Introduction to Exercise Physiology & Sports Performance
Wg Cdr (Dr.) Chandrasekara Guru
Directorate of Medical Services

Lecture - 07
Bioenergetics - Part 2

So, welcome back again to this NPTEL course on Bioenergetics. I am Dr. Chandrashekara Guru, Assistant Professor in the field of Sports Medicine, Armed Forces Medical Services. So, let us continue with Bioenergetics. So, you will be learning about the basic principles, energy currency, the systems, various factors that are influencing and the application of these in sports.

Let us revise what we dealt in the previous session. So we saw that there are three types of energy system which offers immediate, short term and long term energy replenishment. And we also saw that energy systems are based on the availability or non-availability of oxygen into anaerobic and aerobic. And the anaerobic pathways have the phosphogen system and the lactic acid system.

aerobic system is called as the oxidative metabolism. We also saw that the glycolytic system part of the anaerobic pathway wherein the glucose or glycogen enters the pathway and they undergo series of various chemical reactions by which you end up forming pyruvate in the cytoplasm and depending on the various other factors and the availability of oxygen pyruvate may enter you know in the anaerobic pathway wherein it ends up in formation of lactate. Or, if we and in this anaerobic pathway you see we saw that the net ATP gain is both three ATPs if glycogen takes part or 2 ATPs if glucose enters the pathway. and if pyruvate has adequate oxygen availability this pyruvate may get translocated into the mitochondria where the oxidative metabolism happens and this process of chemical reactions that happens in mitochondria are termed as Krebs cycle and electron transport chain. So, in this session We will be discussing in depth about the oxidative system and also various applications and factors that determine the application of these energy systems in sports. So, moving ahead let us focus on the Krebs cycle of the oxidative system. So, you can see the picture where the reactions happen in the mitochondria.

Let me show you in the slide, say you have here the pyruvate which is available in the cytoplasm and, this is entering your mitochondria if oxygen is available, and you also have the various other macronutrients. I had mentioned to you earlier that the fatty acid enters through the process of beta oxidation, and joins the glycolytic pathway; so, this is the place the fatty acid get converted

to acetyl CoA and enters the Krebs cycle. Similarly only in you know when the exercise activity is more than 90 minutes, as I have mentioned here the proteins are involved so the amino acids enters again as an intermediary component of the Kreb cycle thus all three macronutrients can enter this Kreb cycle and contribute in ATP generation. So, because of this factor, and it is the major or the predominant system for all kinds of low intensity activity, generally what we perform or even at rest. So, during rest also we have various bodily functions right. So, these are all you know addressed or catered by this energy system that is the oxidative system where all the three macronutrients can contribute in the energy generation. So here you have at rest about 70 percent of the contribution is by the fat, so the fat contributes 70 percent if you are at rest, and the remaining 30 percent is contributed from your carbohydrates; whereas, when you do some activity there may be reversal of the contribution with respect to carbohydrate and fat depending on the demand that is imposed by the activity, and the training that you undertake over a period of time. That will be dealt separately in another session. So we are speaking about the pyruvate along with the NADH. what is NADH? NADH is a byproduct during the chemical process and it is nicotinamide adenine dinucleotide so this also is shuttled inside the mitochondria. So, inside the mitochondria the pyruvate gets converted to acetyl CoA.

So, we saw that 6 compound glucose 6 carbon compound glucose was converted into 2 carbon G3P. Now, the 3 carbon pyruvate gets converted into 2 carbon acetyl CoA and 1 carbon is released as carbon dioxide. So, when we use our energy resource, finally we end up releasing the carbon dioxide as waste product. The carbon dioxide is formed in this process of energy system. Subsequently, you also have the fatty acids which enters through the acetyl CoA and proteins through the Krebs cycle intermediates.

The important enzyme that you should remember, there are multiple intermediates and various enzymes, the only enzyme that i would want you to remember in this krebs cycle is isocitrate dehydrogenase which will be again part of your questions. So, at the end of this particular Krebs cycle, the glucose molecule gets broken down to form two ATPs with NADH and two FADH2. FADH2 is another byproduct called as flavin adenine dinucleotide. FADH2 is another byproduct called as flavin adenine dinucleotide. Moving ahead we focus on the electron transport chain, so in the electron transport chain you know um this again happens in the mitochondria right so you are seeing this structure of mitochondria where you have two layers the outer layer and the inner layer so in the inner layer on the walls along the walls you have certain compounds called as cytochromes so that's why the presence of the cytochromes is essential for the oxidative metabolism and then it happens in the specialized structure called as mitochondria it doesn't happen in the cytoplasm and these are arranged along the inner wall of mitochondria and they the transfer of all this intermediaries and then final formation of you know water as an oxidation by oxygen in the last step is happening in the group of enzymes called as cytochromes. And the entire process wherein the electron gets transferred through the chain of reaction is called as electron transport chain.

So, at the end of this electron transport chain, the NADH which also got shuttled inside the mitochondria forms three ATPs, however it's an exergonic or an endergonic reaction where oxygen or the energy is also utilized for the transport. So, 0.5 you know mole of ATP is used here, so that's why mathematically you reduce that 0.5 from the 3 so you keep it as a net gain of 2.5 out of NADH. From FADH2 similarly, you have 1.5 ATPs, and calculated collectively at the end of oxidative system if glycogen enters you will get 33 ATPs, and if it is from the glucose it is 32 ATPs, because one ATP is used by glucose to enter into the cell. So let's calculate or see the energy yield in ATPs in a glucose molecule. So, by the anaerobic glycolysis at the level of substrate, you will have 2 ATPs formed.

Through the oxidative phosphorylation using NADH, you have 5 ATPs. In the Krebs cycle, you have substrate level 2 ATPs formed, and in the electron transport chain with NADH and FADH2, you have 20 ATPs. and three so on a total you will have 32 ATPs. So the net gain of oxidative like system if a glycogen is used is 33, as we have seen before now in case if it is a fat molecule say for example, palmitic acid which is the 16 carbon fatty acid, and if it enters into the Krebs cycle, and thereafter electron transport chain, it will end up in forming about 106 ATP molecules. So, that's huge right so that gives an idea to you like how the energy is stored in terms of fat, fat has the largest deposit of or storage of energy, in the fact that molecules are broken down you have excessive amount of energy; however, why you know there is a reversal during activity which i had mentioned before where the maximum energy is contributed by the carbohydrates. That is because of the rate of energy production, so carbohydrates have a faster rate of production energy production compared to the fats, so even though fat has a lot of capacity it cannot give you the ATP as you desire, so it takes some time, so that is the reason if the demand is low and the duration is prolonged fat becomes the predominant source of energy. So that's an understanding that you can have with the simple mathematics, so we saw that with duration and intensity these energy system interplay. Let's see how it happens, say the phosphagen system. It comes into play in the initial 0 to 6 seconds is the time duration for which it can cater. Phosphagen with the fast glycolysis, that is the anaerobic glycolysis, you can, you know, the energy storage can last for about 6 to 30 seconds. With an intensity in a scale of 5 will be 4, whereas for phosphagen it is 5 plus, high intensity, very high intensity.

Only fast glycolysis, if you see, the energy stores will be able to offer you that energy for an event lasting 30 seconds to 2 minutes, up to 2 minutes and with a moderate intensity of 3+. Whereas, if it is of still a kind of low intensity of 2+, and lasting beyond 2 minutes, then you have your oxidative also taking part in the energy generation, ATP generation. and if at all the activity is lasting say for beyond 3 minutes then and it is very low intensity activity then you have predominantly the oxidative system though I have said that you know with duration and this thing first the phosphagen then the fast glycolysis then the oxidative system it doesn't happen like that They are all interdependent and depends on the various other factors each one of them

contribute at various levels. it again depends on the rate and the capacity so if you you see the um phosphagen system the fast glycolysis system the slow low glycolysis is the you know growth cycle and thereafter the oxidation electron transport chain and the fats and the proteins the rate is very high in phosphagen but whereas it is very low in terms of uh breaking down of the facts whereas the capacity as we discussed is very high in facts however it is very very low in oxygen system so that's the inverse correlation between these energy system in terms of rate and the capacity so let's see about certain factors which may influence so as i said all those energy systems doesn't you know function individually they're all interdependent and they're dependent on various factors the factors Primarily hard divided into exercise, so depends on your duration of the exercise, intensity of the exercise and the training status. If someone is already trained will be in a better state to give you that the energy system, activate the energy system.

It also depends on the energy system per se, the rate and the capacity. The fuel has to be there for you to give the energy generation. So that again depends on the energy system. organs that are involved so the organs that are involved in the energy system are the digestion you have to break down the bigger molecules the GIT, the gastrointestinal system you have the liver where metabolism happens with the fat distribution which are the form of adipose store, and the cardiovascular system and the respiratory system for the aerobic pathway, the blood circulation happens and the oxygenation happens in the lungs, and the blood per se where the content of the blood hemoglobin transfers the you know transports the oxygen so the content of hemoglobin also may be a factor the the thinness of the blood also may be a factor. And also the muscle per se, the type of muscle which I had discussed earlier, different types of muscle have different energy system predominating. The type 1 will have more of an aerobic system, the type 2 will have more of an anaerobic system, accordingly the respective enzymes and the chemical intermediates.

So, the activity of these energy systems will be highest in the respective type of skeletal muscle. Coming to the metabolic factor, the substrate level here. So, it is what you consume to have that energy system kick started. So, it is the substrate, the products which are formed also which I have said in the law of mass effect. So, the product again controls the entire you know chemical reaction, and the enzymes certain enzymes are named and each and every system they are the key enzymes which controls, they are called as the rate controlling enzymes. So they control the rate of that particular energy system. These are various factors one need to know, so knowing all these process about this energy system, let us also focus on a small case scenario: say a college athlete is an 800 meter runner, he is able to finish in 2 minutes and 10 seconds you know, so i will ask you what you think is the predominant energy system that contributes to its sports performance? Just take a few seconds and then think over whatever you've learned. So what is the predominating system if this particular 800 meter run lasts for 2 minutes and 10 seconds.

So, it is not one single predominant system, it is mostly a fast glycolysis with oxidative system

because it is crossing 2 minutes, and around 2 minutes it is seen that the contribution of the anaerobic system is 50 percent and aerobic is 50 percent. So, what you understand from this is, when you start an activity, a high intensity activity, your energy transfer is from your anaerobic thing where the rate of production is faster. Meanwhile, the oxidative system is also catered and it takes some time to replenish the ATP generation. So, meanwhile this gives until 2 minutes and beyond 2 minutes, you see already the 50 percent contribution has come from the oxidative system. So, that is an important aspect to remember.

Let us go to another case. in the same individual you know that 50 50 is the contribution of anaerobic and aerobic system, so now if you are the trainer how will you train this athlete ? is there any logic or science behind this? Certainly, so both the systems have to be trained, so you will have to simulate both the systems by means of your training methodology. It is important to correlate your bioanalytics with your training methodology. So that's why I said as a gym trainer, a college athlete, or a working professional you should know what type of activity is required for you to achieve a certain type of sporting excellence. same anaerobic how do you train though this will be covered in detail in independent you know lectures I will just give you a hint of it. In anaerobic, you train by short bursts of sprints you know with increased rest intervals, because you need them to take a replenish so you need to give a prolonged rest interval so that the ATP gets replenished in the stores; and if you are training to aerobic, you will have to train at an LT range where different zones of training your LT training is the lactate threshold training, wherein you are reaching that anaerobic to aerobic or aerobic to anaerobic transition phase; so that means to be triggered so that is when you will have both of a anaerobic involvement as well as an aerobic involvement. Let us proceed further, the same individual you have stimulated both the system by training, so how do you think you can assess it and what is the relevance of the energy system in performance you know assessment. So, you have trained using anaerobic system using you know short duration activities. So, you will have to also assess using all out test, short duration all out test for assessing the anaerobic energy system. There if you want to assess it in the laboratory setup will be a 30 second Wingate ergometer test. If you want to test it in a field you can have a vertical jump test or a standing broad jump test.

The same aerobic system, if you want to assess them in a lab you can use a maximal treadmill test, or a you know submaximal cycle ergometer Astrand test, in a field you can use a very famous test which you would come across in cricket, Yo-Yo test can be used, or you can also use a something called as a beep test which is a very universally followed test across the world. So, you can also use a performance test. This guy is a 800 meter athlete, right. So, you can also time the performance and then you can assess it. So, these are the ways by which you can use the energy system to best of the scientific knowledge which you know to your sports training. To summarize, ATP is constantly replenished even at rest by all this contribution from various energy systems.

immediate is phosphagen, short term is anaerobic glycolysis or lactic acid system, and the long term is oxidative system. No activity is 100% contributed by a single energy system. It's all of a mix. The anaerobic system operates in the cytoplasm in the skeletal muscles called as sarcoplasm, and the aerobic happens in the mitochondria, and the rate is slightly low where oxygen is used in the final step. Fat oxidation has higher capacity, but limited in its rate of production, whereas oxygen has lowest capacity and highest rate of production. So, both sports training or exercise training as well as assessment depends on the energy system involved during that particular event. So, those of you who are interested in further in depth learning, you can consider going through these few books on sports and exercise physiology. Very standard books and those of you who also are interested in the kind of strength and conditioning, can go through this Essentials of strength training and conditioning, which gives you a brief idea and the relation between the training and the energy system. Thank you so much.