Chapter 3

Cell Division

Laboratory Activities

Activity 3.1: Mock Mitosis

Activity 3.2: Mitosis in Onion Cells

Activity 3.3: Mock Meiosis

Goals

Following this exercise students should be able to

- Recognize the stages of mitosis.
- Understand the importance of mitosis in the cell cycle.
- Explain the role of mitosis in growth and repair of the plant.
- Differentiate between cytokinesis and karyokinesis.
- Describe the key events of each stage of mitosis.

Introduction

All cells have a life cycle, which we call the **cell cycle**. The cell cycle begins with the formation of a new cell and continues until that cell goes through cell division to produce its own daughter cells. **Cell division** is a process by which one cell (mother cell) divides to produce two new cells (daughter cells). It is composed of two primary phases: **karyokinesis** and **cytokinesis**. Karyokinesis refers to the division of the nucleus, whereas cytokinesis refers to the division of the cytoplasm.

There are two types of karyokinesis. The most common form, **mitosis**, produces daughter cells that are identical to the mother cell. They have the same number of chromosomes and the same genetic content. Mitosis is critically important for the growth and repair processes of a plant. The second type is **meiosis**, which results in the production of four genetically different daughter cells each of which contain half the number of chromosomes present in the mother cell. Meiosis is typically considered to be a part of the reproductive cycle of an organism. By reducing the number of chromosomes by half, the cells produced are **haploid** (having only one copy of each chromosome). When these cells fuse together, during fertilization (or syngamy), they form a **zygote** that is **diploid** (having two copies of each chromosome). The use of meiosis to produce

a haploid cell, therefore, ensures that with each successful reproductive attempt the chromosome number stays the same. In other words, without meiosis, if a cell with four chromosomes fertilized another cell with four chromosomes, the resulting zygote would have eight chromosomes. Repeat this process again, and the chromosome number increases to 16. The total number of chromosomes would increase each time an organism reproduced sexually. Meiosis prevents this and helps to ensure the chromosome number remains constant in the species.

The division of the nucleus is much more tightly regulated than the division of the cytoplasm. Mitosis is typically divided into four stages, each of which is marked by chromosomal events: prophase, metaphase, anaphase, and telophase. Before mitosis can begin, the genetic content of the cell must be duplicated so each daughter cell can inherit an exact copy of the mother cell's DNA. This occurs during **interphase**, defined as the time in the cell cycle between divisions. Most plant cells spend most of their life cycle in interphase. It is a period of growth and preparation for division. Once the DNA is replicated during interphase, the cell then produces microtubules and other substances necessary for mitosis.

The first stage of mitosis is **prophase**. During prophase the nuclear envelope begins to disintegrate, the nucleoli disappear, and the **chromosomes** condense. There is no specific pattern to the chromosomes during prophase. **Spindle fibers** (microtubules) attach to each chromosome beginning in prophase. Because the DNA of the cell has already doubled through DNA replication in interphase, the chromosomes have a distinct structure. At this point each chromosome contains two identical **sister chromatids**. The chromatids are attached to one another by a **centromere**. It is this centromere that attaches to the spindle fibers.

Prophase is followed by **metaphase**. By now, the spindle fibers have all attached to chromosomes and have pulled the chromosomes to the center of the cell where they align at the cell equator, sometimes called the metaphase plate. The spindle fibers are attached to each centromere, so the centromere is what aligns in the center of the cell. The chromatids will not align perfectly in the center of the cell.

Once the chromosomes align in metaphase, the centromeres begin to break down, freeing the sister chromatids. The spindle fibers shorten, pulling the newly freed sister chromatids, now called **daughter chromosomes**, toward opposite poles of the cell. This is **anaphase**. When the chromosomes reach the poles of the cell, a new nuclear envelope begins to reform, nucleoli reappear, and two new nuclei are formed. This occurs during **telophase**. Telophase is usually accompanied by cytokinesis, which results in two new daughter cells, each with a diploid nucleus identical to that of the original mother cell. There are instances when cytokinesis does not accompany telophase. This results in a multinucleate cell. Keep in mind this is a continual process. It is easier to study the overall process by looking at each stage separately; however, the cell moves continually from one stage to the next.

In plant cells cytokinesis includes the formation of the new cell wall that will border the daughter cells. The **cell plate** forms in the center of the cell and forms the basis of the new primary cell walls. Because this usually occurs during telophase, observing the cell plate can often be useful as a marker for telophase. The contents of the cytoplasm are divided randomly between the two new daughter cells. Organelles are divided into both cells, but each cell may acquire different numbers of chloroplasts or mitochondria. As long as each daughter cell has at least one of each organelle, both can function and produce more organelles as needed.

Remember, chromosomes are only visible during cell division when they are condensed. When the cell is not actively dividing, chromosomes are found dispersed throughout the nucleus in the form of **chromatin**. Chromosomes are composed of DNA, the genetic material of the cell, and histone proteins around which the DNA winds.

Activities

Activity 3.1: Mock Mitosis

Your first priority in this lab is to learn the stages of mitosis. Once you understand what happens in each, especially with regard to the chromosomes, you'll be better equipped to identify cells in each stage.

1. Obtain a piece of scratch paper, eight strips of colored paper (four each of two colors) representing chromosomes, one piece of string approximately 12 inches long, and four paper clips from your instructor.
2. The scratch paper is your cell. Form a circle with the string inside the "cell" to represent the nuclear envelope.
3. Place two strips of paper (one each of two colors) into the nucleus. This represents the cell during early stages of interphase.
4. Mimic DNA replication. The cell must make an additional copy of its DNA. To do this, attach a second strip of paper (same color) to each of the existing "chromosomes" using the paper clips. You now have four chromosomes, each composed of two chromatids.
5. Move your cell's components to mimic prophase. What object did you remove?
6. Move the components to the appropriate conditions for metaphase. Remember, the centromeres align at the cell equator.
7. To mimic anaphase, remove the paper clips that hold your sister chromatids together. That symbolizes the centromere breaking down. Now move the new daughter chromosomes toward the poles of the cell.
8. To mimic telophase, fold the string in half to form two new nuclear envelopes.
9. Cytokinesis usually occurs at the same time as telophase. Draw the cell plate in the middle of the paper.

COMPARE AND CONTRAST

1. How are the daughter cells similar to one another? How are they different?

2. How are the daughter cells similar to the original mother cell? How do they differ?

Activity 3.2: Mitosis in Onion Cells

You will be observing the stages of mitosis in onion root tip cells. The actively reproducing cells in an onion root can be found just inside the tip of the root and extending up either side of the root near the outer surface. The cells have been stained with a dye that makes the DNA appear dark, usually pink or purple in color. By observing the locations of the chromosomes, you should be able to identify cells in each stage of mitosis.

1. Obtain a prepared slide of onion (*Allium*) root tips.
2. Observe the cells under low power.
3. Locate a cell in each of the stages of mitosis: prophase, metaphase, anaphase, and telophase. Sketch an example of each below.

4. Locate a cell that is not currently dividing. This cell will be in interphase.
5. Sketch an example of a cell in interphase.

COMPARE AND CONTRAST

1. How do the cells you observed compare with the one you generated in Activity 3.1?

2. Compare and contrast the appearance of a plant cell in interphase with one in prophase.

3. What does a cell in telophase have in common with a cell in interphase?

4. In looking at your slide of the onion root tip, most of the cells were in one phase of the cell cycle. What is that phase? Why is that not surprising?

Activity 3.3: Mock Meiosis

Meiosis has the same four main stages as seen in mitosis: prophase, metaphase, anaphase, and telophase. The difference is that meiosis involves two successive divisions of the nucleus. During the first division, **meiosis I**, the number of chromosomes is reduced; thus, it is sometimes referred to as a reduction division. During the second division, **meiosis II**, the sister chromatids formed during interphase are separated; however, chromosome number remains the same. It is therefore called an equational division. Because there are two divisions, each stage (prophase through telophase) occurs twice. Roman numerals differentiate between the two divisions. Prophase I, for example, occurs during meiosis I, whereas prophase II occurs during meiosis II.

1. Find one of your daughter cells from the mock mitosis exercise. Cut along the cell plate line you drew earlier to separate the cells. Remove the nucleus from one cell and cut that piece of paper (cell) in half again (for a total of two quarter-page pieces and one half-page piece of paper with intact nucleus).
2. The intact cell will now be going through meiosis.
3. Mimic DNA replication as before. Use paper clips to attach the sister chromatids to one another.

4. Mimic prophase I by removing the nuclear envelope. During prophase I homologous chromosomes pair up in a process called **synapsis**. To represent synapsis, pair up the two chromosomes of matching colors. These pairs are called **tetrads**.
5. **Crossing-over** typically occurs in which nonhomologous members of a tetrad exchange portions of chromatids. On the chromatids of one chromosome, write the letter "A" at the top edge. On the chromatids of the other chromosome, write the letter "a" at the top edge. Now, cut the ends off of one chromatid from each chromosome and switch places with them. Tape them in place. You have now mimicked crossing-over.
6. Move the chromosomes to their positions at the cell equator. In metaphase I the tetrads align at the cell equator with one chromosome on either side of the equatorial line.
7. During anaphase I the homologous chromosomes separate, so move one chromosome from each tetrad toward opposite poles of the cell. Notice that the centromere is still intact and each chromosome is composed of two sister chromatids.
8. Move the chromosomes to the two smaller pieces of paper to represent the cells as they appear after telophase I and cytokinesis.
9. Both of these still have to go through meiosis II. There is no further replication of DNA.
10. Mimic prophase II by removing the nuclear envelope. You no longer have homologous chromosomes pairing, and there is no synapsis or crossing-over at this point.
11. Metaphase II looks much like metaphase of mitosis. The chromosomes align at the cell equator with their centromeres on the equatorial plane.
12. During anaphase II the sister chromatids, now daughter chromosomes, separate as the centromere disappears. They move toward opposite poles of the cell.
13. By the end of telophase II and cytokinesis you have four cells, each with a haploid number of chromosomes.

Study Guide

- Be able to define the terms in bold.
- Be able to describe the processes of mitosis and meiosis.
- Be able to compare meiosis I with mitosis.
- Be able to compare meiosis II with mitosis.

Conclusions

1. Explain the difference between chromosomes and chromatids.

2. When in the life of a cell is DNA replicated? What is the implication of this on cell division?

3. Why is cytokinesis technically not part of mitosis?

4. Describe the role of the spindle fibers in mitosis and meiosis.

5. Describe the key events in each of the phases of mitosis.
   a. Prophase

   b. Metaphase

   c. Anaphase

   d. Telophase

6. Why is crossing-over important to the survival of a population?

7. Describe the products of mitosis with respect to the number of cells produced and their genetic complement.

8. Why is meiosis an essential process in a sexually reproducing species?