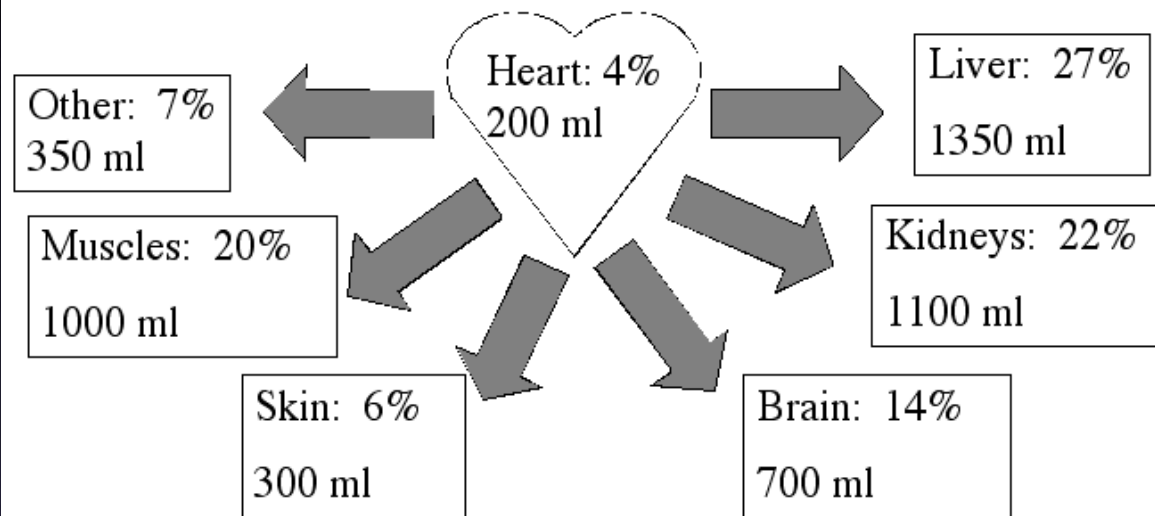


# CARDIAC OUTPUT

## Regulation of Stroke Volume (Preload, Contractility & Afterload)

Cardiac Output at Rest = 5 L/min



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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 CO**
- 5. Know the method for measurement of CO (The direct Fick's method)**

# CARDIAC OUTPUT

Volume of blood ejected by  
each ventricle in each minute

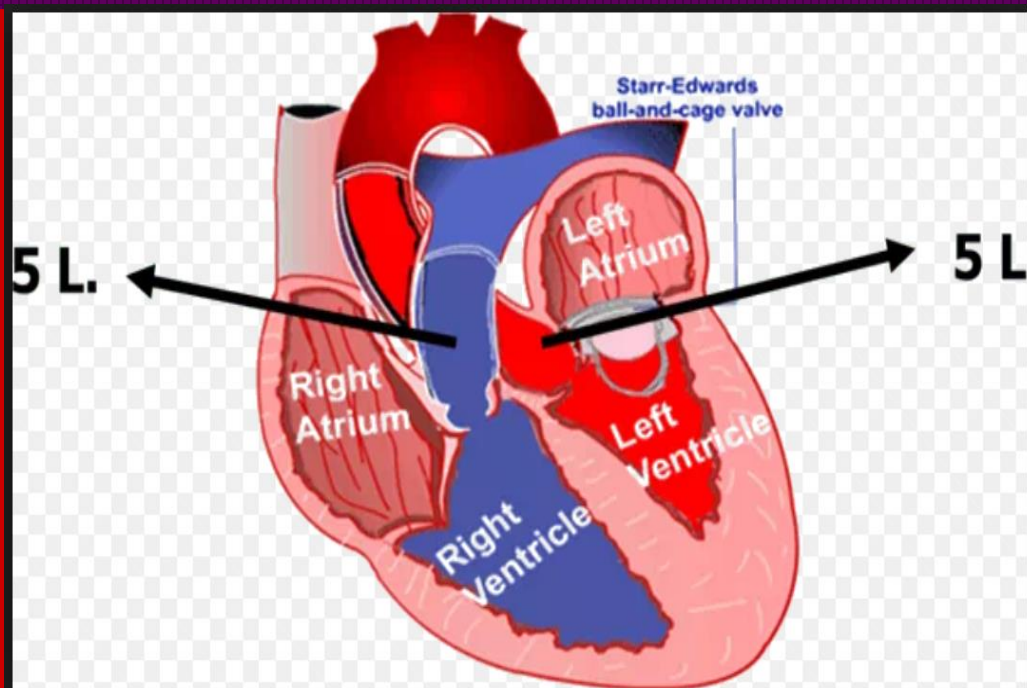
Around 5 liters in an average adult at rest

## STROKE VOLUME

Volume of blood ejected  
by each ventricle per each  
beat

( $SV = EDV - ESV$ )

Around 70 ml in an  
average adult at rest



$$CO = SV \times HR$$

**CARDIAC INDEX** is Cardiac Output  
per Square Meter of Body Surface Area

$$CI = CO/m^2$$

Since : CO vary with Size of individual, Age & Gender  
(For eg: Women have smaller CO than men)

**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 eg:  $\uparrow VR \rightarrow$  Preload

**AFTERLOAD** is the resistance against Which  
the ventricles contract eg: Aortic Stenosis  $\rightarrow \uparrow$  Afterload

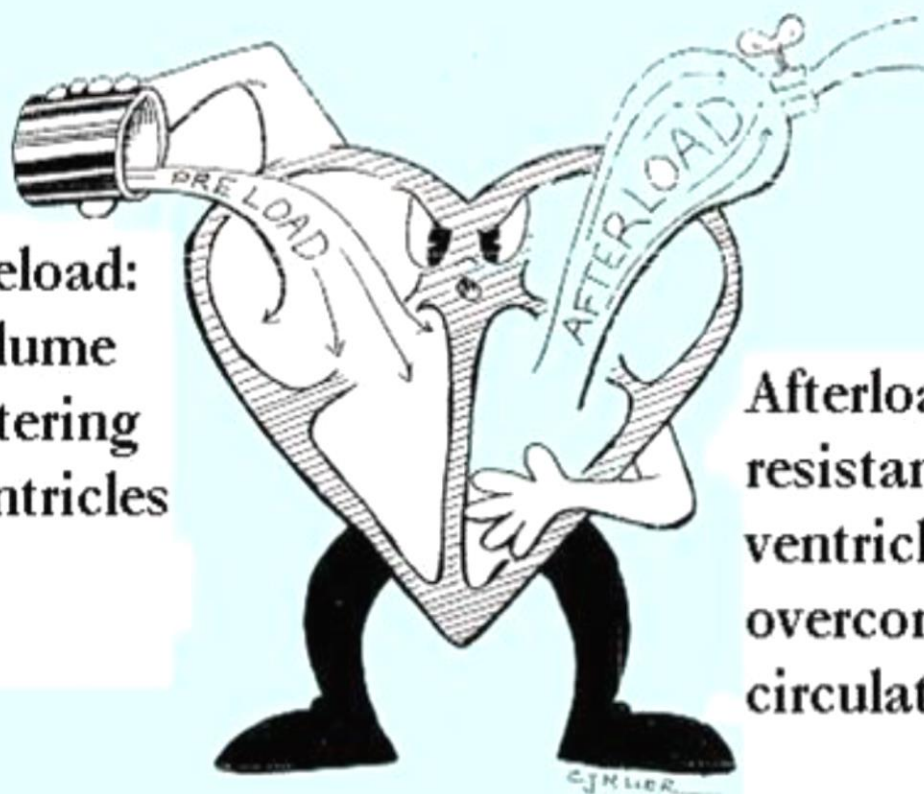
## **CARDIAC RESERVE**

**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.**

# Preload and Afterload

**Preload:**  
volume  
entering  
ventricles



**Afterload:**  
resistance left  
ventricle must  
overcome to  
circulate blood

253  
© 2004  
Pinning  
Education  
Consultants

# 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

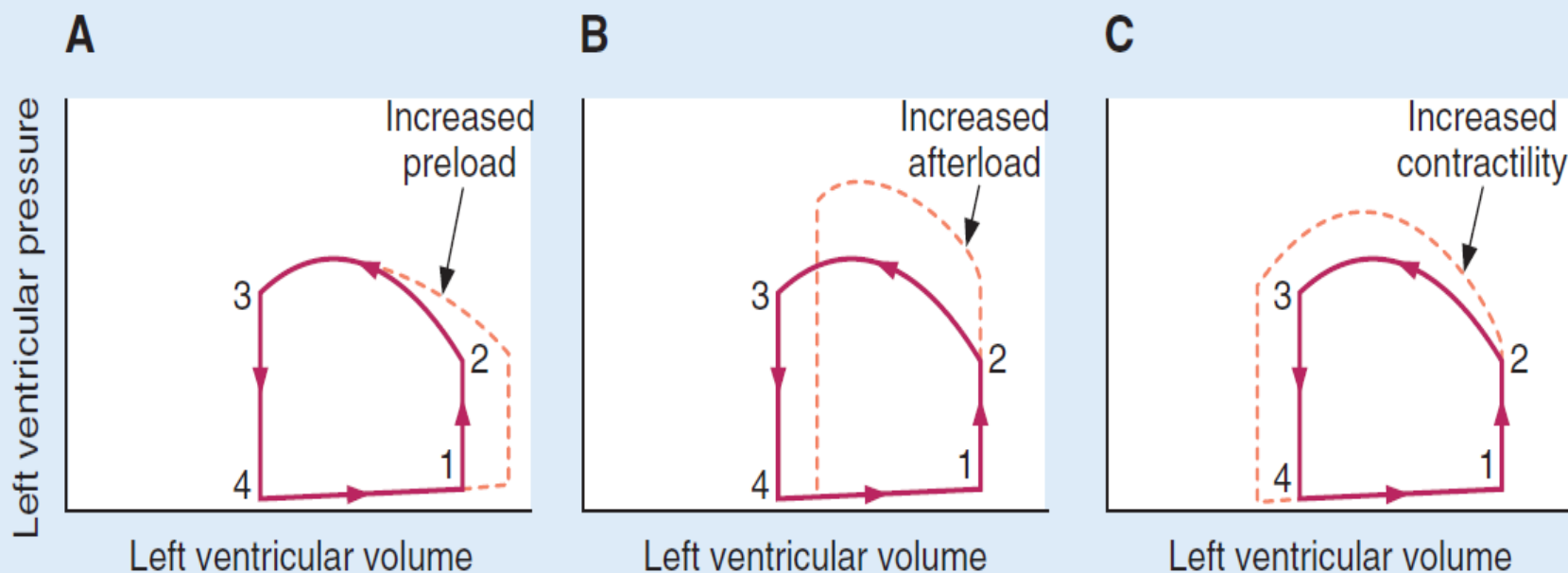
**Afterload:** It is the resistance against which the ventricles contract.

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:** ↑ venous return → increase in SV based on the Frank–Starling relationship....reflected in ↑ width of the PV loop.

**B. Increased afterload:** due to an increase in aortic pressure → decrease in stroke volume....is reflected in ↓ width & ↑ height of the PV loop.

**C. Increased contractility:** → ↑ width & ↑ height of the PV loop.

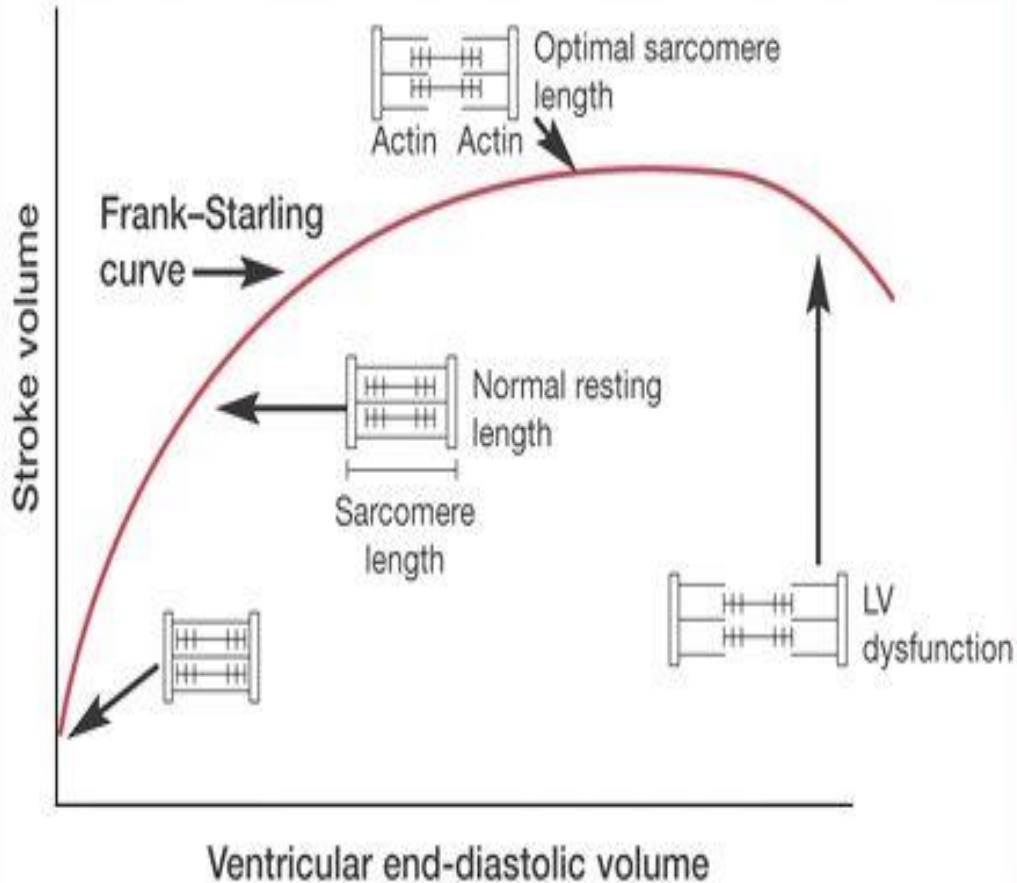


**FIGURE 3-10** Effects of changes in (A) preload, (B) afterload, and (C) contractility on the ventricular pressure–volume loop.



# Determinants of the CO

## 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.**

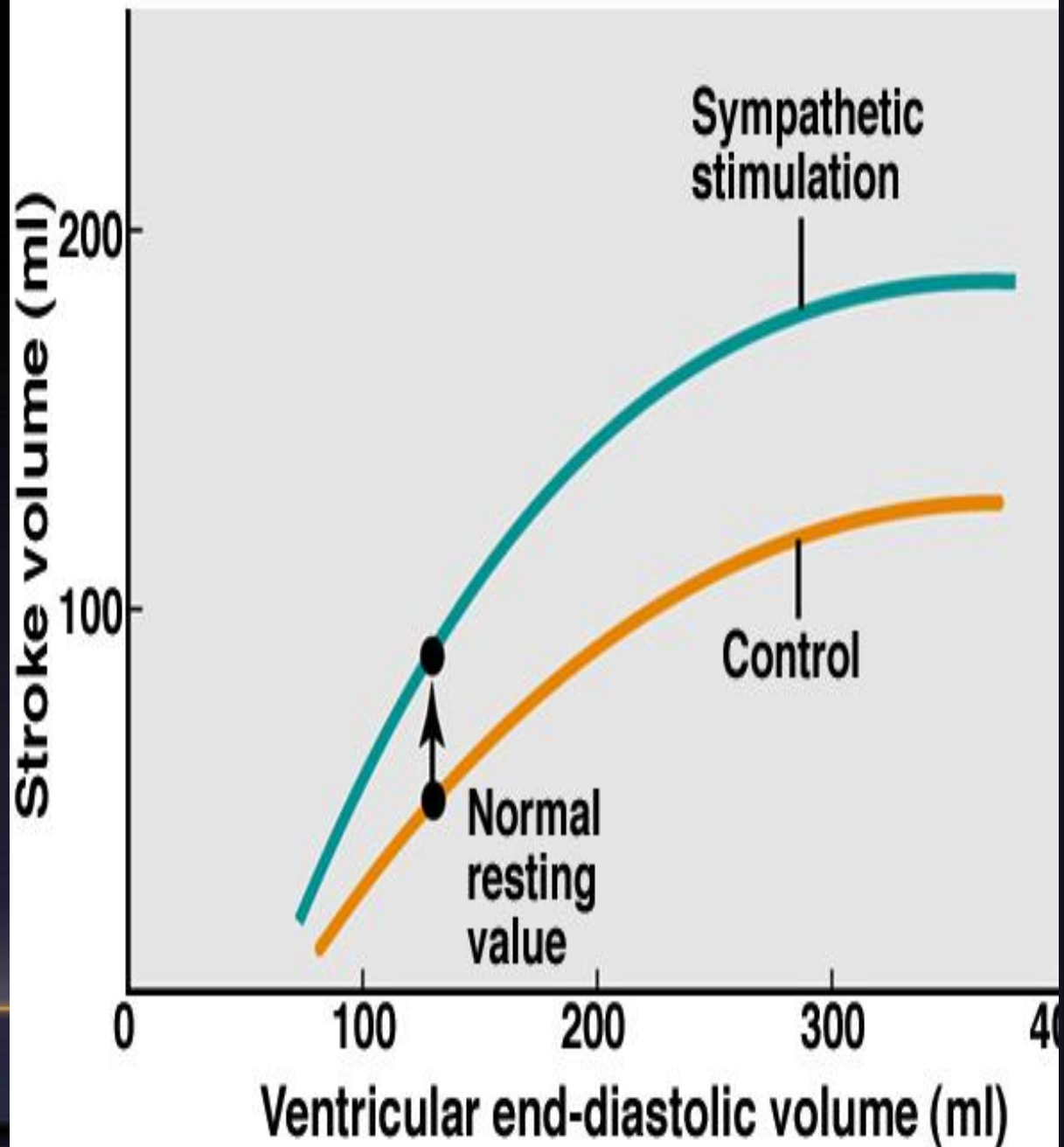
**OR**

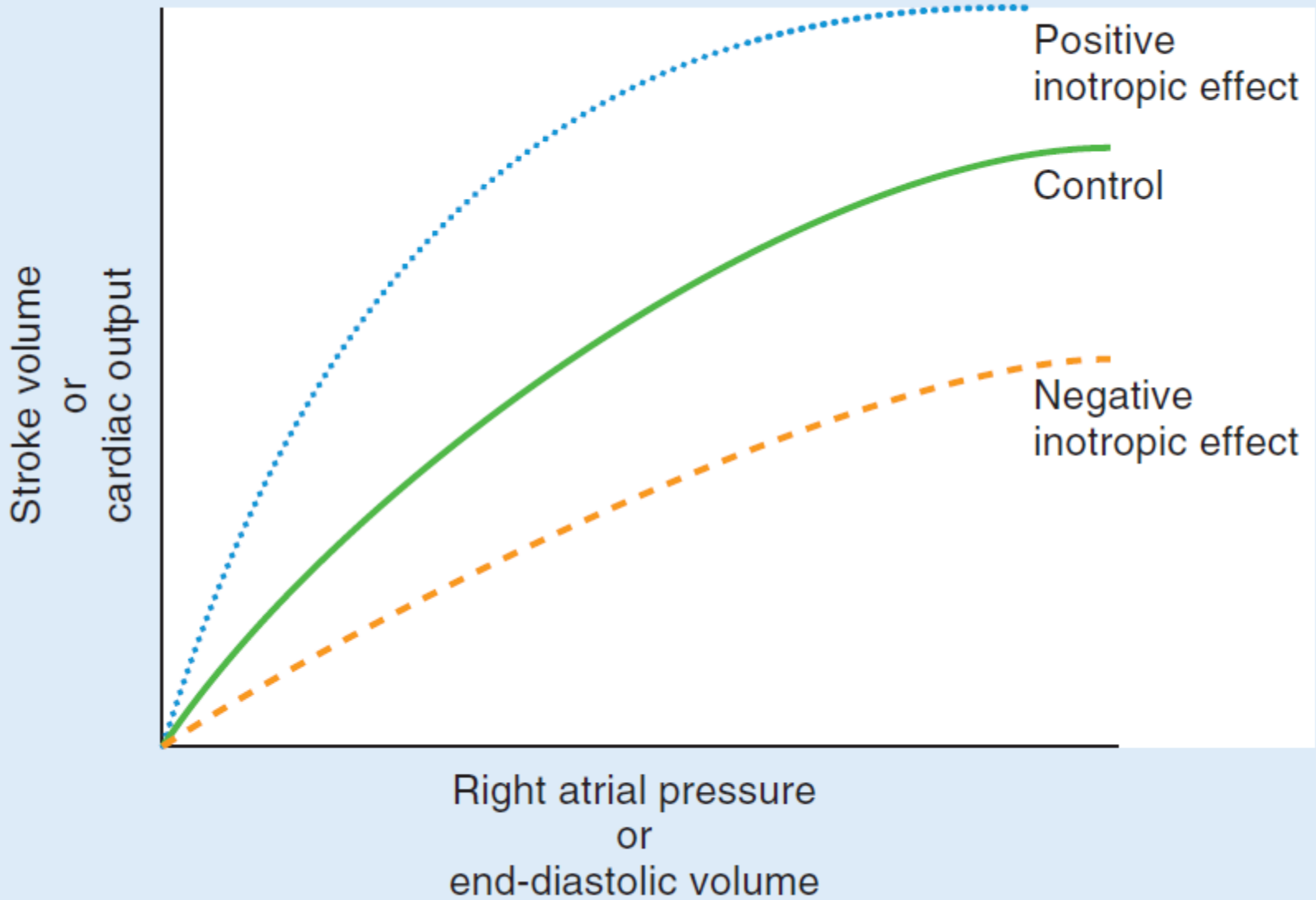
**“The energy of contraction is proportional to the initial length of the cardiac muscle fibers” and for the muscle is proportional to the End Diastolic Volume.**

**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.





# Determinants of the CO

$$CO = SV \times HR$$

OR

$$CO = EDV - ESV \times HR$$

Venous Return

Myocardial Contractility  
(Inotropic state)

Heart rate

(Chronotropic state)

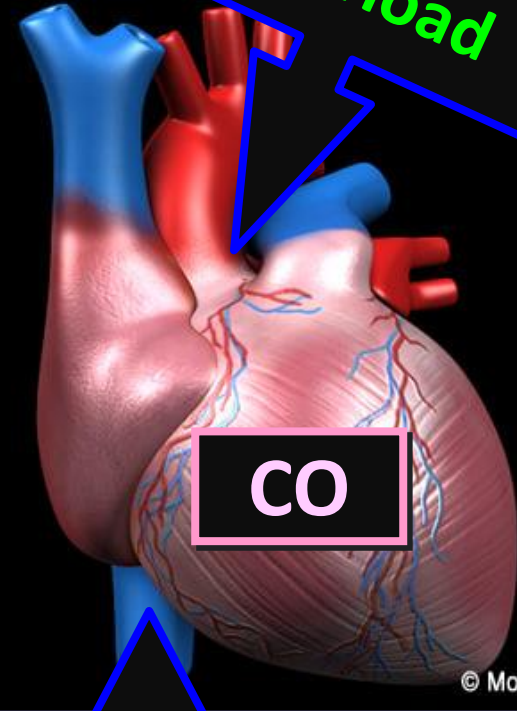
Preload ?

Afterload ?

Preload

Afterload

CO



© MotionCow

# Determinants of the CO

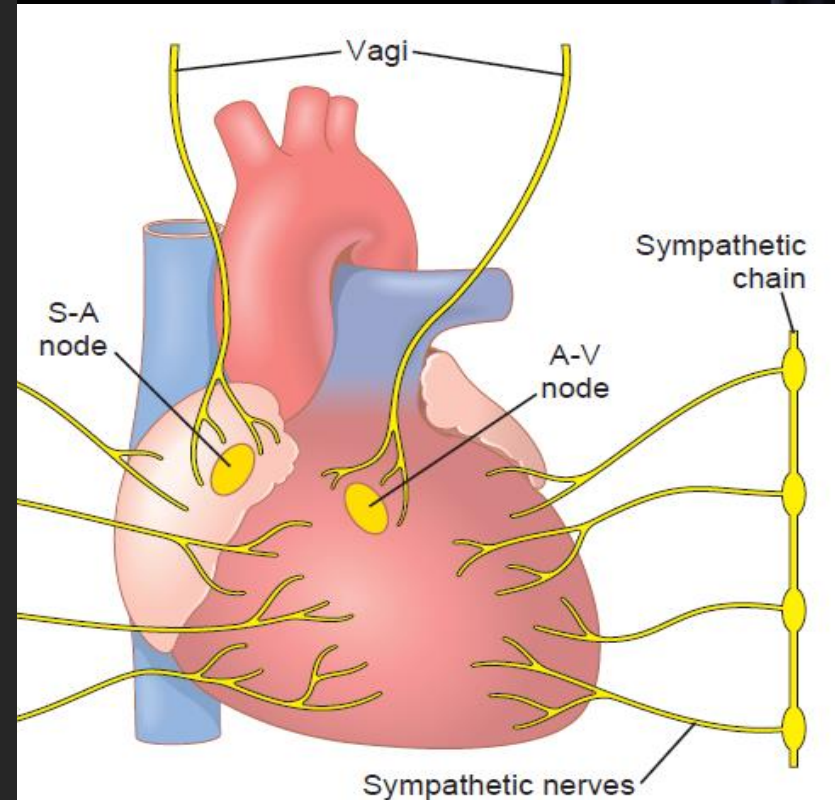
## 1. Heart rate (HR)

- Since the CO is =  $SV \cdot HR$ , 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  $\beta_1$ -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, atrioven-  
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**



# Factors affecting myocardial contractility: (Inotropic factors)

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,  $\text{Ca}^{2+}$  and caffeine)

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

# 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

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

# 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.

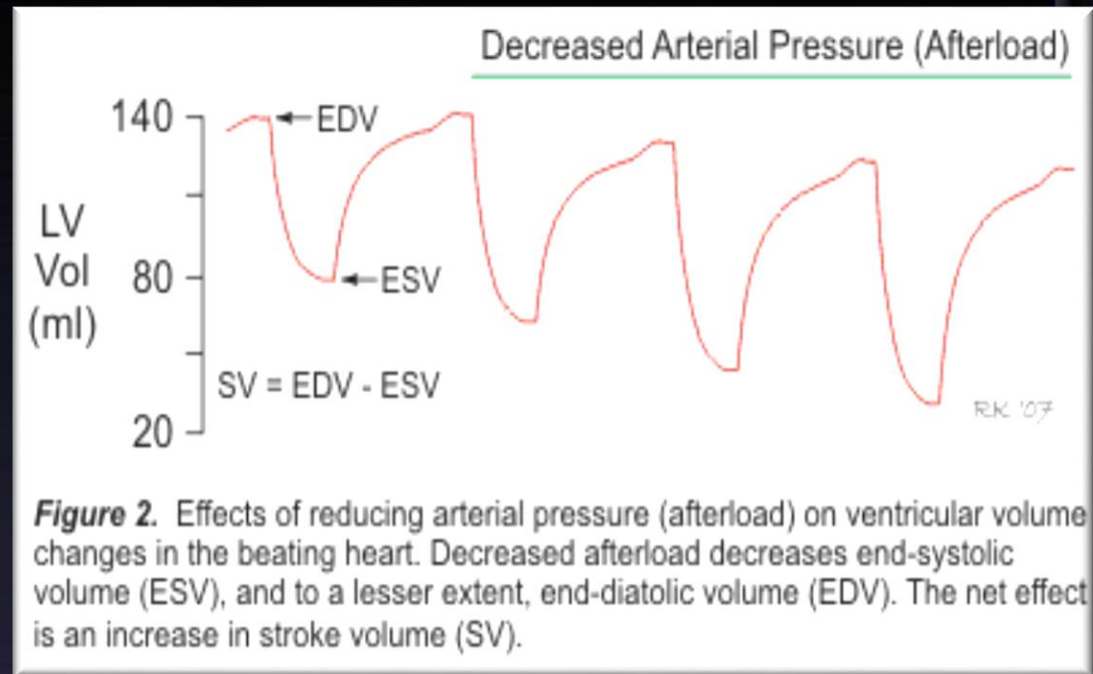
Indices of left ventricular preload:

- 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.

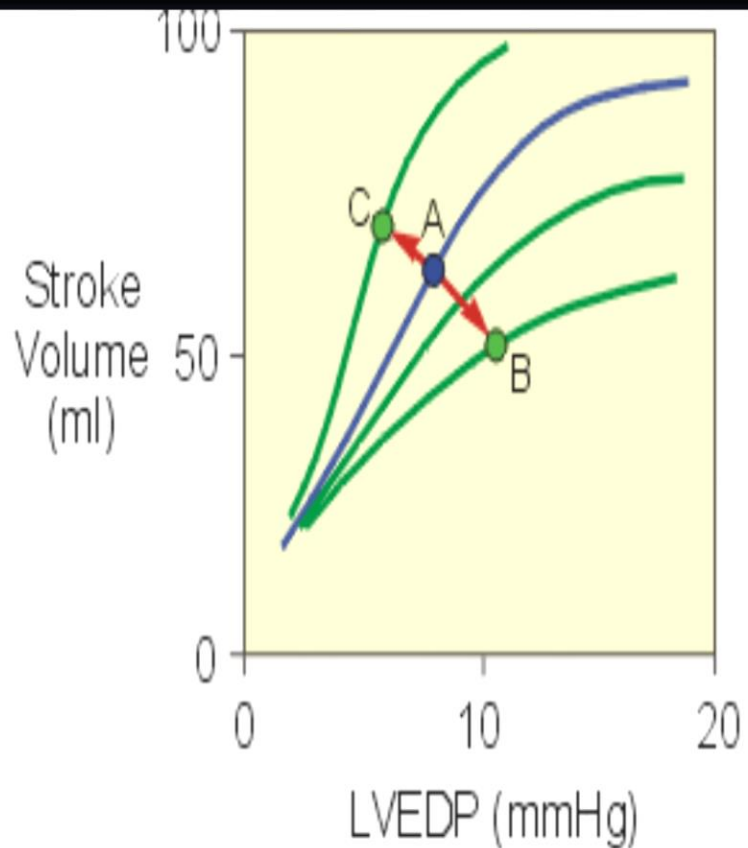
- When the aortic pressure is reduced, the velocity of shortening of the LV myocardial fibers increases.
- Hence, with reduced after load, the LV can eject blood more rapidly  $SV \uparrow \rightarrow \downarrow ESV$ .
- The opposite is true with increased LV after load.



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.

# Physiological changes in CO

- During the first 3 hours **after meals**, the CO is increased by  $\approx 30\%$  to enhance blood flow in the intestinal circulation.
- Later months of **pregnancy** are accompanied by  $> 30\%$  increase in CO due to increased uterine blood flow.
- At environmental **temperature** above  $30\text{ }^{\circ}\text{C}$ , the CO is increased due to increased skin blood flow. Also at low environmental temperature CO is increased due to shivering that increases blood flow to the muscles.
- Increased **sympathetic activity** during anxiety and excitement enhances the CO up to  $50\% - 100\%$ .
- Sitting or standing from the lying position decreases the CO by  $20\% - 30\%$ .
- Exercise:

# Effects of exercise on heart rate and SV

## Moderate Exercise

- HR increases to 200% of resting (140 bts/min)
- SV increases to 120% (85ml)
- CO increases to 240% (12L)

## Severe Exercise

- HR increases to 300% of resting (200 bts/min)
  - SV increases to 175% (125ml)
  - CO increases to 500% - 700% (25 - 35 L)
- In athletes, maximum CO may be 35L or more - can't increase maximum HR beyond 200 bts - hence - SV increases to 175 ml.



# Pathological low or high cardiac output

## Causes of low CO:

- Low VR (e.g., haemorrhage)
- Reduced contractility (e.g., heart failure)
- Tachyarrhythmias (e.g., atrial fibrillation and ventricular tachycardia)
- Marked bradycardia (e.g., complete heart block)

## Causes of high CO:

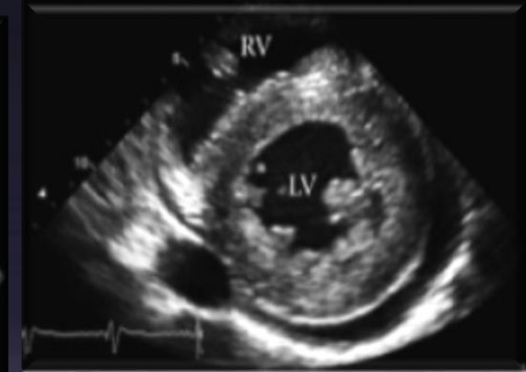
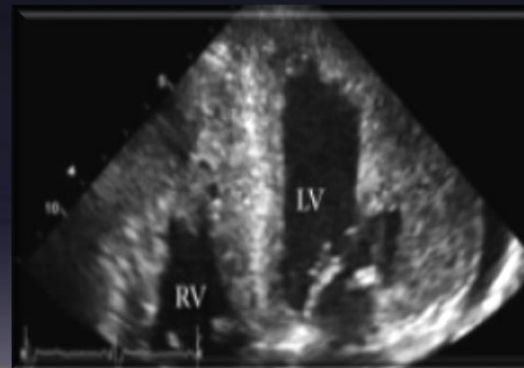
- Hyperthyroidism: the increase in the CO is due to the high metabolic rate → vasodilatation → ↑ CO to 50%+ of control.
- AV fistulas.
- Fever.
- Anaemia.
- Anxiety.

# Measurement of cardiac output

- Ultra-fast computer tomography
- Fick's principle
- 2-Dimensional Echocardiography

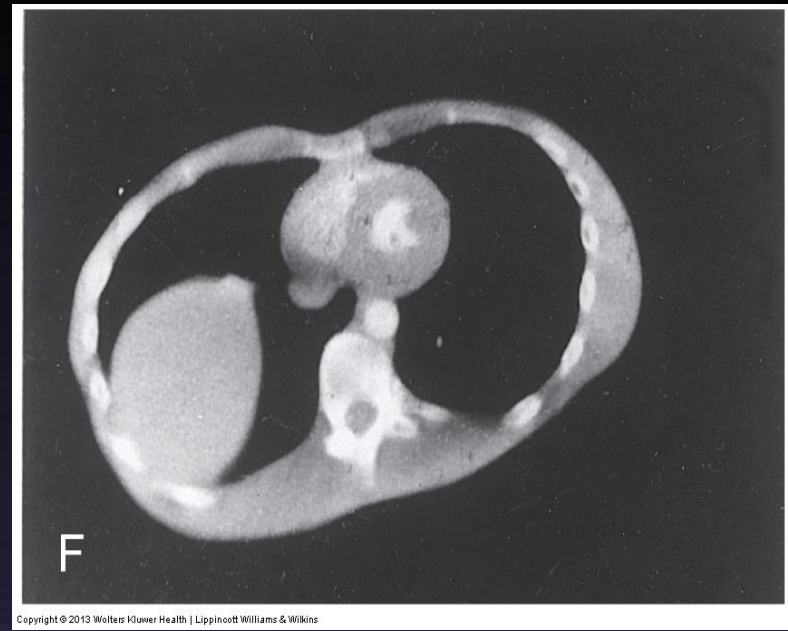
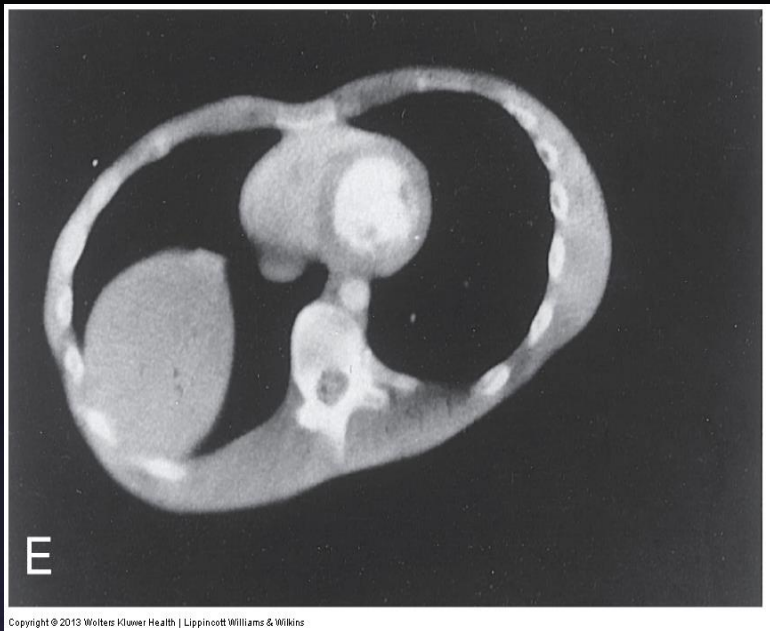
## 2-Dimensional Echocardiography

Records real-time changes in ventricular dimensions during systole and diastole. It thus computes stroke volume, which when multiplied by heart rate, gives the cardiac output.



# Pathological low or high cardiac output

Ultra-fast computer tomography

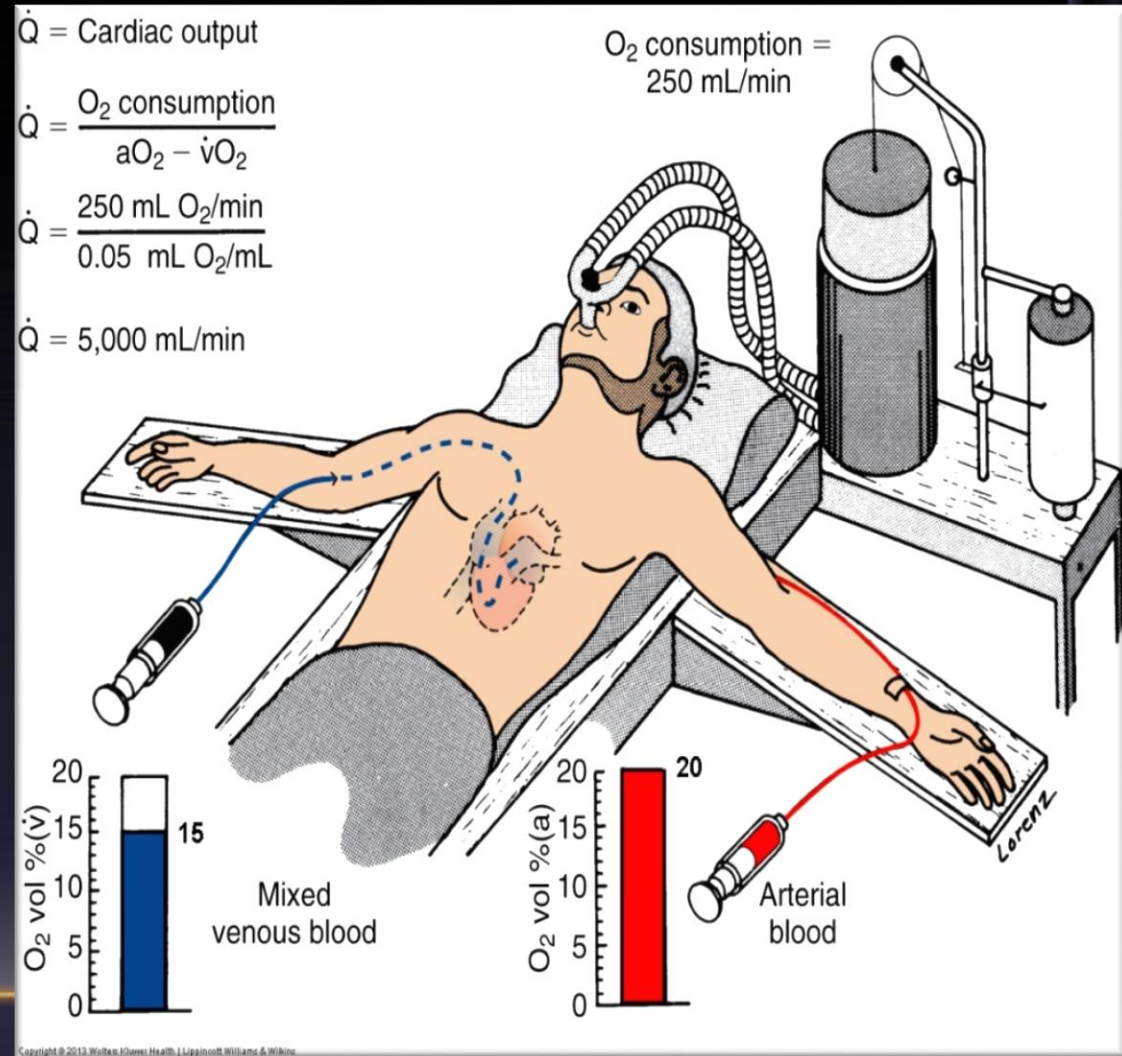


Can measure changes in ventricular diameter at several depths to estimate changes in ventricular volume.

# Measurement of cardiac output

## Fick's principle

Fick's principle assumes that the amount of oxygen consumed = the amount of oxygen delivered by the arterial blood minus the amount of oxygen in venous blood of the organ.



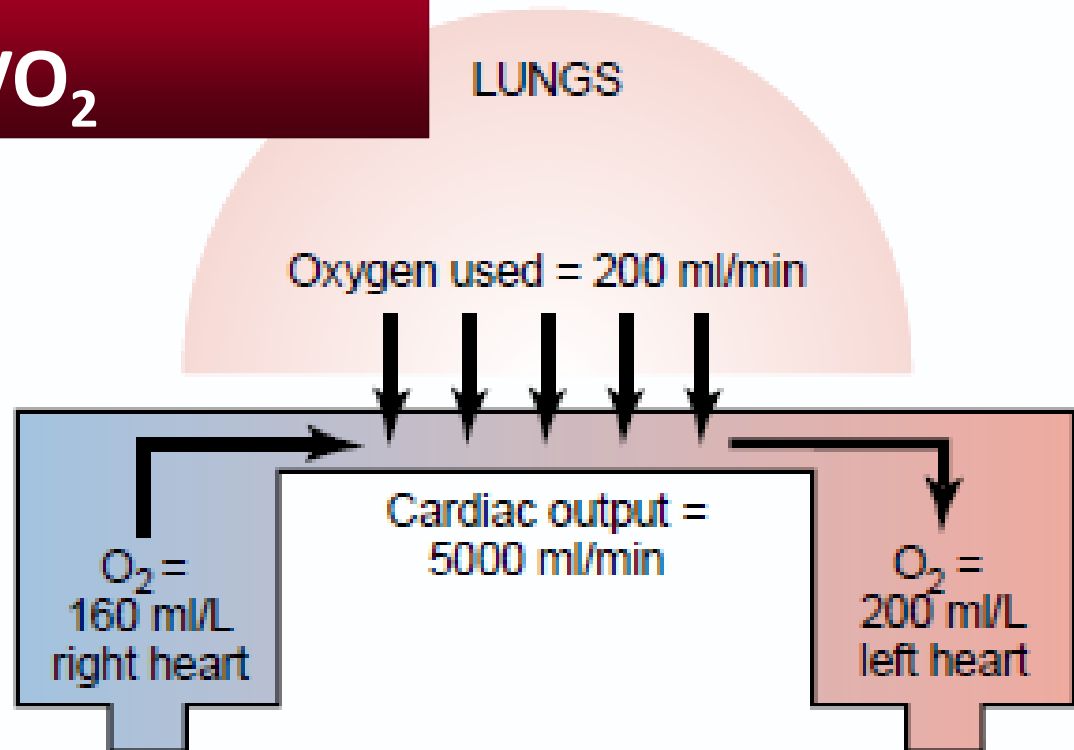
# Measurement of cardiac output

## Fick's method

$$\text{CO (L)} = \frac{\text{Total O}_2 \text{ consumption}}{\text{AO}_2 - \text{VO}_2}$$

$\text{AO}_2$  = arterial  $\text{O}_2$  concentration

$\text{VO}_2$  = mixed venous  $\text{O}_2$  concentration







**THANKS**