Section B: The Role of Meiosis in Sexual Life Cycles

1. Fertilization and meiosis alternate in sexual life cycles
2. Meiosis reduces chromosome number from diploid to haploid: a closer look
Introduction

• A life cycle is the generation-to-generation sequence of stages in the reproductive history of an organism.

• It starts at the conception of an organism until it produces its own offspring.
1. Fertilization and meiosis alternate in sexual life cycles

- In humans, each somatic cell (all cells other than sperm or ovum) has 46 chromosomes.
  - Each chromosome can be distinguished by its size, position of the centromere, and by pattern of staining with certain dyes.
- A karyotype display of the 46 chromosomes shows 23 pairs of chromosomes, each pair with the same length, centromere position, and staining pattern.
- These homologous chromosome pairs carry genes that control the same inherited characters.
• Karyotypes, ordered displays of an individual’s chromosomes, are often prepared with lymphocytes.
• An exception to the rule of homologous chromosomes is found in the sex chromosomes, the X and the Y.

• The pattern of inheritance of these chromosomes determine an individual’s sex.
  • Human females have a homologous pair of X chromosomes (XX).
  • Human males have an X and a Y chromosome (XY).

• Because only small parts of these have the same genes, most of their genes have no counterpart on the other chromosome.

• The other 22 pairs are called *autosomes*.
• The occurrence of homologous pairs of chromosomes is a consequence of sexual reproduction.

• We inherit one chromosome of each homologous pair from each parent.
  • The 46 chromosomes in a somatic cell can be viewed as two sets of 23, a maternal set and a paternal set.

• Sperm cells or ova (gametes) have only one set of chromosomes - 22 autosomes and an X or a Y.

• A cell with a single chromosome set is **haploid**.
  • For humans, the haploid number of chromosomes is 23 (n = 23).
• By means of sexual intercourse, a haploid sperm reaches and fuses with a haploid ovum.

• These cells fuse (syngamy) resulting in fertilization.

• The fertilized egg (zygote) now has two haploid sets of chromosomes bearing genes from the maternal and paternal family lines.

• The zygote and all cells with two sets of chromosomes are diploid cells.
  • For humans, the diploid number of chromosomes is 46 (2n = 46).
• As an organism develops from a zygote to a sexually mature adult, the zygote’s genes are passes on to all somatic cells by mitosis.

• Gametes, which develop in the gonads, are not produced by mitosis.
  • If gametes were produced by mitosis, the fusion of gametes would produce offspring with four sets of chromosomes after one generation, eight after a second and so on.

• Instead, gametes undergo the process of meiosis in which the chromosome number is halved.
  • Human sperm or ova have a haploid set of 23 different chromosomes, one from each homologous pair.
• Fertilization restores the diploid condition by combining two haploid sets of chromosomes.

• Fertilization and meiosis alternate in sexual life cycles.
• The timing of meiosis and fertilization does vary among species.

• The life cycle of humans and other animals is typical of one major type.
  • Gametes, produced by meiosis, are the only haploid cells.
  • Gametes undergo no divisions themselves, but fuse to form a diploid zygote that divides by mitosis to produce a multicellular organism.

Fig. 13.5a
• Most fungi and some protists have a second type of life cycle.

• The zygote is the only diploid phase.

• After fusion of two gametes to form a zygote, the zygote undergoes meiosis to produce haploid cells.

• These haploid cells undergo mitosis to develop into a haploid multicellular adult organism.

• Some haploid cells develop into gametes by mitosis.

Fig. 13.5b

(b) Most fungi and some algae
Plants and some algae have a third type of life cycle, **alternation of generation**.

- This life cycle includes both haploid (**gametophyte**) and diploid (**sporophyte**) multicellular stages.
- Meiosis by the sporophyte produces haploid **spores** that develop by mitosis into the gametophyte.
- Gametes produced via mitosis by the gametophyte fuse to form the zygote which produces the sporophyte by mitosis.

Fig. 13.5c
3. Meiosis reduces chromosome number from diploid to haploid: a closer look

- Many steps of meiosis resemble steps in mitosis.
- Both are preceded by the replication of chromosomes.
- However, in meiosis, there are two consecutive cell divisions, **meiosis I** and **meiosis II**, which results in four daughter cells.
- Each final daughter cell has only half as many chromosomes as the parent cell.
• Meiosis reduces chromosome number by copying the chromosomes once, but dividing twice.

• The first division, meiosis I, separates homologous chromosomes.

• The second, meiosis II, separates sister chromatids.

Fig. 13.6
• Division in meiosis I occurs in four phases: prophase, metaphase, anaphase, and telophase.

• During the preceding interphase the chromosomes are replicated to form sister chromatids.
  • These are genetically identical and joined at the centromere.

• Also, the single centrosome is replicated.

Fig. 13.7
• In prophase I, the chromosomes condense and homologous chromosomes pair up to form tetrads.

• In a process called synapsis, special proteins attach homologous chromosomes tightly together.

• At several sites the chromatids of homologous chromosomes are crossed (chiasmata) and segments of the chromosomes are traded.

• A spindle forms from each centrosome and spindle fibers attached to kinetochores on the chromosomes begin to move the tetrads around.

Fig. 13.7
• At metaphase I, the tetrads are all arranged at the metaphase plate.

• Microtubules from one pole are attached to the kinetochore of one chromosome of each tetrad, while those from the other pole are attached to the other.

• In anaphase I, the homologous chromosomes separate and are pulled toward opposite poles.

Fig. 13.7
• In telophase I, movement of homologous chromosomes continues until there is a haploid set at each pole.
  • Each chromosome consists of linked sister chromatids.

• Cytokinesis by the same mechanisms as mitosis usually occurs simultaneously.

• In some species, nuclei may reform, but there is no further replication of chromosomes.

Fig. 13.7
• **Meiosis II is very similar to mitosis.**

• During prophase II a spindle apparatus forms, attaches to kinetochores of each sister chromatids, and moves them around.

• Spindle fibers from one pole attach to the kinetochore of one sister chromatid and those of the other pole to the other sister chromatid.
- At metaphase II, the sister chromatids are arranged at the metaphase plate.
  - The kinetochores of sister chromatids face opposite poles.
- At anaphase II, the centomeres of sister chromatids separate and the now separate sisters travel toward opposite poles.

Fig. 13.7
• In telophase II, separated sister chromatids arrive at opposite poles.
  • Nuclei form around the chromatids.
• Cytokinesis separates the cytoplasm.
• At the end of meiosis, there are four haploid daughter cells.
• Mitosis and meiosis have several key differences.
  • The chromosome number is reduced by half in meiosis, but not in mitosis.
  • Mitosis produces daughter cells that are genetically identical to the parent and to each other.
  • Meiosis produces cells that differ from the parent and each other.
Three events, unique to meiosis, occur during the first division cycle.

1. During prophase I, homologous chromosomes pair up in a process called **synapsis**.
   - A protein zipper, the *synaptonemal complex*, holds homologous chromosomes together tightly.
   - Later in prophase I, the joined homologous chromosomes are visible as a tetrad.
   - At X-shaped regions called **chiasmata**, sections of nonsister chromatids are exchanged.
   - Chiasmata is the physical manifestation of crossing over, a form of genetic rearrangement.
2. At metaphase I homologous pairs of chromosomes, not individual chromosomes are aligned along the metaphase plate.
   - In humans, you would see 23 tetrads.

3. At anaphase I, it is homologous chromosomes, not sister chromatids, that separate and are carried to opposite poles of the cell.
   - Sister chromatids remain attached at the centromere until anaphase II.
   - The processes during the second meiotic division are virtually identical to those of mitosis.
• Mitosis produces two identical daughter cells, but meiosis produces 4 very different cells.

Fig. 13.8
<table>
<thead>
<tr>
<th>Event</th>
<th>Mitosis</th>
<th>Meiosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNA replication</td>
<td>Occurs during interphase before nuclear division begins</td>
<td>Occurs once, during the interphase before meiosis I begins</td>
</tr>
<tr>
<td>Number of divisions</td>
<td>One, including prophase, metaphase, anaphase, and telophase</td>
<td>Two, each including prophase, metaphase, anaphase, and telophase</td>
</tr>
<tr>
<td>Synapsis of homologous chromosomes</td>
<td>Does not occur</td>
<td>Synapsis is unique to meiosis: During prophase 1, the homologous chromosomes join along their length, forming tetrads (groups of four chromatids); synapsis is associated with crossing over between nonsister chromatids</td>
</tr>
<tr>
<td>Number of daughter cells and genetic composition</td>
<td>Two, each diploid (2n) and genetically identical to the parent cell</td>
<td>Four, each haploid (n), containing half as many chromosomes as the parent cell; genetically nonidentical to the parent cell and to each other</td>
</tr>
<tr>
<td>Role in the animal body</td>
<td>Enables multicellular adult to arise from zygote; produces cells for growth and tissue repair</td>
<td>Produces gametes; reduces chromosome number by half and introduces genetic variability among the gametes</td>
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Fig. 13.8