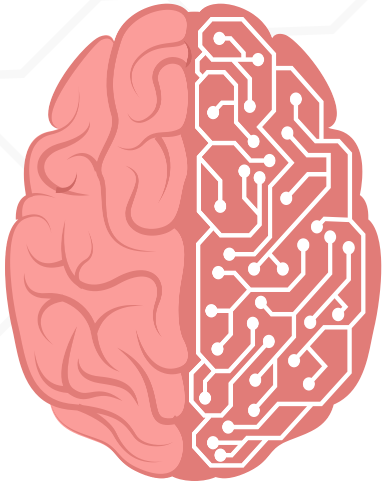
النادي الطلابي
كلية الطب



Physiology - CVS

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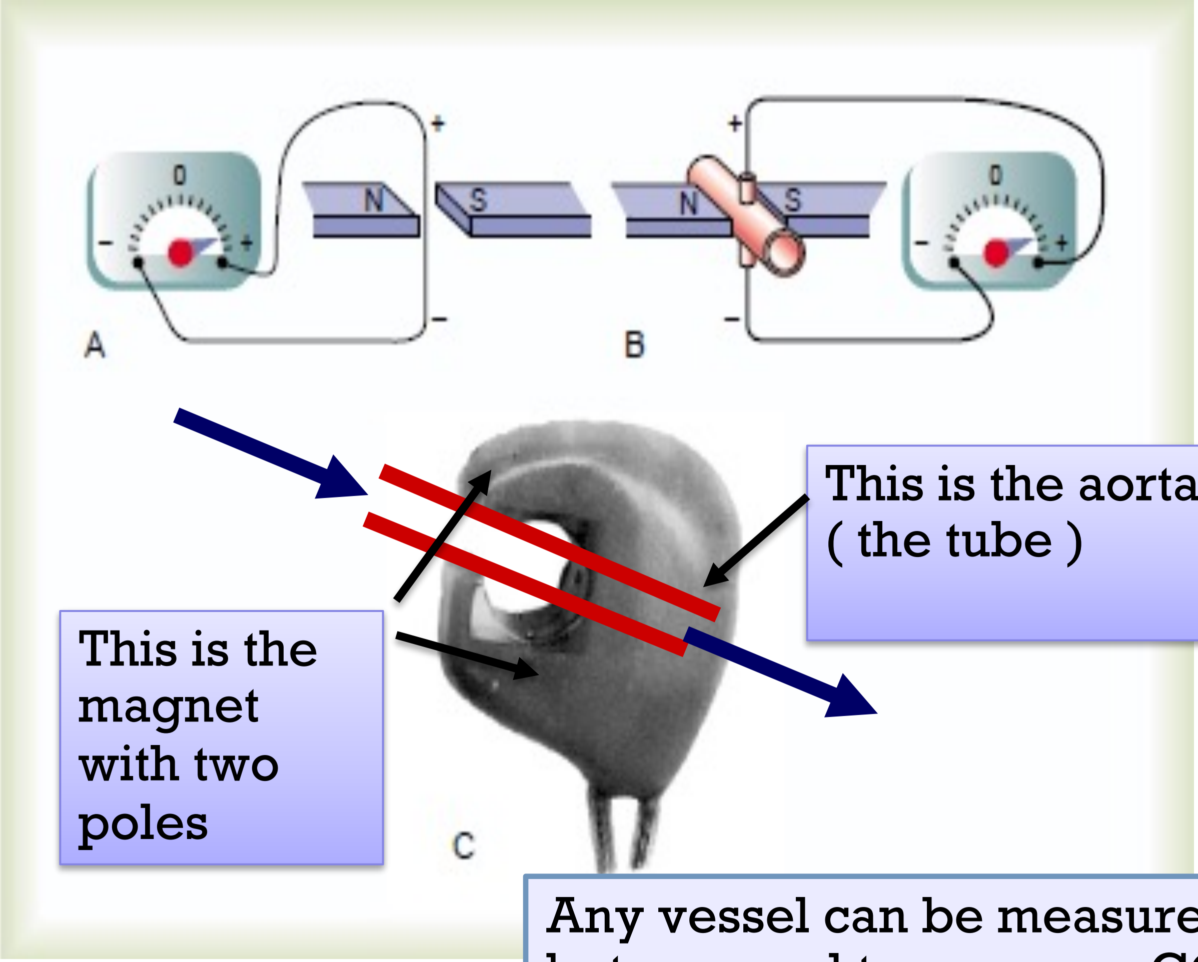
Measurement of Cardiac Output

- Electromagnetic flowmeter (device measures the flow)
- Indicator dilution (dye such as cardiogreen)
- Thermal dilution
- ***Oxygen Fick Method***
- ***CO = (O_2 consumption / (A-V O_2 difference)***

These are indirect methods to measure The CO while the direct way is to cut the aorta and collect the blood per minute (as the cardiac output is the blood flow in aorta per minute) which is not used ofc even in experimental animals

Electromagnetic flowmeter



This is the magnet with two poles

This is the aorta (the tube)

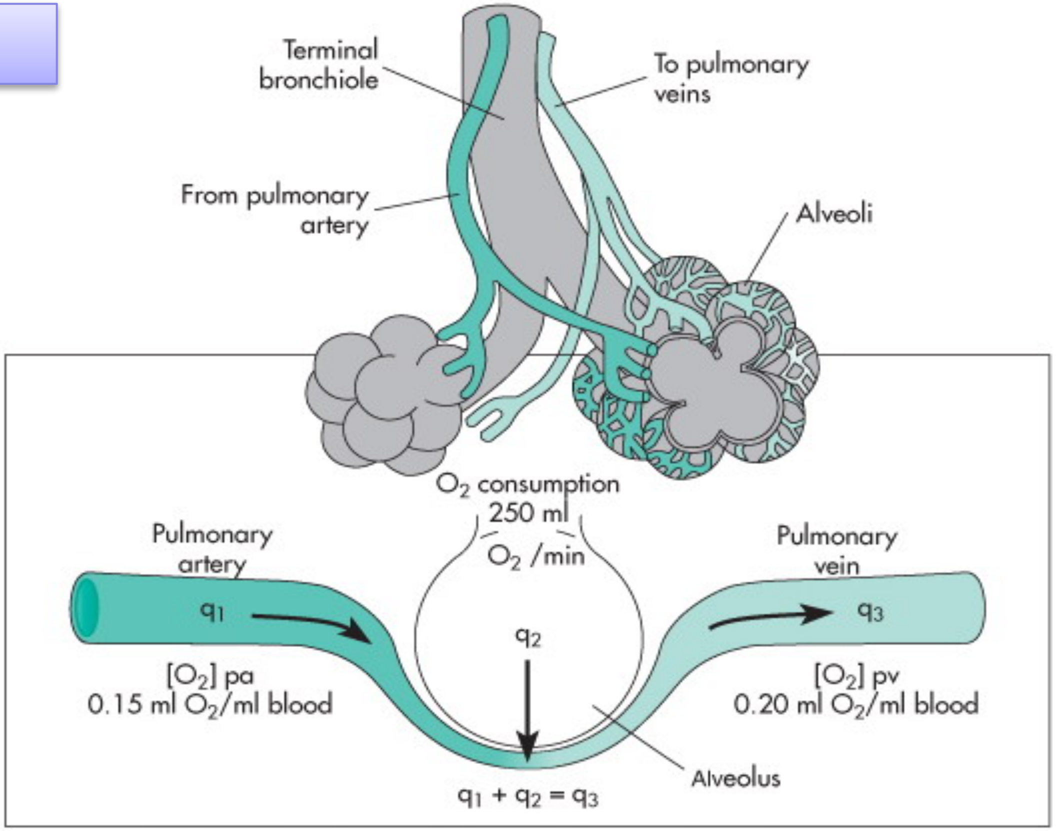
Any vessel can be measured but we need to measure CO so we put the flowmeter around the aorta

Here we have a huge magnet with 2 poles (S,N) , we put a tube in between the poles , so when the fluid is passing through the tube this will cause an electromagnetic field , then we connect the two poles with a calibrated galvanometer and a current will be recorded , this current is proportional to the flow

This method is done when the patient is already under a cardiac surgery and the chest is already opened and aorta is exposed

Indicator dilution

The indicator here is Oxygen



The amount of blood flowing through the pulmonary artery per minute is the cardiac output
And the amount of blood goes from the pulmonary veins to the left ventricle per minute is also the cardiac output
(What comes , goes)
The blood comes from the heart , enters the lung, gets oxygenated, then goes to the heart >>pulmonary circulation

$q_1=\bar{C}O*C_{VO2}$

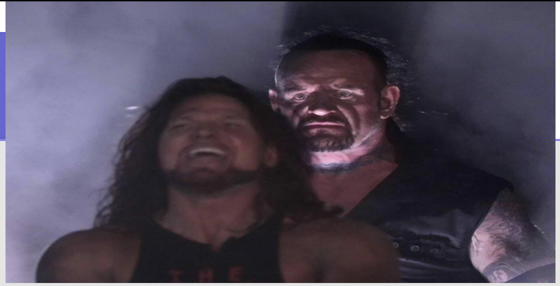
q_2=amount of Oxygen uptake by the lungs

$q_3= \bar{C}O* C_{AO2}$ and equals = $\bar{C}O*C_{VO2}+ O_2$ uptake

Oxygen uptake = $\bar{C}O\{C_{AO2}-C_{VO2}\}$

CO=Oxygen uptake/$\{C_{AO2}-C\ V_{O2}\}$

Explanation of the previous slide



- What about the amount of oxygen?

It's the concentration of oxygen multiplied by the volume of the blood (CO)

✓ So the amount of oxygen found in the pulmonary artery per minute (q1) = CO * oxygen concentration in the venous blood (systemic venous blood)

✓ The amount of oxygen found in the pulmonary vein (q3) = CO * oxygen concentration in the arterial blood) …[1]

q2 = amount of oxygen taken from the lungs

q3 =q1+q2

✓ q3= CO * oxygen concentration in the venous blood + q2 …[2]

q3=q3 >>[1] = [2] >> مساواة المعادلتين

CO* oxygen concentration in the arterial blood =CO* oxygen concentration in the venous blood + oxygen uptake from the lung

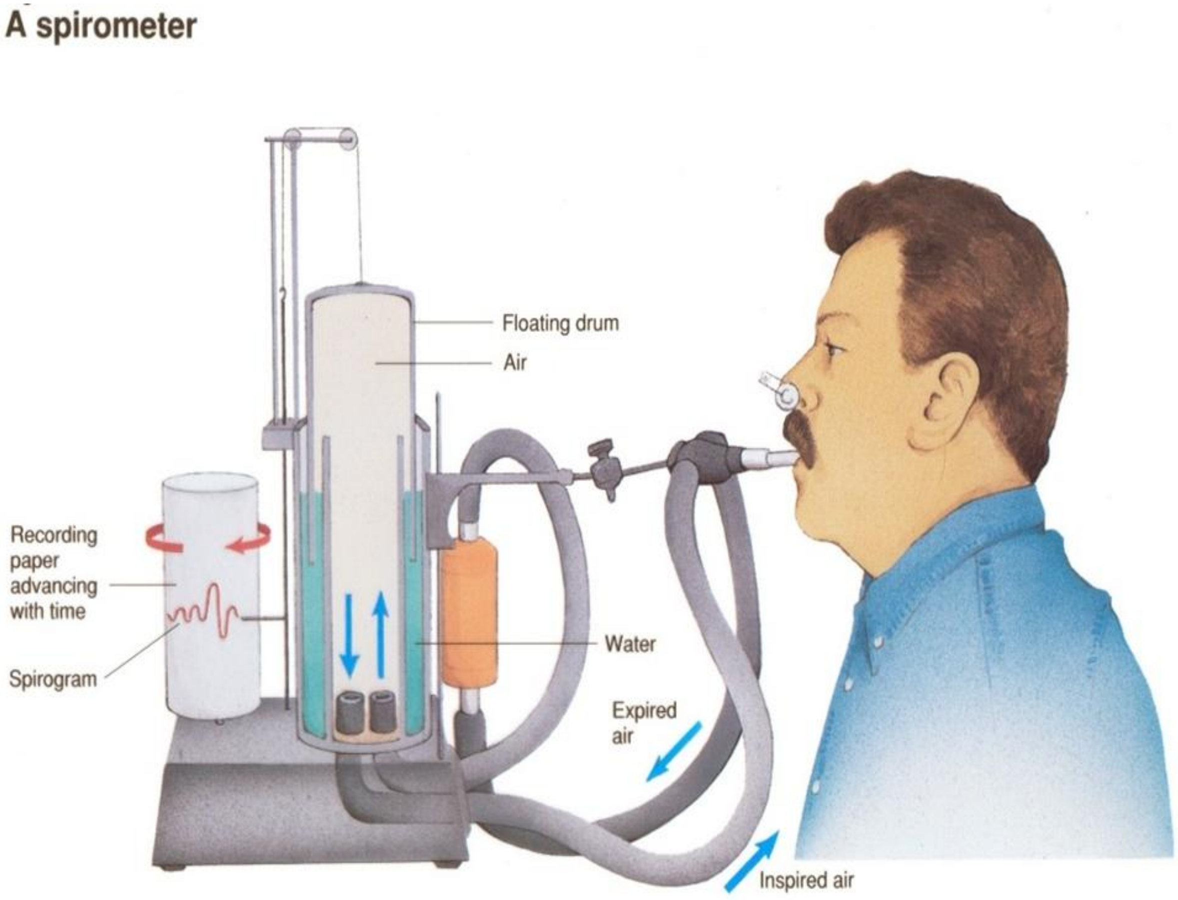
Put the oxygen uptake in one side and take the CO as a common factor (عامل مشترك)

✓ Oxygen uptake = CO (oxygen concentration in arterial blood – oxygen concentration in venous blood)

✓ So the CO = oxygen uptake/ (oxygen concentration in arterial blood – oxygen concentration in venous blood) …[3]

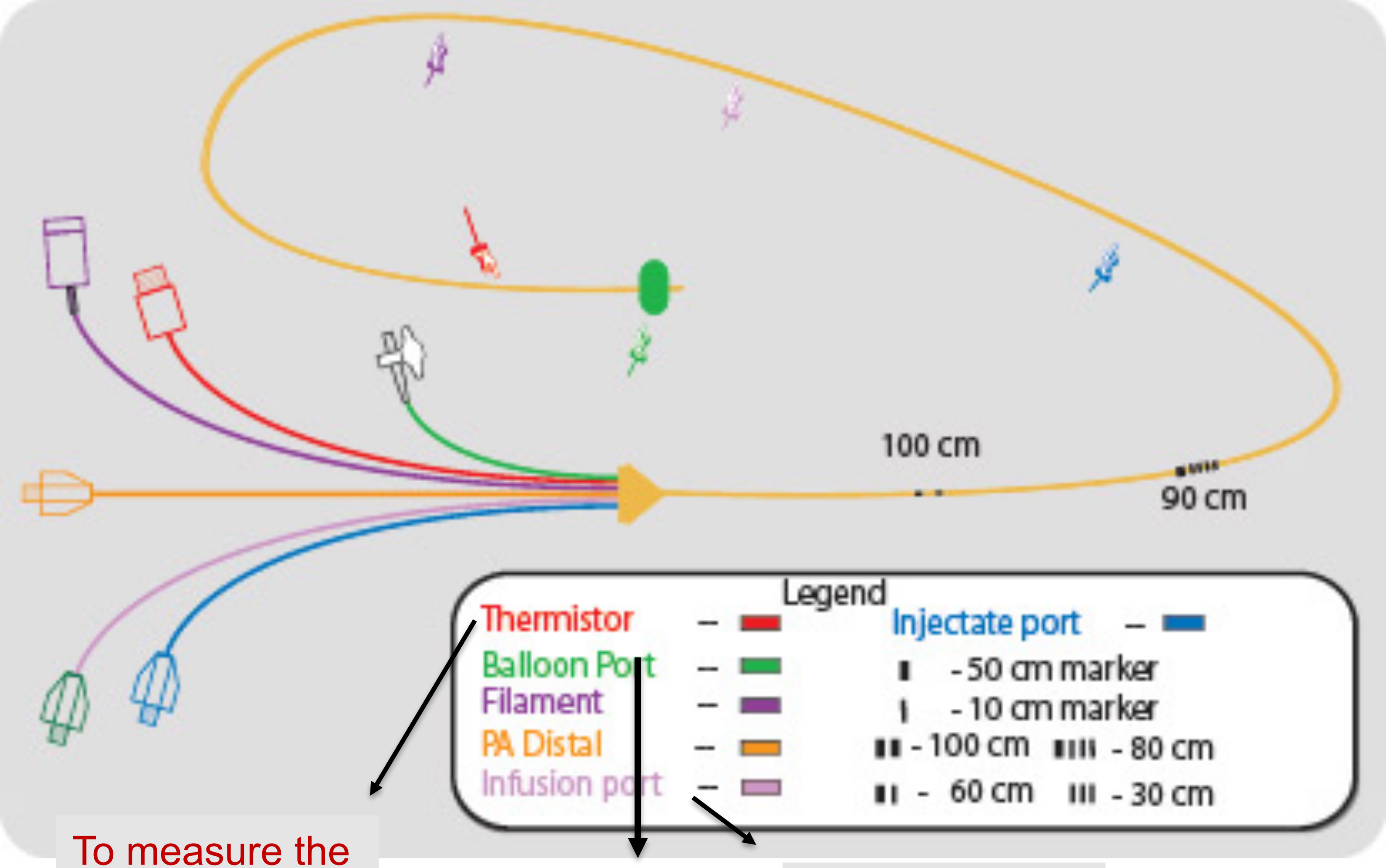
Now …How we get the oxygen uptake? See the next slide

Spirometer



To measure the oxygen uptake, we use a spirometer, we let the person to inspire just through the tube of spirometer and we measure the amount of oxygen before and after inspiration
If we measure the oxygen consumption after 5 minutes of inspiration, we divide the measurement over 5 to get the amount per minute and so on

Swan-Ganz catheter



To measure the temperature

To measure the pressure

To give solution or take blood

How to find the arterial and venous concentrations of oxygen?

All arteries have the same concentration of oxygen because the exchange happens only at the level of the capillaries. That's why you can take a sample from any artery to measure the concentration of oxygen in arterial blood.

However..We can't take venous sample from any vein because the concentration of oxygen differs according to the metabolic needs. So, we take a sample from central venous blood in the right ventricle, we put a special catheter called Swan-Ganz catheter in the pulmonary artery or the right ventricle (using the cubital vein). This blood found there is called central venous blood; as if we mix all venous blood and take the sample.

O_2 Fick Problem

Pay attention to units (L,ml)

- If pulmonary <u>vein</u> O_2 content = 200 ml O_2/L blood

Oxygen concentration in arterial blood

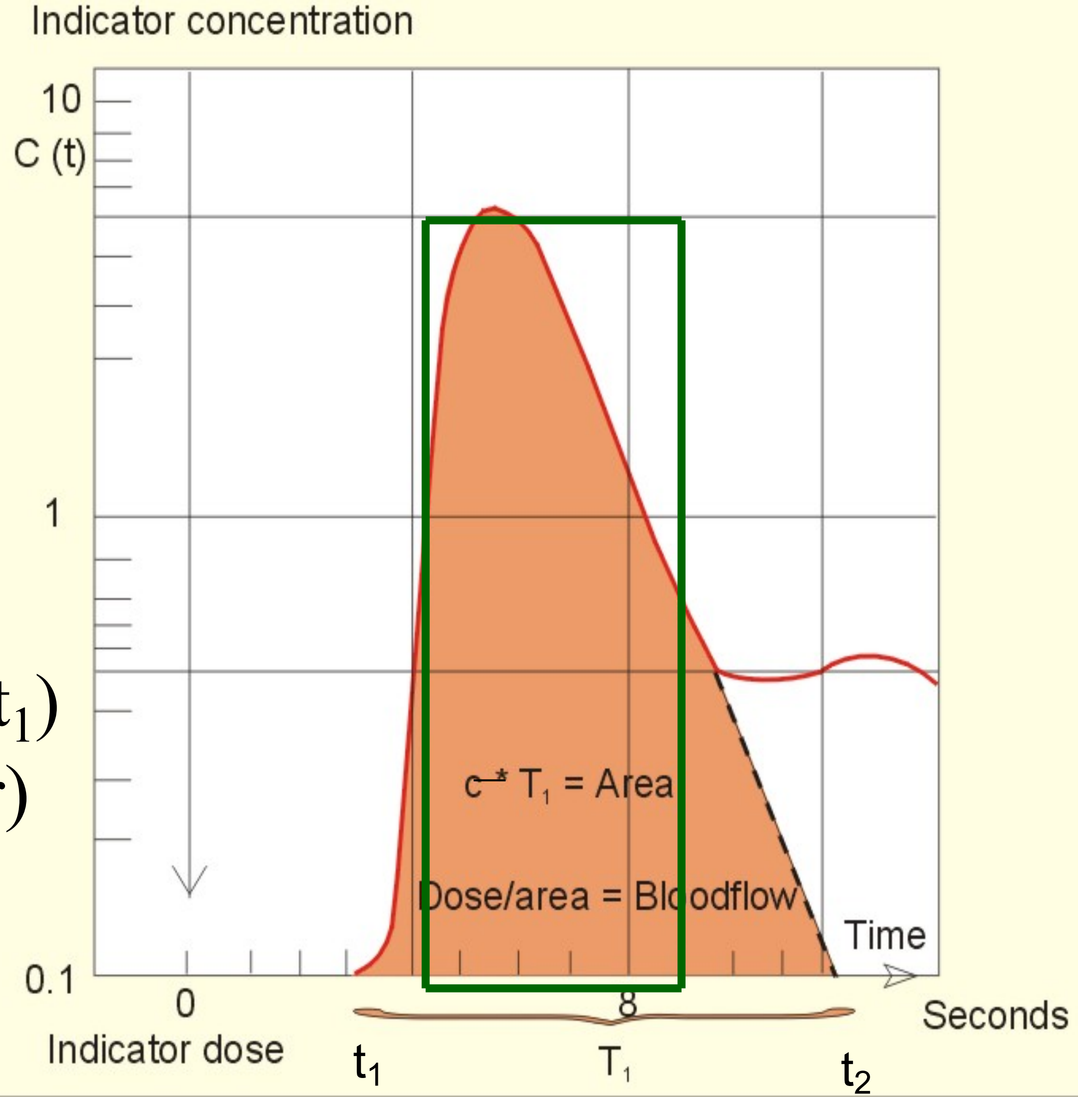
- Pulmonary <u>artery</u> O_2 content = 160 ml O_2 /L blood

Oxygen concentration in venous blood

- Lungs add 400 ml O_2 /min
- What is cardiac output?
- Answer: 400/(200-160) =10 L/min

CO = oxygen uptake /(oxygen concentration in the arterial blood – oxygen concentration in venous blood) …remember [3]

THE INDICATOR DILUTION PRINCIPLE



$$\text{Area} = \int_{t2}^{t1} dc.dt$$

$$\text{Area} = \bar{C} * (t_2 - t_1)$$

(Rectangular)

$$\bar{C} = \text{Area}/(t_2 - t_1)$$

$$\text{Cardiac output} = \frac{q}{C} X \frac{60}{\text{duration in seconds}}$$

Explanation of the previous slide

We use an indicator that is non-toxic, distributed well , non-degradable and colorful. E.g. **Cardiogreen**. We inject a certain amount of this dye (call it q) in the right ventricle (using Swan Ganz catheter we mentioned before).

we draw the curve (notice that the concentration of the dye will increase to a specific value then will decrease) but the concentration will not reach zero,why ?
Because of recirculation, the blood will renter the right ventricle and the concentration will increase (depends on the circulation time)

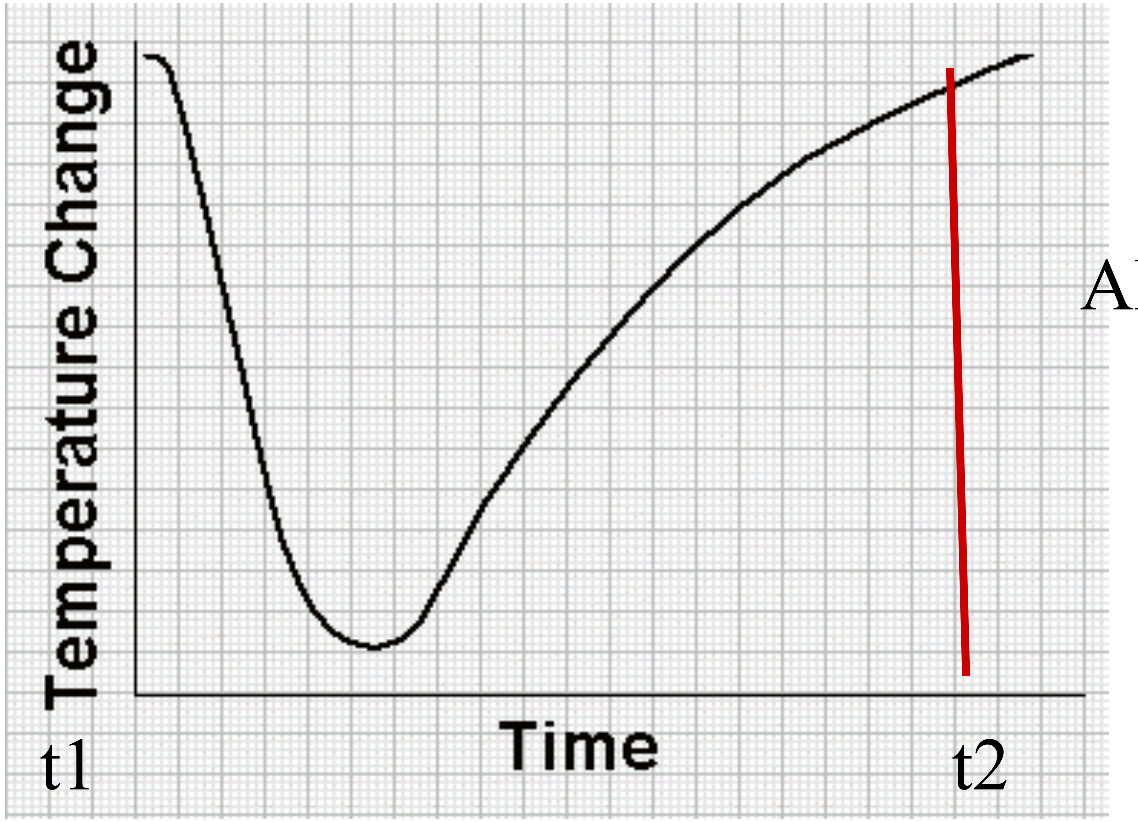
Then we calculate the area (either by integration or by rectangles) (the equation in the previous slide)
and by dividing the area over time duration we get the mean concentration (C) ,to get the CO we divide the amount of dye (q) over concentration (C) to get the volume
Then we divide the volume over time in seconds and multiple it by 60 to get per minute (by this equation)

Area = $C^* (t_2 - t_1)$ (Rectangular)
$C = \text{Area}/(t_2 - t_1)$

$$\text{Cardiac output} = \frac{q}{C} X \frac{60}{\text{duration in seconds}}$$

والله يابني انت كنت
أنت فاهم يبئى انا فاهم

Thermodilution Method Curve



$$\text{AREA} = \int_{t1}^{t2} dT.dt$$

Explanation of the previous slide

We inject **cold saline** with a known temperature and volume (again using Swan Ganz catheter). Notice that this special catheter has a thermistor that measures temperature. We can get the cardiac output. Now using a special computer program we can calculate the cardiac output through integrating temperature changes over time. (or we can use an equation similar to the last method's)
The advantage of this method is that you can use it multiple times to have multiple readings and then take the average

We can use this method to check the cardiac output of a pregnant woman to decide if to deliver her baby by cessation or by normal delivery

Review

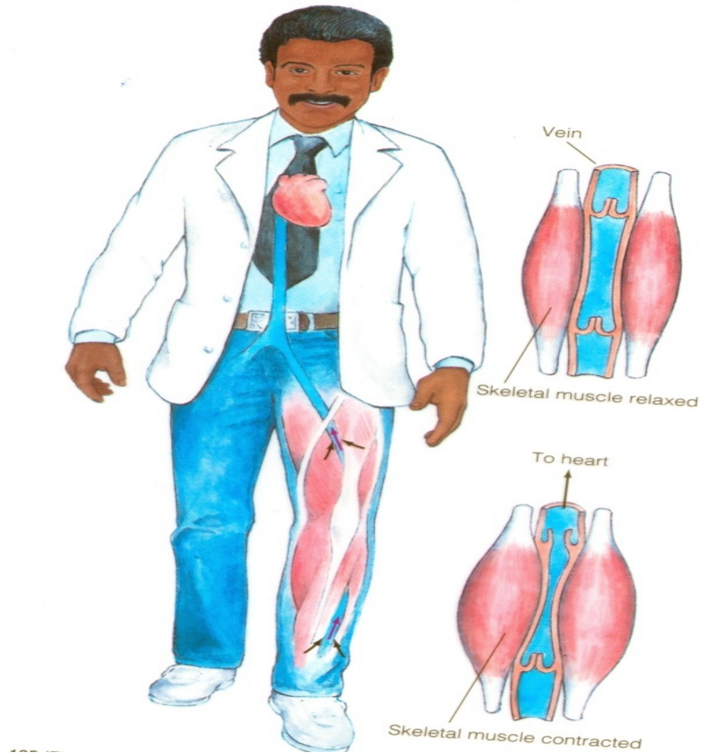
- The cardiac output equals the venous return because according to Frank-Starling; what comes goes, and this is very important.
- If there were different volumes exiting and entering the heart, this is a very large problem. This does not occur normally in the heart, if the volume increases, so does the length of the cardiac muscle and therefore the force of contraction increases and the extra volume is ejected.
- The force of contraction is something other than the contractility. The increased contractility means there is fixed EDV and increased SV/ fixed SV, decreased ESV.
  When the EDV increases, the force increases and so does the SV, but the ejection fraction stays the same, because both are increasing.

VENOUS RETURN

- Definition: Volume of blood returns to either the left side or right side of the heart per minute
- VR = CO =Δ P/R
- VR = (Venous pressure –Rt. Atrial pressure)/ resistance to venous return

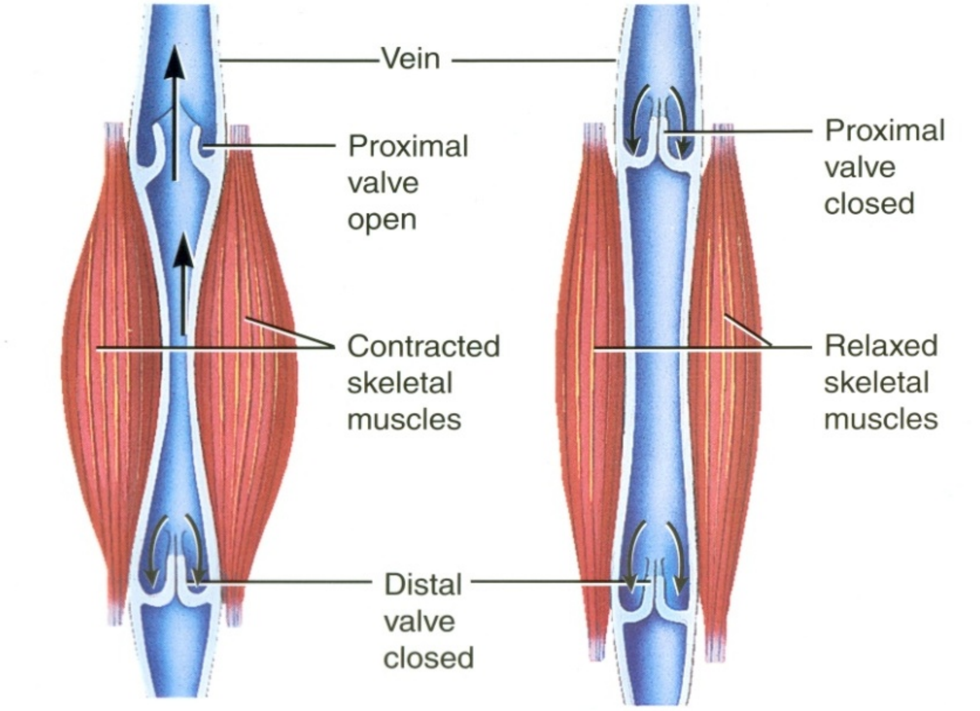
- Veins are the vessels that bring the blood towards the heart.

Effect of Venous Valves



- In veins we have valves, and they are especially important in the deep veins.
- The importance of these valves is to direct the movement of blood in one direction, and they open towards the heart.
- When there is muscle contraction, that compress the veins, this leads to increased venous pressure, they prevent the return of blood in the opposite direction.
- The amount of blood trapped between the two valves is small, if there were no valves, and there was continuous flow, then the pressure on the other side (away from the heart) equals the column of water, and so the pressure here is very low and that is because of the presence of the valves

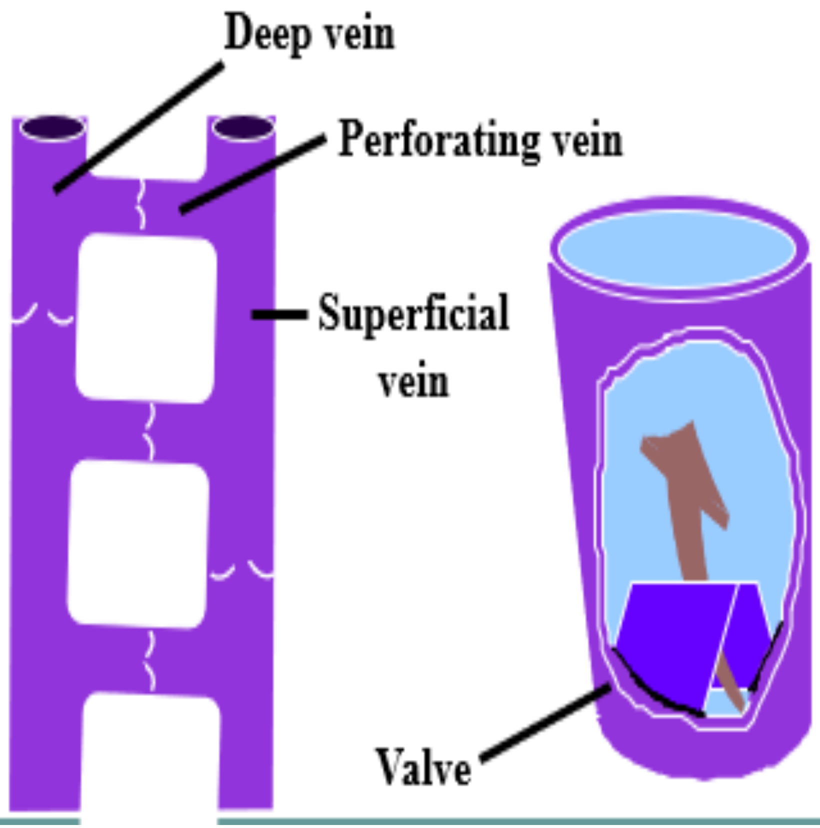
Effect of Venous Valves



(a) Contracted skeletal muscles (b) Relaxed skeletal muscles

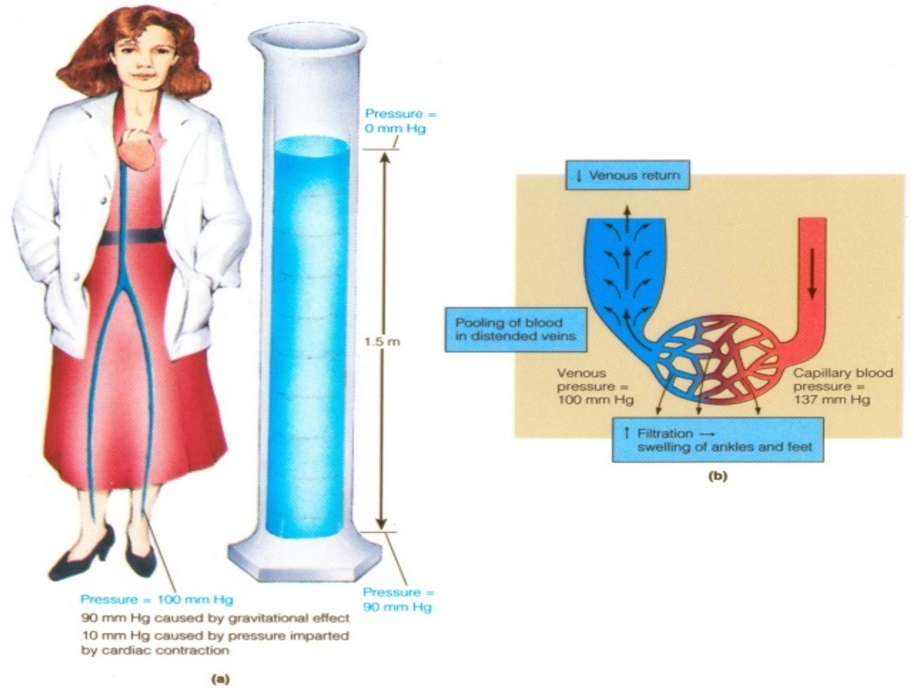
- Veins are surrounded by skeletal muscles, when this muscle contracts this increases the pressure inside the veins, the valve opens and the blood goes to the heart, increasing the venous return.
- This is a very important factor that increases the venous return; muscle contraction.
- This is what we sometimes call the skeletal muscle pump.
- This also highlights the importance of movement, because someone who doesn't move their body will face blood stagnation. Exercise increases the cardiac output because it increases the venous return

Venous Valves



- The valves open towards the heart, and sometimes there are valves between the superficial and deep veins, and they all open towards the heart.

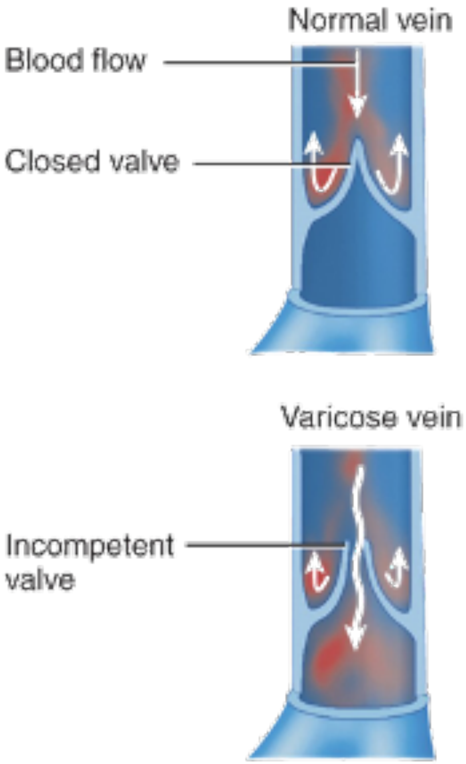
Effect Of Gravity on Venous Pressure



- This instructor for example, is standing all the time while she is teaching, and after long hours of standing the valves will not be able to bear the pressure of the blood, and since the muscle is relaxed there will be collection of blood in the veins, and the pressure of blood down in her legs will equal the column of water.
- After some time, the veins will become dilated, due to the collection of blood, and the valve becomes incompetent.

- If we assumed that the length of this woman from her heart to her feet is 136cm, and she stood still without moving, the pressure at the bottom of her legs (assuming the pressure in the atria is zero) would be 136cm of water, and 100 mmHg (divided by density of mercury (13.6))

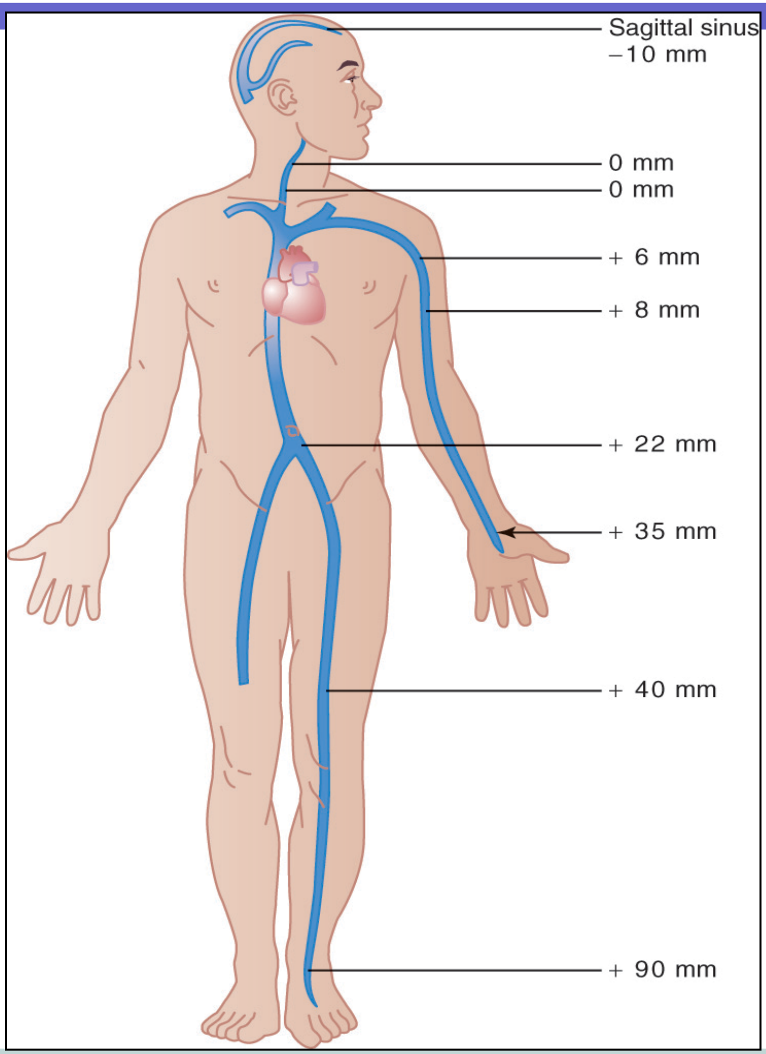
Vessel Structure and Function



Dilated and twisted appearance of varicose veins in the leg

- The veins become torturous, dilated and bluish because they contain deoxygenated blood.
- This phenomenon is called varicose veins.
- Varicose veins are then, dilated torturous veins because of incompetent valves.
- This might also happen when there is increased pressure in the veins. This occurs in the legs of pregnant women commonly. The pregnancy (belly) might compress the lymph nodes in the area and cause increased pressure in the veins, and cause their obstruction, which might lead to these varicose veins. It might even lead to heart failure
- “Pregnancy is a normal tumor of the abdomen”

Venous Pressure in the Body



- Compressional factors tend to cause resistance to flow in large peripheral veins.
- Increases in right atrial pressure causes blood to back up into the venous system thereby increasing venous pressures.
- Abdominal pressures tend to increase venous pressures in the legs.

Explanation

- The right atrial pressure is measured when we take a blood sample from the right atria, the right ventricle or the pulmonary artery, this blood is called mixed venous blood.
- All the veins start there.
- The pressure in the right atrium is called central venous pressure (CVP), and it is normally zero. It can increase in some cases and up to 30 it is considered normal, but if it becomes more than that then we will have a problem.
- Increase in the volume of the blood, the increase in venous pressure, decreases in the resistance (will lead to more flow) and obstruction of the veins will lead to an increase in the CVP.
- If the contractility becomes less, both the EDV and the ESV increase, this will increase the right atrial pressure, and vice versa.
- When giving IV fluids to a patient with heart failure, it most be controlled. First, you measure the right atrial fluid (inserting a catheter into the chest to the SVC and down to the atria to measure the pressure with a manometer) and monitor it, while giving the patient the IV fluids.

Central Venous Pressure

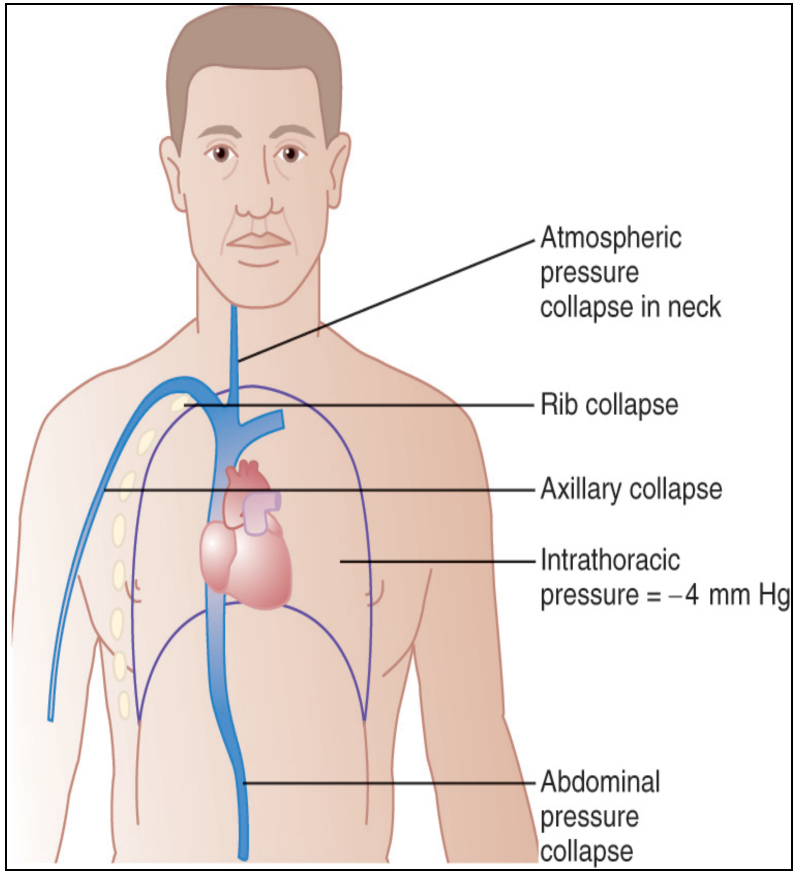
- Pressure in the right atrium is called *central venous pressure.*
- *Right atrial pressure* is determined by the balance of the heart pumping blood out of the right atrium and flow of blood from the large veins into the right atrium.
- Central venous pressure is normally 0 mmHg, but can be as high as 20-30 mmHg.

Due to HF there will be stagnation in the blood, and the RAP may increase

Factors affecting Central Venous Pressure

- Right atrial pressure (RAP) is regulated by a balance between the ability of the heart to pump blood out of the atrium and the rate of blood flowing into the atrium from peripheral veins.

- Factors that increase RAP:
- -increased blood volume
- -increased venous tone
- - dilation of arterioles
- -decreased cardiac function



☼ Increased blood volume

If the venous return increases, this will increase the RAP. If it does, this will lead to an increase in the cardiac output (according to Frank-Starling)

☼ Increased venous tone

- The tone is the minimal contraction of the muscle. In skeletal muscles, they normally have tone even when relaxed, this is because we normally have certain amounts of acetylcholine being secreted during relaxation and so the muscle stays contracted a little bit.
- The smooth muscles in the blood vessels are a little bit contracted, if you increase the sympathetic stimulation, then this will lead to vasoconstriction and if you inhibit the sympathetic stimulation this will lead to vasodilation, this is called sympathetic tone.
- If you increase the venous tone, this will lead to an increase in the contraction of the muscle, and then the venous pressure increases which leads to more blood going to the right atrium and this will increase the pressure inside it and increase CVP.

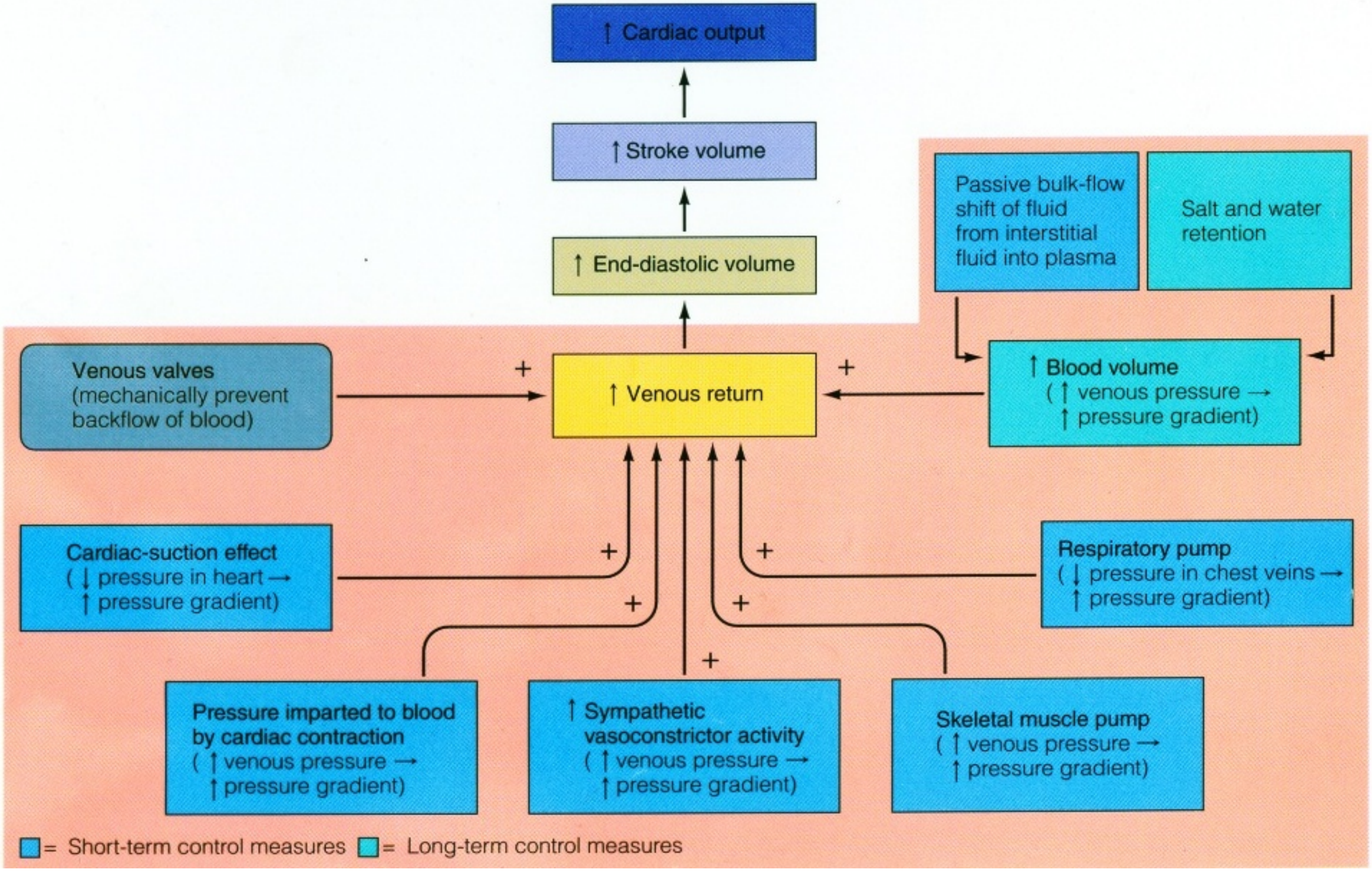
☼Dilation of arterioles

The arterioles are the main resistance vessels, the main resistance of our total peripheral circulation is in the arterioles, so if you dilate the arterioles, this will lead to less resistance, and this will increase the flow and therefore the venous return to the heart and the RAP.

☼ Decreased cardiac function

In decreased cardiac function (contractility), ESV increases and so does the RAP.

Factors that Facilitate Venous Return



Explanation of figure

- Why is venous return important? Because when it increases the EDV and ultimately the SV and the CO increase
- The first way to increase the venous return is through the skeletal muscle pump; when the muscles contract, they compress the vein and cause the valves to open, leading to venous return of blood to the heart.
  when the muscle contracts this will increase the pressure in the veins, this increases ∆ P, which is the venous pressure, and this will increase the flow, and the venous return.
- Also, if you increase the blood volume, this will also lead to an increase in venous pressure and venous return consequently.
- Increased sympathetic stimulation leads to increased venoconstriction, this will also lead to an increase in venous pressure and the pressure gradient and consequently the venous return.
- Competent valves ensure the unidirectional flow of blood to the heart, if they become incompetent, the blood will start to return in the other direction, and this decreases the venous return.
  This is the case with varicose veins, they decrease the venous return and the cardiac output also cause stagnation of blood inside the veins, and this will lead to thrombosis, and if this occurs in the legs it might cause pulmonary embolism.

Explanation of figure 2 (اتحملونا بعينكم الله)

- Cardiac contraction :

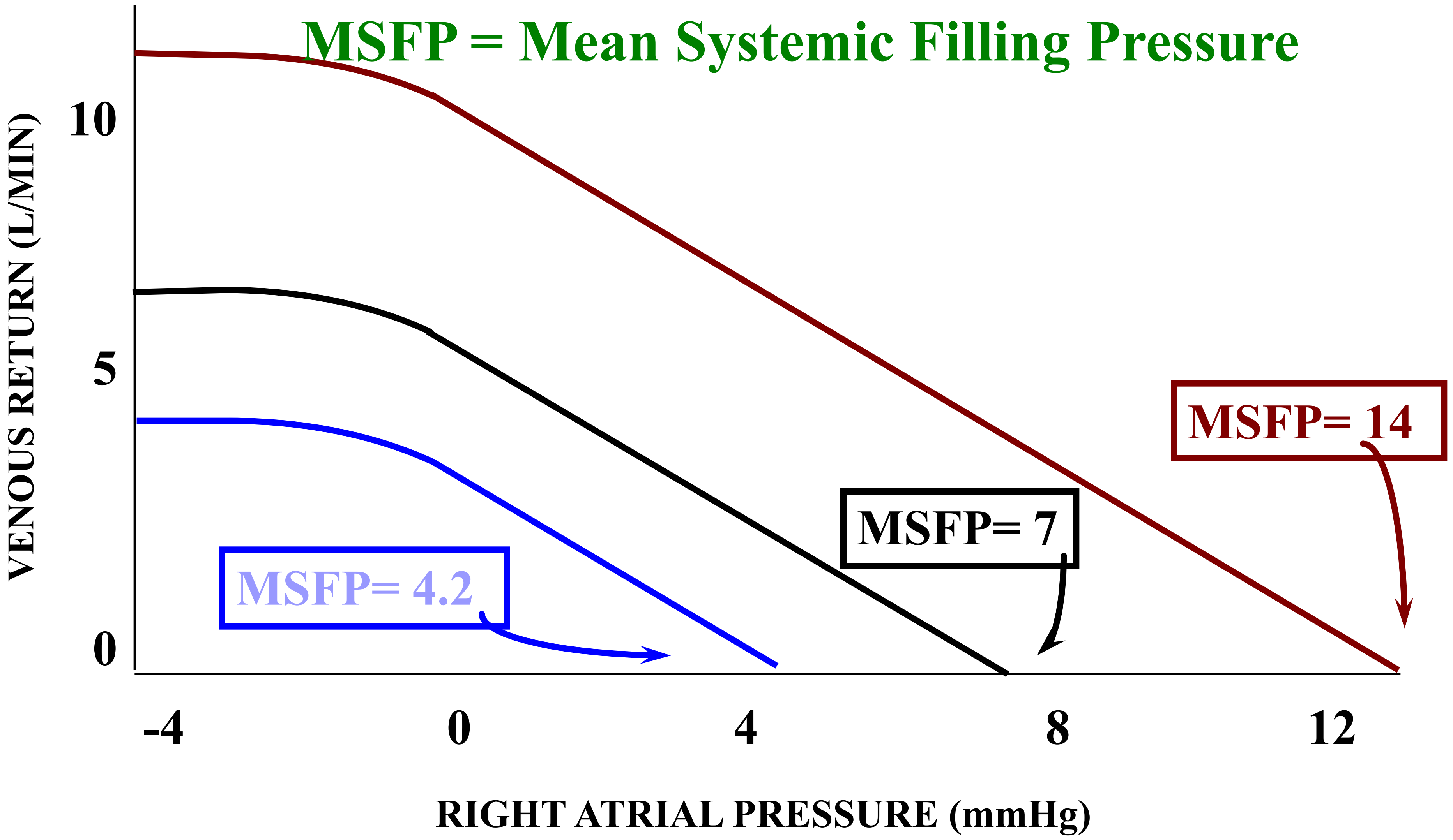
When cardiac contractility increases this will decrease ESV , which will decrease right atrium pressure and consequently increase the pressure gradient and increase the venous return

- Pumping blood : When you pump blood from the left ventricle to the right atrium , the venous pressure increases and the gradient as well

- Respiratory pump :

Respiration is two types : inspiration (inhalation) & expiration (exhalation)
When pressure inside the lungs becomes less than the atmospheric inspiration takes place
When pressure inside the lungs becomes more than the atmospheric expiration takes place
intrapleural pressure controls the pressure inside the lungs
Ok, during inspiration , intrapleural pressure becomes more negative from -4>>-6, the alveolar press will be -2 (0 (the atmospheric press) >>-2) ,so the right atrium pressure will decrease from 0>>-2 , so decrease pressure in the chest and increase in the pressure gradient , which causes increase in venous return
During expiration, the opposite happens but the effect of inspiration is much more

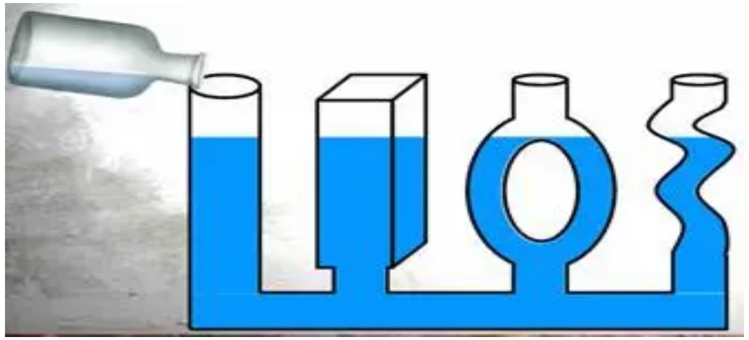
The Venous Return Curve



Explanation of figure

- We can understand the curve by using the concept of communicating vessels. (الأواني المستطرقة)
- We stop the heart and just pour the blood in the vessels , the level of blood will be parallel (equal) in all these vessels including the right atrium (just like the figure),the level of the blood correspond to the pressure (the mean systemic filling pressure) , so the venous return will equal zero as the pressure in the right atrium and in the veins is same, no pressure gradient no venous return

هاي الأواني المستطرقة



- We said that the right atrium has the same pressure as all vessels , and no blood is flowing anywhere. If right atrial pressure decreases below 8mmHg, a gradient will form between right atrium and systemic circulation.If pressure in right atrium is 6mmHg there's a little flow. When it's 5mmHg, flow will increase "more" and so on. That's why we can call the mean systemic pressure (MSPH or mean systemic filling pressure) because the difference (gradient) between MSFP and atrial pressure is what causes its filling.When the atrial pressure reaches zero, the venous return will be max at 5L/min. When pressure in the right atrium becomes negative, however, vessels will collapse and venous return will no longer increase (plateau in the figure in the previous slide).

- The first person to measure the mean systemic pressure was Guyton. He first measured it in dogs, then tried to do so in humans and found out that it was about 8 mmHg

- How to increase the pressure in the circulation (MSFP)
  - By increasing the blood volume , how? IV transfusion (blood, plasma)
  - Sympathetic stimulation: It causes veno-constriction and consequently higher venous pressure

✓ This will shift the curve right and up

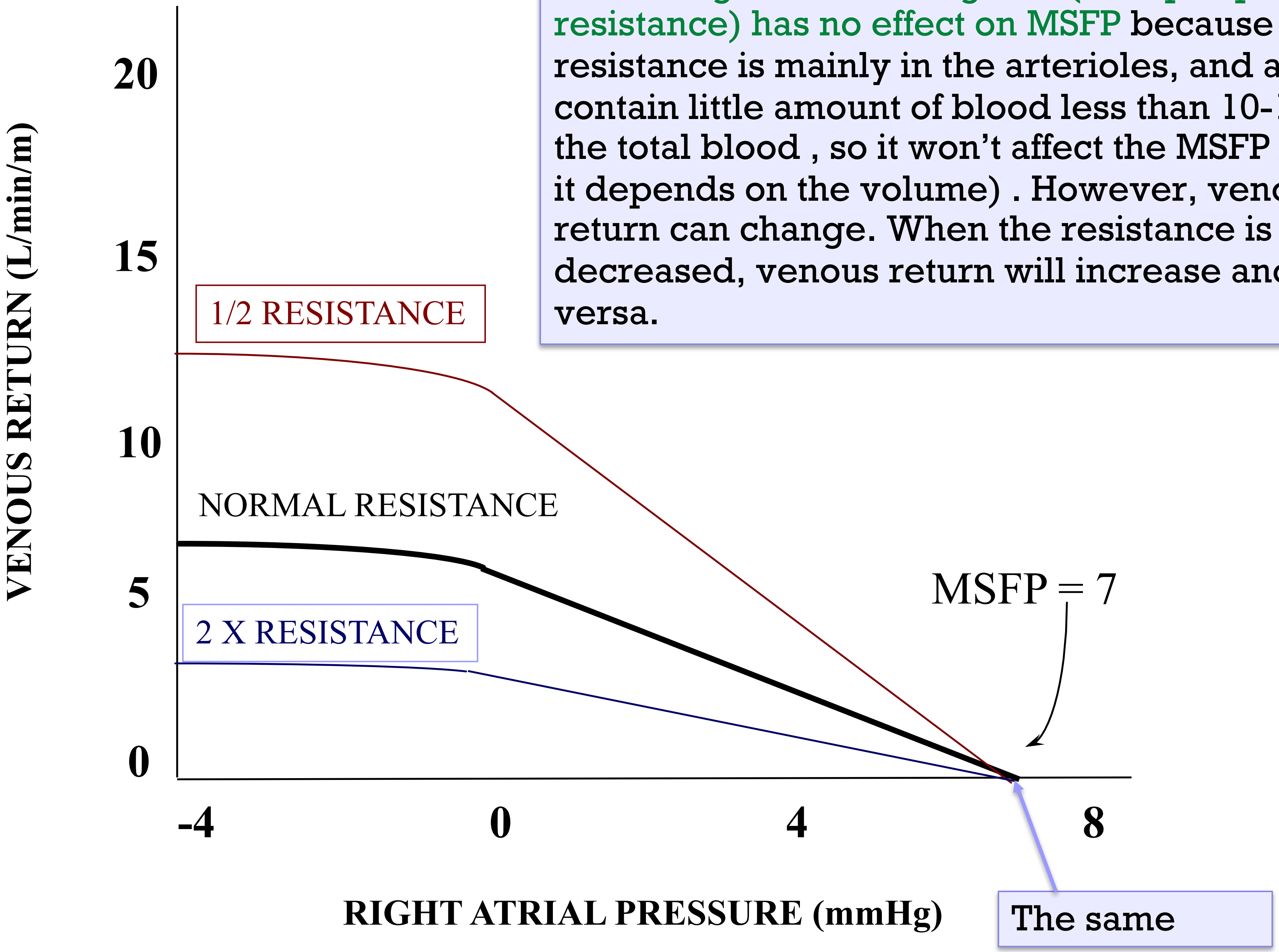
That's why when someone has decreased CO , we give him/her IV blood .

- Now , how to decrease the MSFP ?
  - Hemorrhage, dehydration

✓ and the curve will be shifted to the left and downward

Explanation,explanation

increasing or decreasing TPR (total peripheral resistance) has no effect on MSFP because resistance is mainly in the arterioles, and arterioles contain little amount of blood less than 10-15% of the total blood , so it won't affect the MSFP (because it depends on the volume) . However, venous return can change. When the resistance is decreased, venous return will increase and vice versa.



Venous Return (VR)

- Beriberi - thiamine deficiency ⇒ arteriolar dilatation ⇒ ↓ RVR

Increase in the venous return

- A-V fistula ⇒ (? RVR). ↓ RVR

Renal dialysis means that blood is taken from an artery to be filtered in a machine and then returned to a vein, which is a tiring process,So A-V fistula may be done in this case which is a connection between the artery and the vein as a shunt so the resistance is decreased and the flow is increased but it's acute condition

Could be iatrogenic (made by doctors)

- C. Hyperthyroidism ⇒ (? RVR ↓ RVR

Because of increased metabolic rate ,so more oxygen consumption, more co2 and heat release which causes vasodilation, so the resistance is decreased and the flow is increased

- (RVR= resistance to venous return)
- because VR = (MSFP - RAP) /RVR (good for positive RAP's)

Venous Return (VR) (cont'd)

- Anemia ⇒ ↓ RVR (why?)

decreased number of RBCs which is the major factor that affects the blood viscosity beside plasma proteins → decreases viscosity → ↓RVR → ↑venous return

- Sympathetics ⇒ MSFP
- ↓ Venous compliance (muscle contraction or venous constriction) ⇒ (? MSFP)

More elastic , increase resistance& MSFP, increase blood flow

- Blood volume ⇒ MSFP + small ↓ in RVR

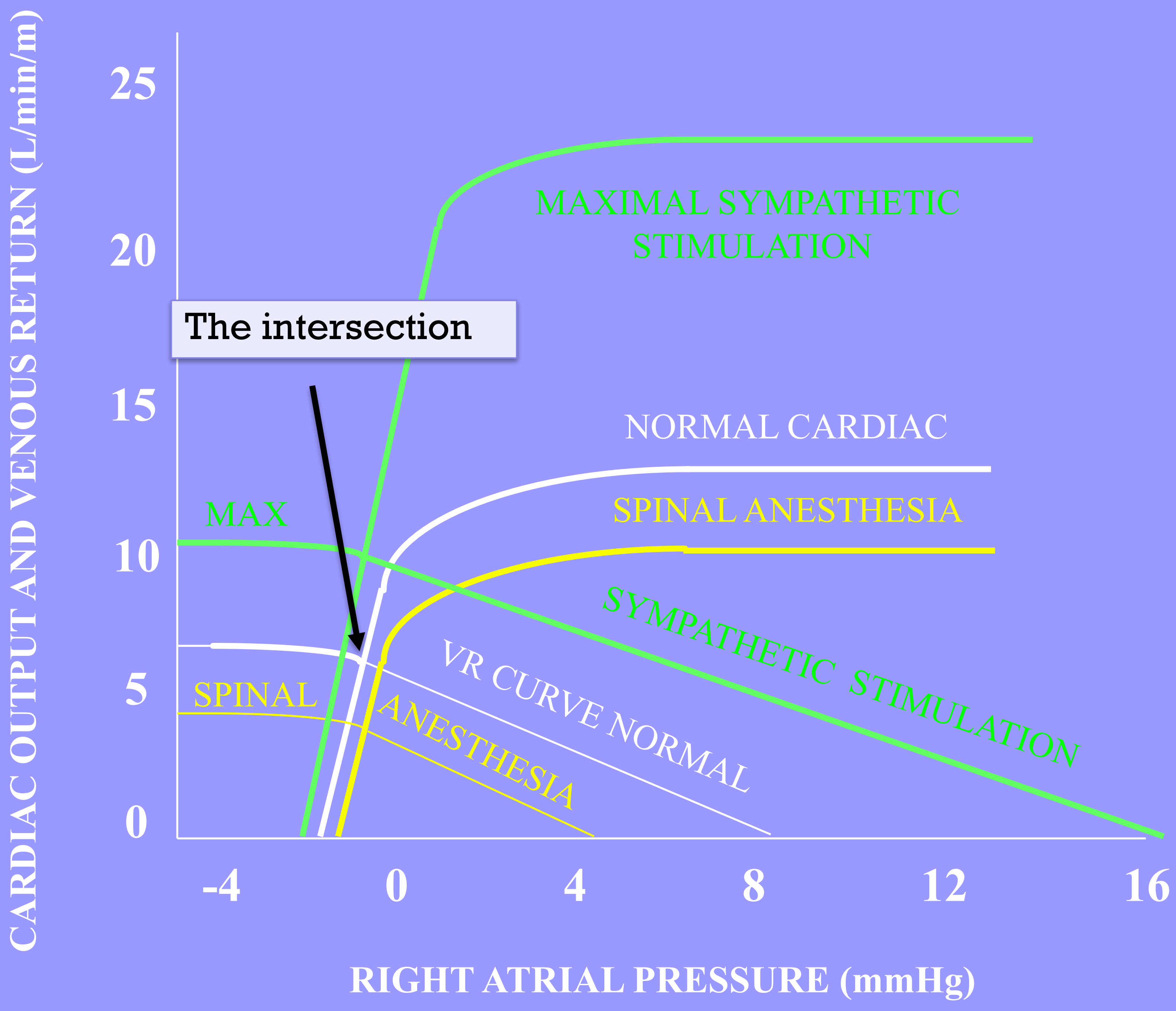
Factors Causing ↓Venous Return

- ↓ Blood volume ⇒ ↓ MSFP
- ↓ Sympathetics ⇒ (? v. comp. and MSFP)
- Venous compliance and ↓MSFP
- Obstruction of veins ⇒ (? RVR)
- RVR

Remember the curve

Increase resistance, decrease flowing there is flow

If the resistance increases more , blood flow decreases
If the pressure increases more , blood flow increases


CARDIAC OUTPUT AND VENOUS RETURN (L/min/m)
25
20
15
10
5
0
-4
0
4
8
12
16
RIGHT ATRIAL PRESSURE (mmHg)
MAXIMAL SYMPATHETIC STIMULATION
The intersection
NORMAL CARDIAC
SPINAL ANESTHESIA
MAX
SYMPATHETIC STIMULATION
VR CURVE NORMAL
SPINAL
ANESTHESIA

Explanation of figure

The figure in the previous slide shows curves of both Cardiac output and Venous return in different conditions. As you can see the points of intersection are the 'working cardiac output' or the cardiac output that's found in our body. So, in normal conditions it is about 6L (white curves). In the case of sympathetic stimulation, the venous return curve is shifted upward and to the right as we said earlier. The cardiac output is also shifted upward so now we have a new intersection point, and the working cardiac output would become higher (10L for instance) (the green one)

Thank You