Mitosis – How a Single Cell Develops into the Trillions of Cells in a Human Body

Every person started as a single cell – a fertilized egg.

1a. How many cells do you think there are in a newborn baby?

1b. How many cells do you think there are in your body?

1c. How do you think a single cell developed into all the cells in your body?

To understand how the trillions of cells in your body were made, you will first learn how a cell divides into two daughter cells and then learn how repeated cell division can produce so many many cells.

Our discussion of cell division will focus on how each daughter cell gets a complete set of chromosomes with a complete set of genes. In the next section you will learn why chromosomes and genes are so important.

Chromosomes and Genes

Each chromosome contains a long molecule of DNA. Each DNA molecule contains many genes. A gene is a segment of a DNA molecule that gives the instructions for making a protein.

Many of the proteins are needed for normal cell structure and function. Therefore, each daughter cell needs to have a complete set of chromosomes with all of the genes that provide the instructions for making these needed proteins.

2. When a cell divides into two daughter cells what steps do you think are needed to ensure that both daughter cells get a complete set of chromosomes?
Different versions of the same gene are called **alleles**. Different alleles give the instructions for making different versions of a protein. This table shows examples for two human genes.

<table>
<thead>
<tr>
<th>Allele</th>
<th>Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Normal enzyme for making melanin, a pigment molecule that gives color to our skin and hair</td>
</tr>
<tr>
<td>a</td>
<td>Defective enzyme that cannot make melanin</td>
</tr>
<tr>
<td>S</td>
<td>Normal hemoglobin</td>
</tr>
<tr>
<td>s</td>
<td>Sickle cell hemoglobin</td>
</tr>
</tbody>
</table>

3. In the above table, circle each symbol that represents part of a DNA molecule. Underline each word that is the name of a protein.

For humans, each cell has 23 pairs of **homologous chromosomes**. In a pair of homologous chromosomes, both chromosomes have the same genes in the same locations. A gene may have different alleles in the two homologous chromosomes (e.g. Aa) or a gene may have the same allele in both chromosomes (e.g. SS).

A **genotype** is the combinations of alleles in a person’s cells. **Phenotype** refers to observable characteristics. This table shows how different genotypes result in the production of different proteins which in turn result in different phenotypes.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Protein</th>
<th>Phenotype (characteristics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA or Aa</td>
<td>Enough normal enzyme to make melanin in skin and hair</td>
<td>Normal skin and hair color</td>
</tr>
<tr>
<td>aa</td>
<td>Defective enzyme that cannot make melanin</td>
<td>Very pale skin and hair color; albino</td>
</tr>
<tr>
<td>SS or Ss</td>
<td>Enough normal hemoglobin to prevent sickle cell anemia</td>
<td>Normal blood; no sickle cell anemia</td>
</tr>
<tr>
<td>ss</td>
<td>Sickle cell hemoglobin, which can cause red blood cells to become sickle shaped</td>
<td>Sickle shaped red blood cells can block blood flow in small blood vessels, causing pain, organ damage, anemia; sickle cell anemia</td>
</tr>
</tbody>
</table>

4. Suppose that Jim’s cells have the pair of homologous chromosomes shown in the circle above.
   - What is Jim’s genotype? **aass** ___ **AaSS** ___ **AASS** ___
   - Is Jim an albino? **yes** ___ **no** ___
   - Which does Jim have? **sickle cell anemia** ___ **normal blood** ___

5. Explain why a person with the **aa** genotype has very pale skin and hair color. Include the words enzyme and melanin in your explanation.
Mitosis – How Each Daughter Cell Gets a Complete Set of Chromosomes

Almost every cell in your body was produced by a type of cell division that includes these three basic steps.

- **Interphase** – The cell prepares for cell division by making more cytoplasm and making a copy of each chromosome. As a result of DNA replication there are two identical copies of the DNA.
- **Mitosis** – The two copies of each chromosome are separated to opposite ends of the cell.
- **Cytokinesis** – The cell divides into two daughter cells, each with a complete set of chromosomes.

7. This figure shows mitosis and cytokinesis for a cell that has one pair of homologous chromosomes. Match each blank with the appropriate description.

   a. At the beginning of mitosis, DNA has been replicated and condensed into sister chromatids.
   b. In the daughter cells, DNA has unwound into long thin threads so genes can become active.
   c. Spindle fibers separate the sister chromatids into independent chromosomes. Cytokinesis begins.

8. The chromosomes in the second and third drawings in this figure have sister chromatids. Explain why the chromosomes in the fourth drawing do not have sister chromatids.
9. Which would have the same alleles for every gene?
   a pair of homologous chromosomes ___ or the sister chromatids in a chromosome ___
   How do you know?

10. What would go wrong if a cell did not replicate its DNA before beginning mitosis?

11. This figure shows six stages of cell division for a cell that has two pairs of homologous chromosomes, but these stages are not shown in the correct sequence.
   - Draw arrows to show the correct sequence for these stages of cell division.
   - Use an * to mark the arrow which shows when sister chromatids separate to form individual chromosomes.
   - Label the drawing that shows the beginning of cytokinesis.
Modeling Mitosis with One Pair of Homologous Chromosomes

Complete each step in this modeling procedure and check the box.

- Get a pair of model homologous chromosomes, one with the a and s alleles and the other with the A and S alleles. Both model chromosomes should be the same color, but one model chromosome will have a stripe on both chromatids to indicate that, although these two homologous chromosomes have the same genes, they have different alleles for many of their genes. The shape of the model chromosomes indicates that the DNA has already been copied and condensed into compact sister chromatids.

- Sit across from your partner and use your arms to represent the spindle fibers that move the chromosomes. Begin mitosis by lining up the model chromosomes in the middle of the cell (see figure below). Use string to indicate the cell membrane that surrounds the cell that contains these chromosomes.

- Demonstrate how the sister chromatids of each chromosome are separated into two separate chromosomes which go to opposite ends of the cell.

- Now the cell is ready for cytokinesis which will produce two daughter cells, each with a complete set of chromosomes. Rearrange the string to demonstrate cytokinesis.

- Prepare to model mitosis again by putting the sister chromatids of your model chromosomes back together, as shown above. (This does not correspond to any biological process – it is a substitute for replicating the DNA in each chromosome.)

12. As you model mitosis again, record the results in the figure below. Draw and label the chromosomes in the oval and in the daughter cells.

13. The original cell had the genetic makeup AaSs.
   - What is the genetic makeup of each daughter cell?
   - Do the daughter cells have the same genetic makeup as the original cell?
Multiple Pairs of Homologous Chromosomes
Each human cell has 23 pairs of homologous chromosomes. Each of these pairs of homologous chromosomes has its own unique set of genes. For example, human chromosome 11 has the genes that can result in albinism and sickle cell anemia. (Chromosome 11 also has more than 1000 other genes.) Human chromosome 12 has different genes, including a gene that can result in alcohol intolerance. This table shows the effects of the L and l alleles of this gene.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Protein</th>
<th>Phenotype (characteristics)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LL or Ll</td>
<td>Defective enzyme that cannot dispose of harmful molecules produced by the metabolism of alcohol</td>
<td>Alcohol intolerance (skin flush and discomfort after drinking alcohol)</td>
</tr>
<tr>
<td>ll</td>
<td>Normal enzyme that disposes of harmful molecules produced by alcohol metabolism</td>
<td>Not alcohol intolerant (no skin flush or discomfort after drinking alcohol)</td>
</tr>
</tbody>
</table>

Modeling Mitosis with Two Pairs of Homologous Chromosomes
➤ Get a second pair of model homologous chromosomes, one with the L allele and the other with the l allele. Model mitosis for a cell with two pairs of homologous chromosomes.

14. Record the results of your modeling in this figure.

15. The original cell had the genetic makeup AaSsLl. What is the genetic makeup of each daughter cell? Do the daughter cells have the same genetic makeup as the original cell?
How Repeated Cell Division Can Make Trillions of Cells

You have learned how a single cell divides into two genetically identical daughter cells. How could this type of cell division begin with a single cell and produce the trillions of cells in a human body?

16a. To begin to understand how so many cells are produced, complete this table. Show the number of cells an embryo would have if every cell divided each day, so the number of cells doubled each day.

<table>
<thead>
<tr>
<th>Day</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td># Cells</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

16b. On day 2 there was only one more cell than on day 1. On day 6 there were _______ more cells than on the previous day. On day 11 there were _______ more cells than on the previous day.

16c. Explain why more cells were added on day 11 than on any previous day.

As an embryo grows, the number of cells available to divide increases, so cell division can add more and more cells each day. This explains how cell division can produce more than a trillion cells in a newborn baby, starting from a single cell just nine months earlier!

17. To summarize what you have learned, explain how a single cell developed into the trillions of genetically identical cells in your body. Include the following terms in your explanation:
   - alleles, chromosomes, cytokinesis, daughter cell, DNA replication, genes, interphase, mitosis, sister chromatids, spindle fibers.

18. Even in a fully grown adult, some cells continue to divide. Why is cell division useful in an adult who is no longer growing? (Hint: Think about what happens when you have an injury that scrapes off some of your skin.)