Cell and Molecular Biology

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Week 09
Central Dogma of Molecular Biology (Part 1)
Lecture - 34
Central Dogma of Molecular Biology

Hello everyone, this is Dr. Vishal Trivedi from the Department of Biosciences and Bioengineering, IIT Guwahati. I think if you recall, we have discussed the different types of activities that happen when you are actually running the life cycle of an intermediate. So, if you see the life activities, what you see here is that an organism is considered to be alive if it is actually performing these four functions: it has the ability of self-growth or self-renewal, and it should have an intrinsic ability to produce energy. Then it should also have a movement from one place to another; in this case, there is an exception that the plants are not moving from one place to another. Otherwise, there are also plants that are moving from one place to another, and they should also have the ability to self-replicate.

Now, if you see how these events are actually happening. For example, if you see the self-renewals, right? So if we take an example of the bacteria, and I think if you remember, we were discussing, when we were discussing cell division, how the bacteria are going to replicate and provide a greater number of bacteria. So if there is a single bacterium, what you have in the bacterial cell is actually a chromosome, so it is going to have the cell wall, right? And then it is also going to have the chromosome, right? So it's going to have nuclear content. And if this bacterium has to replicate and give you the two individual bacteria, then it first has to grow in size.

So it's going to grow in size, which means it is actually going to increase the amount of cytosol, and then it is also going to increase the amount of nuclear content. So what you see here is that the nuclear content is going to be double, right? So, this is going to be 2x the nuclear content, right? And it's also going to have double the amount of cytosol, and then eventually it is actually going to divide into two, right? And it is actually going to give you the two different bacteria. So now what you see here is that it's actually going to have the action of the different types of molecules; right when it wants to grow from one bacterium to a slightly larger size, it is actually required to synthesize the different types of biomolecules. It required the synthesis of proteins. It also required the synthesis of lipids because it had to synthesize the plasma membrane.

And then it also requires synthesizing the nuclear content, right? So it's going to synthesize the nucleus, right? It's going to synthesize both the DNA and the RNA. And what you see here is that the synthesis of these biomolecules is going to be essential for this particular bacteria even to go through a simple process of division, right, where it is actually going to give you the two different bacteria. Similarly, we have discussed how the endogenous ability to produce energy. So, if an organism has an endogenous ability to produce energy, it means that the organism is actually going to have the system and must have the machinery. So, in this case, you can have two different types of examples.

You can have the plants that are actually going to perform photosynthesis. And if you remember when we were discussing the chloroplast, we discussed the complete details of photosynthesis. Where we have the dark reactions and the light reactions, in both cases—whether it is a dark reaction or a light reaction—it is actually going to utilize and synthesize different types of biomolecules. It is also going to synthesize different types of proteins. It requires, for example, ATP synthase for the light reaction.

To produce the amount of ATP required for the dark reactions, it requires different types of enzymes like Rubisco and all other enzymes. So even if you see photosynthesis, the plant also has to synthesize proteins for photosynthesis. and it also requires these different types of receptors and channels to receive atmospheric oxygen. And then it also requires the stomata, doesn't it? So, the opening and closing of the stomata is also going to be governed by the different types of biomolecules. As far as the animal is concerned, right? For example, if the animal is concerned, it is also going to utilize the preformed food.

For example, if you talk about humans, they are actually going to utilize a very well-developed system where they are going to digest the food material in the elementary canal, and then they are going to have the constituent molecules, which are going to be channeled into different types of metabolic pathways. We have also discussed glycolysis and the Krebs cycle and how the different types of enzyme lipids and carbohydrates are participating in energy production. And it also has the ability to self-replicate. So self-replication is also where one organism produces two different organisms. So these are a few of the classical and basic pathways that are actually essential.

And what you see here is that the synthesis of the new biomolecule, or the synthesis of the different types of protein, lipids, and nuclear content, is essential. for performing these functions. Apart from these functions, we have several more examples where life activities also involve the different types of production of various biomolecules. For example, the adaptations are. Adaptation is a very, very important phenomenon for the survival of that particular organism.

Remember that when we were discussing the evolution, we discussed the different types of theories and whether you go with Lamarck's theory or Darwin's theory; both of these theories were heavily dependent on adaptations. While the processes by which they explain adaptation are different, adaptation itself is very successful. Or where adaptation is an essential phenomenon for algorithms to succeed in their life cycle or to complete their life cycle so that they can produce their offspring, adaptation is a multi-dimensional event. Right adaptation is where you actually get protection from the prey, so you can obtain protection from the prey. You might have seen the example of the deer, how it has developed strong muscles, and because of that, it can run very fast; this happens because the deer needs protection or has to remain safe from tigers and other carnivores.

So that is a classical example where the deer has developed the muscle cells. So if the muscle cells are developed, this means it has actually produced a large amount of muscular proteins, the proteins that are responsible for making the muscle cells. And these proteins are actually responsible for providing extra power to the muscles of the deer, and that's how it is actually getting protection. Similarly, we can also have different types of adaptation that may involve some kind of phenotypic changes, such as changes in skin color, right? So if there is a skin color change, it may actually perform a similar function that can also protect the organism from the prey, right? Then it can actually allow the organisms to make a better choice for a sexual partner, which is very important because when you are going to have better coloring patterns. And when you have a better way of attracting your sexual partner, you can actually have a higher chance of engaging in sexual activities, and that's how you can increase your chances of producing a larger number of offspring.

And this also requires the production of different types of biomolecules, so the production of these molecules or biomolecules varies, and eventually all these biomolecules end up in one molecule, which is the protein, because the protein is responsible for the Providing the colors to the skin protein is responsible for making different types of metabolites so that they can give patterns to the skin color and so on. So eventually, what you see here is that whether we are actually going with the basic activities like sexual reproduction or running our own metabolism and all those kinds of things. Or whether we are going with the specific activities where you are actually requiring the adaptations or phenotypic changes, or running your own metabolism, the end comes when you are actually going to produce the different types of proteins, and the protein production is directly linked to the generation of the amino acids, right? which means if you have to synthesize a protein you also have to synthesize the amino acids and then you have to connect these amino acids in a specific order So what you see here is that if protein production is actually essential, then the protein is going to be provided or synthesized by combining different types of amino acids in a particular sequence, and that is done systematically. A series of reactions, and all these reactions come under the big umbrella of the central dogma of life. So, what is the central dogma of life? So, the central dogma of life is that proteins are made up of amino acids, and every protein has a unique amino acid arrangement in a specific sequence.

that we have seen the many examples where the protein is important for the particular activity of those particular organisms. The information to synthesize the protein with a unique amino acid sequence is provided by the nucleic acids present within the nucleus. In a preset sequence, the DNA present in the nucleus gives rise to the specific RNA sequence, which in turn guides the cellular machinery to synthesize the protein. So what will happen is that the DNA that is present in the nucleus or whether it is present in the cytosol, as in the case of prokaryotic cells, is actually going to synthesize the RNA. And then this RNA is actually going to have the sequence information to synthesize the different types of amino acids, and then these amino acids are going to combine to give you the specific proteins.

That is why, if you want to have the proteins, you first have to synthesize the RNA, and then you have to synthesize the DNA, which means it has to be first synthesized from the DNA and then the DNA is going to be synthesized from the RNA. Scientists consider this the fundamental event for sustaining life and regard it as the central dogma of life, which means it will actually be the central theme of any life-related activities. We have seen the many types of life-related activities and where everywhere you have to have some kind of protein production. And if you want to see the production of the protein, you might have to synthesize the RNA, and that RNA has to be synthesized from the DNA. In other words, Francis communicated to the journal Nature that the central dogma of molecular biology deals with the detailed residue-by-residue transfer of sequential information and states that such information cannot be transferred back from the protein to either another protein or to the nucleic acid.

This means that the central dogma of life is also known as the central dogma of molecular biology, as stated by Francis, and it actually deals with the transfer of sequential information, which means you have a residue of DNA that synthesizes RNA, and then it also synthesizes protein. What he also says is that the reversal is not possible, which means that from the protein you cannot synthesize the RNA, and from the RNA you cannot synthesize the DNA, which we now know is not true. Under special circumstances, you can synthesize from RNA to DNA, as well as from protein to RNA or from protein to DNA. That is what you are going to see when we discuss more about the central dogma of life. So what you are going to see is that if we have to follow the central dogma of life, we have to run multiple reactions.

So, the central dogma of life is the basis of life on Earth, and it is required to control biological processes. Following this, the hierarchical flow of information from the DNA to protein allows the nucleus to control all biological activity in a cell. Under normal conditions, the flow of information from sequence to sequence requires three processes. Now, the question is why there is a requirement for the central dogma of life or the central dogma of molecular biology. It is required because then you can have full control over all the activities of a particular cell, as you cannot have that particular type of biological process started or ending until you have the specific protein produced.

For example, if we want to start glycolysis, we have to have a synthesis of hexokinase or glucokinase, but we cannot have the synthesis of hexokinase or glucokinase. It has to be governed by the DNA, and that is why it says that everything will depend on the DNA to first synthesize the RNA, and then the RNA will synthesize the protein. It is actually going to allow the DNA that is sitting inside the nucleus to control all these processes, and because of that, the nucleus can control all the biological processes. The three processes that are required for the flow of information are as follows. You can have the sequence-dependent synthesis of DNA from the pre-existing DNA.

So, you can have DNA, and that DNA also has to be synthesized. Remember that when there is a duplication of an organism, the organism wants to undergo division, whether it is a bacterial cell or a eukaryotic cell; it must have a duplication of the DNA. So, you can have the DNA-dependent DNA synthesis, and that is actually going to be performed by an enzyme which is called DNA polymerase, and the process by which you are going to do this is called replication. Then you can have the sequence-dependent synthesis of RNA from the DNA, so once the DNA is synthesized, you can also have the DNA-dependent RNA synthesis, and that is also going to be performed by an enzyme called RNA polymerase. So once the RNA is made, this process is called transcription.

Then we have the sequence-dependent synthesis of DNA from the pre-existing DNA. So once you have the RNA, it will have the synthesis of the protein from the RNA molecule, and that process is called translation. So, if you want to run the central dogma of life or if you want to continue all the biological activities within the cell, you have to follow these three events. You have to synthesize the DNA from the existing pre-existing DNA, and that process is called replication. Then you can have the sequence-dependent synthesis of RNA from the DNA; that process is called transcription, and then you can also have the sequence-dependent synthesis of proteins from the pre-existing RNA, and that process is called translation.

We can have the more detail about these processes. So, genomic content in an organism needs to be duplicated from the S phase of the cell cycle. Duplication of DNA is done by replication utilizing the sequence information of the parent DNA. The enzyme used in this process is called DNA-dependent DNA polymerase. Then we can have the transcription.

So, DNA is present in the nucleus, whereas the protein synthesis machinery is present in the cytosol. Whereas in the case of prokaryotes, both the transcription and translational machinery are present inside the cell. So, because there is no nucleus. Hence, the information present in DNA is used to synthesize the RNA, which has the ability to transport outside the nucleus to participate in protein synthesis. Synthesis of RNA from DNA is carried out by transcription utilizing the sequence information of the DNA.

The enzyme used in this process is called DNA-dependent RNA polymerase. Then we can also have the translations. The RNA present in the cytosol is utilized by the translational machinery to synthesize the protein in a sequence-dependent manner through a process known as translation. So these are the things we have depicted here: the DNA-dependent DNA polymerase synthesis, which is going to be done by the DNA polymerase.

The process is called replication. Then you can have the transcription, and you also have the translations. But as I said, you know, although Francis has said that these processes cannot be reversed or that the sequence of information can only go from DNA to RNA and then RNA to protein, it cannot be reversed. But under specific conditions, the biological system does not follow the usual pathway to relay the information, which means it can also have reverse directions. So, under normal circumstances, what you have is DNA-dependent DNA synthesis; this is called replication. Then you can have DNA-dependent RNA synthesis; this is called transcription.

And then you can also have the RNA-dependent protein synthesis, which is also called translation. So, these are the normal circumstances that are happening in every cell, but there are exceptional or special cases where you can have other activities. For example, the RNA-dependent DNA synthesis, which is called reverse transcription. So, this is actually a reversal of this; this is a reversal of this. So, it is also called the RNA-dependent DNA synthesis.

So, that is called the reverse transcription. In most organisms, the genomic content is present in the form of DNA, but in a few organisms such as viruses, RNA is also present as the genomic content, and in these cases, RNA needs to be converted into DNA and replicated using the host machinery. It is done through reverse transcription utilizing the sequence information of the parent DNA. The enzyme used for this purpose is called RNA-dependent DNA polymerase, or it is also called reverse transcriptase.

So, this is what is shown here. You can have the normal circumstances where the DNA is actually going to be synthesized, and it is going to give you the results by the replications. Then the DNA is going to give you the RNA by the process of transcription, and then the RNA is going to give you the protein, which is called translation. But you can have the special circumstance where the RNA is actually going to give you the DNA. And that process is called reverse transcription, and the enzyme is called reverse transcriptase. Then we have another example where you can have RNA-dependent RNA synthesis, and that is called RNA replication.

In most organisms, the genomic content is present in the form of DNA, but in some organisms, RNA is present as the genomic content and is replicated using the sequence information of the parent RNA. The enzyme used for this purpose is called RNA-dependent RNA polymerase. And then you can also have the DNA directly synthesize the protein. So, there will be a complete absence of this particular RNA species. So, you can also have DNA-dependent protein synthesis.

So, in that case, the DNA is directly giving you the protein under the in vitro cell-free system. So, it is not possible in an organism, but it is possible under the in vitro cell-free system. So, in a cell-free system, it is possible to translate the DNA directly into the protein in the presence of ribosomes. It is not precisely controlled, and it is not known whether the protein is synthesized in a sequence-dependent manner, which means this is possible, but it is not precisely controlled; it is not necessarily going to give you the specific protein molecules. It may actually give you the protein molecule; it may give you random amino acids combined with each other.

Then we also have another example in which we can have additional possibilities. So, we have an additional possibility where the protein is giving rise to DNA, or the protein is giving rise to RNA, or the protein is doing so without going through the normal circumstances of the central trauma of life. So, we have a protein-to-protein. These are considered the infectious protein.

They are also called prions. In prions, what you have is that the protein replicates from the protein itself. So, these are considered infectious proteins that replicate to form identical copies of themselves. These proteins are known as prions, although they represent the transfer of information, but they are not the usual pathway and are considered to be an exception to the central dogma of life. So, what have we discussed? We have discussed the importance of the central dogma of life, or the central dogma of molecular biology, and how and why there is a requirement for such a pathway. We require that pathway so that the DNA can precisely control the production of RNA, and in turn, it can actually have full control over the protein molecule.

Not only is the DNA actually going to have the information that is going to be more stable. Remember that means we are discussing the DNA, RNA, and the protein. DNA is a very stable molecule compared to RNA because it has a double helix structure, contains deoxyribose sugar, has greater stability, and is protected inside the nucleus by some binding proteins; therefore, it is very stable. So, that is why the information that you have in the DNA is not going to give you any kind of alterations, whereas the information that is present in the RNA is very susceptible to any kind of damage, and the same is true for the protein, right? The protein can also get modified, and it can also get altered, right? And on the other hand, RNA is not stable, right? RNA is less stable compared to DNA because RNA is single-stranded. RNA is susceptible to the different types of RNAases that are present in the cytosol and so on.

So because of that, biology or life has decided that I am going to utilize the information that is given in the DNA. But since the DNA cannot participate directly and give you the protein, if that is the case, the DNA is actually not able to synthesize the different types of proteins. Because if we suppose the DNA has to synthesize the thousandth of the proteins, then the DNA molecule is going to remain open and it has to keep synthesizing the proteins. Because of that purpose, the DNA has decided that, okay, it will take the help of the RNA. So what it will do is it is actually making its own copies in the form of RNA.

And that's how it is actually distributing the work, isn't it? Just like anyone, you remember that, for example, the prime minister of the country, right? The Prime Minister of the country has the ability to perform different types of tasks, right? but it cannot do all those tasks on its own because it has limited resources. So, because of that, what it is doing is actually making different types of portfolios and then distributing those portfolios to different types of ministers. So, these are actually going to be the ministers for the DNA, and that is how they are actually going to perform their special function. For example, if DNA has to synthesize actin, myosin, and beta ATP synthase—some different types of proteins—it cannot do this function in a timely manner. It cannot do that because it cannot channel into the multiple types of activities.

So, what it can do is synthesize the RNA for the actin molecule. It can synthesize the RNA for the ATP synthase, and that is how these different RNA molecules are now going to be taken up by the protein synthesis machinery, and that is how these RNA molecules are going to give you the corresponding proteins. On the other hand, because the DNA is stable, you cannot modulate the expression levels of this particular protein. But at the same time, if the function of that particular process is over and you want to degrade the myosin or ATP synthase, then you cannot degrade that region of the DNA.

What you can do is simply degrade that amount or that particular RNA.

If you degrade the RNA, you are eventually going to degrade the protein because the protein has a definite half-life or definite age; after that, the protein is going to be removed from the system. So that is also another aspect of why biology has decided to go for these kinds of sequential transfers of information from DNA to RNA and RNA to protein. So, the central dogma of life is very important for us to understand the different types of activities that are happening in the cell, and this is what we are going to discuss in the current modules. So, what the central dogma of life is that you are going to have DNA-dependent DNA synthesis, which is referred to as these applications.

So, we are going to understand these applications. Then we can also discuss the DNA-dependent RNA synthesis, which is called transcription, and we can also have RNA-dependent protein synthesis, which is also called translation. So, this is all about the central dogma of life. And what we have discussed is the many events happening inside the cell, what is responsible, and the different types of molecules that are going to be produced. And what we have understood is that the protein is actually responsible for carrying out the different types of activities within the cell. The protein synthesis is always governed by the sequence-dependent synthesis of RNA, and the sequence-dependent RNA synthesis is done by DNA.

And all these events are actually coming together under the central dogma of life or the central dogma of molecular biology, as it has been stated by Francis. So, with this, I would like to conclude my lecture here. In our subsequent lecture, we are going to discuss some more aspects related to the central dogma of life, where we are going to talk about transcription. So, with this, I would like to conclude my lecture here. Thank you.