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Chapter 2: Reproduction and Chromosome Transmission

Student Learning Objectives

Upon completion of this chapter the student should be able to:

1. Know the general features of chromosomes.
2. Understand the process of binary fission in bacteria.
3. Know the stages of mitosis and recognize diagrams associated with this process.
4. Understand the process of cytokinesis and how it differs in animals and plants.
5. Know the stages of meiosis and the cellular processes involved with each stage.

6. Know the end result of mitosis and meiosis in terms of number of cells and their chromosome content.

7. Understand the process of gamete formation in both plants and animals.

Key Terms
Alleles

Anaphase
Asexual reproduction
Binary fission
Bivalents
Cell cycle
Cell plate

Centrioles
Centromere
Centrosomes
Chiasma (pl. Chiasmata)

Chromatids / Sister chromatids
Chromatin
Chromosomes
Cleavage furrow
Condense
Crossing over
Cytogenetics
Cytogeneticist
Cytokinesis

Decondensed
Diakinesis
Diploid
Diplotene
Dyad
Egg cell / Ovum
Embryo sac
Eukaryotes

G1 phase

G2 phase
Gamete

Gametogenesis
Gametophyte
Haploid
Heterogamous
Heterozygous
Homologs
Homozygous
Interphase
Isogamous
Karyotype
Kinetochore

Leptotene
Locus (pl. Loci)
M phase
Meiosis
Metaphase
Metaphase plate

Microtubule-organizing centers (MTOCs)
Mitosis
Mitotic spindle apparatus / Mitotic spindle
Monad
Nucleoid
Nucleus

Oogenesis
Organelles
Pachytene
Pollen grain
Prometaphase
Prophase
Prokaryotes
Reproduction
Restriction point
S phase

Sexual reproduction

Somatic cell
Sperm cells
Spermatogenesis
Spindle pole
Sporophyte
Synapsis

Synaptonemal complex
Telophase
Tetrad
Zygotene

Chapter Outline

## 2.1 General Features of Chromosomes

1. The cellular structures that contain the genetic material are the chromosomes. The structure of prokaryotic and eukaryotic chromosomes differs slightly, although both are comprised of long chains of DNA.

2. Prokaryotic cells, such as the bacteria, typically have a single, circular chromosome located within an area of the cell called the nucleoid (Figure 2.1a).

a. prokaryotic cells also possess a cell wall

3. Eukaryotic cells (fungi, protists, plants, and animals) contain internal compartments, called organelles, that have specialized functions (Figure 2.1b).

a. nucleus of eukaryotic cells contains the majority of the chromosomes and DNA

b. other organelles, such as the mitochondria and chloroplast, contain small amounts of DNA

### Eukaryotic Chromosomes Are Examined Cytologically to Yield a Karyotype

1. The field of cytogenetics involves the microscopic examination of chromosomes.

2. In actively dividing cells, the chromosomes are condensed allowing an easier examination of their structure and number.

3. To prepare an organism’s chromosomes for viewing (Figure 2.2):
a. somatic cells are obtained from the blood.
b. the cells are exposed to drugs that stimulate cell division.
c. the cells are placed in a hypotonic solution that makes them swell, but not burst.
d. the cells are exposed to a fixative to prevent movement.
e. a dye is applied to the cells that binds to the chromosomes.
f. the cells are then placed on a microscope slide and viewed.

4. At this point the chromosomes may be photographed, and a karyotype prepared to aide in the analysis of the organism's chromosomes.

Eukaryotic Chromosomes Are Inherited in Sets

1. The majority of eukaryotic species are diploid, thus all somatic cells have two sets of chromosomes.

a. Pairs of the same chromosomes are called homologs (Figure 2.3).

b. Homologous chromosomes are very similar in sequence and have the same genes, but may contain different alleles of these genes.

c. If the alleles are the same, then they are called homozygous. If the alleles are different, they are called heterozygous.

d. Sex chromosomes are not homologous.
2. Genes on homologous chromosomes have the same locations, or loci.

2.2 Cell Division

1. Asexual reproduction involves the division of a preexisting cell to form two new cells.

a. process is common in bacteria and some eukaryotic species (yeast, amoeba)

2. Cell division is necessary for the formation of multicellular organisms from fertilized eggs.

Bacteria Reproduce Asexually by Binary Fission
1. Prokaryotic organisms typically live as single cells.
2. Some bacteria, such as E. coli, can divide every 20-30 minutes.
a. Prior to cell division the bacteria duplicates its chromosome.

b. Division, called binary fission, occurs by forming a septum down the center of the cell (Figure 2.4).

c. The end result is two daughter cells that are genetically identical.

d. FtsZ, a protein that is evolutionarily related to microtubules, helps to identify the site of wall formation between the two new daughter cells.

Eukaryotic Cells Progress Through a Cell Cycle to Produce Genetically Identical Daughter Cells

1. Eukaryotic cells undergo a cell cycle (Figure 2.5) that consists of several distinct phases.

a. G1 and G2 (gap phases), S and M (mitosis).

b. G1, S, and G2 phases are collectively called interphase.
c. Some cells remain in G0 phase (just prior to S phase) for extended periods of time, thus arresting cell division.
2. Preparation for cell division begins in the G1 phase. Molecular changes accumulate in the cell, allowing it to pass through a restriction point and into S phase.

3. In S phase the chromosomes are replicated, forming the sister chromatids. Sister chromatids are linked together and are considered a single chromosome.

a. at this point the cell has twice as many chromatids as chromosomes (46 pairs of sister chromatids in humans)

4. In M phase (mitosis) the cell distributes the replicated chromosomes so that each of the new daughter cells has an exact complement of chromosomes that were found in the original cell.

2.3 Mitosis and Cytokinesis

The Mitotic Spindle Apparatus Organizes and Sorts Eukaryotic Chromosomes

1. The mitotic spindle apparatus is involved in the organization and sorting of chromosomes (Figure 2.7)

2. The spindle is formed from microtubule-organizing centers (MTOCs). In animal cells, there are two MTOCs called centrosomes. Each is located at a spindle pole.
3. There are three types of spindle fibers, all formed from microtubules.

a. Aster microtubules emanate away from the chromosomes and are important in the positioning of the spindle fibers in the cell.

b. Polar microtubules project toward the chromosomes and are involved in the separation of the two poles.

c. Kinetochore microtubules attach to the kinetochore, a group of proteins that associate with the centromere of each chromosome. Kinetochores also help to hold sister chromatids together.

The Transmission of Chromosomes During the Division of Eukaryotic Cells Involves a Process Known as Mitosis

1. Mitosis proceeds through five phases: prophase, prometaphase, metaphase, anaphase, telophase (Figure 2.8).

2. During prophase the nuclear membrane dissociates and the chromosomes condense. The mitotic spindle also begins to form.

3. The interaction of the spindle fibers with the chromosomes occurs during prometaphase.

a. Once a kinetochore microtubule comes in contact with the kinetochore, it is captured and no longer moves.

b. Kinetochore microtubules connect to the kinetochore from both poles of the cell, and gently tug the chromosomes back and forth during prometaphase.

4. Metaphase occurs when the chromosomes align along a central plane called the metaphase plate.

5. The sorting of the chromosomes occurs during anaphase, when the connection between the sister chromatids breaks. At this point each of the chromatids is linked to only one of the poles.

a. Each chromatid is now considered to be an independent chromosome.
b. The chromosomes now begin to migrate to their respective poles of the cell.

6. When the chromosomes reach opposite sides of the cell, they begin to decondense. This marks the start of telophase. The nuclear membrane then reforms around the chromosomes.

7. Following telophase, the cell proceeds into cytokinesis, or cytoplasmic division (Figure 2.9).

a. In animal cells this involves the use of a cleavage furrow.

b. In plant cells this involves the use of a cell plate constructed from material carried by Golgi-derived vesicles.

8. The end result of mitosis and cytokinesis is two daughter cells that are genetically identical.

a. Small variations are possible due to mutation in DNA sequence during replication.

## 2.4 Meiosis

1. Diploid eukaryotic cells may divide by meiosis to produce cells that are haploid. These cells contain a single set of chromosomes.

### Meiosis Produces Cells That Are Haploid

1. Meiosis is similar to mitosis in many aspects, except that it involves two consecutive cell divisions within an intervening interphase.

2. The following events occur during prophase I (Figure 2.10).

a. The first stage is called leptotene. During this time the chromosomes start to condense, forming threadlike structures.

b. During the second stage, called zygotene, the homologous chromosomes recognize each other by a process known as synapsis. The chromosomes align along their entire lengths. At this point the pairs of homologous chromosomes are called bivalents (or tetrads). There are four sister chromatids in a bivalent.

c. As the bivalent structure forms the synaptonemal complex forms between the homologous chromosomes. The synaptonemal complex consists of lateral and central elements that interact. The synaptonemal complex is not found in all species.

d. Just prior to the third stage, pachytene, the process of crossing over occurs between non-sister chromatids in the bivalent. The site of crossing over is called the chiasma.

e. In the fourth stage, called diplotene, the synaptonemal complex dissociates. The individual chromatids are usually visible at this point.

f. By the last stage, diakinesis, the synaptonemal complex has completely disappeared.

3. The events of prometaphase I resemble those of mitosis, in which the spindle apparatus is complete and the chromatids are attached via kinetochore microtubules (Figure 2.11).

4. During metaphase I the chromosomes align along a central line in the cell in the same manner as mitosis, except for the following:

a. the bivalent chromosomes are aligned in a double row, rather than the single row of mitosis.

b. the kinetochore microtubules link one of the homologous chromosomes to one of the poles, while a second set of kinetochore microtubules link the other homologous chromosome to the other pole (Figure 2.12).

5. At metaphase I, each bivalent pair may align in one of two configurations. The number of different, random alignments for a species is equal to 2n, where n equals the chromosome number.

6. During anaphase I the homologous chromosomes separate from each other and begin to migrate to opposite poles. The sister chromatids remain connected during meiosis I.

7. At telophase I the chromosomes reach the opposite poles of the cell and begin to decondense. The nuclear membrane then reforms around the chromosomes.

8. Following telophase I, cytokinesis occurs. The cell then proceeds directly to meiosis II.

9. The sequence of events for meiosis II is identical to that of mitosis, except that two cells are now dividing and each cell contains half the number of chromosomes. Cytokinesis follows meiosis II.

10. For a single diploid cell entering meiosis, the end result is four haploid daughter cells. These daughter cells vary in their genetic composition (Table 2.1).

2.5 Sexual Reproduction

1. The purpose of sexual reproduction is to produce gametes, a process known as gametogenesis. These gametes then combine by the process of fertilization to produce
a new individual.

2. Isogamous organisms, such as some species of fungi and algae, produce gametes that are morphologically similar. Heterogamous organisms produce gametes that are not morphologically the same.

a. Sperm cells are produced by the male, are typically small, and must travel a significant distance to reach the egg.

b. Egg cells are produced by the female, are typically large, and usually nonmotile.

In Animals, Spermatogenesis Produces Four Haploid Sperm Cells and Oogenesis Produces a Single Haploid Egg Cell

1. In male animals, the formation of the sperm, called spermatogenesis, occurs in the testes (Figure 2.13a).

2. In the testes a spermatogonial cell divides by mitosis to produce two identical cells. One of these is a spermatocyte and enters into meiosis, while the other remains a spermatogonial cell.

3. The four haploid cells produced by meiosis mature into sperm cells. Each sperm cell contains a haploid nucleus, an acrosome that contains digestive enzymes, and a long flagellum.

4. Oogenesis is the formation of the egg cells (Figure 2.13b). It begins with oogonia located in the ovary of the female. The oogonia begin meiosis, but are arrested at prophase I.

a. After the female reaches a reproductive age, the primary oocytes are periodically activated.

b. Unlike spermatogenesis in males, oogenesis only produces a single egg cell. During meiosis the division of the cytoplasm is asymmetric and produces polar bodies. The larger cell is called the secondary oocyte, and represents the cell that is released during ovulation.

c. If the secondary oocyte is fertilized, it completes meiosis II. In the second cytokinesis there is again an unequal division of the cytoplasm, producing another polar body.

Plant Species Alternate Between Haploid (Gametophyte) and Diploid (Sporophyte) Generations

1. Plants alternate between haploid and diploid generations. The haploid generation is called the gametophyte and the diploid generation is called the sporophyte.

2. The process of meiosis produces haploid cells called spores, which then divide by mitosis to produce the gametophyte.
a. For most higher plants, the dominant stage is the sporophyte stage.

3. Gametogenesis in higher plants occurs in the anthers (male) and ovaries (female) (Figure 2.14).

a. In the anther diploid cells called microsporocytes undergo meiosis to produce four haploid microspores. These cells then go through mitosis to produce a pollen grain, or male gametophyte. The pollen grain consists of two cells, the tube cell and the generative cell. The generative cell undergoes mitosis to produce two haploid sperm.

b. In the ovaries a cell called the megasporocyte goes through meiosis to produce four haploid megaspores. Only one of these megaspores survives, the others degenerate. The remaining undergoes three consecutive cell divisions, with asymmetrical cytokinesis, to produce a seven cell structure called the embryo sac. This is the female gametophyte.

4. Fertilization in plants involves the following:

a. A pollen grain lands on the stigma, stimulating the tube cell to form a pollen tube to the ovary of the plant.

b. The generative cell in the pollen grain finishes meiosis, producing two sperm cells. These migrate through the pollen tube to the ovary.

List of Key Investigators

None cited in this chapter.