Introduction to Exercise Physiology & Sports Performance
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Lecture - 06
Bioenergetics - Part 1

Are you a gym trainer who is trying to train your client? Or are you a college athlete who is working for a spot in the university team? Or are you a working professional looking for some energizing exercises? Are you a sports person, who is looking for a better performance and performing better in the competition? If you are a sports person looking for more knowledge or scientific knowledge to perform better then here you are. I am going to cover in this session the secret of energy. We are going to speak about bioenergetics. I am Wing Commander Dr. Chandrasekara Guru.

I am a sports medicine specialist, assistant professor in the field with the armed forces medical services. So, I am going to give you a sports medicine physician's perspective on bioenergetics. And what you will learn in this session is basic principles. What is the energy currency of the cell? What are the different energy systems that are involved in giving you that energy currency? And other factors that would influence this energy system? And how do you apply this in your regular sports practice? So, moving on to the basics.

What is an energy substrate? We will keep coming across this word frequently in this session. So let us understand what an energy substrate is. Energy substrate is nothing but the fuel, the macronutrients which gives you the energy. They are carbohydrates, fats and proteins.
What is bioenergetics? Split the word bio and energetics. Bio means living, energetics is nothing but the chemical process that is involved in conversion of energy for normal cellular function of the living system. So, in order to know better or have an in-depth knowledge of the science of bioenergetics, we need to understand certain principles of thermodynamics. So, what is the first law of thermodynamics? It says that energy can neither be created nor be destroyed but then it can only be transformed. So that is an important aspect that we need to understand that energy can neither be created nor be destroyed but it can be transformed.

So, there are various reactions that happen to yield this energy, they are broadly classified based on presence of oxygen or absence of oxygen. If oxygen is involved in the chemical process, it is called aerobic. If oxygen is not involved, then it is called an anaerobic reaction. The two different types of energy that one needs to understand, potential energy and kinetic energy. What do you mean by potential energy? Potential energy is energy that is stored in a substrate.

What is kinetic energy? The word exactly depicts, it is the energy that is associated with any moving body. You can see an example of water stored in the lake or pond or in a dam. And when the dam is open, you end up having a waterfall. That energy which is stored as potential energy in the dam gets converted or transformed into kinetic energy when it falls down.

So that is an example of potential energy and kinetic energy and how the energy gets transformed. There are two types of exergonic and endergonic reactions. This is basically dependent on the energy that is released during the reaction or absorbed during the reaction. If the energy is released as a process of transformation from potential energy to kinetic energy, it is termed as an exergonic reaction. Or if the energy is absorbed into the reaction from the environment, then it is called an endergonic reaction.

There are certain substances which hasten up the process of these reactions. Those are called catalysts. All of us would have studied in our chemistry classes. Catalyst is the substance which hastens the chemical reaction. In our living body, the human body, it is the enzymes that act as the catalyst.

We also need to understand what is the second law of thermodynamics. When energy transforms from potential energy to kinetic energy, we see that energy is either absorbed or released. But then, there is also some amount of energy or a domain of energy that gets, you know, becomes unused during the process. And that is not actually used in any kind of transformation. So that particular energy which is not used is called as entropy.

I can explain to you with an example. See, you use a battery cell in your torch light, right? So the battery cell, you had put it in your torch light and then you have not switched it on. And then the torch switched off. So even after say 7-8 months, when you try to use it, you will not find the torch light getting on. That is because the energy which is stored in the battery as potential energy has never been used and that unused energy which got wasted, that's called as entropy.

So, that is an example of entropy and it comes under the second law of thermodynamics. So, having had a basic idea about the various principles and the concepts that are involved in bioenergetics, we need to understand why we need energy after all. The biological functions that are required are, you need to eat all the macronutrients in the form of energy substrate and these have to be digested by the body, broken down into smaller molecules and thereafter they need to be transported. To the blood to the various cells to perform the function. All the transport and the transmission of the nerves and the secretion of various enzymes and other aspects also requires energy.

Finally, you also need energy for any kind of movement that happens or also for various tissue synthesis. As we physiologically, as we grow, there are various tissue repair process that happens

in the body which keeps on going 24x7. So these aspects of the biological system require energy. Moving on to what is that currency. Say you know that in India it is the rupee that is the basic currency and if you go to US, dollar or Europe, it is the euros.

Similar to that in the human body, the energy currency is adenosine triphosphate. What is it? It is a chemical compound which is the basic form of energy currency in your body. So, it is an adenosine compound which has three inorganic phosphates, and thus forms the adenosine triphosphate. So how does it release energy? The adenosine triphosphate combines with water. The process is called as hydrolysis, by which one of the phosphate bond which is attached to the molecule gets cleaved off.

These phosphate bonds are high energy bonds. When they get cleaved off, they release a quantum of energy and that is approximately amounting to 7.3 kilocalories for 1 mole of ATP. And, the scientists have measured it within the cell and have found that it is approximately 10 kilocalories within the cell. So, this adenosine triphosphate gets hydrolyzed from adenosine diphosphate and an inorganic phosphate.

In the process, it releases energy and this energy is utilized by your various bodily functions. But then, this is not a unidirectional reaction. The reaction also happens the opposite way as well. So, whenever you need energy ATP is broken down. Whenever you eat and complex molecules are broken down into simple molecules this particular energy is stored in the form of ATP.

Wherein ADP combines with the inorganic phosphate and then it forms the ATP molecules. So, the ATP production involves two broad categories which I had mentioned earlier. Without oxygen it follows the anaerobic pathway, and if oxygen is involved in the chemical process it follows the aerobic pathway. How is it stored in the cell? So, ATP is the basic you know denominator of the energy in the cell and the storage is very limited. In an individual who is weighing about 70 kilograms, the normal storage of ATP that is available is only 80 to 100 grams.

So, how which can only last for a few seconds for your activity. So, this needs to be replenished you know seamlessly so that the activity can continue without any hindrance and energy is available throughout. So, how does that happen? That happens by the process of ATP generation involving various macronutrients. Let us see one by one. So, we said that carbohydrate is one of the important energy substrates.

It is one of the macronutrients. It is formed of carbon, hydrogen and oxygen atoms and it constitutes about you know 60% of the total diet that you eat and this complex molecule is broken down, digested and then thereafter converted into simplest compound called as glucose. Majorly glucose which we will focus here in this session. So, this glucose further gets you know chemically

processed through a series of chemical reactions called as glycolysis. Glyco means glucose, lysis means breaking down.

The glucose is now further broken down and it undergoes various chemical processes to form ATP. This is one of the pathways. So, when energy is not required at that point of time or you have excess glucose that is available from your food, what is done with that? It is not excreted. It is then stored by our body. It is stored in the liver and muscle as glycogen.

The storage form of carbohydrates in the liver and muscle is called as glycogen, and that particular chemical process is called as glycogenesis. Glyco means glucose related, genesis is just accumulating. So, its storage form is glycogen. Whenever there is a need, these storage forms are taken from the muscle and liver and used in the glycolytic pathway and that process is called glycogenolysis. Split the word and you can easily remember glycogenolysis.

The next macronutrient or the energy substrate that we have is the fat. Fat is about 15% of your normal balanced diet, and the simplest molecule that fat gets broken down is the free fatty acids. These free fatty acids undergo a series of chemical processes called as beta oxidation and enter the glycolytic pathway. Thereby they end up in the ATP generation. Again, they can be stored in the body as lipid stores or also called as adipose tissue and the process is called as lipogenesis.

When we are in need, they are again broken down to release free fatty acids and that process is called as lipolysis. Similarly, with the proteins which constitute about 25%, they end up into smaller molecules called as amino acids. More than 20 amino acids that are available. So, these amino acids, again few of the amino acids, not every amino acid, they enter into the process of glycolysis to form ATP generation. The same amino acids are used in the term, for the various building up of body protein in the storage form.

Whenever it is required, and mind you, apart from the carbohydrate and fats, proteins form the last source of macronutrient. When these two are not available or you end up in an activity which is so prolonged that you need more energy and you have not taken anything from external source. Then the protein comes to rescue and they break down the body protein and then give you the energy that is required. So, when you calculate, when you speak about energy, energy is measured in terms of kilocalories. So, we need to quantify how much is the amount of energy that is finally generated from each macronutrient.

So, carbohydrate is one gram of carbohydrate can finally yield you up to 4 kilocalories. With respect to fats, about 9 kilocalories, and with respect to proteins about 4 kilocalories. So, knowing about the basic, you know, broad idea about the process of chemical breakdown of complex substances or the macronutrients into simple, utilizable form of compounds and thereafter further generation through chemical process to produce ATP. Now, we will understand what are the

different energy systems. So based on the need, so everything depends on the need, right? So, we will equate this energy systems in terms of say requirement of money for some kind of expenditure that you would look for.

So, something like immediate requirement, the immediate energy system which can provide you without much hassle. Then you have the short term. Short term is for a certain period of time wherein again you can lend on loan for your activity. This is short term. In the long term, so you need investment for some long, big projects.

So, you need to look out for someone who can lend you a loan over a period of time. So similarly, the energy systems are immediate, short term and long term. So again, you can classify the energy system broadly based on the involvement of oxygen in the pathway or not. If oxygen is not involved, then it becomes anaerobic pathway as we had discussed earlier. The entire energy system of the, you know, anaerobic pathway happens in the cytoplasm of the cell.

So, you would have studied about the basic, you know, component of the cell and cytoplasm forms the base of granular material in which all the organelles float. So, these reactions are happening in the cytoplasm of the cell where the oxygen is not involved. So, what are the conditions when you use anaerobic system of production of energy? That is, when the intensity is very high and you need immediately, the duration during which you will have to perform the activity is very less. Then you use anaerobic energy system. Whereas if oxygen is available and you have adequate time or the, you know, the activity that you need to perform is over a period of time and the intensity is not that much high, then your body, you know, rely more upon the aerobic system.

The aerobic system generally happens in the specified cell organelle in the cell called as mitochondria. You would have studied about the powerhouse of the cell, mitochondria is the powerhouse of the cell where all the aerobic energy chemical reactions happen. Further if you see the anaerobic system is further divided into based on the rate at which the energy is available. If you want, as I said, if you want for immediate, then you rely on something called as ATP-Phosphocreatine or phosphagen system. And if you require energy at a faster rate, but then, you know, over a period of a few seconds, then you rely upon anaerobic glycolysis, the end product of anaerobic glycolysis after undergoing the chemical process is the lactic acid and hence; the other name of it is lactic acid system. Coming on to the aerobic side, the aerobic side, you have the aerobic glycolysis where the glucose gets broken down to form ATP generation through a series of chemical reactions and that is called as oxidative metabolism, which happens partly in the cytoplasm. And after that, if oxygen is available, the compound enters the mitochondria and there the further reaction happens for ATP generation. So let us go to basics. So, that is a 3D model of mitochondria when it is cut open. So, you have an outer layer and an inner layer which is kind of convoluted.

That is a 3D model of a cell where you find the nucleus surrounded by various cell organelles or the plasma. So, that is the plasma and these are the mitochondria which are interspersed in the plasma around the nucleus within the cell. So, the aerobic system happens in the mitochondria and the anaerobic system happens in the cytoplasm. Let us move on to the energy systems. So, we discussed about the immediate system of the anaerobic pathway that is the phosphagen system.

So, the chemical reaction is shown here wherein the name implies ATP phosphocreatine system. So, this is a simple ADP which is adenosine diphosphate. There are only two phosphates in this ADP molecule. It combines with the phosphocreatine.

If you see the symbol, phosphocreatine (PC). That is one phosphate atom in that. So, the phosphocreatine is cleaved and this phosphate joins with the adenosine diphosphate and then forms the ATP and the byproduct called as creatine. So, this particular reaction is mediated by what you call as an enzyme called as creatine kinase. And this system is the simplest energy system that is available in the body and is the most immediate as I had mentioned earlier. And since the phosphocreatine again has a bond which is high energy phosphate bond.

Equation (ATP-PC system): ADP + CP = ATP + C

So, this is a source of again another high energy phosphate bond which gives you the additional energy when in need. The reaction again as before similar to ATP it is bidirectional. So as per the requirement the reaction can go either way. There is something called as law of mass effect that is dependent on the available mass of the product or the reactant.

The reaction can go either way. When you find the increase in the mass of the reactants say for example production of ATP, it negatively sends a signal thereby there is reduction in the process of the reaction. Say for example if the product reduces there is reduced number of ATP. So, you are doing some work ATP which is stored has been utilized. So naturally the ATP has gone down.

So, this also causes increase in the ADP. This ADP again causes a trigger on the reaction so the products are again formed. So that is a continuous feedback loop that happens in the body. The storage is again 4 to 6 times more than the ATP store. We saw about 80 to 100 grams of ATP store. Now it is slightly in a next store of ATP is in the form of phosphocreatine and that is about 4 to 6 times more.

And more so they are present in type 2 skeletal muscle. The various types of skeletal muscle broadly type 1, type 2. Type 1 is more focused on aerobic reactions. Type 2 is more on the anaerobic capacity. So in case of sprinters or in case of short duration activity like swimming for

50 meters, they require type 2 muscle. And in this type 2 muscle these reactions happen at a faster rate so you need immediate responses or release of energy.

That is why it is more present or stored in type 2 skeletal muscle. And again, this is limited only to a very short period of time that is immediately between 3 to 15 seconds only depending on the intensity of the activity. So, one important thing that you should remember here is individuals who have more composition of type 2 by birth or by because of their sports training into the type of activity they perform say for example powerlifters or shotput throwers. So, their activity involves a lot of type 2 muscle activation and training. So, their type 2 muscles are more so their replication of ATP is faster through this phosphagen system. That is why they could perform the immediate explosive activity at a better efficiency compared to someone who is a marathon runner.

Marathon runner naturally has to undertake a long duration activity so you will have more of type 1 type of skeletal muscle. Moving on to the glycolytic system that is the short-term glycolytic system of the anaerobic pathway that is called the fast glycolytic pathway or the lactic acid system. Wherein if you see the chemical reaction starts with the glucose molecule. So glucose molecule is you know finally formed and it is transported via the blood to the required skeletal muscle or the exercising muscle.

When it reaches there, it has to go inside the skeletal muscle. So, going inside the skeletal muscle or transporting of the glucose from the blood into the skeletal muscle requires some energy. And here one ATP is utilized for pushing the glucose from the blood into the skeletal muscle. Whereas we also studied or learnt that glucose is already stored in the muscle and liver in the form of glycogen which is excess. So, this glycogen is also available in the muscle so it is already inside so it does not require that extra additional ATP to go inside the muscle. So, either of these molecules can enter the glycolytic system and the capacity is better compared to phosphocreatine because it is of limited storage and the rate obviously is slightly slower as you relate with the phosphocreatine system.

So, that is why once you have exhausted the phosphocreatine system next comes in place is the glycolytic system from the anaerobic pathway. So, either of these molecules get converted into glucose 6 phosphate by again consuming one molecule of ATP. And this particular reaction is called as we have discussed in the initial basics called as an endergonic reaction where the energy is absorbed for a chemical reaction. So now G6P further gets cleaved into two different molecules as G3P and G3P. So, glucose 6 phosphate gets converted into glucose tri phosphate and glucose tri phosphate.

So, two molecules of glucose tri phosphate. And this particular activity is controlled or catalyzed by phospho-fructo-kinase enzyme. That is an important enzyme that you have to remember. So again, through various series of chemical intermediary compounds which I am not you know

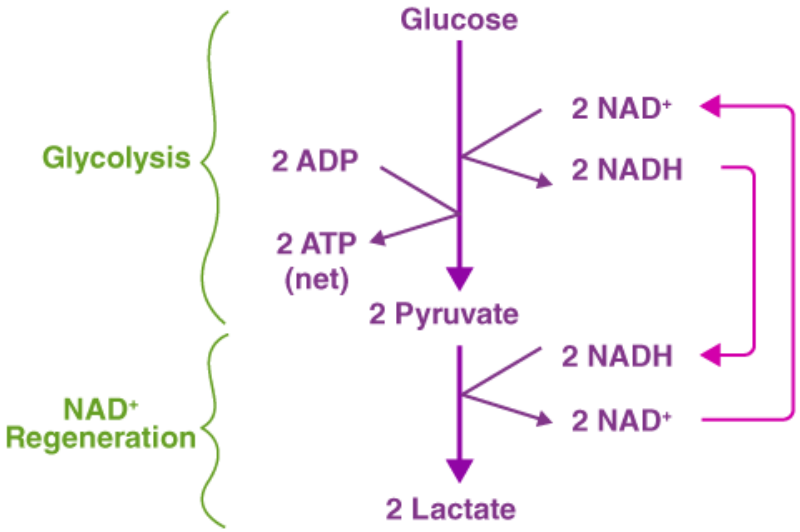
depicting here final product which is formed is the pyruvate. Pyruvate is the final product. And this pyruvate now can enter into the cytoplasm only and already the reaction is happening in the cytoplasm.

So, the pyruvate either can remain in the cytoplasm and enter anaerobic route or if oxygen is available and the demand is not that much this pyruvate can enter the mitochondria or aerobic pathway. So, pyruvate is the intermediary compound which can enter into either the anaerobic pathway or the aerobic pathway. So, in both the glycolytic cases the initial reaction that I have shown is same. So let us focus on the anaerobic pathway as of now.

So, when we focus here the pyruvate is already available in the cytoplasm. In the cytoplasm because of the increased demand and you know in case the reaction or the activity that needs to be done is explosive in nature or it has to be done immediately with reduced time. So, there is not much of you know rate of reaction that can happen through the aerobic. Immediately the body has to supply the ATPs. That is done by conversion of pyruvate into lactate, by lactate dehydrogenase. So, by undergoing this process what is happening? The glucose or glycogen have consumed 2 molecules of ATP and then they form 4 molecules of ATP in the entire process.

So thereby, at this level only you have plus 2 ATPs that are available. So, 2 ATPs are formed at the end of anaerobic glycolysis immediately. So now it has finally got converted into a end product called as lactate. What happens to this lactate? That has been an important aspect of sports science and sports medicine especially in exercise physiology and it is rated well in terms of your training and the assessment of training and the you know prescription of various exercises as well. So, this lactate earlier was thought to be a reason for fatigue. What do you mean by fatigue? Fatigue is when you reach that level of tiredness where you feel that you cannot further perform your activity.

Equation: Anaerobic Glycolysis



That is called as fatigue. So earlier it was thought that lactate was the reason for fatigue. With researches it has been found that the lactate is also used as energy substrate by various other cells. Lactate is used by the neighboring skeletal muscle. Lactate is used also by you know in the liver it gets converted and then finally it is also used by the heart cardiac muscle.

So, lactate is also a source of energy somewhere. It is not a reason for fatigue. Then what is the reason for fatigue? The scientists have postulated that the reason for fatigue probably because of the compound or the accumulation of the acids because of as a result of the as a waste product of the chemical reaction. So, increasing the acidic activity as such you know inhibits various enzymes that are involved in the process. Also, it reduces the calcium binding capacity. So, that also causes reduction in the movement generation in the skeletal muscle.

So, these intricacies you will come across in the skeletal muscle module. These will be dealt separately. So, these are the reason why there is increase in the metabolic acidosis which may would have again kind of postulated as a reason for fatigue. So, what about the blood lactate levels? How they are utilized in sports science? So, blood lactate level gives you an idea about the exercise intensity. If you are an untrained individual, you will generate blood lactate at an earlier phase. So as and when you get trained over a period of time the time taken for you to generate the required blood lactate level that is indirectly a sign of you know fatigue is postponed.

So, that is one of the good indicator for you to design an exercise training program also to kind of know the performance level within same level of athletes that are available in a group. Also, blood lactate can be used as a indicator to identify the recovery status. So, at the end of anaerobic glycolysis the net ATP gain if glycogen is involved is 3 ATPs because it's already in the skeletal muscle it doesn't use that one extra ATP. If glucose is utilized then the net ATP gain is 2 ATPs.

So, if the pyruvate enters the aerobic pathway, it enters the mitochondria where it undergoes a series of oxidative aerobic pathway named as Krebs cycle and electron transport chain.

So, we will see about the oxidative metabolism in the next session. To summarize, whatever we have covered as of now we have discussed about various basic concepts that are related to bioenergetics. We dealt about the laws of thermodynamics, the energy transformation and the entropy concepts. We learnt that energy currency is the adenosine triphosphate and we saw the various ways by which or chemical process by which the ATP generation happens and the breaking down process, the storage compounds and the reactions names and the different energy systems and we covered in depth about the anaerobic energy system namely the phosphagen system and the fast glycolysis. Thank you for now.