9 Chromosomes, Mitosis, and Meiosis

Lecture Outline

I. Eukaryotic chromosomes contain DNA and protein
   A. The chromosomes carry the genetic information in eukaryotes
   B. The chromosomes are so named as they may be stained by certain dyes
      1. Chromosomes are composed of chromatin, which is composed of protein and DNA
         a. When cells are not dividing, the genetic material is decondensed
         b. Chromosomes become visible as distinct structures when the cell divides
   C. DNA is organized into informational units called genes
      1. Chromosomes contain hundreds to thousands of genes
   D. Chromosomes of different species differ in number and information content
      1. Humans and several other species of organisms have 46 chromosomes
         a. The average number of chromosomes is between 10 and 50
      2. The number of chromosomes is not indicative of complexity

II. The cell cycle is a sequence of cell growth and division
   A. Cells divide when they reach a certain size
   B. Cell division involves mitosis and cytokinesis
      1. Mitosis involves division of the chromosomes
      2. Cytokinesis involves division of the cytoplasm
         a. Mitosis without cytokinesis results in multinucleate cells
   C. Chromosomes become duplicated during interphase
      1. Cells are very active during interphase, synthesizing biological molecules and growing— the G1 (gap) phase
      2. The S (synthesis) phase is marked by DNA replication
      3. The G2 (gap) phase occurs between the S phase and mitosis
   D. Mitosis ensures orderly distribution of chromosomes
      1. Mitosis may be divided into 4 stages
      2. During prophase, duplicated chromosomes become visible with the light microscope
         a. Chromatin condenses into chromosomes
         b. Each chromosome has two duplicated units, termed chromatids
         c. Sister chromatids are bound at the centromere
         d. Centromeres have kinetochores to which microtubules will bind
         e. The mitotic spindle, composed of microtubules forms between the poles
         f. The MTOC (microtubule organizing center) is found in plant and animal cells
1. A pair of centrioles are in the middle of each MTOC in animal cells and some plant cells (but not in the cells of flowering plants)

2. The centrioles are surrounded by pericentriolar material
   g. Aster extend from the MTOCs at the poles (in cells that have centrioles)
   h. The nucleolus disappears

3. At metaphase duplicated chromosomes line up on the midplane
   a. Chromatids are highly condensed during metaphase, and may be photographed for a karyotype
   b. Polar microtubules extend from the pole to the equator, and typically overlap
   c. Kinetochore microtubules extend from the pole to the kinetochores

4. During anaphase chromosomes move toward the poles
   a. Chromatids separate at the centromeres and are now referred to as chromosomes
   b. The chromosomes are pulled by the kinetochore microtubules to the poles and form a “V” shape
   c. The mechanism by which the microtubules and other mitotic spindle components move the chromosomes is largely unknown

5. During telophase two separate nuclei are formed
   a. The cell returns to the conditions similar to interphase
   b. The nuclear envelope reforms, the nucleoli reappear

E. Cytokinesis is the formation of two separate daughter cells
   1. Cytokinesis begins during telophase
   2. In animal cells, the cells develop a furrow, caused by contractile actin filaments which encircle the equatorial region
   3. In plant cells, a cell plate forms, originating from the Golgi complex

F. Mitosis typically produces two cells genetically identical to the parent cell

G. Most cytoplasmic organelles are distributed randomly to the daughter cells
   1. Mitochondria and chloroplasts divide independently during interphase

H. The cell cycle is controlled by an internal genetic program interacting with external signals
   1. Eukaryotic cells typically divide less frequently than prokaryotes
   2. Protein kinases are involved in control of mitosis
      a. Protein kinases are active when complexed with cyclins, which are regulatory proteins
      b. When Cdk complexes with a certain cyclin, it activates specific enzymes, and inactivates other enzymes
   3. Colchicine is one of a number of drugs that can block cell division in eukaryotes
      a. Colchicine acts by interfering with spindle formation
   4. Cytokinins are plant hormones that stimulate mitosis
   5. Various protein growth factors stimulate mitosis
III. Sexual life cycles require a mechanism to reduce the chromosome number
   A. Asexual reproduction involves splitting, budding, or fragmentation of the parent
      1. The offspring formed by asexual reproduction are clones of the parent
      2. Asexual reproduction is typically rapid
   B. Sexual reproduction involves the union of gametes to form a zygote
      1. The offspring of sexual reproduction are not identical to the parents
   C. Somatic cells contain homologous chromosomes
      1. The genetic material of homologous chromosomes is not necessarily identical
      2. Diploid cells contain two sets of chromosomes (2n)
      3. Haploid cells have only one set of chromosomes (n)
      4. In humans, the diploid number is 46
      5. Polyploid cells contain more than two sets of chromosomes, e.g. 3n
         a. Polyploidy is important in plant evolution

IV. Diploid cells undergo meiosis to form haploid cells
   A. Meiosis potentially produces four haploid cells
   B. Meiosis produces haploid cells with unique gene combinations
      1. Meiosis involves two separate divisions
   C. The position of meiosis in the life cycle varies among groups
      1. Germ line cells undergo gametogenesis
         a. Spermatogenesis produces sperm
         b. Ooogenesis typically produces eggs, or a single ovum and two or more polar bodies
      2. Meiosis does not always immediately precede gamete formation
         a. Some organisms are haploid for most of their lives
         b. Plants and some algae exhibit alternation of generation
            1). The diploid stage is the sporophyte generation
            2). The haploid stage is the gametophyte generation
            3). In higher plants, the dominant stage is the sporophyte generation
   D. Meiosis produces haploid cells with unique gene combinations
      1. The gametes produced by meiosis differ genetically
   E. In meiosis homologous chromosomes are separated into different daughter cells
      1. Meiosis I and meiosis II each include prophase, metaphase, anaphase, and telophase
      2. Prophase I includes synapsis and crossing-over
         a. Homologous chromosomes pair and undergo synapsis
         b. One member of a pair is the maternal homologue, the other is the paternal homologue
         c. Synapsis is the association of four chromatids (two from each homologue)
         d. The resulting complex is called a bivalent or tetrad
            1). In humans, there are 23 tetrads and 92 chromatids in this phase
e. The synaptonemal complex forms between the members of
the tetrad and genetic material is exchanged by crossing
over
f. Crossing over results in great genetic variation
g. Prophase I in the formation of egg cells is often lengthy
h. In the oocytes of some amphibians, the chromosomes take on
unusual shapes, called lampbrush chromosomes
i. Homologous chromosomes are held together at chiasmata,
which are the sites of crossing over
j. Other typical events of prophase occur

3. During meiosis I homologous chromosomes separate
   a. Tetrads align at the equator in metaphase I
   b. The sister kinetochores of each homologue are attached to
      spindle fibers attached to only one of the poles
   c. During anaphase I, the homologous chromosomes separate
      and move to the poles
   d. Each pole receives a mixture of maternal and paternal
      chromosomes
   e. In telophase I, chromosomes decondense, the nuclear
      membrane may reform and cytokinesis usually occurs
   f. Interkinesis separates meiosis I and II; no DNA synthesis
      occurs
      1). It is a very short period and may be absent in some
         organisms

4. Chromatids separate in meiosis II
   a. Prophase II is brief, involves recondensation of the
      chromosomes, and events are very similar to those of
      prophase in mitosis (as are most stages of meiosis II)
   b. Chromosomes line up at the equator in metaphase II
   c. The chromatids separate in anaphase II (they are now called
      chromosomes)
   d. In telophase I, there is one copy of each homologous
      chromosome at each pole
   e. The end product is typically 4 haploid cells

V. The events of mitosis and meiosis lead to contrasting outcomes
   A. Mitosis is a single division and results in two genetically identical
      daughter cells
      1. Homologous chromosomes do not experience crossing over
   B. Meiosis is two sets of divisional processes, and results in four genetically
different cells
      1. Due to synopsis and independent separation of sister chromatids,
a great deal of genetic diversity results