Course Name: I Think Biology

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W4L20_Cell Cycle

Hello, in this lecture we pick up from the last one where we started talking about cells and we will talk about today one of the most important things that cells do which is go through the cell cycle and actually divide. Right? So as we start, let's first begin with observing cells dividing. So this is a movie of a mesenchymal stem cell. So this is a stem cell that can eventually differentiate into muscle cells or bone cells and I just want you to take a few seconds to observe this video as it's playing on repeat to see what's happening. You may already be familiar with some of the processes so you will see just before when the cell is still a single cell you will see some entity that looks a bit like the nucleus. I'll point this out with my cursor and you also see that DNA starts to get split up and there's a mitotic spindle.

This is the basically string-like structure that you see as the cells pull apart. Right? So as you're watching this video there's lots of questions that you can think about right. Why do cells divide? What do you think needs to happen before a cell can divide in the first place and so on. So let's, let's look look at some of these questions.

So the first of course as I said is why do cells divide but we can also ask what triggers cell division. So when does a cell decide that it needs to divide? What are the things that the cell has to do before it can actually divide and how can we study cell division right because of course cells are micrometers in length and what are the different ways that we can study them. One is of course they are very small. It's how to see them but then also how do we know what are the biochemical processes or even the genetics that are involved in cell division.

So there are actually different kinds of cell division. The first is binary fission. Binary fission refers to essentially cell division that is actually happening for the purposes of reproduction and this refers to unicellular organisms. So most many bacteria for example divide by binary fission and this really is what the name implies that the cell divides into two right the hence the term binary. And it goes in order to go through binary fission first the DNA has to get replicated. As the DNA is replicated the DNA in the form of chromosomes have to get segregated and then the cell has to go through a process called cytokinesis which is exactly where the cytoplasm is split

into two and you actually form two cells. Now mitosis and meiosis occur in multicellular organisms right.

So mitosis happens just as pictured here right where there is you know in red and green here are chromosomes. These chromosomes get replicated and as you can see they're aligned along this sort of plate-like zone and after they get aligned they are pulled apart and eventually you go back to making cells that are more or less exact copies of what we began with right. So they have the same amount of DNA and they will also get to be about the same size. Meiosis is different. Meiosis takes place where you start off with a certain amount of you start off with a diploid cell so there are two copies of each chromosome as you can see here and then once this the initial replication happens these are aligned along again along a kind of plate like structure but actually the cell goes through two rounds of division.

Here is the first round of division you see that here and then eventually you go through a second round of division where you get cells that have half as much DNA as you had in the initial starting condition, so you go from being a diploid cell to being a haploid cell . So you have half the amount of DNA and these are what are the precursors to gametes so they are the you know basically sperm and egg in organisms like humans right and these are eventually would have to combine together to form the fertilized egg right. And once the fertilized egg is formed that has the same amount of DNA as the diploid cell that we began with.

Okay so let's go over this in a little bit more detail and do a comparison across the three different cell types. So binary fission and mitosis are actually quite similar in the sense that both have to do with sort of asexual reproduction which means that you end up getting a cell that is exactly a copy of what you began with or it should be a copy unless something has gone wrong and you get two daughter cells right. And the daughter cells are in the case of mitosis if you start off with a diploid cell you end up with two diploid daughter cells as well. The primary function for binary fission as I mentioned earlier is reproduction so for example unicellular yeast divide by binary fission bacteria do that and that's really to reproduce right to produce more copies of the entire organism which in this case is a single cell.

On the other hand for mitosis the function is can often just be growth or repair as well right so if you I don't know scrape some skin you will eventually need to make more skin cells right and this happens through mitosis. So, another thing that you will note here is that in the case of binary fission DNA replication and like the DNA starts to replicate as division and the cytokinesis actually already begins, but in the case of mitosis replication has occurred, DNA replication has occurred much before the cell begins to divide right. And in both cases the cytoplasm is actually divided through cytokinesis.

Now meiosis on the other hand is a process that is involved for sexual reproduction where you begin with a diploid cell and end up with four haploid daughter cells, right compared to mitosis

where you end up with two diploid daughter cells and meiosis is the process through which we produce gametes right. What I mean by gametes are the sexually reproducing cells of the sperm and egg and again cells divide through the process of cytokinesis but because two divisions take place cytokinesis occurs twice.

So just a little bit more detail we won't go into all of the nitty-gritties but it's important for us to have a good idea of what is involved in the process of cell division and we talk about mitosis briefly okay. So mitosis is part of the entire cell cycle okay. After mitosis there are gap phases so this is the G1 gap phase, S stands for synthesis and G2 is another gap phase.

So when a cell has to undergo division the S phase is where actually DNA replication occurs. It can also go through G0 which is basically a rest phase where the cell is sort of put into stasis before it can continue to go into the cell cycle okay. So here's a few more details about the cell cycle. This is when the cell is in interface and in interface really the cell is just sort of sitting there and it's carrying out its sort of daily daily functions. It isn't actually dividing right.

And then these phases prophase, prometaphase, metaphase, anaphase, telophase and cytokinesis are the phases of mitosis right. And what you see here is actually you should note that there are sort of two overall let's say structures that are forming or functions processes that are taking place and in yellow you see what is called the mitotic spindle forming okay. So this is a spindle that's made up of microtubules and you will see that over the course of mitosis the spindle actually stretches out and occupies the most of the cell and it forms these fiber like structures and in the metaphase is when these spindles when they're attached to the chromosomes which is what you see in purple. Then anaphase, I always remember anaphase as a for apart which is when these chromosomes the duplicated chromosomes are pulled apart and following this the cells start to divide and the cytoplasm is split up through the process of cytokinesis right.

Okay so there's a lot of technical detail here but the important part is for you to remember that there is a kind of let's say stereotypical process through which most cells go through when they are undergoing mitosis, yeah.

Okay, so I've as as I said most cells go through this kind of a process right and it's typically how we study the cell cycle is that there is a mitotic spindle that there is you know these sort of steps through mitosis that the cells go through prophase, metaphase, anaphase and then followed by cytokinesis right. And so in our heads we tend to picture cell division exactly like this and in fact even the movie that I showed you initially of the stem cell looks somewhat like this right if we slowed it down we may have actually identified those different steps. But of course as usual as is the case in nature there are many examples where cell division is sort of unusual. It doesn't quite look like the image that we looked at before and I just want to give you a few examples of this.

So here's an image of a stentor so a stentor is a single cell single celled organism right and it is its nucleus and its DNA it's sort of genetic material is organized in a macronucleus and that's what you see and I hope you can see my cursor that looks a little bit like beads on a string so that's a nucleus right. And when the cell divides this is a single celled organism as I said that is found in freshwater and when the cell divides it doesn't, it doesn't divide the way that we saw earlier naturally because it doesn't have the circular shape first of all but also it divides by splitting and what I mean by splitting is when it is dividing, right you actually see first of all you should observe what the macronucleus looks like it first condenses it you know it loses its beads on a string kind of a shape, okay. And it becomes a sort of coarser structure and then it's really amazing. I really recommend that you go and you know say search on YouTube for looking for stentor cell division and you actually see that is a second cell is pulled out of the first cell so and then the cells actually split.

The other really interesting thing about the single celled organism is that it can also regenerate, so you know we hear about organisms that can regenerate so for example lizards can regenerate their tails right. Lizards In you that may be crawling around on your ceiling, if you cut off their or if not if you cut off but even if they their tails are you know pulled off of their bodies the tails can regenerate a little bit. So if you think about that kind of regeneration it involves many cells right this for a multicellular organism but stentor is really interesting because it's a single celled organism and remember when we talked about in the previous lecture the cell is the fundamental unit right and it's a way to compartmentalize the environment and the contents of the cell.

So when you cut the cell it's really surprising that there's an organism like stentor where that individual cell can also regenerate it's not that the cell just sort of lives and dies off but it actually has the capability as you can see in this the bottom panel it actually has capability to regenerate itself even though it's sort of been opened up to the environment when it's been cut off.

So yeah, so this is an example of pretty unusual cell division right, another example a very recent one where people have looked at skin cells in zebrafish. So one of the things we often emphasize about cell division, especially cells that are going undergoing mitosis an organism really wants a cell to make an exact copy of itself right. You wouldn't want let's say the cell to have less DNA or more DNA because as we discussed DNA are the instructions for the cell right sorry DNA is the instructions for the cell of what to do, how to behave, how to function, how to react to any kind of environmental stimuli etc.

And you wouldn't want it to be the case where cell division is happening and exact copies are not being made because of course when there is such an sort of error in synthesis it can lead to cells that are non-functional or perhaps even sort of a pathogenic state right. But it turns out that in some cases there are some organisms where this is okay it is okay for cells to be to not be exact copies of themselves this is an example from a paper in 2022, where people have shown that this is an image and again.

I recommend you to go to YouTube and watch this video they've actually shown that cells divide by what they've called a synthetic fission so that means that they DNA can often be segregated completely asymmetrically right and so one cell may receive one copy of the DNA, one cell may not receive copy of the DNA, and it seems to be almost haphazard. They haven't quite figured out why this occurs but they believe that it could be because during development right the surface of the basically the surface area of the zebrafish is expanding so quickly that cell division is unable to keep up right.

And so what the zebrafish does is it just keeps dividing and it's not so worried about making cells that are perfect copies right. But it needs something to cover the surface of the body so it needs those skin cells and after development is complete wherever there are errors wherever a synthetic a synthetic fission has occurred it goes back and repairs those cells. So that's a really sort of a new kind of unusual kind of cell division as well. Then there is symmetric and asymmetric cell division. So symmetric cell division is really what we've talked about already where you know something like mitosis where or at least that's how we've talked about mitosis where the mother cell produces daughter cells that are look exactly the same right so this is what's pictured on the left hand side.

So stem cells, the ones that have a potential to divide into any to divide and differentiate into any other kind of specialized differentiated cell have I often have the ability to undergo symmetric cell division. So we make exact copies of each other, but they can also undergo asymmetric cell division. And what this means is that there are as you can see in this image on the right hand panel like the stem cell, as it's dividing there are these little dots right. So these are cell fate determinants, what we mean by that is there are sort of biochemical entities that help determine the fate of the cell right. And by fate here we mean it's differentiated state, so does it become that they specialized and does it become a precursor to be a muscle cell or a bone cell, something of that sort right.

And so what's imaged here in this cartoon version of asymmetric cell division is that on the top side there are these little pink dots right. So, this is one set of a cell fate determinant on the bottom half the precursor of the other cell are green dots and these are basically cell fate determinants for a different kind of cell. and what you see here is that once the cells divide, this cell has gone through an asymmetric cell division and it results in one cell being a copy of the mother cell which is the stem cell. And the other cell the second one has differentiated right, so it is now slight ever so slightly different from the mother cell and this is actually a very special feature of stem cells and this occurs a lot a whole lot in during the course of development and it's actually you know a very special special feature also of most plants sense most plant stem cells.

Okay, and of course there are very interesting example is cancer cell divisions right. So if you have cell division take place let's say through regular mitosis. If a mutation occurs right there is some sort of error in replication for example this might lead to a cell of of a different kind

forming through mitosis right. And once a mutation occurs, mutations can continue to occur and these can accumulate and this often leads to cells of say different size and shape as well. So again this is an example of of let's say mitosis where the daughter cells and the progeny of the daughter cells actually lead to very very different kinds of cells and that this can this sort of let's say abnormal cell division can lead to a really serious problem such as cancer.

Okay so this is just an overview of the different kinds of sort of unusual cell divisions that we've learned about one is the cell splitting in the example of the set of the stentor. Asymmetric division we've seen in two different examples one was for the stem cells right where you get us the outcome of mitosis can be again a cell that is exactly similar or exactly the same as a mother cell and one that has differentiated. We also saw this example of asynthetic fission where zebra zebrafish skin cells can actually divide without actually worrying so much about DNA segregation being exactly the same among the daughter cells, and then between cancer cells we saw that cell divisions and accumulating mutations in the DNA can lead to cells of very different size and shape.

Okay so I want to briefly talk about how you know our understanding of mitosis and the way we think about it has been challenged actually by looking at these unusual examples. And why this is important is because throughout this course and throughout basically most of what we learn, we tend to categorize the things that we learned right. So we learned about mitosis and we said it goes through these different phases right. There is prophase, metaphase, and so on.

So we talked about these different phases of mitosis, and we said that this is the there are these kinds of buckets in which we can put in mitosis. But one thing is for sure is that mitosis is a continuous process, it's not as though there is a switch, and a switch turns on, and then the cell is going through metaphase or then that there is another switch and the cell is going through anaphase right. It is a continuous process but it makes it easier for us to understand mitosis to put this process into these kinds of buckets right and it gives our knowledge a kind of simplifying structure right. It gives structure to help us think about processes.

But, as we discovered after that there are many different kinds of cell division as well right. And it isn't that we can necessarily put everything into those buckets. But, we still have to call those processes mitosis right. So we have to ensure that every time we are thinking about categorizing knowledge right. We have to ensure that we have to be open to processes that don't quite fit into those buckets but are still the same right. So we shouldn't let categorizing while useful we shouldn't let it blindside us to new ways of thinking right. So for example when people were studying the zebrafish skin cells dividing because they didn't see this equal segregation of of genetic material of the DNA they could have just said well this isn't mitosis right or this isn't cell division but it is. It's just that it's an unusual kind of division right.

So in summary in this lecture we've talked about three different kinds of cell division: binary fission, meiosis and mitosis. I would encourage you to go up and look up resources to look at

the those processes in a lot of detail. We have not covered those in detail in this session mainly because we wanted to expose you to different ways of thinking about the cell cycle. We then talked about briefly the different phases of the cell cycle and mitosis. We then covered really unusual kinds of cell division and cell cycles and we briefly discussed how categorizing knowledge can be useful in terms of simplifying our ways of thinking but that we should also not allow it to blindside us from making new discoveries.