In the previous lecture:

I. We talked about variation in tissue blood flow. And that the heart has one of the highest blood flow per 100gm of tissue (around 70ml/min/100gm).

• Other tissues have higher blood flow but this is not for oxygen consumption, it's for filtration like in the kidney.

• Other tissues like adrenal and thyroid glands, they are small glands, the blood that is going to them is much higher than they need.

II. Other things we talked about:

✓ CO=SV*HR

• SV: regulated intrinsically by EDV and extrinsically by the sympathetic (positive inotropic effect).

• The HR is regulated by both the sympathetic and parasympathetic + several chemicals and ions.

✓ Regarding SV regulation, we can say it in other way:
1-The preload which is proportional to the EDV.
2-The afterload: is the pressure on the muscles during contraction (the pressure that the Lift or right ventricle muscles must overcome to pump the blood, it depends on the T.P.R generated by the arterioles), if you notes in the picture it says (a decrease in the arterial blood pressure will decrease the afterload).
In other words, it is the pressure in the aorta and the pulmonary trunk that the ventricle must push against it.

**3-contractility** → increased by the sympathetic as we said (positive inotropic).

III. **we talked about the work load of the heart:**

External work = volume * pressure

From dr. Najeeb videos:

The work = D* force

D= the displacement = in cardiac work it represent the SV

Force = the pressure → which pressure ?? the aortic pressure

If we want to calculate the cardiac work in one minute ??

It is simple we replace the SV by the CO = SV*HR (beats/min)

Min. Cardiac work= CO*Aortic pressure (AP)

What if the aortic pressure increased → the ventricle must work herded to overcome this pressure. And if aortic pressure is decreased → the work needed will be less.
So If we want to increase the CO → we must increase the work

I hope everything is clear until now 😊

At this moment we must build another concept:

- More heart work = more oxygen consumption.
- So O2 consumption and cardiac work = \( \text{CO} \times \text{aortic pressure} \).
- You must know that both ventricles have the same CO.
- What do you think about the work, which one work harder?? Yes exactly, the left ventricle work more because the aortic pressure is higher than the pulmonary pressure ,as simple as that.
- So which ventricle needs more O2 → of course the left one.

- In aortic stenosis → we will have high aortic pressure.
- In exercise → the tissue will need more O2, so the CO will increase but the cardiac work will not increase that much, why?? Because ,as the doctor said, while exercising the vessels will be dilated → lowering the cardiac work.

In patients with systemic hyper-pressure → we must lower their aortic pressure, so the L.ventricle will work less and will not need high O2 consumption.
This figure summarizes the factors that affect the cardiac output:

- Increased diastolic volume (stretches the heart)
  - Increased PRELOAD
  - Within limits, cardiac muscle fibers contract more forcefully with stretching (Frank-Starling law of the heart)

- Positive inotropic agents such as increased sympathetic stimulation, catecholamines, glucagon, or thyroid hormones in the blood; increased Ca²⁺ in extracellular fluid
  - Increased CONTRACTILITY
  - Positive inotropic agents increase force of contraction at all physiological levels of stretch

- Decreased arterial blood pressure during diastole
  - Decreased AFTERLOAD
  - Semilunar valves open sooner when blood pressure in aorta and pulmonary artery is lower

- Increased SYMPATHETIC STIMULATION and decreased parasympathetic stimulation
  - Increased STROKE VOLUME
  - Semilunar valves open sooner when blood pressure in aorta and pulmonary artery is lower

- Increased HEART RATE
  - Increased CARDIAC OUTPUT

- Increased sympathetic stimulation
  - Catecholamine or thyroid hormones in the blood, moderate increase in extracellular Ca²⁺

- Infants and senior citizens, females, low physical fitness, increased body temperature

NERVOUS SYSTEM
Cardiovascular center in medulla oblongata receives input from cerebral cortex, limbic system, proprioceptors, baroreceptors, and chemoreceptors

CHEMICALS

OTHER FACTORS
Notice in the figure:

- On the Y axis the stroke work (work done by heart), in the right ventricle it range from 0-4, while in the left ventricle it ranges from 0-40.
- Same curve (shape), but in the left ventricle it's ten times higher “ the work ” than on the right.
- The pressure in the left atrium and right is almost the same (indicating that the difference is not in the volume).

The cardiac output curve

Notes:

- The normal curve by frank starling law:
  More EDV MORE SV and CO until you reaches the optimal Langhe of the muscle, the CO will be (15 L), after that
the more the increase in the EDV the less SV because you reached heart failure.

- congested heart failure $\rightarrow$ stagnation (ركود) of blood:

If there is a 1ml difference in stroke volume between the (R. and L.) ventricles, after one hour all the blood will be in the ventricle.

- In the case of sympathetic stimulation or athletic training (hypertrophy) we can have **HYPEREFFECTIVE** heart (as a result of increasing contractility) were the CO can reach 25L (sympathetic stimulation) or 35L (athletes).

Note: The parasympathetic has its main effect on the heart rate rather than contractility

- **HYPOEFFECTIVE** $\rightarrow$ when the sympathetic is inhibited or the cardiac mass decrease how??

In MI, ischemia, myocarditis, scarring of the muscle, valvular heart disease or stenosis.

**From the slides:**

Plateau of CO curve determined by heart strength (contractility + increased HR):

- increase Sympathetic $\rightarrow$ increase plateau.
- decrease Parasympathetic (HR increased) $\rightarrow$ (??plateau) remember parasympathetic effect mainly on the heart rate $\rightarrow$ increase Plateau.
- Heart hypertrophy’s $\rightarrow$ increase plateau.
- Myocardial infarction $\rightarrow$ decrease plateau.
- Valvular disease $\rightarrow$ decrease plateau (stenosis or regurgitation)... shift in the curve downward and to the right.
- Myocarditis $\rightarrow$ decrease plateau.
- Cardiac tamponade $\rightarrow$ decrease plateau (you can maintain the plateau but you need very high pressure).
• Metabolic damage $\rightarrow$ decrease plateau by decreasing cardiac mass and so maximum CO.

**Effect of intra-plural pressure on CO:**
- The heart is in the chest, that also contain the lungs and the pleura that surround the lungs.
- The intra-plural pressure is always negative $\rightarrow$ that’s why the lungs are distended and there is a vacuum around them.
- So around the heart the pressure is the same as in the pleura (-4mmHg) ... in this case, the pressure in the right atrium is zero and the CO is 5L.

- If the intra-plural pressure increase what will happen??

  It means that there will be an increase in the pressure around the heart and the heart will need higher pressure to keep the CO the same (constant). So in the figure, the increase in intra-pleural pressure from -4 mmHg to -2 mmHg will be followed by a proportional increase in the right atrial pressure from 0 mmHg to 2 mmHg to keep a steady cardiac output of 5L/min, and as you can see the curve will be shifted to the right. (If the intra pleural pressure decreases, a decrease in the right atrial pressure is seen).

- If the IPP changed from -4 to -2 (increased) the R.A.P will increase 2mmHg, so the curve is shifted to the right but the **maximum CO is not affected** because the muscle is not affected directly (we can still reach the same CO).

- If the IPP decrease, it will become easier to fill the heart $\rightarrow$ Shift to the lift

- **In the case of Cardiac tamponade (change in pericardial pressure)** $\rightarrow$ the heart is affected directly, so to fill the heart you will need higher pressure, to attain the same CO (we can reach the maximum but with a very high pressure).
- This eventually could lead to heart failure (CO might reach 0 since the heart is unable to pump blood anymore), thus this condition is an emergency that needs to be relieved by cutting through the chest using a sharp object.

### Factors Affecting Cardiac Output:

Again the doctor is repeating the same things:

- The SV = EDV-ESV ..... The EDV is affected by venous return (increase EDV).
- Also we can say that the **filling time** (time of diastole) affect the SV by affecting EDV. So as we increasing the heart rate to a very fast rate → this meanly will affect the diastole (filling time) by decreasing it.

- If you remember we said that the cardiac cycle is 0.8sec, so when we increase the HR the cardiac cycle will be less than 0.8, let's say it will be 0.6sec, and off cores the main decrease will be in the diastole time ,it will change from 0.5 in normal to 0.32 or less, this will cause → very short filling time → decrease SV and CO. This is the problem of tachycardia, even if it increase the HR the end result may be a decrease in the CO. In this case, the atria systole and its time become very important.
Note: The maximum heart rate any one can attain is (200 - our age in years).... you should not exceed 90% of it.

- Summary for the above:
  IF THE TIME OF FILLING DECREASED → decrease EDV
  If VR decreased → decrease EDV

(Take a look at slide number 16 in the slides).
Now we will talk more about the VR:

- Also when we have an increase the V.R → increasing the blood volume → increased EDV → increased SV → increased CO → increased the pressure.

But how the blood volume increased??

✓ Simply in the case of giving fluid to the patient or transfusion of blood or giving a vasoconstrictor.

MAP = CO * TPR (this is correlation between the pressure and the CO or the VR).

TPR → total peripheral resistant.

MAP → mean arterial pressure (we can say it equals 2/3 of the diastolic pressure + 1/3 of the systolic pressure because as we all know that the diastolic is longer and contribute more to the MAP).

So if we increase the systolic pressure → that’s mean we increase the CO. And if we increase the diastolic pressure → that’s mean we increase the CO.

SO, a 10 mmHg increase in the diastolic pressure, 2/3 of that increase will contribute to the MAP. while in a 10mmHg increase in systolic pressure, only 1/3 of that increase will contribute to the MAP.

The main point is if we increase one of them we will increase the MAP.

So in person with hypotension what should we do???
Increasing the CO or TPR (by Vasoconstriction).
✓ Increased venous pressure \rightarrow increased venous return \rightarrow increased ventricular filling.

**V.R : regulator of the preload:**

- Increasing the venous pressure \rightarrow increase the VR \rightarrow increase preload.

*how??* V.R is a flow and the \( F = \frac{dP}{R} \)

So, \( F = \text{the VR or Venous flow.} \)

\( dp = \text{The difference in pressure between the venous pressure and Rt. atrial pressure.} \)

\( R = \text{the resistant.} \)

- So if we increased the veins pressure \rightarrow delta p will increase... flow will increase... and (VR/ preload) increase... (Frank–Starling law).

✓ If you remember when we talked about the Rt. atrial systole and we said that it is not essential for filling, but if someone have an increased HR (tachycardia) and the time of the filling is already short in this person the atrial systole will be very important and will contribute more for filling.

✓ In exercising \rightarrow the maximum HR will = (200- your age in years )

You should not exceed 90% of your maximum HR, why ???

\( \Rightarrow \text{Increase in HR eventually will lead to decreased CO} \rightarrow \text{because the filling time will decrease.} \)

**REGULATION OF STROKE VOLUME by CONTRACTILITY:**

- You know that the increase in contractility also affect the SV and the CO

*How??*

- When we increase the contractility \rightarrow we decrease the ESV \rightarrow increase the SV \rightarrow INCREASE CO.
What affects the contractility?
1) Sympathetic stimulation: have positive inotropic effect. (sometimes they mention parasympathetic stimulation, but really it has no effect).
2) Hormones: epinephrine/nor-epinephrine, glucagon (positive inotropic agent) and thyroxin.
3) Ions: increased potassium decreases the contractility which is treated by administration of insulin because insulin increases the excretion of K+.

How to measure contractility??
The best measure for contractility is change in pressure per time (maximal change in pressure during ventricular systole).

Measurement of Cardiac Output

Direct methods:
- In animals you cut the aorta, collect the blood ejected per min, this gives you cardiac output. Obviously we can't do this in humans ;)

- In humans: it can be measured directly to some extent by certain machines like the electromagnetic flow meter (discussed later).

Indirect methods:
1) Indicator dilution (dye such as cardio green).
2) Thermal dilution.
3) Oxygen Fick Method (oxygen dilution). (the best one)
1) Electromagnetic flowmeter:

- We have two poles of magnate (north and south).
- When a charged flow passes between the two poles, an electrical current formed and can be followed up by a calibrated galvanometer.
- Because blood is full of electrolytes, it is a charged flow, and the current that would be formed (we can also call it voltage difference or potential difference) between the magnate is proportional to the flow.
- If we measure this flow per min, we can calculate the cardiac output.
- This method can be used around any artery, and many times, (only used during cardiac surgery).

2) Fick’s principle:

Notes:
- The blood that is ejected to the lung by pulmonary artery is equal to CO.
- The blood that come to the left ventricle by pulmonary veins is equal to CO.
- The amount of oxygen that come to left ventricle by pulmonary veins = the amount of blood* the concentration of oxygen in blood.

How to know the oxygen concentration? ... spirometer.

If we make a person Inhale from a spirometer (closing his nose) ... through this device we know the concentration of the O2.

\[
CO = \frac{O_2 CONSPMTION}{\text{arterial blood } O_2 \text{ CONCENTRATION} - \text{venous blood } O_2 \text{ CONCENTRATION}}
\]

- So why we take venous blood from the pulmonary trunk ?? And how???
In arteries the O₂ CONCENTRATION will not change until it reaches the capillaries. So there is no difference if we measure oxygen in any artery . (we use radial artery ).
- But in the veins it will be different so we need to take a blood sample that represent all the veins in the body (mixed (central) venous blood)→ pulmonary trunk or right ventricle.
- How we take a sample from the pulmonary trunk ??
By Swan-Ganz catheter→ which have too many tubes in it for different functions . ( this catheter is especially important in anesthesia).

Example : If we assume that the concentration of oxygen in a mixed venous blood = 140ml/L  (which is going to the lung) and we assume that the concentration of blood when it gets out of the lungs and it was 190ml/L.

So let’s assume that his lung took 250ml of O2 per min. Can you calculate how many liters OF BLOOD passed through the lung in a minute (CO)??
YES
250ml per min/(190-140)= 5L/MIN

Example:
If pulmonary vein O2 content = 200 ml O2/L blood
Pulmonary artery O2 content = 160 ml O2 /L blood
Lungs add 400 ml O2 /min
What is cardiac output?
Answer: 400/(200-160) =10 L/min

You must be very careful with the unites the question in the exam will not be direct.
remember :(1L=1000ml)

3) Indicator dilution:
- Inject a dye in the right ventricle or pulmonary artery and measure the Change in the concentration of the dye in the arterial system with time.
- The dye: should be non-toxic, not excreted very fast because we want to monitor it, the dye should be non-metabolized and not allergic.
4) Thermo- dilution Method Curve:

- **Thermo- dilution**: we measure the change in the temperatures during certain period of time.
- **We use cold normal saline** for example (4 C) and inject it into the right Ventricle, the temperature drops, and then it goes up, this is because new blood comes.
- **Thermal-dilution**: how much the temperature drops (change) over time, and using Calculation to measure cardiac output.

- **Normal saline**: NaCl conc. 0.9% , 300 ml osmoles.

- Inject low amount (depend on the age and mass of individual).

- We Use a catheter and this method can be done many times, especially for pregnant women's that present to you for labor( if they have heart disease, we must measure their cardiac output to decide whether to go for a normal delivery or cesarean section, because stress during normal delivery can lead to heart failure and death of the patient if her CO is low.

- So calculate the area under the curve $\rightarrow$ mean droop in temperature (computer work ;)
  - The benefits of this method:
  - Very fast.
  - Can repeated many times and take the average of one hour.

PLEASE take a look to the slides it will be **very , very, very** helpful.
NEXT LECTURE: venous return.