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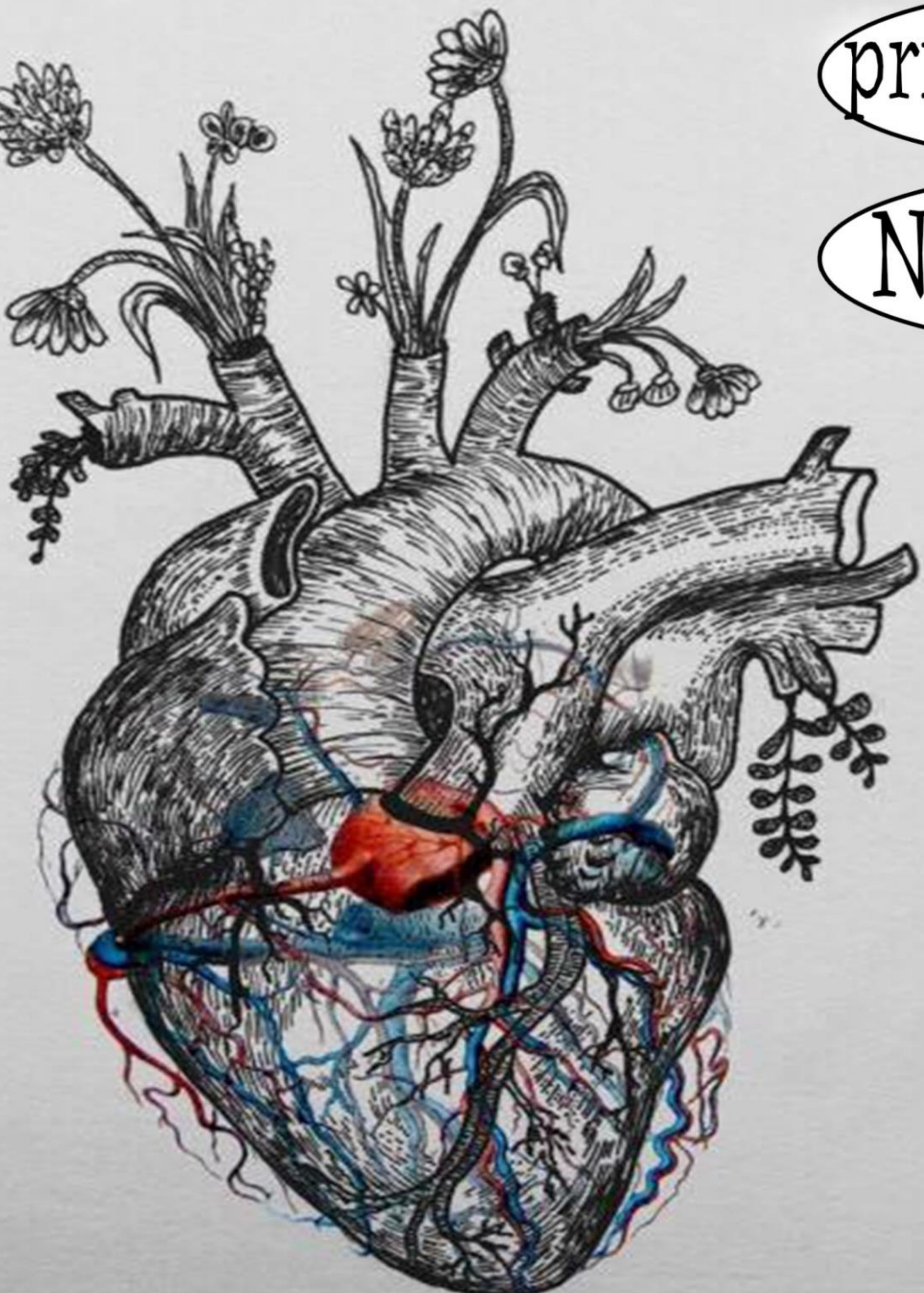

CVS

sub-system: **Physiology**

lecture: **#01**

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Date: **16-3-2016**

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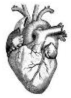


Physiology of the cardiovascular system

- ✓ **The main function of the cardiovascular system is to generate pressure and force to pump blood to the tissues.**

In basic physics, any fluid flow depends on pressure gradient. Pressure gradient is the difference in pressure values at two ends of the container of the fluid and if this gradient is absent there will be no fluid flow.

- Please note that the pressure gradient does **not** necessarily mean high absolute pressure.

Example for better understanding:

If blood vessel (A) contains 100 ml of mercury at both ends. This high concentration of mercury would result in a very high absolute pressure, but due to that both ends have the same pressure values with no difference and no pressure gradient there will be no flow.

And if blood vessel (B) contains 1 ml of mercury at one end and 0.5 ml of mercury at the other, in this case there will be blood flow due to the presence of pressure gradient although the absolute value of pressure at each end is low.

Most of the functions in our body depend on physics, the function of our body in the normal state is called physiology. The function of our body in the abnormal state is called pathophysiology/ pathology.

The cardiovascular system is a closed system that has three basic components:

1) The heart – a pump that generates and transfers pressure to the blood to establish the pressure gradient that is needed for the blood to flow to the targeted tissues.

2) Blood vessels – pathways through which the blood is distributed from the heart to all parts of the body and then returned to the heart.

And they are divided into 3 types:

a. **Arteries**: transfer oxygenated blood away from the heart.
b. **Veins**: transfer deoxygenated blood to the heart.

3) Capillaries: which are the smallest and thinnest blood vessels in which the process of exchanging nutrients and wastes between the surrounding tissue and blood takes place.

- Note:

An exception to this rule is the pulmonary vein and artery, where the pulmonary artery transfers deoxygenated blood away from the heart to the lungs and the pulmonary vein transfers oxygenated blood from the lungs to the heart.

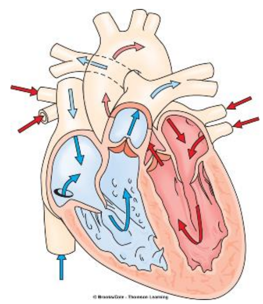
● The exchange process depends on the constituents and forces of the blood and it is **not considered** as a function of the cardiovascular system .**The only function of the cardiovascular system is to generate pressure and to pump blood.**

In physiology, Blood flow in blood vessels is called **hemodynamics**.

An example for better understanding:

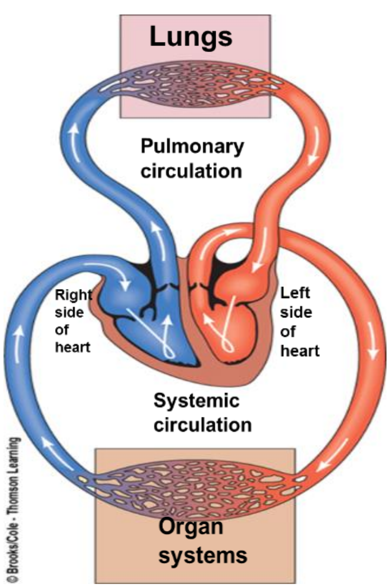
each one of us must be in a specific hemodynamical state in order to function effectively You can't see someone walking down the street with a systolic pressure of 80 where the normal value is 120, this value is required in order for the walking process to be achieved.

The heart:



The heart is divided:

I. Anatomically into 4 chambers (2 atria and 2 ventricles), 2 great arteries (pulmonary artery and the aorta), 2 AV valves and 2 semilunar valves.
II. Physiologically it is divided into 2 divisions; a right side and a left side. Each as a unit of circulation
   a. The left half is responsible for the Systemic circulation: closed loop of vessels carrying blood between the left side of the heart and the peripheral tissue.
   b. The right half is responsible for the pulmonary circulation: closed loop of vessels carrying blood between the right side of the heart and the peripheral tissue.



Both circulations have the same mechanism of action but differ ONLY in that the pressure and the total peripheral resistance are higher in the systemic/peripheral circulation.

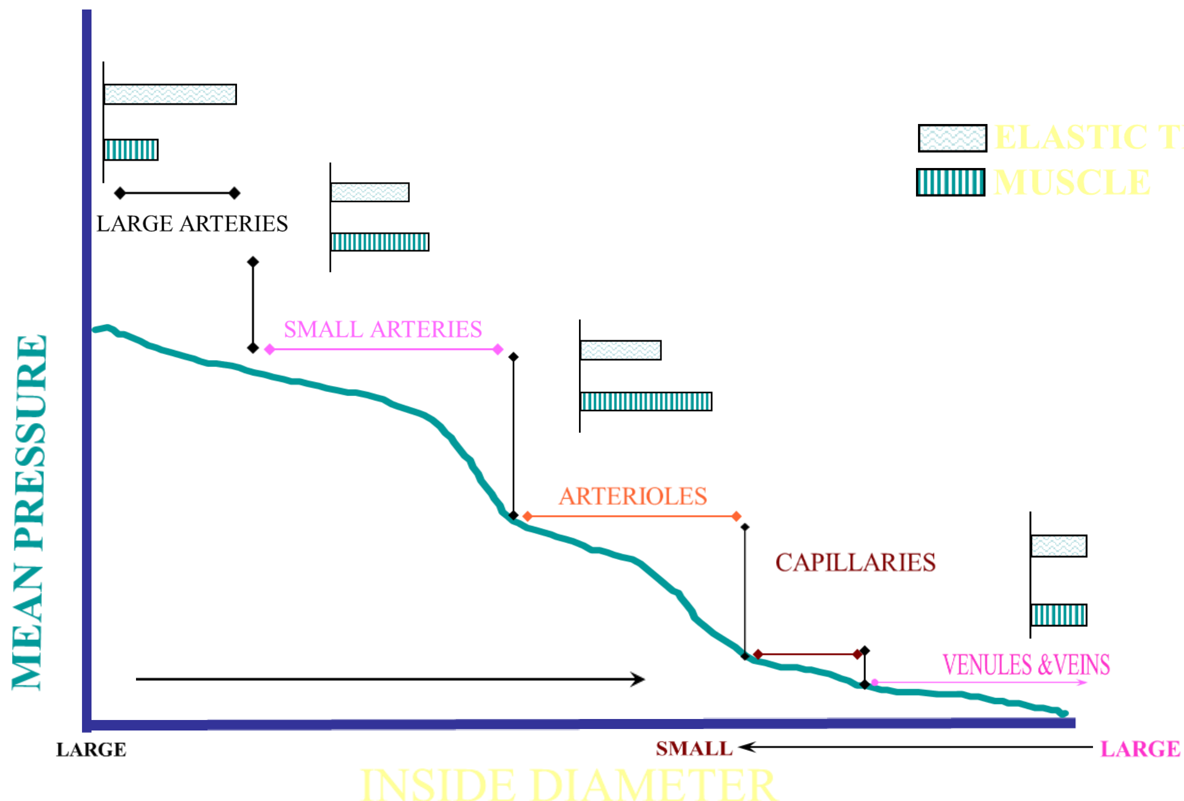
And that is logical, because the distance between the heart and the lung is shorter than the distance between the heart and the peripheral tissues so it has lower resistance and needs lower pressure in order to pump blood sufficiently to the targeted tissue.

✸ There's an important concept that we need to realize, when we talk about the heart ECG, cardiac cycle and blood pressure, we relate that to **the left ventricle**, except for when we specify otherwise.

For example, when we say that the blood pressure is 120/80, we're referring that to the left ventricle, which is essential for life unlike the other heart compartments which life can be sustained without them.

- Note: The right ventricle and the right atrium are important but not as much as the left ventricle. For example in some cases a baby is born with congenital abnormalities so the right ventricle is excluded and the vena cava is connected directly to the pulmonary artery to sustain life.

Pressure Drop in the Vascular System:



Blood flow goes form the left ventricle, aorta, large, medium and small arteries, arterioles, capillaries, venules, small, medium and large veins, superior and inferior vena cava, then to the right atrium.

In the vascular system, the pressure decreases starting from the left ventricle to the right atrium. The highest pressure gradient or difference develops from the left ventricle and the least pressure is in the right atrium.

As we mentioned, the exchange process takes place in the capillaries; You can imagine the capillaries as a lake with a water input and output. In the case of capillaries, the input is the artery and the output is the vein

When you look at a lake, most of the seen motion takes place at the entrance (Artery) and the exit of the water (Vein) while in the middle of the lake it is usually quiet and no motion can be observed.

● When we say **"blood flow"**, we are talking about how much blood is flowing per minute. Which is the same in any blood vessel, because the same amount of blood will be entering and exiting each of the artery/capillaries/vein in this minute.

But when we say **"blood velocity"** we are talking about how much blood is flowing per second and it differs significantly because even though the amount of blood is the same but the surface area is different.

✓The more surface area would lead to less velocity.

In arteries and veins, the surface area is small so the blood velocity is high and it is higher in arteries than in veins.

But in the capillaries, the surface area is very large resulting in decreased blood velocity which is needed to facilitate in the exchange process.

So in the artery, we will have a small volume of blood with the highest pressure and a small surface area resulting in increased velocity.

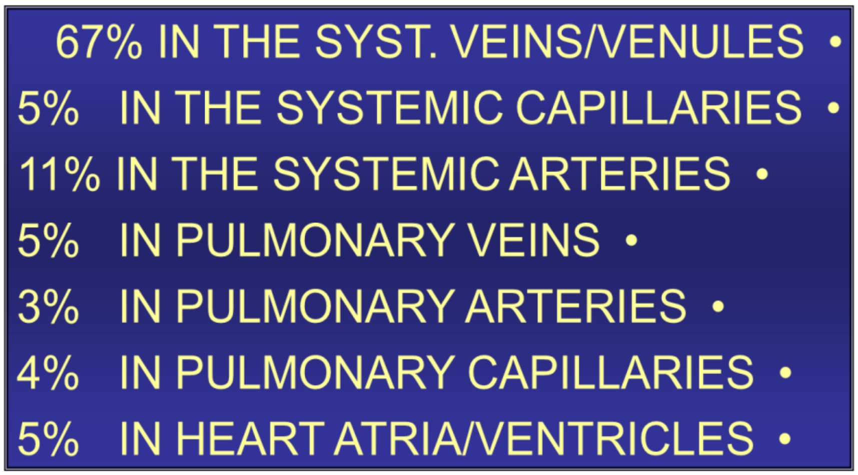
While in the capillaries, we will have larger surface area resulting in low blood velocity and a low pressure.

- Even though the pressure in the capillaries is low, it is still higher than the pressure in the vein. And this is essential to maintain the pressure gradient and to continue the blood flow.

In the veins, we will have large volume of blood with the lowest pressure and a velocity lower than the artery and higher than the capillaries.

The volume of the blood is the cardiac output so imagine if the heart stopped for a second.

The distribution of the blood in the vessels is as the following:



☜ **The doctor said that you don't have to memorize the exact numbers, just know where the blood volume is distributed the highest and the lowest.**

Those values are at normal physiological condition and at rest.

The heart is composed of three types of fibers:

1. Atrial Muscle Fibers
2. Ventricular muscle Fibers

Both of them are muscle fibers, meaning that they are contractile fibers and when they contract they produce a force, the only difference is that the ventricular muscle fibers are thicker than the atrial fibers producing stronger contraction.

3. Conductive fibers:

Specialized fibers because they are neither nerves nor muscles:

i. Not nerves because they don't conduct the action potential as fast as the nerves.
ii. Not muscles because they are non-contractile fibers.

iii. Self-excitable:

They are able to generate the impulse by their own and transmit it.

- Note:

Transmission velocity: Nerve fibers > conductive fibers > muscle fibers

They are divided into:

1- SA Node (Sinoatrial node) near the Superior vena cava.

2- AV Node

Internodal (sub nodal) fibers – between the SA node and the AV node.

3- AV Bundle (Bundle of His)

Further divided into: A. Right Branch B. left Branch

4- Purkinje Fibers

If we want to compare between the skeletal and cardiac muscles in terms of structure and contraction, we will find that:

The skeletal muscle is striated, meaning that it is made of fibers and each fiber is separated from the other and contracts alone. And in order to increase the force of contraction, we have to increase the number of muscle fibers.
Put in your mind that the skeletal muscle contraction is very short in terms of duration

The cardiac muscle is striated also but the fibers are divided and then united so they are all connected to each other in what is called (Syncytium) thus they all contract together (all or none).

So for example, if the atria were stimulated, all of the atrium will contract at the same exact time as a one big fiber.

The atrium and the ventricle are not connected to each other. They are separated by a fibrous tissue that is considered the point of origin and insertion for the cardiac muscle.

And in order to increase the force of contraction in the cardiac muscle, we have to increase the intensity of the stimulus - not the number of fibers - and the duration of contraction which has to be long in order to give enough time for pumping.

NOTE: I added a quick revision of the action potential in the skeletal and cardiac muscle in the last page, and these were not mentioned by the doctor and will be discussed in the coming lecture, but may increase your understanding of the next topic in this lecture ☺

When the cardiac muscle gets stimulated it will generate an action potential that would result in its contraction. The stimulation process of the cardiac muscle have a specific unidirectional pathway:
SA Node ➡ AV node ➡ AV Bundle ➡ Purkinje fibers

⛔This pathway is a unidirectional pathway with no reverse spread.

For the heart to contract it needs a stimulus, each part of the conductive fibers has the ability to generate that stimulus by itself but each component has a different rate of excitation. In normal conditions, the SA node has the highest rate of excitation for a couple of reasons:

1. The Resting membrane potential is around (-60 mv) which is higher than the other fibers and nearer to the threshold
   While in other tissue it is -70 mv so needs more time to reach the threshold

2. the SA node cells membrane is leaky to (Na+)

This occurs during the resting period between two beats, so after the first beat more sodium will enter the cells and they will gradually increase the resting potential until reaching threshold and generating a stimulus for a new contraction.

So the stimulation of the SA node, this will result in the stimulation of the atrium and its contraction as a whole unit due to **Syncytium**, the action potential needs around **30 milliseconds** to reach the AV node and for the whole atrium to be stimulated

After that the action potential will reach the AV node, where it will be delayed for about **90 milliseconds** and there will be another **40 milliseconds** delay in the AV bundle to give time for the emptying process of the atrium which takes 130 milliseconds.

The causes for the delay in the AV Node is that the AV node fibers are small sized and low in number with a decrease in gap junctions between them resulting in increasing the resistance for the action potential and delaying it.

After that it reaches the Purkinje fibers that need about 60 milliseconds to stimulate the ventricles and eventually results in ventricular contraction.

- The process of stimulating the whole ventricle by the Purkinje fibers needs only 60 milliseconds, even though the size of the ventricle is way bigger than the size of the atrium. This indicates that the Purkinje fibers transmit the action potential in a high velocity and the reason for that is the high number and large sized of fibers.

- To understand the difference in velocity between the AV node and Purkinje fibers:
  1) AV Node: transmits the action potential in a velocity of 0.4 m/s
  2) Purkinje fibers: transmit the action potential in a velocity of 35 m/s

  - The whole process from stimulating the SA node until ventricular contraction needs about (220 milliseconds)

  - The Highest rate of Excitation: SA Node

  - The Highest velocity rate: Purkinje fibers

    The process of recording the action potential in the cardiac muscle is done by the ECG (electrocardiogram) which will show you what happened electrically in the heart.

Action Potential revision

- In the skeletal muscle, the action potential is composed of depolarization and repolarization processes.
- Depolarization occurs by opening of sodium channels (Na+ Influx).
- Repolarization occurs by opening of Potassium channels (k+ Efflux).
- The resting membrane potential is -70 (due to equilibrium between NA,K when there is a stimulus there will be an opening of the sodium channels that will lead to the movement of sodium ions to the inside of the cell which increases the potential (less negative) until reaching the threshold and stimulating the contraction of the skeletal muscle.
- The repolarization process occurs by opening of the potassium channels and the movement of the potassium ions to the outside of the cell decreasing the potential (more negative)

- While in the cardiac muscle, there is a difference, which is the presence of calcium channels that increase the duration of the depolarization by balancing the potassium efflux (repolarization) by calcium (Ca+2) influx resulting in a phase know as (the plateau) leading to a prolonged contraction:
    1. Resting membrane potential
    2. Depolarization : Na+ Influx
    3. Begging of repolarization : k+ efflux
    4. Plateau : Ca+2 influx
    5. Repolarization : at the end due to continuous k+ efflux

We have 3 types of channels:

1. The sodium (Na+) channels for depolarization:

Increase in Na concentration that will increase the Heart Rate.

2. The potassium (k+) channels for repolarization:

Increase in potassium concentration that will decrease the Heart Rate.

3. Calcium channels for mainly contraction in cardiac muscles

Increase in Calcium concentration that will increase the contractility.