Cell Division and the Cell Cycle

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CHAPTER 1

Cell Division and the Cell Cycle

Lesson Objectives

- Contrast cell division in prokaryotes and eukaryotes.
- Identify the phases of the eukaryotic cell cycle.
- Explain how the cell cycle is controlled.
- Define cancer, and relate it to the cell cycle.

Vocabulary

- binary fission
- cancer
- cell cycle
- cell division
- cytokinesis
- DNA replication
- interphase
- mitosis
- tumor

Introduction

You consist of a great many cells, but like all other organisms, you started life as a single cell. How did you develop from a single cell into an organism with trillions of cells? The answer is cell division. After cells grow to their maximum size, they divide into two new cells. These new cells are small at first, but they grow quickly and eventually divide and produce more new cells. This process keeps repeating in a continuous cycle.

Cell Division

Cell division is the process in which one cell, called the parent cell, divides to form two new cells, referred to as daughter cells. How this happens depends on whether the cell is prokaryotic or eukaryotic.

Cell division is simpler in prokaryotes than eukaryotes because prokaryotic cells themselves are simpler. Prokaryotic cells have a single circular chromosome, no nucleus, and few other organelles. Eukaryotic cells, in contrast, have multiple chromosomes contained within a nucleus and many other organelles. All of these cell parts must be duplicated and then separated when the cell divides.

Cell Division in Prokaryotes

Most prokaryotic cells divide by the process of **binary fission**. A bacterial cell dividing this way is depicted in **Figure** 1.1. You can also watch an animation of binary fission at this link: http://en.wikipedia.org/wiki/File:Binary_fission_anim.gif .

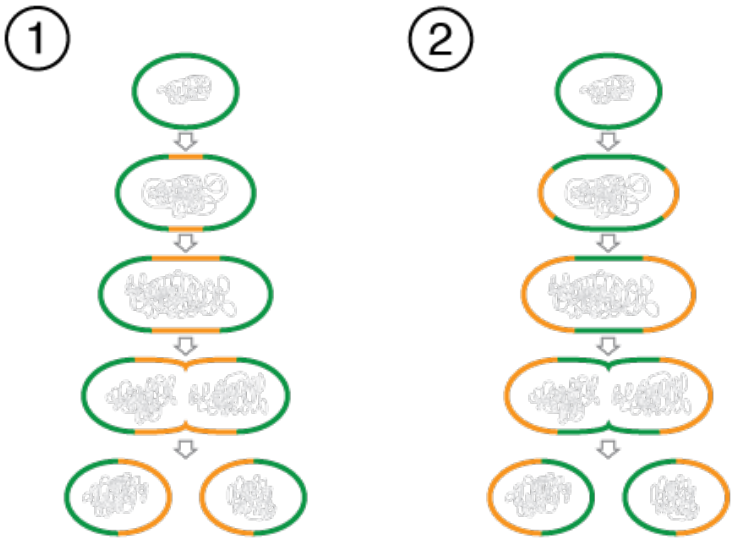


FIGURE 1.1

Binary Fission in a Bacterial Cell. Cell division is relatively simple in prokaryotic cells. The two cells are dividing by binary fission. Green and orange lines indicate old and newly-generated bacterial cell walls, respectively. Eventually the parent cell will pinch apart to form two identical daughter cells. Left, growth at the center of bacterial body. Right, apical growth from the ends of the bacterial body.

Binary fission can be described as a series of steps, although it is actually a continuous process. The steps are described below and also illustrated in **Figure** 1.2. They include DNA replication, chromosome segregation, and finally the separation into two daughter cells.

- Step 1: **DNA Replication**. Just before the cell divides, its DNA is copied in a process called DNA replication. This results in two identical chromosomes instead of just one. This step is necessary so that when the cell divides, each daughter cell will have its own chromosome.
- Step 2: Chromosome Segregation. The two chromosomes segregate, or separate, and move to opposite ends (known as "poles") of the cell. This occurs as each copy of DNA attaches to different parts of the cell membrane.
- Step 3: Separation. A new plasma membrane starts growing into the center of the cell, and the cytoplasm splits apart, forming two daughter cells. As the cell begins to pull apart, the new and the original chromosomes are separated. The two daughter cells that result are genetically identical to each other and to the parent cell. New cell wall must also form around the two cells.

Cell Division in Eukaryotes

Cell division is more complex in eukaryotes than prokaryotes. Prior to dividing, all the DNA in a eukaryotic cell's multiple chromosomes is replicated. Its organelles are also duplicated. Then, when the cell divides, it occurs in two major steps:

- The first step is **mitosis**, a multi-phase process in which the nucleus of the cell divides. During mitosis, the nuclear membrane breaks down and later reforms. The chromosomes are also sorted and separated to ensure that each daughter cell receives a complete set of chromosomes. Mitosis is described in greater detail in the lesson "Chromosomes and Mitosis."

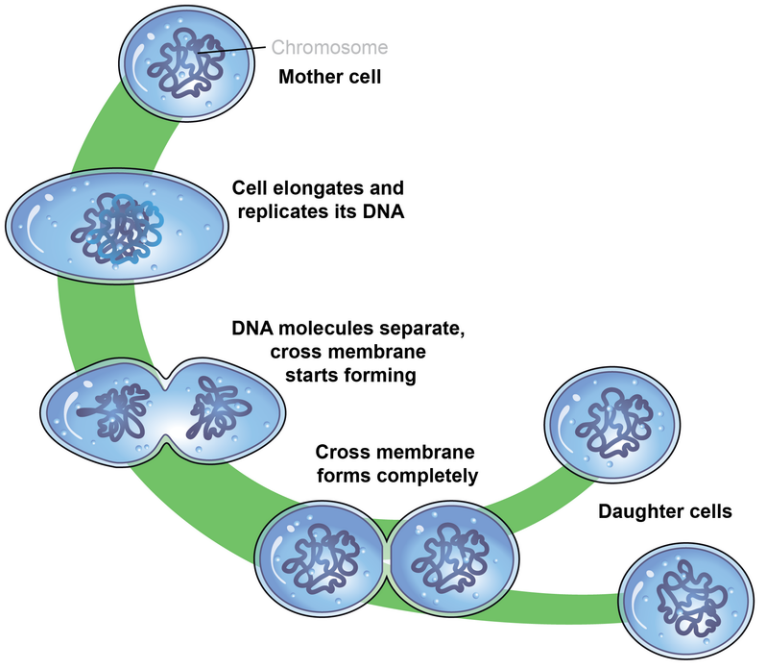


FIGURE 1.2

Steps of Binary Fission. Prokaryotic cells divide by binary fission. This is also how many single-celled organisms reproduce.

- The second major step is cytokinesis. As in prokaryotic cells, during this step the cytoplasm divides and two daughter cells form.

The Cell Cycle

Cell division is just one of several stages that a cell goes through during its lifetime. The **cell cycle** is a repeating series of events that include growth, DNA synthesis, and cell division. The cell cycle in prokaryotes is quite simple: the cell grows, its DNA replicates, and the cell divides. In eukaryotes, the cell cycle is more complicated.

Eukaryotic Cell Cycle

The diagram in **Figure** 1.3 represents the cell cycle of a eukaryotic cell. As you can see, the eukaryotic cell cycle has several phases. The mitotic phase (M) actually includes both mitosis and cytokinesis. This is when the nucleus and then the cytoplasm divide. The other three phases (G1, S, and G2) are generally grouped together as **interphase**. During interphase, the cell grows, performs routine life processes, and prepares to divide. These phases are discussed below. You can watch a eukaryotic cell going through these phases of the cell cycle at the following link: http://www.cellsalive.com/cell_cycle.htm .

Interphase

Interphase of the eukaryotic cell cycle can be subdivided into the following three phases, which are represented in **Figure** 1.3:

- **Growth Phase 1 (G1):** during this phase, the cell grows rapidly, while performing routine metabolic processes. It also makes proteins needed for DNA replication and copies some of its organelles in preparation for cell division. A cell typically spends most of its life in this phase. This phase is also known as gap phase 1.

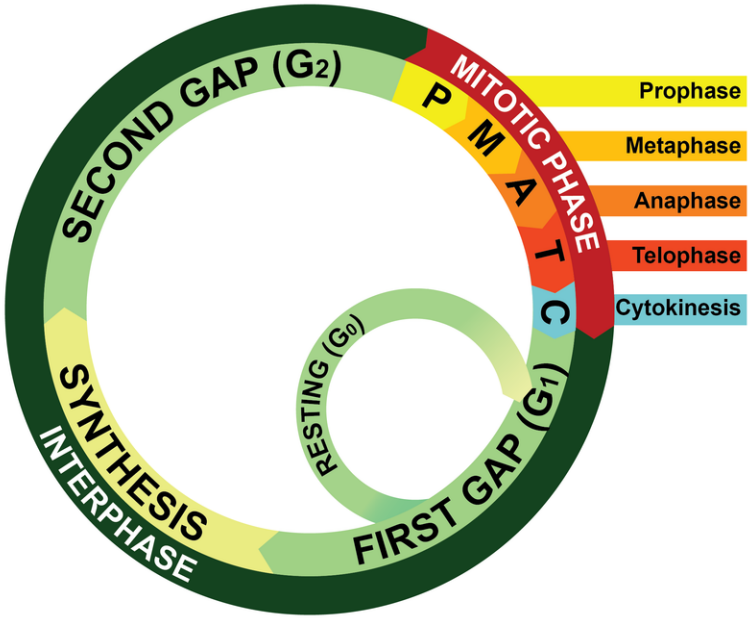


FIGURE 1.3

Eukaryotic Cell Cycle. This diagram represents the cell cycle in eukaryotes. The First Gap, Synthesis, and Second Gap phases make up interphase (I). The M (mitotic) phase includes mitosis and cytokinesis. After the M phase, two cells result.

- **Synthesis Phase (S):** during this phase, the cell's DNA is copied in the process of DNA replication.
- **Growth Phase 2 (G2):** during this phase, the cell makes final preparations to divide. For example, it makes additional proteins and organelles. This phase is also known as gap phase 2.

Control of the Cell Cycle

If the cell cycle occurred without regulation, cells might go from one phase to the next before they were ready. What controls the cell cycle? How does the cell know when to grow, synthesize DNA, and divide? The cell cycle is controlled mainly by regulatory proteins. These proteins control the cycle by signaling the cell to either start or delay the next phase of the cycle. They ensure that the cell completes the previous phase before moving on. Regulatory proteins control the cell cycle at key checkpoints, which are shown in **Figure** 1.4. There are a number of main checkpoints.

- The G1 checkpoint, just before entry into S phase, makes the key decision of whether the cell should divide.
- The S checkpoint determines if the DNA has been replicated properly.
- The mitotic spindle checkpoint occurs at the point in metaphase where all the chromosomes should have aligned at the mitotic plate.

Cancer and the Cell Cycle

Cancer is a disease that occurs when the cell cycle is no longer regulated. This may happen because a cell's DNA becomes damaged. Damage can occur due to exposure to hazards such as radiation or toxic chemicals. Cancerous cells generally divide much faster than normal cells. They may form a mass of abnormal cells called a **tumor** (see **Figure** 1.5). The rapidly dividing cells take up nutrients and space that normal cells need. This can damage tissues and organs and eventually lead to death.

Cancer is discussed in the video at http://www.youtube.com/watch?v=RZhL7LDPk8w .

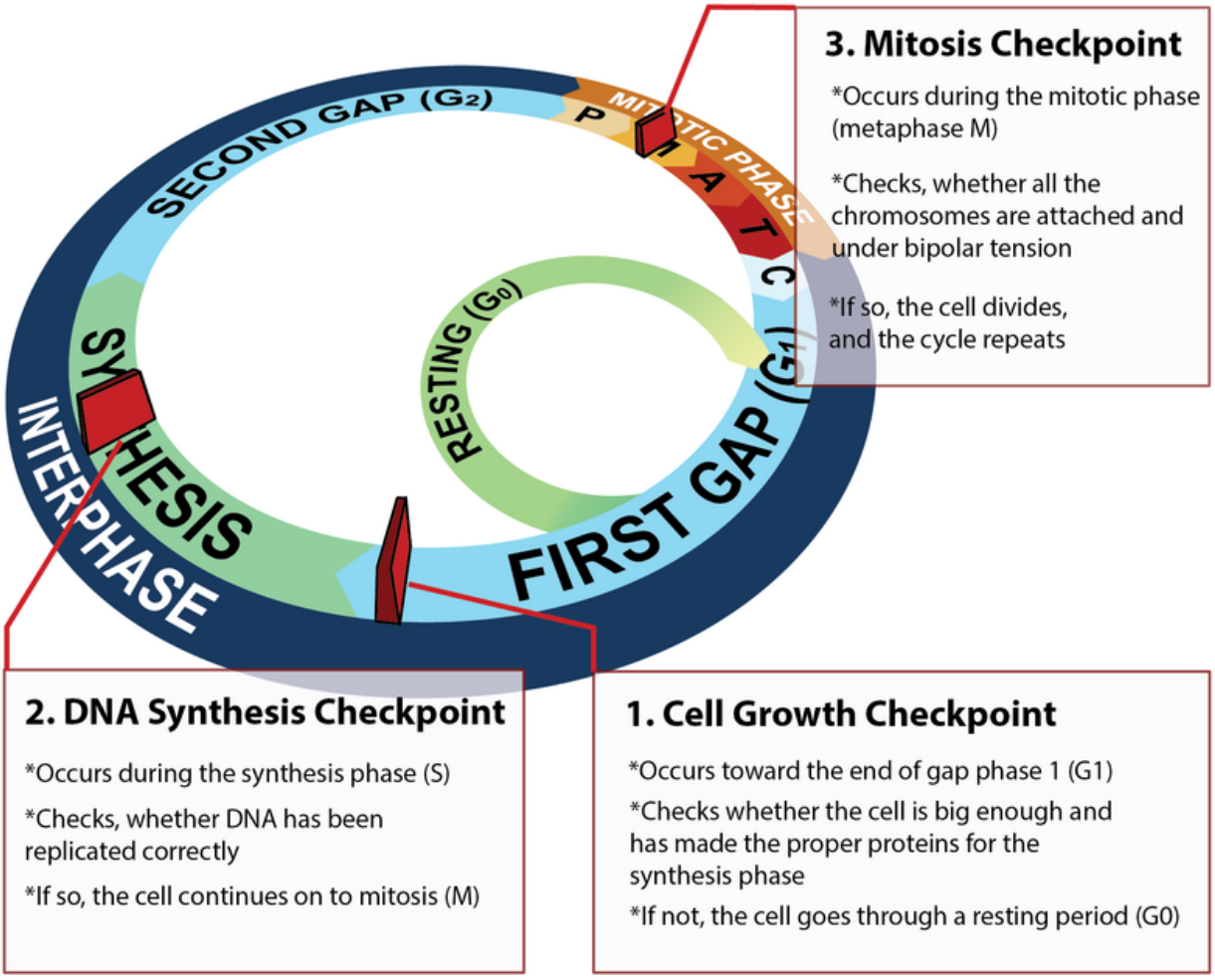
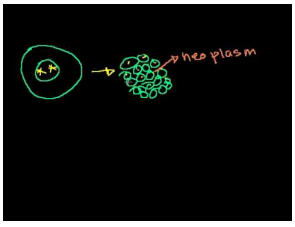


FIGURE 1.4

Checkpoints in the eukaryotic cell cycle ensure that the cell is ready to proceed before it moves on to the next phase of the cycle.



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Lesson Summary

- Cell division is part of the life cycle of virtually all cells. It is a more complicated process in eukaryotic than prokaryotic cells because eukaryotic cells have multiple chromosomes and a nucleus.

FIGURE 1.5

These cells are cancer cells, growing out of control and forming a tumor.

- The cell cycle is a repeating series of events that cells go through. It includes growth, DNA synthesis, and cell division. In eukaryotic cells, there are two growth phases, and cell division includes mitosis.
- The cell cycle is controlled by regulatory proteins at three key checkpoints in the cycle. The proteins signal the cell to either start or delay the next phase of the cycle.
- Cancer is a disease that occurs when the cell cycle is no longer regulated. Cancer cells grow rapidly and may form a mass of abnormal cells called a tumor.

Lesson Review Questions

Recall

1. Describe binary fission.
2. What is mitosis?
3. Identify the phases of the eukaryotic cell cycle.
4. What happens during interphase?
5. Define cancer.

Apply Concepts

6. How might the relationship between cancer and the cell cycle be used in the search for causes of cancer?

Think Critically

7. Cells go through a series of events that include growth, DNA synthesis, and cell division. Why are these events best represented by a cycle diagram?
8. Contrast cell division in prokaryotes and eukaryotes. Why are the two types of cell division different?

9. Explain how the cell cycle is regulated.
10. Why is DNA replication essential to the cell cycle?

Points to Consider

When a eukaryotic cell divides, the nucleus divides first in the process of mitosis.

- What do you think happens during mitosis? Can you predict what molecules and cell structures are involved in this process?
- How do you think mitosis might differ from binary fission? What steps might be involved in mitosis?

References

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