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Physiology sheet

Doctor 2022 -أثر- I medicine I MU

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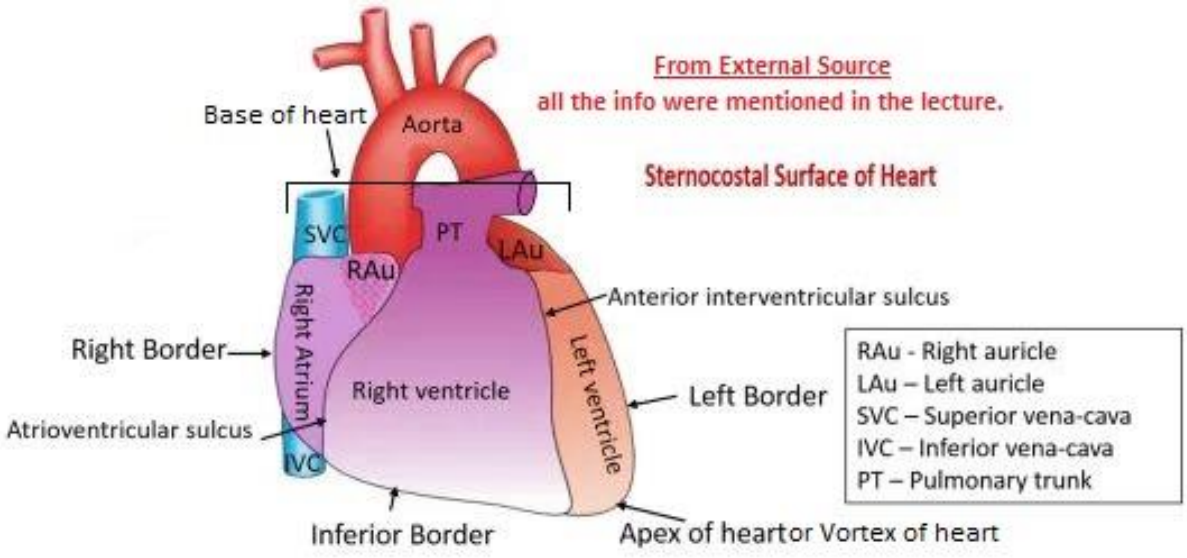
Physiology of Cardiac Muscle

Introduction:

- When we talk about cardiovascular system (CVS) we mean heart and blood vessels (BVs) that are responsible for pumping of blood. So, the main function of the heart is pumping blood by contractions of heart muscle cells (cardiomyocytes) that are only found in heart.
- Our bodies contain 3 types of muscles: 1) skeletal muscles, 2) Smooth muscles mainly in visceral organs and 3) cardiac muscles.
- A simple physiological definition of heart: a muscular pumping organ that pumps blood to all body organs. Now let's take a journey in the pumping process before discussing heart's anatomy.

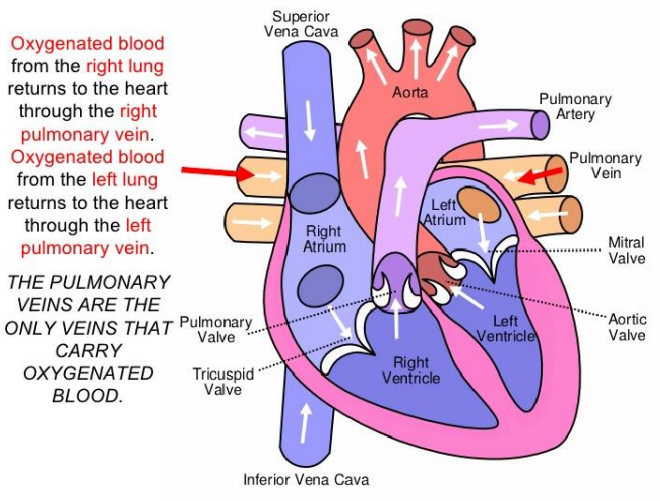
Pulmonary and Systemic Circulations:

- **The following figure** shows the heart from anterior point of view (POV). However, it can also be seen from posterior POV.
- The heart has lots of complicated structures; veins, arteries and chambers (atria [singular is atrium] and ventricles). The top of the heart is its base while the bottom of it is its apex or vortex. **Note the base and the apex, the rest will come.**



- Understanding the function depends on memorizing its anatomy; whether its internal or external structures.
- Externally, we have 4 chambers superior to the apex and inferior to the base, those are the atria followed by the ventricles. Note that ventricles are bigger and to/ from them the blood is pumped. So, the deoxygenated (Deoxy.) blood from all over the body then upon oxygenation (oxy.) in lungs it will be pumped out again to the body organs.

- **Now let's talk about the circulations. Use the next figure to link everything.**
- **Heart is divided into right (R) and left (L) parts that are separated by septa (singular is septum). However, these septa are not external structures, I have to cut sagittally to see.**
- **Blood arrives to heart by 2 major veins: 1) superior Vena Cava (SVC) near the base of the heart and 2) inferior Vena Cava (IVC) near the apex of the heart, so, it's destined for all the blood to get back to the heart by these too veins. Since this blood is arriving from all body organs but lungs, it is deoxy. Blood and I have to oxy. It. But first, what are the physiological definitions of arteries and veins?**



- **Veins are BVs that are responsible for delivering blood into the heart while arteries are BVs taking blood away from heart. WE CAN NOT SAY that veins always carry deoxy. blood and arteries always carry oxy. blood, as this GENERALIZATION IS NOT ACCURATE.**
- **After the blood is received by SVC and IVC it will be stored in the R atrium. We all know that cardiac output is the volume of the blood pumped into/ out of the heart per minute which is equal to 5 L/min in a 70 kg adult. After R atrium the blood will go to R ventricle, since a large volume of blood is arriving, in a very high velocity and from a smaller (R atrium) to a larger (R ventricle) chambers, valves are needed. We call the valves on the R side tRicuspid valves (you can see it in the figure above); because each has 3 cusps (leaflet- like structures). Note that all the valves in the hearts are of 3 cusps except one (we will talk about it later). This tricuspid valve is linked from both the top (to R atrium) and the bottom (to R ventricle). So, this valve has no free margins; constant or fixated when opens to receive blood. Due to the high (↑) volume of blood delivered to the R atrium → ↑ pressure inside it → pushing against the valve →↑ pressure against the valve→ the valve will open → all blood in the R atrium will go to R ventricle (which has zero pressure at (@) this point). So, according to pressure gradient, the blood will flow smoothly (it is still deoxy. blood).**
- **Now, I have to oxy. this deoxy. blood, where can this happen? ONLY in lungs. Heart and lungs are connected together through pulmonary trunk (large pulmonary arteries and veins, you can see it in page number (#) 1 figure). The deoxy. blood in R ventricle will go through pulmonary arteries to the lungs (the only arteries in our bodies that carry deoxy. blood instead of oxy. blood).**

- When a large amount of blood in a chamber (R ventricle) needs to go to a smaller area (pulmonary artery) I need a valve, which is called pulmonary valve **(you can see it in page #2 figure).** What is the difference between the pulmonary valve and the aforementioned tricuspid valve? Both are of 3 cusps but the pulmonary one is of a crescent or semi- lunar (half- moon) shape and it has free margins; free opening/ closing upon the arrival/ departure of blood. Now, the pressure is ↑in R ventricle while almost zero in pulmonary artery → ↑ pressure againt pulmonary valve → the valve opens and all the blood will eneter to both R and L lungs where the blood will be oxy.
- Now, this oxy. blood has to be pumped back to heart from lungs; this will happen by pulmonary veins (the ONLY veins in our body that carry oxy. blood instead of deoxy. one). This pulmonary vein will have a lot of blood so it'll also need a valve (**not present in the figure but it has one**) to deliver blood to L atrium. The process of transferring blood by SVC and IVC till it reaches the pulmonary veins is called pulmonary circulation; because all the blood went to the lungs by pulmonary arteries and got back to heart by pulmonary veins. This circulation is responsible for transferring deoxy. blood from R side of the heart to the lungs.
- Now, the other side of the heart (L side) received lots of blood by pulmonary veins to L atrium precisely→ ↑ pressure in it→ ↑ pressure against the valve separating L atrium from L ventricle; which is called bicupid valve (or mitral valve or left atrio-ventricular valve) which is the only valve in the heart with 2 cusps, to be pumped from L ventricle to all body organs. Note that the amount of blood received by R atrium has to be= to the amount of blood pumped by L ventricle= cardiac output= 5 L/min in a 70 kg adult.
- Now, this oxy. blood will be pumped from L ventricle to all body organs by a very, very, very large artery (the largest artery in our bodies) called the Aorta. This aorta – no matter how large it is- is smaller than L ventricle chamber. So, a valve must separate them, we call this valve the aortic valve **(you can see it in page #2 figure).** Aortic valve is also considered a semi- lunar valve with free margins; just like the pulmonary valve. The circulation I'm talking about from the moment the L atrium received its blood till it reached the aorta to be pumped to all body organs is called systemic circulation (the fate of all the blood reaching the aorta to be delivered to all our systems). Again, it's true that we are talking about 2 chambers on 2 different sides that work separately. However, if the R side received 5 L/ min the L one should pump 5 L/ min. If any mismatches happened between them → problem in the heart→ the heart is not working sufficiently.
- That was a brief about the two types of circulations: systemic and pulmonary ones, what types of valves are involved and where they are located internally and externally.

Clinical Topography of the Heart:

- Where is the heart localized? What is the position of it? Those questions are explanation of hearts topography (which in general means the distribution of parts or features on the surface of or within an organ or organism). The topography of heart is very important in heart sounds, circulations and in heart diseases.

1. **Holotopy**: it means the position of the heart in relation to the whole body. Which is located **intercostal**ly in the **middle of mediastinum** space (a Latin word for center or middle partition). Is it enough to know this position? No, I still have: 1) valves I need to know their exact locations, 2) arteries, 3) veins and 4) relations of hearts to near-by organs. Why? So that if any problems rise, I'll be able to say it's due to this and that.

2. **Sceletopy** (skeletopy): **Refer to page #1 figure for this part.**
   - It means the position of any organ in the body (heart in this case) in relation to our skeleton (ribs or cartilages in this case). We draw a line from **right to left** and we will get the following 4 borders:
   - **Upper border**: draw a line from the L of the **3rd rib horizontal**ly to the R of it. So, it has the large base with the great BVs like Aorta and SVC.
   - **Right border**: **1.5cm** away from the sternum, from the **3rd to 5th rib parasternal.** It has the R atrium and openings of pulmonary trunk.
   - **Lower border**: **5th rib cartilage to 5th intercostal obliquely.** This border is very significant. In it the heart tilts forward and its apex tilts to the L. So, the heart in general is tilted forward and to the L side. Accordingly, to detect the base I draw an oblique (diagonal) like from 5^{th} cartilage to 5^{th} intercostal space which will have the lower border of the heart.
   - **Left border:** start from the **5th intercostal** space near the **apex** and then go upward towards the **3rd rib.**
   - Now, why is it very important to hear the sounds of the valves? We know that valves open to allow the blood flow and closes to prevent the backflow. For example, blood from R atrium will go through the tricuspid valve to R ventricle. Now, to guarantee that blood will stay in the R ventricle and wont backflow to R atrium, this valve must close. If blood by any means flow from R ventricle to R atrium → a valve related problem → a defect in valves closure→ called murmurs or regurgitations. So, hearing hearts valves' sounds→ ensures its proper function → the urge to perfectly locate the valves positions.
   - Where to put stethoscope (physician's earpieces) to listen to valves sounds? Draw a line from **left to right**, starting from **3rd** downward **to 6th rib** of the **sternal junction** to find **AV openings.** Now, put the **stethoscope** on **the 5^{th}** to hear tricuspid valves (Atrioventricular valves, on both R and L sides) opens. As per **aortic and pulmonary** valves: draw a line from left to right of the **3rd**

downward to 4th sternal junction. Now to hear the sound put the stethoscope on the 2nd intercostal space.

3. **Syntopy:**
   - It means what neighboring organs are beside the heart.
   - **Anteriorly**: sternum, that is why it is a hard bone to fracture. If it ever happens to fracture in any incident, I fear for R side of the heart especially the auricles (you can see them in page #1 figure).
   - **Inferiorly**: just below the apex, I will find the diaphragm. When it is elevated it ↓ the size of the thorax and vice versa.
   - **Laterally**: pleura of the lung on both sides. Pleura is considered a part of the heart's mediastinum.
   - **Posteriorly**: esophagus, trachea and vasculature (SVC and aortic arch).
   - **Superiorly**: great blood vessels, aorta and its branches including: 1) brachiocephalic artery, 2) subclavian artery, 3) left common artery and 4) left carotid artery.

Layers of the Heart:

- The major component of the heart is cardiomyocytes to suit its function. However, the heart has 3 layers:

1. **Myocardium:** 90% of the heart; to perform its pumping function. It can be seen as an external feature.
   - It forms 3 parts: atria, ventricles and the fibrous ring.
   - Atrium which is made up of 2 layers: 1) Superficial (sup) circular and 2) deep long (longitudinal) muscle which is called pectinate muscle.
   - Ventricles made up of 3 layers: 1) sup longitudinal layer from L to R side till we reach apex or vortex of the heart it becomes deep longitudinal (trabeculae craneae and papillary muscle), 2) another exact layer starts superficially from L till it reaches R side it become deep and 3) middle layer surround each ventricle within both the superficial and deep layers.
   - Fibrous ring: This ring is located superiorly to AV openings (on top of each Atrioventricular valves; the tricuspid and bicuspid ones). Which is guarded on the R side by 3 cusps that sick to it from its upper part and 2 cusps on the L side. So, this works as anchors to fixate the cusps of the valves and prevent any damage from happening due to the ↑ velocity, volume and force of blood flow.
2. **Endocardium:** I can see it when I have a sagittal section from L to R; it appears as an internal (endo-) layer that is in direct contact with blood vessels and valves, to line them. So, it is considered a special endothelium.
3. **Pericardium:** If I opened the chest and got out the heart, it will be enclosed by another protective layer which is called the pericardium. It is made of 2 layers:

a. **Serious** layer: a very strong layer that 1) anchors and fixate the thorax and 2) provides protection. It has itself 2 parts: **Visceral** (of a direct contract to the heart) **and parietal.**
b. **Fibrous** layer: external layer.
c. Between those two layers there is a fluid that has to be maintained in a fixed volume. Any irregularities → a problem.

- The more you go from internal (deep) to superficial, the thicker the layers are to provide better protection.
- **To sum up,** the functions of the 3 layers are: 1) anchoring and protecting: pericardium, 2) pumping all the time: myocardium and 3) direct contact like valves: endocardium.

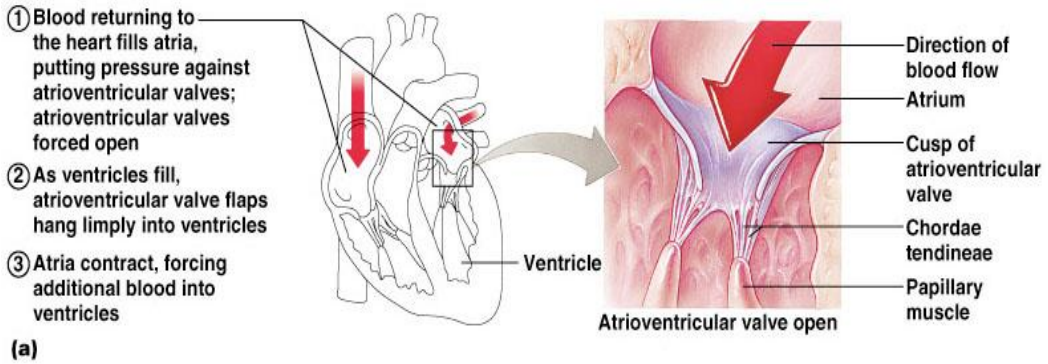
External and Internal Heart Structures:

1. **Coronary** (crown- like shape) **sulcus**; it encloses the base of the heart and it separates **the atria from ventricles,** so, by which I can differentiate between atria and ventricles. **You can see it in page #1 figure.**
2. **Anterior interventricular sulcus to posterior: separate the right from lift ventricles,** it starts anteriorly and ends posteriorly. **You can see it in page #1 figure.**
3. **Right Atrium:** it can be seen anteriorly, it has some important components:
   a. **Anterior and lateral pouch** (sac- like) **auricles**
   b. **Superiorly: superior vena cava** (SVC) to collect blood from upper body parts **between sinus venarum** (upon sagittal sectioning it appears, with embryonic-only function (no function in adults).
   c. **Posterior:** 1) **inf vena cava** (IVC) to collect blood from lower body parts. Note that valves are only needed when blood has to flow between large and small chambers where pressure is not high enough. However, when the pressure is very high (as in vena cava) no valves are needed to deliver blood from body systems to R atrium since the pressure will be ↑↑ compared to zero in R atrium. The problem (that needs valves) happens when the pressure is not high enough; so a guardian (a valve) is needed to guide this opening (when the pressure increases) and closing (when the pressure decreases), 2) **valve of inferior vena cava**, that links IVC **to oval fossa** (or Fossa Ovalis) that works **during fetal life (** transfers **blood from right to lift atrium)**as there is **no pulmonary circulation** yet in the embryo.
   d. **Medial wall: Fossa Ovale** only found during fetal life then closes shortly after birth.
   e. **Coronary sinus:** it is composed of coronary arteries and veins. Very important, as it works as venous drainage of heart's deoxy. blood (coronary veins) and supplies all cardiomyocytes with O2 rich blood (coronary arteries).
   f. **Inferior wall: Right atrioventricular opening (tri valve)** or tricuspid.

4. **Right ventricles**
    a. **right atrioventricular opening Tricuspid valve (2 margin fibrous ring and tendinous chord)**
    b. **Opening of pulmonary trunk which is guarded by:**
    c. **Pulmonary valve**
    d. **Trabecula carneae which is a very important structure to prevent any potential air embolism). When blood arrives from atrium to ventricle with its high velocity, if the surface is not rough → air bubbles will form. So, this structure inside R ventricles ↓ this velocity by making some kind of friction→ no air bubbles form.**
5. **Left atrium: It can only be seen posteriorly.**
    a. **Left auricles pectinate muscle (longitudinal muscle).**
    b. **4 opening of posterior pulmonary veins**
    c. **Left ventricular opening**
    d. **Bicuspid valve**
6. **Left ventricle**
    a. **Bicusps valve**
    b. **Aortic opening (between L ventricle and aorta) with its 3 semilunar cusps**
    c. **commissural cusps very small ones. Works to fixate the semi- lunar valves.**

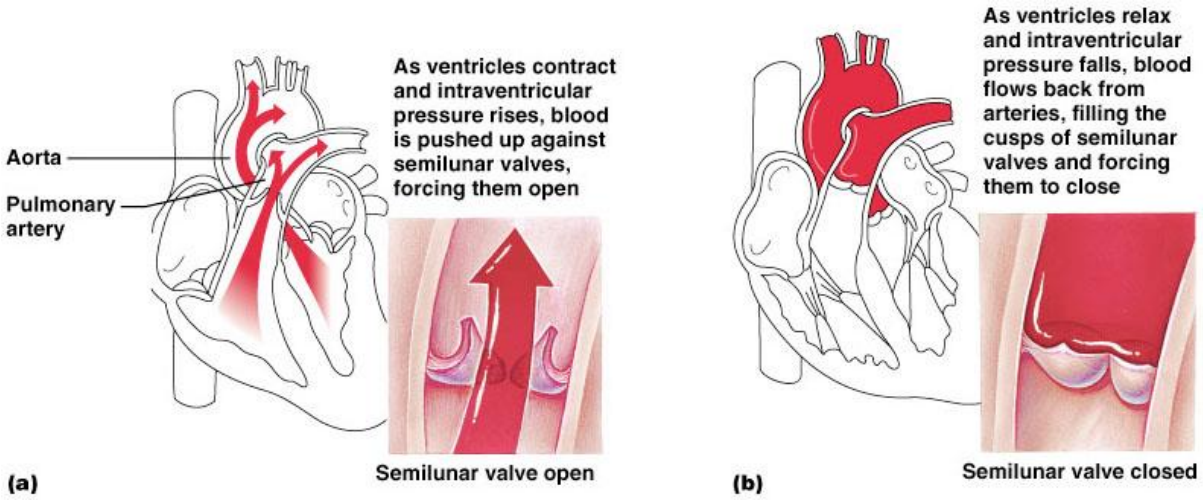
Atrioventricular (AV) Valves Function:

- **Upon arrival of blood to L atrium it will then go L ventricle. At this point, cusps open to "welcome" the blood. Note that the cusps of the valves are fixated: anteriorly by the fibrous ring and posteriorly by papillary muscles with Chordae tendineae connecting the two structures.**



Semilunar Valves Functions:

- Now, for semilunar valves (aortic and pulmonary), the cusps are free; so, whenever the blood enters/ exits it'll strike (collide with) the margins (contrary to AV valves).



Limiting Product is Oxygen:

- **Timely manner function properly:**
- The main function of the heart: pumping of blood. So, to pump a huge amount of blood → lots of oxygen (O2) is needed. As cardiomyocyte must adapt to its functions' demand.
- Thus, cardiomyocytes contain lots of **myoglobin** with its function of **storage of O2.**

The following table shows a brief comparison between myoglobin and hemoglobin

#	Criterion	Hemoglobin	Myoglobin
1	# of O2 molecules it binds:	4 molecules	1 molecule
2	Is it affected by blood pH?	Yes	No
3	Affinity (amount to be transferred with) especially @ low partial pressures of O2	Lower	Higher

- **Coronary arteries**: by which O2 reach cardiomyocytes through aortic sinus (L/ R) which is close to aortic valve. These arteries give branches to all cardiomyocytes.
- Cardiomyocytes are rich with **mitochondria** for ATP production. It gets this **Fuel from:**
  1. **Glucose** with its end product: **pyruvate** in Krebs cycle which also forms acetyl coA.
  2. **Fatty acids** by **beta oxidation**
  3. **Lactate** which is converted to **pyruvate** (a common misconception is that lactate is an end product that can't be used further more).
  4. **Amino acids** by **ketogenic and non-essential one**
  5. **Ketone bodies** to form pyruvate and ATP in **fasting state**

- All these are fuel contents in cardiomyocytes. Now, If I ever had a problem in amount of blood reaching the heart (blockage or occlusion of BVs) → ↓ or block of blood flow to cardiomyocytes → it will cause one of two things: 1) angina pectoris and 2) Myocardial Infarction (MI).

Myocardium Clinical Disorders:

1) **Angina pectoris:**
   a. **Due to strenuous activity**, so, it may happen in middle aged people.
   b. **Tissue becomes ischemia**; it happens when O2 is not enough in cardiomyocytes.
   c. **Pain subsides at rest**; the most important feature to distinguish between it and MI; as MI pain does not subside with rest. The nature of pain is a very sharp one (like knife stabbing pain) in the chest in both cases.
   d. **Nitroglycerin**
2) **Myocardial infarction MI (heart attack):**
   a. A very dangerous case. Upon blockage (due to atherosclerotic plaque [fat accumulations]) cardiomyocytes will die and be replaced with scar tissues; as there is no regeneration of cardiomyocytes. According to the speed (degree) of ischemia (↓ in blood arriving an organ; cardiomyocytes in this case) → the infarction (obstruction of the blood supply to an organ or region of tissue, typically by a thrombus or embolus, causing local death of the tissue) will be determined. For example, a very large infarction (even if acute) may lead to death.
   b. **Death of cardiac muscle replaced by scar tissue and could lead to death**. That being said, it is a type of heart attack that needs urgent care and NEVER subsides with rest. However, Nitroglycerin can work too here in case of acute MIs.

" أكمل أحلامك ولا تستسلم فالمشوار طويل ويحتاج إلى اجتهادك.
واعمل كل يوم بأمل جديد. وتذكر أن الله ييسر الأمور. فلا داعي للقلق...
افعل ما بوسعك وتوكل على الله... أيام السعد آتية "