Human Physiology
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Lecture – 32
Excretory system : Regulation of Osmolarity and counter-current mechanism - Part 1

So, regulation of osmolarity and sodium concentration, so we are now going to talk about something very interesting and I just want you to follow through. We are looking at the kidney under two extreme conditions. We have done it once, I am doing it once again. What was one condition? You have the patient, the subject has taken one liter of water, lot of water. And then it is necessary that - then we are trying to in these two figures, we are trying to look at the journey of the fluid and keep on monitoring its osmotic value.

So, if I am in the cortex at the level of the ultrafiltration. The osmotic value of the fluid that is being filtered that is under filtration and also filtered 300 milliosmoles. How much it is? Osmolarity is just 300 milliosmoles. However, by the time the fluid enters into the, it goes to how much? How does it go to 600 is the question. Then it goes here and then by the time it goes back ascends, it goes to about how much? 100.

I am not giving any answer, I am only posing questions. I am inviting inquiries. Then by the time it goes here, it is 100, it is 70 and by the time the fluid is being thrown to the outside, what is osmolarity? What is osmolyte of blood to begin with? 300. Okay, means this kidney is capable of throwing a lot of water, make sure that it is dilute. Why do you want to make sure that it is dilute? Because you do not want to lose sodium.

You do not want to lose sodium. Had it not been diluted, had it been as same as blood, then this would also be 300 milliosmoles. And if 300 milliosmoles means how much of sodium will you be losing? And for humans, it is okay, we can supplement our sodium, but compare yourself to some deer or some animal in the wild, you see for the animals in the wild, not even that, even for the human population, adivasis which live in very rural areas, you know for them, it is very sad. For them, salt is a luxury. You do not get, salt is very important.

So you want to retain the salt. So when you take a lot of water, what is the challenge for you? Number one is to make sure that extra water goes away, make sure that the osmolyte of blood does not go down for long and number two, the sodium is not lost. The blood and the kidney is able to do that. Now we go to another phenomenon. What is another phenomena? The phenomena is - you are under dehydration.

Do not drink water for six hours and go out in the sun. What happens after six hours is this another scenario. To begin with is 300. By the time the fluid enters into the loop of Henle, into the U-turn there of the loop of Henle, what is the osmolarity there? 1200.

1200. Now this fluid is four times more concentrated than blood. Four times more concentrated. But then by the time it goes again, it is again how much? You would wonder what to make this, if you want to make it 100, why to make 1200 here? Good question. We will talk about it. And then 300 and then again water is absorbed, water is absorbed and by the time the urine is ready to be expelled out of the body, what is osmolarity? 1200.

1200. Okay. Which means what? You want to get rid of the solutes and the excretory products. But you want to conserve water. What is this? This is your typical physiological response to the stress to which your body is being subjected. What is the stress? The stress is that the osmolality of the blood is rising which you should actually replace by drinking water.

You have not been able to do that. Therefore, this is a physiological response. You want to conserve water, reduce the quantity of water and during the process increase the osmolarity. Okay. Just let us see what happens to the urine and the osmolarity.

Okay. To begin with, this is the under normal conditions, collect the urine and find out its osmolarity. It is about how much? About 600 milliosmoles. It is already concentrated in blood. Under very normal, ordinary normal intake of water, everything normal, 600 milliosmoles. Then at that point, can you see - written at the top what has the author given? What has the subject been subjected to? Drinking 1 liter of water.

And when you do that and then you keep on collecting the urine at 60 minutes, 120 minutes, 180 minutes, etcetera, urine collection. Okay. What do you find that the osmolarity of urine has fallen to how much? 50, 60, 70? Same as the previous diagram, very low. And it will remain low for about how long? 120, 150 minutes.

Okay. And by about 3 hours, it has gone back. So if you collect the urine after 4 hours, you will find it is osmolarity is again same. During that period, however, if you find that if you also keep on collecting the plasma osmolality to begin with, which was 300, it may fall to 295 or something like that during the same period. And again, it went back. It again went back to 300.

Okay. Our homeostatic mechanisms, okay, are making sure that just water is thrown away. Okay. What is happened to the urine volume? Not at all surprising, urine volume has gone up certainly, lot of it for that period. And then this is what urinary solute excretion that has also gone up.

Okay. Now, we have two animals in front of us, extreme animals, both mammals. You see, you know what has happened is in the course of evolution, as the animals came on land, they got off water and came on land. Okay. They had to face a different set of challenges. They had great solutions.

One great solution was abundance of oxygen, which is not true when you are in water.

Hello. You have to the moment again great, I mean, it is land is great, so much oxygen is there. But it comes with certain problems. One problem was the moment you step out of land, you start dehydrating.

Okay. So, how you conserve water depends on how successful you are going to be on the land. Are you with me? And two groups of animals which have been extremely successful, actually three groups of animals which have been extremely successful. Number one is of course insects.

Okay. Number two birds. Okay. And number three mammals. Okay. One of the reasons why mammals have been so successful on land, you would be surprised to know.

Okay. Lot of credit goes to anti-diuretic hormone and to this system - into that system, the earlier system. Okay. Where the mammals are capable of what? Conserving a lot of water and I am going to show you two extreme examples. One example is this Australian hopping mouse or also called as Australian desert mouse.

Okay. You collect the urine of this animal and this osmolellity is 10,000 milliosmoles. How much is it? Look, look, look. Blood osmolarity is 300.

Okay. Same, same, same. You see whether you are an elephant or a mouse. Okay. Blood osmolarity is going to be about how much? 300. Okay. When a human being excretes urine the best the kidney can do.

Okay. You can conserve water and make sure that urine is concentrated. You can go as far as 1200 milliosmoles. Okay. But this amazing animal can extract almost every, every, every, every molecule of water, very little water and the urine is so strong.

Okay. That its osmolarity is about how much? As a result that animal can live in water without drinking water. All it needs is number one, whatever water it takes by way of its food or its prey and the metabolic water. Metabolic water. What is metabolic? We generate a lot of water. You see every time you break a glucose molecule, you break a glucose molecule, what do you get finally? Carbon dioxide.

Carbon dioxide and? Water. Water. That is metabolic water. Are you with me? That is metabolic water. So that, that we do not care about it, but that guy cares. And he uses that metabolic water. As against that, now we go to the other end of the spectrum.

And this is a, this is a beaver that is an aquatic animal. That is a mammal that lives in water. And since the water is so abundantly available and adapted to water, this guy can concentrate urine only to about 500 milliosmoles. Now if you compare the length of the loop of Henle, loop of Henle, just compare the loop of Henle. Start from Bowman's capsule, go to the tip of loop of Henle and again come back to the distal tubule.

Humans are somewhere here. Those hopping animals are somewhere here. And that, that, that guy, beaver is only short. The capability to concentrate urine depends on actually on what? The length, the length and how it works that we shall, I will try to address shortly. What we will do with the human kidney? You know in the study of kidney, people have used a very, very simple technique, very widely used.

The technique is called a micro-puncture. What did I say? Micro-puncture. Micro puncture technique is, there is nothing a capillary. It is just a capillary, very fine capillary. You introduce that capillary in the Bowman's capsule, collect a sample and find out how much of sodium potassium is there. Then you do it in proximal convoluted tube with an interstitial space, they are made a different, you just collect samples and find out and then you can draw a huge amount of information, that is your data and you try to interpret it.

Now what you do is, you collect samples with your micropuncture technique. Make sure that you do not enter into any tubule. So you are always in the interstitial fluid. So from the interstitial fluid in the cortex, superficial level, middle level, deeper level, medulla, superficial, deeper, deeper, deeper, deeper. You go on collecting samples and you do the analysis and find out just the osmolarity and you get a very interesting picture.

You find that in the cortex what is osmolality of the interstitial fluid and then you go in the medulla and how much it becomes? Read there. 400, 600, 900, 1200. Only here 300, 300, 400. So as you go deeper into the medulla, the osmolality of the fluid goes on increasing. Now you should immediately ask a question, how is it possible? Is it a separate compartment from the rest of the body? How do you do it? I mean you see after all diffusion, must happen.

Equilibrium must be established. In spite of all those basic laws of physical chemistry which must bring about equilibrium, here is one compartment in your body where the osmolality is about how much? 1200. Why do not the solutes flow somewhere or why does not the water come from somewhere and establish equilibrium everywhere? Those are the laws of physics and chemistry. It should happen. Why it does not happen is a question I want you to think about and I will give you the answer.

We have done this. Do you remember what this is? Two kinds of, very good, two kinds of what? Two kinds of nephrons. One of them is cortical and the other one is what? Juxtamedullary. Okay. Now we will focus on juxtamedullary which over 15, 20% of the nephrons are of the juxtamedullary and these juxtamedullary nephrons play a very important role in generating that gradient which we saw in the previous slide. In another few slides, we are going to focus on very important, very important point.

That is the heart and soul of the kidney, heart and soul of the kidney, funny language. So here we have the, so I am going to talk about the what? Juxtamedullary nephrons. Are you okay so far? Now we find that, now let us be very careful about it. Here is the Bowman’s capsule, here is the pericapillary tubule and you go proximal, proximal convoluted tube and here the tubule goes, goes, goes, goes, goes, goes, goes, goes all the way, takes a U-turn and goes here. Are you okay so far? Now what I showed you just now is also indicated by the arrows there.

Can you see the downward arrows and then? Now going along with that is a certain part of the peritubular capillary network which also goes, accompanies this blood vessel which carries oxygenated blood goes along. So they are parallel, parallel, parallel, parallel, parallel and they are parallel. Are you with me so far again? So there are actually four tubes. There are four tubes, there are four tubes, two tubes go down, turn around and two tubes come up. Now I want you to look at the arrows in those four tubes and make your observation.

There in the, the flows are in what direction? Very good. The flows are in what? Opposite direction. The flows are in what? Look at the beautiful anatomy. This is, this you will get in mammals, okay. This anatomy is very critical. Now this, this system of blood flow which goes parallel, anti-parallel I can use that word okay to the loop of Henle is called as vasa recta.

What do I call it? Blood system is called as what? Vasa recta, this composite system plays a very important role in generating whereas the osmotic value here is about 300 milliosmoles, 500, 600, 700, 800, 900, 1200 milliosmoles. This anatomical system plays a very important role and how this system functions and achieves - to explain the phenomena, I will take you to this very interesting diagram. Look at the image on the left.

There is nothing special. We have done it 100 times, okay. Now what author has done is, author has cut here, cut here and you have two tubes. Are you okay so far? But of course we know that in one tube the fluid is going down and another tube the fluid is going up. We are ignore the rest of the part, okay. Why because the author is trying to give us the principle on which the whole system is based and that system is called as single effect in the loop of Henle. Now how that happens? Let us see that.

So I can show you the two tubes. So I have taken this tube, put it here, I have taken this tube, put it here and there is interstitial fluid everywhere and to begin with to understand the whole phenomenon, let us presume that there is salt everywhere, sodium chloride everywhere, equal distribution to begin with, okay so far. Now but we have made one change which you must remember. Is this tube equipped with aquaporins? Yes or no? Yes. Is the other tube equipped with aquaporins? No.

So with aquaporins, without aquaporins, okay. To indicate the difference, can you see what author has, what code author has given, he has made the wall thick. Hello, can you see what is the difference between the wall? Are the two tubes identical? No, one is thin and other is thick. Why has author given the thick one here? To indicate that the water does not go, okay and we know why water does not go. Why? Because there are no aquaporins, okay. In this system, the second thing which author has done or our biological system has done is on this membrane you give sodium potassium pump, okay.

So from here, so from here, follow the story, if you follow this you will follow everything. So from here, the ions will be pumped out. So along with the ions, the water will like to go. Can it go? No, after 5 minutes, therefore after 5 minutes you will get a picture in which less ions, but these ions, the ions which are in the cylinder and these ones, the aquaporins are here also, okay.

So there will be free exchange. As a result of that, fluid here is same as fluid here, but the fluid here is much dilute. Have you followed this point? So you have been able to create a difference, okay. In the descending tubule, ion concentration in the descending is same, but in the ascending tubule the ion concentration is same because simple you have not provided, you have done two things. Give lots of pumps and do not give aquaporins and you have been able to achieve this gradient.

Now move on. I will explain this diagram quickly. This is important because I want you to appreciate the importance of the loop of Henle. Here I have first simple starting point, everything is 300. We are trying to understand 300. Then as a result of the, we are now comparing this tube and this tube, there are pumps here, no aquaporins. As a result of that you will have 200 here, 400 here, are you okay so far? And the pumps are so much that they are competent enough to generate a osmotic difference of about 200 milliosmoles.

So it can generate, it was 300, 300. Now because of the pump, outside has become 400 and inside has become how much? 200. We are okay so far? Now we will go ahead and then, and then, and then, now something, so this is 200, 200, 200, 400, 400 has come to an equilibrium, okay so far? But do the fluids stay where they are? No, they go on flowing. So as a result of that, this 400 will go there. The beauty of the U of the loop of Henle, as a result of that you have 400 here.

But the pumps are working, okay. So once you go, so 400 here, 400 here, now because of that now again it will be 500 here, it will be 300 here. Go on repeating, go on repeating, go on repeating, okay. And inside at the bottom you will have 1200, 900, 800, okay, 600, 500, 300 in the cortex. Have you understood the entire principle now? This is called as counter current - beauty, absolute beauty of physiology.

We call it as counter current multiplier. What do you call it as? Counter current multiplier. And in the counter current multiplier, Vasa recta has a very important role which I did not discuss today. I will talk about it in the next class. Thank you.