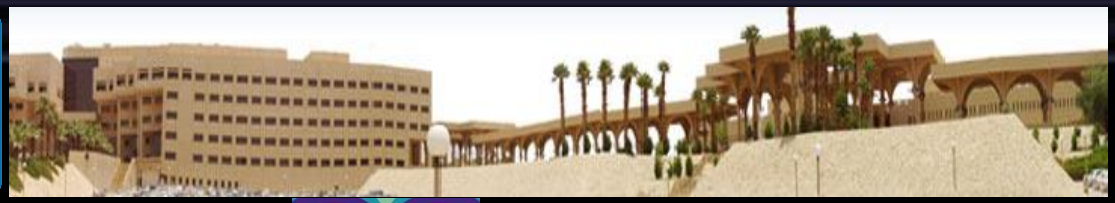
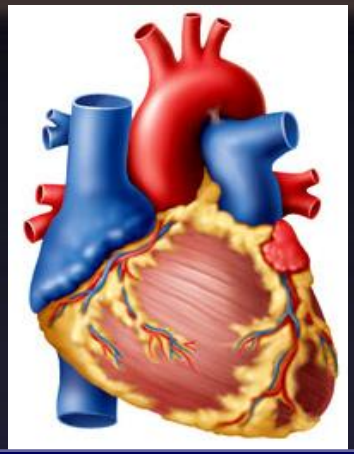
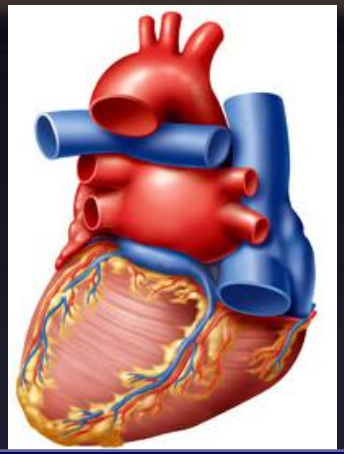


CARDIOVASCULAR SYSTEM

STROKE VOLUME





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OBJECTIVES

- **At the end of the lecture you should be able to …..**

1. **Define stroke volume, cardiac output, venous return, cardiac index & cardiac reserve**
2. **Understand the concept of preload and afterload**
3. **Describe the factors affecting the SV & CO**
4. **Explains how cardiac contractility & rate affects SV**
5. **Describe and explain the pressure-volume loop**

CARDIAC OUTPUT

Volume of blood ejected by each ventricle in each minute

Around 5 liters in an average adult at rest

STROKE VOLUME

Volume of blood ejected by each ventricle per each beat

(SV = EDV - ESV)

Around 70 ml in an average adult at rest

Cardiac output = Heart Rate × Stroke volume

CARDIAC INDEX is Cardiac Output
per Square Meter of Body Surface Area
$CI = CO/m^2$

VENOUS RETURN is the Quantity Of Blood Flowing
from the Veins into Right Atrium each Minute
$CO = VR$

PRELOAD is the amount of blood presented
to the Ventricles
AFTERLOAD is the resistance against Which
the ventricles contract

CARDIAC RESERVE

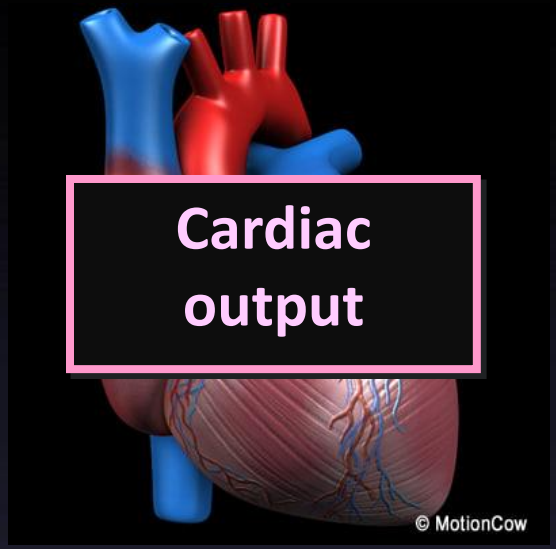
During exercise, the CO can increase to 20 - 25 liters/min and to as high as 35 - 40 liters/min in well trained athletes.

The difference between the resting CO and the maximum volume of blood the heart is capable of pumping per minute is known as the cardiac reserve.

Determinants of the CO

Afterload

Preload



Myocardial Contractility (Inotropic state)

Heart rate (Chronotropic state)

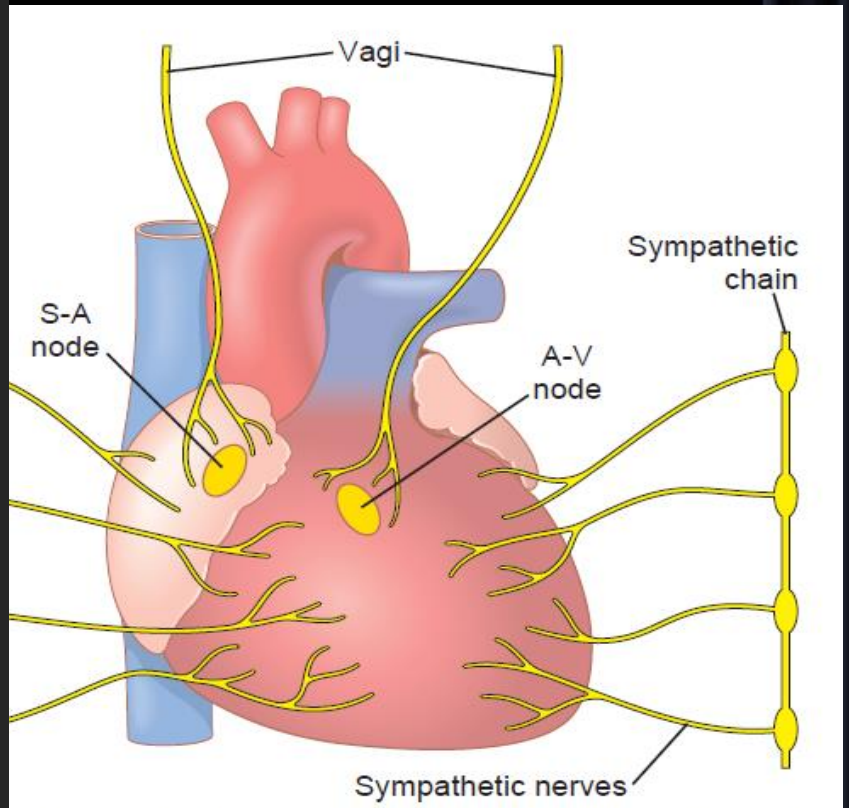
Determinants of the CO
1. Heart rate (HR)

- Since the CO is = SV . HR, as the heart rate increases, CO increases.
- At heart rates up to about 180, ventricular filling is adequate as long as there is enough venous return, and cardiac output per minute is increased by an increase in heart rate.
- However, at very high heart rates, filling may be compromised to such a degree that cardiac output per minute falls.
- The heart rate has an influence on cardiac contractility as well (Frequency-force relationship).

Regulation of heart rate

Effect of Sympathetic & Parasympathetic Nerves

- Sympathetic nerves innervate the whole heart.
- Sympathetic stimulation increases heart rate (and also the contractility).
- Sympathetic nerves release noradrenaline (adrenaline), which stimulates heart β_1-receptors.
- Parasympathetic nerves innervate the SA and AV nodes, and the atria and Purkinje system.
- Parasympathetic nerves do not innervate most of the ventricular myocardium.
- Parasympathetic stimulation slows the heart but has little inotropic action.
- Parasympathetic nerves release ACh that stimulates muscarinic (M_2) receptors.



9-13. Cardiac *sympathetic* and *parasympathetic* nerves. (The nerves to the heart are parasympathetic nerves.) A-V, atrioventricular; S-A, sinoatrial.

The SA node, atria, and AV node have vagal innervation, but the ventricles do not.

Inotropic Chronotropic & Dromotropic

CONTRACTILITY

Positive inotropic agents produce an increase in contractility.

Negative inotropic agents produce a decrease in contractility

HEART RATE

Positive chronotropic effect

Negative chronotropic effect

CONDUCTION VELOCITY

Positive dromotropic effect

Negative dromotropic effect

Parasympathetic effects on heart

Negative chronotropic effect:

- decreases heart rate by decreasing the rate of phase 4 depolarization.
- Fewer action potentials occur per unit time because the threshold potential is reached more slowly .
- The mechanism is decreased If, the inward Na+ current that is responsible for phase 4 depolarization in the SA node.

Negative dromotropic effect

- decreases conduction velocity through the AV node.
- Action potentials are conducted more slowly from the atria to the ventricles. increases the PR interval.
- The mechanism is decreased inward Ca2+ current and increased outward K+ current.

Negative inotropism

- ACh via muscarinic receptors decreases the force of contraction in the atria by decreasing the inward Ca2+ current during the plateau of the cardiac action potential.

Sympathetic effects on heart

Positive chronotropic effect

- increases heart rate by increasing the rate of phase 4 depolarization.
- More action potentials occur per unit time because the threshold potential is reached more quickly .
- The mechanism is increased If, the inward Na+ current that is responsible for phase 4 depolarization in the SA node.

Positive dromotropic effect

- Increases conduction velocity through the AV node.
- Action potentials are conducted more rapidly from the atria to the ventricles, and ventricular filling may be compromised. decreases the PR interval.
- The mechanism of the positive dromotropic effect is increased inward Ca2+ current.

Positive Inotropism

- Increases the force of contraction by two mechanisms:

(1) It increases the inward Ca2+ current during the plateau of each cardiac action potential.

(2) It increases the activity of the Ca2+ pump of the SR (by phosphorylation of phospholamban); as a result, more Ca2+ is accumulated by the SR and thus more Ca2+ is available for release in subsequent beats.

NE Alpha1 receptors.

Effect 0f Sympathetic and Parasympathetic Stimulation on Prepotential (Pace Maker Potential)

The $ß_1$-adrenoreceptors on SA node cells cause

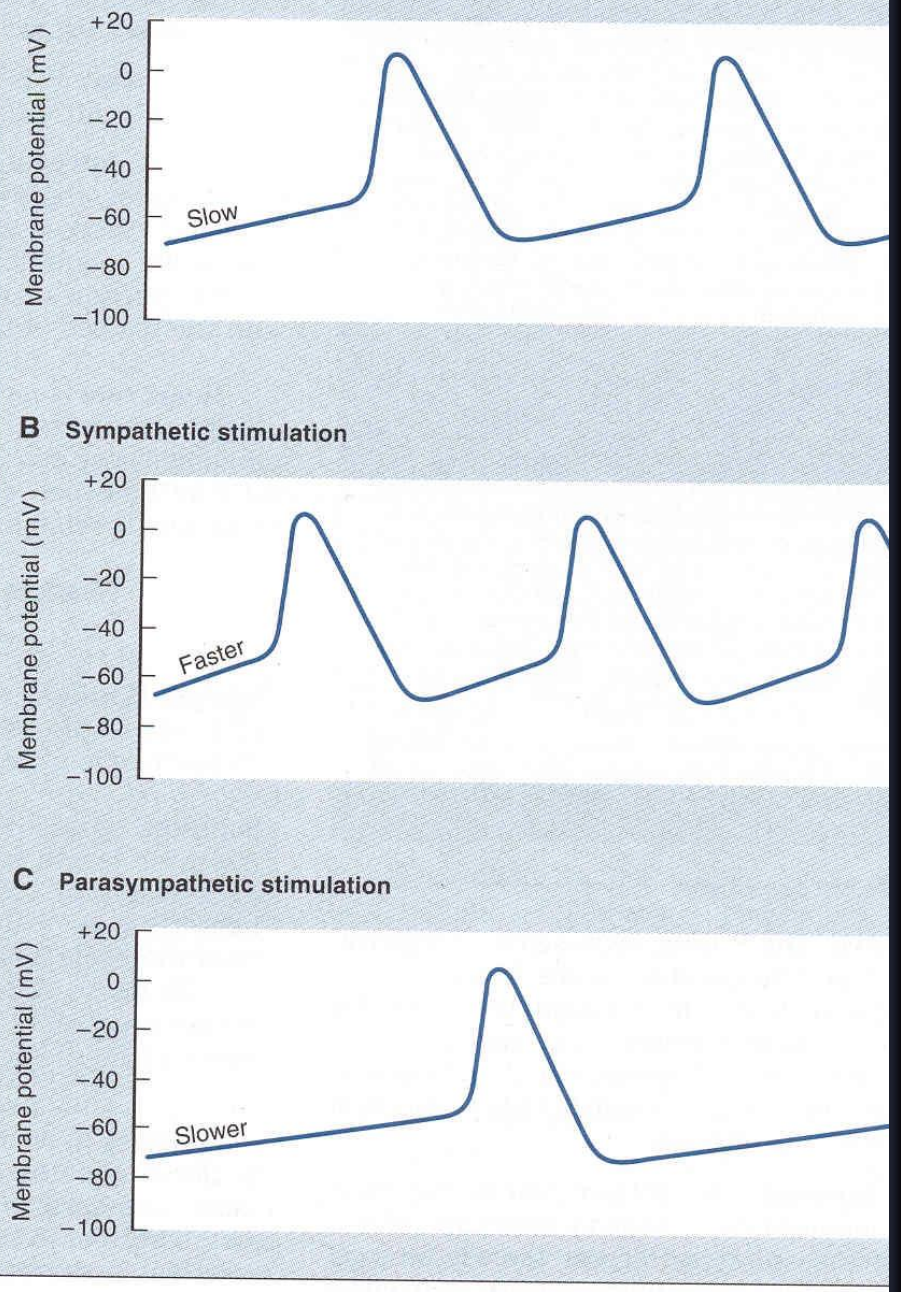
- Opening of Na^+ and Ca^{2+} channels → speed up the rate of depolarization and hence the heart rate.
- Decrease in K^+ permeability by accelerating inactivation of the K^+ channels. Thus, fewer positive potassium ions leave the cell → the inside of the cell becomes less negative → depolarizing effect.

The net effect is: → swifter drift to threshold → greater frequency of action potential → increase the heart rate.

M2 (muscarinic-2) ACh receptors cause:

- closure of Na+ and Ca2+ channels.
- opening of potassium channels in the cell membrane → hyperpolarises the cell and makes it more difficult to initiate an action potential.

The net effect is: → slower drift to threshold → lesser frequency of action potential → decrease the heart rate.



Effect of Ions and Temp

- ↑K…. in the extracellular fluids causes the heart to become dilated and flaccid and also slows the heart rate… ↑K decreases the resting membrane potential in the cardiac muscle fibers… the intensity of the action potential also decreases, which makes contraction of the heart progressively weaker

- ↑Ca causes spastic contraction. This is caused by a direct effect of calcium ions to initiate the cardiac contractile process. ↓ Ca causes flaccidity.

- ↑ Temp… causes a greatly increased heart rate, sometimes to as fast as double normal [↑ permeability to ions that self-excitation]. Decreased temperature causes a greatly decreased heart rate, falling to as low as a few beats per minute

FACTORS AFFECTING CONTRACTILITY

- **Positive ionotropic effect. (FORCE OF CONTRACTION)**
  - ✓ Sympathetic stimulation
  - ✓ Adrenaline & Noradrenaline
  - ✓ Calcium ion
  - ✓ Caffine
  - ✓ Drugs e.g. Digitalis (Digoxin)
- **Negative ionotropic effect:**
  - ✓ Parasympathetic stimulation
  - ✓ Acetyl choline
  - ✓ Potassium ion
  - ✓ Hypoxia (Decrease oxygen)
  - ✓ Acidosis
  - ✓ Bacterial toxin
  - ✓ Drugs e.g.. Calcium channel blockers, β- Blockers

Factors affecting myocardial contractility: (Inotropic facctors)

1. End-Diastolic Volume [Starling's law of the heart]
2. Cardiac innervation [SNS → ↑, PNS → ↓]
3. Oxygen supply [Hypoxia → ↓ contractility]
4. Calcium ↑ & potassium ions ↓ contractility.
5. Physical factors [Warming → ↑, Cooling → ↓]
6. Mechanical factors [syncytium, cannot be tetanized]
7. Hormonal & chemical factors (drugs).

Positive inotropic: (Adrenaline, noradrenaline, alkalosis, digitalis, Ca^{2+} and caffein)

Negative inotropic: (Acetylcholine, acidosis, ether, chloroform, some bacterial toxins (e.g. diphtheria toxins), K^{+}, …)

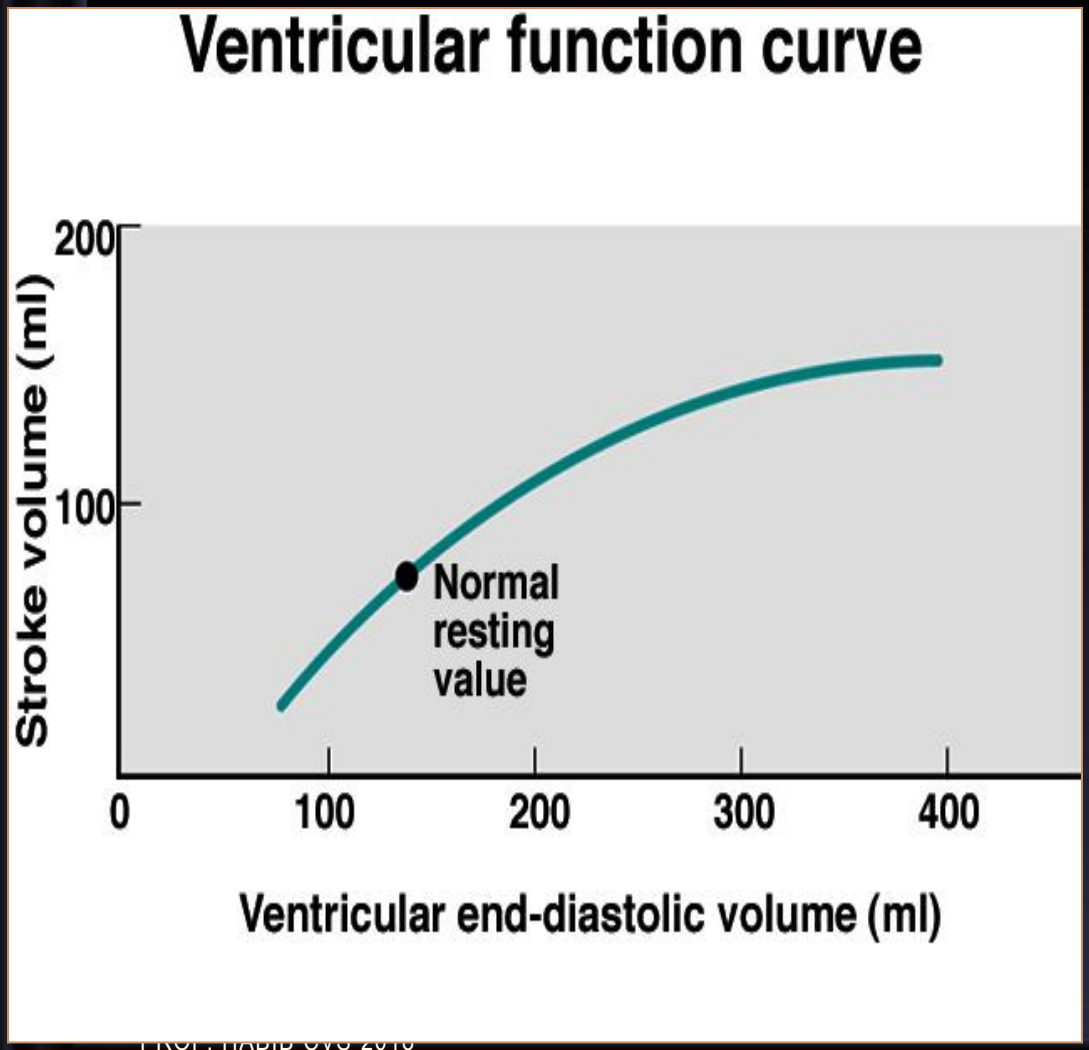
What is the influence of heart rate on myocardial contractility?

Frequency-force relationship

Increasing heart rate increases contractility.

- This frequency dependency of force generation in the heart is probably due to accumulation of Ca^{2+} ions within the myocytes as a result of:
- The increased in number of depolarizations/min → more frequent plateau phases → more Ca^{2+} entry.
- The magnitude of Ca^{2+} current is also increased → increases the intracellular Ca^{2+} stores.
- Both effects enhance the release and uptake of Ca^{2+} by the sarcoplasmic reticulum, thus Ca^{2+} availability to the contractile proteins with more force generation through cross-bridge cycling.

Determinants of the CO
2. Stroke volume (SV)



The intrinsic relationship between EDV and SV is known as Starling's Law of the heart. It reflects the ability of the heart to change its force of contraction and therefore stroke volume in response to changes in venous return.

FRANK – STARLING'S LAW

Within physiologic limits, the heart pumps all the blood that returns to it by the way of the veins.

OR

The greater the stretch of the cardiac muscle the greater would be the force of contraction.

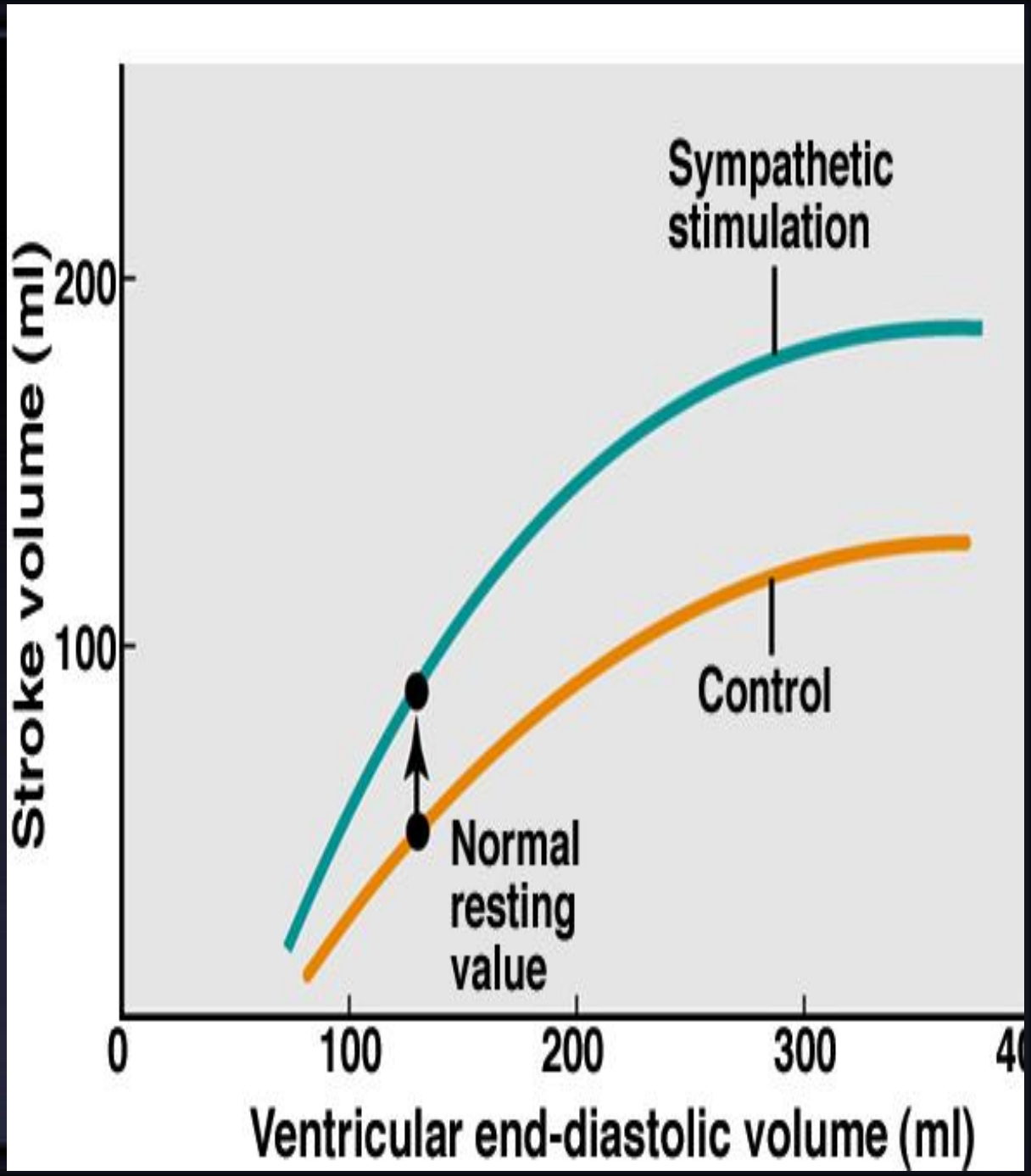
OR

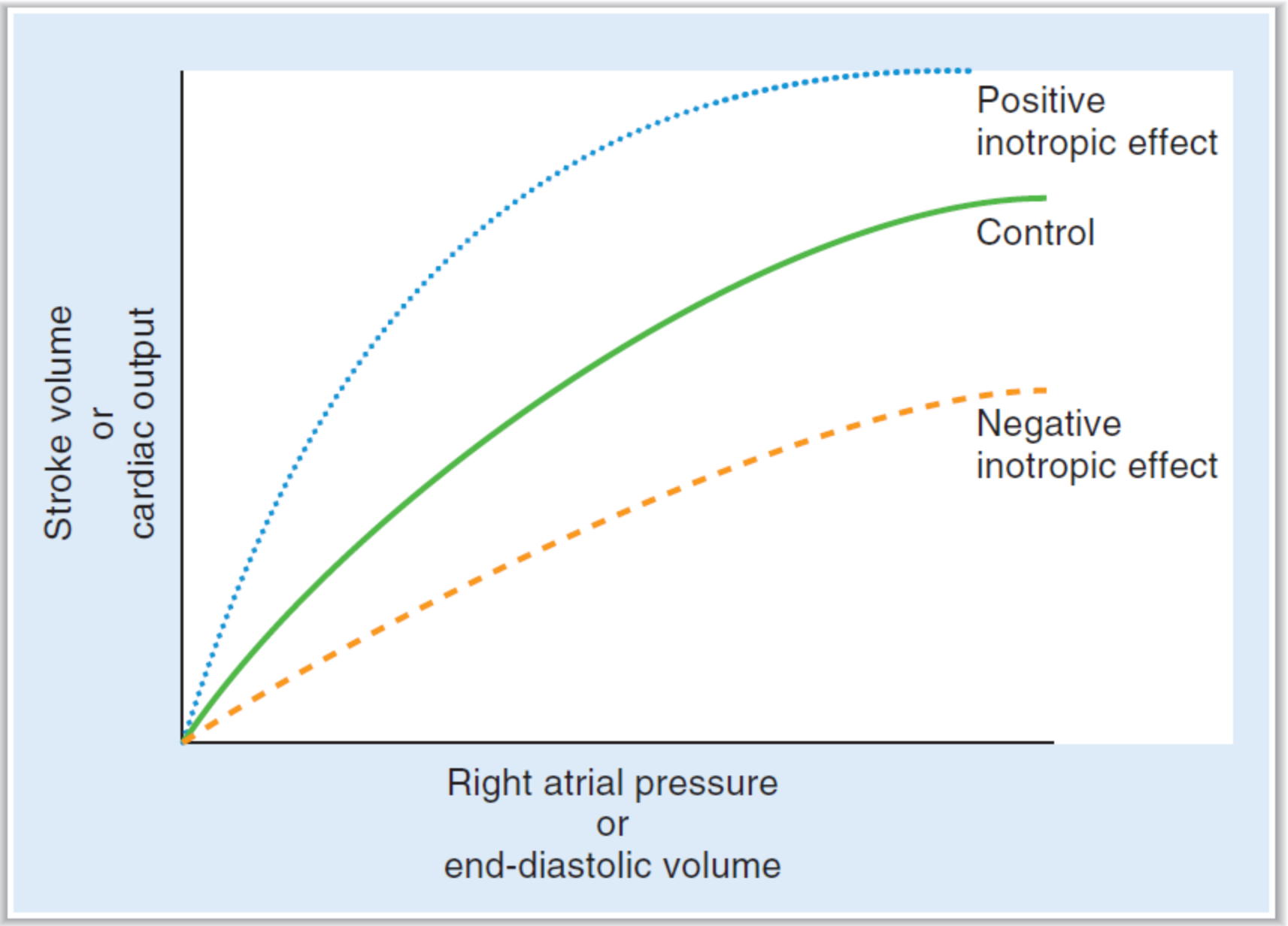
"The energy of contraction is proportional to the initial length of the cardiac muscle fibers" and for the muscle is proportional to the End Diastolic Volume.

Because Actin & Myosin filaments are brought to more optimal degree of sliding therefore increase force of contraction.

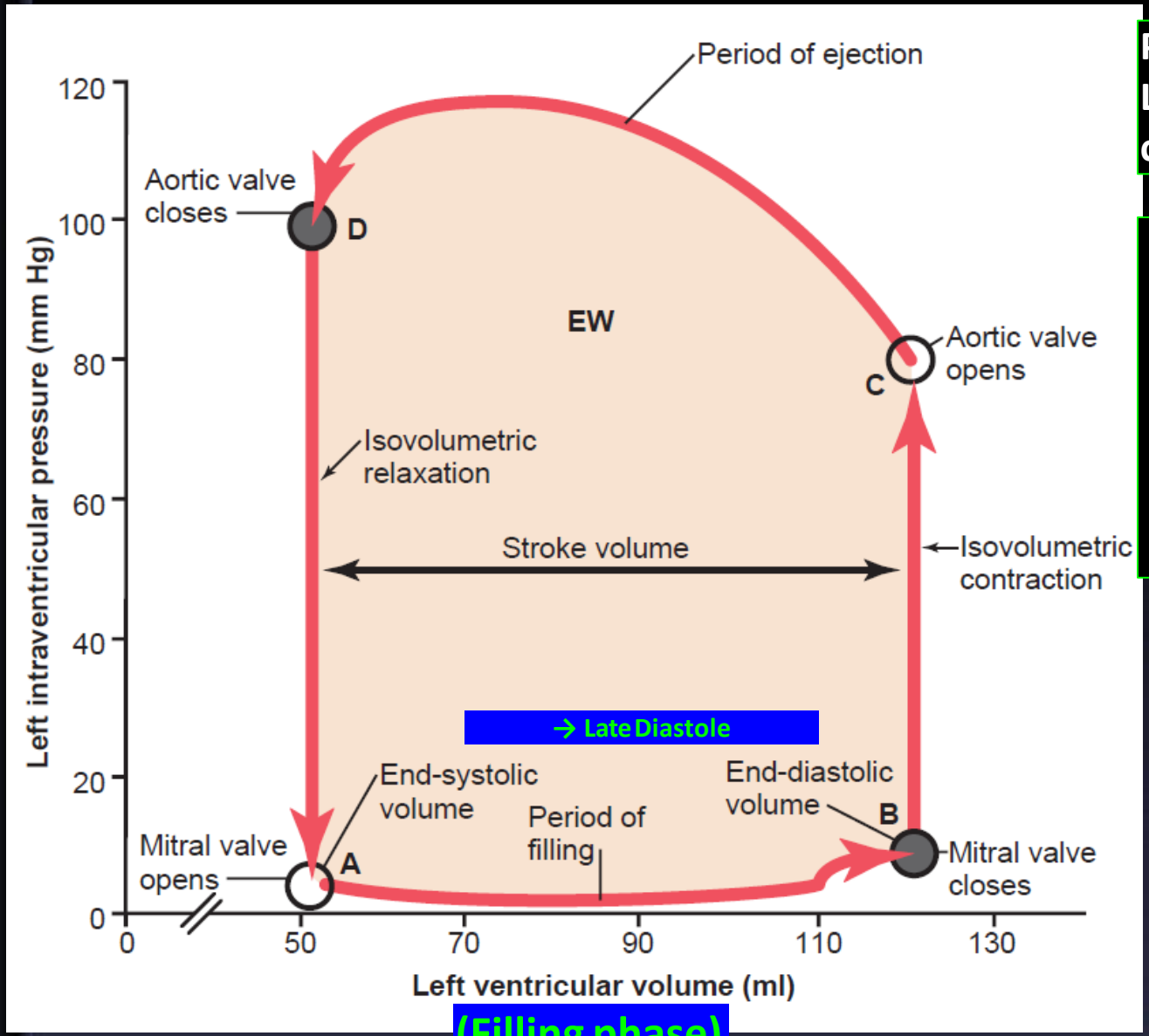
- When the mean RAP is about 0 mmHg (note that RAP normally fluctuates with atrial contraction and respiration), the cardiac output in an adult human is about 5 L/min.

- Because of the steepness of the cardiac function curve, very small changes in RAP (just a few mmHg), can lead to large changes in cardiac output.




Positive
inotropic effect
Control
Negative
inotropic effect
Stroke volume
or
cardiac output
Right atrial pressure
or
end-diastolic volume

VENTRICULAR PRESSURE - VOLUME LOOP



Plots LV pressure against LV volume through one complete cardiac cycle

Systole: divided into

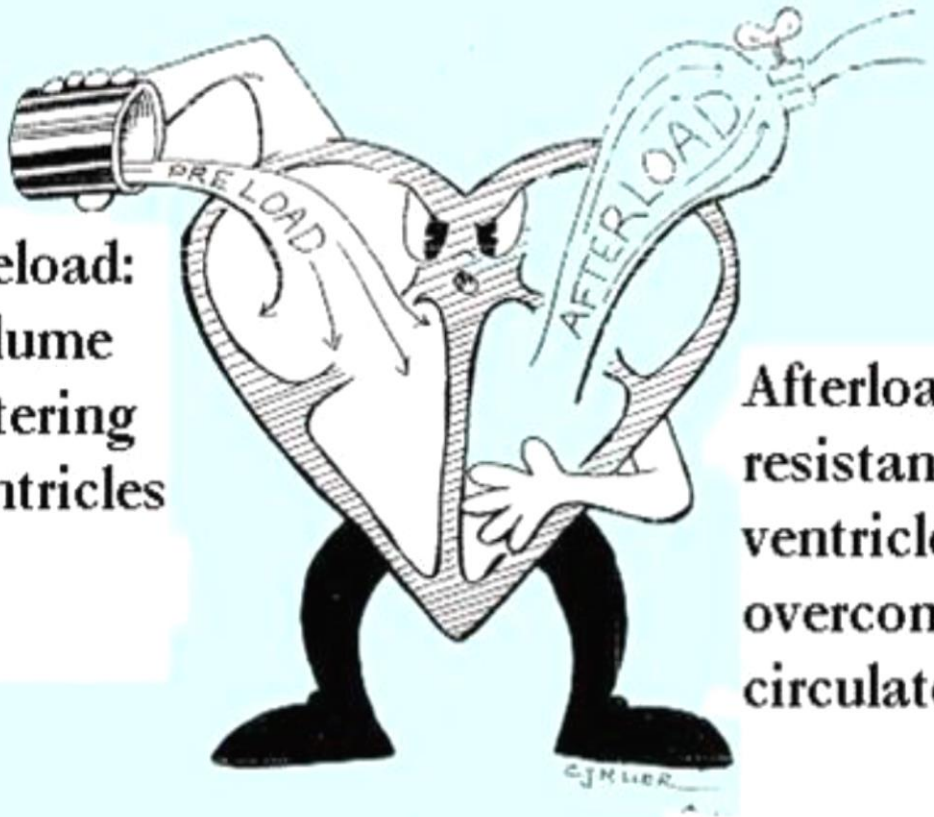
Early systole Late systole

Diastole: divided into

Early diastole Late diastole

(Filling phase)

Preload and Afterload



Preload: volume entering ventricles

Afterload: resistance left ventricle must overcome to circulate blood

CARDIAC SYSTEM
Memory Notebook of Nursing

Preload & Afterload

Preload: It is the amount of blood that returns to the heart from veins.

Preload is the load on the muscle in the relaxed state.

Is end-diastolic volume, which is related to right atrial pressure. When venous return increases, end-diastolic volume increases and stretches or lengthens the ventricular muscle fibers

Afterload: It is the resistance against which the ventricles contract.

For the left ventricle is aortic pressure. Increases in aortic pressure cause an increase in afterload on the left ventricle and for the right ventricle is pulmonary artery pressure. Increases in pulmonary artery pressure cause an increase in afterload on the right ventricle.

a. Increased preload: n refers to an increase in end-diastolic volume and is the result of increased venous return.
causes an **increase in stroke volume** based on the Frank–Starling relationship….reflected in **increased width** of the pressure–volume loop.

b. Increased afterload refers to an increase in aortic pressure.
n The ventricle must eject blood against a higher pressure, resulting in a decrease in stroke volume….is reflected in decreased width of the pressure–volume loop.
The decrease in stroke volume results in an increase in end-systolic volume.

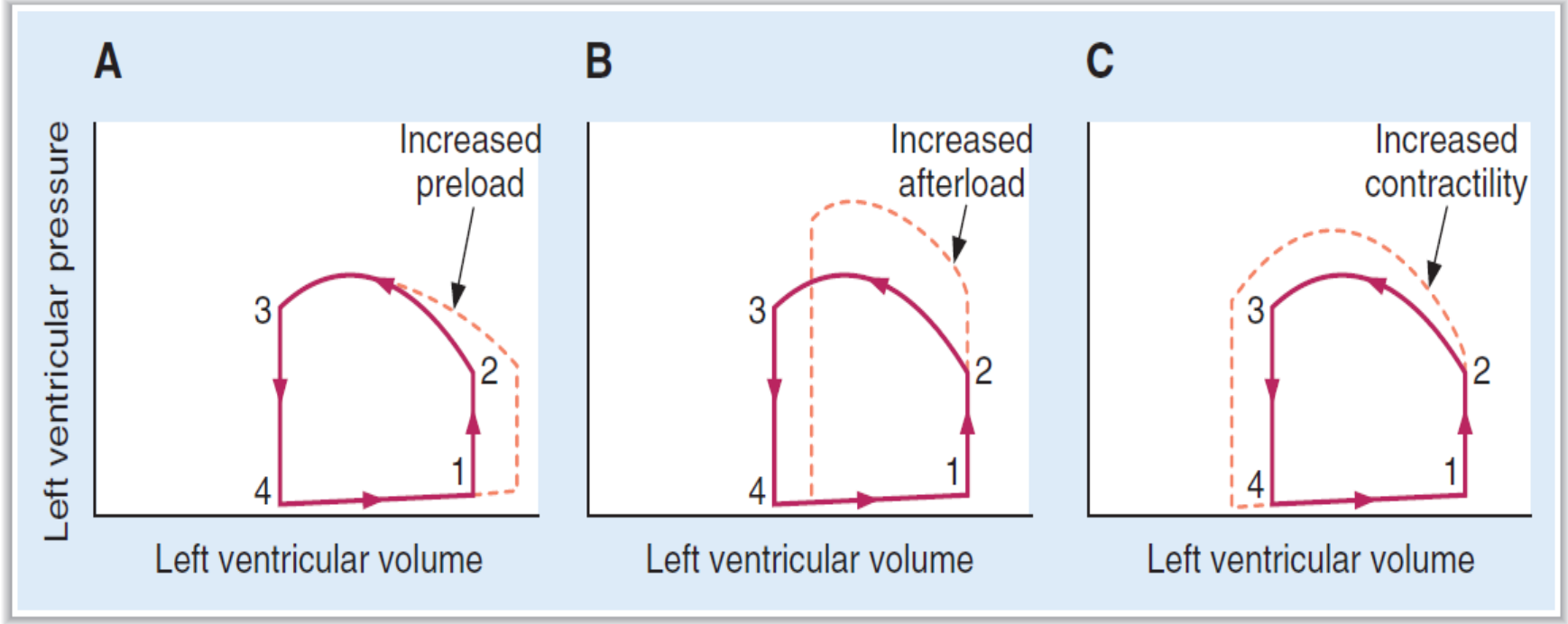


FIGURE 3-10 Effects of changes in (**A**) preload, (**B**) afterload, and (**C**) contractility on the ventricular pressure–volume loop.

Factors affecting preload (EDV)

EDV is ↑ with:

- ❑ Increased total blood volume.
- ❑ Increased venous return.
- ❑ Increased venous tone.
  - ❑ Increased skeletal muscle pump (exercise).
  - ❑ Increased negative intrathoracic pressure.
- ❑ Stronger atrial contraction.

EDV is ↓ with:

- ❑ Standing.
- ❑ Decreased venous return.
- ❑ Increased intrapericardial pressure.
- ❑ Decreased ventricular compliance.

Indices of left ventricular preload:

- Left ventricular end-diastolic volume (LVEDV).
- Left ventricular end-diastolic pressure (LVEDP).

Factors affecting Afterload

Left ventricular afterload represents the force that the muscle must generate to eject the blood into the aorta.

- When the aortic pressure is reduced, the velocity of shortening of the LV myocardial fibers increases.
- Hence, with reduced after load, the LV can eject blood more rapidly SV ↑ → ↓ ESV.
- The opposite is true with increased LV after load.

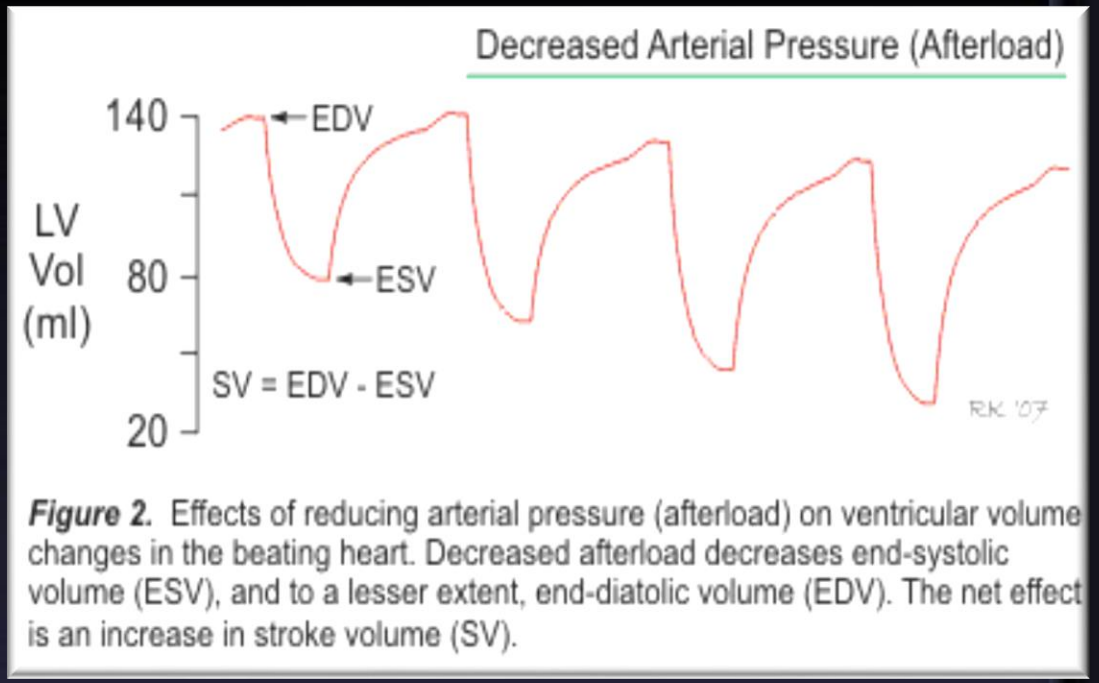


Figure 2. Effects of reducing arterial pressure (afterload) on ventricular volume changes in the beating heart. Decreased afterload decreases end-systolic volume (ESV), and to a lesser extent, end-diatolic volume (EDV). The net effect is an increase in stroke volume (SV).

LV afterload is increased in conditions of aortic stenosis, arterial hypertension & vasoconstriction.

Effect of Afterload on Frank Starling Curve

- An increase in afterload leads to an increase in ESV and a decrease in SV. An increase in afterload shifts Starling's curve down and to the right (from A to B).
- A decrease in afterload shifts Starling's curve up and to the left (A to C).

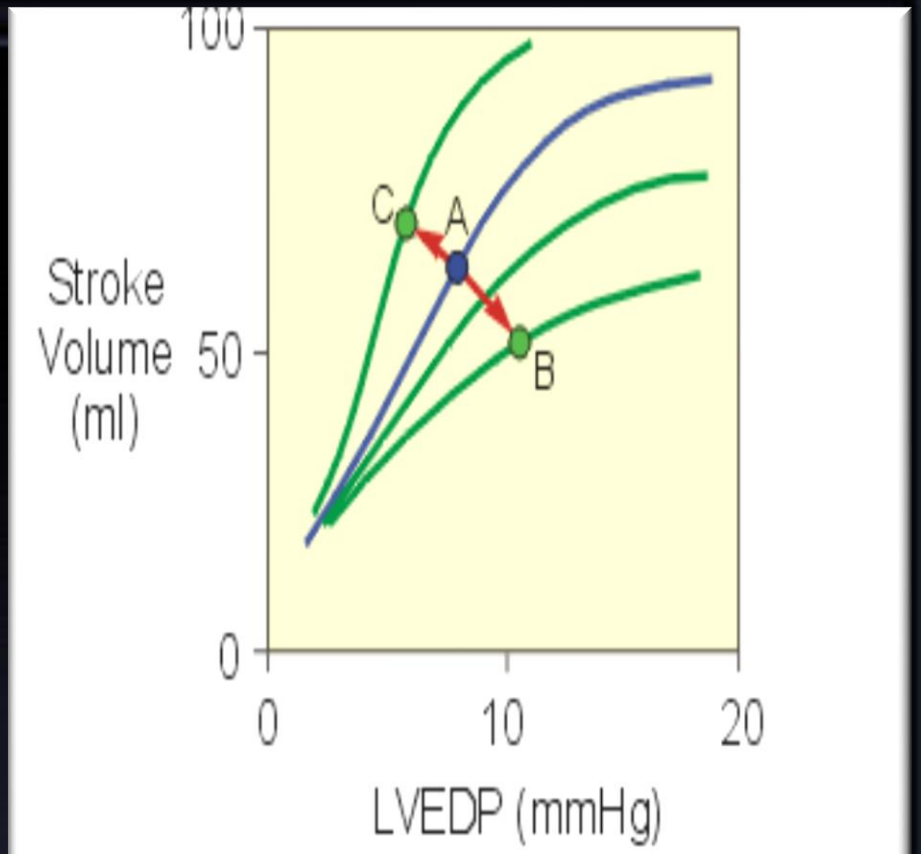


Figure 1. Effects of changes in afterload on Frank-Starling curves. A shift from A to B occurs with increased afterload, and from A to C with decreased afterload.

Explanation: an increase in afterload decreases the velocity of fiber shortening. This reduces the rate of volume ejection so that more blood is left within the ventricle at the end of systole → ↑ ESV.


THANKS