Meiosis

Slide 2 In a previous lesson, we discussed a type of cell division called mitosis that involved the division of one parent cell into two genetically identical daughter cells. This type of cell division is important in the growth and asexual reproduction of many types of organisms. Mitosis, however, is somewhat limiting for cells in an evolutionary sense, because it results only in the production of genetically identical individuals, or clones. Without a mechanism to increase genetic variation, species have difficulty adapting to changing environments. Many species counter this difficulty by constantly generating genetic variation through sexual reproduction, which involves combining the genetic material from two different organisms to produce new, genetically unique offspring. At the foundation of sexual reproduction is a process of cell division that results in the production of genetically variable cells. This process is called meiosis.

Slide 3 Although meiosis, like mitosis, is a process of cell division, it differs from mitosis in several key aspects. First, meiosis involves two rounds of cell division, instead of one, and so results in the production of four daughter cells from each parent cell. Only one round of DNA replication occurs prior to cell division, however, so the four daughter cells produced by meiosis contain only half of the chromosomes from the original parent cell. For instance, if a diploid cell undergoes meiosis, it will produce four haploid daughter cells. Finally, a process called crossing over occurs in meiosis. During crossing over, homologous chromosomes physically exchange segments of their DNA. This mechanism is an important way by which meiosis generates genetic variation.

Slide 4 Both rounds of cell division in meiosis contain essentially the same stages as mitosis: prophase, metaphase, anaphase and telophase. We refer to the first round of cell division in meiosis as meiosis I, and the second round as meiosis II. The stages are similarly named. For example, prophase of meiosis I is called prophase I, metaphase of meiosis II is called metaphase II. After meiosis I, the cells of some organisms move directly into meiosis II. In other types of organisms, meiosis I and meiosis II are separated by a short period called interkinesis.

In the following slides we will discuss some of the key aspects that occur during meiosis I and meiosis II, and how they differ from the corresponding stages in mitosis to produce four, genetically distinct daughter cells.

Slide 5 During prophase of meiosis I, the DNA of the cell is condensed into chromosomes, and homologous chromosomes pair tightly together in a process called synapsis. Recall that prior to meiosis, the cell has undergone DNA replication. Because of this, each chromosome consists of two identical sister chromatids. The chromatids of homologous chromosomes become physically connected at points called chiasmata (singular chiasma). Crossing over occurs at chiasmata when segments of DNA are exchanged between homologous chromosomes. Crossing over results in a recombination of genetic material, meaning that the sister chromatids of the homologous chromosomes become genetically distinct from each other. This is the first way by which meiosis generates genetic variation. In the illustrations on this and the following slides, note that each member of a pair of homologous chromosomes is indicated by a different color. Each color represents the genetic material (i.e., the chromosomes) donated by one parent. When pieces of chromosomes are exchanged, this is indicated by the different colors, as well.

Slide 6 During metaphase I, homologous chromosomes line up at the equatorial plate in the plane of cell division. At this point, each homologous chromosome will become attached to kinetochore microtubules from only one end of the cell. Because of this arrangement, during anaphase I the homologous chromosomes, each with two chromatids, separate and move to opposite ends of the cell (recall that in mitosis it was the sister chromatids that separated and moved to opposite ends of the cell). In this way, each of the two new cells formed in meiosis I will have one of each type of chromosome, but only half the total number of chromosomes as the parent cell. For example, a diploid cell going through meiosis I will produce two daughter cells, each with one set of chromosomes instead of two. Meiosis I therefore results in a reduction in the ploidy level, or the number of sets of chromosomes. Further, while each end of the cell will receive one member of each pair of homologous chromosomes, exactly which member it receives is a random process. This random assortment of homologous chromosomes into daughter cells during meiosis I is a second mechanism employed by meiosis to produce genetically diverse daughter cells.

Slide 7 In some species, anaphase I is followed by telophase I and cytokinesis, during which time nuclear envelopes reform around the condensed chromosomes at each end of the cell, and the cell divides into two daughter cells. In some organisms, there is an interphase between cytokinesis of meiosis I and the beginning of meiosis II, called interkinesis. During this stage each of the daughter cells will prepare for a second round of cell division by synthesizing enzymes, cell membrane, and other components necessary for meiosis II. It is important to note, however, that DNA is not replicated during interkinesis, as it is during interphase of the mitotic cell cycle.

Slide 8 Meiosis II involves cell divisions that are essentially identical to mitosis. During meiosis II, each of the two cells produced during meiosis I will divide, resulting in a total of four daughter cells. At prophase II, the chromosomes of each cell re-condense, and the nuclear envelopes begin to break down. The chromosomes line up on equatorial plates during metaphase II, and the sister chromatids of each chromosome are pulled apart to opposite ends of the cell during anaphase II, just as they are in mitosis. The assortment of the genetically variable sister chromatids into daughter cells is a random process, similar to the assortment of homologous chromosomes in meiosis I. And, as in meiosis I, the process of random assortment aids in the generation of genetic diversity among the daughter cells produced by meiosis. This is the third way by which meiosis generates genetic variation. After the chromatids have moved to separate poles of the cells, they begin to decondense while nuclear envelopes reform in telophase II. A second round of cytokinesis, resulting in the four final daughter cells, follows telophase II.

Slide 9 To review, let's briefly look again at the specific processes in meiosis that result in four, genetically unique daughter cells. First, DNA is exchanged between homologous chromosomes during the crossing over events of prophase I, resulting in genetically variable sister chromatids. Second, the homologous chromosomes of meiosis I, and the sister chromatids of meiosis II are randomly assorted into daughter cells prior to each cell division. This assures that while each daughter cell has a complete set of chromosomes, it will differ genetically from the chromosomes of the other daughter cells.

Slide 10 So how exactly does meiosis play a role in sexual reproduction? In sexual reproduction, the genetically variable cells produced by meiosis in two different individuals combine. The resulting cell, called a zygote, develops into a new, genetically unique individual. As an example, consider the egg and sperm cells of animals. Both of these cell types are produced by meiosis, and so carry unique genetic material from the parent that produced them. When these cells fuse to form a zygote during fertilization, the resulting cell will carry only half of the chromosomes from each of its parents, and so will differ to some degree from both of them. However, as we know from meiosis, it is purely chance as to exactly what genetic material from each parent ends up in each egg or sperm cell. When a number of offspring are produced, the odds are that each offspring will be genetically distinct from all of the other offspring. In this way, the process of meiosis generates the genetic variability that is the cornerstone of sexual reproduction, and which is essential for the process of evolution.

Slide 11 In addition, meiosis plays one other important role in sexual reproduction. Remember that because of the reduction in chromosome number that occurs during meiosis I, each gamete produced contains only half of the chromosomes from the parent that produced it. When gametes combine, the resulting zygote will then contain the same total number of chromosomes as each of its parents. If a reduction in chromosome number did not occur during meiosis I, each time a zygote formed it would have twice as many chromosomes as its parents. In a short time, of course, this could cause major difficulties for the survival and reproduction of cells and organisms. Through the reduction in chromosome number that occurs in meiosis I, meiosis acts to maintain the ploidy level, or number of sets of chromosomes, of sexually reproducing species.