Animal Physiology

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Module - 1
Lecture – 8

Welcome back to the lecture series in animal physiology. So, we are in section 4 which pertains to the circulation and cardiovascular physiology. So, in section 4, we have dedicated three lectures and out of three lectures, we have done with the first lecture. In a first lecture, we talked about the anatomical features of the arteries, veins, capillaries, arterioles, venules and the zone of exchange of these materials by which the cells are supplied with nutrients and gaseous exchange and everything.

So, now in this section what we will be doing? We will move on to the cardiovascular physiology of it. So, we have already talked about the heart physiology that how the heart is pumping, but then how the network of vessels carrying the blood all over our body is being governed. So, what are the governing dynamics which are regulating that flow, we will be discussing that. So, in this section what I will do? I will first of all draw the outline of the forces, where it is involved and in that process we will move on to enumerate.

So, it will be much of slightly more informative than previous one. So, here you have to kind of gather certain information and analyze them. So, it will be much of once the information is there, you need to analyze them, and then you have to put them in perspective. So, let us start with the broad outline of where all the check points are in, where we really need to put our maximum understanding in figuring out the dynamics of this network.

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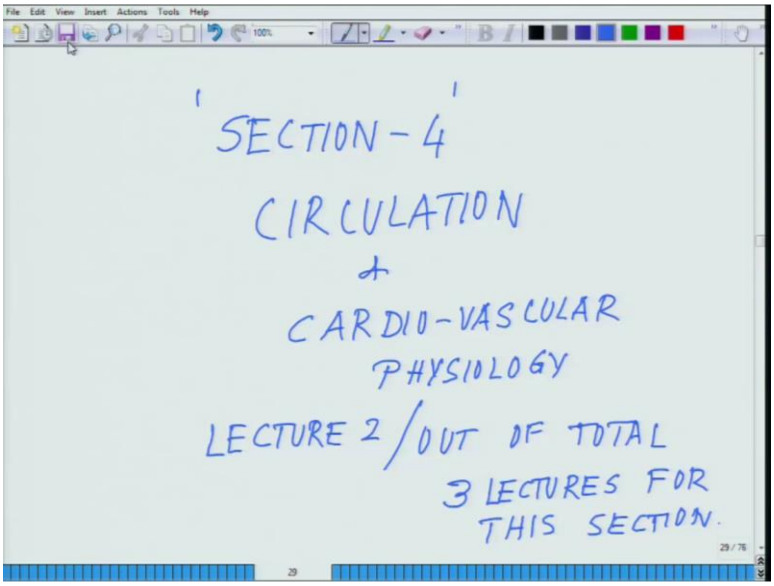

So, let us start with the section 4, the circulation and cardiovascular physiology.

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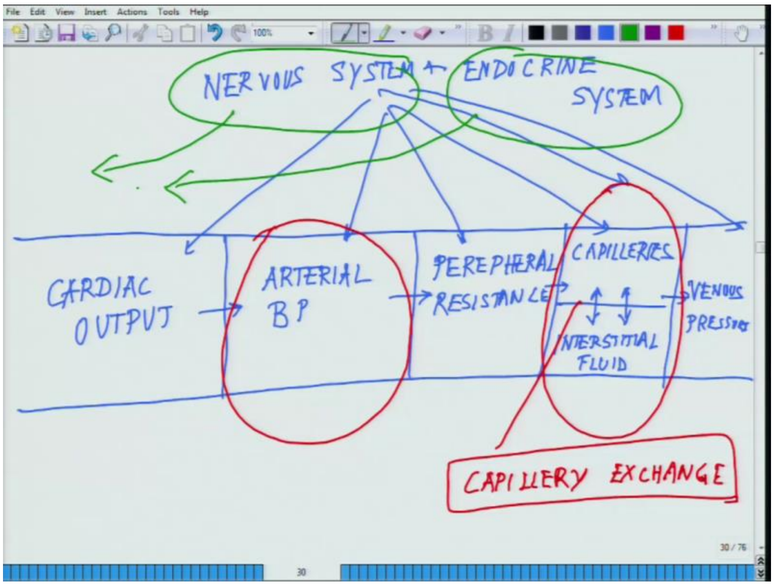

This is the second lecture. So, from here we move on to see what the control units are. So, this will be a diagrammatic schematic view of it, where all we are having the control. So, we talked about the cardiac output while we are talking about the heart. So, this is very important cardiac output. This is first thing. The cardiac output has been generated by the heart, and that leads to the arterial blood pressure which is the actual blood pressure. Arterial blood pressure lead encompasses something called and will come to that peripheral resistance because as you remember in the last class, I was telling you know because of the reduction in the size or the reduction in the diameter of the vessels.

So, for example, the arteries of huge diameter and you are moving to the arterioles, and let us start elastic arteries, then moving into the muscular arteries, then we are moving to the arterioles and then you are moving to the capillaries. So, there is a continuous decline in the diameter as the diameter keeps on decreasing the pressure changes. So, you are reducing the diameter. So, the radius is continuously varying. So, that reduction in radius leads to a resistance in the flow of the blood, and we will be talking about that and those resistance which are generated by the arterioles and the capillaries falls under the peripheral resistance and from there, the blood moves on to the capillary.

Capillaries which are exceptionally perforated vessels as we have discussed in the last class, and this is the zone where the maximum gas and fluid exchange is taking place with the interstitial fluid and then from the there it leads to the venous pressure or the pressure in the vein and this whole process is being controlled at every level by the nervous system and the endocrine system. So, what essentially we will do is today we will talk about the cardiovascular physiology at two levels. The first level will be carrying at the level arterial blood pressure. This is a very critical point what we are going to cover here.

Second thing in the next lecture we will be talking about the capillaries and the interstitial fluid exchange, where basically all the capillary exchanges are taking place. Then, what we will do at this stage? We will stop with the section, but what we will partly come back to this section again. Why we will be dealing? Once we are done with the endocrine system and nervous system or while we will be doing the endocrine system, we will talk about the endocrine control and we will talk about the nervous control, but at this stage since I have not taught you the nervous control or endocrine control, so I will not deal with it because that would not make sense to you people because without getting a fair idea about the molecules which are generated by the nervous system or by the endocrine system, it would not make sense.

So, again to summarize what we will be dealing with? We will be dealing with the arterial blood pressure and we will be dealing with a capillary exchange and then we will be dealing with the fatal circulation and in between we will talk about the blood pressure, pulse and all those different parameters which are very essential for you people to know in day to day life. So, always remember that by the end of the course I expect that you people should know whenever you go and talk to doctor what the doctor is telling, or you see a prescription somewhere a doctor tells you this is your pulse, this is your blood pressure, these are the problems, this is artery arterial sclerosis or this is your ECG, this is your EKG. You should have some degree of basic understanding what that means, and that is the whole purpose of this course. It is very practically oriented that you should be able to figure out these things. So, let us move on to the arterial blood pressure. In order to explain the arterial blood pressure, what I will do as I told you this will be slightly more informative section.

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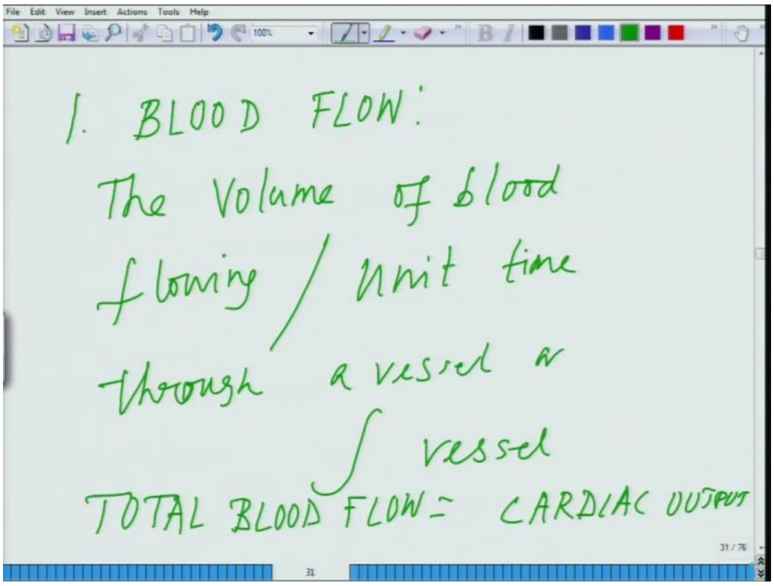

So, I will account you with some of the basic definitions and these definitions are very important and then we will draw up the story. First definition you have to understand is the blood flow. Blood flow is essential. So, I will write it down, so that you guys start analyzing this definition. The volume of blood flowing per unit time through a vessel or integration of several vessels as long as you know the total surface area and the volume and total blood flow is essential. Total blood flow is essentially equals to the cardiac output and cardiac output. We have already done in the previous class. This is the first definition and I expect you guys to know.

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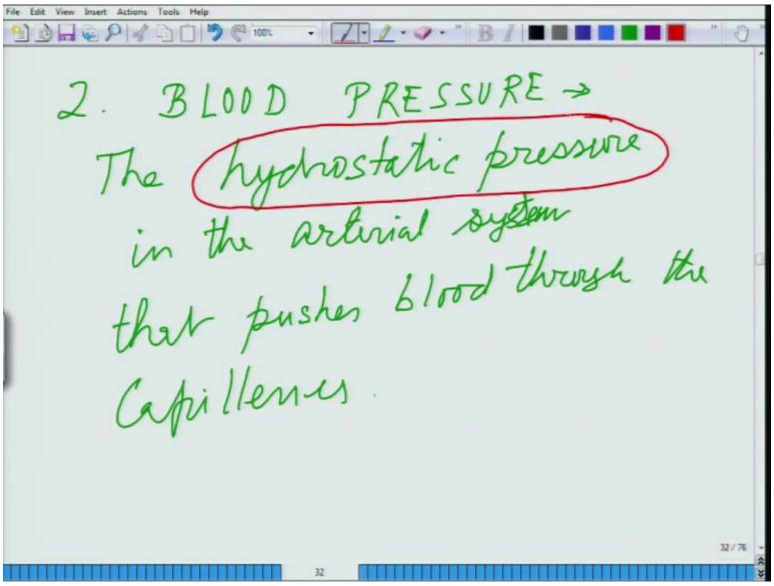

The second definition is what blood pressure is. So, blood pressure is essentially the hydrostatic pressure in the arterial system that pushes blood through the capillaries. So, one term which may confuse is what hydrostatic pressure is. So, what we will do is let us understand what hydrostatic pressure is. It is using certain very simple diagrams that will help you to understand what hydrostatic pressure is.

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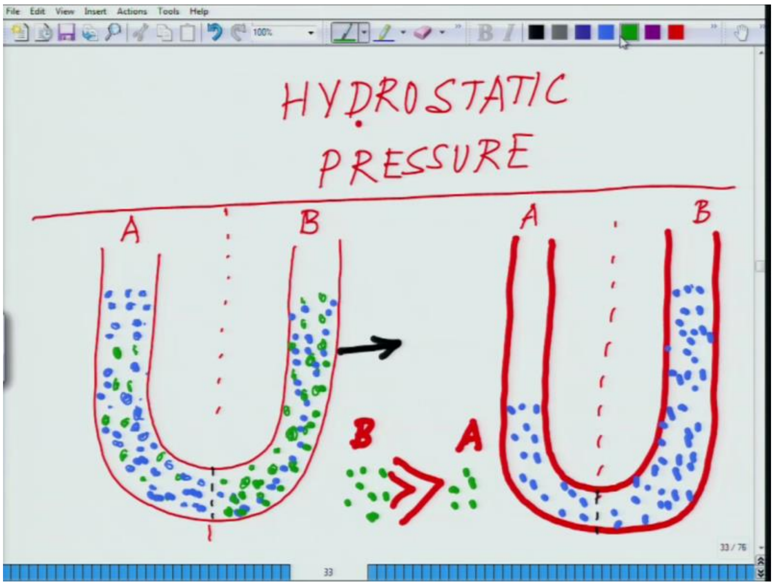

We have talked about the osmotic pressure in the membrane section, membrane physiology. So, here we will talk about how we actually measure the osmotic pressure.

So, let us think of a situation, let us think of U tube like this. This is the U tube and at the bottom of the U tube, you have a membrane like this which I am indicating in black. This membrane only allows and this membrane marks my word very carefully. This membrane only allows the water molecules to pass through it. It does not allow any other molecules which I will be drawing, any other solute molecules to pass through it. So, let us add up a whole range of solute molecules. These greens are solute molecules. This could be sugar, this could be something else or desk rotes or x y z. It could be anything and everything, but mind it these molecules cannot pass through the semi-permeable membrane.

So, let us mark this side. My left is this A, and this part of the tube is B. Now, what I do is I add water to both sides and mind it, this will allow water molecules to pass through them. So, how about we show the water also in terms of you know the molecules that will make life easier for you guys to understand. These are the water molecules. I am adding these all the green, all the blues are the water molecules. What I take slightly bigger, yeah little make it easier. So, this is the first case scenario. Now, what will happen if we allow this to equilibrate for a while, what will you see?

So, if you look at it very carefully into this picture, you will see the solid particles are more on one side as compared to the other side. So, in other words, solute particles are more in B as compared to A much more. You look at it carefully or I can add few more. So, these solute particles will try to draw as much as water possible towards B in order to equilibrate the situation. So, what eventually happens in order to reach the dynamic equilibrium, this is what is going to happen. The same tube I am just using thicker point make it bright too fine.

So, what will happen is that essentially what you will see is and here is your semi-permeable membrane, this is your side A and this is side B. So, eventually what will you see is that there are more water molecule on this side as compared to the water molecule on the other side because of the fact that these are the water molecules, and if I have to put there is a slight disturbance. Let us come back to picture.

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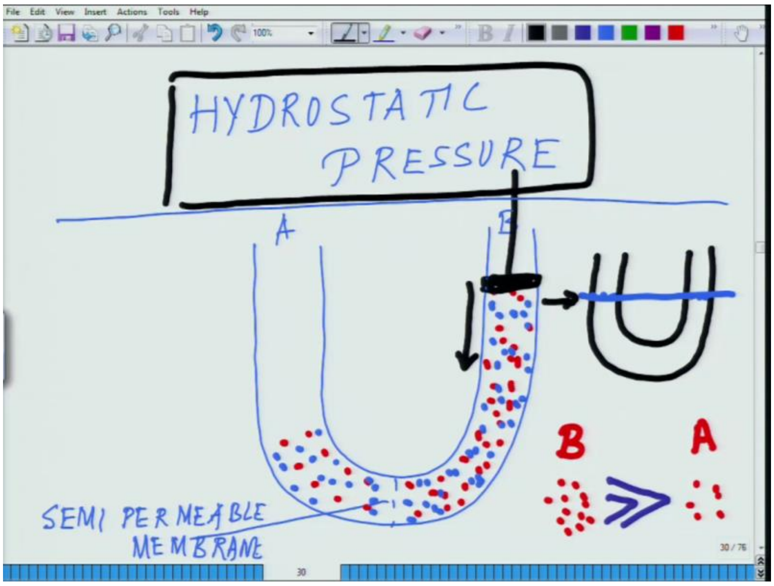

Talking about the hydrostatic pressure, this is what we are going to discuss. So, I told you the solute concentration on the side A, this is A, and this is B. The solute concentration on the side of B is more. This is a semi-permeable membrane which only allows water to pass. Semi-permeable membrane allows water molecules to pass and I told you that since on the side of B, the solute concentration is higher. So, automatically now I am showing the solute by red. Actually solute is higher and here is by blue I am showing water molecule. There will be shift of lot of water molecules on the side B. So, again to show you, so this is number of solute molecule is extremely high compared to the solute molecules on one side. So, this is side B, side A, side B. So, number of solute molecules in side B is exceptionally higher as compared to solute as compared to the solute concentration in side B.

Now, what will happen is that side B will rag a lot of water molecules towards it because of the osmotic pressure. So, now, in order to equilibrate in terms of the potential difference, if I want to get back to a situation like this again where I am just showing where drawing a small U tube. If I draw 1, 2, something like this on both sides, the equal I have put certain amount of pressure from here on this. This pressure has to be put in order to bring it back to equal potential difference on both sides which will be against the solute gradient and everything.

So, in order to do that, the amount of pressure what I have to put on the side B is equivalent and opposite to the osmotic pressure and that pressure is called the hydrostatic pressure. This is the hydrostatic pressure for your understanding. So, the amount of equal and opposite pressure to the osmotic pressure which has to be given in order to bring it back at the same potential difference, something like this from where we started which I showed you. So, these are the three cases in order to explain the hydrostatic pressure.

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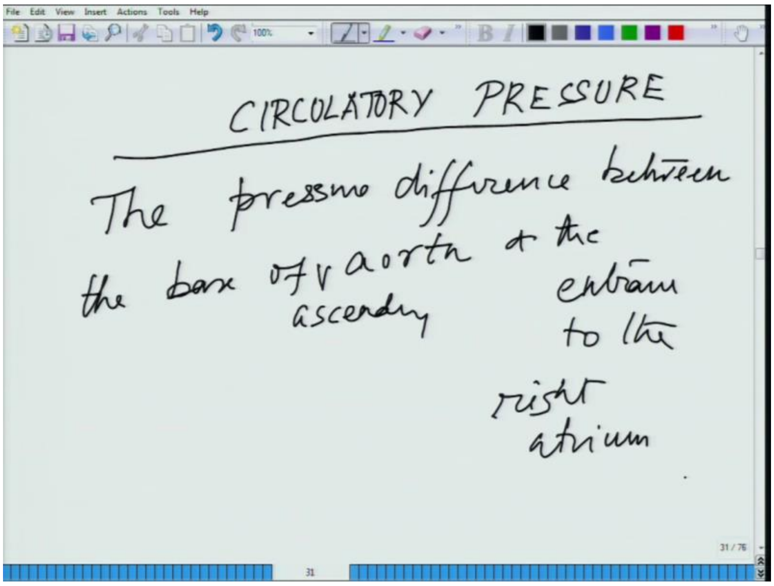

From here we will move on to the next slide which is our circulatory pressure. What is circulatory pressure? So, this is very important. Circulatory pressure is the pressure difference between the base of the ascending aorta and the entrance to the right atrium. So, in other words, atrium is the one which is receiving all the impure blood or the deoxygenated blood, and the ascending part of the aorta is the one which is the maximum pressure from the left ventricle which is circulated all over the body. The pressure as compared to the pressure with which the blood is coming back to the heart into the right atrium, that pressure difference is a circulatory pressure.

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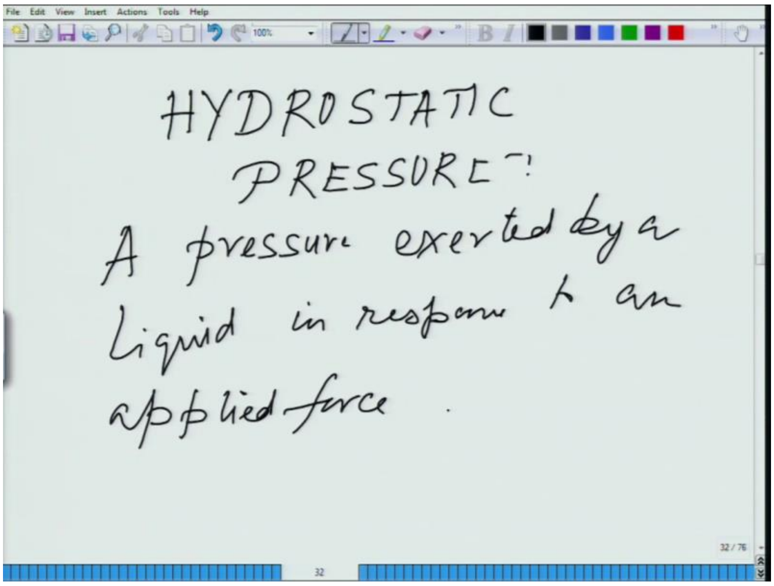

Now, what is the technical definition of hydrostatic pressure? I have already explained. The hydrostatic pressure I am just giving the definition. Hydrostatic pressure is a pressure exerted by liquid in response to an applied force.

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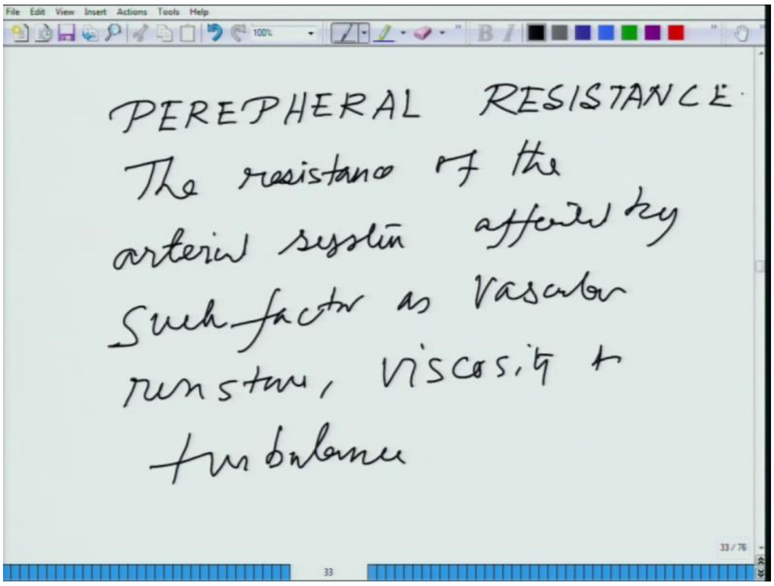

Next, we will go to what is peripheral resistance? As I told you there are bunch of definitions which I have to kind of appreciate and realize. Peripheral resistance is the resistance of the arterial system affected by such factor as vascular resistance, viscosity and turbulence. So, these are the resistances which are offered due to vascular resistance, viscosity and turbulence falls under the peripheral resistance.

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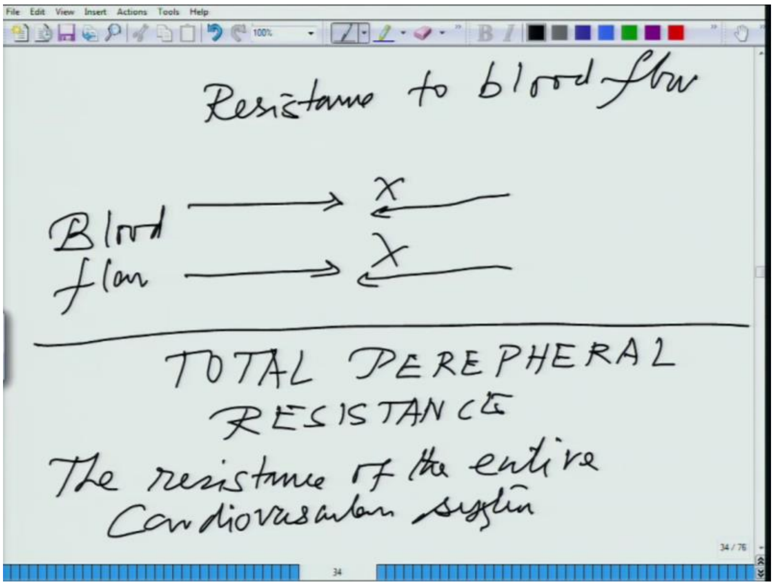

Then, we move on to what is basically the resistance is in terms of blood flowing is anything which is opposing the blood flow or kind of you know that is called the resistance to the blood flow. We talked about the total peripheral resistance. Total peripheral resistance is resistance of the entire cardiovascular system.

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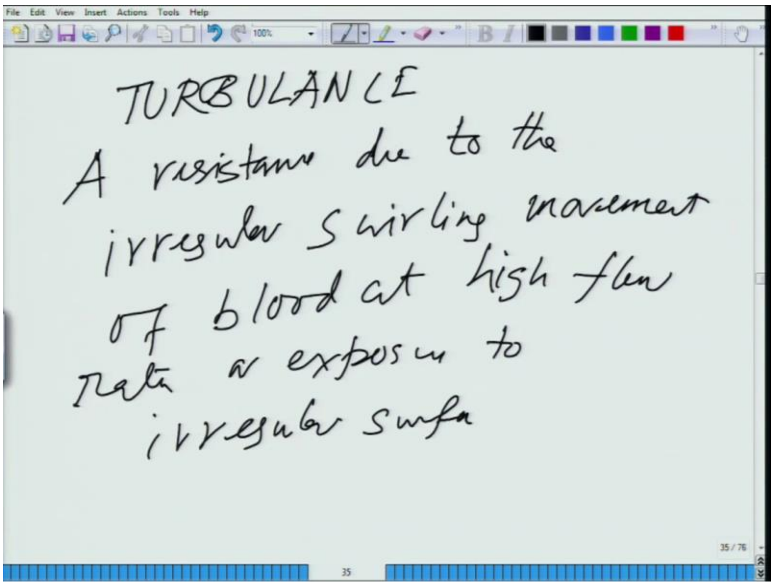

There is another term which I just mentioned is called turbulence. What is turbulence? Turbulence is a resistance which is generated due to the irregular swirling movement of blood at high flow rates or exposure to irregular surfaces something like this say for example, this is the blood vessel and here you have the surface becomes like this.

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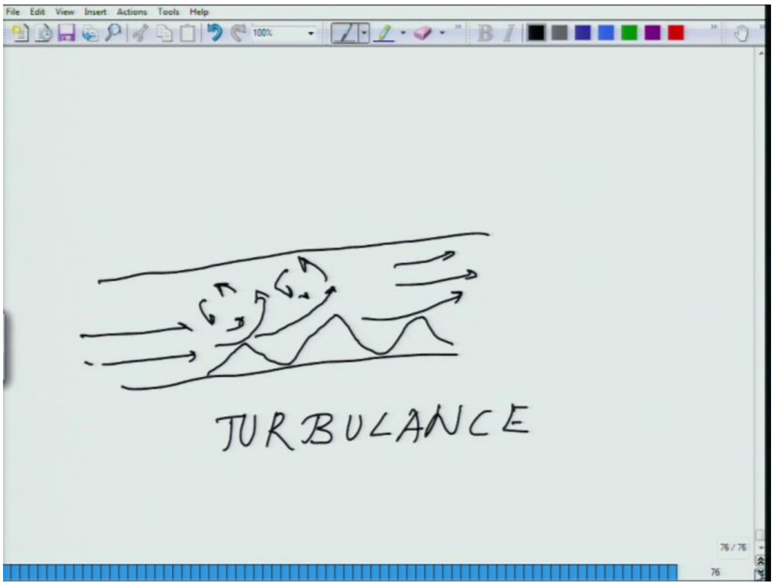

So, what is happening is the blood which is coming like this is kind of you know start moving like this here kind of create in these out. Here these are the turbulent nature of the flows. This is the basic example of turbulence. It is the same thing which happens while you are in the aero plane and we get trapped in an air pocket.

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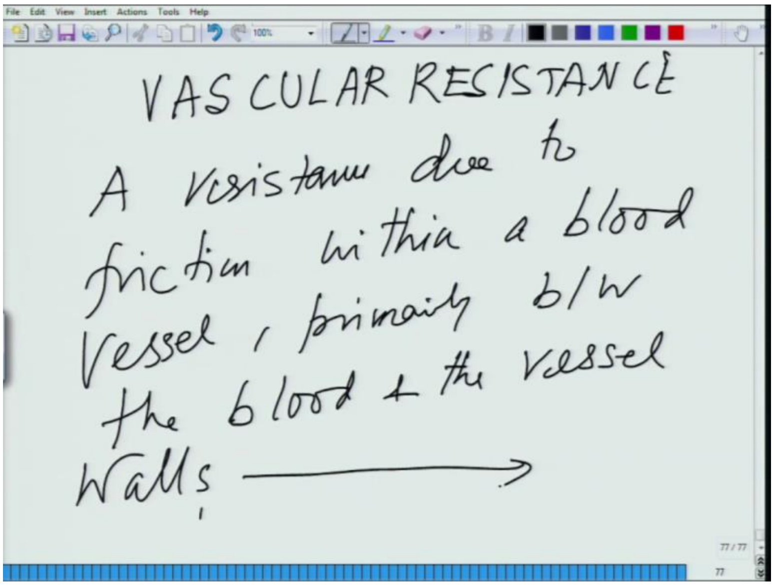

Then, there is something called vascular resistance. What is vascular resistance? Vascular resistance is a resistance due to friction within a blood vessel primarily between blood and the vessel walls.

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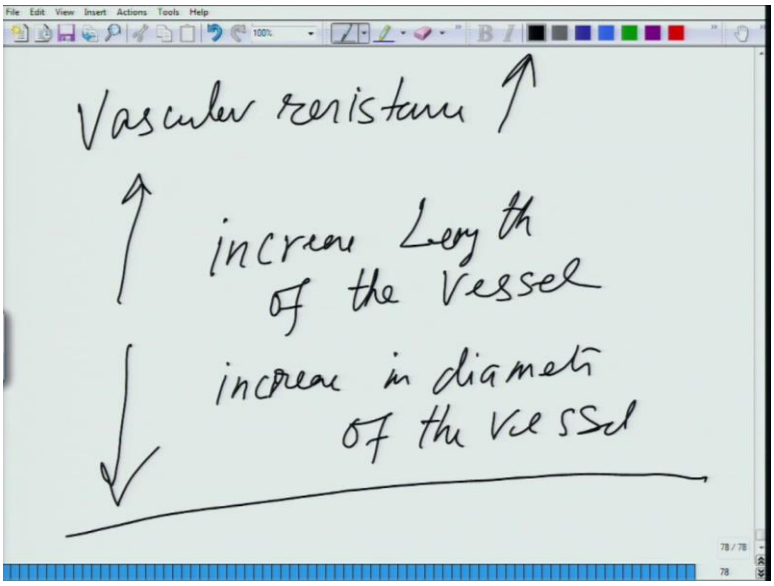

Next slide and this vascular resistance increases with increase length of the vessel. This is important and this decreases with the increase in diameter of the vessel. So, if you realize this, this is exactly what a situation in the veins is, where the veins, the diameter of the vessel are fairly high as compared to the arteries. So, as the diameter of the vessel increases, the vascular resistance decreases. So, it moves without much resistance likewise. So, we will come to all the mathematical derivation of it.

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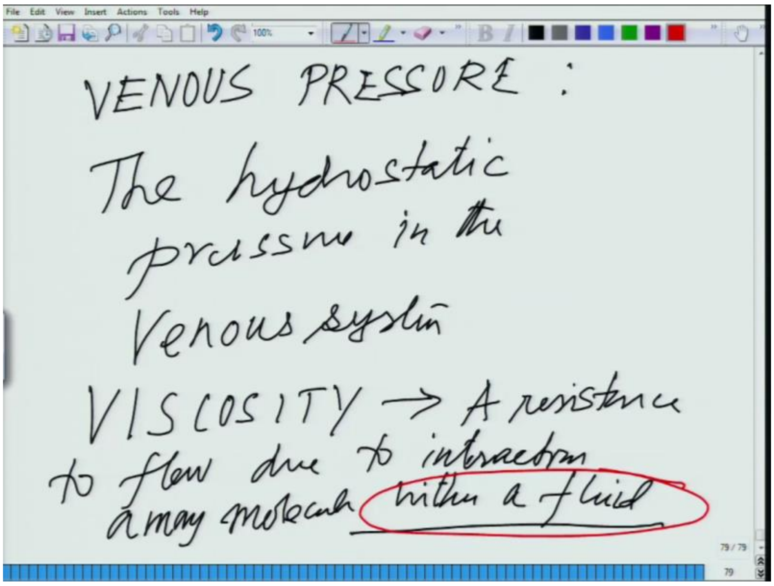

Then, we move on to the venous pressure. We talked about the arteriole pressure and now we are talking about the venous pressure or the hydrostatic pressure. In the venous system that is talking about the venous pressure, then we talk about the viscosity, the nth we have mentioned this. So, viscosity is essentially say, for example, you take water, you try to flow water on a surface. It fairly flows without much problem, but you take some kind of syrup, some kind of sugar syrup or some other syrup fluid which have lot of carbohydrates and sucrose. You try to flow it something like hamarmalet or jelly or something that all flow because it is exceptionally viscose and in other words, the interaction, the resistance which is created.

So, there are several ways of resistance. So, water is flowing on a surface. So, the surface is kind of you know surface is rough. So, automatically it faces resistance. There is another form of resistance say for example, the surface is same, but you are trying to flow water and you are comparing this while flowing some kind of syrup. So, that is a situation where we will see syrup would not flow faster because there is a friction which is generated because of the interaction of the molecules within the syrup something like a resistance to flow due to interaction among molecules within a fluid. This is very important. This is the key point. This is a resistance which is created because of the interaction between the molecules within the fluid.

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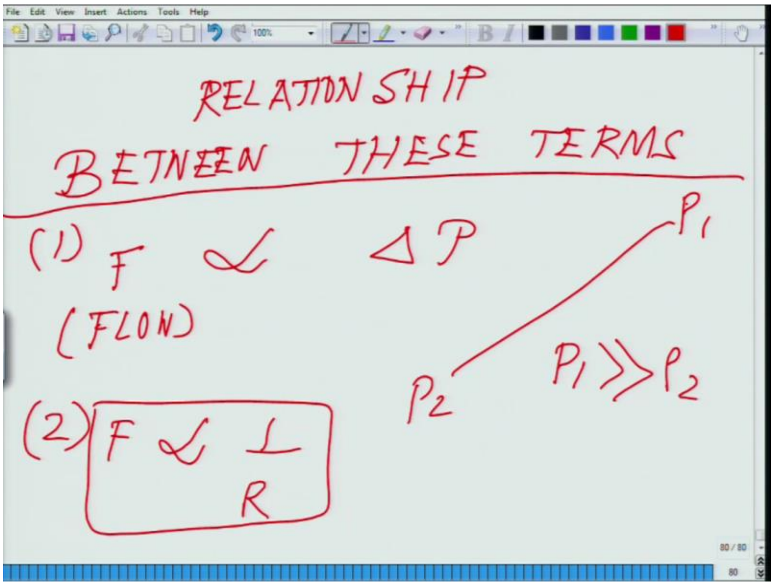

Now, if we have to draw the relationship among these terms, let us put all the relationship between the terms we have just now written. Let us talk about the relationship. So, the flow is proportional. F stands for the flow and flow is proportional to change in pressure delta. P is the change in pressure. This is the first relation. So, there will be more flow if the pressure gradient is more. So, it is something like that here they have p1, here you have p2 and p1 is far greater than p2. Then, there will be more flow. Flow is inversely proportional to resistance. There is more resistance, there will be less flow. If there is less resistance, there will be more flow.

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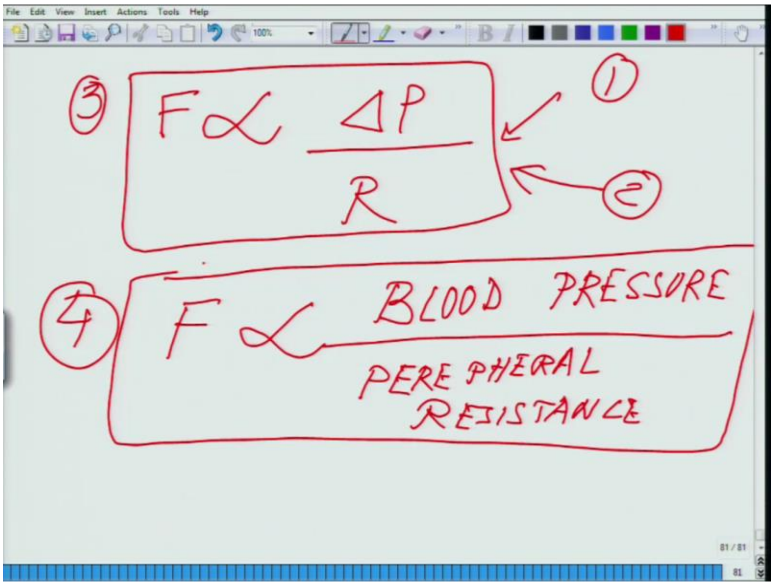

Third relation flow is if we add these two equations, flow is directly proportional to change in pressure and inversely proportional to resistance. This is coming from equation 1 and equation 2. Now, the fourth relationship flow is directly proportional to blood pressure. Of course, we have to explain what blood pressure is. Blood pressure is inversely proportional to peripheral resistance. This is the fourth relationship.

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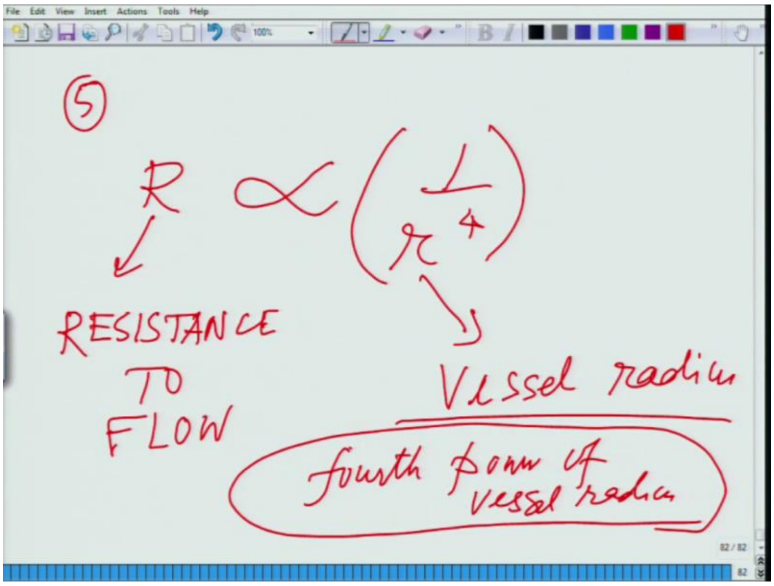

The fifth relationship is r which is the resistance to flow of blood. It is inversely proportional to 1 by small r to the power 4 whereas, small r is the vessel radius. So, in other words, resistance is inversely proportional to the fourth power of vessel radius. This you can always plug in the values of the veins and the arteries, especially the diameters or internal diameter what I had given you. You just make it half and get the radius and you plug in the values, and you will see how the resistance varies in terms of what is experienced by the blood in artery vessels as compared to the one which is experienced in the veins vessels.

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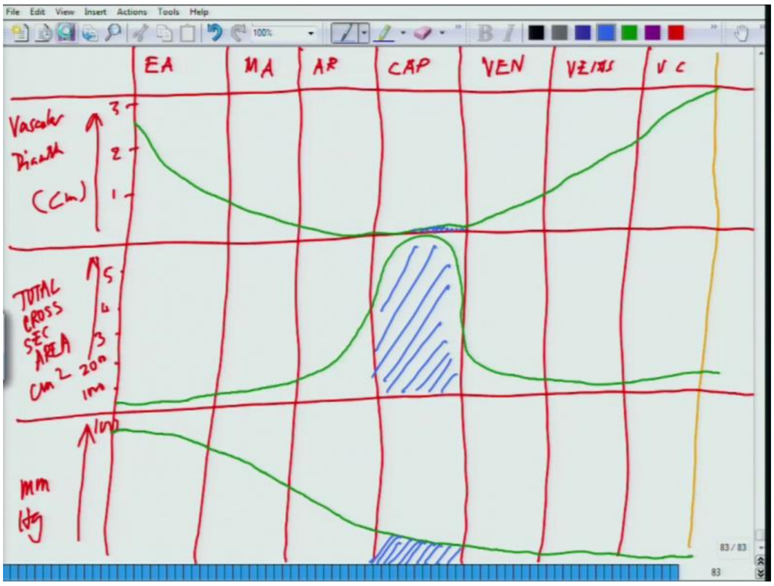

Let us move on to the next slide which I will be talking about. Let us diagrammatically show how these values are changing. What I will do now is I will divide the page into all the vessels. Let me do like this, 1, 2, 3 and I will just give me a minute. What I wanted to show you here 1, 2, 3, 4, 5, 6, 7. Now, the first thing what we will be talking about is the vascular diameter and how that is changing. So, this section is elastic artery. I am just putting it here because it is space constraint. Here muscular artery and this is arterioles and this is capillaries, this is venules, this is the veins and this is vein cava.

So, now the first parameter we will be dealing here is the vascular diameter just kind of putting it in perspective 1, 2 and 3. This is in centimeters. So, the way the vascular diameter varies is something like this. So, vascular diameter from here, I will put another goes down at the arterioles. It has come down with the capillaries. It is the least and it increases with the venules, veins and the vein cava. So, this is how the vascular diameter changes. It is the least in the capillary section. What I will do like I will just keep on this is the base line. What the maximum exchange is taking place? The vascular diameter decreases.

Now, we will talk about the total cross-sectional area in terms of the vessel, total cross-sectional area in centimeter square. How that is varying? So, we have 1000, 2000, 3000, 4000 and 5000. Now, the way it varies is let me use some color here. The way it varies is something like this. It moves like this, this, this. This increases and then it becomes highest out here and then it falls down like this. So, if you look at it, the total cross-sectional area is highest in the capillaries. So, actually this graph should shift slightly, sorry. Let me redraw the graph here. It is more like this. This is how the total cross-sectional area changes.

The next we will talk about the pressure in these vessels in terms of let us put this 100 millimeter mercury. This is in millimeter mercury the way the pressure changes is that. So, it is highest at the elastic or the aorta and then it goes down, down, down, down, down, down, down, down, down and it becomes even lower out here on and then lower, lower, lower, lower, lower, lower, lower, lower, lower, lower, lower, lower. So, if you look at it, here the capillary pressure is sitting. So, I am keeping this as constant reference. Now, on top of this if you wanted to check what the velocity of the blood is…

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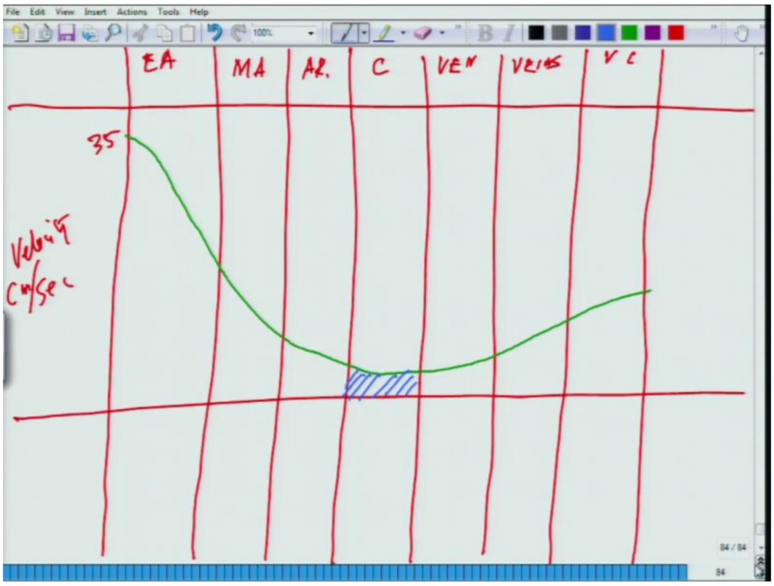

So, let us move on to the next slide. Again let us draw those lines that will be helpful to understand it i.e. 1, 2, 3, 4, 5, 6, 7. So, in terms of the velocity I have to measure which is in terms of centimeter per second. So, the velocity profile and this is the elastic artery. Again this is muscular artery m a, this is arterioles, this is capillaries, this is venules, this is veins and this is vein cava (VC). So, the maximum approximately is 35 and this is the base line. So, it shifts like this. So, maximum out here and then it goes down, down, down, down. It is the lowest out here and then there is a slightly increase. Likewise, this is where the capillaries look like.

So, these are the changes of the four parameters which enclosed in vascular diameters cross-sectional area, average blood pressure and your speed or the velocity with which the blood is flowing. Next, what we will do? We will move on to what the arterial blood pressure is and how it looks like. This is very interesting to realize the arterial blood pressure never is context because there is the continuous (( )).

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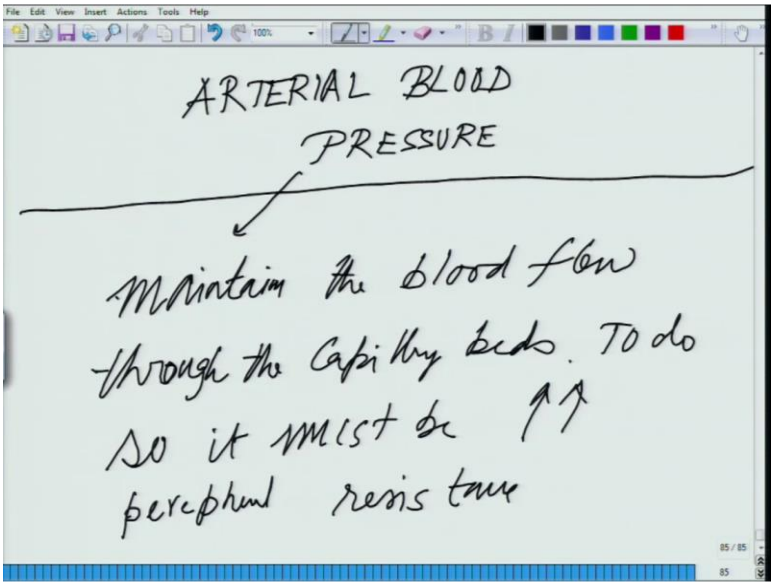

So, it is something like this if I had to give a definition of arterial blood pressure. Now, I will diagrammatically show like this arterial blood pressure. So, arterial blood pressure is important because it maintains the blood flow through the capillary beds. How it maintains, that we will be coming to that. It maintains the blood flow through the capillary beds and to do, so it must be enough to do. So, it must be greater than or more than the peripheral resistance. It has to be more. Otherwise, the arterial blood pressure cannot make blood flow through the capillaries.

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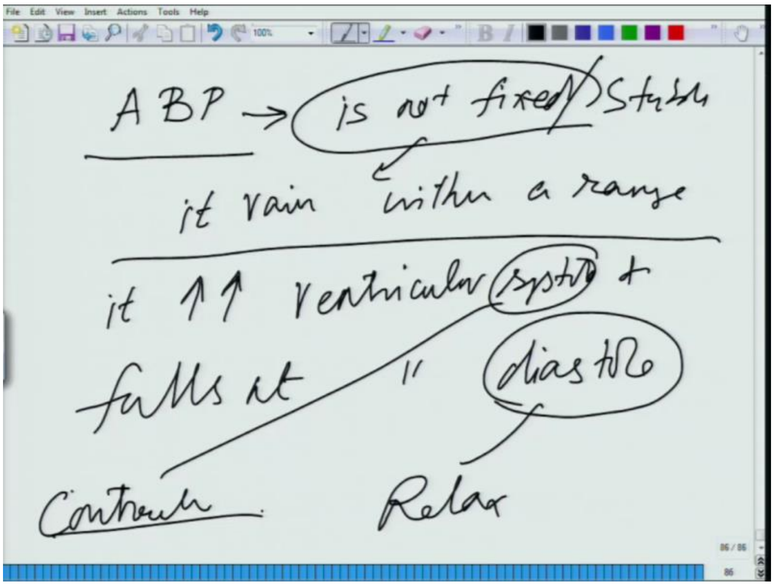

So, arteriole I am just putting it as ABP. The arterial blood pressure is not stable and it is not fixed, or rather that is not a right way to put it. It actually varies within a range. So, it is just a practical situation. So, let me come back to give you practical idea what really blood pressure is. Whenever we report a blood pressure, we say higher pressure and lower pressure. We say 120/80 or we say you know 150/90. Likewise, we are collapsing two numbers. Why is it? So, why is it two numbers? This is something what we have to realize. Simple, if you remember before I will give you the real definition we have.

So, if you remember when I was telling that blood from the left ventricle is pumped through the aorta, the oxygenated blood to the whole body and the pressure is maximum when it leaves the artery and especially when the semi-lunar wall closes, and it would not allow the back flow of the blood. So, at this stage when this blood moves here, the left ventricle goes into diastole. It is in a relaxed phase and it goes into the systolic phase. So, there are two shifts. One, it is in a relaxation phase, one it is in a contraction phase. Contraction phase IA systolic phase when there is a maximum pressure on it, then that we call as the blood pressure measured at the time on the arteries is called higher side of the blood pressure and then it goes down because of the diastolic pressure. When the left ventricle is in relaxed state, then that is called the lower blood pressure. Based on that, we will put the definition.

Now, in perspective of the arterial blood pressure is not stable. That is why it varies in or it is not fixed or is not stable. So, it increases during ventricular systole and falls at ventricular diastole, because this is the relaxed phase and this is the contraction phase.

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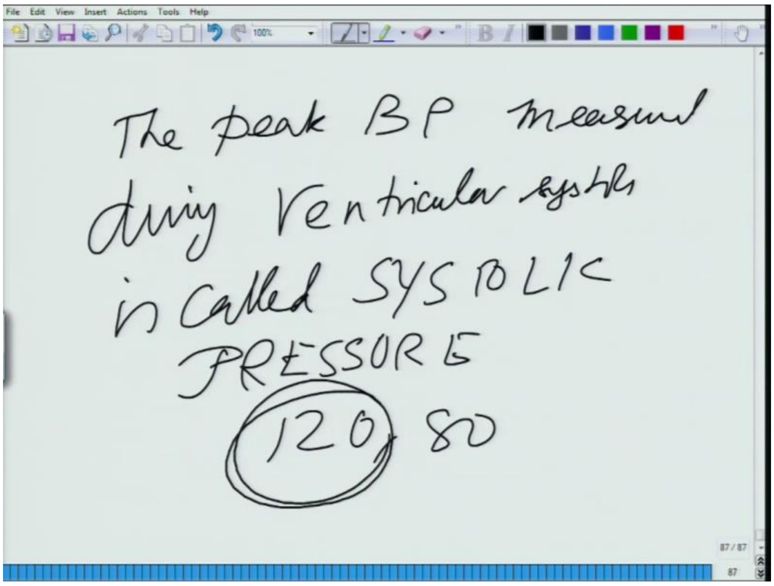

So, what we do essentially is that the peak blood pressure measured during ventricular systole is called systolic pressure or the higher, the upper regime of the blood pressure. So, when we talk about 120 by 80, so this is systolic pressure is 120 and sorry the minimum during ventricular diastole. So, 120 by 80 what we see 80 is the one which is the diastolic phase. So, it could be 120 to 80, it could be 110 to 75. So, these are all the diastolic regimes. So, it is the way it is being reported.

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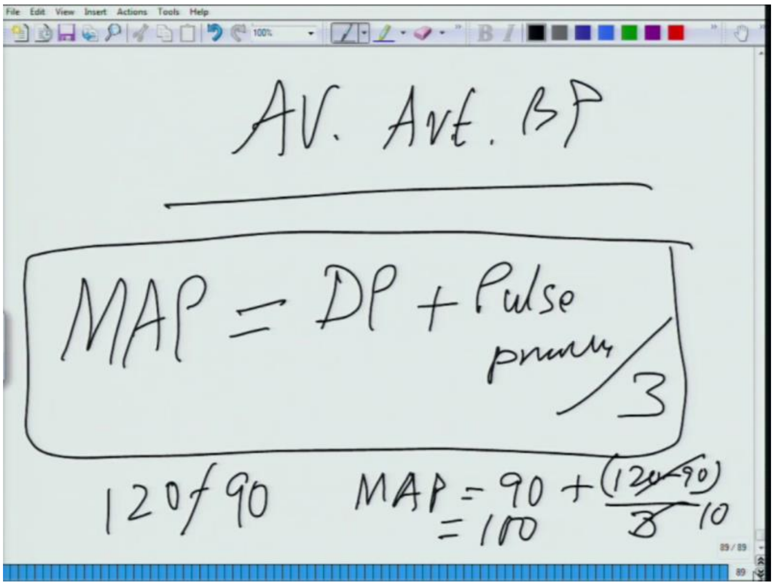

So, it is white is called as average blood pressure or average arterial blood pressure. Sorry, an average arterial blood pressure. This is basically the way it is or it is also called mean arterial pressure. It is equal to diastolic pressure plus pulse pressure divided by 3 pulse pressure is the difference between the diastolic pressure and the systolic pressure.

So, for example, you have somebody has say 120/90. The systolic pressure is 120 and 90 is the diastolic pressure. So, what you do is, you plug-in the formula. Mean arterial pressure will be 90, the diastolic pressure plus, so the pulse pressure here is 120 minus 90 which is 30 divided by 3. So, that becomes 10. So, the mean arterial pressure of this individual is 10 millimeter mercury. So, this is how the blood pressure is being reported.

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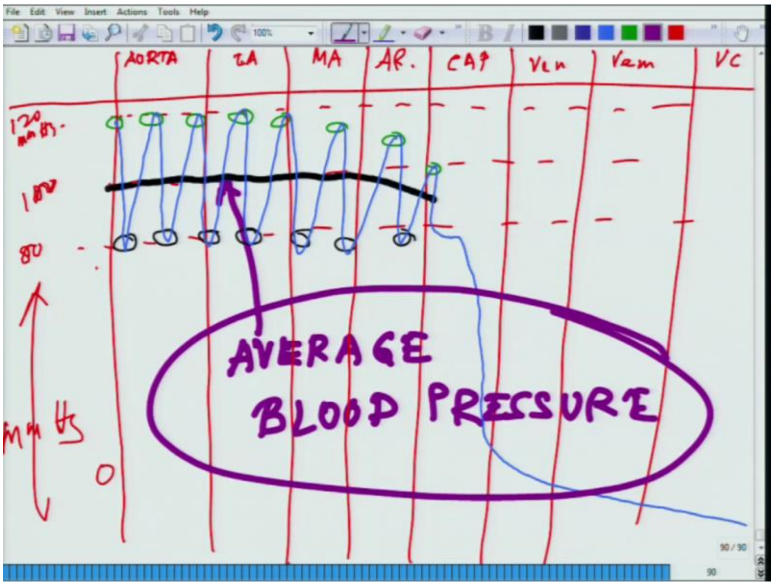

So, now, diagrammatically I have to show you this again. I will follow the same diagram that will help you 1, 2, 3, 4, 5, 6, 7. Here the aorta, here elastic artery, muscular artery, arterioles and we have the capillaries, venules, veins and vein cava. These are all the vessels in a sequence when comes back here, let me write it. So, the way it varies, this is 180 is the top line in the y axis and here, you have 80, this line here, 100 out here and likewise you can go down to 0 and likewise. So, this is millimeter mercury. The way it varies is something like this out here. So, it varies like this. So, this is what happens if you mark them with different colors.

Now, systolic pressure, the diastole and systole. Now, what I do is that I draw an average between the systole, other additional line. Let me draw it which is 80. This is the average line what I am drawing. This is your, one second. So, this is your average blood pressure. This is very important for you to understand what I was trying to verbally tell. This is how the pictorially it looks like. This is the average blood pressure actually what we measure from here. We move on to another very interesting term which is very important for us to understand is, one more thing here just for those of you who suffers from hyper tension or high tension is a situation when from this diagram itself I can tell you what that means is when this value from 120, it exceeds, it exceeds up.

So, your blood is moving really fast. So, there is always a chance when they say you do not get very angry, you are in a high potential mode. What happens is that blood is moving really fast because pressure is very high. Under that situation, there is always chance of hemorrhage and vice versa if you are a loop pressure person, you are sinking. It is here the pressure goes down. So, the blood is moving very sluggishly out there in to your blood vessel. So, these are the two extreme situations. Hyper tension is very interesting. I mean the module is such showing those who continuously take drugs on hyper tension actually suffers from hyper tension. You are taking drugs in order to bring down your movement of the blood along the vessel and eventually, you actually suffer from this kind of situation when you become a high potential. After a point of time your body kind of gets used to it and it just brings it down.

So, these are some of the things which may help you to you know see certain with physiological regime of certain drugs whenever we use from here. I will move on to one of the very interesting part which is called elastic rebound. What really is elastic rebound? So, let me try to explain it first and before I draw it or give you basic definition. So, one of the essential point is that the blood, the oxygenated blood from the left ventricle is pumped all over the body. The pressure is very high at that point of time. So, now how that pressure is being sustained, so that the blood flows to the capillaries which if you look back into the slides while I was showing diagrammatically.

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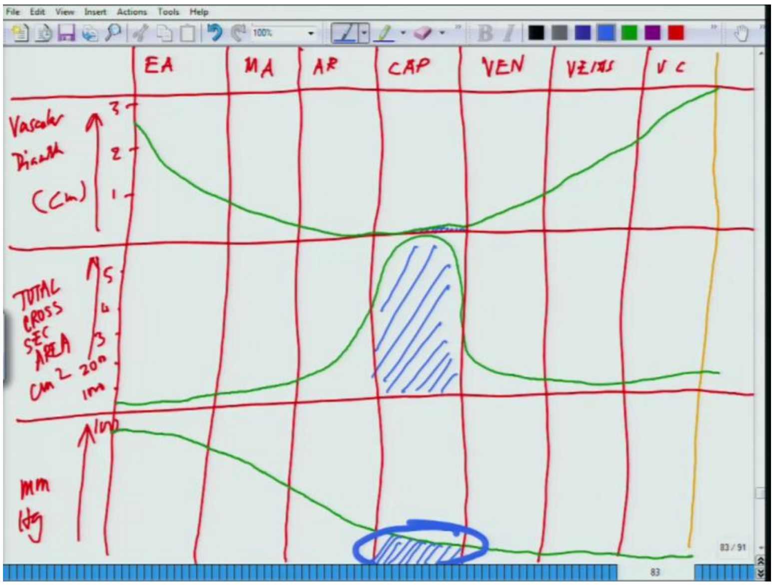

If you look at the velocity, the velocity goes down in the capillaries. Look at this go back. Further if you look at it, the pressure goes down in the capillaries and yeah, I think this is good enough point to make my statement. So, if these pressures are going down in the capillaries, how it is being maintained out there? So, even that much pressure, how it is being maintained? Pressure at the aorta, there is no problem. That is being maintained by something called elastic rebound. What exactly happens is that whenever there is systolic pressure, the aorta is kind of filled with blood. Now, blood is about to be pumped out and as it does, so it accommodates a significant amount of blood into these vessels and when it goes to the diastole, even the residual blood moves into the artery. It has a lot of elasticity to accommodate the additional amount of blood.

Now, it can accommodate. It is just like a pipe. It can accommodate certain things, but then what I do is I close the source. So, say for example, from the top the blood is coming out into these vessels. If this is the vessel, imagine this is vessel. Now, it is coming out, but it has a limit. It cannot really expand to beyond the point. So, then what I do is I close down. So, it cannot bounce back. Then, it has to exert its pressure. So, back towards the heart, it cannot because it is being closed because of the semi-lunar valve closes and once the semi lunar valve closes, the blood cannot flow back from the aorta to the heart. So, now, it recoils back, it generates a forward pressure and that forward pressure is nothing, but is called elastic rebound which is essential for the capillaries to function.

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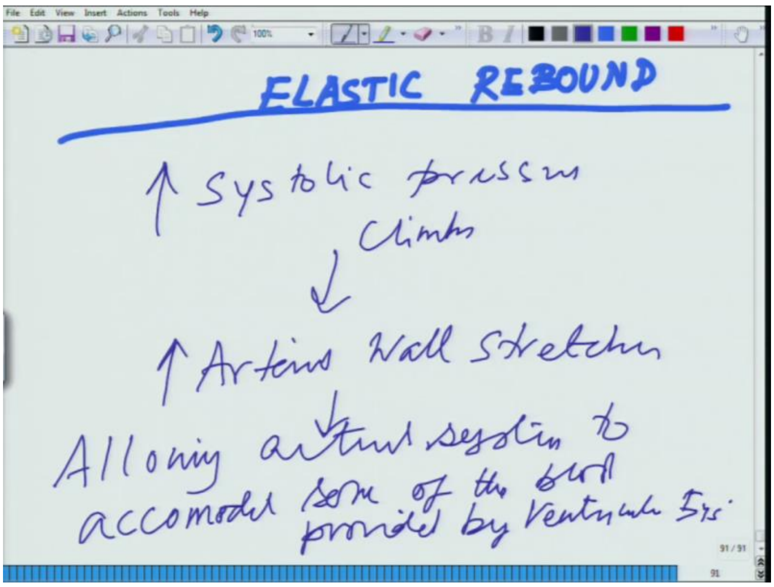

So, let me just put it in terms of the definition that looks like elastic rebound. Elastic rebound is essentially situation like this. There is an increase in systolic pressure claims. First step leads to the arterial wall stretches, then these leads to allow arterial system to accommodate some of the blood provided by ventricular systole.

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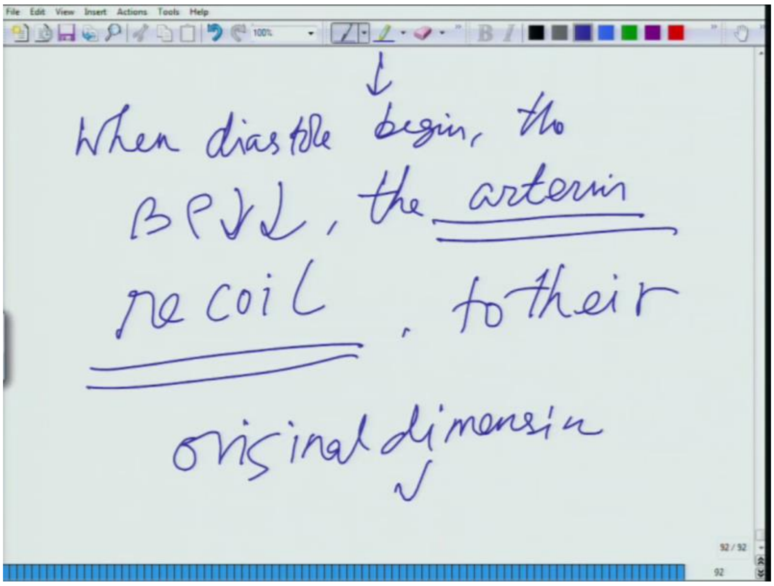

Next, let us continue when diastole begins the blood pressure falls as I have already shown you in the graph. The arteries recoil. This is highlighting point. The arteries recoil and the diastole begins to their original dimension. Now, when it has to recoil back to its original dimension, the aortic semi- lunar - SL stands for semi lunar valve prevents back flow of blood to the heart. So, what are your options? So, arterial wall recoil pushes blood in forward direction towards capillaries, and this phenomena is called elastic rebound.

This elastic rebound is exceptionally important for you people to understand that this is the one, which ensures the blood move, the pressure is maintained in the capillaries and one more thing I will just add here is the pulse is basically your rhythmic pressure oscillation that accompanies each heart beat.

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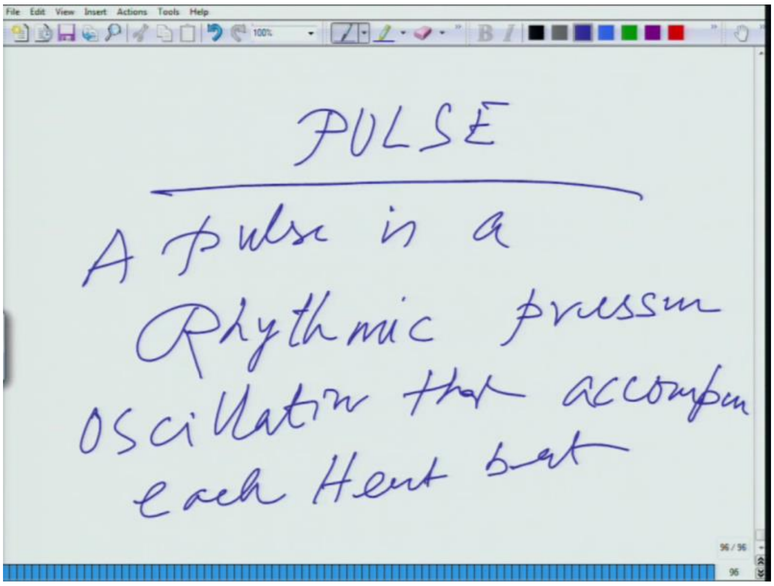

Then, the definition of pulse is essential here. Pulse is a rhythmic pressure oscillation that accompanies each heart beat, ok. So, this is I talked to you about the pulse pressures. So, this is essentially is what you people needed to know about the cardiovascular physiology, and it is as you go through all the definitions and everything that will make more sense that how all these things are related. So, what is left currently when we started, I gave you drawing saying that that we will be talking about all the control units. So, in the next class, what we will be doing? We will be talking about the capillary exchange and we will talk about the fatal circulation. So, that way we will conclude this section.

Thank you.