Animal Physiology
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Lecture - 9

Welcome back to the course in animal physiology in NPTEL. So, we are into the section 4 and this will be third and the final lecture of the section 4. So, in this section we are talking about the circulation process.

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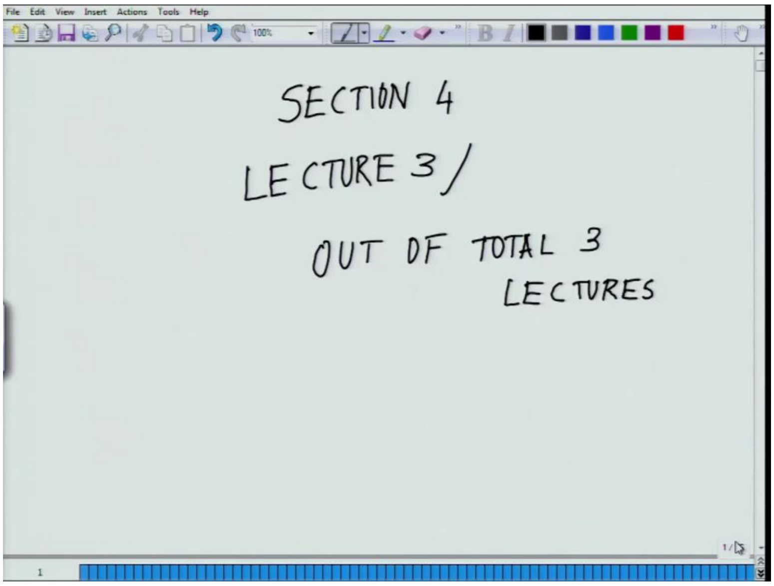

We have already discussed about the different vessels, their cross sectional area and how the pressure changes; how it is flowing; once the blood is being pumped from the heart.

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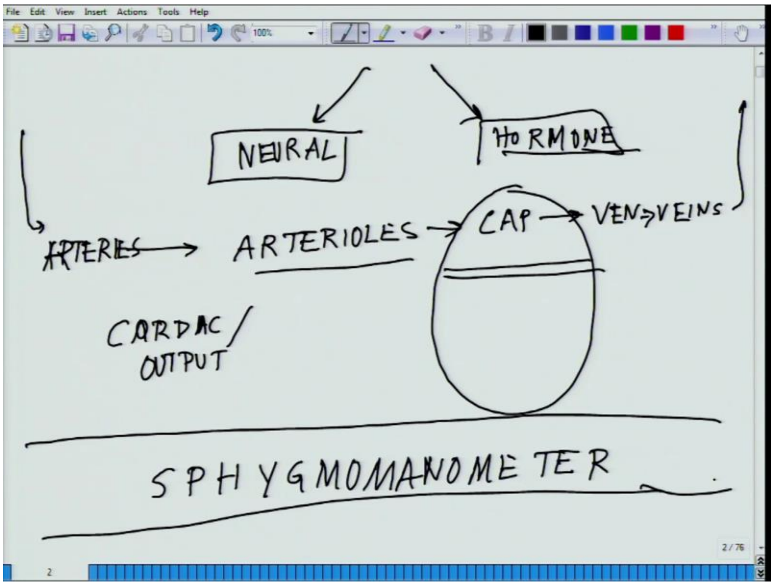

If you remember, when we drew the first overall outline of this section, we talked about the blood is flowing from the arteries to the arterioles, then through the capillaries to the venules, and to the veins and back. We talked about the cardiac output and the pressure differences. In the section of that, we talked about that we will be discussing the hormonal and neural control of this whole dynamics at some other point. Well, we will be talking about, once we are finished with the neural and the hormonal part of it. Today, we are going to deal with this part; the capillary and the capillary exchange. Before I move on to the capillary and capillary exchange, while talking about all the different pressures, what we have talked about, I just wish to ensure, that you people are aware of a sphygmomanometer. This is the one, which is used by doctors, to measure the pressures and the pulse. Just to update you on that one, some of you are not aware of it. It is a simple device. You have seen the doctor, a kind of put it there, and kind of check your pulse and everything.

So, this is the device which is being used. It has a valve, which can see the undulation of the blood vessels, and it can measure and it can hear to the noises, and can give a whole bunch of information. You talked about that lap dap, what we have talked about all the four sounds, and everything is being done with this sphygmomanometer along with the stethoscope attached to it. Now, we will move on to the capillary exchange. Let me give you; before I get into any technical detail, let us see a practical situation.

That will help you to appreciate this problem much better. Whenever, you have, say for example, honey bee bites you or some kind of bites you, you see there is a swelling at some point or other, wherever it bites. You see a swelling. Why there is a swelling? Did you ever ask this question? In very people or the doctors or some learned person. So, there is an inflammation. That is why, there is a swelling. What really is that swelling? If you go to the doctor, doctor use a technical terminological edema; it is an edema likewise, and if you go through the dictionary, it is accumulation of fluid is called edema.

Why that edema occurs or why that accumulation of fluid occurs? Whenever, there is some kind of insect bite, vas bite or honey bee bite, x y z situation; there could be many other pathological situation; physiological disturbance during which happen, but overall, in a normal condition like, I am standing here. I do not have any edema or any kind of inflammation at any part or any kind of fluid accumulation at any point. Then, what is the fluid accumulation? Why there is a fluid accumulation? Because, if you realize while talking about; this is something people have to realize first, before I get into the technical details of this definition, formulae and all those things. Those come later.

What is the first thing you have to realize, that there is a philosophical understanding of the problem, and that is very critical for you people to appreciate. If you look at the blood vessels, and if you look at way, our network of blood transport is being designed, what is happening? From the heart, the blood is pumped out through the vessels. It moves along the arteries, and at the capillaries there is an exchange phenomena taking place.

All the oxygenated blood is downloading the oxygen to the different tissues, and from those tissues or cells, it upload the carbon dioxide into the vessels, and from there it comes back through the venules, the veins and the vinacava back to the heart. It is a kind of close loops system, which is continuously flushing every component. For example, this is me. So, from here, like you know, blood is moving all over the hands, all over the legs, all over the body, across the brain and everywhere. It is continuously flushing it out. So, there is no room that any. Whenever, this flushing will stop; it is just like, say for example, in your community or in your colony or wherever, you are staying, continuously there is a switch, sewerage or sewerage line, which is continuously flushing out all the things, which are being dumped from your house or x y z houses. Whenever, there is an accumulation of fluid taking place, it means, there is some kind of a leakage in some kind of a vessel. This is very critical. There could be two, three possibilities. Either there could be a leakage or there could be an abnormal situation by which, the flow cannot ensure that everything is being flushed out. This simple understanding is very essential to understand the capillary exchange process.

As of now, if I go back, where I am repeatedly telling you, that at the capillaries like, if this is a capillary network; imagine this is my capillary network, where I was drawing that if, imagine that this thumb is the artery and this thumb; the other thumb on the other side is your vein. From the arteries, it is coming, another capillary exchange is taking place. What ensures that carbon dioxide will be taken up by these capillaries, and oxygen will be given out by these capillaries?

What ensures that some of the solutes, which are present there, will be given out and some of the toxins, which are present there, will be taken in? What are those foods or what are those physical phenomena, which dictates all that thing? In order to discuss this, I will take you back to my lectures in the membrane physiology section. There we talked about some of the forces, if you remember. We talked about osmosis; one of the forces. We talked about diffusion, another forces. If you remember in the diffusion, I told you, that basically, from higher concentration to lower concentration.

Say for example, you have lot of sugar out here and lesser sugar here in solution. From the higher sugar, the sugar will try to diffuse to the lower concentration sugar. Then, we talked about filtration; what filtration we talked about? There should be a pressure difference by with, the filtration will take place. We talked about osmosis, and even in the last class also, I told you how to measure the osmotic pressure. If you remember, I showed you that on a U tube, I told you. Not the U tube, what we talked about in the net. This was the U shaped tube I showed you, that from one side, there is semi permeable membrane in between, and you are filling water on both sides.

Water can pass through the semi permeable membrane without any problem. But the condition is that the solute cannot pass through. So, if a higher concentration of solute on one side; one arm of the tube as compared to the other arm of the tube, the solute concentration side or the arm, where the solute concentration is higher, water molecules will try to move towards that. If you want to create a potential difference; if you want to balance the potential difference, somewhere or the other, then you have to give equivalent opposite force, which is in the form of hydrostatic force.

So, these are some of the forces. Let me enumerate; 1. Diffusion, 2. Filtration, 3. Osmosis. These are some of the forces which dictates and will come to the different values, which will help you to appreciate, why oxygen is being downloaded, carbon dioxide is being uploaded, and all these features. These are the simple basic forces which ensures that the exchange takes place. Now, coming back, where I started this I asked you like, think of a situation, when there is a fluid accumulation.

During fluid accumulation, what happens is, that the permeability, because, this is happening ensuring that the vessel permeability remains constant; you cannot change all the parameters; you can change one parameter and you can read, study the other parameters. Because of x y z conditions, the vessel permeability changes. It mostly happens and I will again reiterate at the end of the discussion when I will talk about all the forces.

What happens, whenever a toxin, whenever a vas or honey bee or insect bites? It secretes certain toxins into your blood vessel, and that toxin form the arteries, travel all the way to the capillaries or from the veins, it will go to the heart and comes back to the capillaries, where the actual exchange taking place. At the capillary, what it does? If you again recollect the structure of the capillaries; it has fenestrated capillaries; we have you know, continuous capillaries; and all. At the capillaries, what it does is, it binds to the wall of capillaries and change the permeability or the exchange phenomena. By the virtue of if the body loses, or not the body; the vessel loses some of more water which cannot take up.

If I take you further back, in my lectures in membrane physiology, if you remember, I was telling these. There are toxins which can make channels. If you go back to the membrane physiology lecture, you will see. I talked about some of the valenomicy in gramicidin and in that section, while I was showing you, there are circular peptides which can form channels through which the water molecules can pass in and out. I talked to you about gramicidin and I specifically, I remember, I drew the structure of valenomicy and gramicidin and I talked there may be a series of toxins, and type of which has the ability to form a pour along any kind of a membrane. That is exactly what a toxin does. When the toxin travels at the capillaries, where the wall is much more thinner because, you know it is almost a single red blood cell, which is around 8 micron. If you see the dimensions, which I have already taught you people. So, at 8 micron diameter basically, it is almost one cell thick membrane like this. So, it creates holes along it.

Now, what we will do, we will come back to this. You will be able to appreciate it much better, once I tell all the forces which are involved. And the generic calculation; based on that what I expect by the end, in next 15 to 20 minutes, once I am done with all the forces, what I expect is that whenever, you see a edema; whenever you see a accumulation of fluid, immediately these forces should come into your mind what are the filtration forces? What are the osmotic forces? What are the diffusion forces? What are the re-absorption? and everything, this should come straight, without even a second thought. It should be your second nature; you should be able to immediately pick it up. That is basically, these forces which are playing a role, and based on that you should be able to you know at least some form of diagnosis into the situation.

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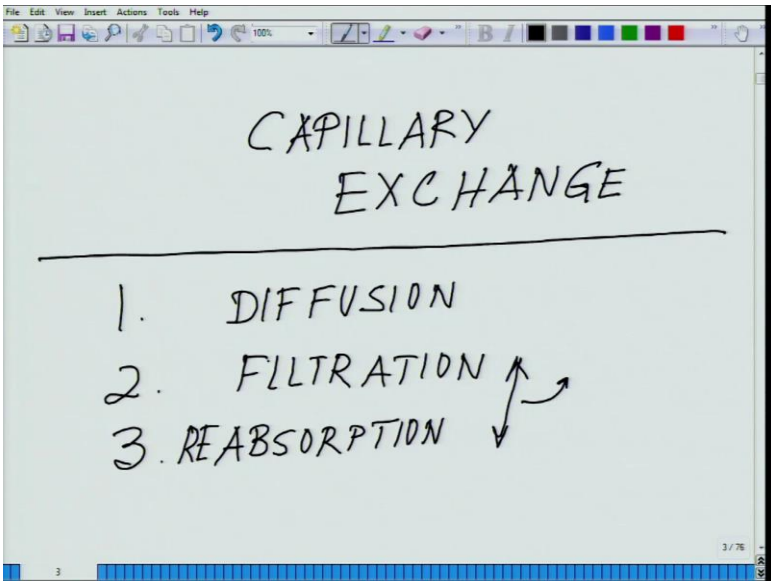

Now, let us enumerate the forces, which are involved in the capillary exchange. The forces, what we will be talking in this capillary exchange, will be diffusion, filtration and re-absorption. It is basically, the interplay between filtration and re-absorption. This is interplay of this, which regulates the exchange of the fluid across the capillary membrane.

Just to give you some of the numbers. One more thing, which I actually, did not mention. I thought, I mean to discuss that first, whenever I showed you this diagram. This is, one side is the capillaries, sorry, the arteries, arterioles and one side is the venules, and here is the exchange taking place. At this exchange zone, along the blood vessel, there is a parallel vessel, which runs. That vessel is call link fatigue vessels, will come to this link fatigue vessels, while we will be talking about the white blood cells and the immunity.

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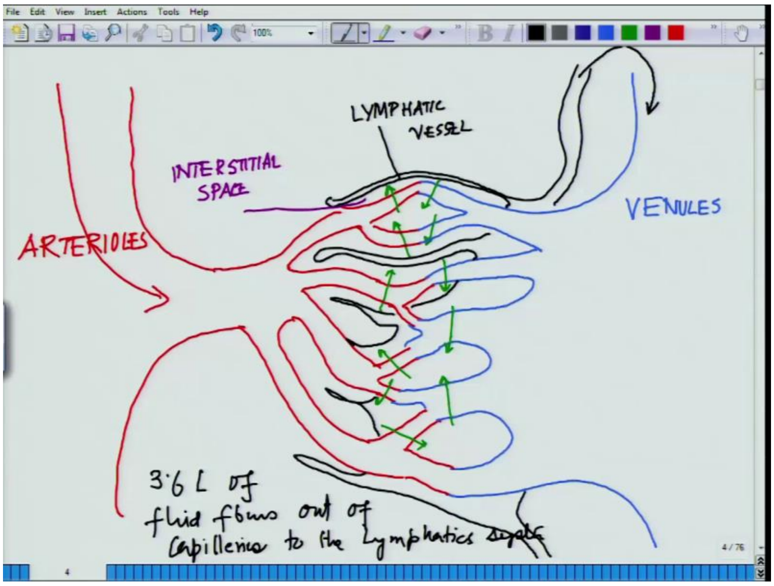

How it looks like physically, is if you draw this then, this is the artery side of it and this is where, this is the network of the capillaries. This is the capillary network. The red is, from here the venule network is breaking up. The blood is coming like this. So, these are the arterioles and these are the venules. So, the blood is coming from the arteriole side and here, is the exchange taking place. Let us represent the exchange by different arrows. Here is the exchange zone. At this zone there is a parallel vessel which is running. I am representing parallel vessel in black. So, that you can distinguish it, something like this. This vessel equally has a very fine mesh network, and this whole network is a parallel system along with the blood vessel, which is called a lymphatic system. This runs parallel. So, whenever there is fluid which is being given out and this space, which is imagined. This space is called interstitial space.

This black one is your lymphatic vessels. Whenever, there is a fluid which is coming out from the capillaries, it is being reabsorbed by the lymphatic vessel. This is how the blood; it is being ensured by the body, the fluid does not get accumulated. So, as a matter of fact, approximately about 3.6 liter of fluid flows out of capillaries, to the lymphatic system, which is further, this lymphatic system, what it does is, it brings the blood black to the blood vessels.

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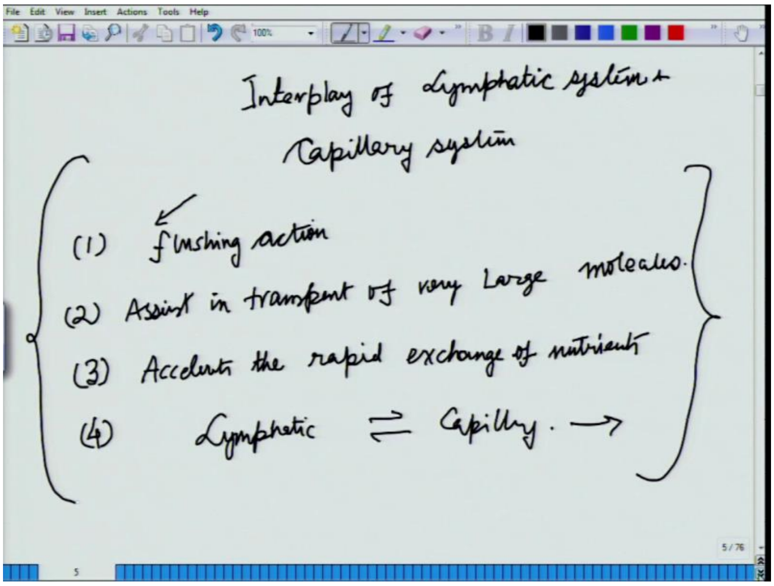

So, this is very important for you to understand that there is a continuous interplay of lymphatic system and the capillary system. What it leads to this interplay of lymphatic and capillary system ensures that there should be a continuous flushing action; which will continuously flush all the tissues. It assist in transport of very large molecules which, otherwise, cannot be really transported.

This is the process which accelerates the rapid exchange of nutrient and moreover, it is the exact interplay between lymphatic; this is the balancing of the lymphatic and the capillary vessels, which ensures that we do not suffer from any kind of fluid accumulation, or any other kind of situation. So, this is very important for us to appreciate. These are some of the major functions; is part of the interplay of lymphatic system and the capillary system. From here, we move on to all the forces what we have already discussed. Now, we will come to the exact values. I am not again describing all the forces, because I have already done that.

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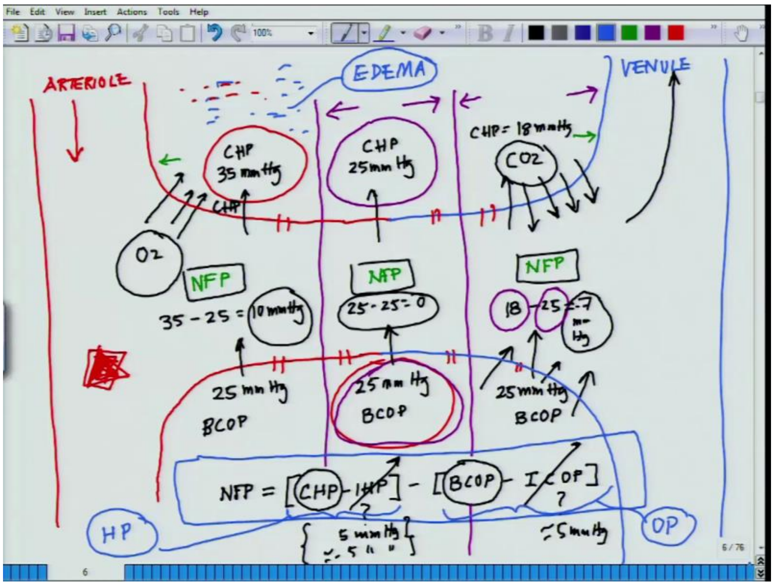

Now, what I will do; I will redraw the vessel and I will highlight the different forces, which are involved here. This is the blood vessel. Let me draw it in a way that it makes. So, this is the venule side, little more. This is arteriole side taken. This is the venule side. Here, you have the arteriole. So, blood is coming from this direction; entry of the blood into the capillary network. This is the venule.

Imagine this zone is the capillary network zone. This zone is, the both arrows showing, is the capillary network zone. There are two or three terminologies, which I am going to come. Let me. The first terminology is NFP; net filtration pressure. You will be measuring the net filtration pressure at three different zones; at the beginning of the capillaries, the middle of the capillaries and at the other end of the capillaries. If you look at the three zones, this is the zone where capillaries involved in giving away oxygen.

Because, this is oxygen rich blood which is coming. This is the zone where, capillaries are taking in carbon dioxide from the surrounding tissue. These are the two zones. How it does so? Before we understand this, we have to realize the capillary hydrostatic pressure. So, I have already talked to you about this hydrostatic pressure. If you remember that when you put an equivalent opposite pressure in that U tube kind of things, where I showed you, that you put, you give an equivalent opposite pressure against the osmotic pressure, which is the hydrostatic pressure.

What are the hydrostatic pressures, capillary hydrostatic pressure? The hydrostatic pressure of the capillaries is called capillary hydrostatic pressure. It varies from 35 millimeter mercury to 18 millimeter mercury in the capillary zone. At the beginning, the capillary hydrostatic pressure at this zone is, let us represent it by CHP- capillary hydrostatic pressure at this zone is 35 millimeter mercury. Capillary hydrostatic pressure in between, out here, is approximately 25 millimeter mercury. At this end, where it is venules, capillary hydrostatic pressure is equal to 18 millimeter mercury. These three values are exceptionally important. All along this point; there you see, if I talk about the capillary hydrostatic pressure, there is another pressure which is coming into play, which is called colloidal osmotic pressure. Colloidal osmotic pressure, which is out here, remains constant all throughout. That is almost out here, look at it, colloidal osmotic pressure is 25 millimeter of mercury.

So, this is basically, bulk colloidal osmotic pressure, BCOP. Now, your net filtration pressure, if I have to calculate these values, I have input. All these green values, I have input. So, your net filtration pressure is equal to; let us put the NFP is equal to capillary hydrostatic pressure, minus interstitial hydrostatic pressure, minus bulk capillary osmotic pressure, minus interstitial capillary osmotic pressure.

Now the values, what you know, people know is, this value is known to you, which I am circling. This value is known to you. You do not know these values; IHP, ICOP. These values are extremely difficult to calculate. This value, interstitial hydrostatic pressure, it varies from different part of the body. In the brain it is approximately 5 millimeter mercury and in other tissues, it is around minus 5. It is a negative hydrostatic pressure. Let us assume this as around 5 to minus 5 whereas, interstitial capillary osmotic pressure where, is approximately around 5 millimeter mercury.

If you ensure that these two terms; you are ignoring these two terms and down to capillary hydrostatic pressure minus capillary osmotic pressure. Now, if you do the calculation here, it is capillary hydrostatic pressure is 35 millimeter mercury, and your capillary osmotic pressure is 25 millimeter mercury. This makes 10 millimeter mercury. Whereas, if you do it here this is 25 minus 25, it becomes 0. If you do it here, this becomes capillary hydrostatic pressure is 18 minus 25, that makes it minus 7.

If you look at these three values, that will give you a very simple idea of exactly what is happening. This is the zone where net filtration pressure favors NFP; favors that nutrients goes out of the vessel. So, in that process the oxygen is getting downloaded because, NFP or net filtration pressure is 10 millimeter positive; 10 millimeter mercury. Whereas, at this zone, if you concentrate at this zone, out here, it is good to put this line to mark it all the three zones, there is hardly any exchange taking place. Because, here the pressure difference between inside and outside it is 0.

If you remember in the membrane physiology talked about, it is the pressure difference which ensures the filtration is taking place. If there is no pressure difference, there would not be any filtration taking place. So, at this zone, where it is 25 minus 25, you cannot expect any filtration to taking place. This value and this value ensures. So, the colloidal osmotic pressure and capillary hydrostatic pressure are equal, whereas, if you move to this zone, where it is in the close proximity of the venules. It is in this zone, where colloidal hydrostatic pressure is the smaller; it is approximately 18, whereas, colloidal osmotic pressure is 25, and that gives you total of minus 7 millimeter of mercury. This is the zone which ensures, that different stuff which are present, which has to be thrown out by the body, is being picked up by the capillaries enclosed proximity of the venules. This is where carbon dioxide is being uploaded into the blood vessels, and which eventually, reaches along the venules to the veins, to the veinaccave, to the heart, to the right entry and right ventricle, and then sent to the lungs, where it is being downloaded, and again, will come back to this. All these forces will come into play while we will be talking about the lungs; how exchange is taking place in the lungs? How in the lungs the carbon dioxide is being downloaded and oxygen is uploaded from outside?

That is the reverse process, which takes place in the lungs, and again, all these forces will come into play there. We will talk about it. So, this is an overall simplified summary of the exchange process in the capillaries, for downloading oxygen and uploading carbon dioxide, and ensuring any kind of other exchange processes. Here, if you look at, if you come back to the diagram again, and if you look at the diagram; what is very important to ensure is, that if, say for example, some XYZ toxin is coming into play.

If this is a toxin; if this toxin reaches at some point, and kind of you know, change the permeability all along these places. This is the zone where, all these forces; all these capillary hydrostatic pressure; capillary osmotic pressure; all these are getting disturbed and whenever, there is a disturbance in all these things, the possibilities are, there will be some fluid accumulation, or some kind of a fluid accumulation at some point. This fluid accumulation is what you call as edema.

Now on, whenever, you will see a edema or some form of accumulation of fluid, always refer to this diagram. Try to request the doctor or ask yourself. What is the capillary hydrostatic pressure? What is the colloidal osmotic pressure or capillary osmotic pressure? What is the interstitial hydrostatic pressure? What is the interstitial osmotic pressure? As long as you follow the simple equation of understanding, where net filtration pressure is equal to capillary hydrostatic pressure, minus interstitial hydrostatic pressure, or in other word, this is the net hydrostatic pressure. If this wholesome term, I have to put it in terms of simple hydrostatic pressure, and this; sorry for the interruption. If this whole term has to be put together, then this is called the osmotic pressure. If you look at it, this is a very simple term; hydrostatic pressure, osmotic pressure and all other details. These are very simple terms and they ensure that your body is in perfect homeostasis.

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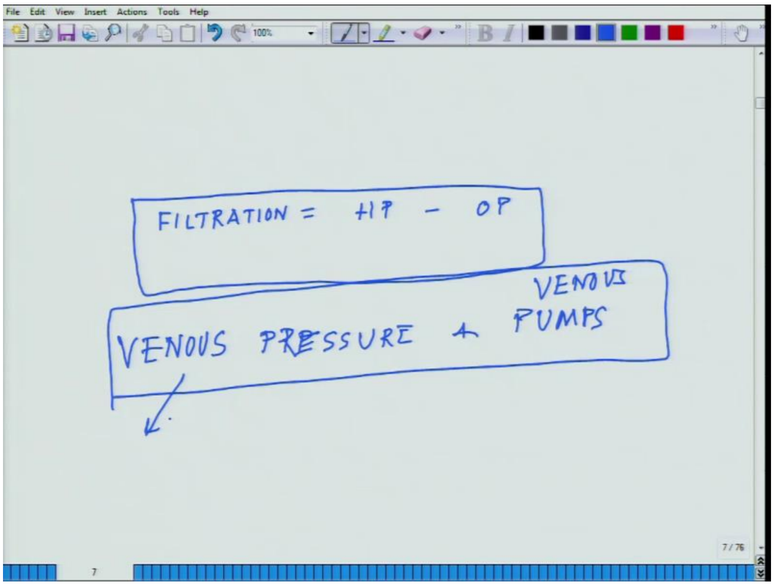

In other words, if I have to put it in terms of, basically, filtration is equal to hydrostatic pressure minus osmotic pressure. This is the broad term, which describes this whole process. With this, I will move on to last tailpiece of this, which is basically, the venous pressure and sorry, venous pressure and venous pumps.

Again, I will take you to a practical situation, which will help you to appreciate this. You must have seen, that at times in the schools, where you are standing in an assembly or you are standing in a like, kind of you know, very attention position. Some of the students faint down. Why that happens? Have you wondered? Is it some problem in the brain or something? These are very simple problems? So, what is happening? Think of it. You stand up and look at yourself, your blood from the rear part of the body, almost from your legs or something, has to come back to the heart. It is doing so, and especially along the vessels, specially along the vessels or the veins. Because for the arteries it is easy. Already, there is a huge amount of pressure or force with which, it is being pumped and it goes all the way, down and down, and up of course. But, there is a huge amount of pressure involved in it and it flows through, but in the veins, the only assisted mechanism is your valves. It does not allow the black through. The blood has to flow against the gravity at times. How that is being taken care? There are two distinct forces which takes care of it. One is called muscular compression. Muscular compression is all these muscle, compression, all these taking place. That generates sufficient pressure for the veins to ensure that the blood comes back to the heart.

Say for example, you were standing an attention position and none of your muscles are really activated at that time. You are in standing position. There is a possibility, that because of lack of muscular compression, the sufficient force which is needed by the veins, to ensure that the blood flows fully to the heart, is being reduced. That simultaneously ensure, leads to reduction in the cardiac output. That reduction in the cardiac output causes your fainting. So, next time when you see a friend of yours, fainting, and standing in an assembly or you know, in some prayer meeting or something, ask them to just relax, and kind of you know, much more easy position.

Because, it may be because of the lack of muscular compression they may faint down especially, in a bright sunny afternoon of anywhere, in the tropics or sub-tropics, this is fairly prevalent. There is another pump which helps us to ensure, that the blood flows through the veins, that is called the respiratory pump. That basically, because of this, you see, the whole chest is moving. That respiratory pump ensures that the veinous blood comes back to the right atrium, without much delay. So, these are some of the basic forces; some of the very basic mechanisms, by which our whole complete network of the cardiovascular system works. I did not go into the anatomical details.

But, you can go through that, is much of academic interest to understand; what are the different names of the different arteries? But, what is more important than that is, to understand the mechanism by which it does. So, with this, I will close on this part, this section of cardiovascular physiology, but while we will be doing the nervous physiology and of course, I will take out scoop out certain time, to talk about the hormonal control of the blood flow. And the nervous control which ensures blood flow, and another situation, which we will be talking about; how those are helpful in ensuring, that we do not suffer from some kind of edema, or something? And how the anti inflammatory drug works? As we will proceed through the course, probably, once you read the tail piece of the course, we will be able to understand all these by ourselves, as kind of, these things and will try to analyze all the situations. So, what is the most important, as we are proceeding through the course is, that you people, please think try to realize our day to day life situation. What exactly is happening? Because, that is the best way to learn physiology.

I can tell you a whole bunch of formulae and situations, or you know, diagrams or anything, but in your visual plane or in your mental plane, you have to have visualization of the situation. What possibly is happening, and that is how, most of the bigger discoveries are being made. If you see something, try to rationalizing it in terms of simple physics, chemistry and mathematics, then come back to biology and explore it and make some very fundamental discoveries. I am closing here. So, in the next section, we will be taking up, partly the muscular system and nervous system.

Thank you.