Physiology

Cardiovascular system

Sheet Slide

Number: - 11

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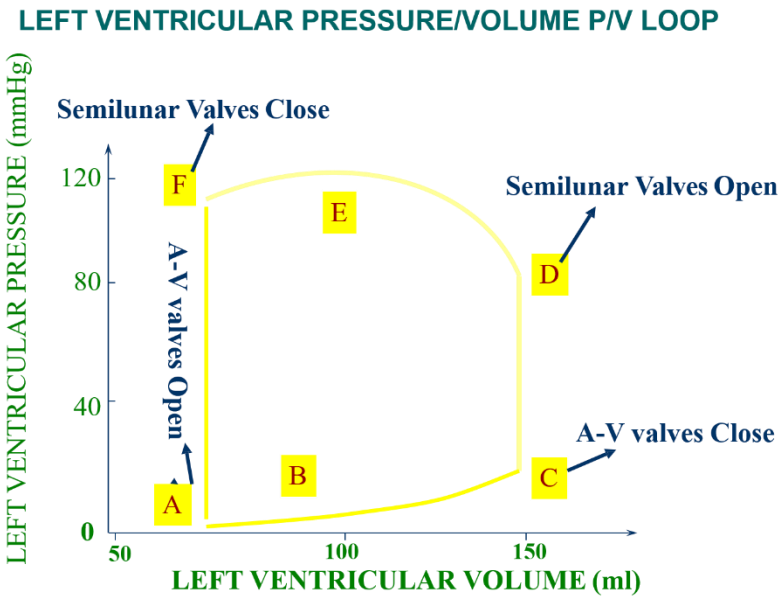
<u>This sheet isn't done by me, It's a correction for 2015 sheet with some additions and new organization.</u>

In the previous lecture:

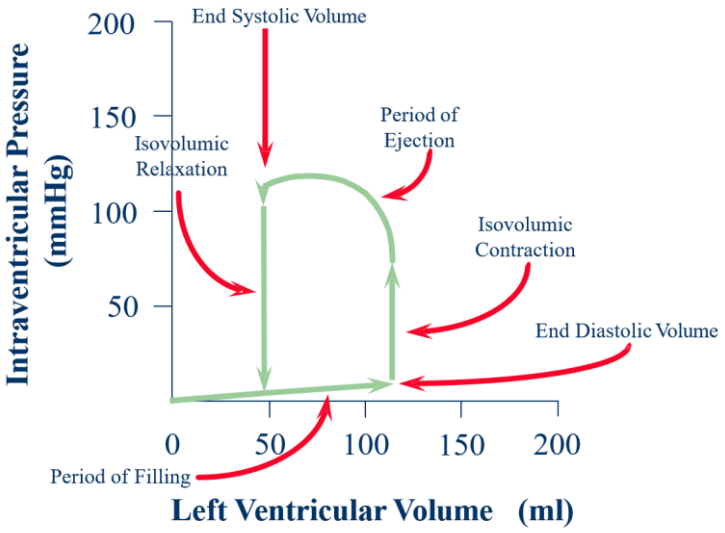
*We talked about the mathematical representation of the cardiac cycle, we put left ventricular volume on the x axis and the left ventricular pressure on the y axis then we draw the curve, the phases that we get: filling phase, isovolumic contraction phase, ejection phase and finally isovolumic relaxation phase.



Then we talked about the work and we said that:

1) External work is the most important one and it's the energy spent by the heart to move the blood inside the circulation
2) Potential energy, it is the energy that stored in the system that we might use it if we want to increase the SV without increasing the EDV, and equal to area under the triangle.
3) Kinetic energy, it is the amount of energy that spent to move the blood inside the orifice that guarded by the semi-lunar valve and its negligible as the blood can move easily through the SL valve, it might be important in some cases where SL valves are stenosed, such as in aortic stenosis, when the stenosis happened, we need more kinetic energy to move the blood across this narrow orifice. In this case, it might increase to 50%.
   <u>Total Energy = kinetic energy + external work</u>

Work Output of the Heart



We talked about the cardiac cycle regulation as in the following points:

-The cardiac cycle's regulation is either intrinsic or extrinsic.

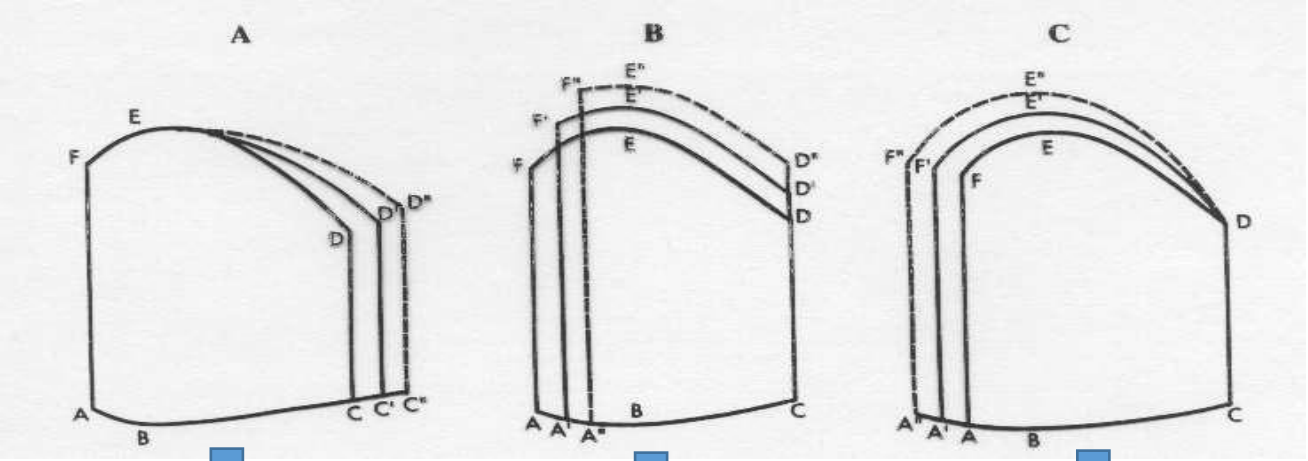
- Intrinsic regulation is represented by the Frank-Starling mechanism, which states that within physiological limits, an increase in diastolic volume will increase the stroke volume. - Maximum cardiac output might reach normally around 15 L/minute. (Keep in mind that this maximum value is reached without extrinsic stimulation).

- We talked also about these pictures in the following page:

Study it then refer here

- keep in mind that this increase in the preload and afterload occurs when the external work is constant which is the area under the curve

- on the other hand, to maintain the stroke volume constant while increasing or decreasing the preload or the afterload, you have to increase the external work (the area under the curve).



Increase in the **preload** ⟶ an increase in end diastolic volume ⟶ an increase in the stroke volume (Frank-Starling low)

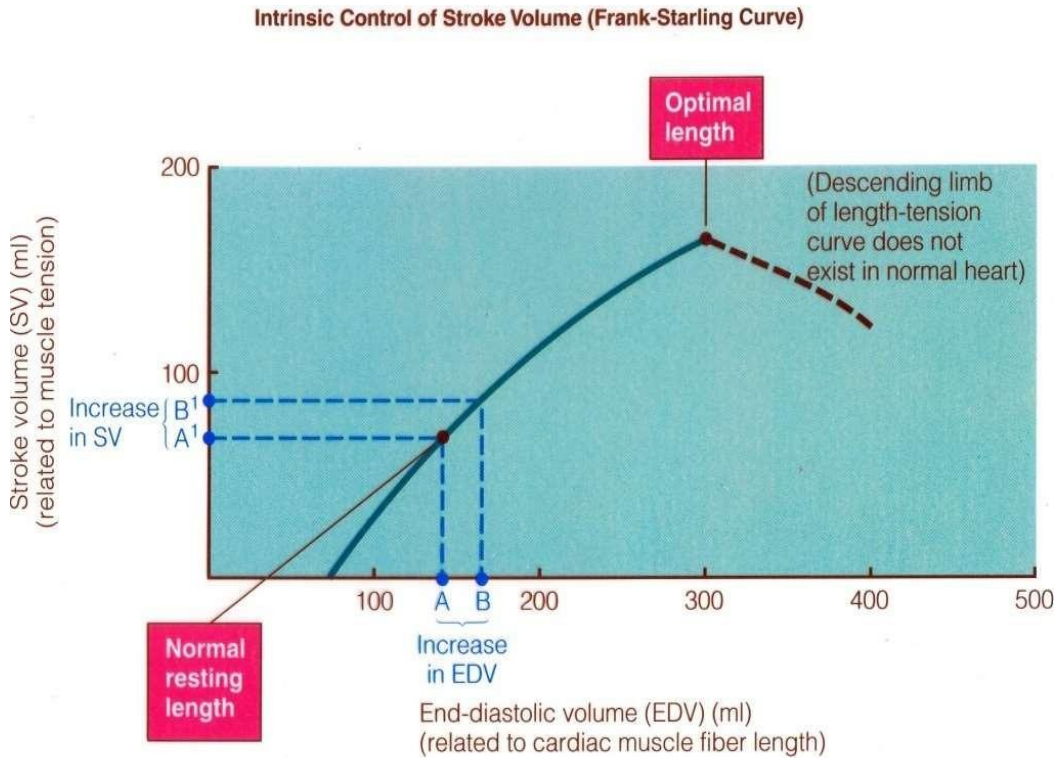
Increase in the **afterload** ⟶ end systolic volume increases ⟶ stroke volume decreases

Diastolic volume in the aorta increases ⟶ the diastolic pressure of the aorta increases ⟶ so the stroke volume decreases

The **contractility** of the heart increases ⟶ the SV increases

(positive inotropic)

In this figure you should notice the following:



- EDV presented on the x-axis and Stroke volume presented on the y-axis
- As we said and according to Frank-Starling an increase in EDV will increase SV until it reaches the optimal length.
- When it reaches the optimal length, the stroke volume will start to decrease, that means cardiac failure has occurred.
- This figure is the same as that of the Length-Tension Relationship graph, where the length of the cardiac muscle is analogous to EDV, and muscle tension or intraventricular pressure is analogous to stroke volume.

Regulation of Heart Rate (Autonomic Nervous System):

1- Sympathetic nervous system (SNS) has both positive chronotropic and inotropic and its stimulation is activated by stress, anxiety, excitement, or exercise. Its dominant effect is to increase contractility.

2- Parasympathetic nervous system (PNS) has only positive chronotropic and its stimulation is mediated by acetylcholine and opposes the SNS.

SNS is dominant in term of contractility, while PNS is dominant in term of heart rate (vagal tone).

*So, if you cut the sympathetic innervations, the contractility will decrease without much change in heart rate.

* If you cut the parasympathetic, the heart rate will increase without much change in contractility.

*If you cut both PNS & SNS, the heart rate will increase, and contractility will decrease.

Atrial (Bainbridge) Reflex

It is a sympathetic reflex initiated by increased blood in the atria.

- Increased blood volume or pressure (increase in pressure is due to increase in volume) in the right atrium will stimulate the SA node so permeability of Na in the SA increases and the threshold will be reached faster, leading to increase in heart rate (positive chronotropic effect).

Chemical Regulation of the Heart

- Heart rate increases in response to the hormones epinephrine and norepinephrine (all hormones derived from tyrosine).

- Intra- and extracellular ion concentrations must be maintained for normal heart function, especially the concentration of Ca+2.

- **Contractility increases in response to**: Epinephrine and norepinephrine, sympathetic stimulation and drugs like glucagon.

- **Contractility decreases in response to:** hyperkalaemia and acidosis.

Cardiac Output (CO)

We know that the Cardiac Output is the amount of the blood produced by the heart per

one minute CO= stroke volume * heart rate.

- You should know that there are differences in the basic cardiac output values between individuals, since it is affected by the size and weight so to solve this there is what we call the **cardiac index** which equals to cardiac output divided on surface area (m^2):

Cardiac index = CO /surface area, so if the CO=5 L/min & surface area=

1.6 m^2, then Cardiac index= 3L/min/ m^2

* Cardiac index allows us to compare the heart's functioning in different people, as we alleviate the effect of difference in surface area between different people.

>> Now we will present what happen in the heart according to frank-starling law:

-In the diagram that we will draw, right arterial pressure on the x-axis corresponds to the EDV on frank-starling curve, and cardiac output on the y-axis corresponds to stroke volume on frank-starling curve. (CO represents stroke volume since CO=stroke volume * heart rate)

When the EDV increases the pressure in the right ventricle will increase and accordingly the pressure in the right atrium must increase to keep the flow from right atrium to right ventricle (if atrial pressure doesn't increase, there won't be blood flow from right atrium to right ventricle!!) in other words to keep the AV valve opened. For example, if the ventricular pressure becomes 3, the atrial pressure must become 5 and so on. Remember that the pressure of the atria is always higher than the pressure of the ventricles except at ventricular systole.

- And that's why we can make the right atrial pressure a representation for EDV on the X axis, since we can measure the right atrial pressure better and easier than the EDV.

The pressure in the atria will have the same increase as the pressure in the ventricles but not the same value (it's an indicator).

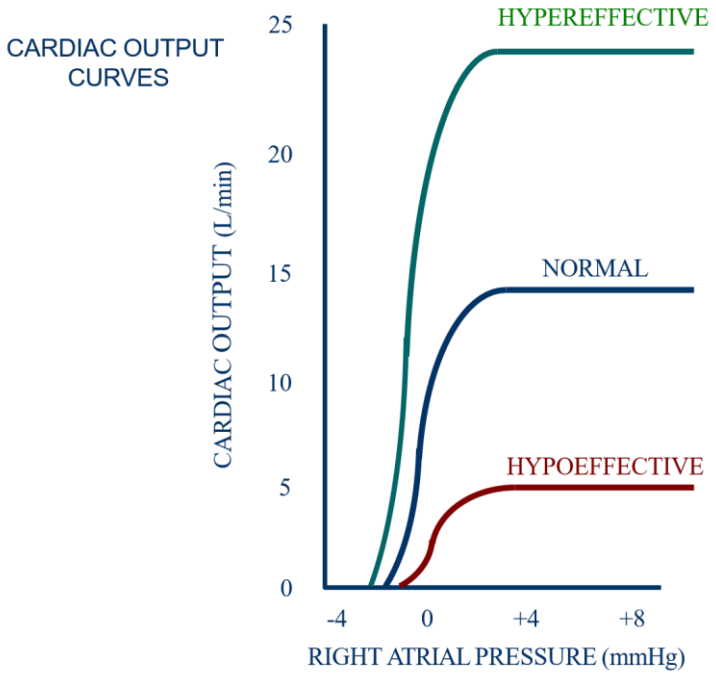
- as a measure of intraventricular pressure, we put on the y axis cardiac output, because when the ventricles have higher pressure they will eject more blood.

- In this figure, we can see the relationship between right atrial pressure and the cardiac output:

- Normally, when the right atrial pressure equals zero, the CO will be 5 L/min.

- when the right atrial pressure increases due to an increase in EDV (Frank-starling) the CO increases, until it reaches its optimal (Maximum value) which is 15 L/min, we will observe a brief plateau in this curve.

- If we increased the right atrial pressure more and more, the cardiac output will decrease, leading to heart failure. (Not seen in the figure)



The maximum cardiac output within normal conditions is 15L/min, here the cardiac reserve will equal 15-5=10

Remember: cardiac reserve= maximum CO- normal CO

- If there is positive inotropic effect (contractility; constant EDV and increased SV):

Let's assume the EDV is constant (fixed) on zero. So, as mentioned before, at normal conditions (when there is no sympathetic stimulation), when the right atrial pressure is zero, the CO is 5L/min. However, as illustrated in the graph, under sympathetic stimulation (or a positive inotropic effect), when

the right arterial pressure is zero, the cardiac output is 15 L/min. Thus, under positive inotropic effect (or sympathetic stimulation) the curve will shift to the left and upward. The curve shifted to the left and upward represents a hyper-effective heart (Cardiac hyperactivity).

Remember in cardiac hyperactivity, it does not always happen due to sympathetic stimulation, as it can normally occur in athletes.

The optimal (maximum) value of cardiac output in a hyper-effective heart in non-athletic individuals is about 25 L/min. However, in athletes, the max. value for CO may reach 35 L/min, here the cardiac reserve= 35-5=30 L/min.

In case of cardiac hypoactivity (in MI, sympathetic block (inhibition).. etc), the curve will be lower as the CO will be decreased (the curve will be shifted downward and to the right). The value of the CO when the right atrial pressure is zero may reach only 2 L; as a result, the optimal value of CO here is 5L/min (according to Frank starling).

** Hypoactivity & hyperactivity (upward and downward) happen due to an increase or decrease in contractility (inotropic effect).

Ejection Fraction

- Ejection fraction is the fraction of blood ejected from a ventricle of the heart with each heartbeat and it is an inherent volumetric measure of the pumping **efficiency** of the heart.

- it's the fraction of the end diastolic volume ejected in each stroke volume and normally equals 60%, between 55% &75%. We can calculate it by:

Ejection fraction = stroke volume /EDV

- It is a measure of contractility, so it will increase in case of hyperactivity.

let's take an example:

If the End diastolic volume= 125 ml, End systolic volume = 55 ml, Ejection volume (stroke volume) = 70 ml

We can calculate:

1- Ejection fraction which will be equal 56%

** stroke volume can be calculated as EDV minus ESV

2- If the heart rate is 70 beats/minute, what is cardiac output?

Cardiac output= HR * stroke volume

=70/min. * 70 ml

= 4900ml/min.

another example:

If HR =100, end diastolic volume = 180 ml, end systolic vol. = 20 ml, what is cardiac output? CO= 16,000 ml/min and Ejection fraction= 160/180%=~ 90%

-Notice that Ejection fraction is 90% which is very high and indicate positive inotropic effect.

Aortic Pressure Curve

*Aortic pressure starts increasing during systole after the aortic valve opens.

* Aortic pressure decreases toward the end of the ejection phase.

* After the aortic valve closes, an incisura (dicrotic notch) occurs because of sudden cessation of back-flow blood from aorta toward left ventricle. It will stop on the semilunar valve. The aortic wall will stretch a little and the pressure will increase leading to this incisura.

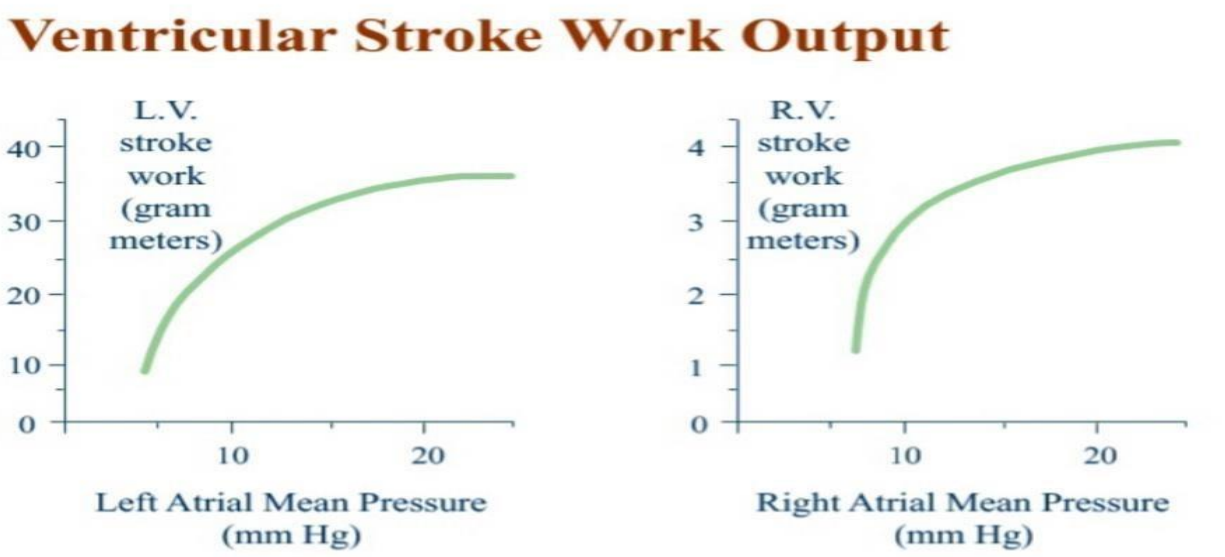
*Aortic pressure decreases slowly during diastole because of the elasticity of the aorta. As we said before and according to Frank-Starling Mechanism:

- Within physiological limits, the heart pumps all the blood that comes to it without excessive damming in the veins (if it has 50, it will pump 50 and so on).

- If there is an abnormality like the heart have 70 but it pumps 30, it means we have heart failure. It will make congestive heart failure (stasis)>> (if what comes more than what goes, congestion results).

-Extra stretch on cardiac myocytes makes actin and myosin filaments interdigitate to a more optimal degree for force generation.

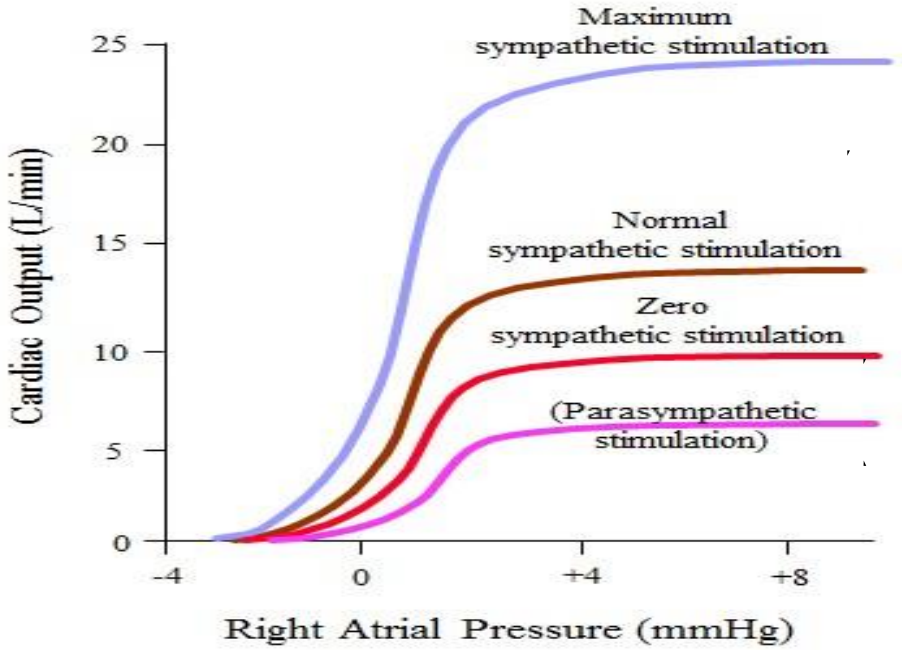
In the figure below:



It shows the difference in work done between the two ventricles. The curves have similar pattern, but the left ventricle does higher work (10 times) as it pumps the blood against higher resistance (**notice the differences in the scale**).

Remember that the work has energy and the energy is calculated by multiplying volume with pressure, the volume of both ventricles is the same, but the pressure is different, so the work will be different (look to Y axis; The work done by the left ventricle is ten times more than the work done by the right ventricle).

Look at this figure it's the same thing; read the description about it below:



-Sympathetic stimulation causes increased HR and increased contractility with HR = 180-200 and C.O. = 15-20 L/min.

-Parasympathetic stimulation decreases HR markedly and decreases cardiac contractility slightly (Vagal fibers go mainly to atria).

** Sympathetic inhibition: decreases contractility and heart rate, decreases cardiac output we say that we have hypo-effective heart. (Shift downward and to the right).

** Forget the parasympathetic effect on the curve; it's neglected (its effect on the CO is because of negative chronotropic effect, not negative inotropic "it doesn't affect the contractility; it only affects the heart rate").

**We have a basal rate for the sympathetic effect on the heart and vessels; this is what gives us the tone of the vessels and heart.

From 2015 sheet, not mentioned by the doctor:

- Because we have this basal tone, we can have positive feed-back (stimulation) and negative-feedback (inhibition).

- If we don't have the negative control, this would be very dangerous, as we only can increase the impulse and never decrease it.

- For example: if the basal rate was 100 impulse/min then we can decrease it down to 20 and increase it up to 200 or 300, but if the basal rate was 0 impulse/min, we can't decrease it.

NOTE: Fast heart rate (tachycardia) can decrease C.O. because there is not enough time for heart to fill during diastole.

Cardiac Contractility

We can measure cardiac contractility as a Maximum change in pressure per time (dP/dt), its decreased by hyperkalaemia and increased by hypercalcemia.

Let's talk again about……. **Cardiac output**

- Cardiac output: is the volume of blood ejected from either the ventricle per minute.

- It's usually equal the amount of blood that return (venous return) to the heart; this is according to Frank-starling mechanism.

**Venous return is the amount of blood return to the heart per minute.

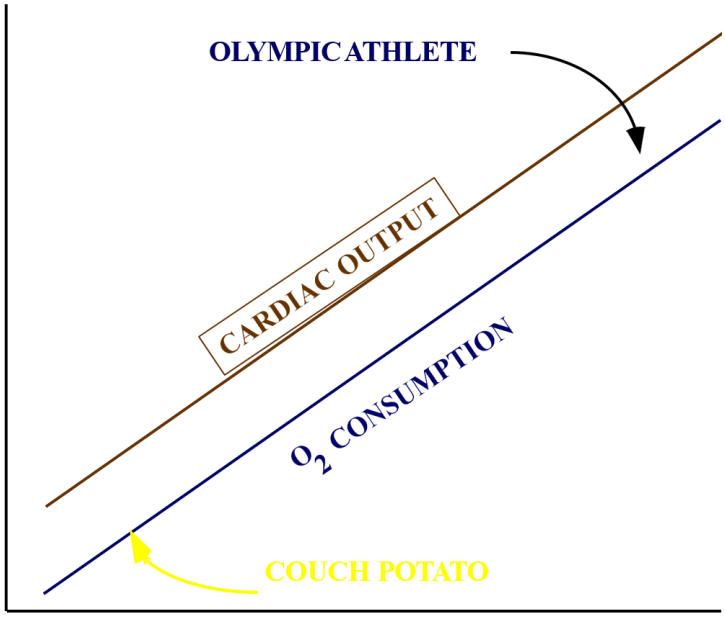
- Cardiac Output is the sum of all tissues' blood flow and is affected by their regulation; if blood flow in the tissue increases due to higher oxygen consumption, the cardiac output will increase (the more oxygen consumption, the more the blood flow and the more the cardiac output).

** What affects the blood flow to tissue?

The blood flow to the tissues (CO) is mainly affected by its oxygen requirements and consumption, if the oxygen requirement increases, the blood flow increases.

- So, the cardiac output is thus proportional to the oxygen consumption by the tissues.

** This relation is shown in the figure (in the next page), on the Y axis we have the cardiac output (CO), and on the X axis we have the work output during exercise.



The CO & venous return is a **flow** of blood, F= ΔP /R (Ohm's law)

- Cardiac output is from aorta to the right atrium, so ΔP is difference of pressure between aortic pressure and right atrial pressure. Total peripheral resistance equals all the resistance in all the vessels from aorta until reach the right atrium (total peripheral resistance/systemic resistance).

* Let us talk about ΔP, we learned that it is difference of pressure between aortic pressure and right atrial pressure, so what we mean by aortic pressure? Is it diastolic or systolic pressure?

It is neither diastolic nor systolic pressure. Actually, we calculate the mean arterial pressure (MAP); keep in mind we don't calculate the mean like we learned in math!! You can't say mean = diastolic + systolic /2, why?

Because diastole and systole occur at different times in cardiac cycle and they are not in linear relation.

We calculate the mean proportional to the time of systole and diastole during the cardiac cycle (calculated by integration), so:

mean arterial pressure (MAP)= 1/3 of systolic pressure + 2/3 of diastolic pressure

*Because the time for the diastole (0.5 sec) is longer than the time for systole (0.3 sec),

this means that the diastole contributes more to the MAP than does the systole (that's why diastolic hypertension is worse than systolic hypertension).

equation become: CO = (MAP - RAP) / TPR

- RAP (right atrial pressure) is equal Zero (it is normally zero), so we can neglect it; thus, CO equals:

CO = MAP/TPR

- **MAP=CO X TPR**, so if we want to change MAP, we change the CO or TPR or both.

Sorry for any mistake

Best of luck