Human Physiology
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Lecture – 18
Hemodynamics & Regulation - Part 2

We will do a very simple experiment, I am sure you exactly know what I am talking about, what am I talking about? How to monitor the blood pressure? How many of you have been subjected to? Oh sure, it is very simple, very simple experiment. So all that the clinician does, is first of all he ties a cuff here, okay and then if you are sitting, why I tie a cuff here? Because when you are in a sitting position, the cuff is at the same level as your heart, either you lie down or you sit, okay it is very important that, very important that you are monitoring the blood pressure at the same level as your heart, because otherwise the gravity will contribute to it, okay. So, you tie a cuff here and then, and then you can blow air into it, okay you can blow air into it and let us start with this individual is a very healthy and normal person and he has, let us presume that he has blood pressure oscillating between 120 - 80, 120 - 80. So what you really do is with that, with that blower there, you go on blowing the air in it and take the pressure straightway to 150 or 140, it will start here, okay and that is because, because the blood is flowing, maximum pressure the blood can take air 120 mm Hg, now from outside you are applying the pressure of 140 mmHg, as a result of that there is no blood flowing this way or there is no blood flowing that way, you have literally stopped the blood supply from this point downwards or upwards, are you with me. There is no flow of blood out of question, no, no it does not happen, okay. Now the second thing I want to tell you is somewhere here, just on this, on the other side of your elbow, okay, there is a major artery which is called as a branchial artery, what do you call it as? Branchial artery, what do you call it as? Branchial artery, you see whereas we all know that if this is your thumb on the wrist, you can feel the pulse, you can feel your pulse and you can find out how many heart beats you have per minute. Now whereas this blood vessel pulsates normally, this branchial blood vessel does not pulsate, so if you put here a stethoscope with finger nothing, you would not notice anything, you cannot know it, you cannot know it there, you put a stethoscope also you would not know it, it does not, you cannot feel it, okay.

Now what you do here is now okay you have taken the pressure, you have taken the pressure to how much? 140 mm Hg, so is any blood flow going down the hand? No, is it going up the hand? No, nothing, you have completely stopped the traffic of blood this way or that way. Now what you do is you release that knob there gently so that the blood pressure will start falling from 140, 138, okay, 136, 130, are you okay? 125, okay, 122, 120. The moment you go from 120 to 119, okay, suddenly in this branchial artery blood under pressure of 1 mm Hg will start gushing, are you with me? How much is inside 120, inside the blood pressure, how much is it 120 and outside you had taken to 140 but you reduce it to what? 119, so the 1 mm Hg difference, as a result of 1 mm Hg difference the blood suddenly rushes through your branchial artery and if we are putting that stethoscope you can hear that sound, look at the top there, look at on the extreme you can get a little sound there.

What are you doing? That is the plotting the sound that you are getting through the stethoscope and that is because the blood has started rushing, that rush you can get. Now you slowly go from 119, 118, go to 100, okay you find that the sound goes on increasing, about 100 the sound is maximum, okay? Then you go down to 90, you go to 80, once it goes to 80 then the blood flow starts flowing normally and you do not hear anything, you do not hear anything because it is not the property of the branchial artery to pulse. So what you really do is you take it to 140, you bring it to, then he (the clinician) keeps on monitoring and he suddenly finds that my pressure is at 130 and I hear that first sound, he will say, doctor will say hello, hello your systolic is 130, are you getting my argument? And then let the sound increase, let the sound decrease and the moment the sound disappears that is your diastolic. Have I made point? This is a very simple principle, but as students of physiology I think we need to understand the phenomenon. See we always talk of the mean blood pressure, okay? It is convenient way actually, I mean actually in biology does not have anything mean, it has systolic and diastolic but for all practical purposes we use the word mean blood pressure, okay? One figure we take.

So how do we calculate the mean blood pressure? Now if your heart, now I will go to this image, a sinusoidal curve. Now this is from physics I have got, it is a perfect sinusoidal curve and for me if I want to, there is a peak there and there is a trough there and in a perfect sinusoidal curve it is okay for me to take the peak point and the trough point and I can calculate the mean, simple. This plus this divided by 2, simple. But can I do it in the case of heart? I cannot. Why I cannot do it? Because the systole, if it is a cardiac cycle is of 0.8 second, out of that 0.8 second systole is about 0.3 seconds and diastole is about 0.5 seconds, diastole is longer. Because diastole is longer it is simply not a good idea to take a systole, take a diastole, add them up and divide by 2.

No, that is not correct. Therefore, the clinicians have improved the method, they improve the method. It is not perfect but it is okay. What they do is because the diastole is for a longer period what they suggest is, here is a patient of low blood pressure and his systolic, SBP is systolic blood pressure is about how much? You read there 83, is a low blood pressure patient. It should not be 83, it should be 83. So how much is systolic? 83.

What is the diastolic there? You can read there. 50. 50. The formula says that 83 + (50 x 2) divided by 3. So how much it comes to? 183 divided by 3, it comes to how much? 61.

We will say that the mean blood pressure of this patient is about how much? 61. So if you are given the systolic blood pressure, diastolic blood pressure you can use this very simple formula and work out the mean that will be used by the clinicians. It is not just taking systole, let me take diastolic divided by 2. No, we do not do that because it does not give us the real figure. For a fluid to flow in any tube, the most important thing is you have to apply pressure.

And there should be pressure difference. If you apply same pressure at the ends, the fluid will not flow. You have to have a pressure difference. So author tells us that you have a pressure P1 there, P2 there, P1 is more than P2 and therefore the fluid will flow. And the second important factor of course is the diameter.

The smaller the diameter, the more the resistance, the more resistance, the more strength you will require to pump the blood. Now have you seen these images in physics? We are just talking about what? It is very simple, the laminar flow. There is fluid that is flowing if you see here in the lower image, you see there are arrows, though each arrow represents the speed which the fluid is travelling and obviously the fluid that is in immediate contact with the wall is the slowest because it is in the contact with the wall and then as you go towards the centre, the speed increases. Are you with me? And the speed in the middle will be the fastest. This is the reason, I mean therefore if the tube is very small, the resistance will be more and the blood will flow slow compared to the larger blood vessels, okay.

This is just to give you a rough idea as to how profound is the importance of the diameter of the tube. We have, the author has given three examples, diameter 1, 2, 4. 2 is more than twice 1 and 4 is twice than 2. Are you with me? And then if you apply the same pressure whatever you do, in the first case how much of fluid can go through the tube? And the second? And the third? This is just to appreciate what a profound it is. So little increase in the diameter can have a profound effect on the amount of blood that can, or amount of fluid that can travel through the.

So what are the different factors which are - this tells us that okay, the length of the tube is important, diameter of the tube is important, organization of the vascular network, what do I mean by that? I have a tube here, okay, I have a tube here and that tube divides into two, okay. The two tubes have of course lesser diameter in the first tube. Are you with me so far? Lesser diameter. Because of lesser diameter, more resistance but the fact remains that there are two tubes, okay, so the blood is getting distributed, okay. So that means the organization of vascular network, physical characteristic of the blood, that is very important, the viscosity of the blood, blood is not water, okay.

And now let us take a, try to understand, I am going to talk about very interesting, almost physical and physiological property of the blood, we call it as hematocrit, what did I say? Hematocrit. Hematocrit, what do you call it as? Hematocrit. It is very simple, let us take, I will put a syringe in one of this and draw say about 10 ml of blood, it is a lot of quantity. How much of blood? 10 ml of blood.

Good. Now it is there, it is in front of me in the test tube and to that I will add a little anticoagulant, okay, like heparin or calcium oxalate, something I will add, as a result of that, just to make sure that it does not clot, okay, step number 2. Then what I will do is, I will put it in a centrifuge and spin it, okay, just for 5 minutes - that is good enough. Now I will find that, at the end of that I will find that the RBCs, okay, which have the relative density slightly more than the plasma, they will settle to the bottom, okay. And I will find that almost if I have a tube like this, there is a clear plasma at the top which is about 55% of the volume and the lower 45%, about 45% of the volume is the compact RBC, are you okay so far? It is very simple, I am sure you are aware of this, it is compact RBC, okay. Now actually this in theory is, it should be in the case of men, it should be 42% and in the case of women it should be 38% ideally.

What am I talking about? Hematocrit, what am I talking about? Normal, healthy, hematocrit, in the case of men is about how much? In the case of women how much it is? 38. Now if you are less than that, you are anemic, very important, anemic, you are anemic, okay, less than that is not a great idea, it is anemic, okay. So here is an example, that is normal, here is an anemic, here is the hematocrit of an anemic person and if you for some reason if you have more than that, that is also dangerous and that happens very rarely, it is a case of polycythemia, we will talk about it sometime. Why am I talking about hematocrit at this stage? Because let us take water, let us take water, is plasma water? Yes or no? So from plasma we have, our RBCs are gone, but there are still lot of proteins, okay.

Those proteins and there are lot of substances in solution, they will all add to the viscosity of the blood and therefore now if we compare the three solutions in front of us, so what do we have? Look at the lowest line, it is a blue line, it is 1, what is it viscosity of water? Whatever it is we will call it as 1. Then I will compare it with the viscosity of what? Plasma and viscosity of plasma is about how much? About how much? 1.8 or whatever it is, about 1.8 viscosity of plasma, okay. Now I will go to the viscosity of the blood, presuming that it is a normal healthy blood which means hematocrit is about how much? 42.

Let us see, hematocrit is how much? It is 42. In that particular case, in that particular case, the viscosity of the blood is about 3. How much is it? 3. So in a healthy person, if your hematocrit is 42, then the viscosity of your blood is about 3. But if you are anemic, then the viscosity will be less.

And if you are suffering from a disease in which you have, so this is normal point, but if you have, now you imagine there is a cancer, actually this is cancer, something has gone wrong and as a result of that the RBCs, there is more percentage of RBCs and it goes from, the hematocrit may go from 42, 45, 50, 55. In that case, what will happen to the viscosity? And if the viscosity increases, what will happen to the load on the heart? You understand? It will be very difficult for the heart to pump the blood of higher viscosity. Again homeostasis, amongst the n number of factors which have to be maintained as a matter of homeostasis, viscosity is very important because heart is all designed, the nature has designed the heart to continuously pump the fluids in this particular organization of your circulatory system, a fluid which has a certain viscosity. It cannot tolerate more, is the point well taken? Good, good. Remember the importance of hematocrit and viscosity when it comes to the, see the, I said that when you want to take the blood pressure, you sit down and make sure that the cuff is at the same level at the heart.

That is because of what? Gravity. Gravity, gravity. So look at this image and I am sure you can understand there is a column there, there is water there, there is a pressure. Look at the tube on the left. Is the pressure at the top and at the bottom same or different? Different.

Obviously it is different. Now the author translates that information into this diagram where there is a human being standing with a hand raised and we are just, just you are in a standing position and then you are trying to measure the blood pressure, mean blood pressure at different heights. At the level of the heart it is about, that is okay, that is okay about 90 or whatever it is. But if you go, if you go, oh very interesting, very interesting. When you are standing what is the blood pressure with which the blood is flowing, mean blood pressure with which the blood is being delivered to your brain? 60.

60. It is not, it is not, it is not, it is not about 100. It is not about 100. Okay, in standing position when you lie down it may be. But when you are standing the brain, your brain is getting blood at what pressure? 60 mm Hg.

60, remember that. At the same time the, look at the blood pressure in your legs. 170.

170, huge, huge. So this is the effect of gravity that our blood pressure is.

Just one, one question. Will this be same if you are in a swimming pool? I do not know, you tell me. Think about it. I would not give the answer, you can think about it. Obviously. Okay, so you know something, we always say that there is, the heart is there and heart keeps on pumping the blood.

That is of course most important. But you know it is something like we have the function is being performed by other parts of the body. And that other part of the body in this particular case happens to be your calf muscles. Look at the calf muscles in that image. There are two calf muscles and going right between the two calf muscles is a major vein. It is in your leg and every time you walk or you move your leg, those two muscles, those two muscles, they press on the blood vessel and they relax.

They press on the blood vessel and they relax. They press on the blood vessel and they relax. Are you with me? And as a result of that, when the blood has to flow from the, you know we are talking of a vein. So this is taking the blood from your foot to your heart and it is going against the gravity. And this is greatly aided by these skeletal muscles.

This is a vein. This vein has a pair of valves. So because of this pair of valves, the blood cannot go down. And when the muscles contract, as you walk, the vein is literally pressed. When it is pressed, it pushes the valve and pushes the blood towards the heart.

The blood obviously cannot go back. And then when you relax again, the more blood can go from the other end, it can go upwards. So, actually this is like an additional heart which you all have. Now you see in the forces, in the military, you know if they ask, what is it? Stand in attention. You know people faint. People faint after 15 minutes, 20 minutes, 30 minutes.

You know why? Because when you stand in absolute attention, your ‘heart’ (into inverted commas) is not working. Are you with me? So certain, so moving your leg or walking is a very necessary activity. Now I will ask you another question. Supposing as we get old and these valves don't really function well, then what will happen? The blood will stagnate. And as it stagnates, that phenomenon is called as what we discussed yesterday? It is called as what? It is called as the varicose vein.

In physics, you have all heard of Poiseuille's law, right? Yes or no? It is just for my understanding, it is a mechanism which helps us to understand the flow, understand the flow of fluid in a tube. Depends on what we have already done. Let us do it once again.

Flow is equal to pi, delta P is pressure difference.

We have already seen. Are you with me? Delta P, radius of the tube divided 4 times, raise to the power of 4 divided by 8, etc. is viscosity of the blood and L is the length of the tube. This just tells us, this is basic physics, this tells us as to how the flow of blood will go through a tube. Now this is a point I raised yesterday and I will try to raise it once again. The point that I raised yesterday was how do you justify that although the blood as it enters into the capillary has a pressure of about 30 mmHg, done? 30 mmHg, by the time it goes to the other end, it may be about 8 or 10 mmHg, but then we also appreciated that 30 mmHg is a very high pressure and given the fact that capillary is extremely delicate, why does it not burst? The answer to that question is provided by, I am sure you have done this also in physics but that is called as, read the bottom line. Laplace laws, it states that the pressure exerted by the fluid on the wall is proportional to the radius.

What did I say? In the fluid, the fluid is directly proportional and if the radius is very small, if the radius is very small, the relative pressure is less and therefore it can stand. Because if you were to keep the thickness of the wall of the capillary same and increase the diameter of the capillary 4 times, it will definitely burst. Hello, are you getting the essence of the Laplace law? We are trying to answer a very fundamental question. What question we are trying to answer? Why does not the capillary burst given so much pressure inside? Well, it does not burst because it is tiny. So please remember this is a very interesting principle of physics that is applied to.

How do you measure the blood flow? The rate at which the blood is flowing? The physics people have come to our rescue and they have given us what they call as piezoelectric crystal. It is some physics device I think you know better. When you activate it, it starts sending ultrasound at a very high frequency of 100,000 times per second or something like that and then it can penetrate through our skin and as the blood is flowing and then some of those waves, they hit and they come back. When they come back, they pick up those waves and from those, the physics people will tell you how to calculate the speed with which the blood is flowing in your vessels.

So this is a very interesting point. Not all capillaries, we did this yesterday, I am doing it again. Not all capillaries are allowing the blood to flow through them at every minute. No, no, no, no. Several of them in the resting tissue, a large number of capillaries are inactive. What do I mean by inactive? What do you mean by inactive? They do not allow the blood.

There is no blood flow. There is no blood flow. It is only when a tissue becomes active that some of them will allow. When it goes more active, then more will flow, ok. And depending on the activity, the blood will flow. So here you have a classic example. Here you have an arteriole, meta-arteriole and at the beginning of every capillary, you can see a smooth muscle sphincter there.

Can you see the smooth muscle sphincter there? And you will find that all the sphincters are open and therefore, the blood can flow, oxygenated blood can flow into the entire capillary. It will come and it will go to the other end, ok. But this is because all the capillaries are inactive. But under resting conditions, all of them, most of them may be inactive only this is active.

So the blood just flows and it does not flow through the rest. You can ask a very important question, very important question. How do you tell the sphincter that you open now or you close now? Autonomous nervous system is a great answer, ok. But that is only part of the answer. You had asked the question yesterday, I know the question. Ok, I will give a detailed answer to that in the next lecture, but I will not keep the suspense for long.

Whenever a tissue experiences, ok, let us see. I am in this position, resting stage. Is every blood flowing through every capillary? No. Why not? Because a lot of sphincters are closed. Now suddenly, this is a, this is a system say of the hand and then you have started doing exercise. As a result of that, these cells will experience suddenly, I am not getting enough oxygen, ok, ok.

As a result of that, there will be certain change in the metabolism of the cell. I will tell you later what that change is. In response to that, they will release certain signalling molecules, one of them is adenosine. Those signalling molecules will diffuse and they will talk to the sphincter and the sphincters will have the receptor for that signalling molecule adenosine as a result of that - What am I showing you by my action? What is it? They will dilate and they will allow the blood.

So, the cell, says, that whenever I want oxygen, I will send a message to my sphincter, I will ask the guy to open the door so that the blood can come to me. Are you getting the physiology? It is instant, it is there, it is there, ok. Autonomous nervous system plays a role at a higher level. But this is exactly at the level of tissue, ok, the tissue can decide as to, as to make sure that I get the blood, I get the blood supply enough for my need at every given moment. No, no, the answer to that, the answer to that question, we do not use, ok, ok, this is a very interesting topic.

Are they sensing oxygen? The answer to that question is no, no, they are not. Oxygen sensors are there, ok. We also have oxygen sensors, ok. But this is not oxygen sensor.

Yes, it is, it is like, it is like, I will give an example. Where is the glucose sensor in our body? I have told you. Beta cells. Beta cells, alpha cells, beta cells, they have glucose sensors, ok. Do you some other cell have a glucose receptor? No, no, but if you stop glucose supply to that the cell will die.

Are you with me? So, it is something like this, ok. So, these cells are, these are all cells, oxygen, they have oxygen receptors, no, no, but if you stop the supply, their metabolism undergoes a change and as a result of that, but we do not call them as, they are not, we do not call them as oxygen receptors. Oxygen receptors are separate, they have different physiology, talk about it in animal physiology II too, sometime if you are still there, ok. So here we have the, ok. Now, actually this observation, you know, what observation that some are active, ok, and they are inactive and then as and when necessary they become active, ok.

This such a simple and elegant observation was done by August Krogh. What is it? August Krogh, ok. I mean, just imagine what a simple observation, ok, that capillaries are active and the capillaries are inactive, ok, and not all capillaries are active and Nobel 1920 or so. Now, why I am placing the picture of this great man, this great biologist is for another reason and another reason is I want you to know about that reason and remember the reason, ok.

August Krogh. Now, I will tell you something. Tomorrow if you happen to continue your pursuit of biology and if you happen to work on an animal model, likely you will use a rat or a mice or a zebra fish or a C. elegance or a drosophila, am I right? Am I right? You will be using that animal. Now, the moment you select, you come to me after one or two years and say that sir, I am working on drosophila, I will ask you a very simple question, why do you, tell me why drosophila is the best model for your problem? Are you with me? You are selecting drosophila because you want to study a particular biology phenomenon and you particularly want to test a hypothesis and want to find out and therefore you say that ok, for my, I want to do it because drosophila has a life cycle of 15 day, da da da, you can give it 10 reasons. Are you with me? So for addressing your problem, there is a, you have selected a suitable model. Krogh told us then that for asking every biological question, there is in the nature a very suitable model, you try to find out that model and better work on that model.

Are you getting the argument? And this is called as Krogh's principle. What do you call it as? What do you call it as? Krogh's principle. Remember Krogh, remember principle and whenever anybody says that I have used this particular animal, the first question that you ask is for the problem that you are asking or you want to address, why is that animal the best suitable model? And this thought we get from August Krogh.

This is just to tell you there are different kinds of capillaries, you know, I just make a brief comment and I will conclude today's talk. There are different kinds of capillaries. In some of the capillaries, there is a capillary and around that there is a basement membrane.

When I say basement membrane, it is made up of cells or it is not made up of cells? It is not made up of cells. It is extracellular matrix, ok. Whereas, and its outside, it is outside and these are endothelial cells and in the endothelial cells, there are often gaps are there, there are certain gaps and through those spaces, the water again, the water-soluble molecules can go, oxygen and carbon dioxide can directly go through the plasma membrane, these cells by exocytosis, endocytosis, the useful molecules can go through them, no problem. However, in the case of brain and skeletal muscle, these spaces are not there and the endothelial cells are communicating with one another by way of tight junction.

What junction? Tight junction. Tight junction. It is to, it is not to allow the free passage of material from inside to outside and that phenomenon we call as blood brain barrier. What do you call it as? Very good. We call it as what blood brain. Opposite to that is in many cells where you want to promote profound interaction between a capillary and a cell and the classic example is that liver ok, where the basement membrane is also broken ok and the endothelial cells ok, become extremely flat, extremely flat and plasma membranes come very close of the two side plasma, inner and outer plasma membrane. The same endothelial cell come very close and greatly facilitate the exchange of material.

It does not mean that there is an open window. Such a capillary is called as fenestrated capillary there and some of these capillaries for example, this is a picture of a marrow, bone marrow, bone marrow. What is the function of the bone marrow to everyday synthesize thousands and thousands of RBCs. From the bone marrow they need to get into the capillary.

Hello. The newly born RBC in the marrow needs to get into the capillary. How will it get into the capillary? The capillary has to, the capillary has to have lot of space between the cells and that is how those cells get in. So, so these cells are outside there in the bone marrow, they are getting into the capillary. Once they mature, they get into the capillary and they undertake and they join the general circulation.