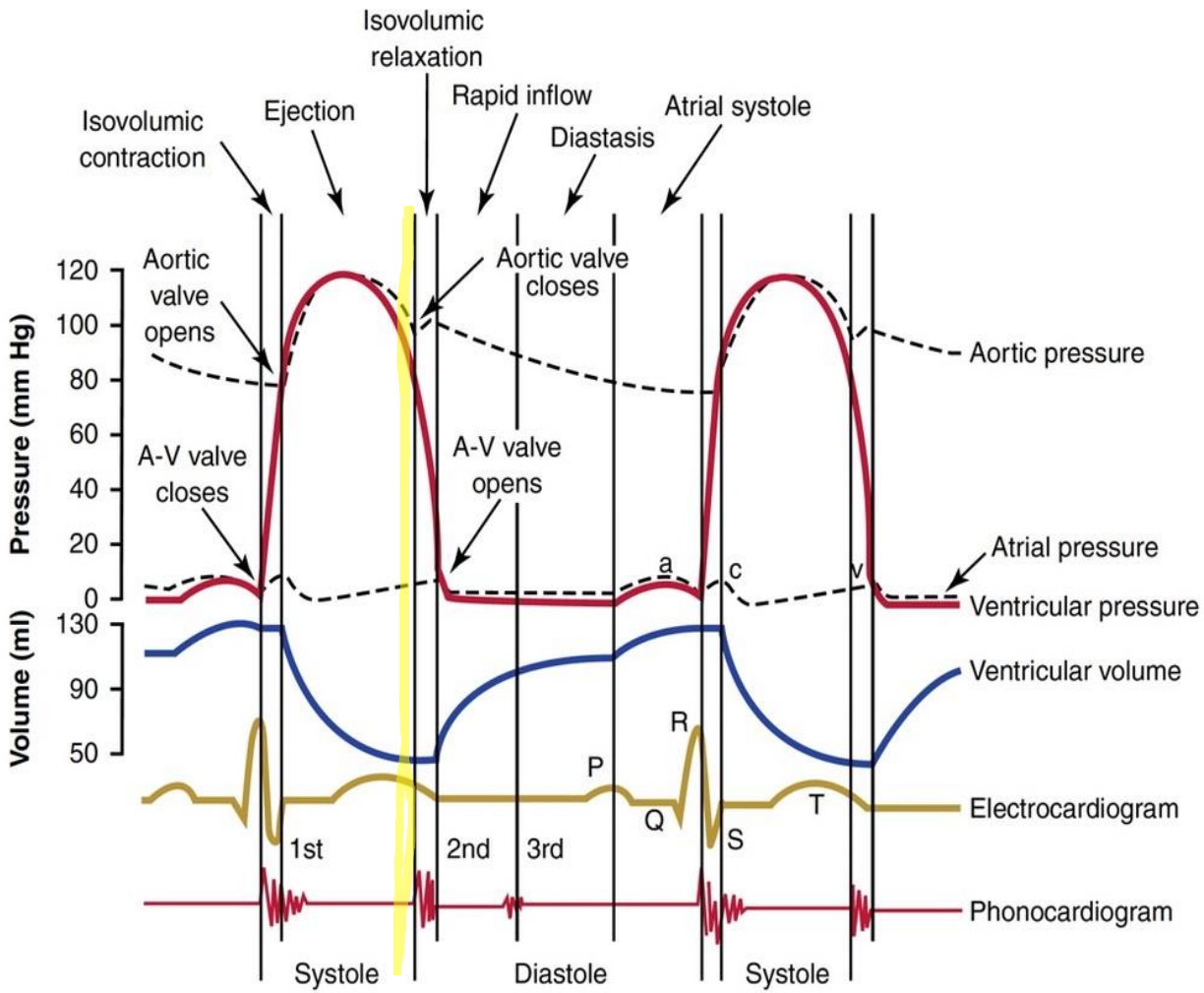
Stroke volume is the amount of volume of blood ejected from the ventricles

SV= EDV - ESV



6.End of ventricular systole

- The ventricle does not empty completely during ejection.
- The amount of blood left in the ventricle at the end of systole when ejection is complete is the end systolic volume (ESV), which averages about 65 mL.
- This is the least amount of blood that the ventricle contains during this cycle.
- The difference between the volume of blood in the ventricle before contraction (EDV) and the volume after contraction (ESV) is the amount of blood ejected during the contraction,that is, SV (strok voulme).
- In our example, EDV is 135 mL, ESV is 65 mL, and SV is 70 mL.


Isovolumic relaxation
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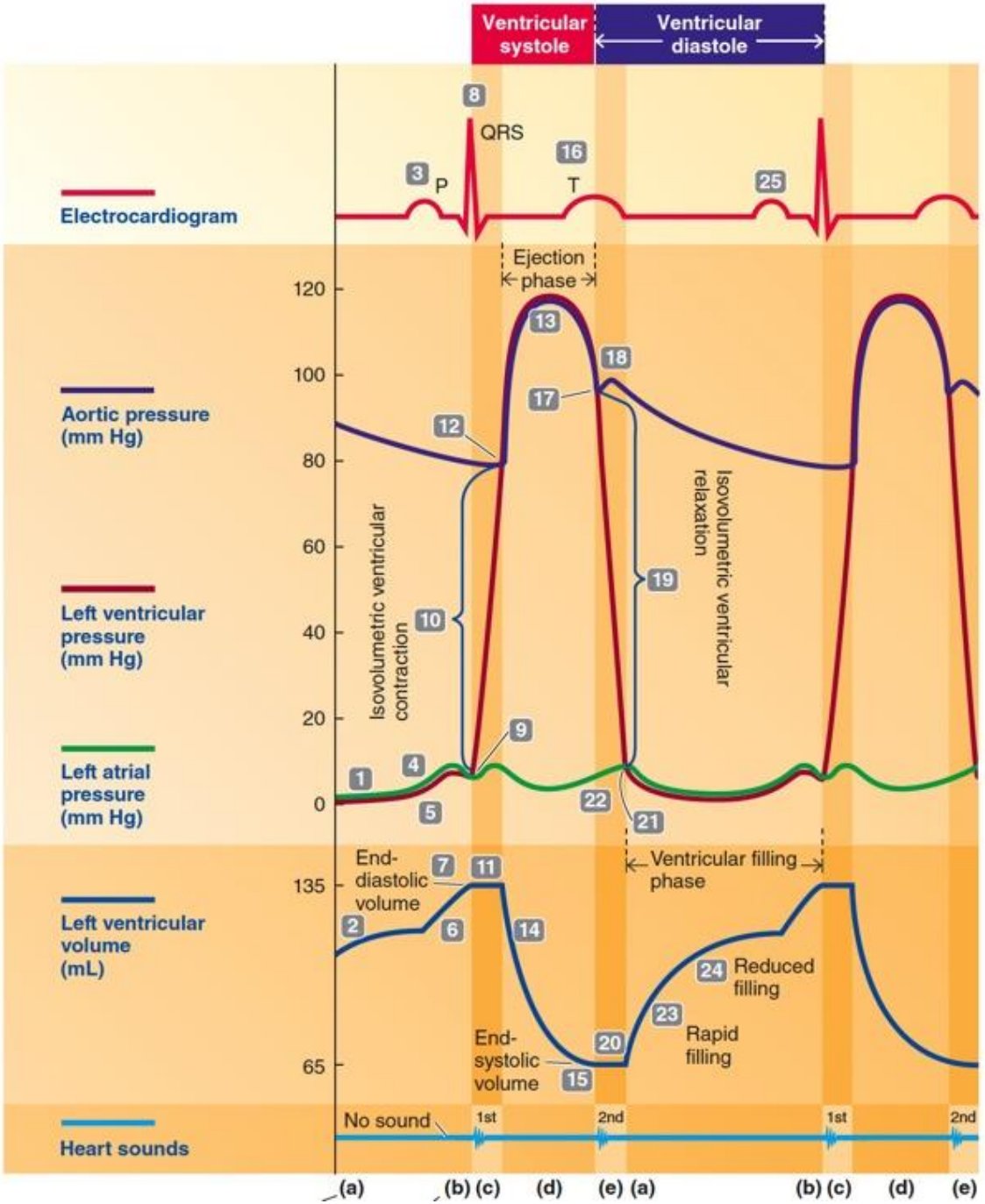
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End-systolic volume
Reduced filling
Rapid filling
Ventricular filling phase
No sound
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2nd
(a)
(b)
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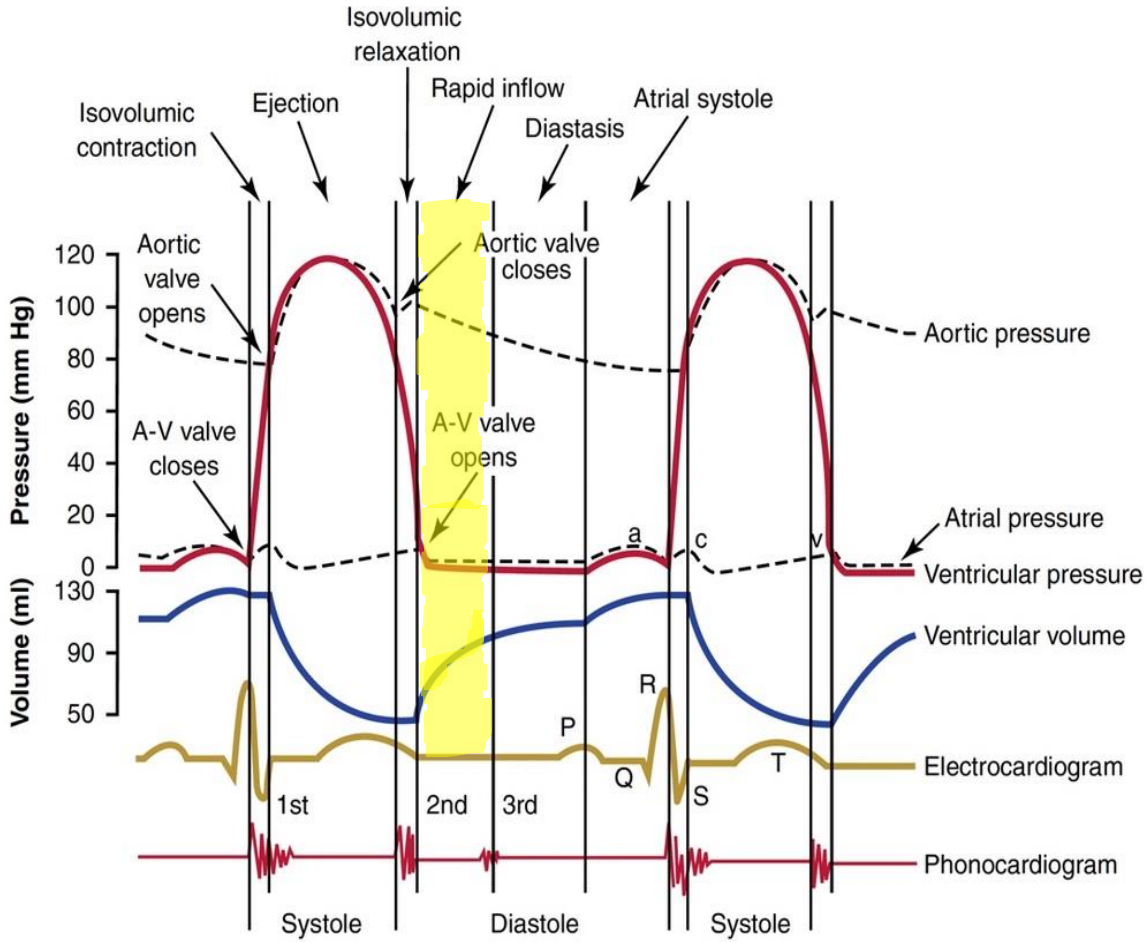
7.Onset of ventricular diastole

- ECG: T wave signifies ventricular repolarization.
- When the ventricle repolarizes and starts to relax, ventricular pressure falls below aortic pressure and the aortic valve closes.
- Closure of the aortic valve produces a disturbance or notch on the aortic pressure curve, the dicrotic notch.
- No more blood leaves the ventricle during this cycle because the aortic valve has closed.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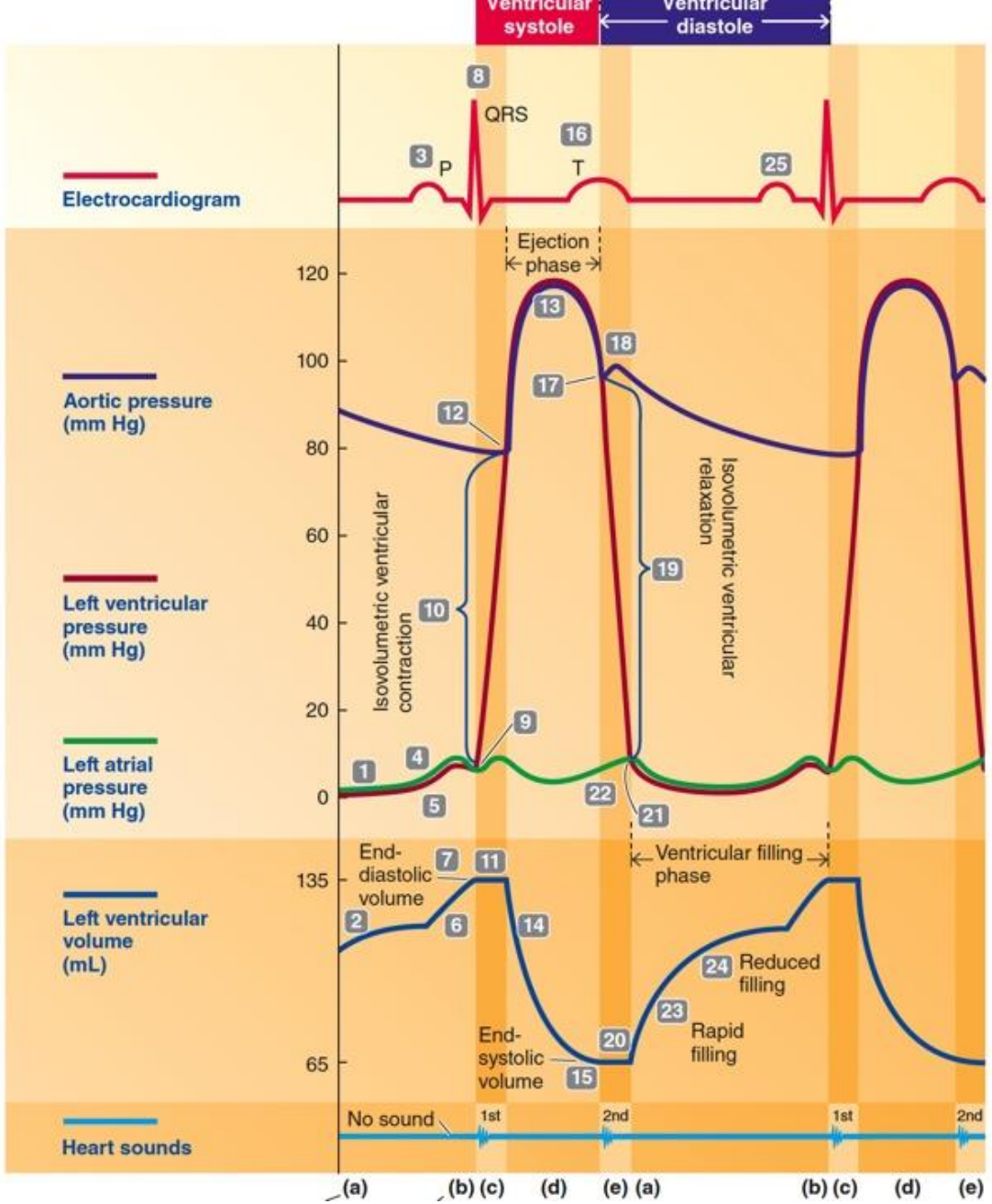
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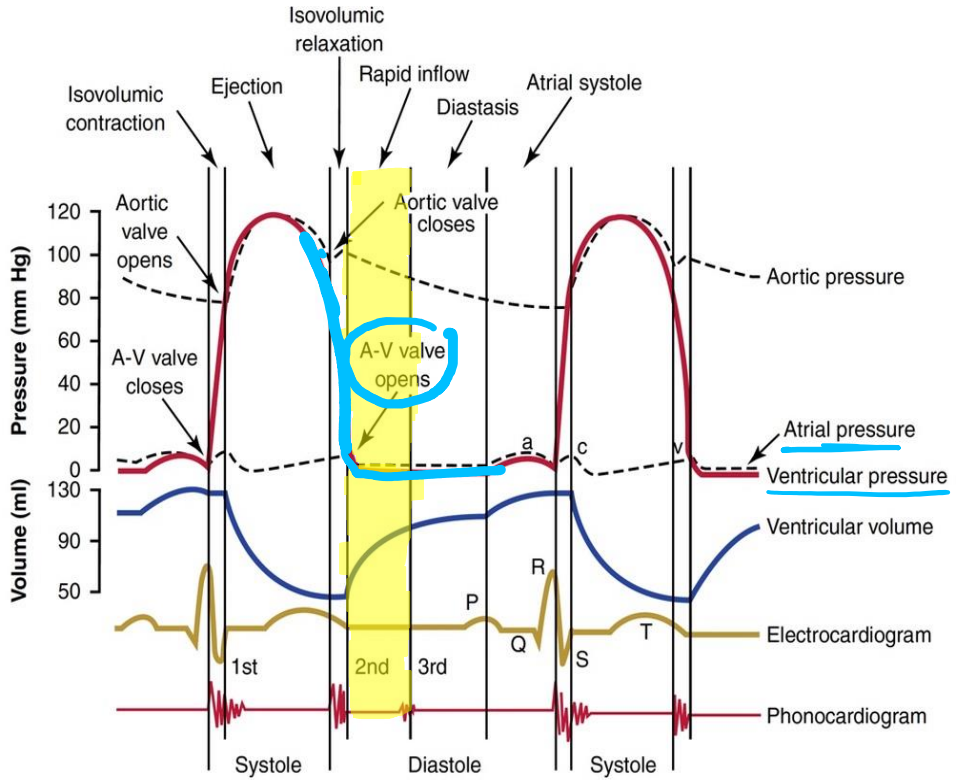
Isovolumetric ventricular relaxation
End-diastolic volume
End-systolic volume
Ventricular filling phase
Reduced filling
Rapid filling
No sound
1st
2nd
120
100
80
60
40
20
0
135
65
(a)
(b)
(c)
(d)
(e)



The beginning of ventricular diastole (relax and fill).

The ventricular pressure decreases below atrial pressure, so the AV valve opens, leading to rapid blood flow into the ventricles. But why is it rapid even though the atria are not contracting 🤔? This is because the atrium alredy is full of blood [as it was filling during ventricular systole (diastole of the atria)].

- So again, once the ventricular pressure becomes lower than the atrial pressure, the valve opens, and rapid filling of the ventricles begins. After this, we move to the diastasis phase, and the cycle is repeated again.

Ventricular filling

- Atrial repolarization and ventricular depolarization occur simultaneously, so the atria are in diastole throughout ventricular systole.

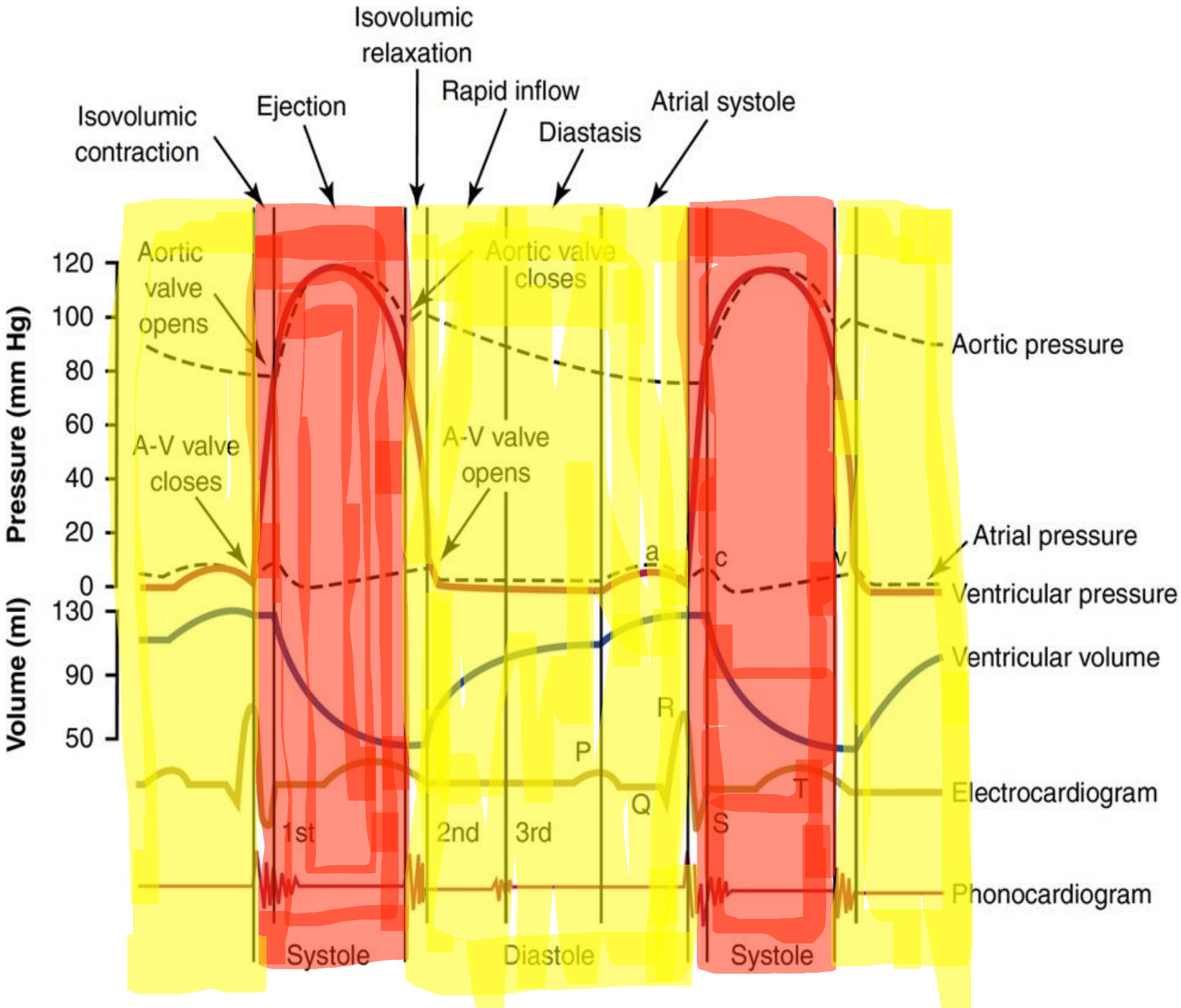
- Blood continues to flow from the pulmonary veins into the left atrium. As this incoming blood pools in the atrium, atrial pressure rises continuously.

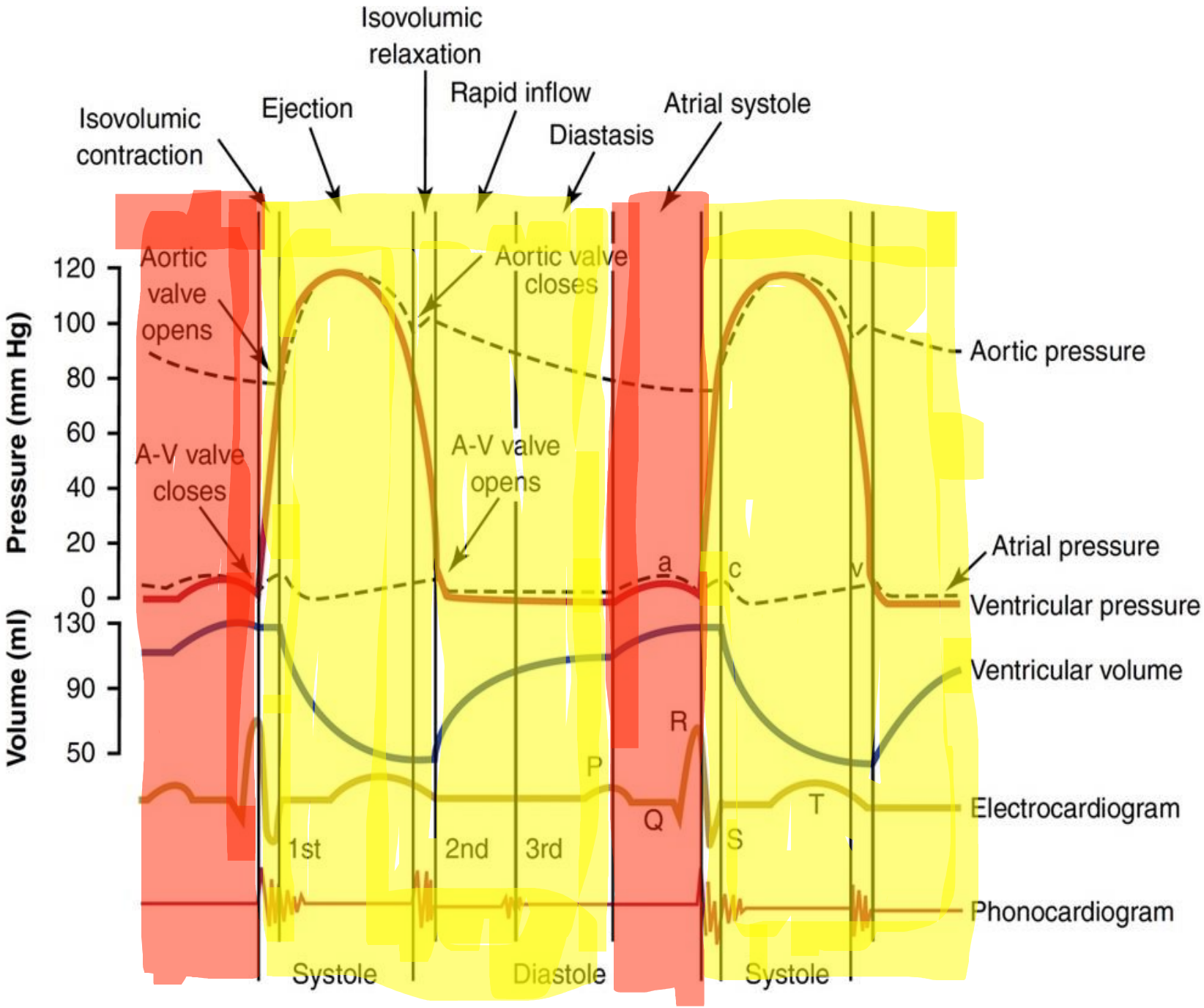
- When the AV valve opens at the end of ventricular systole, blood that accumulated in the atrium during ventricular systole pours rapidly into the ventricle.

- Ventricular filling thus occurs rapidly at first because of the increased atrial pressure resulting from the accumulation of blood in the atria.

Ventricular filling

- Then ventricular filling slows down as the accumulated blood has already been delivered to the ventricle.
- During this period of reduced filling, blood continues to flow from the pulmonary veins into the left atrium and through the open AV valve into the left ventricle.
- During late ventricular diastole, when the ventricle is filling slowly, the SA node fires again, and the cardiac cycle starts over.
- Ventricular diastole includes both isovolumetric ventricular relaxation and ventricular filling.


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
Aortic pressure
Atrial pressure
Ventricular pressure
Ventricular volume
Electrocardiogram
Phonocardiogram
a
c
v
R
P
Q
S
T
1st
2nd
3rd
Systole
Diastole
Systole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Ventricular volume
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Electrocardiogram
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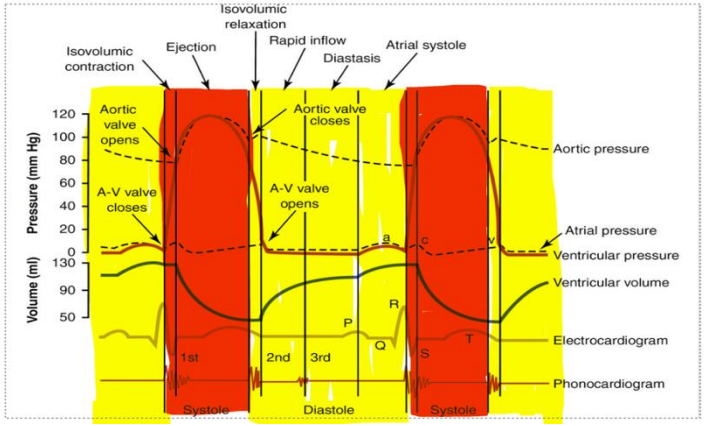
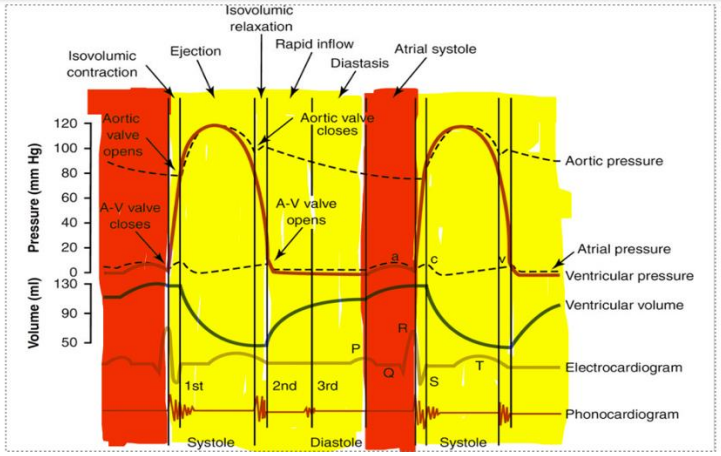
3rd
Phonocardiogram
Systole
Diastole
Systole

Further explanation from the doctor about the two previous slides:

👉The yellow color represents the diastolic phase, while the red color represents the systolic phase of the cardiac cycle.
👉The diastolic phase is longer than the systolic phase, indicating that the heart spends more time in relaxation and filling than in contraction and ejection.



In the ventricles (The first one): For example, if the cardiac cycle lasts 0.08 seconds, the diastolic phase will take 0.05s, and the systolic phase will take 0.03s.



In the atria (The second one) , **the ratio of diastole to systole is much higher.** For example, the same cardiac cycle (lasts 0.08 seconds) the diastolic phase would take 0.07s, and the systolic phase would take 0.01s.

Cardiac cycle

- The cardiac events that occur from the beginning of one heartbeat to the beginning of the next are called the cardiac cycle.
- Each cycle is initiated by the spontaneous generation of an action potential in the sinus node.
- The total duration of the cardiac cycle, including systole and diastole, is the reciprocal of the heart rate.
- For example, if the heart rate is 72 beats/min, the duration of the cardiac cycle is 1/72 min/beat—about 0.0139 min/beat, or 0.833 sec/beat.

Increase heart rate effect on cardiac cycle

- The duration of the action potential and systole also decrease, but not by as great a percentage as diastole.

- This means that the heart beating very rapidly does not remain relaxed long enough to allow complete filling of the cardiac chambers before the next contraction.

- An increase in heart rate, due to faster firing of the SA node, will shorten the duration of the cardiac cycle. The duration of diastole is affected more than systole.

Why the duration of diastole is affected more than systole?

👉 Explanation from ChatGPT: When the heart rate increases, the whole cycle of the heart beat becomes faster, meaning both the contraction phase (systole) and the relaxation phase (diastole) happen more quickly. However, diastole (when the heart fills with blood) shortens more than systole. This happens because, at faster heart rates, there is less time for the heart to relax and fill with blood between each beat. Since the heart still needs time to contract and pump blood, it can't shorten the systole phase as much, but it reduces the diastole phase more to fit in the faster cycle. So, in a faster heart rate, the filling phase (diastole) gets the most time cut.

volumes

- End diastolic volume (EDV): The volume of blood in a ventricle at the end of diastole (just before contraction).
- End systolic volume (ESV): The volume of blood remaining in a ventricle at the end of systole (after contraction).
- Stroke volume (SV): is is the amount of volume of blood ejected from the ventricles.

- (SV)=EDV-ESV

- Ejection fraction(EF): is the percentage of blood that is ejected from the ventricles compared to the total volume of blood present in the ventricles at the end of diastole (just before contraction).

- EF = SV/EDV

- Ejection fraction (EF) is very important clinically. For example, if an echocardiogram for a patient shows that the EF is 30%, it means that only 30% of the blood volume in the ventricles is being ejected during each heartbeat. Since a normal EF ranges from 50% to 70%, an EF of 30% is considered low and suggests heart failure. This condition is known as heart failure with reduced ejection fraction (HFrEF) .

Atria as a primer pump

- Blood normally flows continually from the great veins into the atria; about 80% of the blood flows directly through the atria into the ventricles, even before the atria contract. (passive filling)
- Then, atrial contraction usually causes an additional 20% filling of the ventricles.
- Therefore, the atria function as primer pumps that increase the ventricular pumping effectiveness as much as 20%.
- However, the heart can continue to operate under most conditions even without this extra 20% effectiveness because it normally has the capability of pumping 300% to 400% more blood than is required by the resting body.
- Therefore, when the atria fail to function, the difference is unlikely to be noticed unless a person exercises; then, symptoms of heart failure occasionally develop, especially shortness of breath.

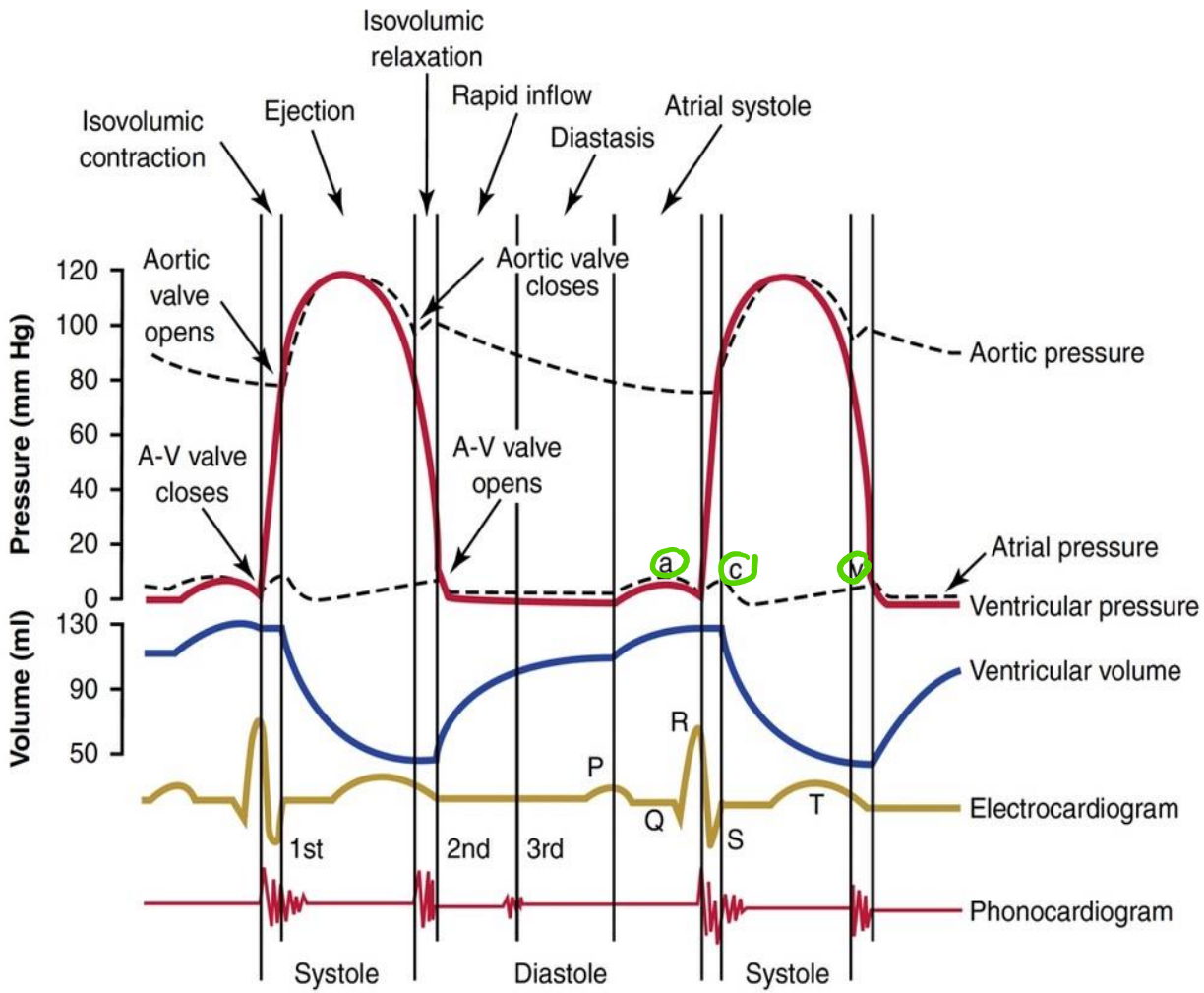
Atrial pressure waves (reflected on venous pulse)

- The **a wave** is caused by atrial contraction. Ordinarily, the right atrial pressure increases 4 to 6 mm Hg during atrial contraction, and the left atrial pressure increases about 7 to 8 mm Hg.

- The **c wave** (Cusp wave) occurs when the ventricles begin to contract (closure pf AV valve) it is caused partly by slight backflow of blood into the atria at the onset of ventricular contraction, but mainly by bulging of the A-V valves backward toward the atria because of increasing pressure in the ventricles.

- The **v wave** occurs toward the end of ventricular contraction (opening of AV valve); it results from slow flow of blood into the atria from the veins while the A-V valves are closed during ventricular contraction.

- Then, when ventricular contraction is over, the A-V valves open, allowing this stored atrial blood to flow rapidly into the ventricles, causing the v wave to disappear.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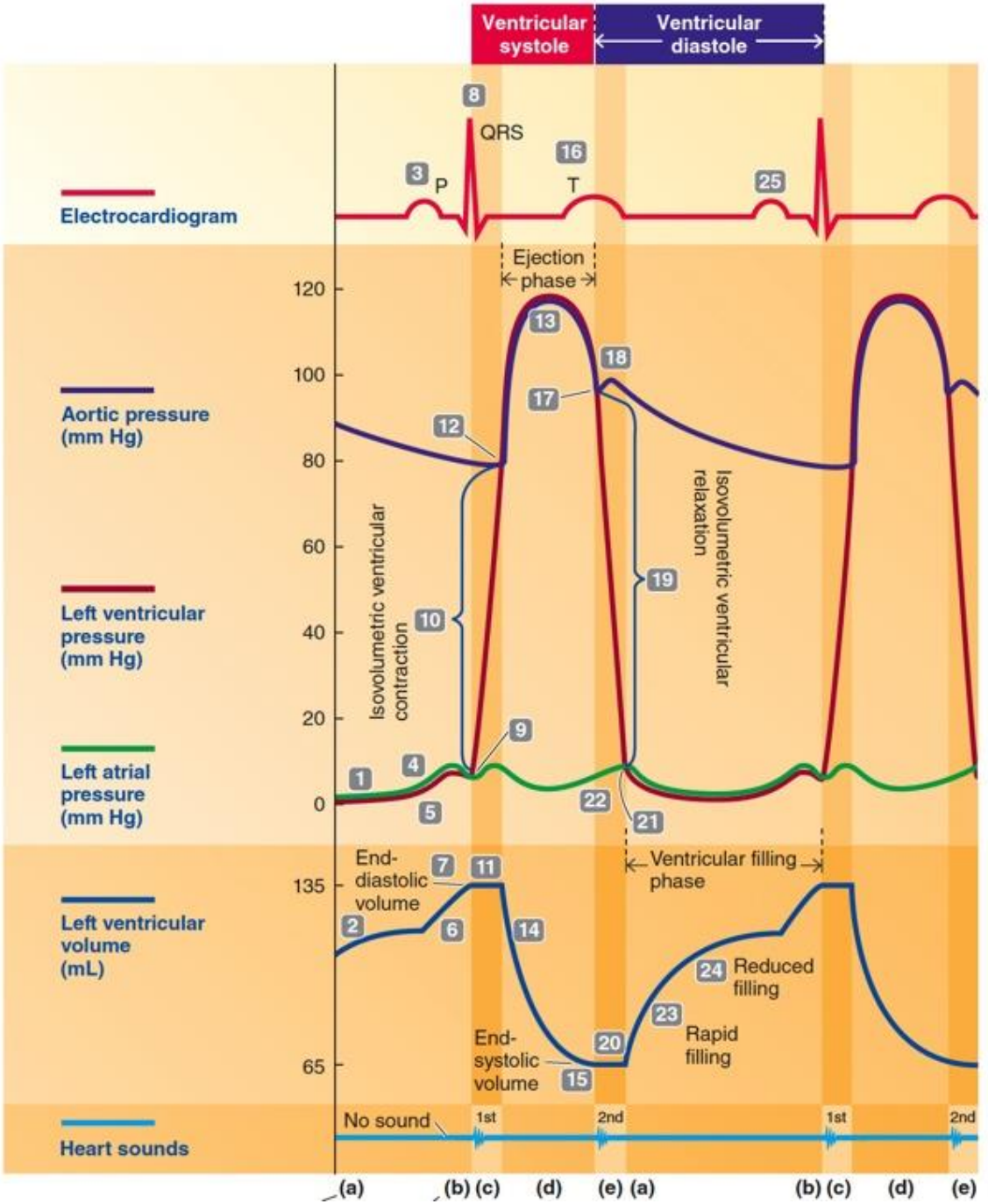
Ventricular systole
Ventricular diastole
Electrocardiogram
Aortic pressure (mm Hg)
Left ventricular pressure (mm Hg)
Left atrial pressure (mm Hg)
Left ventricular volume (mL)
Heart sounds
QRS
P
T
Ejection phase
Isovolumetric ventricular contraction
Isovolumetric ventricular relaxation
End-diastolic volume
End-systolic volume
Reduced filling
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Ventricular filling phase
No sound
1st
2nd
120
100
80
60
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(a)
(b)
(c)
(d)
(e)

Thank you

Additional Sources:
The Cardiac Cycle, Animation

VERSIONS	SLIDE #	BEFORE CORRECTION	AFTER CORRECTION
V1→ V2			
V2→V3			

امسح الرمز و شاركنا بأفكارك لتحسين أدائنا!!