Introduction to Exercise Physiology & Sports Performance

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Lecture – 31

Hydration and Fluid Balance (Part -1)

Miss Vanishri is a college student and she wants to take part in the Mumbai Half-Maratha next year. She has been trained by you since last month. She has heard about a commercially available sports drink from a friend and asked suggestions from you. As a trainer or a coach or a sports scientist, what type of fluid will you recommend for fluid replenishment? For the sports event, she is being trained what must be the composition of the fluid drink? What are the factors that needs to be considered for calculating the water and fluid requirements? If you are looking for answers to such questions, you have landed the right platform.

Welcome you all to this NPTEL course on introduction to exercise physiology and sports performance and to this module on hydration and fluid balance. I am here with you, Wing Commander Chandrasekara Guru. I am a sports medicine specialist and assistant professor in the field with the armed forces medical services. I shall share with you the medicinal aspects related to the hydration and fluid balance in this module.

So, in this module, you will be learning about the balance and the function of water, dehydration and its role in performance, electrolyte regulation in the body and during exercise, how do you calculate sweat loss and sweat rate and some pointers with respect to sports drink, the concept and what is the recommendation.

So, we know water is elixir of life. It does not have any caloric value. Still, it is the second most important thing next to oxygen for living. Why is it called so? Because human life can survive even up to 40% loss in body weight due to any macronutrients in the form of fat or carbohydrates or protein. However, with mere loss of 9 to 12% of body water, it can turn catastrophic and be fatal.

In the human body, water constitutes about 60% in a young man and about 50% in a young woman. When you see the relative composition in terms of fat free mass, it constitutes about 73%. Imagine three fourth of the fat free mass is composed of water and with respect to fat free mass, it varies anywhere between 20 to 50%. So, these variations or concentration of the body water in the body depends on the age. It varies with the gender, either male or female. They have different composition of body water and as well as the composition per se with respect to the fat free mass and the fat mass.

This water stays in the compartment in the body. Let us see what are the compartments. So, the bulk of the water constituent is located inside the cell called the intracellular fluid. This constitutes about two third of the total body water called as the intracellular fluid. The rest of the water stays in the extracellular compartment as extracellular fluid. Extracellular means outside the cell. So, it is located outside the cells of the body in this compartment as

extracellular fluid. This constitutes about one third of the total body water of the body and what all constitutes the extracellular fluid. In the previous module on cardiovascular system, we went through about the constants of blood. Plasma forms the major fluid constants of the blood. So, 20% is plasma in the extracellular fluid and remaining is by the interstitial fluid. What is interstitial? Interstitial is the space which is present between the cells. So, within the cell, it is called as intracellular and between the cell is the interstitial space. So various interstitial fluids are lymph, saliva, eye fluids, fluids which are secreted by the glands, by the gastrointestinal tract, fluids which is situated along the spinal cord as well as the fluids which are excreted by the kidney and the bladder as the urine.

What is the function of the water in the body? So, body acts as a main transport medium. So, everything transports within the body in the form of blood. So, in the blood is a liquid medium, right? The water constitutes major transport medium of the body and diffusion of gases happens along the moist surfaces and this again water is an important aspect of that. Excretion of waste products, all the waste products are excreted in the form of feces and urine and these have water and it is important to have adequate body water for this function to happen. And most important aspect is the regulation of body temperature. We all know that the body functions, all the enzymes and all the metabolism of the body functions within a range of thermo-neutral environment. So, the regulation of the body temperature is very critical for normal day to day functioning of various organs of the body. So, for this water plays a major role. Joint fluid, yeah, water is again present in joint fluid. So, with joint fluid there is a decrease in the friction, it causes lubrication of the joints. So, water plays a major role here too and it also is present in the tissues and the fat-free mass as we said earlier. So, that gives the turgor and the shape to the tissues per se. So, body water functions also in this aspect as well.

So having known about the various body function it is also important that we understand certain terminology related to water balance in the body. So, when you have a normal range of daily water variation that is termed as euhydration. Hydration is water, euhydration which is normal. You know, water balance is normal that is called as euhydration. Whenever there is a decrease in this level and it is a normal steady state, it is a new normal steady state then that is called as hypo-hydration. Hypo means lower. So, the hydration status is slightly lower and it is in still a steady state. It is not impairing the normal function. So that is called as hypo-hydration. When it progresses and leads to kind of a transient state where it can also impair the function then it is called as dehydration. And when the same you know hydration state, euhydration state it is increased. When the new steady state is more than the normal water content in the body then that is called as hyper-hydration. So, whenever we try to kind of bring the hypo-hydrated state to euhydrated state that phase is called as rehydration. You are rehydrating the body. So, this is a process by which by getting more water by various means by which you are increasing the water content to a set point. So that is called as rehydration.

Going further let us see what is the water balance in the body normally. Under thermo-neutral condition when the temperature outside is normal and you are not doing any activity or at rest the daily water input and output varies between 2.5 liters or so somewhere around that point. So, the water intake mainly constituted by drinking. So, we drink water right so it consists about 1.2 liters on an average. Additionally whatever food we take also contain water. So, the carbohydrates which we take the fat and the protein in different composition contains water and this again constitutes the daily water intake to the body. This obviously varies with respect to the change in the weather or change in the physical activity whenever your body temperature

increases this also increases. So, when we see the you know distribution the metabolism of the body constitutes about 350 ml wherein the breaking down of all the you know macronutrients and then leading on to water as a byproduct. We saw in the module of bioenergetics the final product is where the oxygen combines and then forms the water. So, this water constitutes about 350 ml fluid about 1.2 ml and in the food it is about 1 liter of water we consume every day. What about the output in terms of lungs? Lungs I would mean that when you breathe you also you have, we saw during the respiratory system module that whenever you inhale you kind of try to moisten the hair and bring it to the ambient temperature. When at ambient temperature accordingly the humidity is modified and then you the body in the external nostrils tries to kind of humidify this air so there, water is used. Again, when you exhale the water is also lost so this is through the lungs and that constitutes about 350 ml normally. The other important aspect is through skin where you have specialized glands called as sweat glands. So, you lose water through the sweat also right so that constitutes about 850 ml. In the feces also about 100 ml of water is lost and major chunk is in the urine normally at rest it is about 1.2 liters per day so that's the water balance during a normal day at rest with the temperature being normal. So, urine constitutes about 60 percent of the total water output from the body and at a rate of 50 to 60 ml per hour. So, interestingly the entire body water gets undergo circulation and then at the kidney level it is first excreted and thereafter during the process it is also reabsorbed.

So, finally you excrete in the form of urine only the waste products which is totally not required by the body said that the reabsorption of a more than 99 percent of water and electrolytes happens in the tubules of the kidney. So, that's one thing that we should know.

What about the water balance when there is a change in the temperature or when there is you know increase in the activity during activity so the input remains almost the same whereas with the output the output increases because the temperature has increased either ambient temperature because of the increase in the temperature outside or the internal body temperature because of the activity that you do. So, when you do the exercising muscle also undergoes metabolism and in the process of you know providing energy it is also releasing more and more heat so the temperature of the body has to be maintained so for that water plays a crucial role. So how do you maintain this, so, say you can roughly estimate with every kg of body weight loss you can estimate that about one liter of water is lost so how is this water lost so the major effect which happens is that we studied or we learned earlier in the module on respiratory system and exercise that when you start doing exercise you start breathing faster. So, the ventilation rate increases. So, obviously the humidification also increases. So, by which you also increase the output of water through the lungs. The other aspect is through your skin. So, majority of your water loss during such increase in the body temperature happens through skin that is through the sweat glands. The sweat rate can go up to one liters per hour in certain long, you know endurance activities. So, that is the kind of compensation or the adaptation that the body makes or the change the body makes to the change in the internal milieu or the increase in the body temperature by means of feces also there may be increase in the water loss so when you have watery diarrhea or you vomit so, obviously you expel a lot of water along with it, so, that again can contribute to increased water loss. And, by urine contrast to what happens in the rest period during exercise the water loss by urine is conserved. So, you need to, the body compensates for the loss which is happening in the sweat by decreasing the, you know, water loss by urine and it tries to conserve so that you don't get into a state of dehydration and increased body temperature during the process. And, more so one needs to understand that

whenever the solute is the waste product in the form of solute like urea, is excreted by the kidney it also carries some amount of water along with it, say generally, one gram of solute requires about 50 ml of water along with it so this why it is important because in case if you take high protein diet so obviously the breakdown product is urea right of high protein product so this urea when it is getting excreted it also carries some water along with it. It is important that when you take high protein diet you need to consume more water to normalize this particular water wastage during excretion of this urea.

What about the aspect with respect to the output during exercise? So, the water loss is predominantly through the skin and the lungs, as I said, it contributes more than 90 percent of the water loss during activity and the three factors which determine this one is the intensity of exercise if the exercise intensity is so fast and then obviously it will be more and as well as the outside temperature so you're doing activity you're doing an high intensity activity but then outside also the temperature is more so it is going to amplify the water loss and also the relative humidity. Humidity is the moisture content of the air which is outside. So, if that is also more then it will also affect your process of sweating so with every liter of sweat you release about 600 kilocalories of heat and that actually, kind of you know kind of, causes cooling by the process of evaporation from your skin by the means of evaporation of the sweat. So, for evaporation to happen you should have a normal humidity outside if the humidity is more so already the water content is high. So, obviously the evaporation is not so effective so the sweating also will not be there. So, that is the reason why you will have to also consider the relative humidity which is there outside when you are going for outdoor activities. So, you may not be able to appropriately maintain your body temperature and neutralize that, you know, heat loss. The other aspect is with increased water loss during the activity there is also a process of dehydration. You're losing water. So, the water content decreases. That's called as dehydration. It's a transient loss, right. So, with reduction in the water loss causing dehydration the performance also comes down. Why?

Because, let's see this, with increase in exercise, there is increase in addition, you also add another variable, there is increase in hot weather condition as well. In both these conditions there is increased fluid loss, so, as the fluid is lost from the body the plasma volume, which is available in the fluid for circulation, has come down, so, the decrease plasma volume causes a decrease in blood pressure. When the blood pressure goes down, we have seen that the blood flow to the exercising muscle as well as to the skin may be compromised. So, this can cause reduction in the heat dissipation mechanism. As a compensatory thing, we have read in cardiovascular system and exercise, that it's the, cardiac output is the product of heart rate into stroke volume.

Cardiac Output= Heart Rate X Stroke Volume.

So, here the plasma volume has gone down. That means the stroke volume has reduced. So, in order to compensate for a cardiac output, your body is trying to increase the heart rate. So, the heart rate increases. In addition, because of the decreasing heat dissipation, your body temperature has started increasing. So, how these two, kind of, contributes to decrease performance? We have already learned that increasing in heart rate will reduce your, you know, diastolic volume. So, the diastolic filling time is reduced. So, the volume is also reduced. So, ultimately your cardiac output is also reduced. So, in one side, on one side your body is trying to increase the heart rate to compensate for the decreasing plasma volume but because of the

increasing heart rate this adequate feeling is not there the time for the feeling is not there so because of which is again reducing the stroke volume. So, over a period of time when you continue the activity heart rate keeps on increasing so this keeps on coming down so ends up and decrease cardiac output so that will compromise your performance. Body temperature, as I said, every muscle's, you know, the activity, the metabolism, the enzymes which functions during the activity they all work, optimum, under optimum range of body temperature and that is deranged when there is increase in the body temperature the denaturation of these proteins can happen and that may lead on to decrease in the performance. So, even the dehydration of two percent of loss of body weight can result in impaired sports performance. So, let's take an example of a two percent would be like in a 100 kg individual, it comes to about two kg of body weight loss after an activity or in a 50 kg individual who is weighing 50 kilos the loss of body weight of even one kilo will uh you know affect his affect his or her performance. So, that's an important aspect that one needs to understand.

So, there are various, you know, evidence have proved that with increasing dehydration percentage in terms of loss of body weight there is increasing harmful effects, like two percent we said that it affects the performance, right. The performance effects may be in terms of reduced, you know, run time to exhaustion, so the time to which you exhaust, which used to be earlier, say for a for a say for a five-kilometer run, if it was 20, 20 minutes earlier, then that would have got a kind of increased further. So, that would have gone up, there is total work performed also reduces the work output comes down the work efficiency comes down. It is also seen that the attention and focus also will come down with respect to the skill aspect of the sport because of the reduction in two percent also the skill per se by the individual also comes down. When it further degrades to four percent of body weight, you start to develop the signs of heat illness. So, as the percentage of dehydration increases you find that the chances of progression of the heat illnesses is seen. So, with six percent you may have heat stroke kind of signs and symptoms. With ten percent it is seen that it can be very fatal also for the individual. So, that's the importance of avoiding this particular condition.

So, how do you assess whether you are having a normal fluid hydration or not? So, there are certain indices. So, one of the common indices which we have discussed till now is the percentage of body weight change. So, how do you calculate it? Before going to the activity, you measure the weight and then after the activity you measure the weight. So, by using the weight into this formula, you will be able to see the percentage body weight. The other important and easy way which is frequently used also in medical setup as well as in sports setup is urine color. So, we have seen in schools also educating the children to look for their color of the urine and so that accordingly they can keep themselves hydrated, right. So, urine color with with various colors you have different grades or percentage of dehydration that can be made and if it is light yellow it's kind of a lighter end of dehydration and with dark brown extreme kind of dehydration. So, accordingly, you can have grading of the hydration status. The third one is the urine specific gravity. Urine specific gravity measurement obviously requires a densitometer. So, based on that you can measure the urine specific gravity. If you are in a kind of a sports institute setup with a backing of a sports science faculty or a high performance, you know, team, then you can have a simple tool like a densitometer to assess the urine specific gravity of the individual. It's a very simple to use tool, wherein, you put the densitometer and it gives you the reading. So, if, if the well if you are well hydrated, it is generally, the urine specific gravity should be less than 1.010 and gradually if the if the specific gravity increases

that means your solute level has increased and the water level has come down right and that means accordingly the gradation of the dehydration aspect can be you know graded.

So, this okay, from external you'll be able to understand. What about the body, you know compensation? How the body reacts to the dehydration? So, whenever there is decrease in fluid loss, we've seen that there is decrease in the plasma volume. The other aspect is the, because of the decrease in the water content, there is increase in the concentration of the plasma. So, that's plasma osmolarity. So, the plasma osmolarity increases. When the plasma osmolarity increases, so, everything in the body has a range, normal range. So, beyond, or you know, beyond that range certain receptors are activated, you know, sensing organs basically. So, the sensing organs for this plasma osmolarity is the osmoreceptors, which which again stimulates the thirst in the hypothalamus, okay. So, however, as I've depicted the longer arrow, so that means the stimulation of the osmoreceptors, because of the change, detecting the change in the osmolarity and then stimulating thirst and then inducing you to making you to drink water that takes a lot of time. So, that, that is a sluggish process. There is also a backup feedback mechanism in the body wherein because of the decrease in the plasma volume we have certain receptors called baroreceptors. So, they address to the change in the pressure. So, that again causes stimulation of the thirst center. Then, this is also sluggish. So, because for this to happen you need to have massive loss of volume in the plasma. So, that that's when this particular backup mechanism gets kicked in. So, this sluggish process is not a useful kind of mechanism for you to wait for you to have the thirst sensation and then to drink water. So, it is always advised to drink before you have, get the sensation of thirst. So, that means that if you feel that you are thirsty, you've already undergone your, entered the stage of dehydration. So, as a sports person you don't want that to happen because the moment you get into the dehydration aspect, your performance is going to go down, right. So, there's no point of actually participating in the sports then if your performance is going down, knowing that you can prevent it. So, rehyderation during the exercise or after the exercise will help you in keeping the maintenance of the body temperature and it kind of increases the work efficiency and also the performance.

So how do you replenish? So, you can start it beforehand. So, we are thinking about prevention, right. So, we can prevent it by hydrating properly before the event. So, before the event you should be, you should not start the event in a state of dehydration. So, you should always be in a euhydrated state and it is advised that if your event is planned, three to four hours before the event, you take at least five to seven ml of per kg of your body weight. So, if you're weighing 50 kgs then you take at least 50 X 5 = 250 ml, at least three to four hours before. If if you don't have enough time. It is an early morning event, so you get up early and then you know have to get ready and then be ready for the event. So, just few hours are there. So, at least two hours before you should take half the amount of that particular advised recommended volume of water. During the event when you are going, you know already with the training aspect that this means the this is going to be the duration and the intensity of the event, right. The exercise that you're going to do, so, accordingly you should try to prevent dehydration by replenishing during the activity per se. So, that can be calculated based on how much you sweat, how much is the rate of sweating, what is the duration, what is the intensity of the activity that you want to do during the event and it is generally recommended as a thumb rule 150 to 200 ml every 15 minutes so this also has a scientific reason which we will come to know subsequently and after event. After event is once the event is completed, once you have done up with the event then you will have to rehyderate whatever the body fluid that you have lost. So, that's called as

rehydration process and this needs to be generally 150 percent of whatever the fluid loss that has happened. So, there is a way to calculate this also and we will see it subsequently. So, in this particular thing after the event when you're replacing it is not only the fluid that you need to take care of it is also that you should look after the electrolyte that has been lost during the event per se.

So, coming on to some practical recommendations, I would say, an important aspect that one needs to consider if you are thinking about fluid and water balance in your field of sports. So, it's a simple logic when the fluid passes, you drink, right, it goes to the esophagus and then it reaches the stomach and then from the stomach it has to it is a kind of a bag through which the the fluid passes and enters the intestine. When it reaches the intestine, it is in the intestine that the water gets absorbed and then enters the plasma. So, the final target is that whenever you replace fluid it should happen so in a short manner that it should be available in the plasma, isn't it? So, for that to happen, so, you need to kind of pass through the stomach at a faster pace that is called as gastric emptying time so the faster you kind of make the water flow through the stomach, the gastric emptying time is more. So, various factors affect this gastric emptying time. So, one needs to be aware of these factors, so that you can accordingly play around with the fluid and water electrolyte replenishment. So, temperature of the fluid that you take. So, if the temperature of the fluid is cold or normal room temperature this is going to travel faster from the stomach and it will reach the intestine for absorption. The fluid volume is more. So, volume obviously it is like a bag which I said. So, more the volume the flow will be faster right, it is a simple physics. So, the volume has to be at a certain level, so that there is movement of the fluid to the intestine. So that is the reason why we advocate every 15 to 20 minutes during the activity you will have to increase the fluid intake. Third one is the calorie content. The fluid which you are taking if they have macronutrients in it to provide energy, so that again decreases, because there is some amount of digestion that starts happening in the stomach. So, if that is kicked in so that process is kicked in obviously the movement is delayed. The other aspect is the concentration of the fluid that you're taking. So, if you have some solute into it and then the concentration is more, that again kind of you know, decreases the movement of fluid from the stomach. So, the ideal composition which with various studies they found that it should be between five to eight percent of the carbohydrate in the fluid and the third the other aspect is the exercise intensity. If your exercise intensity is beyond 75 percent, obviously the body is focused towards the exercising muscle to the demand that is there so the the gastric emptying is delayed in case of increased exercise intensity and pH is a very important factor. The normal pH has to be maintained for proper gastric emptying. Hydration level with reduced water levels the gastric emptying is further reduced obviously because of the decreased plasma volume. So, these functions are reduced, so, the reduced in a dehydrated state your gastric emptying is going to be delayed. So, these aspects you will have to understand. The other important practical consideration is, we discussed that the first, you know response to take place, it is it takes some time, it is sluggish. So, in order to activate it, it is found that with increase in the sodium content in the fluid that you take it stimulates thirst response. So, sodium again it increases the first response. So, that can be added to the fluid that you are giving. It also replaces the electrolyte. And, one more thing is, if your exercise is lasting for up to one hour, then it is not necessary to add electrolyte to it just increasing water intake is enough to replenish the water loss and there is also another important aspect in in case of overzealous you know athletes or coaches they try to kind of keep them in a super hydrated state so in that kind of attempt they try to drink more water. So, because of which what happens is the normal

concentration that needs to be maintained between the water and the electrolyte is lost. So, there is dilutional hyponatremia. So, sodium level is normal but then because of the increased water content, the sodium concentration decreases. So, this dilution of the sodium that leads to something called as decreased sodium levels in the body called as hyponatremia which may result in disorientation you know even in extreme cases confusion and coma also.

So, these are the practical recommendations with respect to maintenance of water balance. To summarize, we saw about the various functions and the balance which is maintained during rest as well as during exercise with respect to water. We saw how you know body kind of try to maintain the water balance during exercise and what are the compensatory mechanism that happens when you have dehydration. How dehydration influence performance, even with reduction of two percent of body weight. How it kind of impacts the performance and we saw about various grades of dehydration and their effect on the body. Then, various assessment methods as well, using the hydration indices. How one can identify this and we also saw about the various mechanism by which the body kind of address this condition naturally and how you can avoid this preventable condition by kind of replenishing the fluid the recommendation before the event during the event and after the event as well as certain practical points that one need to consider with respect to the gastric emptying and the addition of other constituents along with water and whether it is necessary for you know activity lasting less than one hour. So, these are the practical things that we discussed in this module.

So, those for those of you who are interested in further in-depth learning, I would direct you to go through the standard textbooks on exercise physiology and sports performance. Thank you.