Overview and Integration of Cellular Metabolism

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Lecture 54: Integration of Metabolism I (Cellular and Organ level integration)

Hello everyone, welcome back to the lecture series sessions of NPTEL, Overview and Isntegration of Cellular Metabolism. Now, till date what we have completed is the overview of metabolism, overview of all the biomolecular metabolism like carbohydrate metabolism, lipid, proteins, amino acids as well as nucleotide metabolism. Now, in today's class we are going to start integration of all these metabolism, how this integration occurs in our body. The concepts here will be covered are the integration at both cellular as well as tissue level, then metabolic profile of different organs that important organs are like brain, heart, liver and adipose tissue. Also the metabolic profile of skeletal muscle both during rest as well as exercise. Next we will proceed to the different metabolic status in our body, how the metabolism occurs in well fed state as well as how it is adapting in during fasting as well as starvation.

Then we will discuss metabolic control analysis. So, let us start now what is metabolic homeostasis? Remember in our body the human body or the all the cells of every species every animals they depends on energy which they obtain from nutrients. Most of the organisms or human here important we obtain energy via oxidation of different nutrients. Now, those energy either can be utilized based on the requirement or can be stored for further usage for that can be derived from the stored storage on demand.

As well as energies can be utilized for synthesizing different biomolecules. Now, that is the homeostasis or balance. So, metabolic homeostasis or calorie homeostasis talks about the balance between need and mobilization of stored energy. Now as I have told you the overview or the different metabolic reaction for all the biomolecules like carbohydrate lipid, protein, nucleic acids. They take place in different cells and cellular compartments of specific tissues and organs.

Now what are those different types of metabolic pathway? So, metabolic pathway can be grossly of two types catabolic and anabolic and of course, there is a mixture or in between metabolism that is amphibolic pathway. Now what is catabolic pathway? You

must be knowing it still I am revising it that catabolic pathways are where the energy rich complexes or macromolecules they are degraded into the smaller molecules and during this process energy is released and that released energy is trapped as a inside ATP that is the energy currency in our cell and as well as different high energy phosphates or high energy molecules in our body. So, those are the storage of energy. Now anabolic pathways are basically utilization of those stored energy. So, that is energy investment.

So, what happens that in anabolic pathways cells synthesizes molecules. So, catabolic was degradation and anabolic is the biosynthesis where energy is invested the stored energy is invested or the energy in different biosynthetic molecule can be stored as well. Now amphibolic pathway is the in between of these two that is in different amphibolic pathway like very one very important you all know TCA cycle their catabolism as well as anabolism both occur. Now the nutrients their degradations occur in three stages first is the primary metabolism that is about digestion. So, basically in the first stage what happens the nutrients are digested in GI tract and then absorbed in smaller units.

Now those smaller units undergo secondary or intermediary metabolism how? Now those absorbed product they have been already catabolized in smaller components during intermediary or secondary metabolism they are more degraded and ultimately oxidized to form carbon dioxide and in this process what is formed reducing equivalence like NADH, FADH2 these are the reducing equivalence which are formed during intermediary metabolism. And finally, tertiary metabolism where this reducing equivalence are utilized in cellular respiration which occurs in mitochondria in the mitochondrial respiratory chain or electron transport chain where finally, synthesis of ATP occurs. So, these are the major metabolic pathways occurring in our body related to carbohydrate metabolism you know glycolysis, glycogenesis, glycogenolysis, then neoglucogenesis minor pathways like HM patients, uronic acid pathway or lactose synthesis or lactose metabolism rather. Then related to lipid metabolism there is fatty acid synthesis as well as fatty acid oxidation, lipogenesis like phospholipid triacyl glycerol formation, cholesterol formation as well as their degradation lipolysis, then ketone body synthesis ketogenesis or their degradation ketolysis. And finally, in protein metabolism we talk about both protein synthesis as well as protein degradation like proteolysis, amino acid oxidation and the excretion of urea in urea cycle how urea is synthesized.

So, these are the major metabolic pathways we have already discussed. Now how they are integrated in our body is actually what we are going to discuss. So, that is integration of metabolism that all these anabolic and catabolic pathway they are present and they are occurring synergistically in a cell. So, basically all these pathways are actually happening at the same time in a cell. So, they are synergistic, they are interdependent

linked with each other closely interrelated and they are well coordinated and regulated by different regulatory signals in our body.

So, that is integration of metabolism that all these metabolism all these anabolic and catabolic pathway in a single cell they are actually occurring synergistically with coordination or relation to each other and they are regulated by some common signals. So, that is interdependence. Now why this integration is basically required what is the importance or significance of integration of all these pathways. So, basically that integration is required for our body for the maintenance of our all the cells they are survivals they are quality functions for that this integration is required. Because finally, integration of all these pathways actually decides the or rather ensure the supply of fuels.

Fuels suitable fuels to all the tissues which tissue chooses which fuels based on that the supply occurs for all the times from fate state to starvation this integration actually decides which fuels to be which fuel to be supply to which tissues and to which extent. Now if we talk about positive caloric balance in that case when there is excess supply of nutrients or adequate supply of nutrients in that case what this integration does they store energy whatever is excess there are stored in the form of either glycogen or fat or even protein synthesis those things are actually is a future storage when required we will derive from the storage. So, that is occur that occurs when there is negative calorie balance. So, in negative calorie balance like starvation fasting these stored form glycogen fatty acids lipids even proteins they are broken down to provide energy to provide fuels to the tissue. So, that is the crux of integration of metabolism the purpose is to provide energy or the mode of survival to the tissue.

Now, as we can see that human body or even in a multicellular organism all the cells in a unicellular organism the cell all the functions they occur as one community and this communication is delivered or mediated via one is very important that is nervous system our brain gives the signal actually through the nerves how things to be coordinated then availability of circulating substrates what are the available fuels what are the available substrate which can be utilized as fuels which can be utilized as future fuels is the deciding factor or the communication and finally, the most important one which is the triggered for all these switches rather which decides when to be stored when to be utilized is different or different hormones. Hormones like insulin glucagon epinephrine they give signal to our body. Now, based on these concepts the major organs which we are going to discuss for their fuel metabolism are liver the most important organ then adipose tissue muscle and also brain we are going to discuss the metabolism of all these organs, but before that let us see how integration occurs at cellular level. Now what happens as I told you that all these anabolic and catabolic pathways are synergistic occurring in a single cell at the same time now definitely there is interrelation or

interconversion between one biomolecules to the another. So, that is the flow of metabolite from one pathway to another pathway.

So, there can be conversion of carbohydrates into fat or the vice versa fats fat can be can converted to carbohydrate. Similarly, carbohydrate can be converted to protein and protein can be converted to carbohydrate. So, these are remember fat to carbohydrate or protein to carbohydrate that is neo glucogenesis then protein can be converted to fats also fat cannot be converted to protein please, but then here you can see that this is the inter different links or inter conversion of biomolecules. So, you can see lipid from triacylglycerol when it is broken down gives rise to fatty acid now that fatty acid on oxi beta oxidation or other types of oxidation finally, synthesizes acetyl coenzyme A that acetyl coenzyme A enters TCA cycle can produce energy or that TCA cycle on requirement from oxaloacetate can form phosphanol pyruvate. So, that is our neo glucosin acid.

So, here you can see lipids can form energy can form can be in converted to carbohydrate. Similarly, carbohydrate it forms acetyl coenzyme A and that acetyl coenzyme A is utilized to form fatty acid or different from fatty acids different other types of lipids like triacylglycerol cholesterol they are synthesized from acetyl coenzyme A even ketone bodies also. Then also proteins amino acids via neo glucosin acids can take parts in formation of carbohydrate whereas, once again carbohydrate pyruvate oxaloacetate oxaloacetate via transamination they can form amino acids. So, these are the links between the biomolecules in the at the cellular level that is cellular inter integration of metabolism. Now this flow of biomolecules can occur at tissue level.

So, this exchange of biomolecules metabolite flow or exchange of metabolic pathway can occur in tissue level or organ level. Here you can see that liver liver is the central organ actually it it liver decides which nutrients to be supplied to which organ who needs the who should be given the priority who need it now who can be provided later which metabolite can be um exchanged at different stage. So, liver is the central hub of metabolism. So, liver provides nutrients to all these organs starting from skeletal muscle brain heart adipose tissue everywhere liver distributes nutrients, but these organs on requirement provide energy to liver as well provides new exchange nutrients with liver as well you can see muscle supplies lactate alanine to liver that is our alanine glucose alanine cycle then adipose tissue can exchange fatty acid with muscle also brain can exchange ketone bodies with liver then heart takes nutrients from liver. So, that is integration at the tissue level.

So, integration of metabolism is not just the in contact between cells it is the whole metabolism of our body at a single point of time or different phases that is the integration

of all the metabolism for running or for the proper functioning of our body. Now, let us move to individual organs individual important organs how their metabolism occurs. So, as I told you already that liver is the metabolic hub of our body because liver gets the first access to the ingested nutrients the portal when is the connection from GI tract via portal when nutrients come to circulation first to liver and then liver decides their distribution. So, that is the supply of fuel to brain muscle and all the other organs and definitely all these metabolism carbohydrate lipid amino acids they are centrally regulated in liver. Now, liver has remarkable metabolic flexibility when we take a very rich protein high protein diet what happens the amino acid metabolizing enzymes present in liver they are stimulated they are synthesized are increased.

So, they are basically in a high when the high protein diet is supplied to liver those enzymes catabolizes or metabolizes the proteins. Now, just after that if you take after 1 hour suppose you take a carbohydrate rich diet liver adapts then what happens this protein metabolizing enzymes decrease and the carbohydrate metabolizing enzymes they are increased. So, you can see there is metabolic flexibility because those enzymes present in liver they have very high turnover rate remember enzymes are the proteins which have high turnover rate, but even the enzymes of liver are having higher turnover rate if you compare it with the other organs. So, synthesis and degradation of the liver enzymes are very fast and based on the requirement of body. Now, how liver handle carbohydrates in them in in it? Now, liver removes around two third of the supplied glucose from intestine it absorbs and it converts it to glucose 6 phosphate.

Now, this is very important this molecule is basically the it is present at the cross road of carbohydrate metabolism basically when glucose is converted to glucose 6 phosphate it is entrapped within the cell. Remember glucose 6 phosphate the phosphate groups are glucose 6 phosphate firstly is not freely permeable the glucose transporters which uptake which are responsible for glucose uptake from circulation glue transporters. So, those are not allowing glucose 6 phosphate to flow back to the circulation. So, first thing it is entrapped entrapment of glucose within the cell and the molecule is glucose 6 phosphate. Now glucose 6 phosphate now decides where this glucose 6 phosphate will be channelized to which pathway, but before that remember one important thing I want to highlight that this metabolic efficiency of liver actually based on two important thing.

One is the transporter the type of transporter present in liver that is GLUT2 and another is the hexokinase which is present in liver. Now hexokinase 4 is the hexokinase or the isofoam of hexokinase which is present in liver which is also known as glucokinase. Now what happens the efficiency of GLUT2 transporter is such that it can maintain the concentration of glucose inside the cell at per with the circulation. Now when we take high carbohydrate meal or at the post absorptive phase there is around 10 millimolar

concentration of glucose in the circulation and GLUT2 is such efficient transporter that it maintains the concentration of glucose in liver around 10 millimolar and also it is accompanied by the function of glucokinase. Now if you remember that glucokinase the K m value for glucokinase is very high that is around 10 millimolar once again.

So, what happens whenever there is a very high rise of blood glucose level there is uptake of glucose inside the cell and that is converted via glucokinase. Another important role of glucokinase is it is not inhibited by the product that is glucose 6 phosphate. So, what happens even if there is glucose 6 phosphate is built up inside the cell glucokinase continues it action till the blood glucose level drops. So, it is not inhibited by glucose 6 phosphate. Now the form the product glucose 6 phosphate it is channelized to different pathway based on the requirement, but the most important one is not producing ATP in liver rather to provide glucose to all the other tissues present.

So, basically what happens glucose 6 phosphate it is from phosphorylation of glucose glucose 6 phosphate is formed, but this form glucose 6 phosphate once again undergoes dephosphorylation to form glucose and that glucose is actually supplied to blood. Now the important enzyme here is glucose 6 phosphatase. Now this glucose 6 phosphatase enzyme is one integral membrane protein and that integral membrane protein of endoplasmic reticulum. Now what happens here you can see there are different glucose transfer glucose 6 phosphate transporter. Now the first one is the T 1 glucose 6 phosphate transporter.

So, during glycolysis glucose 6 phosphate is formed from glucose in cytosol of the hepatocyte. Now that glucose 6 phosphate enters inside the endoplasmic reticulum with the help of the glucose 6 phosphate transporter T 1. Now this glucose 6 phosphate is via glucose 6 phosphatase it forms glucose and inorganic phosphate those come out from the endoplasmic reticulum glucose come out via T 2 receptor and inorganic phosphate comes out via T 3 receptor and finally, these glucose are provided to the circulation or enters the circulation via GLUT 2. Now this part is important because this supply of glucose in liver actually decides where it where it will be providing energy to liver or to other cells or for biosynthetic property. So, existence of those separate enzymes at cell different cellular compartment actually important for smooth flow of different metabolic pathways.

Next we move on to the what are the fates of glucose 6 phosphate in liver. So, you can see apart from provision of blood glucose in circulation glucose 6 phosphate can enter glycolysis via formation of pyruvate through ECA cycle or this acetyl coenzyme can be utilized for formation of different other biomolecules. Now glucose 6 phosphate it can undergo other minor pathways like pentose phosphate pathway to form ribose 5

phosphate which further can be utilized for nucleotides as well as NADPH formation which is one important reducing reductive important for reductive biosynthesis of different molecules biomolecules like cholesterol fatty acids or even it is important for maintaining membrane integrity in RBCs as well. Then how liver deals with fatty acids in body? Now remember the dietary lipid once again comes to liver forms fatty acid. Now these fatty acids can form liver lipids the integral liver lipids can be formed from fatty acid or it can undergo beta oxidation to form acetyl coenzyme.

Now remember one very important thing fatty acid is the primary oxidative fuel in liver it is not glucose it is fatty acid which is the primary choice of liver. So, acetyl coenzyme you know what is the fate of acetyl coenzyme. Then liver it can release free fatty acid in circulation which goes to different tissues as well as for storage via lipoprotein to adipose tissue in forming VLDL triacylglycerol like that. Now importantly in fasting condition liver can synthesize ketone bodies as well. Next we move on to how liver deals with amino acids via different functions.

Now amino acid the most important thing is amino acid the pro amino acid provided in liver mostly utilized to form different liver proteins integral proteins enzymes which have been turned over also for formation of different plasma proteins. It provides amino acid in circulation to form different tissue proteins and also other non protein substances like nucleotides, porphyrins, peptide, hormones those are formed from those amino acids. Now amino acids which is excess that can be deaminated or transaminated to form pyruvate, then pyruvate can be flow to different other cycle. On deamination remember ammonia is formed and this disposal of ammonia is another function of liver via urea cycle. Now remember one important cycle here that entry of amino acid can be not only can be not only from dietary amino acids different organ can also provide amino acid to liver one such very important organ is skeletal muscle.

So, skeletal muscle proteins can be degraded to provide amino acid like important one is alanine via glucose alanine cycle. So, if you do not remember please go through the previous slides where I have discussed glucose alanine cycle how glucose alanine is provided to liver from skeletal muscle. The main purpose is not only to provide the carbon skeleton during new glucogenesis, but also ammonia which is formed in during the deamination or transamination of amino acids or proteins in skeletal muscle cannot be excreted it has to come to liver for its excretion. Then we are moving to metabolism in skeletal muscle. Now remember skeletal muscle is the organ which has an intermittent fashion of energy demand and the ATP here is utilized as the immediate source of energy.

Now in skeletal muscle the skeletal muscle fibers can be of two types one is slow twitch

muscle another is fast twitch muscle. Now slow twitch muscles are those which are acting slow they, but they are acting in a steady fashion the contraction are occurring in a steady fashion and they are rich in mitochondria that is why they are also called red muscles they are rich in mitochondria as well as capillary supply. So, in those slow twitch muscles the functions are stable steady, but slow whereas, fast twitch muscle they act rapidly the tension generated in those fast twitch muscles are very high and their ATP depletion rate or energy utilization rate is very high. So, you can see the energy nutrient requirement in skeletal muscle are different at different phases. When skeletal muscle is at resting phase their oxygen utilization is around 30 percent whereas, in case of intense exercise that can goes rise that can go up to 90 percent of oxygen utilization when it is in active exercise.

Now resting in resting muscle the major fuel of choice is fatty acid and can can be ketone bodies as well whereas, in moderately exercising muscle the fuel choice is glucose and also ketone bodies. Now you can see that when there is light activity these are our substrates, but when there is burst of activity these substrates are depleted very fast not only that the ATP requirement in fast acting or muscle or intense muscular activity can be raised so, much that the supply of oxygen or the supply of glucose from circulation cannot meet the requirement at par with the exercise intensity or the intensity of the requirement. So, what happens in muscles there are stored form of nutrients around 2 percent of glycogen is present as well as one very important molecule phosphocreatine is present in muscle as storage. Now during burst of activity these glycogen are broken down for provision of energy and also phosphocreatines are utilized. Phosphocreatines basically it when ADP is formed by hydrolysis of ATP phosphocreatine helps to regenerate this ATP.

So, ADP forms ATP for by phosphate group donation and phosphate phosphocreatine from creatine. So, that is the important of phosphocreatine it helps in regeneration of ATP, but remember when all these storage are depleted then only muscle proteins are broken down. When glycogen is depleted phosphocreatine starts to deplete then fatty acids via fatty acid triacylglycerol degradation stops providing energy to skeletal muscle after that only amino acid degradation starts. And all these all these requirement change of fuels are actually signaled importantly by epinephrine as well as insulin and glucagon. So, here you can see on intense exercise there is formation of lactate because of course, there is anaerobic glycolysis occurring in skeletal muscle during intense activity because definitely there is energy deficiency or rather the nutrients cannot be supplied at per with the requirement.

Now, what is the fate of this lactate? It is described by Corey cycle. Now, in Corey cycle what we have discussed that lactate formed during anaerobic glycolysis is actually

comes back to liver in liver lactate once again forms glucose via neo glucagon acid and glucose then once again is circulated back to skeletal muscle. And these glucose forms glycogen once that intense exercise phase is done. Then comes the restoration of the energy molecules in skeletal muscle like glycogen the glycogen storage which has been already depleted can be restored. Then metabolism in heart now remember skeletal metabolism and cardiac muscle metabolism they differ in their actions because skeletal muscle are having varied type of exercise pattern.

It can be steady slow it can be fast, but for short action, but for heart heart is active continuously in a regular rhythm and another very important thing is heart is completely aerobic organ it needs aerobic glycolysis. Now, the choice of fuel in heart is majorly fatty acids, but glucose lactate ketone bodies also are utilized. Now, the differences of cardiac muscle and skeletal muscle as I have told the pattern of work is different then because heart is aerobic tissue continuous supply of oxygen should be there continuous supply blood circulation should be there and also the stored form of energy or the storage molecules in heart is very low like glycogen lipid storage are present in very small quantity. So, supply of oxygen and supply of fuel should be continuous in heart or else what we know is the anoxic changes which we describes in myocardial infarction.

Now comes to metabolism in adipose tissue. Now, remember adipose tissues are the storage or we consider adipose tissue as the storage of energy in our body and here glucose acts as the sensor for what type of metabolism should be there. Now, there are two types of adipose tissue present in our body one is white adipose tissue this is our white adipose tissue cells and another is brown adipose tissue. Now, in adult the majority of adipose tissue around 99 percent of adipose tissue are of white adipose tissue type. In white adipose tissue as you can see in all the cells there is one single lipid droplet consisting of mostly triacylglycerol which occupies around 65 percent of the cell mass. So, much so that the nucleus and mitochondria they are pushed towards the membrane to the periphery and they act as a energy fat lipid droplet act as a energy storage.

Now, why we are saying glucose acts as a sensor? Basically the metabolic pattern of adipose tissue depends on the blood glucose level. When there is high blood glucose level adipose tissue or adipocytes act as a storage organ So, what happens? The triglycerides are stored or synthesized how the fatty acids which are supplied to the adipose tissue they are utilized for synthesis of triacylglycerol, but once again remember triacylglycerol synthesis mainly occurs in liver. So, whatever triacylglycerol are synthesized in liver they are circulated via VLDL to adipose tissue and stored. Now, what happens when there is fall of blood glucose level? You know the hormone that is hormone sensitive lipase. So, hormone sensitive is lipase hormone sensitive lipase it

sense the fall of blood glucose level via the hormone glucagon.

Now, hormone sensitive lipase if you remember the function it basically phosphorylates the perilypene the outer layer of the lipid droplets and they are perilypene phosphorylation finally, finally perilypenes are phosphorylated and finally, those phosphorylation of perilypene makes the lipid droplet available to the lipase and those lipase actually are responsible. So, the lipases are breaking the triacylglycerol to free fatty acids. Now, this free fatty acids then are supplying glucose how fatty acids bound to albumin are supplied to different exported to different tissues like skeletal muscle and heart and there they are utilized for beta oxidation providing energy. So, this is the role of adipose tissue based on the blood glucose available in it. Then there is a substrate cycle which is present in adipose tissue.

Now, you are much aware about this diagram already discussed in the class of triacylglycerol synthesis. Now, this cycle is known as triacylglycerol cycle where you can see there is continuous breakdown of triacylglycerol in adipose tissue forming glycerol and free fatty acid. Now, these fatty acid remember the fatty acid provided by adipose tissue 100 percent are not utilized for providing energy. Only 25 percent of these fatty acids are actually utilized in beta oxidation or provision of energy. 75 percent of these fatty acids goes back to liver there it forms triacylglycerol and these triacylglycerol comes back to adipose tissue for reformation of for providing this once again for storage of triacylglycerol in adipose tissue.

Now, why this glycerol cannot be reutilized for formation of triacylglycerol? Remember in adipose tissue glycerol cannot form glycerol 3 phosphate in adipose tissue because there is no glycerol kinase. So, for reformation of triacylglycerol or reesterification glycerol 3 phosphate is actually provided by pyruvate via neo glucogenesis. So, basically if you remember once again pyruvate forms phosphanal pyruvate, phosphanal pyruvates via neo glucogenetic pathway forms dihydroxy acetone phosphate, dihydroxy acetone phosphate forms glycerol 3 phosphate and that glycerol phosphate is utilized for triacylglycerol formation in adipose tissue not this glycerol which is high which is formed during hydrolysis. Next the brown adipose tissue now brown adipose tissue is present mostly in hibernating animals as well as neonates. At birth this brown adipose tissues are actually present in those regions where preservation of heat is required.

Now one very important characteristics of this brown adipose tissue is it has one protein which is known as thermogenin. Now thermogenin protein is important uncoupling protein. Now what happens inside mitochondria reducing equivalents are utilized for formation of ATP, but due to presence of thermogenin those energy cannot be utilized for ATP formation rather it is dissipated as heat. So, brown adipose tissue provides heat for

those animals which are hibernating or for neonates who needs preservation of heat. So, basically brown adipose tissue in neonates are present in regions or in those around those organs which needs to be preserved like brain like abdominal organs even kidney they should be prevented from cold exposure.

Now when in case of adults as I told there is very minimal amount of brown adipose tissue present, but during cold exposure chronic cold exposure cold adaptation can be there where there are pre adipocyte tissue which can be differentiated to brown adipose tissue even in case of adults. Now we are coming to metabolism of brain. Now brain is one very exemplary organ because it has specific characteristics related to metabolism. Brain utilizes around 120 grams of glucose per day which is around 60 percent of the requirement of or utilization of whole body glucose and that is around 15 percent of the total energy which is consumed in our body. Not only that it access completely aerobic organ around 20 percent of the total oxygen consumed in our body is utilized in metabolism of metabolism in brain.

So, it requires continuous constant and steady supply of its fuel glucose as well as oxygen both during x active phase as well as rest or sleep. So, it needs fuel, but the problem is there is no significant glycogen storage as well as other fuel storage are also very low. Not only that fatty acids cannot be utilized in brain because neurons firstly they do not have enzymes for beta oxidation of fatty acids. Moreover free fatty acids which is circulated in albumin bound condition they cannot pass the blood brain barrier remember albumin cannot pass the blood brain barrier. So, fatty acid albumin complex also cannot pass the blood brain barrier.

So, what will happen? If there this energy deficiency is there there will be anoxic damage. So, to prevent that whenever there is fasting condition or there is fall of blood glucose level whatever glucose is available actually siphoned for brains utilization. So, the other organs are basically secondary at that time. Now, in fasting condition apart from glucose brain can utilize ketone bodies as well. So, in starvation you can see ketone body is the main fuel whereas, normally or all the time or as long as possible in fasting glucose is the most important fuel in brain and why this is required? Remember the nervous system is the connection to all the functions in our body and that is done via the electrical impulse impulse transmission of the electrical impulses which are generated in brain and for that one very important transporter is there that is sodium potassium ATPase and that this transporter is based on the constant availability of ATP.

So, if there is fall of ATP there is fall of this transporter activity what happens transmission is hampered. So, all goes in a geoparty. So, constant and regular supply of oxygen and glucose should be there in brain and brain is the first priority organ in our

body. So, till now in this class we have discussed the metabolic integration in cellular and tissue level as well as the metabolic profile in different important organs like liver muscles both cardiac muscles and skeletal muscle brain as well as adipose tissue.

These are my references. Thanks for your attention. See you in the next class.