

CHAPTER 10 MEIOSIS AND SEXUAL REPRODUCTION

Chapter Outline

10.1 Halving the Chromosome Number

1. **Meiosis** is nuclear division, reducing the chromosome number from the **diploid (2n)** to the **haploid (n)** number.
 2. The **haploid (n) number** is half of the diploid number of chromosomes.
 3. Sexual reproduction requires **gamete** (reproductive cell, often sperm and egg) formation and then fusion of gametes to form a **zygote**.
 4. A **zygote** always has the full or diploid (2n) number of chromosomes.
 5. If gametes contained same number of chromosomes as body cells, doubling would soon fill cells.
- A. Homologous Pairs of Chromosomes
1. In diploid body cells, chromosomes occur as pairs.
 - a. Each set of chromosomes is a **homologous pair**; each member is a **homologous chromosome** or **homologue**.
 - b. Homologues look alike, have the same length and centromere position, and have a similar banding pattern when stained.
 - c. A location on one homologue contains gene for the same trait that occurs at this locus on the other homologue, although the genes may code for different variations of that trait; alternate forms of a gene are called **alleles**.
 2. Chromosomes duplicate immediately prior to nuclear division.
 - a. Duplication produces two identical parts called *sister chromatids*; they are held together at the *centromere*.
 3. One member of each homologous pair is inherited from the male parent, the other member from the female parent.
 4. One member of each homologous pair will be placed in each sperm or egg.
- B. Overview of Meiosis
1. **Meiosis** involves two nuclear divisions and produces four haploid daughter cells.
 2. Each daughter cell has half the number of chromosomes found in the diploid parent nucleus.
 3. **Meiosis I** is the nuclear division at the first meiotic division.
 - a. Prior to meiosis I, DNA replication occurs, each chromosome thus has two sister chromatids.
 - b. During meiosis I, homologous chromosomes pair; this is called **synapsis**.
 - c. During synapsis, the two sets of paired chromosomes lay alongside each other as a **bivalent** (sometimes called a **tetrad**).
 4. In **meiosis II**, the centromeres divide and daughter chromosomes (derived as sister chromatids) separate.
 - a. No replication of DNA is needed between meiosis I and II because chromosomes are already doubled (DNA replication occurred prior to meiosis I).
 - b. Chromosomes in the four daughter cells have only one chromatid.
 - c. Counting the number of centromeres verifies that parent cells were diploid; each daughter cell is haploid.
 - d. In the animal life cycle, daughter cells become gametes that fuse during fertilization.
 - e. Fertilization restores the diploid number in cells.
- C. Fate of Daughter Cells
1. In plant life cycle, daughter cells become haploid spores that germinate to become a haploid generation.
 2. In the animal life cycle, the daughter cells become the gametes, either sperm or egg.

10.2 Genetic Variation

A. Genetic Recombination

1. Due to genetic recombination, offspring have a different combination of genes than their parents.
2. Without recombination, asexual organisms must rely on mutations to generate variation among offspring; this is sufficient because they have great numbers of offspring.

3. Meiosis brings about genetic recombination in two ways: *crossing-over* and *independent assortment*.
4. Crossing-over of non-sister chromatids results in exchange of genetic material between non-sister chromatids of a bivalent; this introduces variation.
5. At synapsis, homologous chromosomes are held in position by a nucleoprotein lattice (the *synaptonemal complex*).
6. As the lattice of the synaptonemal complex breaks down at the beginning of anaphase I, homologues are temporarily held together by *chiasmata*, regions where the non-sister chromatids are attached due to crossing-over.
7. The homologues separate and are distributed to daughter cells.
8. Due to this **genetic recombination**, daughter chromosomes derived from sister chromatids are no longer identical.

B. Independent Assortment of Homologous Chromosomes

1. During independent assortment, the homologous chromosomes separate independently or in a random manner.
2. Independent assortment in a cell with only three pairs of chromosomes is 2^3 or eight combinations of maternal and paternal chromosomes.

C. Significance of Genetic Variation

1. In humans with 23 pairs of chromosomes, the combinations possible are 2^{23} or 8,388,608, and this does not consider the variation from crossing-over.
2. When gametes fuse at **fertilization**, chromosomes donated by parents combine.
3. The chromosomally different zygotes from same parents have $(2^{23})^2$ or 70,368,744,000,000 combinations possible without crossing-over.
4. If crossing-over occurs once, then $(4^{23})^2$ or 4,951,760,200,000,000,000,000,000 genetically different zygotes are possible for one couple.
5. A successful parent in a particular environment can reproduce asexually and produce offspring adapted to that environment.
6. If the environment changes, differences among offspring provide the sexual parents with much improved chances of survival.

10.3 The Phases of Meiosis

1. Both meiosis I and meiosis II have four phases: prophase, metaphase, anaphase, and telophase.

A. Prophase I

1. Nuclear division is about to occur: nucleolus disappears; nuclear envelope fragments; centrosomes migrate away from each other; and spindle fibers assemble.
2. Homologous chromosomes undergo synapsis to form bivalents; crossing-over may occur at this time in which case sister chromatids are no longer identical.
3. Chromatin condenses and chromosomes become microscopically visible.

B. Metaphase I

1. Bivalents held together by chiasmata have moved toward the metaphase plate at the equator of the spindle.
2. In metaphase I, there is a fully formed spindle and alignment of the bivalents at the metaphase plate.
3. Kinetochores, protein complexes just outside the centromeres attach to spindle fibers called *kinetochore spindle fibers*.
4. Bivalents independently align themselves at the metaphase plate of the spindle.
5. Maternal and paternal homologues of each bivalent may be oriented toward either pole.

C. Anaphase I

1. The homologues of each bivalent separate and move toward opposite poles.
2. Each chromosome still has two chromatids.

D. Telophase I

1. In animals, this stage occurs at the end of meiosis I.
2. When it occurs, the nuclear envelope reforms and nucleoli reappear.
3. This phase may or may not be accompanied by cytokinesis.

E. Interkinesis

1. This period between meiosis I and II is similar to the interphase between mitotic divisions; however, no DNA replication occurs (the chromosomes are already duplicated).

F. Meiosis II and Gamete Formation

1. During **metaphase II**, the haploid number of chromosomes align at the metaphase plate.
2. During **anaphase II**, the sister chromatids separate at the centromeres; the two *daughter chromosomes* move toward the poles.

3. Due to crossing-over, each gamete can contain chromosomes with different types of genes.
4. At the end of **telophase II** and cytokinesis, there are four haploid cells.
5. In animals, the haploid cells mature and develop into gametes.
6. In plants, the daughter cells become **spores** and divide to produce a haploid generation; these haploid cells fuse to become a zygote that develops into a diploid generation.
7. The type of life cycle of alternating haploid and diploid generations is called **alternation of generations**.

10.4 Meiosis Compared to Mitosis

1. Meiosis requires two nuclear divisions; mitosis requires only one nuclear division.
 2. Meiosis produces four daughter nuclei and four daughter cells; mitosis produces only two.
 3. The daughter cells produced by meiosis are haploid; the daughter cells produced by mitosis are diploid.
 4. The daughter cells produced by meiosis are not genetically identical; the daughter cells produced by mitosis are genetically identical to each other and to the parental cell.
- A. Occurrence
1. In humans, meiosis occurs only in reproductive organs to produce gametes.
 2. Mitosis occurs in all tissues for growth and repair.
- B. Meiosis I Compared to Mitosis
1. DNA is replicated only once before both mitosis and meiosis; in mitosis there is only one nuclear division; in meiosis there are two nuclear divisions.
 2. During prophase I of meiosis, homologous chromosomes pair and undergo crossing-over; this does not occur during mitosis.
 3. During metaphase I of meiosis, bivalents align at the metaphase plate; in mitosis individual chromosomes align.
 4. During anaphase I in meiosis, homologous chromosomes (with centromeres intact) separate and move to opposite poles; in mitosis at this stage, sister chromatids separate and move to opposite poles.
- C. Meiosis II Compared to Mitosis
1. Events of meiosis II are the same stages as in mitosis.
 2. However, in meiosis II, the nuclei contain the haploid number of chromosomes.

10.5 The Human Life Cycle

1. **Life cycle** refers to all reproductive events between one generation and next.
 2. In animals, the adult is always diploid [Instructors note: some bees, etc., have haploid male adults].
 3. In plants, there are two adult stages: one is diploid (called the **sporophyte**) and one is haploid (called the **gametophyte**).
 4. Mosses are haploid most of their cycle; the majority of higher plants are diploid most of their cycle.
 5. In fungi and some algae, only the zygote is diploid, and it undergoes meiosis.
 6. In human males, meiosis is part of **spermatogenesis** (the production of sperm), and occurs in the testes.
 7. In human females, meiosis is part of **oogenesis** (the production of eggs), and occurs in the ovaries.
 8. After birth, mitotic cell division is involved in growth and tissue regeneration of somatic tissue.
- A. Spermatogenesis and Oogenesis in Humans
1. Spermatogenesis
 - a. In the testes of males, **primary spermatocytes** with 46 chromosomes undergo meiosis I to form two **secondary spermatocytes**, each with 23 duplicated chromosomes.
 - b. Secondary spermatocytes divide (meiosis II) to produce four **spermatids**, also with 23 daughter chromosomes.
 - c. Spermatids then differentiate into **sperm (spermatozoa)**.
 - d. Meiotic cell division in males always results in four cells that become sperm.
 2. Oogenesis
 - a. In the ovaries of human females, **primary oocytes** with 46 chromosomes undergo meiosis I to form two cells, each with 23 duplicated chromosomes.
 - b. One of the cells, a **secondary oocyte**, receives almost all the cytoplasm; the other cell, a **polar body**, disintegrates or divides again.
 - c. The secondary oocyte begins meiosis II and then stops at metaphase II.
 - d. At ovulation, the secondary oocyte leaves the ovary and enters an oviduct where it may meet a sperm.
 - e. If a sperm enters secondary oocyte, the oocyte is activated to continue meiosis II to completion; the result is a mature egg and another polar body, each with 23 daughter chromosomes.
 - f. Meiosis produces one egg and three polar bodies; polar bodies serve to discard unnecessary

chromosomes and retain most of the cytoplasm in the egg.

g. The cytoplasm serves as a source of nutrients for the developing embryo.

10.6 Change in Chromosome Number and Structure

A. Aneuploidy

1. **Chromosomal mutations** are changes in chromosome number or structure.
2. Mutations, along with crossing-over, recombination of chromosomes during meiosis, and gamete fusion during fertilization, increase the amount of variation among offspring.
3. The correct number of chromosomes in a species is called **euploidy**; changes in chromosome number resulting from nondisjunction during meiosis is called **aneuploidy**.
4. **Monosomy** ($2n - 1$) occurs when an individual has only *one* of a particular type of chromosome.
5. **Trisomy** ($2n + 1$) occurs when an individual has *three* of a particular type of chromosome.
6. **Nondisjunction** is the failure of chromosomes to separate at meiosis—both members of the homologous pair go into the same gamete.
 - a. *Primary nondisjunction* occurs during meiosis I when both members of a homologous pair go into the same daughter cell
 - b. *Secondary nondisjunction* occurs during meiosis II when the sister chromatids fail to separate and both daughter chromosomes go into the same gamete.
7. Monosomy and trisomy occur in plants and animals; in autosomes of animals, it is generally lethal.
8. **Trisomy 21** is the most common autosomal trisomy.
 - a. Trisomy 21 (also called *Down syndrome*) occurs when three copies of chromosome 21 are present.
 - b. Usually two copies of chromosome 21 are contributed by the egg; in 23% of the cases, the sperm had the extra chromosome 21.
 - c. A Down syndrome child has many characteristic signs and symptoms, including a tendency for leukemia, cataracts, faster aging, mental retardation, and an increased chance of developing Alzheimer disease later in life.
 - d. Chances of a woman having a Down syndrome child increase with age.
 - e. A **karyotype**, a visual display of the chromosomes arranged by shape, size, and banding pattern, may be performed to identify babies with Down syndrome and other aneuploid conditions.
9. Nondisjunction during oogenesis can result in too few or too many X chromosomes; nondisjunction during spermatogenesis can result in missing or too many Y chromosomes.
10. **Turner syndrome** females have only one sex chromosome, an X; thus, they are XO, with O signifying the absence of a second sex chromosome.
 - a. Turner females are short, have a broad chest and folds of skin on back of neck.
 - b. Ovaries of Turner females never become functional; therefore, females do not undergo puberty.
 - c. They usually have normal intelligence and can lead fairly normal lives with hormone supplements.
11. **Klinefelter syndrome** males have one Y chromosome and two or more X chromosomes (e.g., XXY).
 - a. Affected individuals are sterile males; the testes and prostate are underdeveloped.
 - b. Individuals have large hands and feet, long arms and legs, and lack facial hair.
 - c. Presence of the Y chromosome drives male formation but more than two X chromosomes may result in mental retardation.
 - d. A *Barr body*, usually only seen in the nuclei of a female's cells, is seen in this syndrome due to the two X chromosomes.
12. **Poly-X** females (or *superfemale*) have three or more X chromosomes and therefore extra Barr bodies in the nucleus.
 - a. There is no increased femininity; most lack any physical abnormalities.
 - b. XXX individuals are not mentally retarded but may have delayed motor and language development; XXXX females are usually tall and severely mentally retarded.
 - c. Some experience menstrual irregularities but many menstruate regularly and are fertile.
13. **Jacobs syndrome** (XYY) are males with two Y chromosomes instead of one.
 - a. This results from nondisjunction during spermatogenesis.
 - b. Males are usually taller than average, suffer from persistent acne, and tend to have speech and reading problems.
 - c. Earlier claims that XYY individuals were likely to be aggressive were not correct.

B. Living with Klinefelter Syndrome (*Health Focus* box)

1. Stefan Schwartz is a man who has Klinefelter syndrome.
2. As a child, some of his symptoms included being shy, trouble making friends, and emotional instability.
3. Teacher and doctors thought he had “learning disabilities,” and was lazy.

4. Eventually a doctor tested his blood and discovered he had Klinefelter syndrome, a genetic disorder having sex chromosomes XXY.
 5. Physical treatment can include testosterone injection. Emotional treatment can include support groups.
- C. Changes in Chromosome Structure
1. Environmental factors including radiation, chemicals, and viruses, can cause chromosomes to break; if the broken ends do not rejoin in the same pattern, this causes a change in chromosomal structure.
 2. **Deletion:** a type of mutation in which an end of a chromosome breaks off or when two simultaneous breaks lead to the loss of a segment.
 3. **Translocation:** a chromosomal segment is removed from one chromosome and inserted into another nonhomologous chromosome; in Down syndrome, 5% of cases are due to a translocation between chromosome 21 and 14, a situation that runs in the family of the father or mother.
 4. **Duplication:** the presence of a chromosomal segment more than once on the same chromosome.
 - a. A broken segment from one chromosome can simply attach to its homologue or unequal crossing-over may occur.
 - b. A duplication may also involve an **inversion** where a segment that has become separated from the chromosome is reinserted at the same place but in reverse; the position and sequence of genes are altered.
- D. Human Syndromes
1. Deletion Syndromes
 - a. *Williams syndrome* occurs when chromosome 7 loses an end piece: children look like pixies, have poor academic skills but good verbal and musical skills; lack of elastin causes cardiovascular problems and skin aging.
 - b. *Cri du chat syndrome* (“cry of the cat”) is a deletion in which an individual has a small head, is mentally retarded, has facial abnormalities, and an abnormal glottis and larynx resulting in a cry resembling that of a cat.
 2. Translocation Syndromes
 - a. If a translocation results in the normal amount of genetic material, the person will remain healthy; if a person inherits only one of the translocated chromosomes, that person may have only one allele or three alleles rather than the normal two.
 - b. In *Alagille syndrome*, chromosomes 2 and 20 exchange segments, causing a small deletion on chromosome 20 that may produce some abnormalities.