Bioengineering: An Interface with Biology and Medicine

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Lecture - 04
Cell and Its Properties

Welcome to the MOOC NPTEL course on bioengineering, an interface with biology and medicine. In the last lecture, we started discussing some of the life properties and processes which govern life. Today, let us talk about the cell which is an organism's basic structural, functional and biological unit. We will also discuss about how eukaryotic cells got evolved, some of the brief evolutionary context to that.

And then finally we will talk about the cell communication, why do cell need to communicate and how do they communicate? But before we talk about that let me kind of show you the basic structural detail of the prokaryotic and eukaryotic cell.

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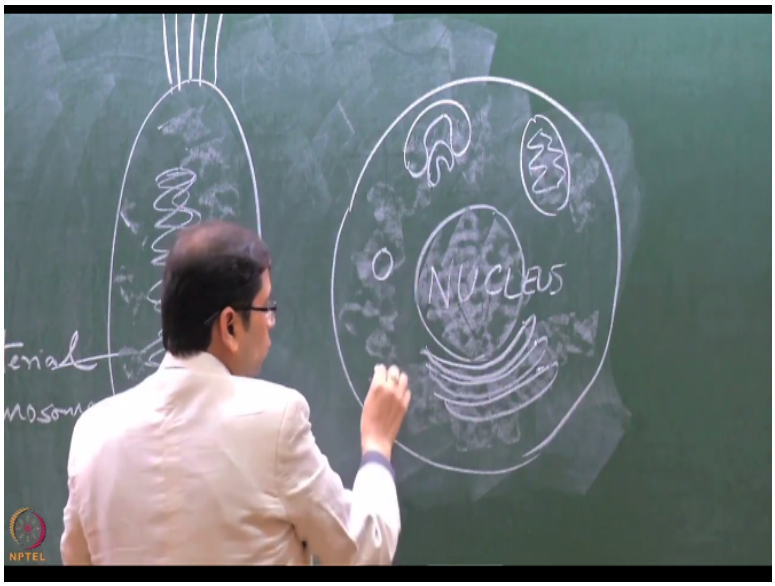

So in case of prokaryotic cell, it is like a balloon right in which we have these nucleoid or the chromosomal material of bacteria which is almost free-floating. Now other hand in the eukaryote, the nuclear material is within a defined nuclear membrane. So that is something which you know distinguishes the prokaryote with the eukaryote. You know this nuclear membrane outside them there is you know surrounding endoplasmic reticulum.

And then we have the complex network of Golgi body and the you know various Golgi apparatus. Then, we have this mitochondria which is the powerhouse of the cell and we have you know lysosomes and different other organelle which is all required for a eukaryotic cell function. So in the last lecture, we had discussed these prokaryotic cell and you know some of the specific organelle.

And you are rightly guessed about the even animal cells especially the eukaryotic cell we have looked into various organelle and the plant cell and its different organelle and what is the distinguishing feature of animal and the plant cell?

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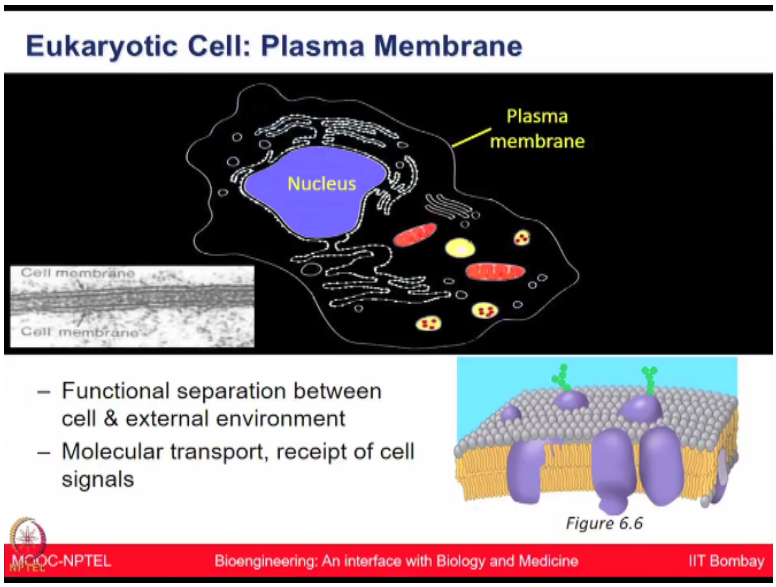

Let us now discuss one by one role of different organelles in the eukaryotic cell. Let us first start with plasma membrane and I will come to you now and ask you that what is your understanding about this organelle and how do they function. Alright, this provides a functional separation between the cell and the external environment and also provides you know way to transport the material which cells perceive as a part of the signal.

And then cell could move the things around based on what signal it perceives, so provides molecular transport and various type of signal which can be transduced from this cell. Now let us talk about what is cytoplasm. So cytoplasm is a region between the plasma membrane and nucleus.

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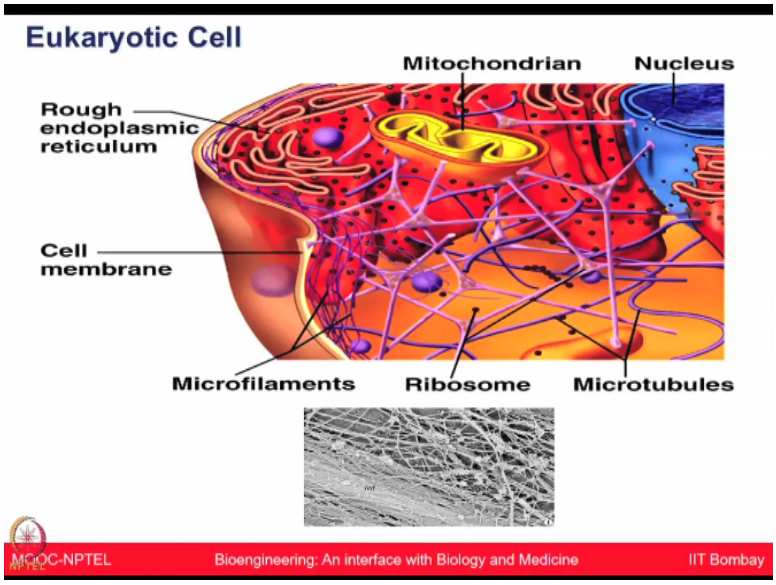

And it refers to the cytosol which is in aqueous phase and the protein complexes are added to that such as ribosomes and cytoskeletal material and together they constitute the cytoplasm. Now what is the role of cytoskeletal elements or cytoskeleton? It provides a structural framework of cell and their positioning, how the organelles are positioned in the cell that is governed with the cytoskeletal elements.

So it provides both intracellular transport as well as also involved in the chromosome moment.

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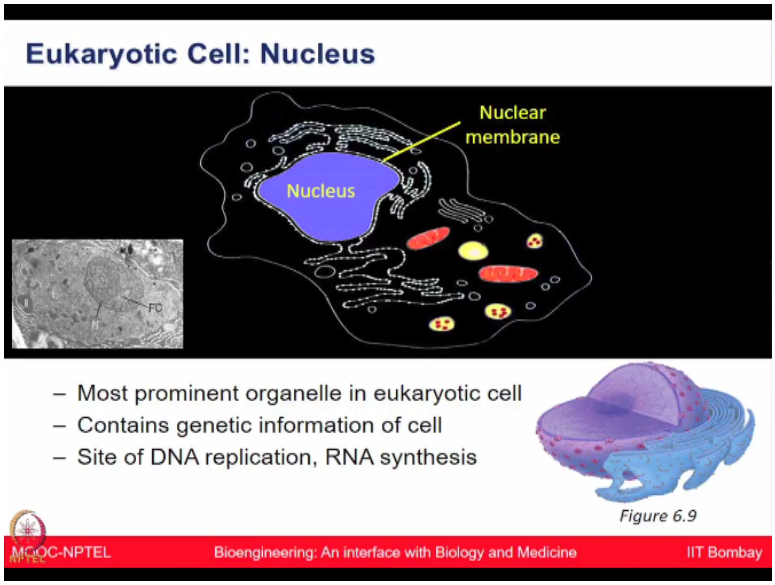

Let us now move on to a next organelle which is nucleus. This is most prominent organelle in the eukaryotic cell and you have rightly mentioned that it contains the genetic information which is required for the cell and provides a site of the DNA replication and also the RNA

synthesis which happens inside the nucleus. So nucleus is one of the most prominent and important organelle which is of course governing many of the crucial activities for the cell.

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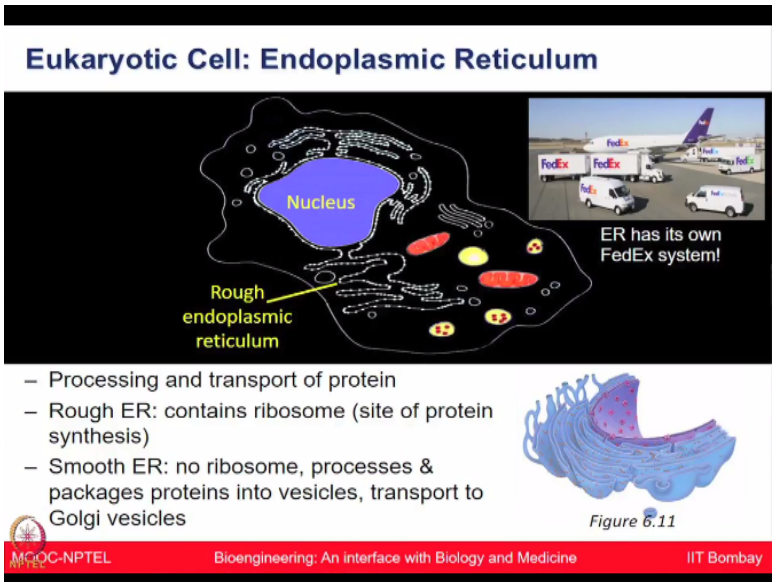

Let us now talk about another organelle which is endoplasmic reticulum. So endoplasmic reticulum is involved in processing and transport of proteins and it is like you know the FedEx system, the way our letters comes and you know a series of different vans from the you know and the aeroplanes are involved in moving your parcels, moving your letters I think you know in similar way the body's endoplasmic reticulum is actually involved.

So can you now tell me what is the role of endoplasmic reticulum? Yes, so there are 2 different types, one is a rough endoplasmic reticulum which contains a ribosome and you have rightly mentioned it is the site for the protein synthesis. Now what about a smooth endoplasmic reticulum? So smooth endoplasmic reticulum does not contain ribosomes and it is involved very intricately with Golgi vessels for packaging proteins into vesicles and transporting to the Golgi vesicles.

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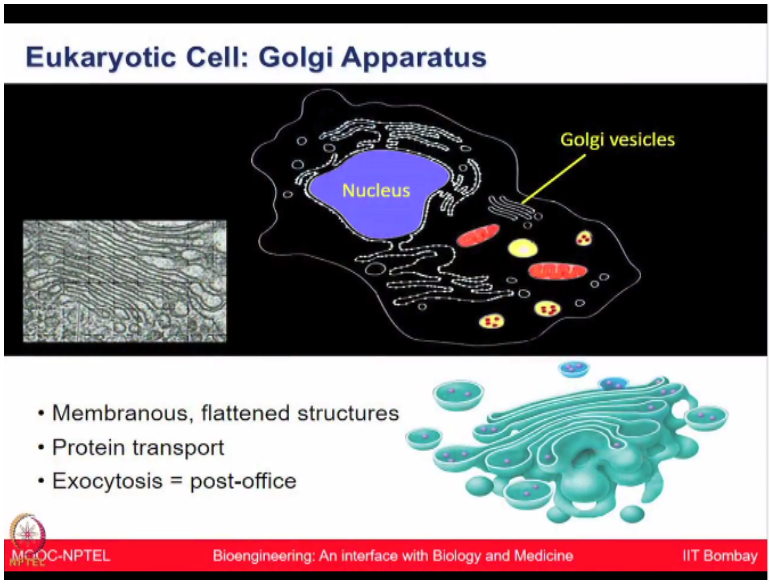

Let us not talk about Golgi apparatus. So again Golgi apparatus is one of the membranous flattened structures which helps for the protein transport and also it is helpful for exocytosis which is like you know the post-office work it does and it is very much involved in how the proteins can be transported from the cell from one part to other part and it is you know very closely working with endoplasmic reticulum especially smooth endoplasmic reticulum.

Let us now talk about peroxisomes. Does anybody know what is the role of peroxisome?

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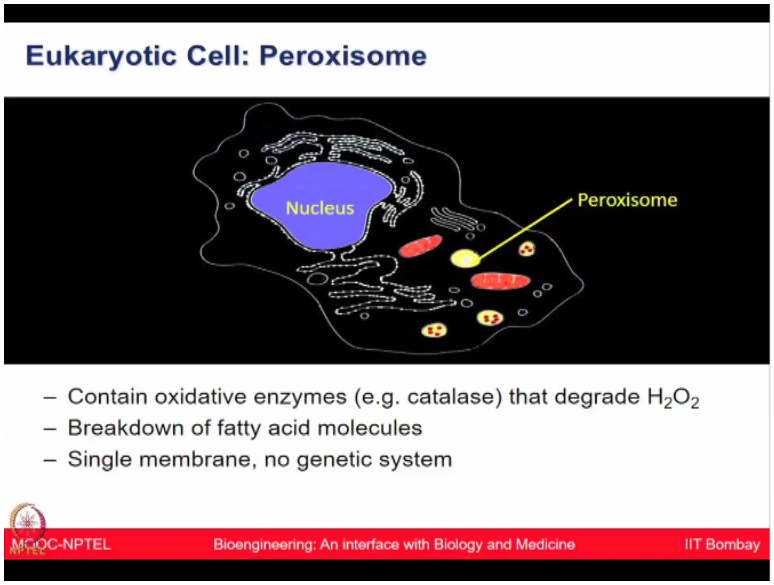

So it contains oxidative enzymes, for example catalysis which could degrade hydrogen peroxide H2O2. It is also involved in breakdown of the fatty acid molecules; it is single membranous structure and does not have a genetic system. So some of the organelles which we will be talking they are double membranous structure and they have their own genetic

setup whereas the peroxisome a single membranous and does not have the genetic system okay.

Let us talk about now the next major organelle which is mitochondria.

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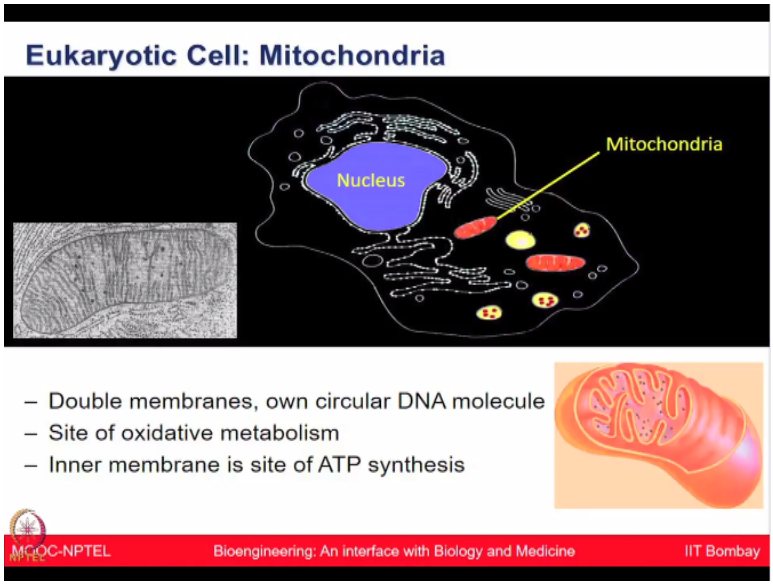

So mitochondria is of course very important and can you tell me the role of this? Yes, it is the power generation system, it is the ATP powerhouse. So it is double membranous structure which has its own circular DNA molecule. It is the site of oxidative metabolism and the inner membrane is where the ATP synthesis happens in mitochondria. So mitochondria is very unique in different ways.

And the way it has its own genetic system and the double membranous structure provides some sort of peculiar clues that how evolution would have happened. So let us think about mitochondria in the evolutionary context. What are the progenitor cells for the evolution to happen?

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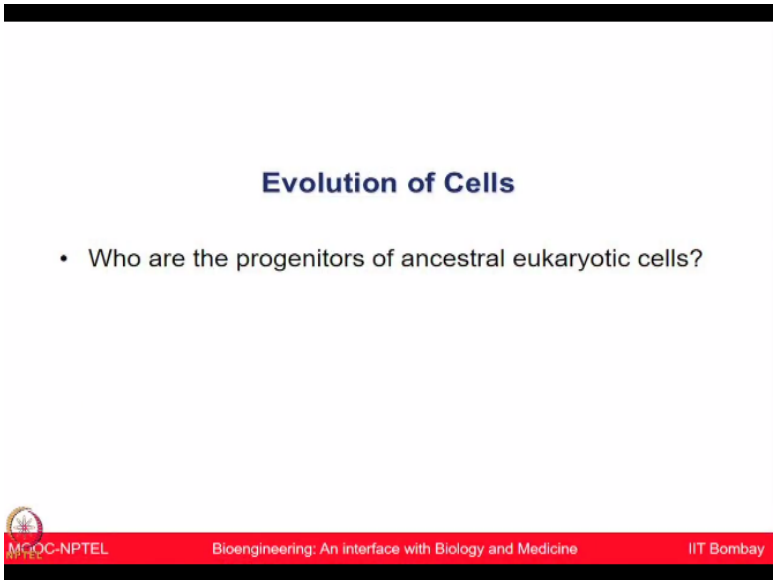

So think about you know the sea environment the kind of extreme conditions we had and in which way the eukaryotic cell would have got originated.

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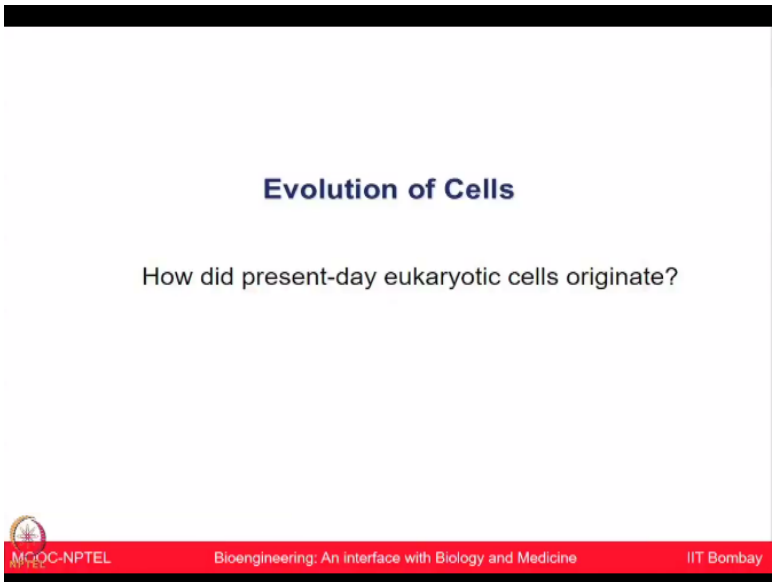

So this (()) (07:48) let us say you know in the sea environment there was one cell let us say one of the eukaryotic cell which has a defined nucleus.

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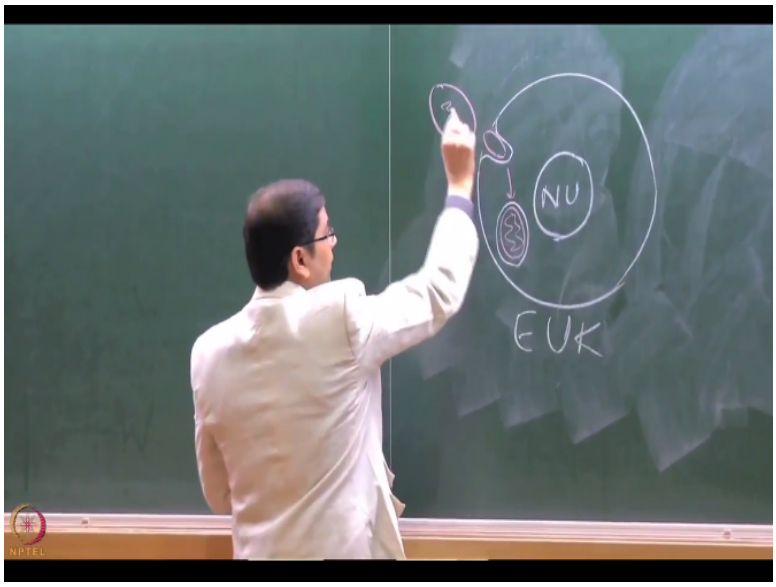

Now within that eukaryotic cell you know probably there was a free-floating bacteria which just came you know close contact to this particular cell and now with this the membrane it kind of now got protruded inside the eukaryotic cell. So this prokaryotic bacteria is now engulfed inside the eukaryote and this one has its own you know the DNA the bacterial chromosome.

So inner membrane is now from the bacteria and the outer membrane comes from the eukaryotes. So now this became double membranous structure and probably this was you know one of the bacteria which was involved in the respiration process, it has the machinery for doing the phosphorylation and ATP synthesis. So probably it eventually gave rise to mitochondria.

Alright, so then that makes it really peculiar right. So mitochondria the organelle is actually probably the ancestor of having the bacteria inside the cell and over the period it became the part of the eukaryotic cell.

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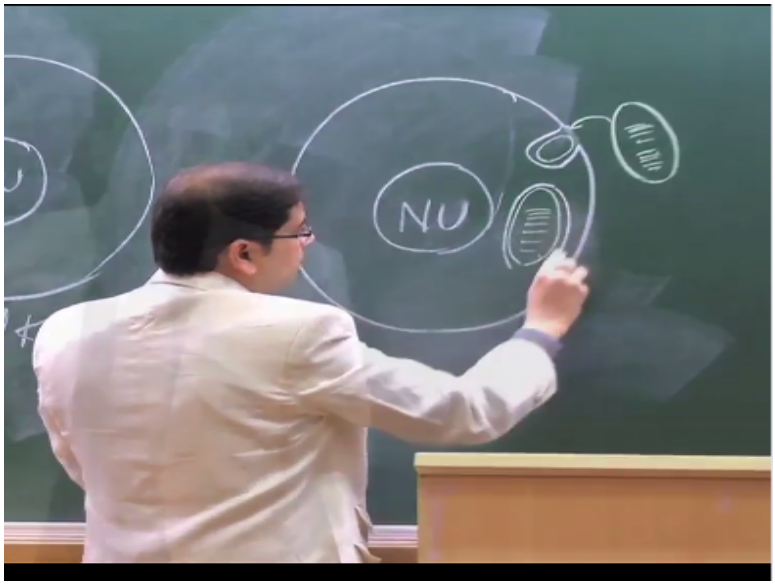

Let us now think about another situation where you know another bacteria now which was came in contact with another eukaryotic cell. Now this new bacteria which was having capacity to do photosynthesis and now it got in close contact to the eukaryotic cell and again it got engulfed inside the eukaryotic cell and now like the previous context we have the inner membrane coming from the prokaryote or the bacteria.

And outer membrane coming from the eukaryote and this bacteria has the machinery to do photosynthesis. So now in this manner, you know we can see that how evolution would have happened. So let us review this again now. So who are the progenitors of ancestral eukaryotic cells? And now if you review this concept back again what we talked in the last lecture about looking at the prokaryotes and eukaryotes.

I think you know then you can probably think about in which way eukaryotic cells got specialized with you know with some bacteria which became part of the eukaryotic cell and gave rise to mitochondria or the chloroplast. So in which way the present-day eukaryotic cells originate is still one of the you know research areas for the evolutionary biologist but you know different scientists have tried to put forward some hypotheses and one of the hypotheses which is popular that is endosymbiotic origin.

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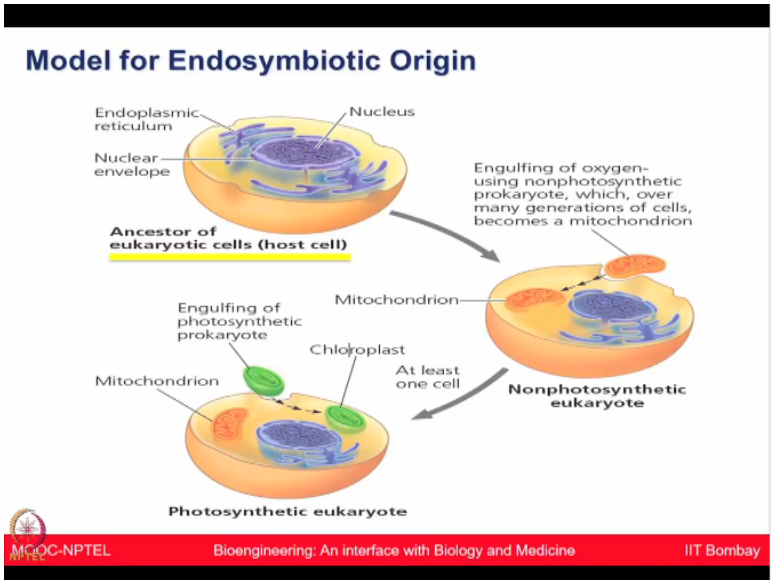

The model for endosymbiotic origin is shown here that you know an ancestor of eukaryotic cell or the host cell to start with has engulfed some of the non-photosynthetic prokaryotes which you know after many generations became like a mitochondria and then you know probably another photosynthetic prokaryote got engulfed and then that became the photosynthetic eukaryote.

So this theory is very popular because you know how mitochondria and chloroplasts have been evolved from the free living bacteria that formed the symbiotic relationship with primordial eukaryotic cells and probably that could be the reason why mitochondria and chloroplasts they possess their own genetic material and have the protein synthetic machinery.

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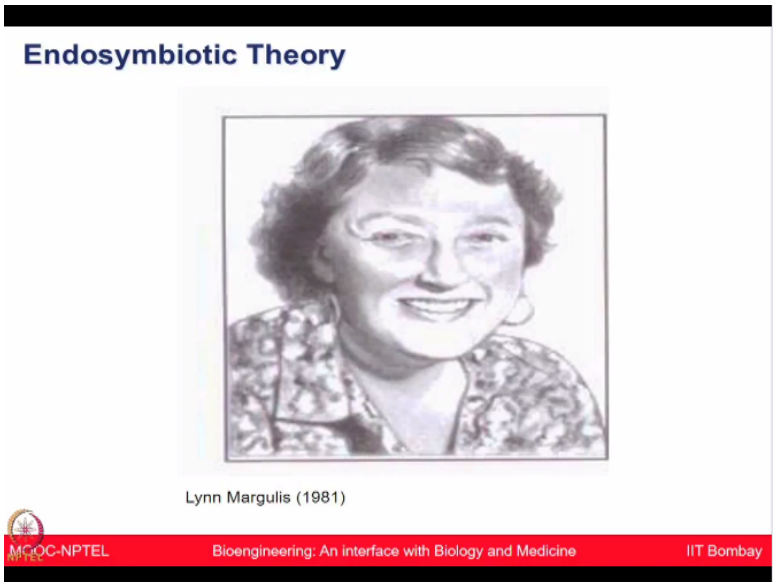

So scientist Lynn Margulis gets credit for proposing this particular theory and you know she proposed that probably about the evolutionary time period most of these bacterial genes were lost from the organelles DNA and therefore only the you know useful properties are retained.

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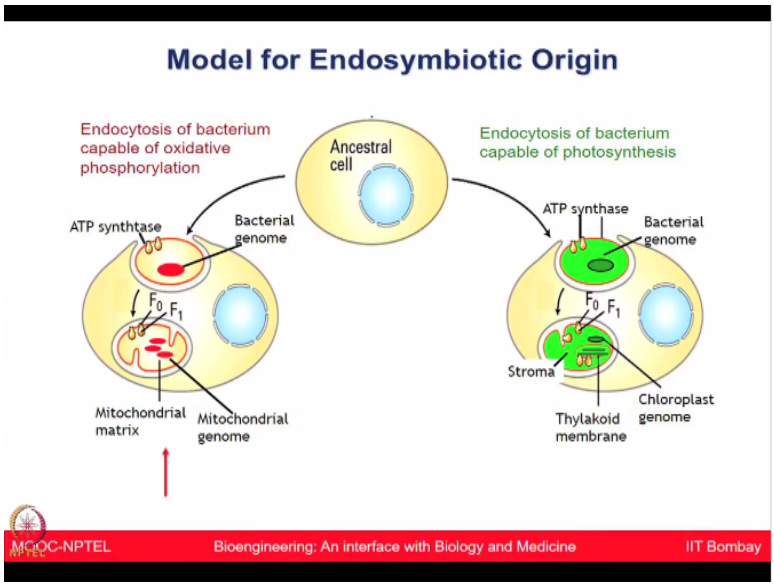

So this place you can see the model for endosymbiotic origin, the way we discussed in which way from the ancestral cell the specialized plant and animal cell could have originated and the mitochondria and chloroplasts, why they are double membranous organelle, now we have some better understanding of it that outer membrane comes from the eukaryotic plasma membrane and the inner membrane comes from the bacterial plasma membrane.

And it probably you know that is why it has its own genome, it has its own genetic components and kind of you know it works very uniquely inside the cell and has you know certain superior role because it has its own DNA contents and it can perform any specialized functions.

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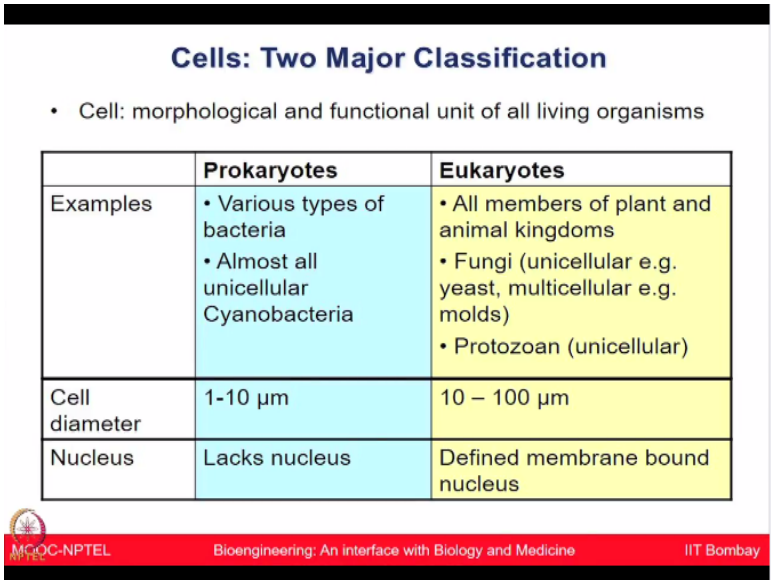

So let us look at broadly the cells. The two major classifications of cell are the prokaryotes and eukaryotes. In prokaryotic category, we can keep all the bacteria and unicellular organisms including cyanobacteria. Eukaryotes are essentially all the plants and the animal kingdoms. We have various fungi, yeast, different protozoans these are part of the eukaryotes.

The cell diameter is usually around 1 to 10 microns in prokaryote and in eukaryote it is 10 to 100 microns. Prokaryotes, their primitive nucleus, they lack the nuclear membrane. The eukaryotes are having the defined nuclear membrane.

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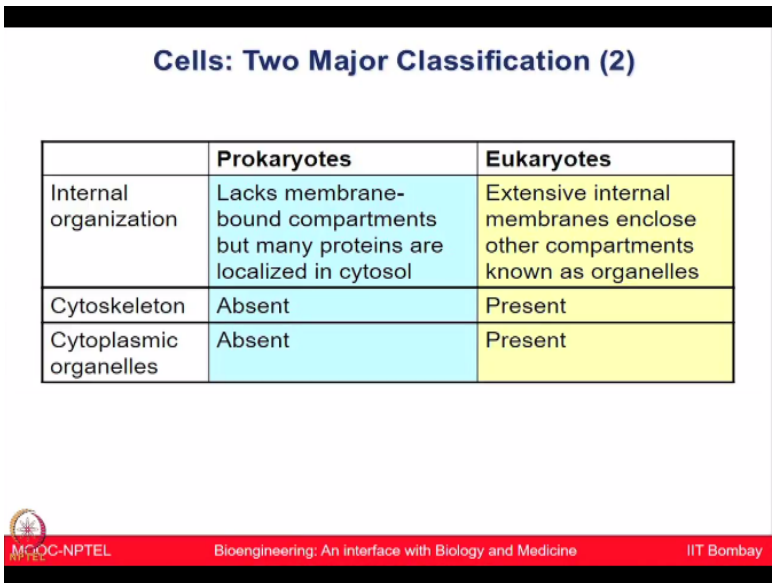

The internal organization wise, the prokaryotes actually lack lot of membrane-bound organelles and things actually pretty much free-floating in the cytoplasm whereas eukaryotes a very defined organelles which are having distinct membranes either a single membrane or

double membranes. Cytoskeletal elements and various cytoplasmic organelles are absent in prokaryotes which is present in the eukaryotes.

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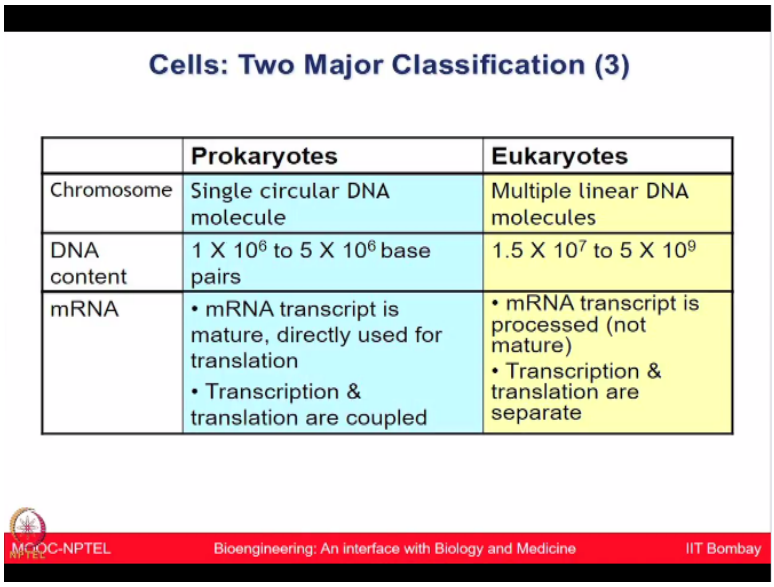

Thinking about the genetic components of it, the chromosomes are single circular DNA molecule in prokaryote whereas it is multiple linear DNA molecules in eukaryotes. The DNA contents can range from 1*10 to the power 6 to 5*10 to the power 6 base pairs in case of another prokaryotes but it is much larger (()) (14:02) 10 to the power 7 or 10 to power 9 in eukaryotes.

In prokaryote, the transcription is much more straightforward, much simpler and both transcription and translation are actually coupled processes whereas in case of eukaryote the translation and transcription processes are separate and it is much more complex. Now let us look at the distinguishing feature of plant and animal cells which we discussed in when we were discussing about the you know various cell organelle.

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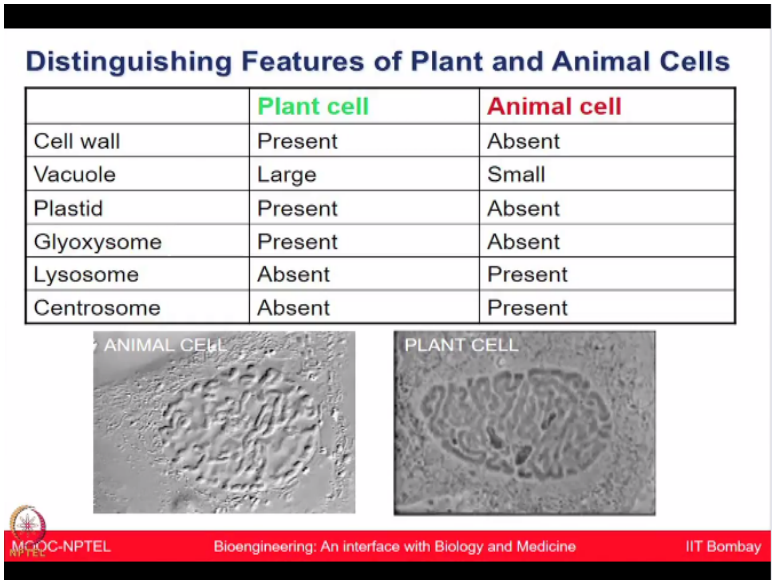

So in the plant cells, we have a defined cell wall which is present, which is absent in the animal cells. We have vacuole which is very large entity, which is very small in animal cell. Then, we have the plastids and glyoxysomes which are unique organelles found in the plant cells which is absent in the animals and lysosomes and centrosomes are absent in the plant which is present in the animal cells.

So these are some of the you know distinguishing characteristics and different organelles which are present or absent in plant or animal cells. So far we have covered about you know just refreshing you about the basic role of different organelle and at some sort of you know the broader context of evolution, how the eukaryotic cell would have got evolved and originated.

And different specialized organelles like mitochondria and chloroplast had some sort of evolutionary you know context to that and then we have tried to understand one of the popular theory in that line.

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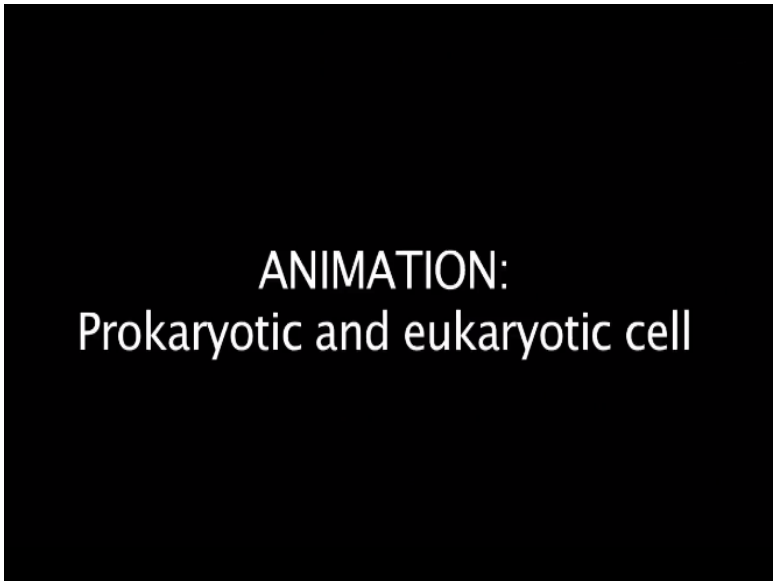

Let me explain you this in more detail in the following animation.

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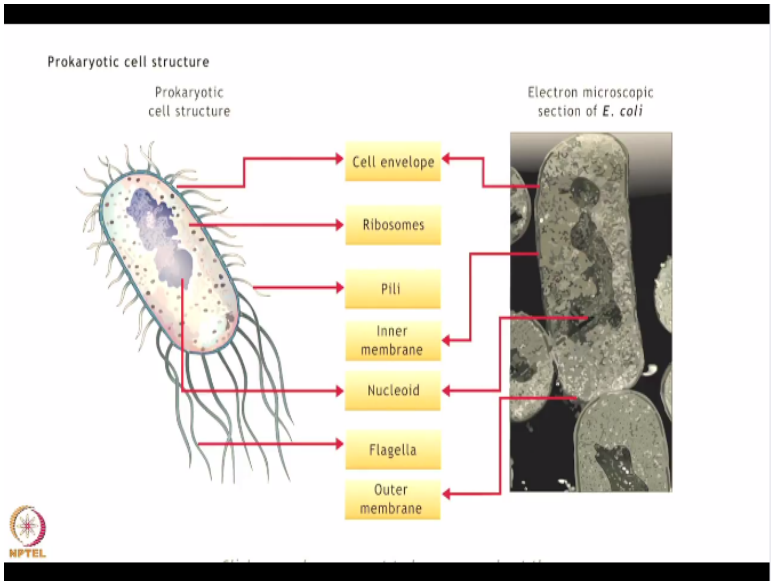

Prokaryotes are simple unicellular organisms that lack a well-defined nucleus for carrying their genetic material. They are usually a few microns in size and a one of the most ancient life forms known from which eukaryotes are believed to have evolved. Click on each component to know more about them.

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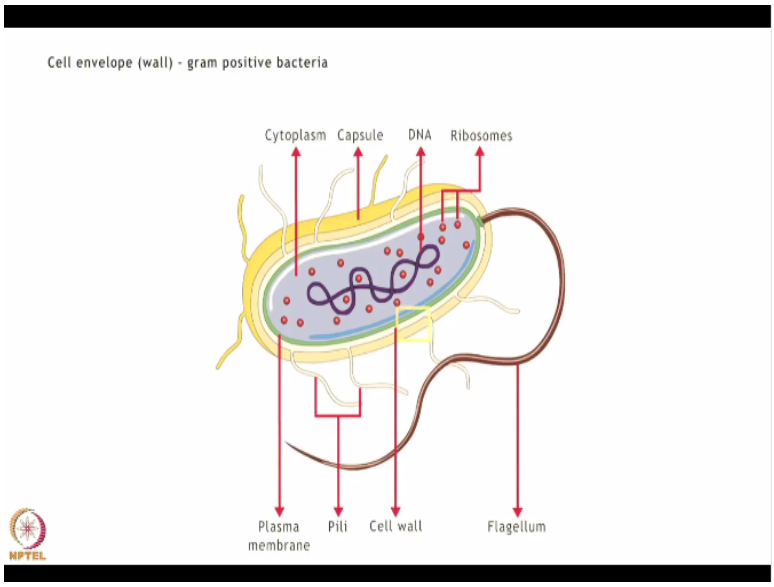

Bacteria can be divided into 2 major groups based on the structure of their cell wall and thereby their response to gram staining.

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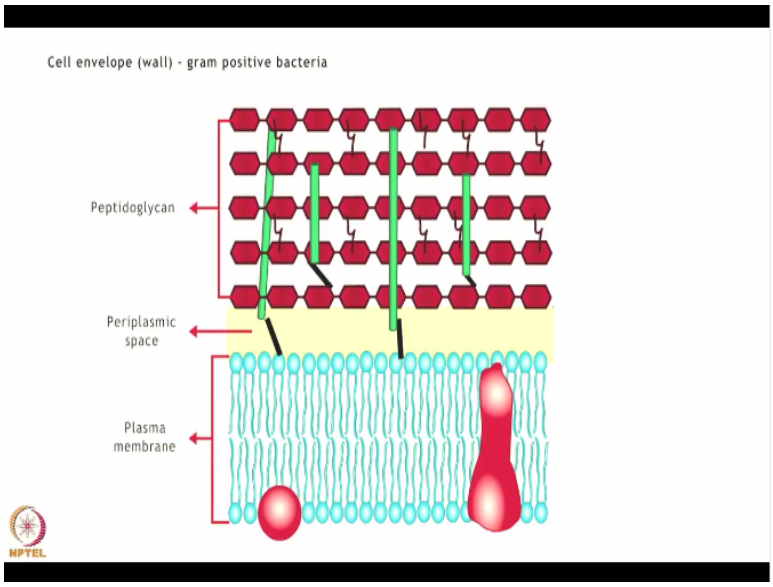

The cell wall of gram positive bacteria is composed of mainly polysaccharides and glycosylated molecules. It is made up of a single 20 to 80 nanometer thick homogeneous layer of peptidoglycan. In addition, cell wall usually contains teichoic acid, which is covalently connected to either peptidoglycans itself or to plasma membrane lipids.

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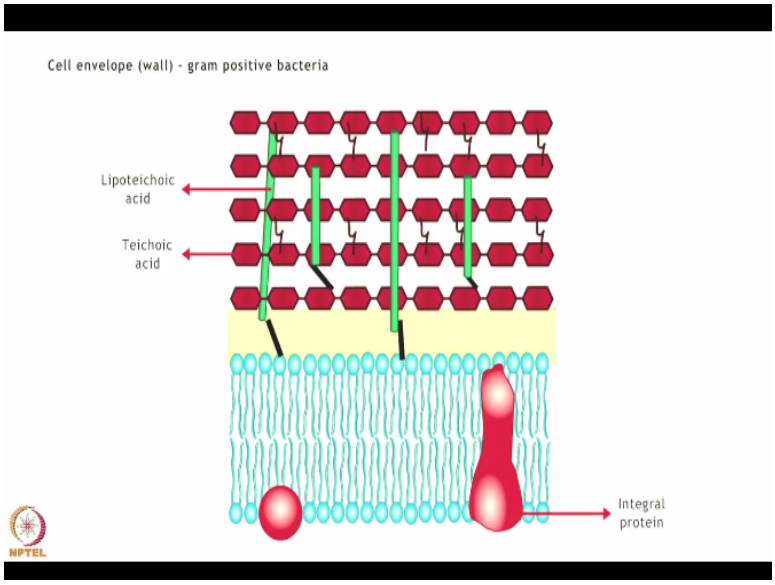

Plasma membrane is composed of a bilayer sheet of phospholipid molecules with the polar heads on the surface and their fatty acid chains forming the interior.

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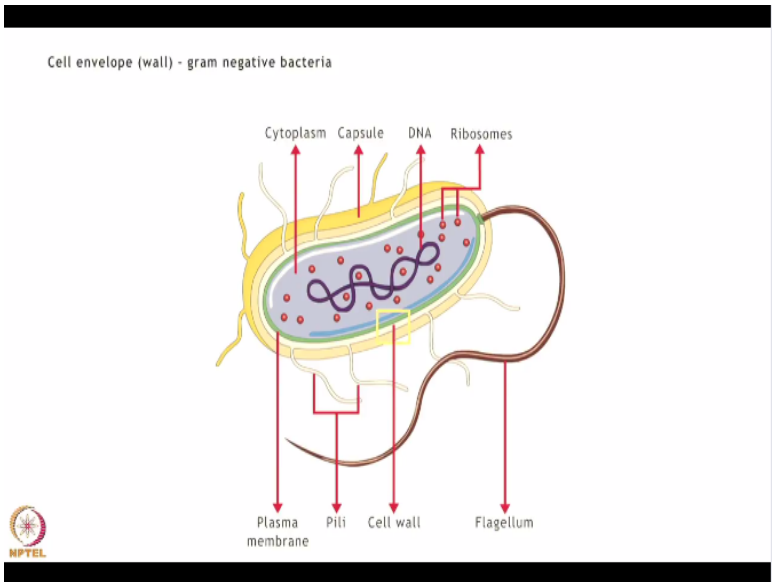

Gram-negative bacteria have a more complex cell wall.

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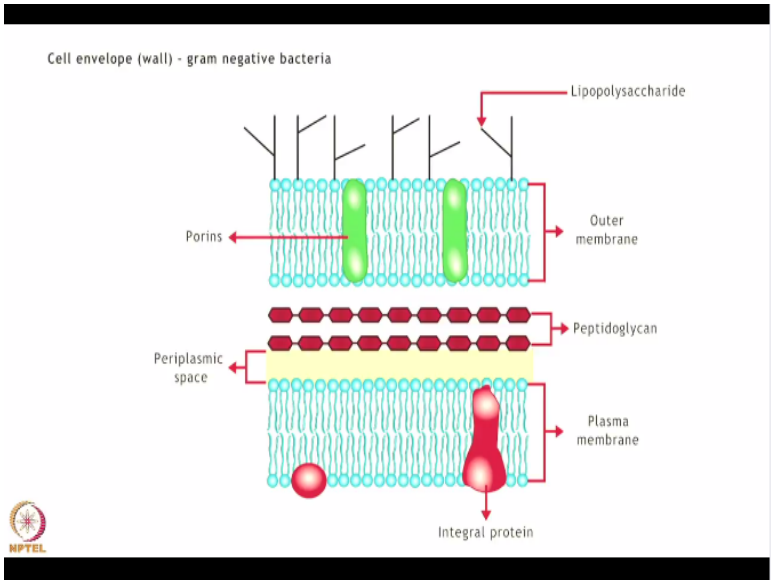

They have a relatively thin peptidoglycan layer around 2 to 7 nanometer covered by a 7 to 8 nanometer thick outer membrane made up of lipopolysaccharides. Porin proteins are present in the outer membrane which allows passage of small molecules across the membrane.

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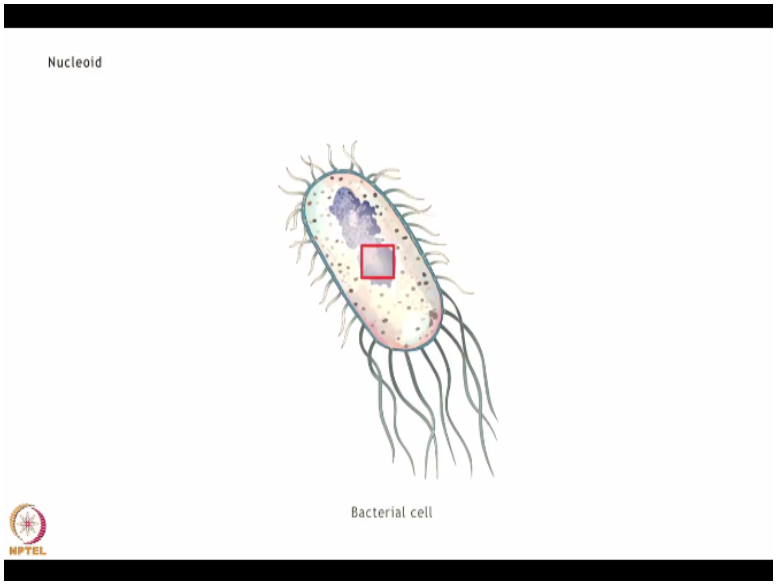

Nuclear material in the bacterial cell is not separated from the cytosol by a distinct nuclear membrane.

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However, it is usually concentrated in a specific clear region of the cytoplasm called the nucleoid. The genetic material usually contains a single circular DNA molecule. Ribosomes are composed of proteins and ribosomal RNA.

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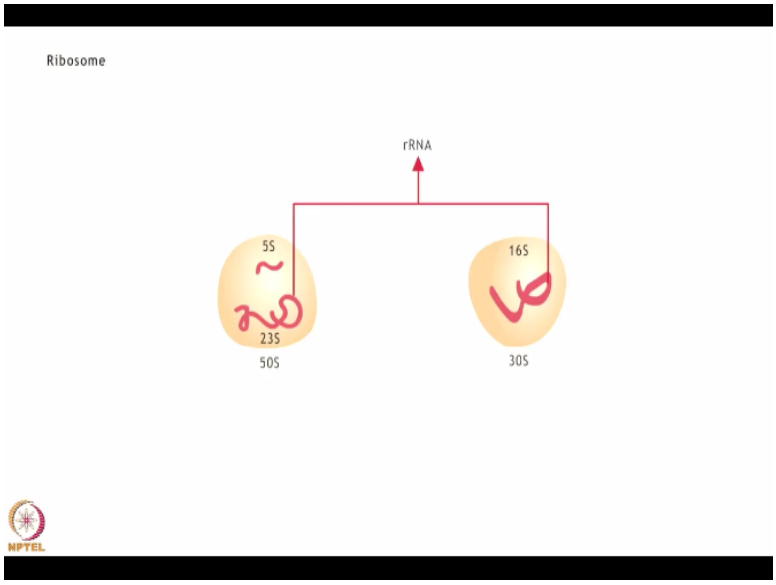

The prokaryotic 70S ribosome is made up of a 50S large subunit and 30S small subunit where S refers to the Svedberg coefficient which provides an indication about rate of sedimentation of the particle.

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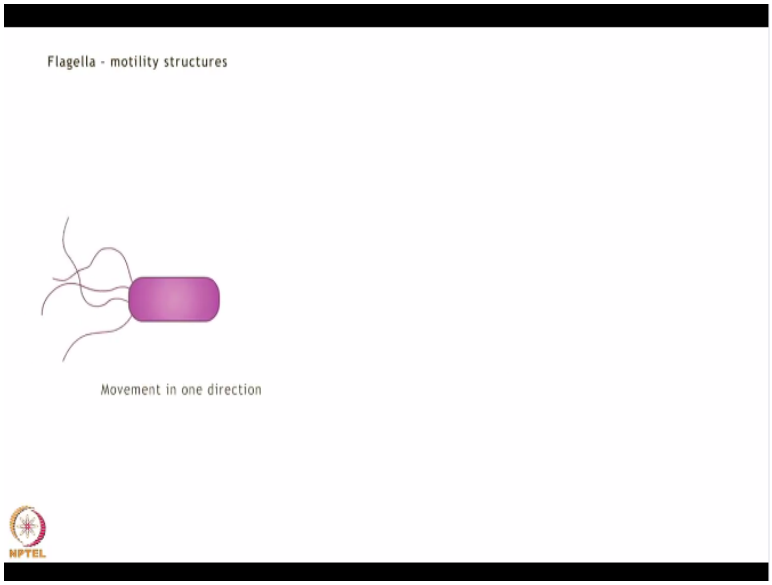

A motile bacterium propels itself from one place to another within the medium by rotating its flagella. A bacterial flagellum is made up of the protein flagellin. It has a helical structure with a sharp bend called the hook just outside the membrane and a basal body containing the motor just below the membrane.

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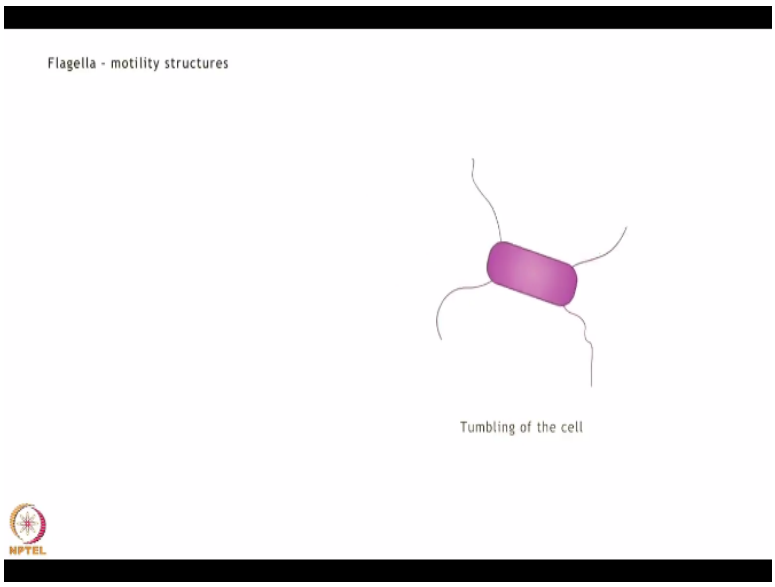

To swim forward, the flagella rotate in counterclockwise direction; however, when flagella rotation abruptly changes to clockwise direction, the bacterium tumbles in its place and seems incapable of moving. It then begins swimming again in another new random direction.

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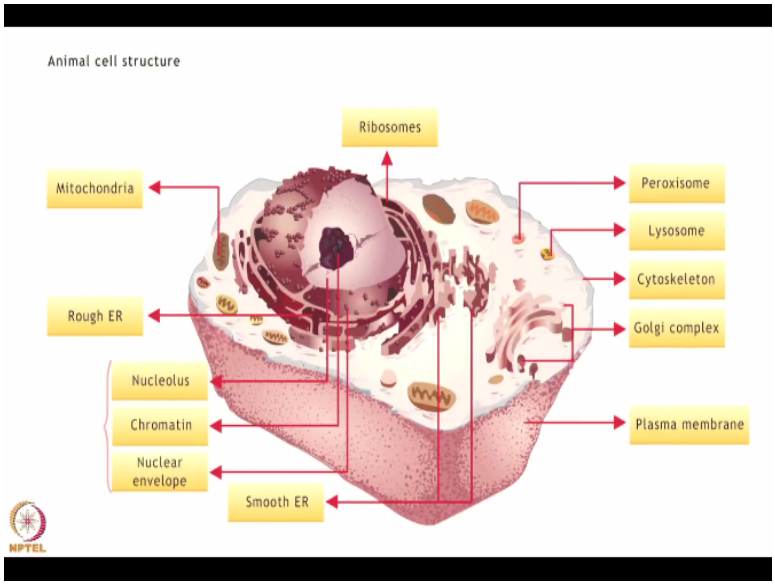

Typical animal cell lacks a cell wall and contains several membranes bound organelles such as nucleus, mitochondria, endoplasmic reticulum ER, Golgi apparatus, lysosomes and peroxisomes. Click on each component to know more about them.

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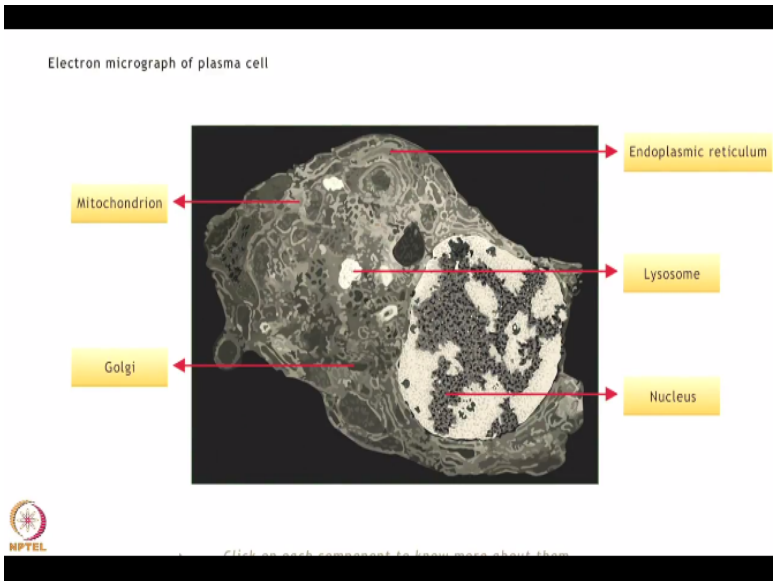

An electron micrograph image of a plasma cell is shown here clearly depicting the nucleus, Golgi material, lysosome and mitochondrion. Click on each component to know more about them.

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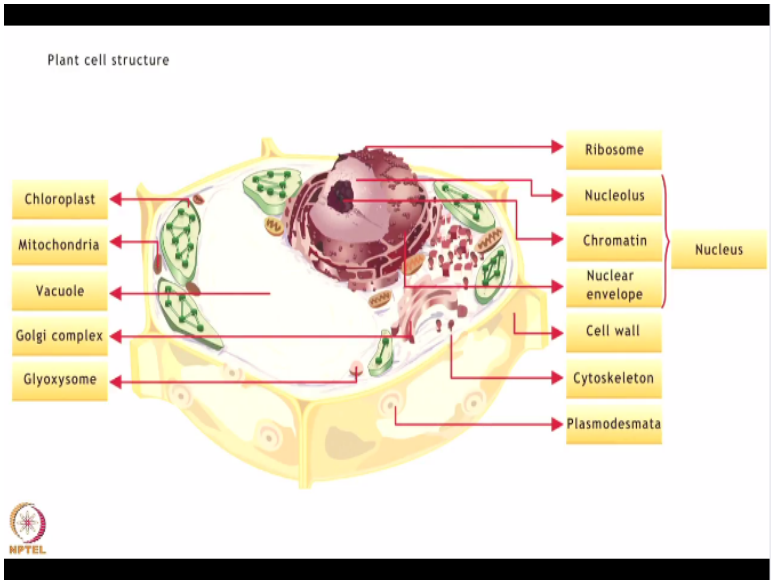

Plant cells have a rigid cell wall and membrane-bound organelles such as nucleus, mitochondria, chloroplast, endoplasmic reticulum ER, Golgi apparatus, lysosomes, vacuoles and peroxisomes. Click on each component to know more about them. Mitochondria commonly referred to as powerhouse of the cell or membrane-bound organelles found in eukaryotic cells.

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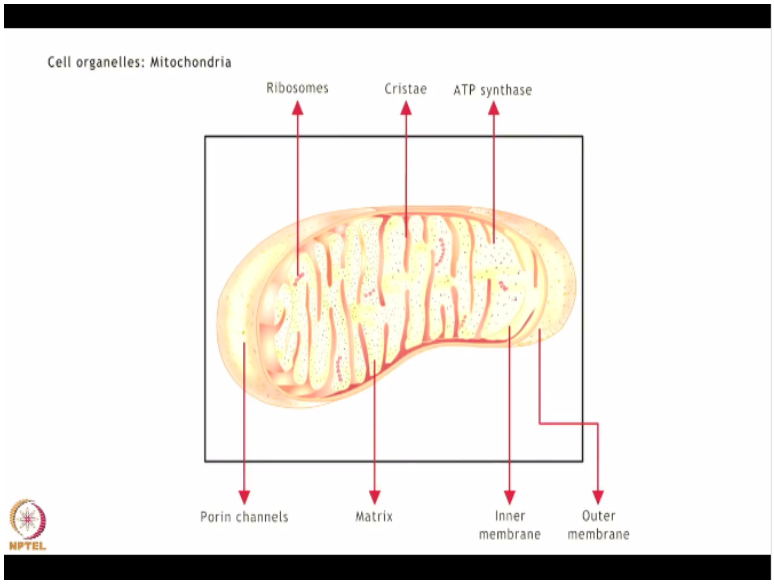

They are responsible for generation of ATP to satisfy the body's energy requirements and are also involved in other processes such as cell signaling, cell cycle control and cell growth. The organelle is made up of several compartments that carry out specialized functions and also contains its own independent genome that codes for mitochondrial proteins. Ribosomes which are composed of proteins and ribonucleic acids RNAs play a central role in protein biosynthesis.

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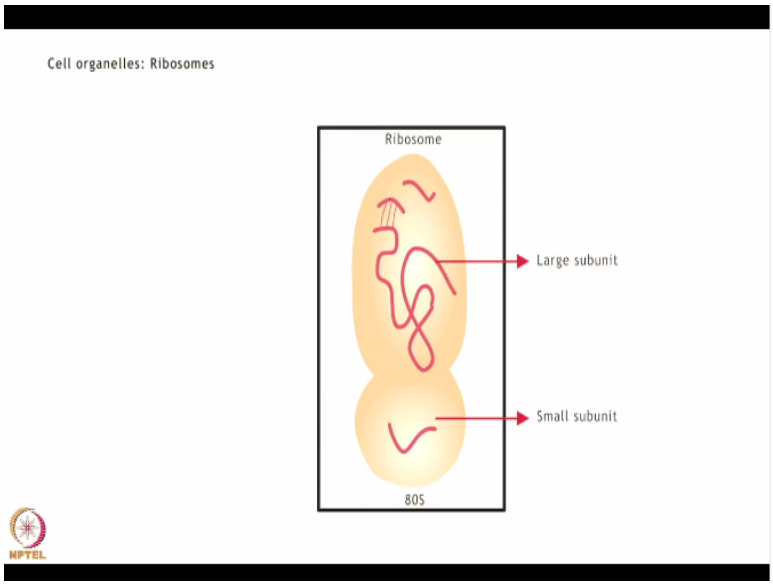

They read the nucleic acid information from messenger RNA and convert this into the corresponding amino acid code of proteins. Eukaryotic 80S ribosomes are composed of a large 40S subunit which binds to tRNA and amino acids.

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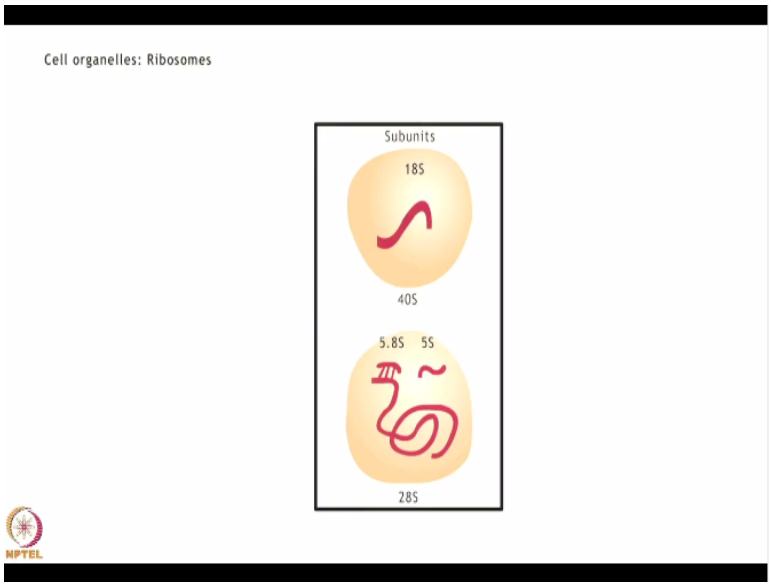

At a small 28S subunit which binds to mRNA during protein synthesis. The subunit structure of prokaryotic and eukaryotic ribosomes differ from one another. The endoplasmic reticulum and Golgi apparatus are involved in synthesis packaging and transport of various biomolecules.

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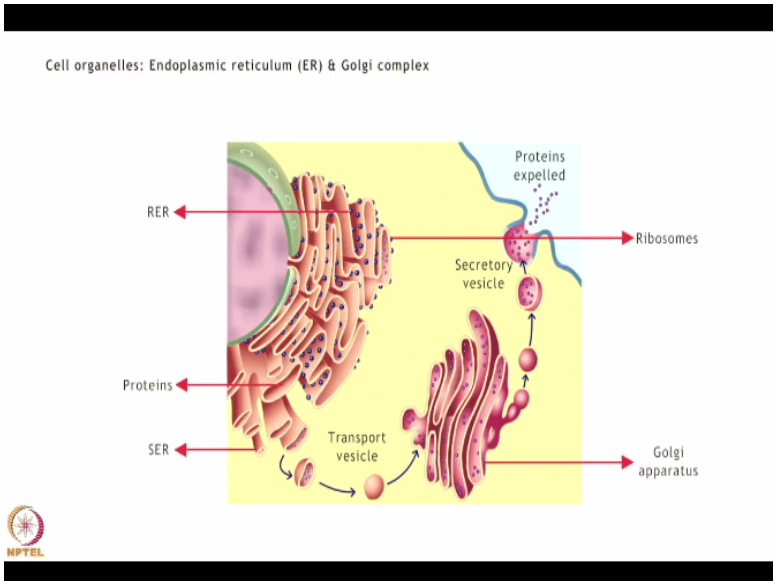

The ribosome studded rough ER is a major site for protein synthesis while the smooth ER synthesizes lipids, steroids, metabolizes carbohydrates and steroids and regulates calcium concentration in muscles. The Golgi complex functions to process and package macromolecules such as proteins and lipids for their export to various other cellular organelles or outside the cell.

The nucleus is a membrane-bound organelle found in eukaryotic cells that is often considered as a control center of the cell.

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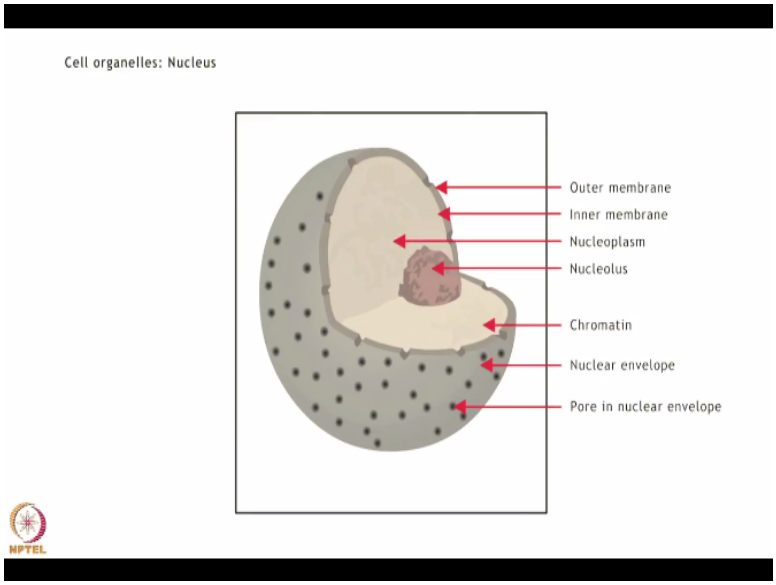

It houses the genetic material of the cell in the form of chromosomes containing DNA molecules complexed with proteins known as histones. The nucleus is responsible for maintaining this genetic information by replication and for expression of genes performing

various functions. The nucleolus is mainly involved in ribosome assembly after which the ribosomes are exported to the cytoplasm for protein synthesis.

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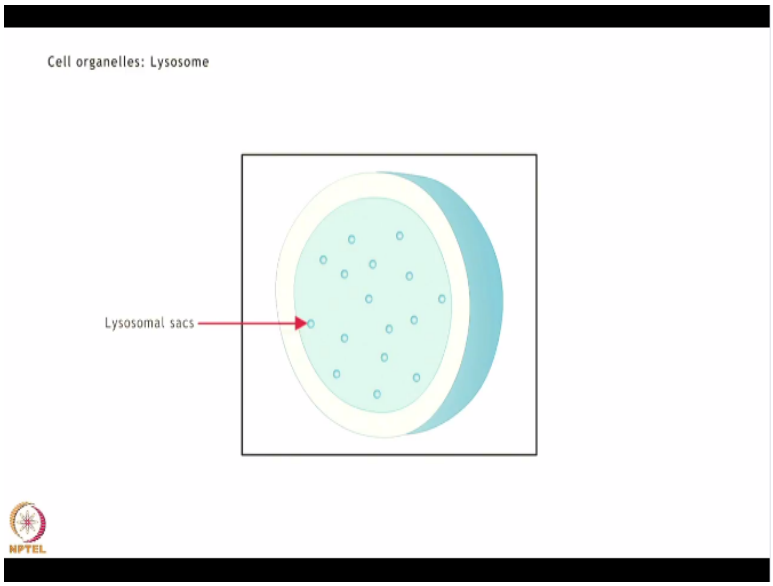

Lysosomes are found exclusively in animal cells for degrading any intracellular debris. They contain hydrolytic enzymes within sacs which can digest and degrade any unwanted material when released. Peroxisome is an organelle containing enzyme like catalase that are responsible for protecting the cell against free radicals and peroxides.

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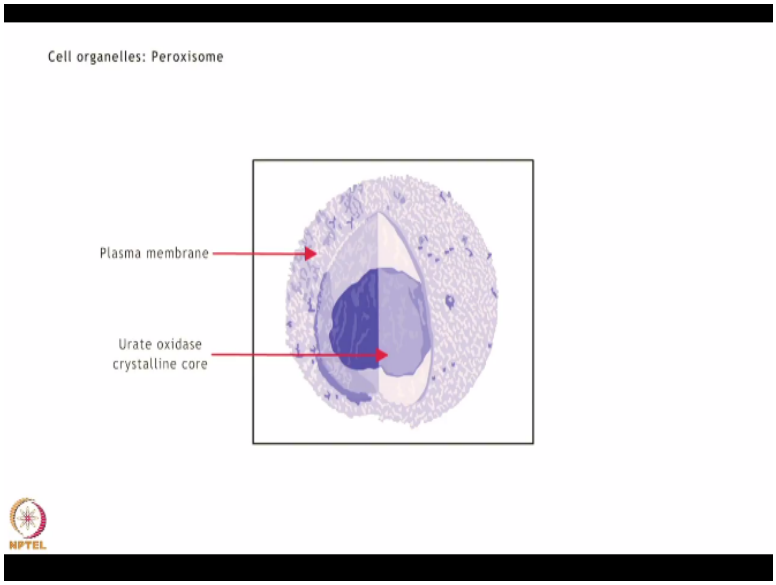

They also play a role in metabolism of very long-chain fatty acids. They have a single membrane and no independent genetic system. So now let us think about another topic which is cell communications.

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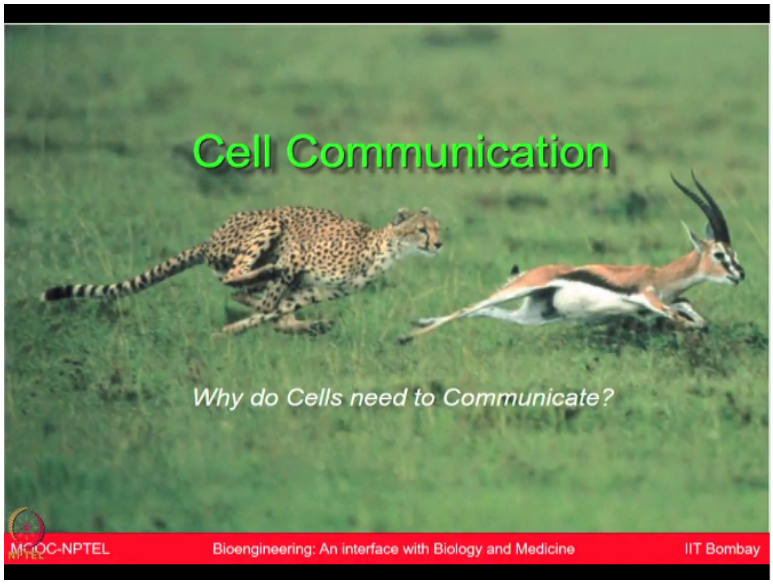

How cells communicate to each other and you know why at least they do need to communicate to each other is very important to know. So let us think about you know the cell communication, why it is crucial?

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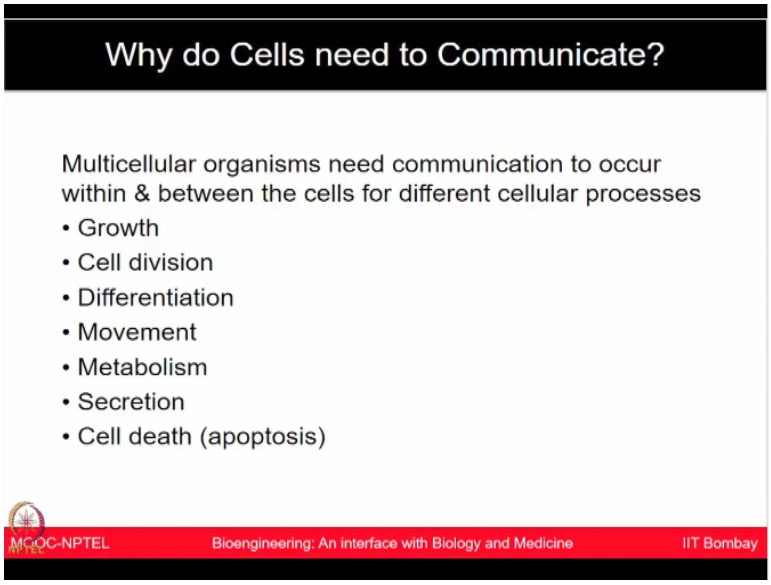

So for many different processes to happen especially all the cellular processes like growth, cell division, differentiation, moment, metabolism, secretion, cell death. For many of these processes to happen, the cells need to communicate. The communication or the signaling processes could be 2 types, it could be a short-distance signaling or it could be long-distance signaling.

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So let us first look at the short-distance signaling which is how the cells communicate by the direct contact and especially the local signaling could be performed with the cell junctions.

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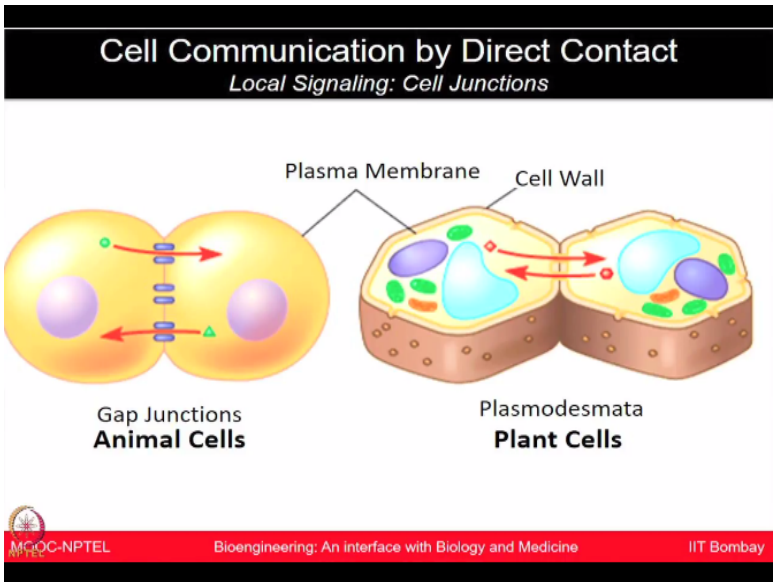

So in the images shown here is for the animal cells; we have gap junctions, in case of plant cells; there are plasmodesmata. The animal and plant cells they possess cell junctions for example gap junctions or plasmodesmata which directly connect the cytoplasm and cell junctions actually allow molecules to pass really between the adjacent cells. Now let us look into the cell-cell recognition.

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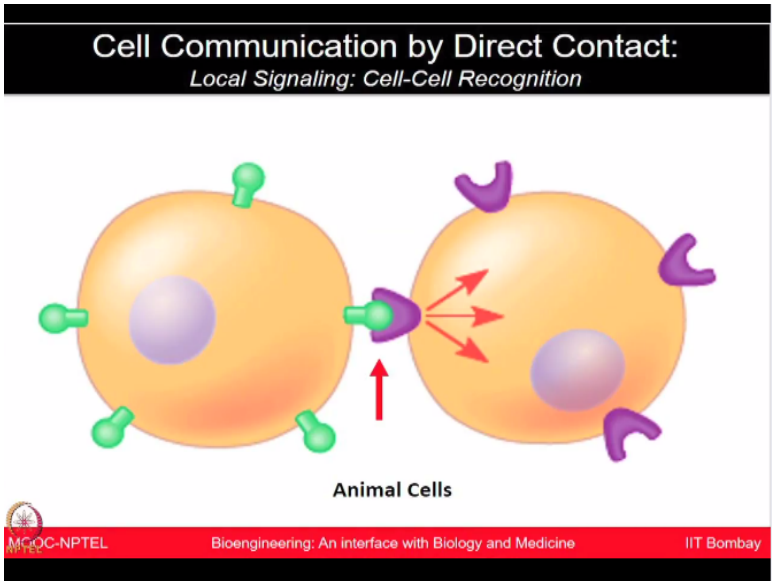

So animal cells can communicate by the direct contact between the membrane bound cell surface molecules and that is actually required for many important processes like if you think about in many development or immune response etc this becomes very crucial.

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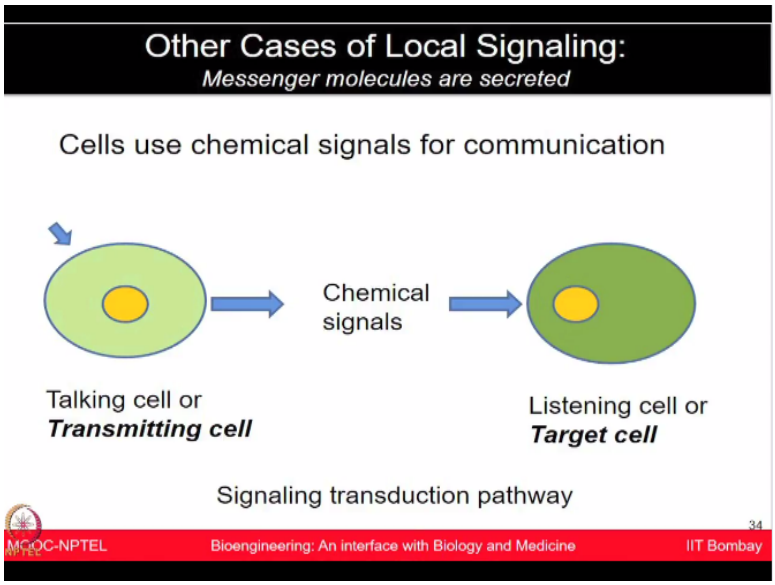

Let us now think about you know various messenger molecules which are secreted which are you know other cases of local signaling. So cells use some of these chemical signals for communication and those are you know very crucial for signal transduction pathways to happen in which way a cell which is now shown on the left side a talking cell transmitting the chemical signals.

And then another cell which is the listening cell or the target cell perceive those chemicals and that actually you know communicates and creates the signal transduction pathways.

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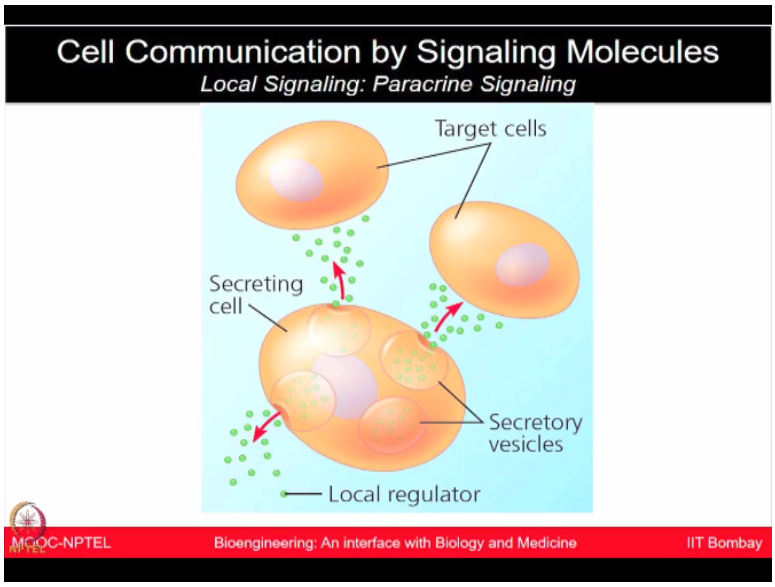

So there are different examples of local signaling. For example, paracrine signaling where local regulators they influence cells the nearby target cells by discharging the molecules, for example the growth factors into extracellular fluids and these growth factors then stimulate the nearby target cells to grow and divide which is a part of the paracrine signaling shown here with the growth factors.

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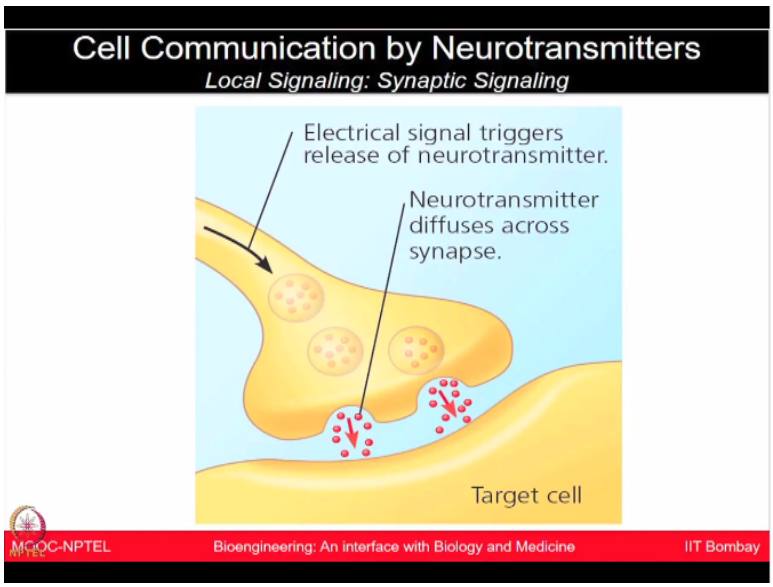

Then let us talk about the synaptic signaling which is you know very important for the neurotransmission. These are specialized local signaling which are found in the nervous system. So nerve cells they release neurotransmitters and those molecules passes from the synapse and stimulate the target cells. So that is you know another way of thinking about the

local signaling, how the synaptic signaling or the neurotransmitters play an important role over there. So these are the part of the short-signaling, some of the examples we talked.

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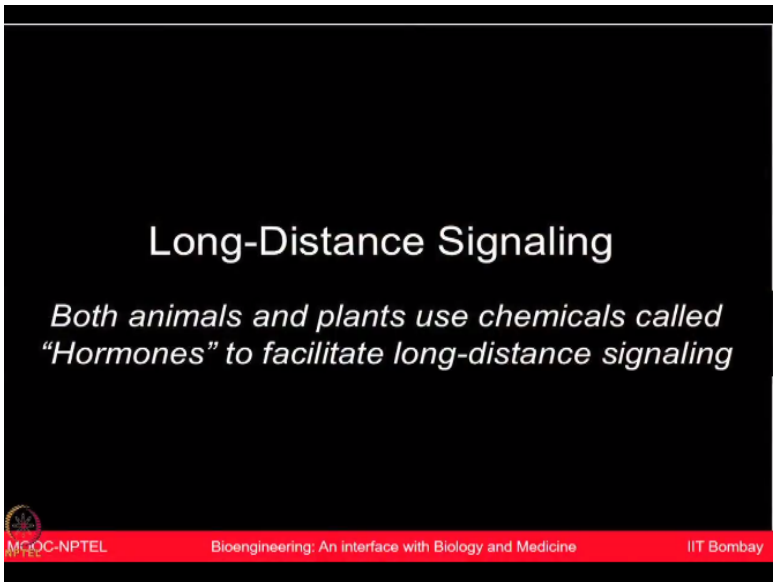

Now let us think about the long-distance signaling. So both animal and plant cells they use chemicals called hormones which facilitate the long-distance signaling.

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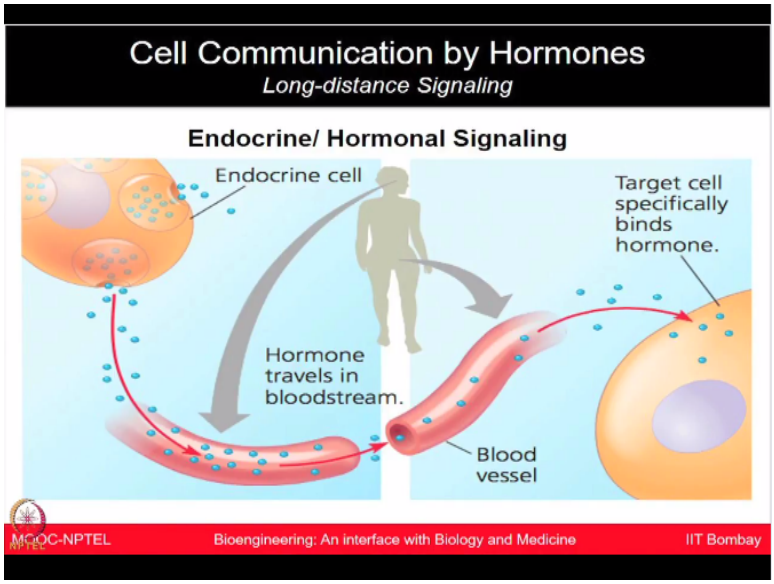

So I have shown you here endocrine or the hormonal signaling. These are the specialized endocrine cells which secrete hormones into the body fluid or the blood. These hormones then travel where the circulatory system to the other parts of the body and some of the examples of this includes the insulin which regulates the sugar level in the blood. For the long-distance signaling then we have the plant growth regulators.

These growth regulators they moved through the cells by the process of diffusion and then you know there are many examples of plant growth hormones like ethylene which actually helps to promote the fruit ripening.

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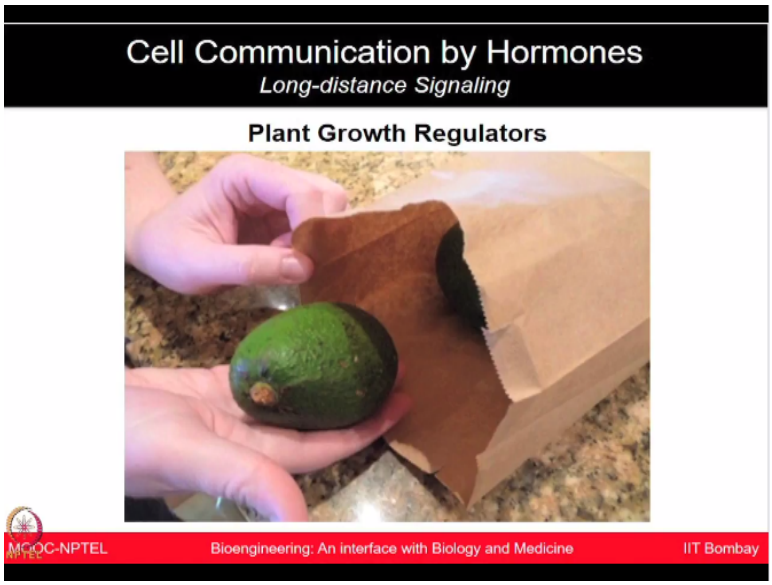

So if you pick you know a green fruit and then now if you are able you want to speed up the ripening of them you can actually you know add ethylene hormone that will stimulate the fruit ripening process. Also think about you know why when you are having the apples, when that is stored in the bins they actually flush with the carbon dioxide. So think about the role of these hormones and how they govern even the fruit ripening processes.

Now you know thinking about how to accelerate these processes and how to control them.

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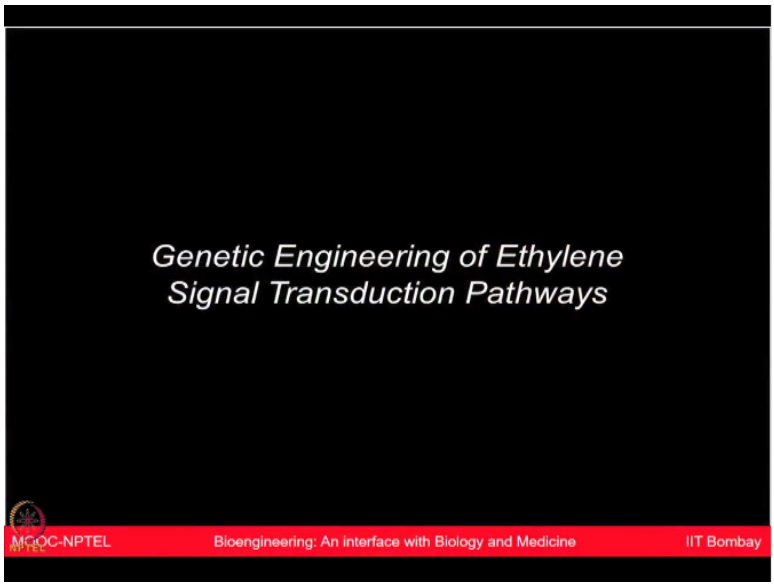

Scientists in the plant biotechnology and genetic engineering era, they are looking at the ethylene signal transduction pathways. So they are thinking about how to use genetic engineering to block the transcription of a gene which could be required for the hormone ethylene synthesis.

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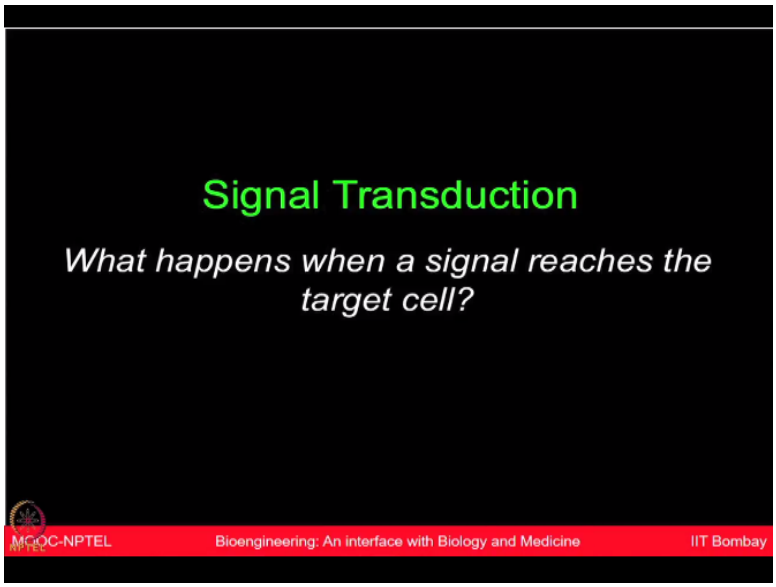

And therefore if you want to have the you know tomato fruit ripening, it can be done on the demand because you know that when to accelerate their gene and when you can trigger the ripening of the fruit. Signal transduction is very important which governs you know many important cellular activities. So let us think about what happens when a signal reaches from one cell to the other target cell.

And the ability of the cell to respond is determined by whether it has a specific receptor molecules that can bind to the signal molecules or it does not have receptor molecules.

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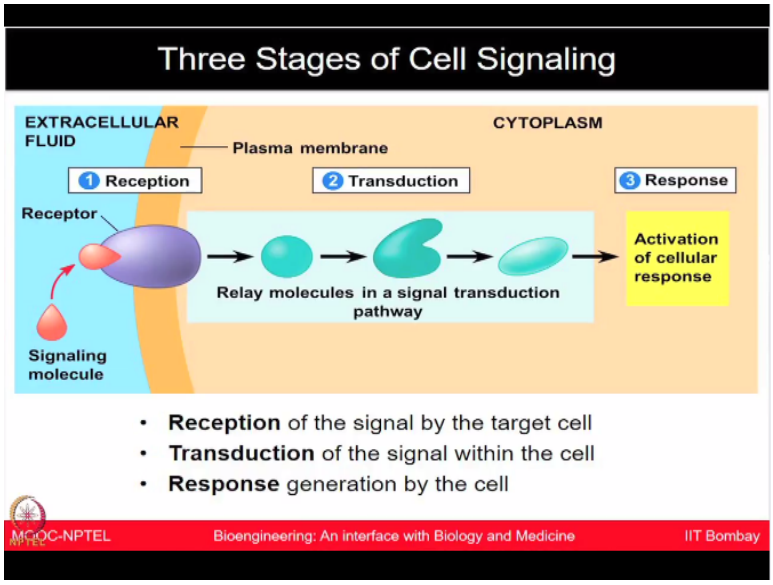

So let us look at the 3 major stages of cell signaling. First is the reception where the signals are received by the target cell and then the signal has to transduce, within the cell it has to move from like a relay race when the molecules has to relay from one to other molecules and then a response has to be generated by the cell which is activation of the cellular responses to happen.

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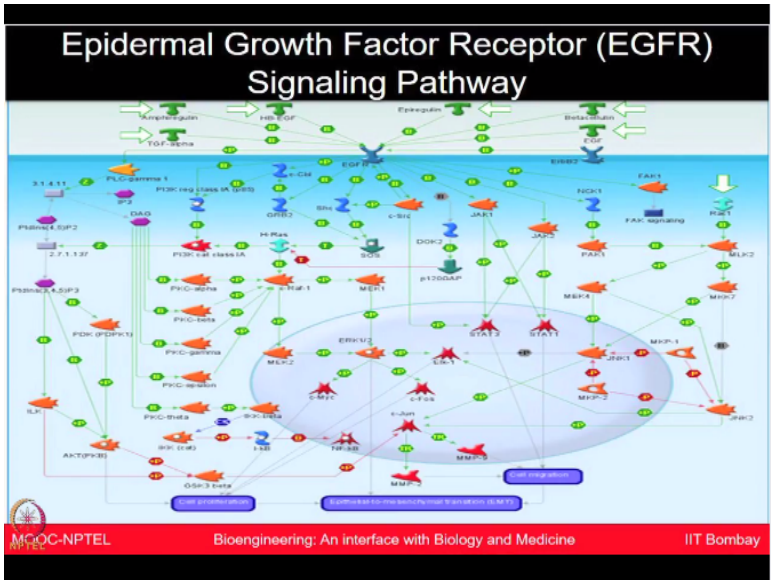

So shown here is one of the complex signaling pathway of epidermal growth factor receptors or EGFR. It is sure that you know how many molecules, how many you know the connectors are involved to just regulate one particular signaling pathway and you know any of these aberrations actually happening in the cell may result into various disorders and you know EGFR pathway dysregulation have been found into many diseases especially in different type of cancer as well alright.

So now to just summarize what we have discussed in today's lecture.

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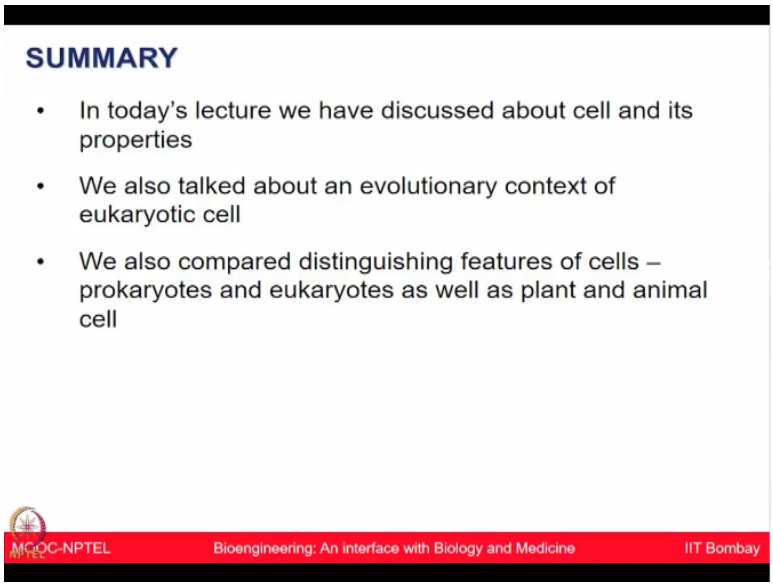

We started talking about a cell and its properties, you know it was very brief just to kind of remind you about the cells property. We talked about in which way specialized organelles like mitochondria and chloroplasts would have got evolved. Some of the evolutionary context to that we discussed. Then, we you know had a broad overview of prokaryotic and eukaryotic cell so as the plant and animal cells.

And then we kind of moved on to think about the cell communications, how cells communicate and different type of signaling from the short-signaling to the long-signaling and this kind of you know gives you some sort of you know a good start of understanding the life processes and the cell and different you know cell organelles. We will continue our discussion about you know these important fundamental concepts in the next lectures. Thank you.

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References

• Campbell Biology - Reece, Urry, Cain, Wasserman, Minorsky, Jackson 10th Edition, Pearson

•*Acknowledgment*

Animations: In house animations OSCAR project, IIT Bombay