

# Cell Division and Complex Organisms

## Objectives

- Describe the purpose of the cell cycle
- Describe cell differentiation
- Explain how the cell cycle and cell differentiation help maintain complex organisms

## Key Terms

Cell cycle  
Mutations  
Diploid  
Stem cells  
Differentiate

Have you ever stopped to think about how you grew from a small infant and developed into the person you are today? The answer lies in the fact that you have more cells now than you did as an infant. In fact, you began as a single, fertilized egg, and as you grew and developed, your cells went through constant rounds of cell division. During your lifetime, trillions of your cells will undergo the **cell cycle**. This process allows you to grow, heal, and maintain your vital tissues and organs.

## The Cell Cycle

Eukaryotic cells grow and divide through a series of events called the **cell cycle**. The cell cycle consists of the following stages: interphase, mitosis, and cytokinesis. During the cell cycle, a cell grows, prepares to divide, and then divides into two identical daughter cells. A cell spends the majority of its lifetime in interphase, and is then followed by a short mitosis and cytokinesis phase.

The cell cycle can be represented as shown in figure 1. It is a cycle that will continue to repeat as cells are needed for growth and maintenance in an organism. Cells will go through the cell cycle to grow and repair the body. As you age and get bigger, your cells are not becoming bigger. Instead, your body is producing more cells than you previously had. You start your journey through life as a single cell and by the time you are an adult you will have trillions of cells.

## Interphase

A cell spends 90% of its life in interphase, which includes  $G_1$ , synthesis, and  $G_2$ . These are growth and development stages. There is also a resting phase called  $G_0$  where the cell has exited the cell cycle.

$G_0$

When a cell is not actively needing to divide or when a cell has reached maturity, it will enter a resting phase known as a  $G_0$  phase. When a cell is in  $G_0$  phase, it is no longer participating in the cell cycle. An example of mature cells that will no longer divide are your neurons. However, some cells can reenter the cell cycle if they are triggered to divide again.

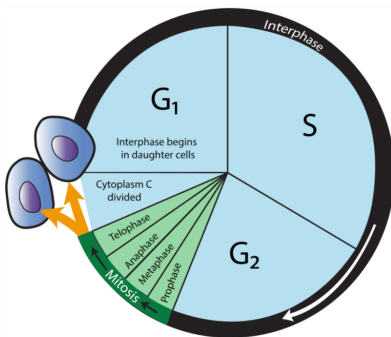


Figure 1

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$G_1$

This phase is characterized by cell growth to ensure that the daughter cells will be large enough to survive. In this phase, which stands for “Gap 1,” the cell grows larger, makes new proteins, and develops organelles. There is a checkpoint during this phase that ensures there is the required machinery for DNA synthesis that takes place in the next phase.

## *Synthesis*

From  $G_1$ , cells move into the S phase, or synthesis. This phase is characterized by the replication of the DNA found in the nucleus. The purpose of DNA replication is to make an exact copy of the genetic material, which will be passed onto each daughter cell during mitosis.

DNA replication begins when enzymes unzip the DNA molecule, forming two strands (figure 2). Then, nucleotides are added to each of the strands, following the rules of base pairing. For example, a section of the template DNA strand reading TGATC would be paired with the nucleotides ACTAG. At the end of the S phase, the cell contains double its normal amount of DNA. If the cell did not replicate its DNA prior to cell division, the daughter cells would not have the correct amount of DNA and would not be identical to the parent cell.



**Figure 2**

$G_2$

This is the last phase before the cell enters mitosis. During  $G_2$ , the cell grows and prepares for mitosis by producing the structures needed for the upcoming cell division. Another checkpoint at the end of  $G_2$  determines if the cell has the required components to proceed into mitosis and divide.

## **Mitosis**

Although it is the shortest phase of the cell cycle, mitosis is a time of great activity. Mitosis divides the nucleus, distributing DNA to each daughter cell.

### *Prophase*

The DNA condenses into chromosomes made up of two sister chromatids connected at the centromere. The chromosomes are now visible under a microscope. The spindle fibers form and start to spread from the centrioles. Towards the end of prophase, the nuclear envelope will break down and the centrioles will move to opposite ends of the cell.

### *Metaphase*

The centromeres that connect the two sister chromatids will attach to the spindle fibers that extend from the centrioles, and the chromosomes will line up at the center of the cell at the metaphase plate.

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## Anaphase

Sister chromatids separate at the centromere and are now known as *individual chromosomes*. The chromosomes move to opposite ends of the cell along the spindle fibers. As the chromatids are being pulled apart, they make the characteristic V shape. The cell also begins to elongate at the ends. At the end of anaphase, there will be a complete set of chromosomes at each side of the cell.

## Telophase

The chromosomes uncoil, the spindle fibers break down and disappear, and the nuclear envelope forms around each of the sets of chromosomes. The mass of the uncoiled chromosomes are called *chromatin*. The events of this phase are basically the opposite of prophase. In animal cells, the cytoplasm will start to pinch and form a cleavage furrow. In plant cells, the cell will start forming a cell plate along the equator of the cell.

## Cytokinesis

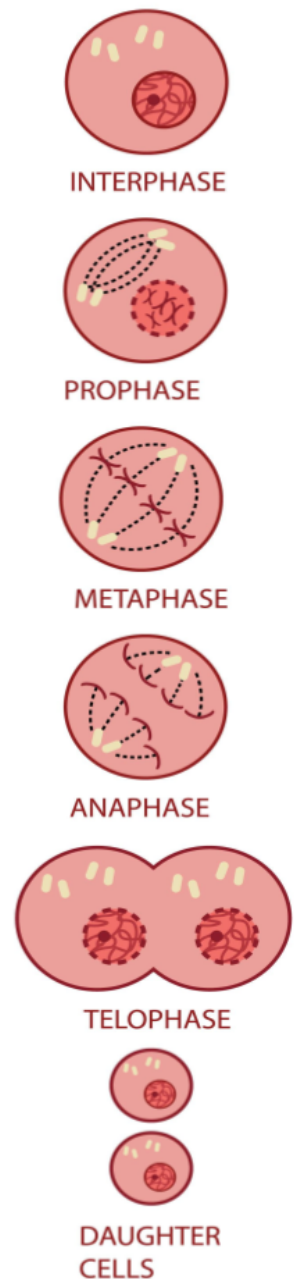
The final stage of the cell cycle divides the cytoplasm and separates the cell into two individual daughter cells that are exact copies of the parent. In animals, the cytoplasm is drawn in until it is pinched in two. In plants, the cell plate gradually forms a membrane and cell wall separating the two daughter cells. Figure 3 shows the cell cycle with cytokinesis producing 2 daughter cells.

### The Nature of Science in Action

#### Scientific Knowledge is Open to Revision in Light of New Evidence

Most scientific knowledge is quite durable, but is in principle, subject to change based on new evidence and or reinterpretation of existing evidence.

Advances in microscopes have allowed scientists to examine the process of cell division with greater magnification and resolution, supporting and advancing the understanding of the cell cycle.



**Figure 3**

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## The Result of Cell Division

At the end of one round of the cell cycle, two identical daughter cells are created from a single parent cell. These daughter cells are considered **diploid** ( $2n$ ) because they have two sets of each chromosome (one maternal and one paternal chromosome). Since they are identical, the parent cell is also diploid ( $2n$ ). This type of cell division will take place in somatic, or body cells, and is used for growth, repair, and a type of asexual reproduction in some organisms.

### Connect to Your World

How would the world be different if all the human babies born in one year were twins?

Only eukaryotic cells perform the stages of the cell cycle, including mitosis. Prokaryotic cells undergo a simpler form of cell division, called *binary fission*. It is a form of asexual reproduction, resulting in two identical cells. It begins when a prokaryote replicates its DNA and attaches the copy to one part of the cell membrane and the original DNA to another. The cell pulls apart, separating the copy of DNA from the original genetic material, forming two identical cells.

## How Often Do Cells Divide?

Most cells will grow and divide to make more cells at some point during their lifetime, but how often and the time to complete this process varies between cell type and organisms. For example, some cells such as skin cells, are constantly dividing to repair and replace dead cells. Other types of cells, such as nerve and heart cells, do not divide after they have become fully mature and specialized.

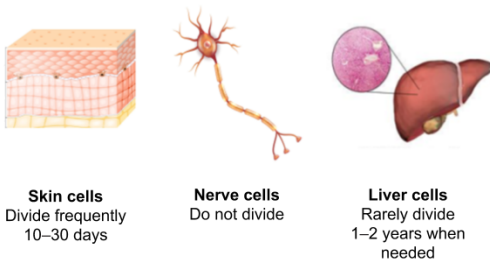


Figure 4

Figure 4 shows the relative rates of cell division among various cell types. Certain body cells are replaced when needed. Lung cells are replaced approximately every 2–3 weeks. That is why doctors say that lung damage from smoking can be reversed if a person stops smoking.

### Connect to Your World

How would the world be different if the cell cycle did not fix mutations?

## Disruptions in the Cell Cycle

The timing and organization of the cell cycle is important to the growth of an organism. Disruptions to the cycle can lead to diseases, including cancer. Organisms begin as a single cell and multiply into the billions of cells that make up living things. Cells increase in size, synthesize proteins, and develop organelles during the cell cycle. If errors, or **mutations**, occur that disrupt any part of the cell cycle, it can lead to disorders and disease.

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There are checkpoints throughout the cell cycle that ensure normal operation of the various stages of the cycle. For example, a checkpoint at G2 monitors the cell for any mutations that may disrupt normal cell function. If one is found, the cell does not enter mitosis. However, disruptions may still occur, especially when checkpoints are bypassed, as is the case with many cancers (figure 5).

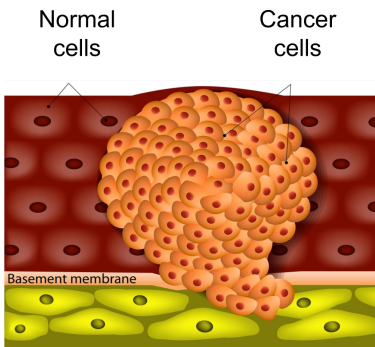


Figure 5

A high number of cancer cells have a defective p53 gene. This gene codes for a tumor-suppressing protein that regulates the cell cycle. When p53 is mutated, the cell cycle loses the ability to control normal growth.

Cancer develops when the cell cycle goes unchecked and cells begin to grow and divide uncontrollably. The rapid growth causes cells to amass into tumors. Not all tumors are cancerous. Benign tumors are also masses of cells, but they do not spread and infect surrounding, healthy tissue. Malignant tumors, on the other hand, are cancerous.

The cancer cells invade healthy tissue, absorb the nutrients the normal cells need, and prevent organs from functioning properly. Cancerous cells that reach the bloodstream can travel to other parts of the body and spread cancer to many organs. This process is called *metastasis* and is very difficult to treat.

It is not always known what causes disruptions in the cell cycle. It is often the result of a random mutation. However, scientists know that certain external factors, such as viruses, extreme physical or emotional stress, and aging can cause the cell cycle to go haywire. Toxins, or poisons, that mutate cells and result in cancerous cell cycles are called *carcinogens*. Common carcinogens include tobacco smoke, asbestos, radiation from X-rays and microwaves, and smog.

## Stem Cells and Cell Differentiation

Over the past several years, a debate has been brewing over the use of **stem cells**. Stem cells can be used to treat certain diseases and conditions such as spinal cord injuries, diabetes, arthritis, and heart disease. The sources of stem cells include umbilical blood, bone marrow, specially treated peripheral blood, and embryos. The use of embryos as a source of stem cells has stirred controversies over the past several years.

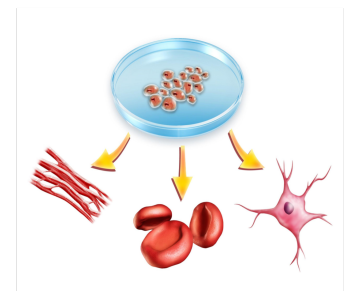


Figure 6

Interestingly, stem cells are unique because, while not specialized, they have the potential to specialize into a variety of cell types (figure 6). Since stem cells are undifferentiated, meaning they have not yet developed specific structures or functions, they can be used to replace unhealthy cells. Stem cells found in embryos are different than those stem cells found in adults because they have the potential to develop into any type of cell, whereas the adult stem cells are more limited in what type of



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cell they can differentiate into. As cells grow and divide in an embryo, they **differentiate** or become a distinct type of cell. For example, muscle cells and nerve cells in animals, and root cells and leaf cells in plants are differentiated. So what controls how cells know to differentiate into a wide variety of specialized cells with specific functions? Every eukaryotic, somatic cell, or body cell contains

similar structures, including a complete set of identical DNA. Even though every somatic cell in your body has the same DNA, it is how the DNA is expressed that determines what a cell will differentiate into.

Only the necessary genes, or segments of DNA (figure 7), that are needed to specialize a specific cell will be expressed. As certain genes in somatic, or body cells, are expressed, the cells become specialized to perform specific tasks the organism needs. For example, the cells found in the roots of plants differ from those found in their stems or leaves. This is because different parts of a plant perform different functions.

Root cells absorb minerals and water from the soil, while cells that make up the stem provide structure and height for a plant to hold up its leaves to sunlight. Leaf cells must express the genes that build structures for photosynthesis.

The same is true in animals. Differentiated cells perform different functions, so they express different genes. Red blood cells, for example, express the gene for the protein hemoglobin because it is necessary for transporting oxygen. Muscle cells are differentiated to build many mitochondria, which produce energy in a cell, because muscles are responsible for movement and physical activity. Bone cells provide strength, support, and protection to the body. Nerve cells are quite unique in their structure. Their shape is differentiated to receive signals from stimuli and pass them between the brain and the rest of the body. Epithelial cells are differentiated to control absorption and secretion.

External factors in the environment can affect cellular differentiation by disrupting gene expression. Certain genes may become activated or inactivated in response to triggers such as temperature changes, injury, exposure to chemicals, and lack of nutrients.

## The Nature of Science in Action

### Scientific Investigations Use a Variety of Methods

Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.

Scientists are using a variety of methods, tools, and techniques to investigate the differentiation of stem cells to differentiated cells.

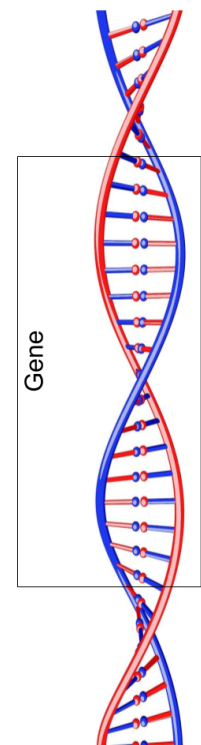


Figure 7

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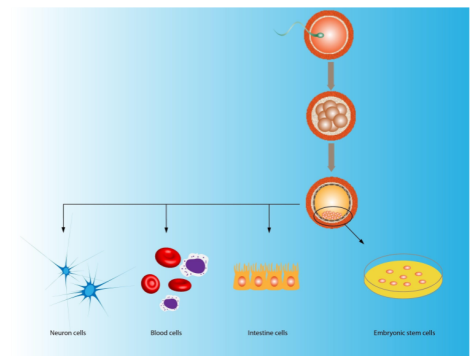
For example, when the body is infected with a disease, white blood cells of the immune system will express genes that produce antibodies. Injuries, such as cuts and wounds, will initiate the expression of genes in the cells of the injured tissues for clotting factors.

Temperature even determines male or female differentiation in some organisms. In certain species of alligators, eggs incubated at temperatures below 30 degrees Celsius will typically develop into females, while eggs incubated above 34 degrees Celsius will typically develop into males.

## Beyond the Classroom

Embryonic stem cells are a hot topic today in the medical world because of their ability to differentiate into any type of somatic cell. However, there are many people on both sides of the argument of whether or not use of embryonic stem cells is ethical.

Human embryonic stem cells capture the imagination because they are immortal and have an almost unlimited developmental potential. After many months of growth in culture dishes, these remarkable cells maintain the ability to form cells ranging from muscle to nerve to blood—potentially any cell type that makes up the body. The developmental potential of human embryonic stem cells promises an essentially unlimited supply of specific cell types for basic research and for transplantation therapies for diseases ranging from heart disease to Parkinson's disease to leukemia.



Use a variety of internet resources to learn more about embryonic stem cell research, how scientists plan to use them in medicine, and the ethical dilemma scientists face.

Write a one-page news article taking a stance on either side of the debate for the usage of embryonic stem cells for medical research. Make sure to include valid evidence supporting your stance.

# Cell Division and Complex Organisms

## Cell Division and Complex Organisms Review

### Reviewing Key Terms

Use each of the following terms in a separate sentence.

1. Cell cycle
2. Mutations
3. Stem cells
4. Differentiate

Use the correct key term to complete each of the following sentences.

1. \_\_\_\_\_ is the stage of the cell cycle where cells are actively dividing.
2. Daughter cells are \_\_\_\_\_ which means they contain two copies of each chromosome.
3. Specialized cells are \_\_\_\_\_ into cells with specific functions.

### Reviewing Main Ideas

1. What are the three main phases of the cell cycle?
  - a. Interphase, mitosis, and cytokinesis
  - b.  $G_1$ , S, and  $G_2$
  - c. Anaphase, telophase, and cytokinesis
  - d.  $G_0$ , mitosis, and cytokinesis
2. What can occur if the cell cycle divides uncontrollably?
  - a. The cell dies
  - b. Cancer
  - c. Stem cells
  - d. Cell differentiation

3. The process of cell division results in—
  - a. two identical daughter cells.
  - b. two different daughter cells.
  - c. unregulated cell growth.
  - d. sister chromatids.

### Making Connections

1. Describe the relationships between the cell cycle and cell differentiation and how they maintain complex organisms.

### Open-Ended Response

1. Explain why the rate of cell division differs among different somatic cells.
2. Explain why injury to tissue can prompt cells in the surrounding area to undergo cell division.
3. Describe the importance of interphase to cell division.
4. Compare and contrast cancer cells and noncancerous cells.