Cardiovascular Physiology

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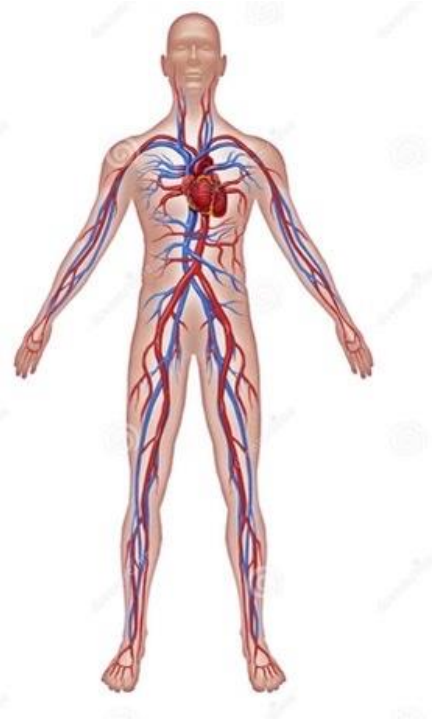
School of Medicine, University of Jordan



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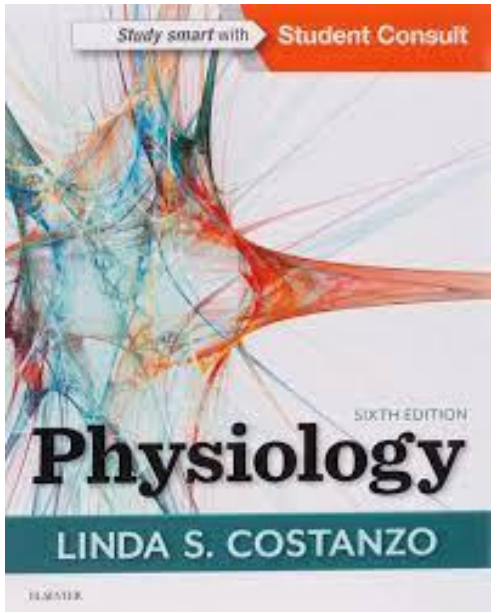
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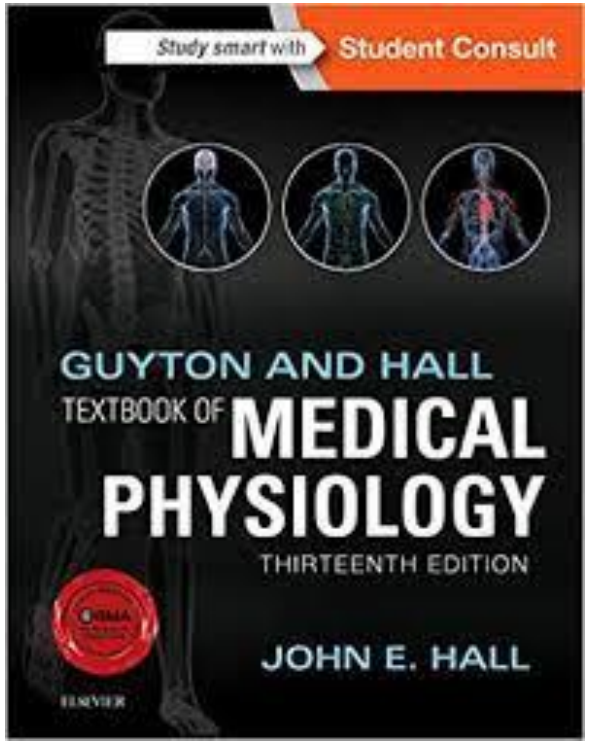
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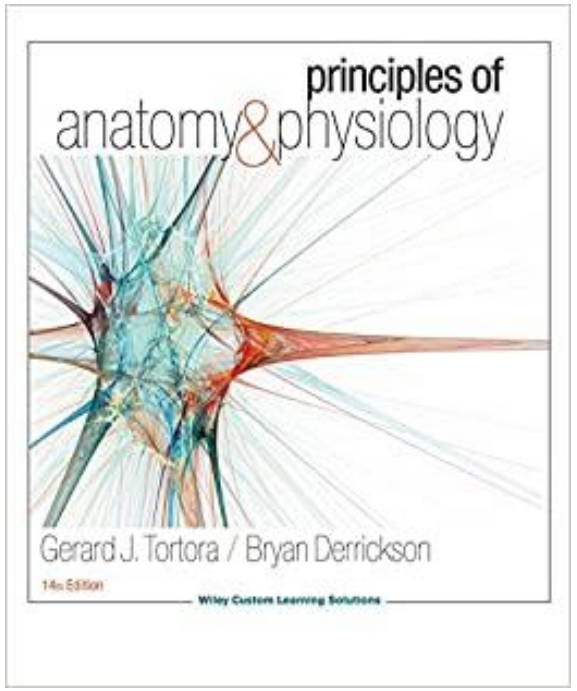
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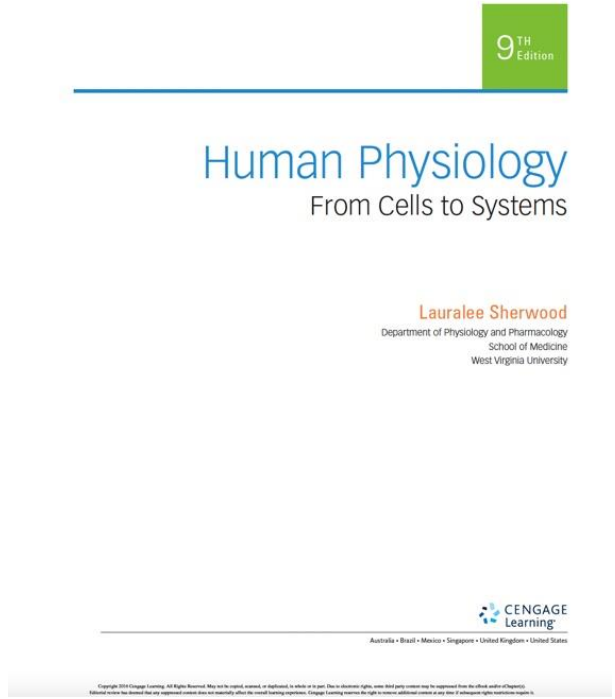
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Cardiac cycle

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).

Cardiac cycle basics

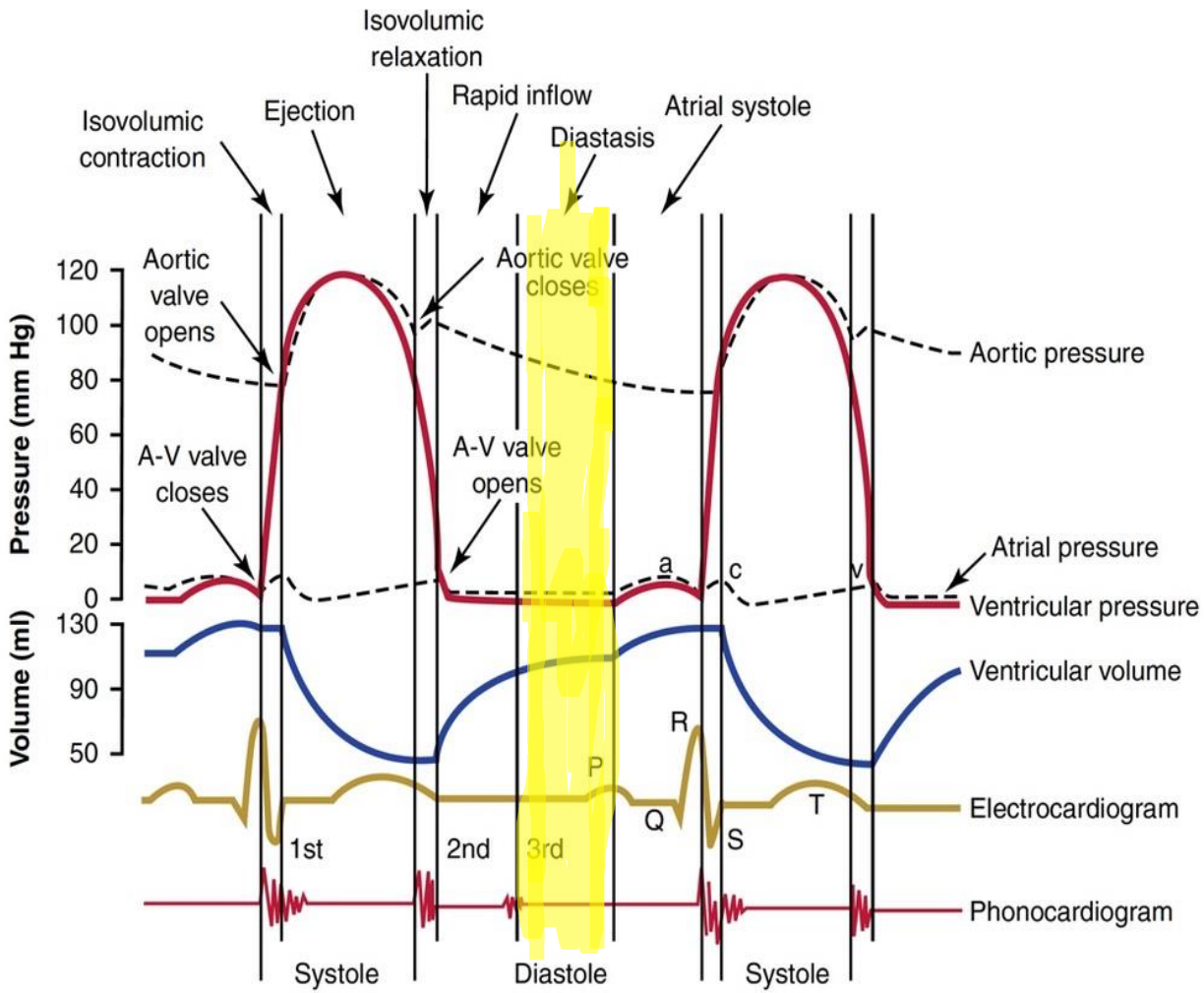
- The cardiac cycle consists of alternate periods of systole (contraction and emptying) and diastole (relaxation and filling).
- Contraction results from the spread of excitation across the heart, whereas relaxation follows the subsequent repolarization of the cardiac muscle.
- The atria and ventricles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

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).
- Ventricular volume slowly rises (diastasis or reduced ventricular filling).
- Long phase, affected by increased heart rate the most.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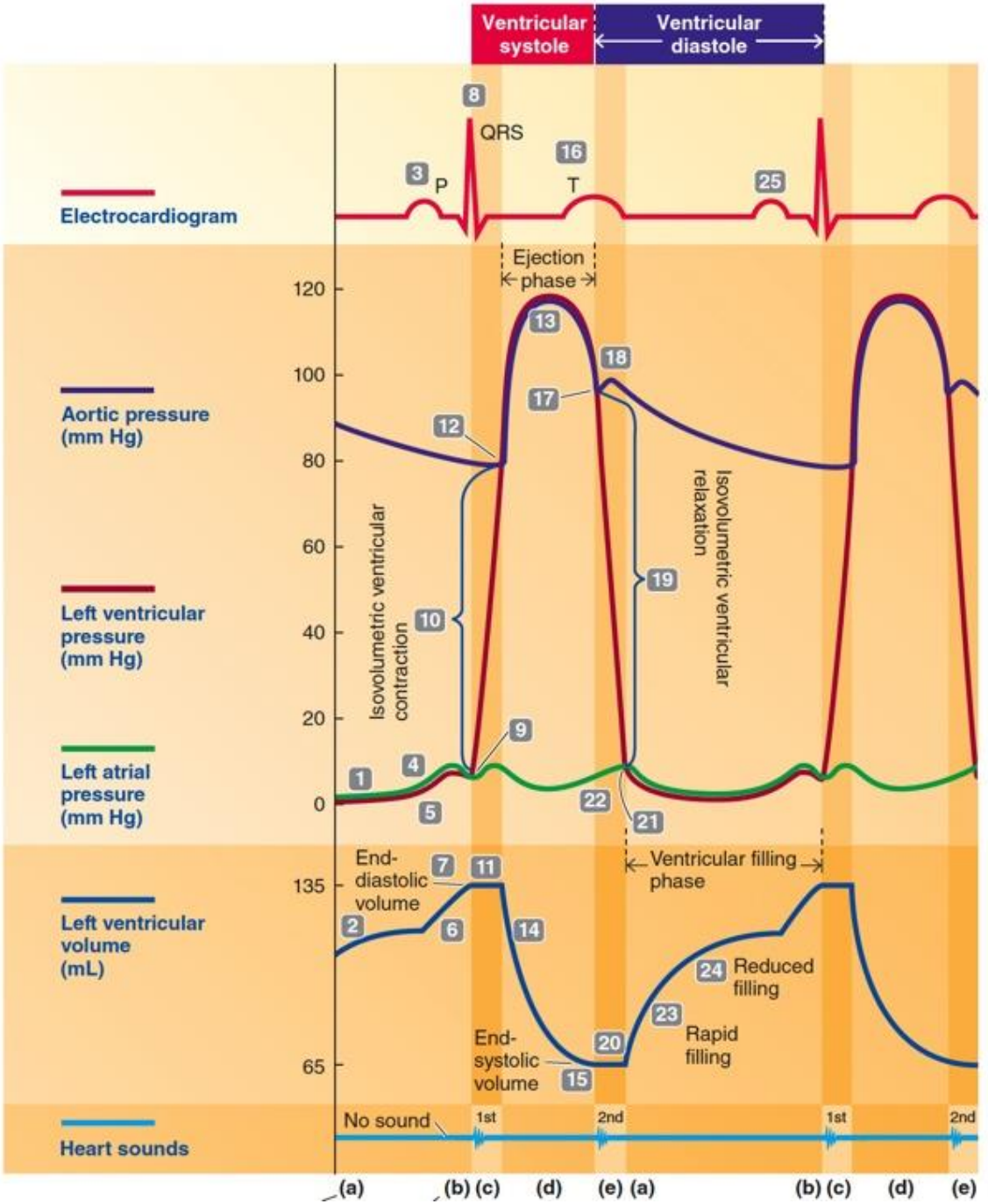
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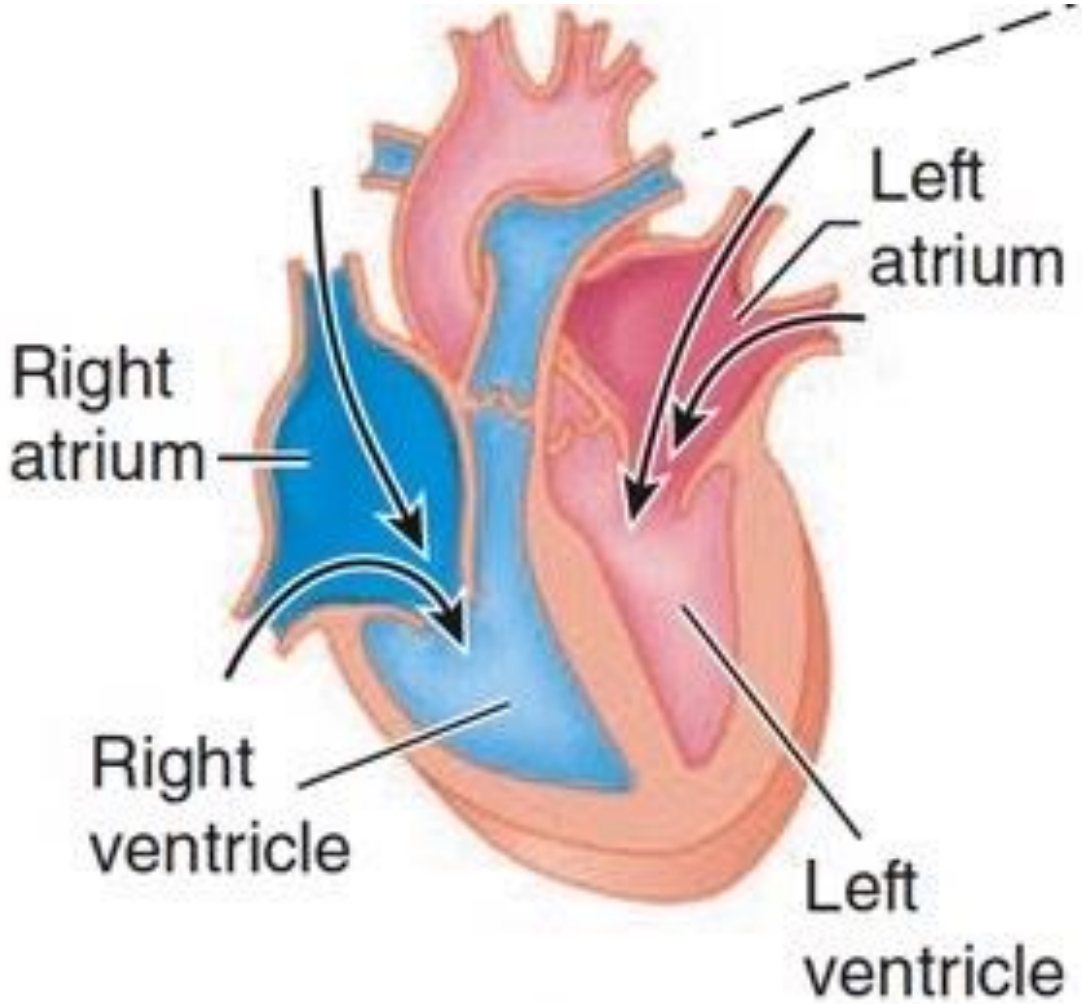
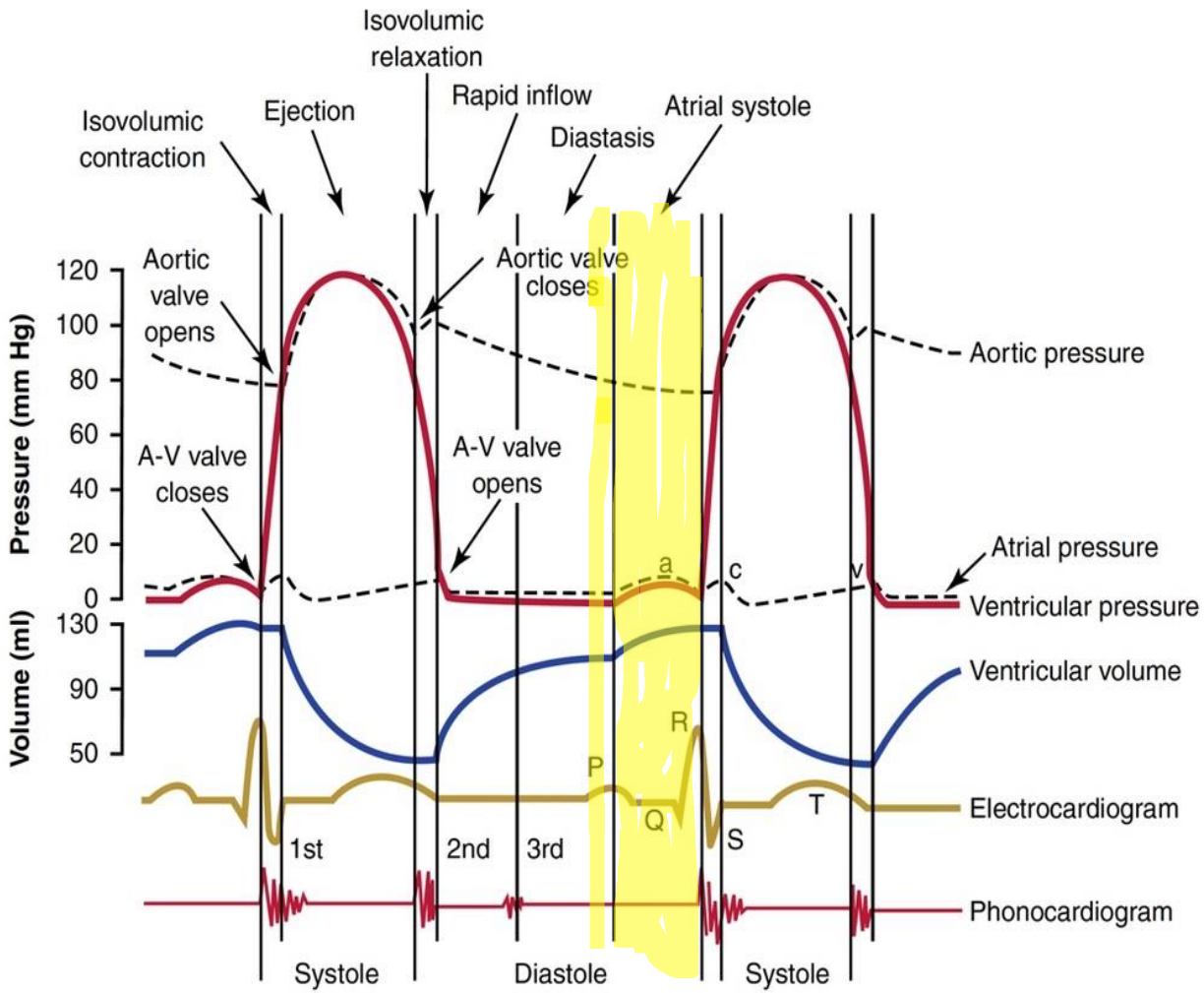


(a) Passive filling during ventricular and atrial diastole

Atrial systole

- ECG: P wave.
- SA node initiates a new cycle, atrial depolarization leads to atrial contraction.
- Atrial pressure increases, blood is pumped from atrium to the ventricle.
- Pressure in the ventricle starts to increase but still below the atrium, therefore, AV valve is still open.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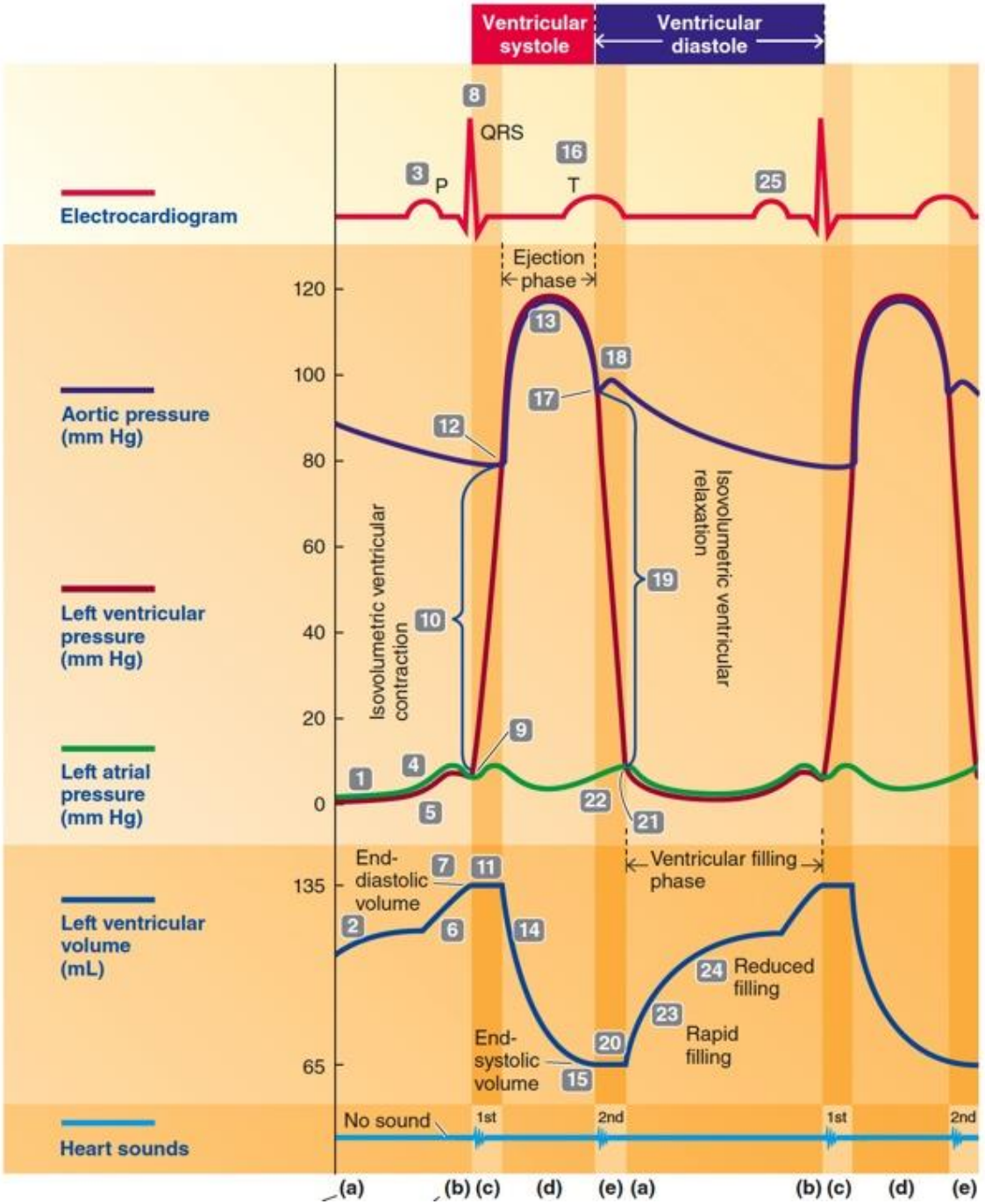
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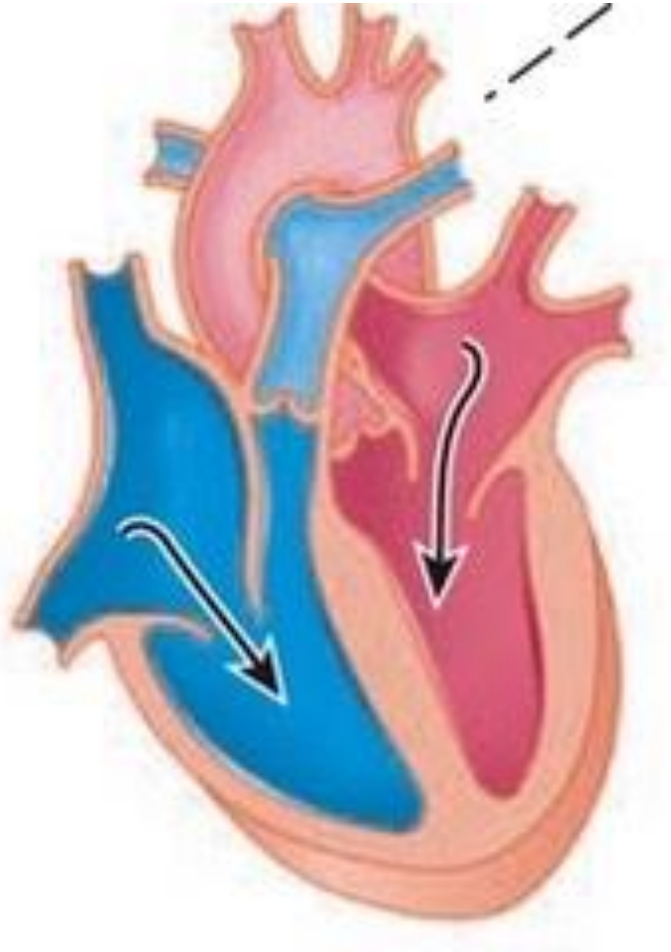
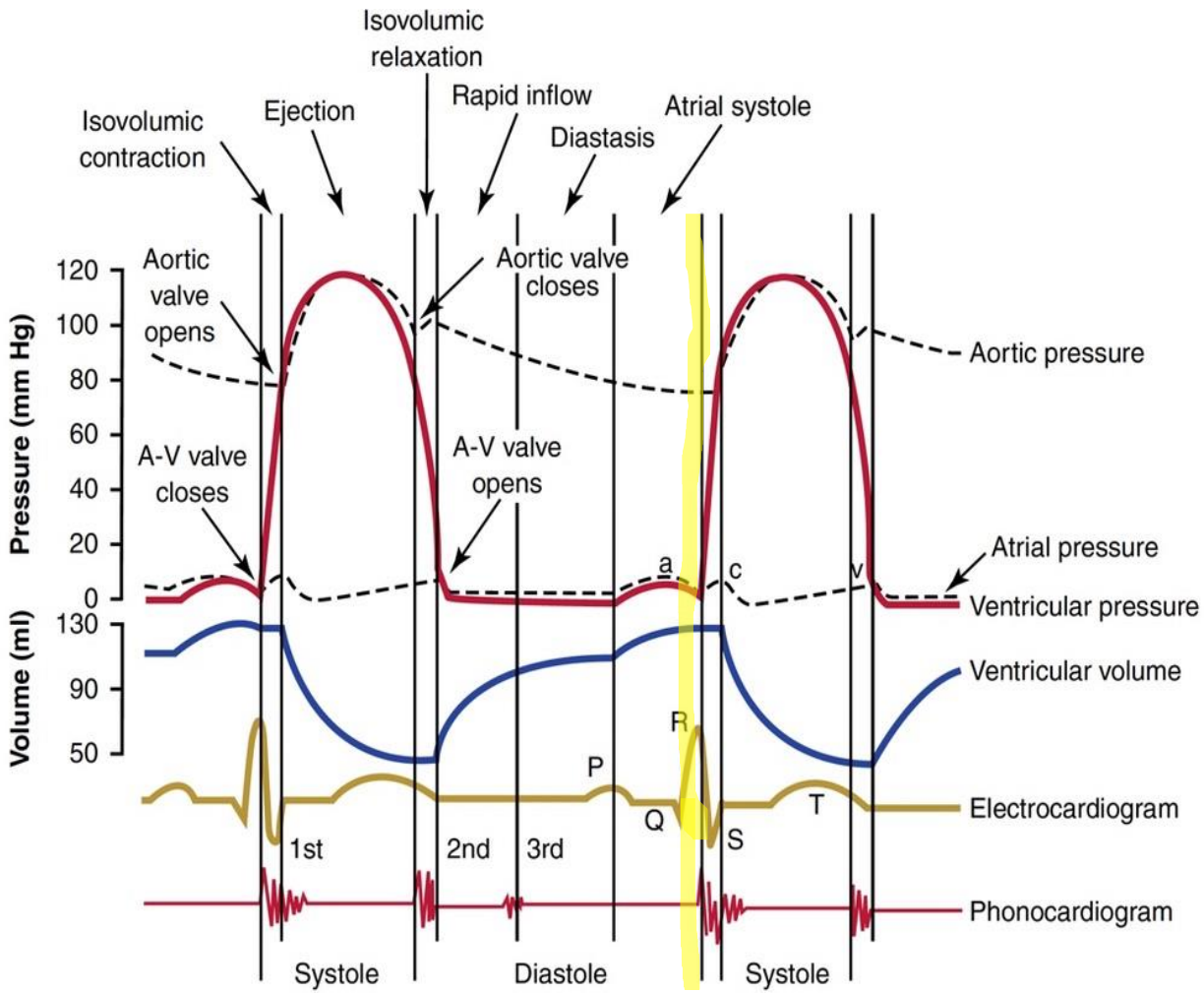


(b) Atrial contraction

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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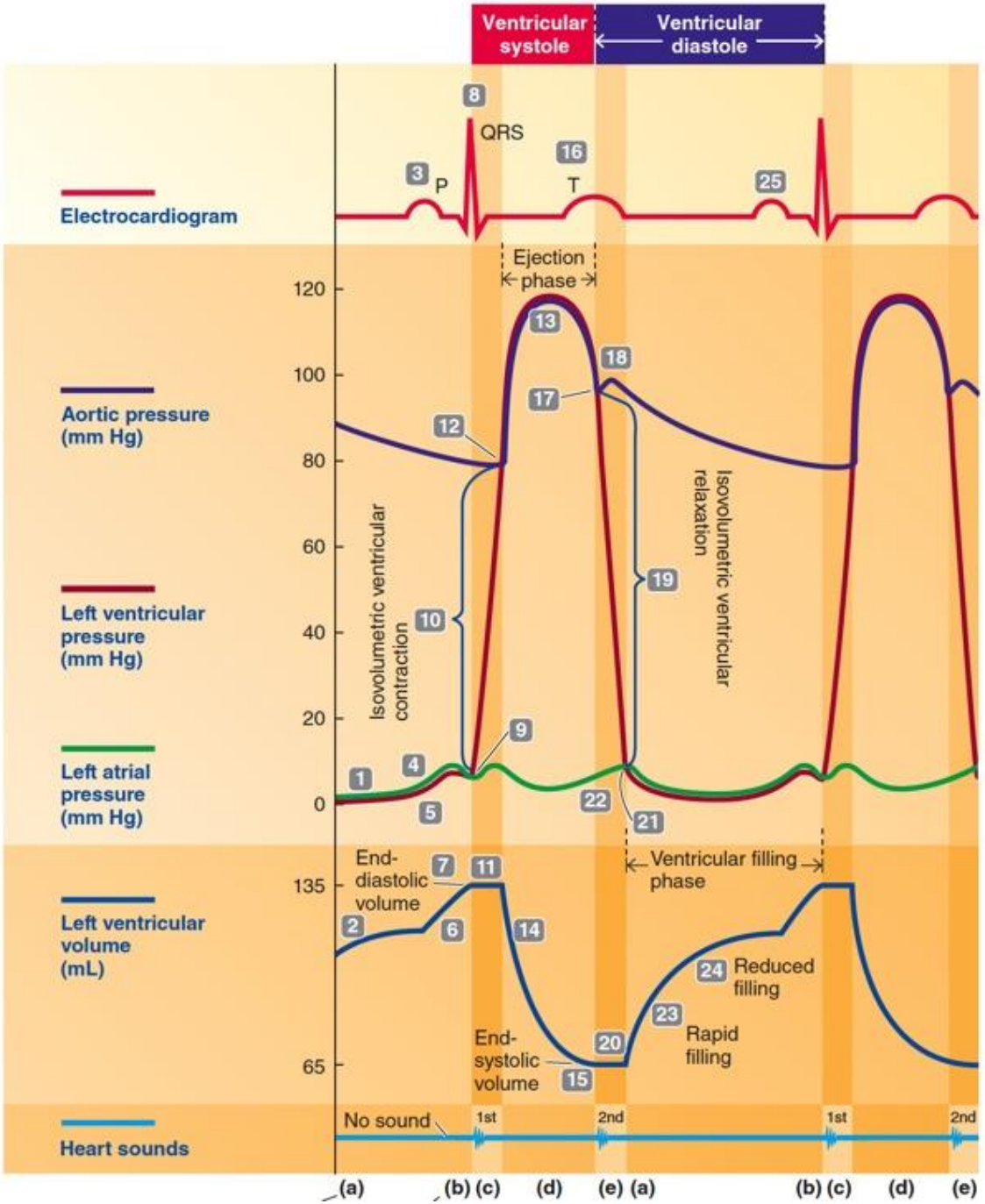
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Isovolumetric ventricular contraction
Isovolumetric ventricular relaxation
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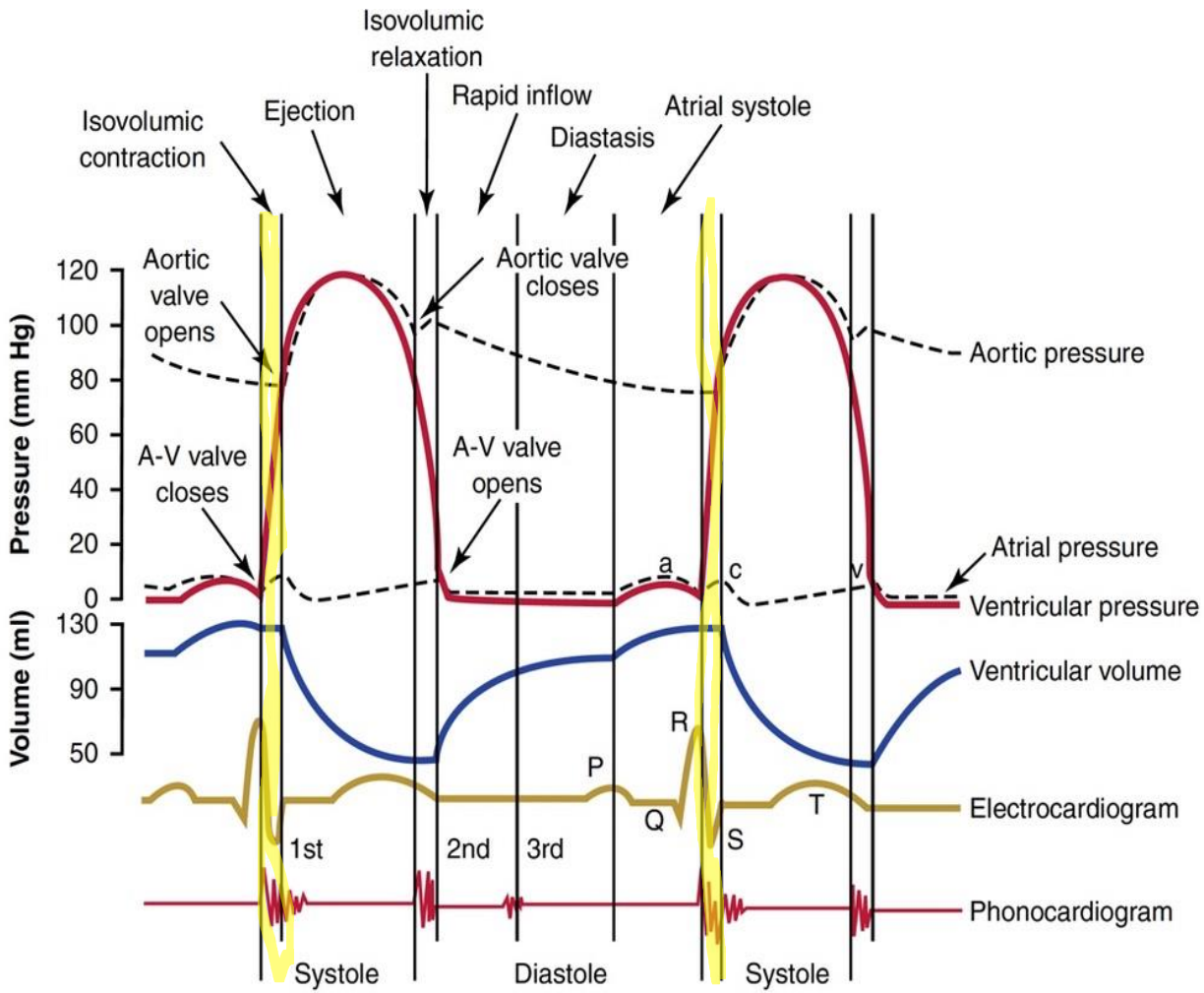
Onset of ventricular systole

- 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.
- This backward pressure differential forces the AV valve closed.

Isovolumic ventricular contraction

- All valves are closed.
- No blood flow, so isovolumic.
- Isometric contraction.
- Ventricular pressure continues to increase to exceed aortic pressure.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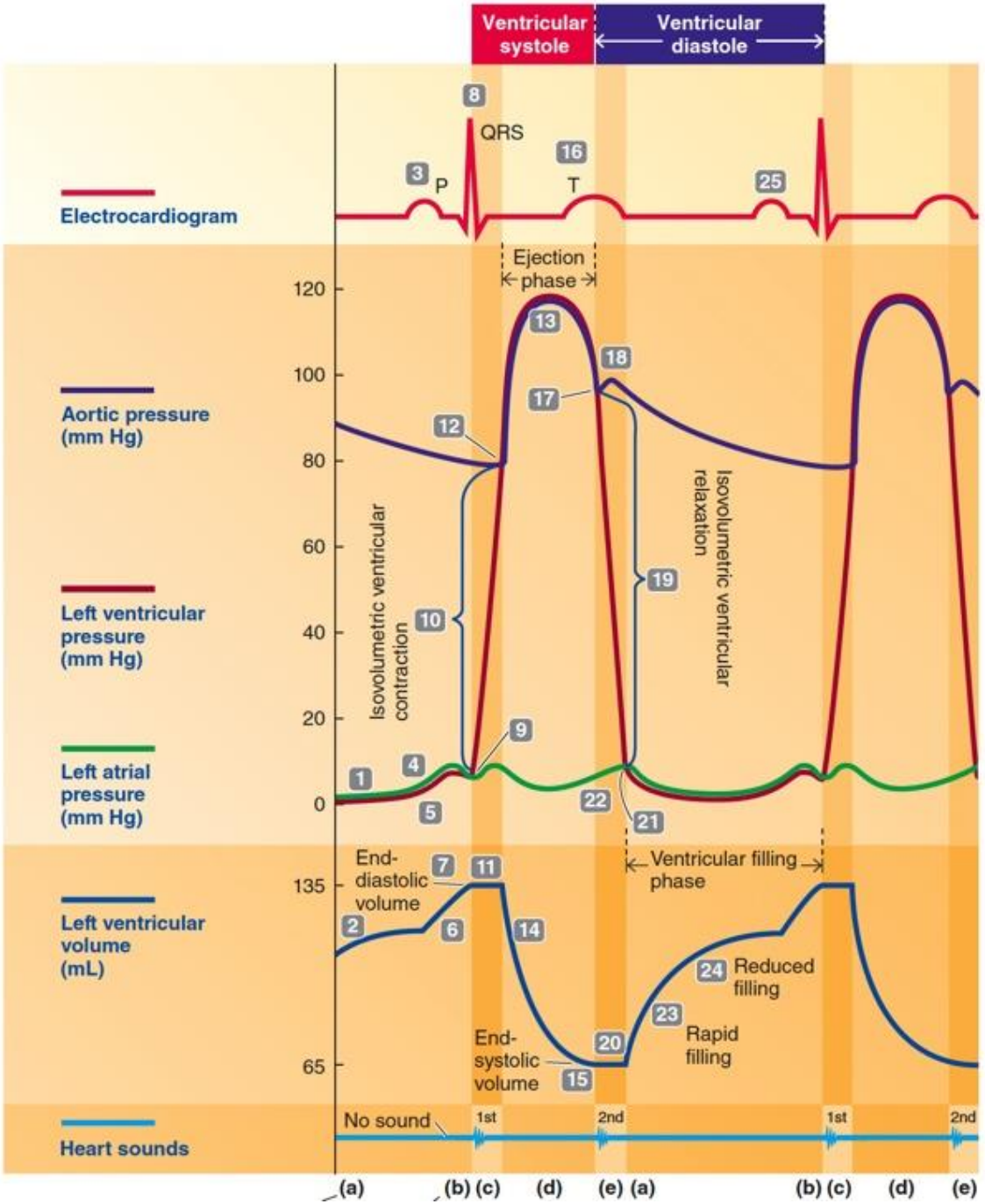
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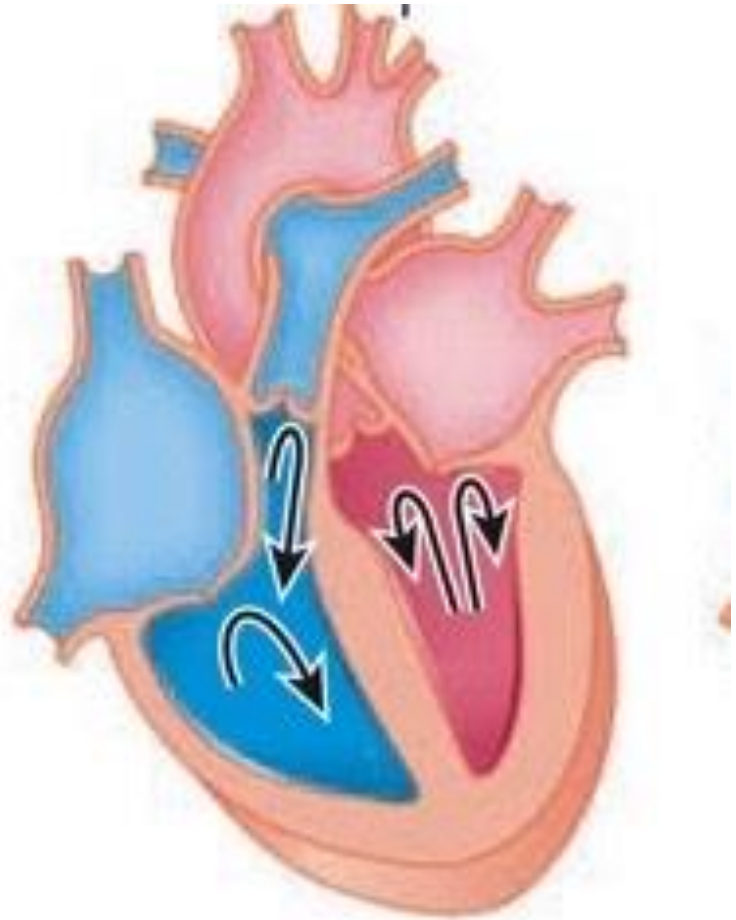
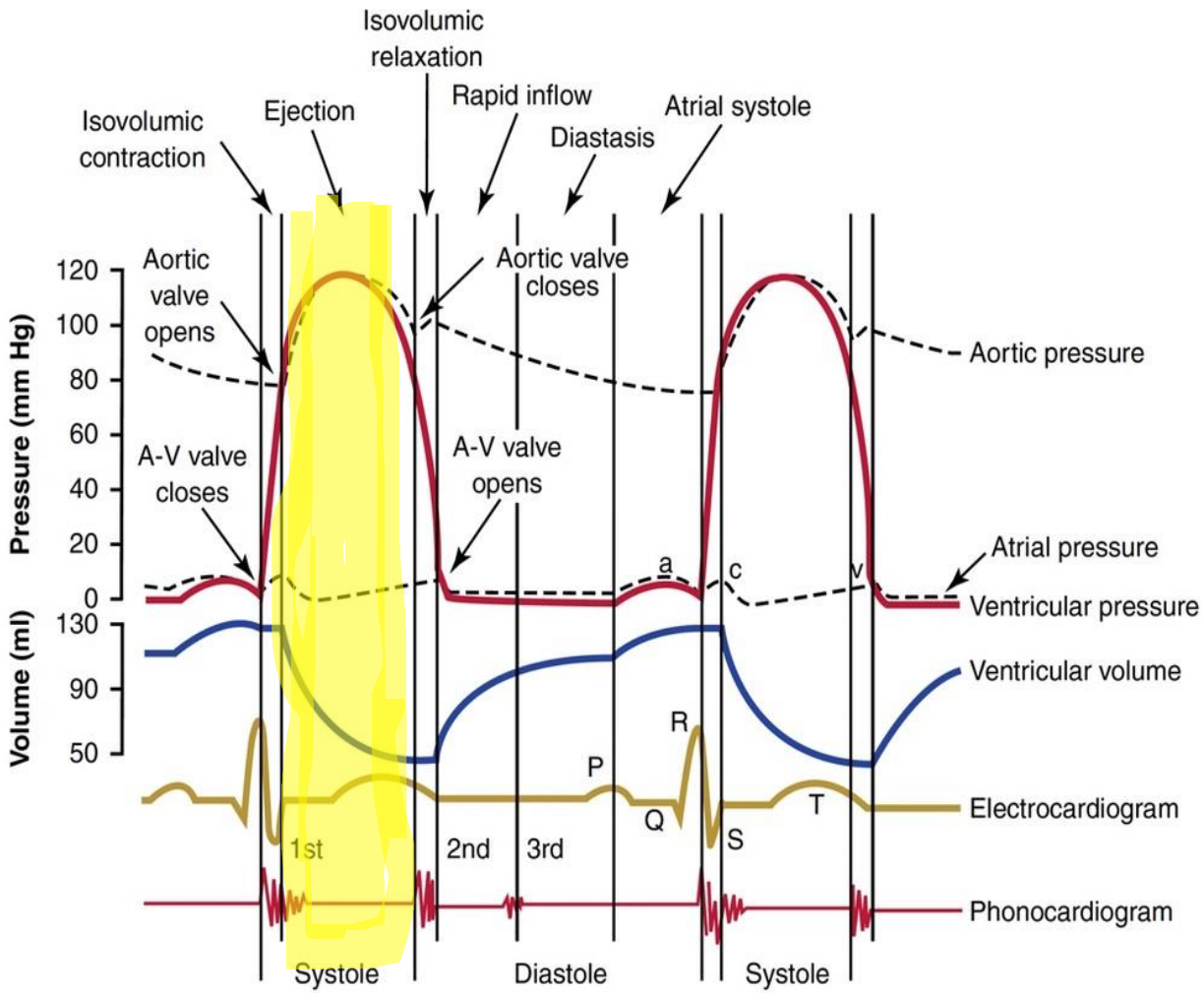


(c) Isovolumetric ventricular contraction

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.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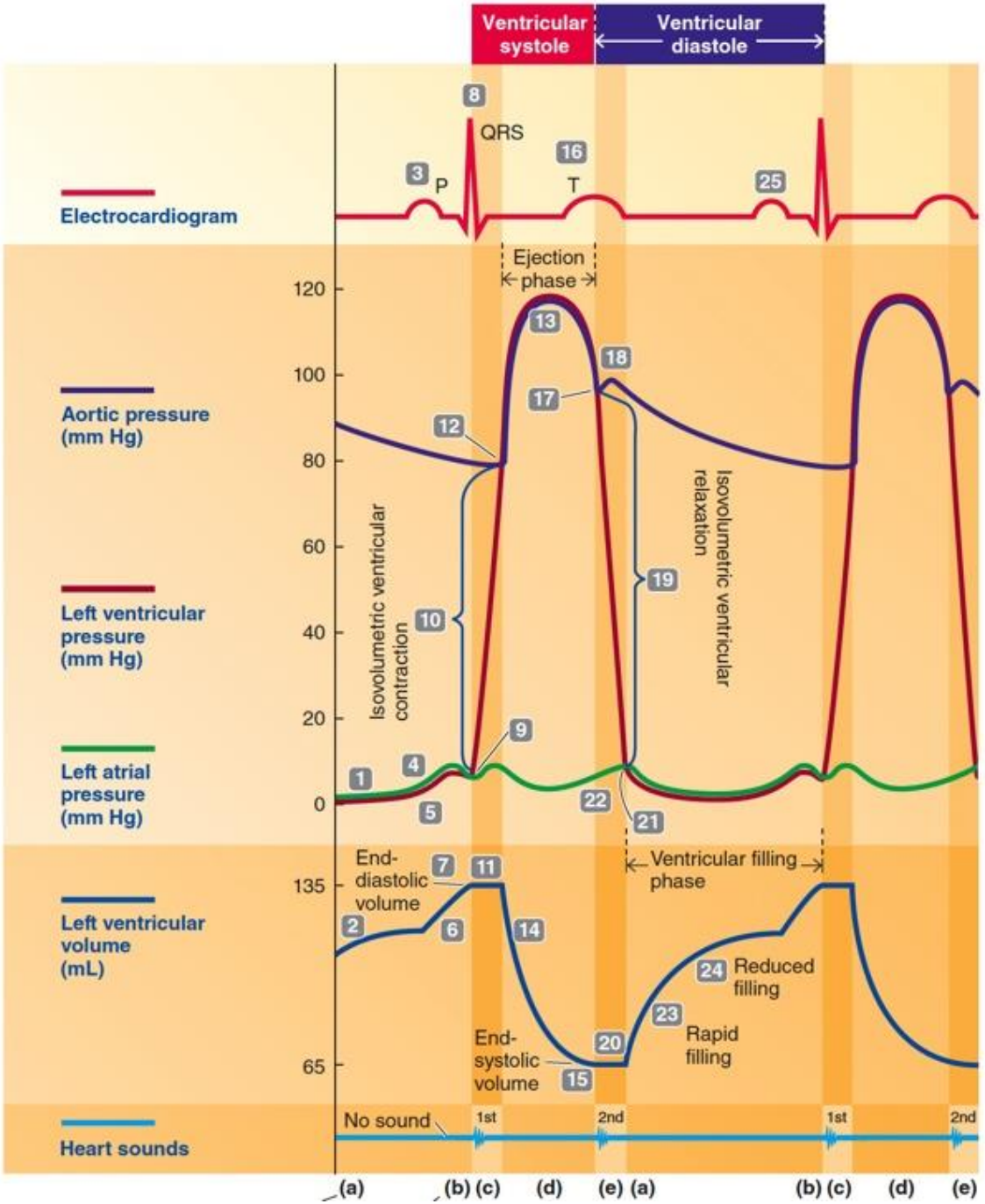
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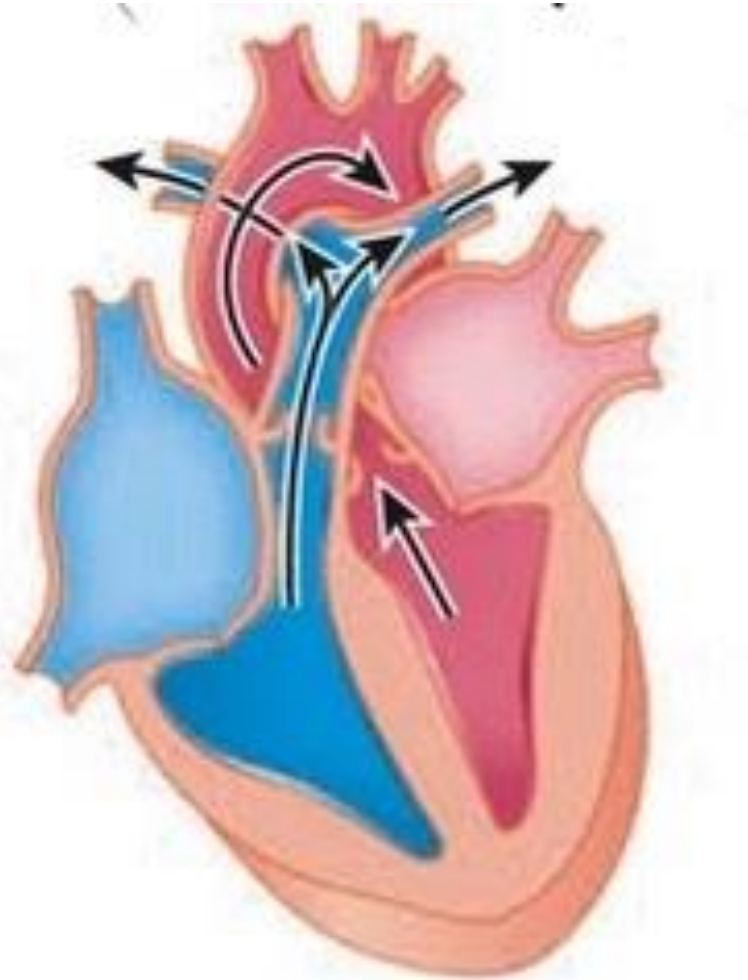
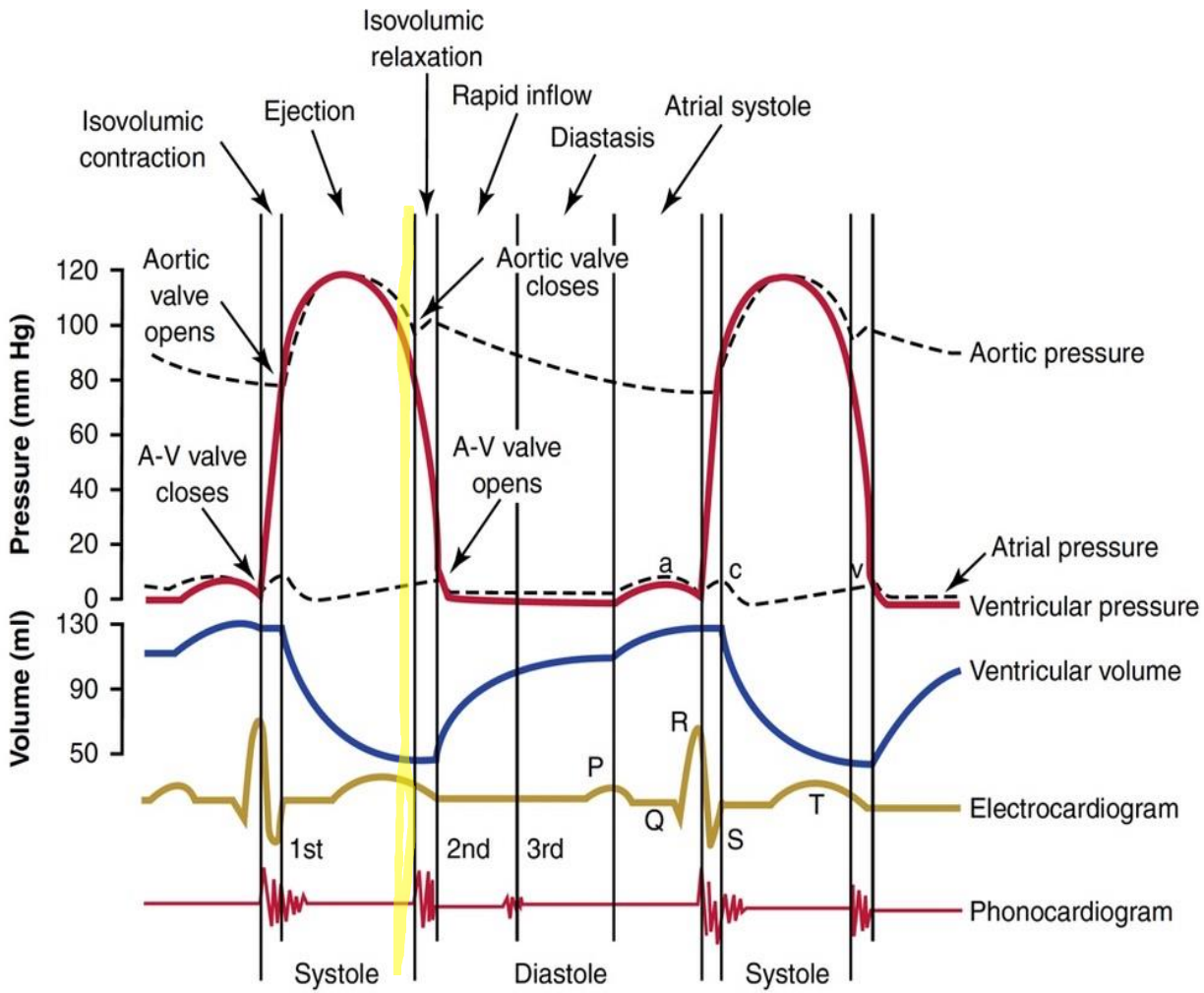


(d) Ventricular ejection

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 and the volume after contraction is the amount of blood ejected during the contraction, that is, SV.
- In our example, EDV is 135 mL, ESV is 65 mL, and SV is 70 mL.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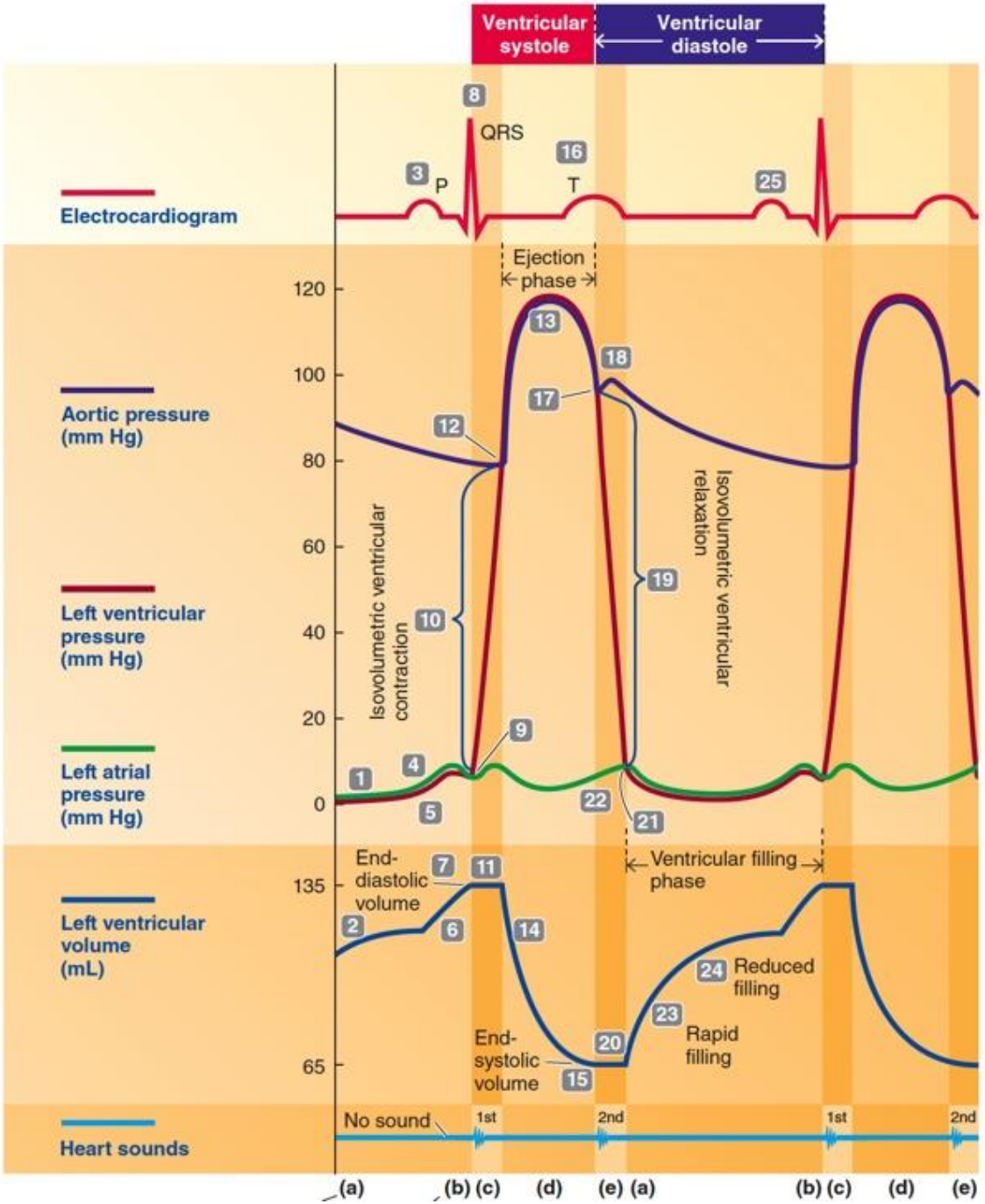
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No sound
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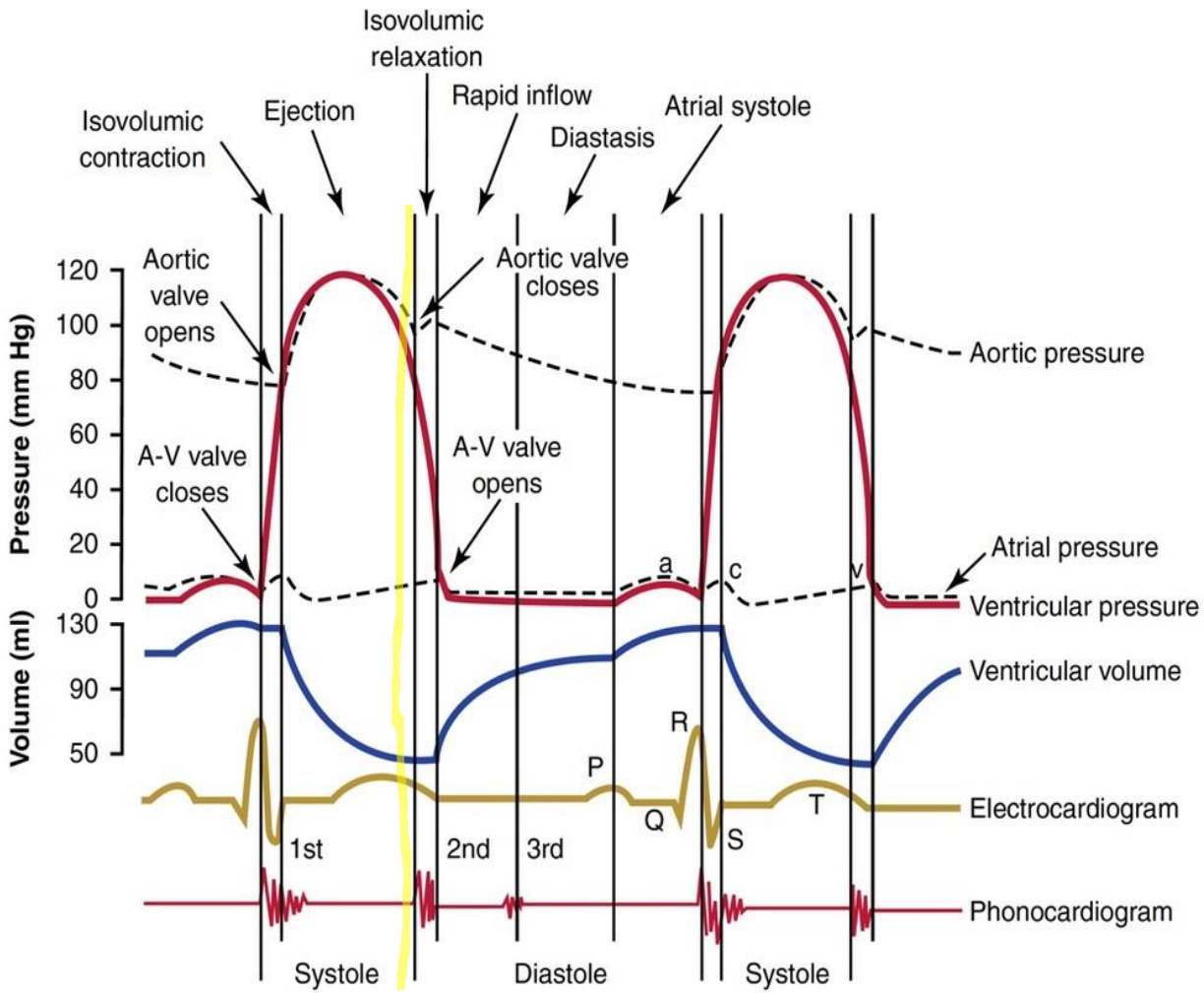
Onset of ventricular diastole

- 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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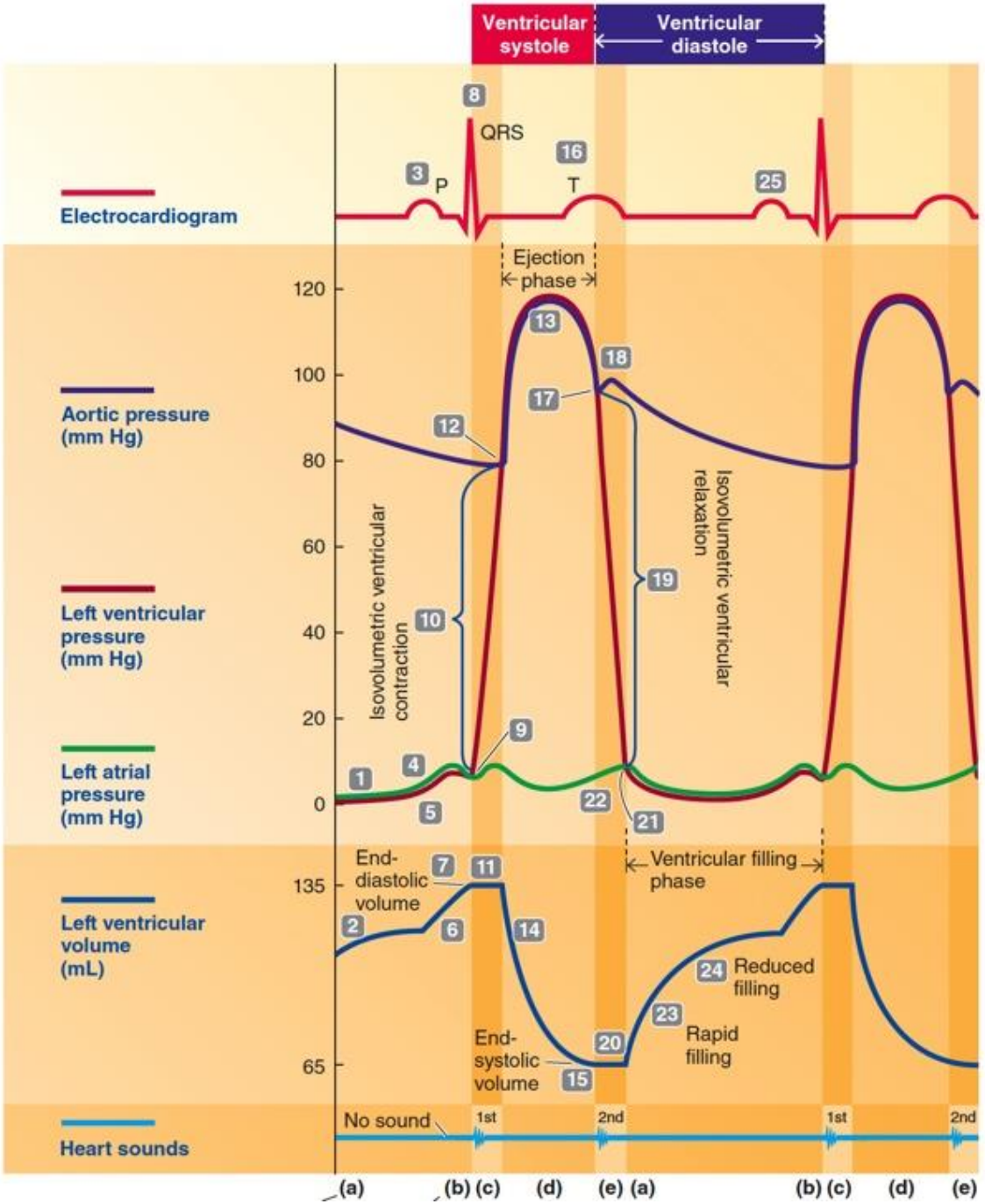
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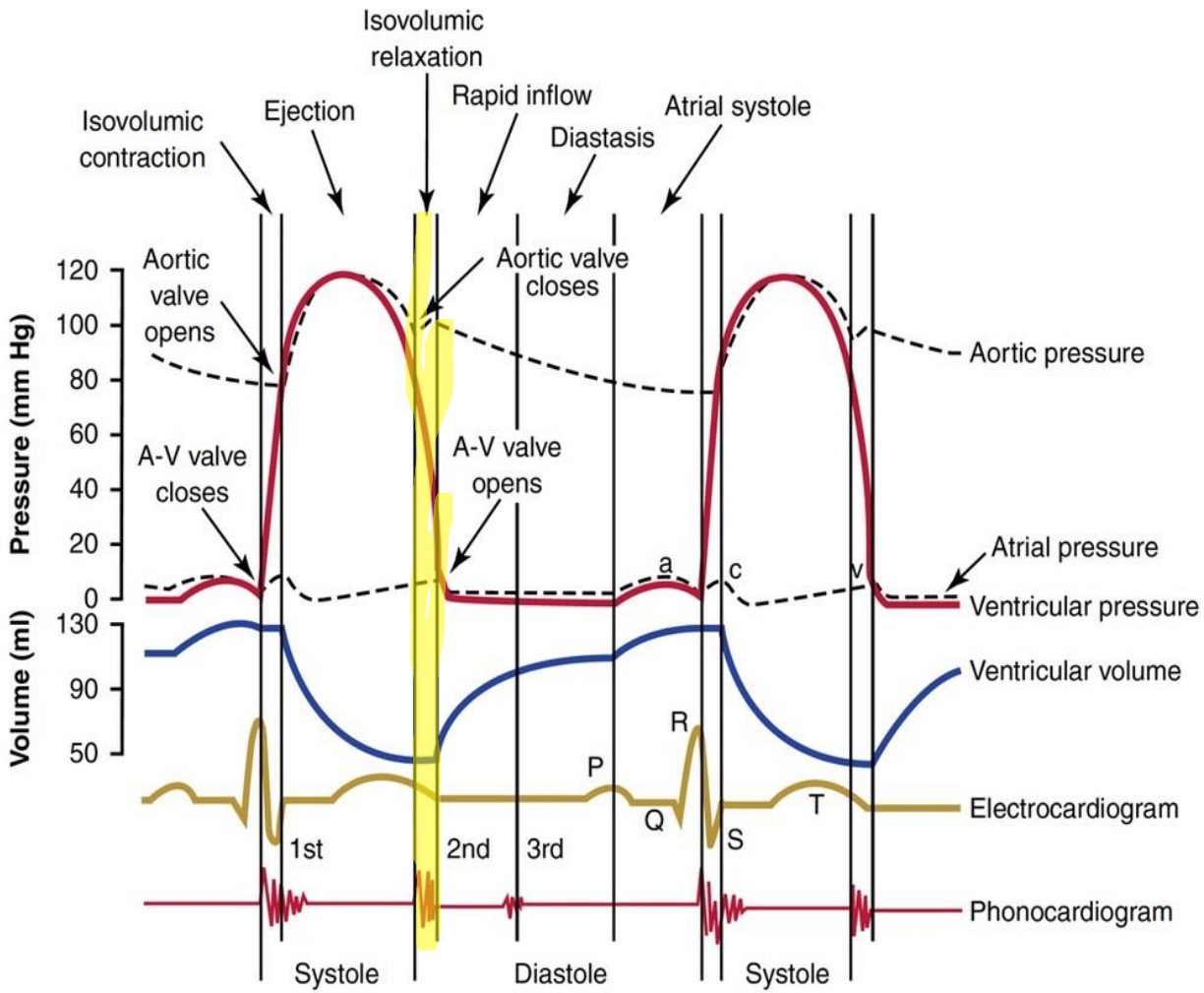
Isovolumic ventricular relaxation

- 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.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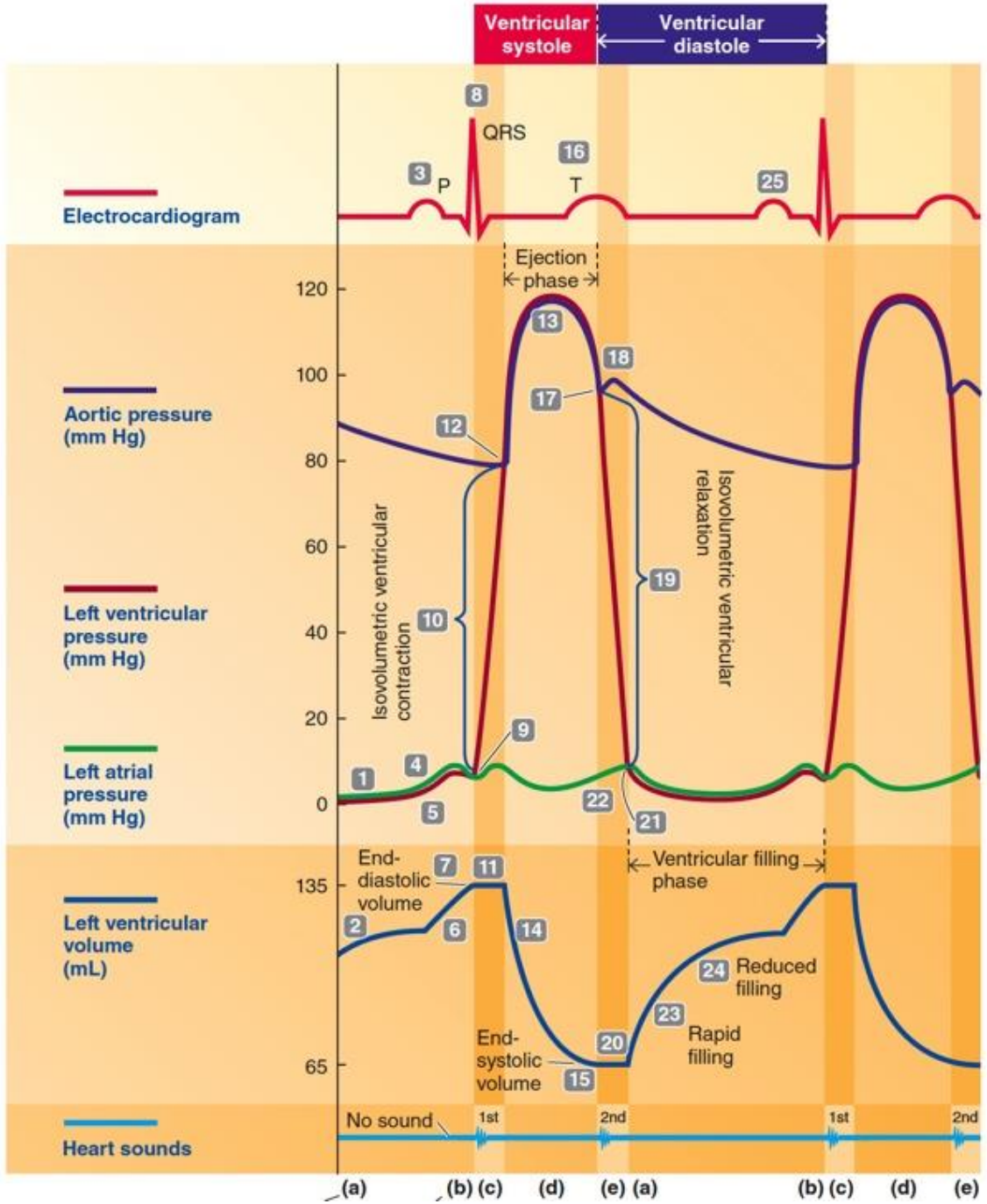
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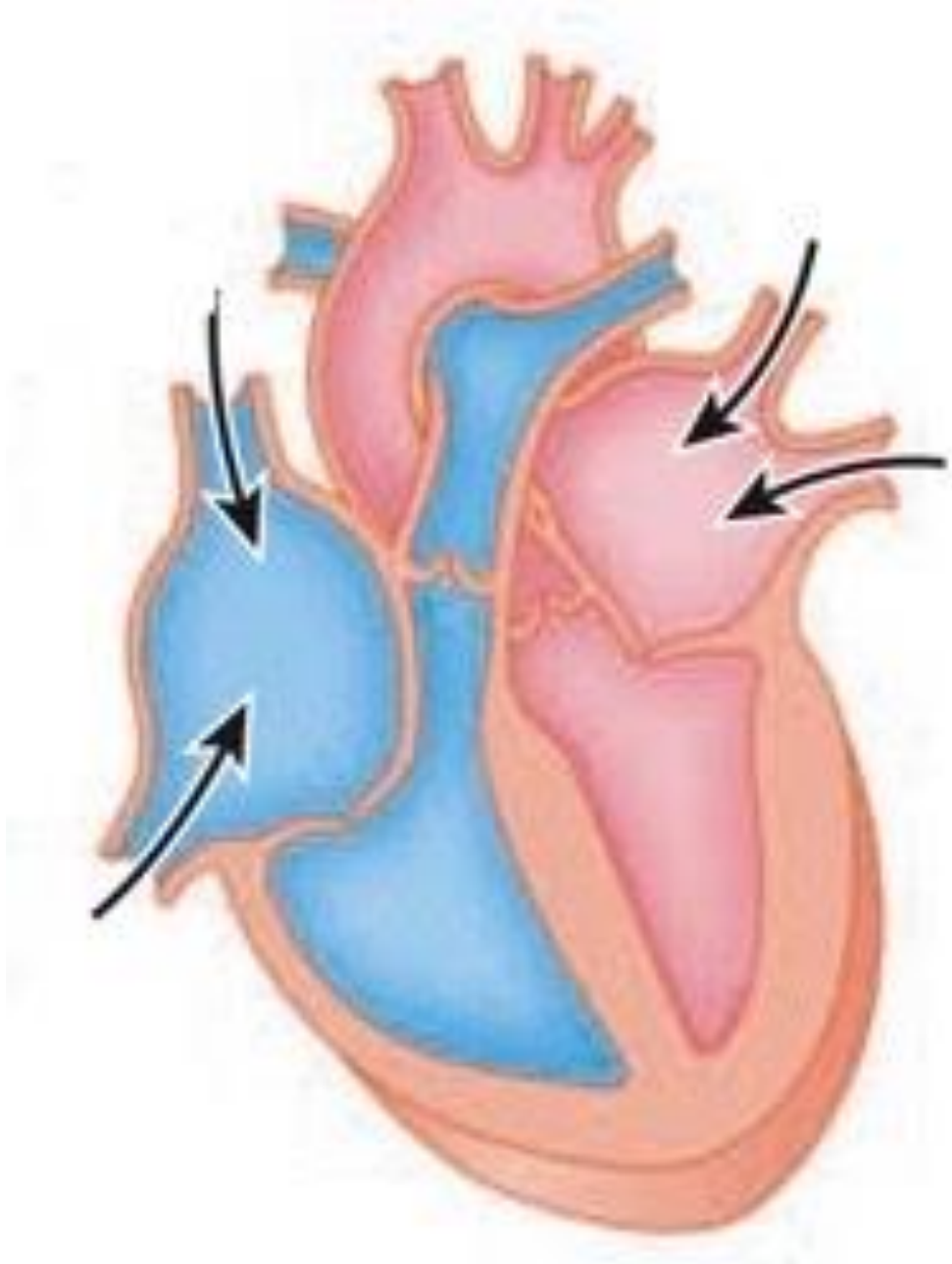
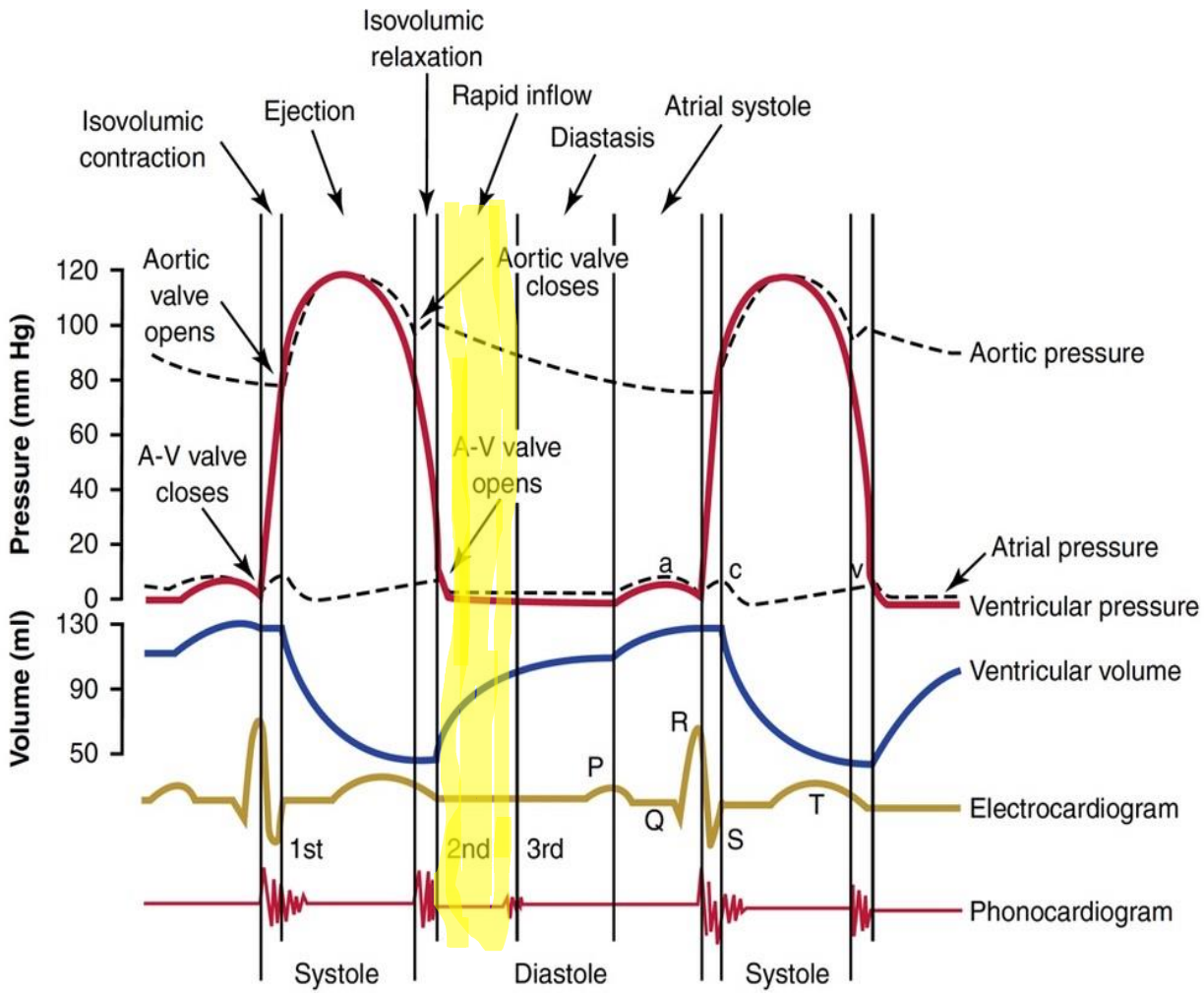


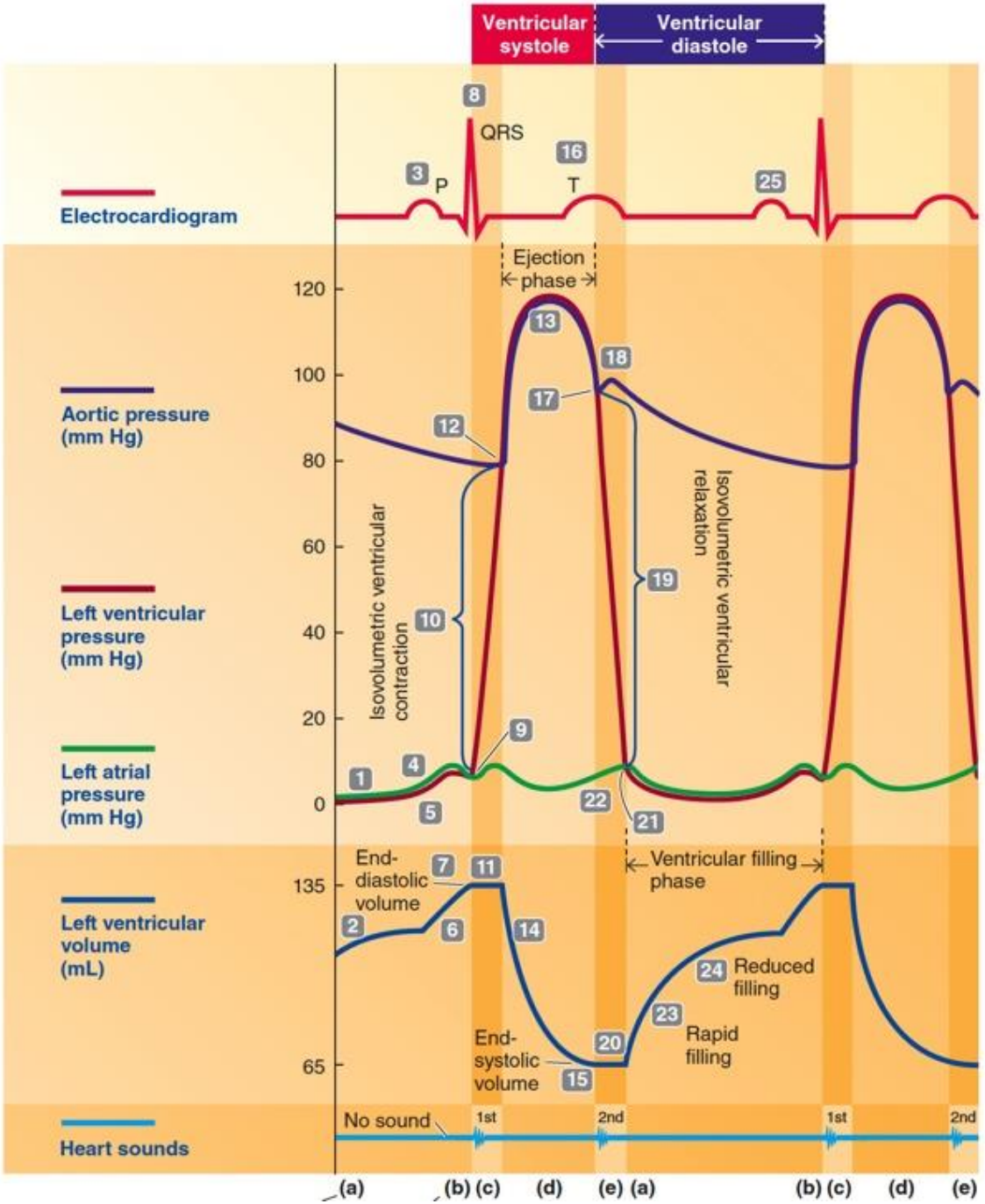
Ventricular filling

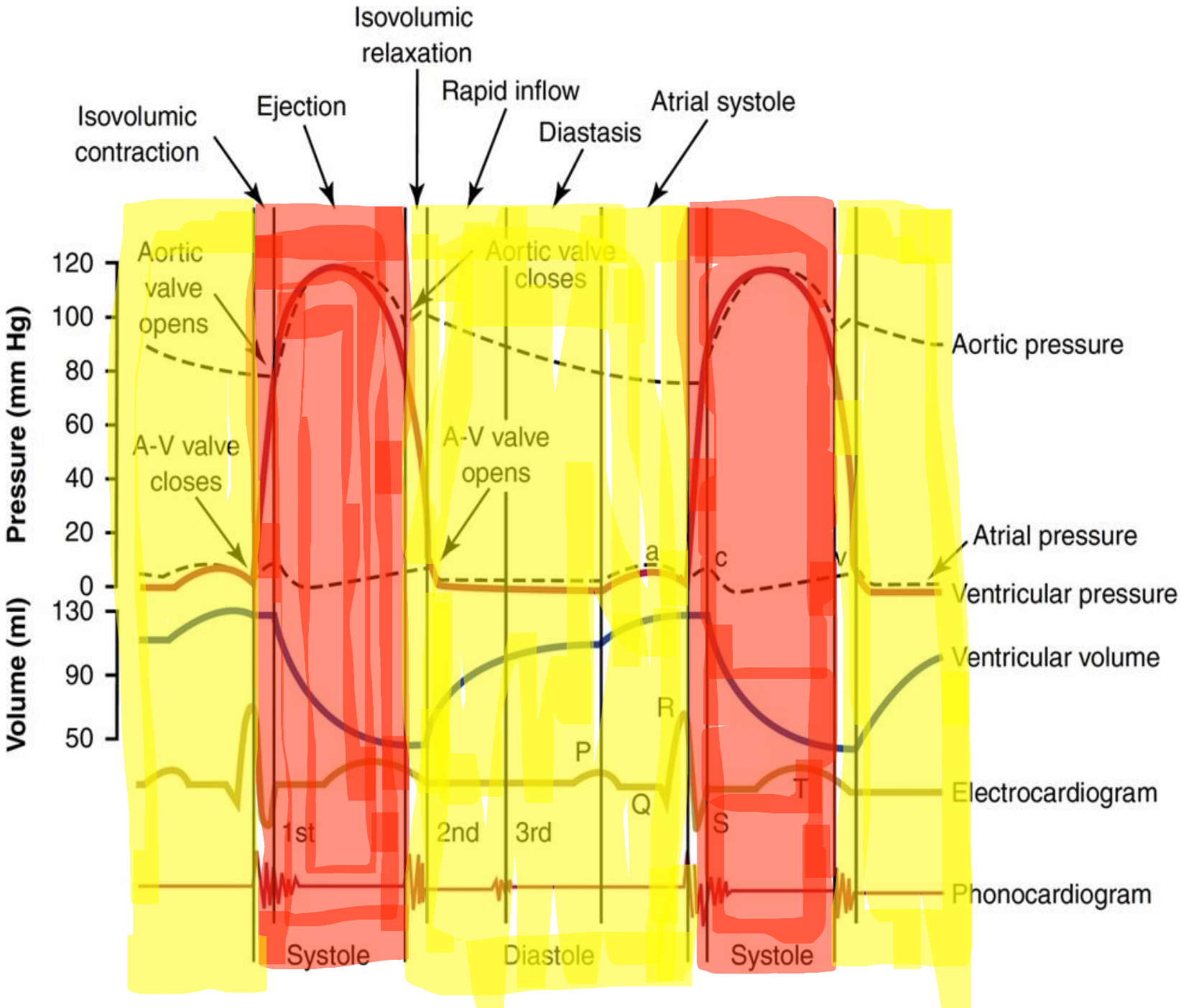
- Atrial repolarization and ventricular depolarization occur simultaneously, so the atria are in diastole throughout ventricular systole.
- Blood continues to flow from the pulmonary veins into the left atrium. As this incoming blood pools in the atrium, atrial pressure rises continuously.
- When the 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
Ejection
Rapid inflow
Atrial systole
Isovolumic contraction
Diastasis
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
Electrocardiogram
Phonocardiogram
P
Q
R
S
T
1st
2nd
3rd
Systole
Diastole
Systole


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
Rapid filling
Ventricular filling phase
No sound
1st
2nd
(a)
(b)
(c)
(d)
(e)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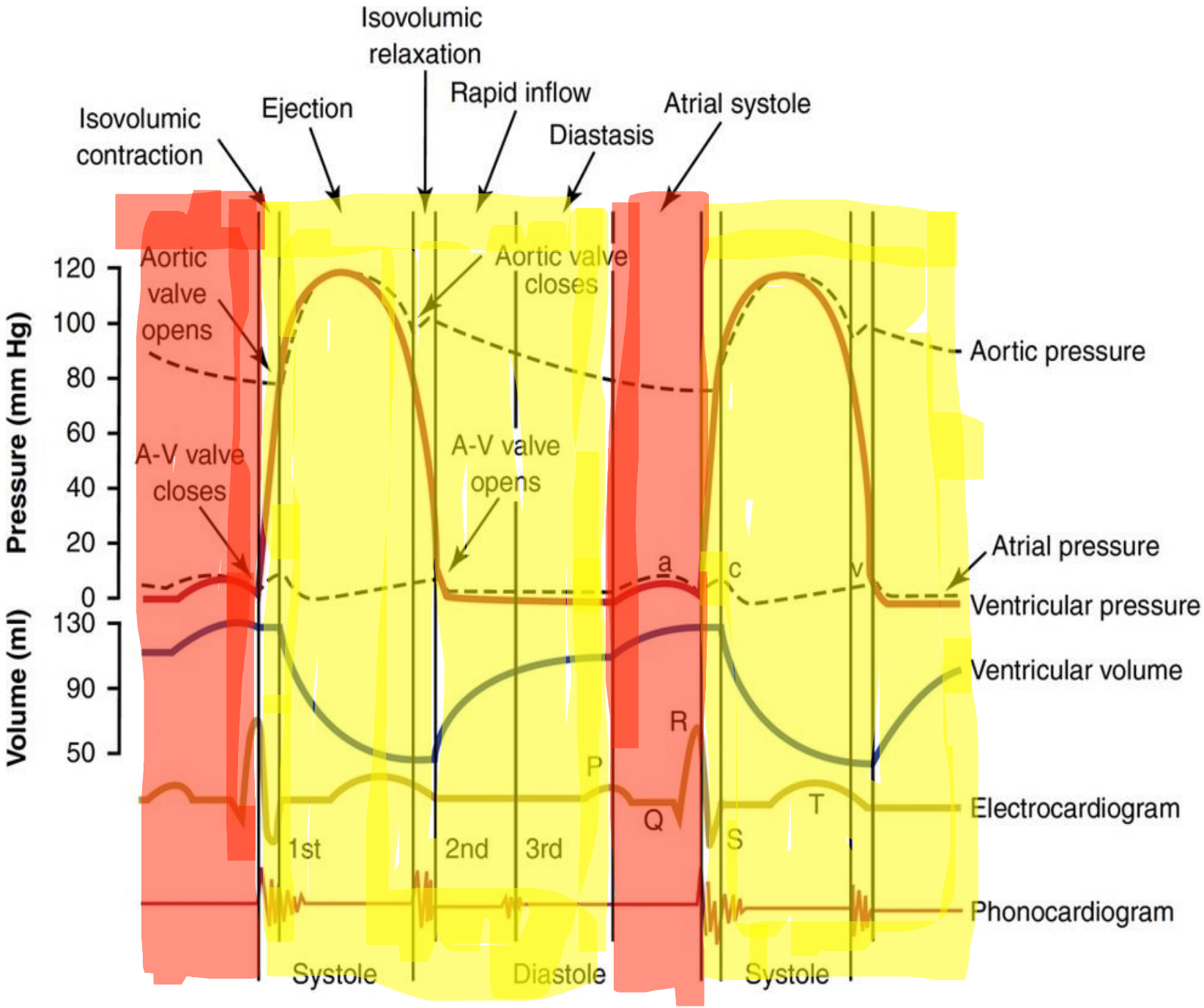
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1st
2nd
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Systole
Diastole
Systole

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.

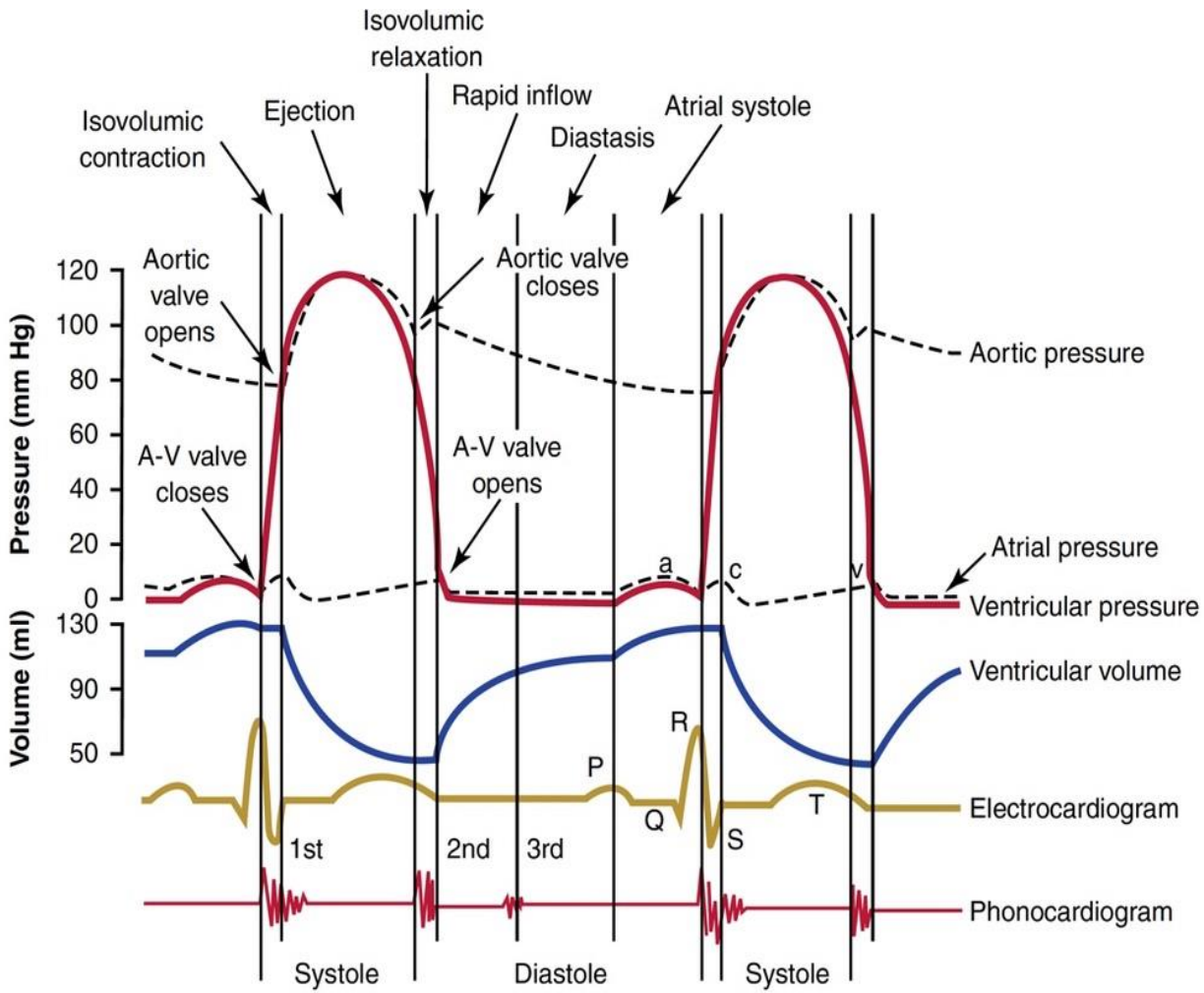
- This means that the heart beating very rapidly does not remain relaxed long enough to allow complete filling of the cardiac chambers before the next contraction.

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.
- 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** occurs when the ventricles begin to contract; 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; 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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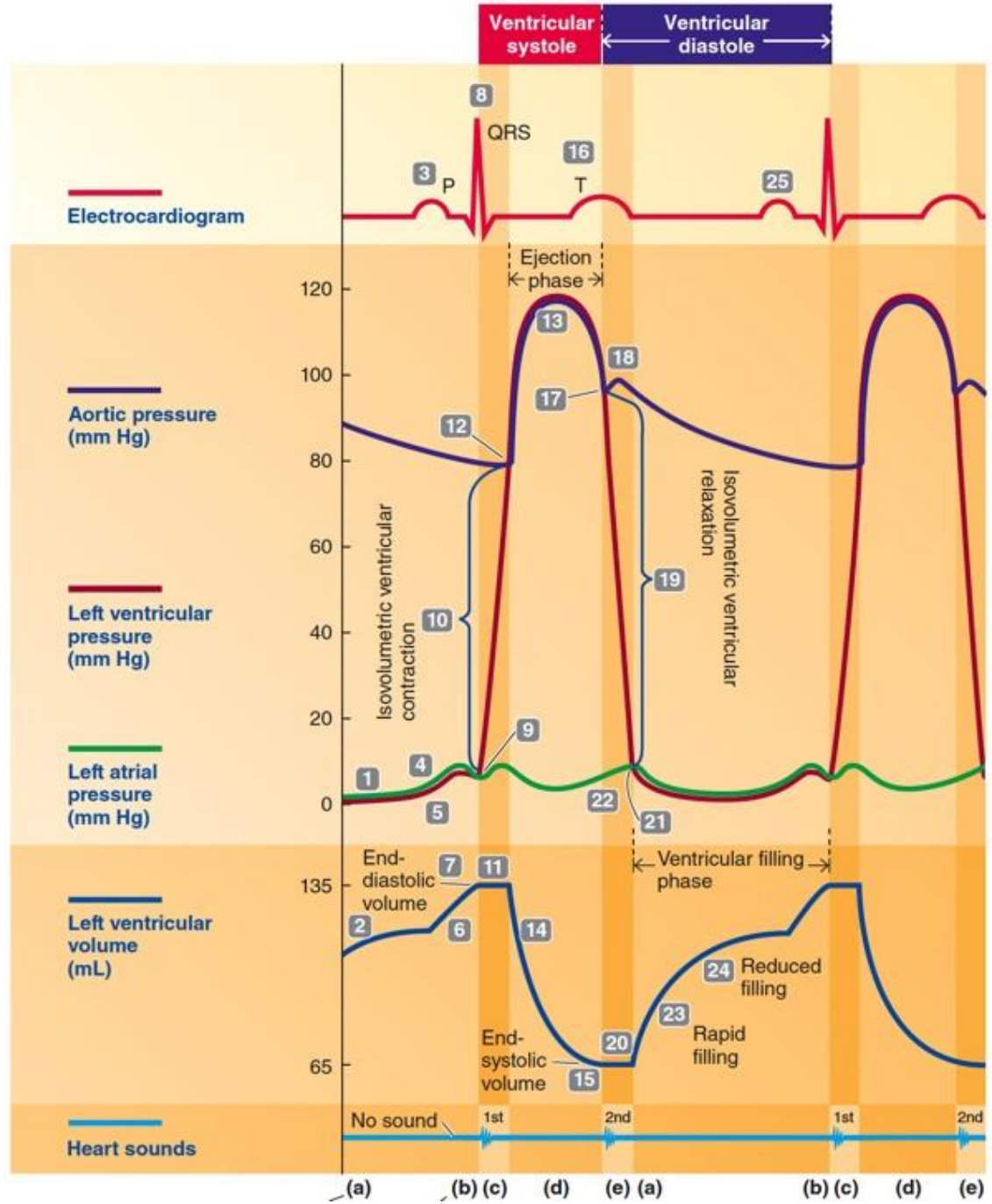
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65
(a)
(b)
(c)
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(e)

volumes

- End diastolic volume (EDV)
- End systolic volume (ESV)
- Stroke volume (SV)
- Ejection fraction (EF = SV/EDV)

Thank you