Lecture 10: Cell Cycle and Cell Division

I. Overview
A. Function of cell division
1. Reproduction in unicellular, non-sexually dividing, organisms
2. Multicellular organisms
   a. Growth and development
   b. Replacement of damaged cells

B. Characteristics of the process of cell division
1. Identical hereditary material—DNA is distributed to two daughter cells
   a. DNA is replicated
      2N2n to 4N2n
   b. Two copies is physically relocated to the ends of the dividing cell
   c. Cell and its contents are separated to form two daughters each with identical genetic material
2. Organisms with large genomes
   a. Genome cannot be distributed as a single unit
   b. Regions of the DNA (chromatin) condense to form chromosomes
   c. Duplicate copies of each chromosome is referred to as a chromatid
   d. Chromatids when physically connected are referred to as sister chromatids
      i. Attached via centromeres

C. Cell cycle includes all events from a cell’s formation until it divides
1. Two major periods
   a. Interphase
   b. Cell division (mitosis)

II. Chromosomes
A. Composition
1. Chromatin
   a. DNA and protein
   b. Present in non-dividing cells
   c. De-condensed chromosomes
   d. Chromosomes condense during cell division

B. DNA (*molecular aspects will be discussed in future lectures)
1. Organized into informational units called genes
   a. Chromosomes contain hundreds to thousands of genes
   b. Humans have less than 30,000 genes that code for proteins
2. DNA in chromosomes is packaged in a highly organized way
a. DNA is associated with positively charged histone proteins
b. Form beadlike nucleosomes

3. Each nucleosome is composed of 146 base pairs wrapped around 8 histones
4. Scaffolding proteins aid in the formation of chromosomes
   a. Non-histone proteins
5. Linker segments of DNA and histones that are not part of the nucleosome
   a. Contribute to structure of the chromosome

C. Nucleosomes
1. Part of the chromatin
2. Packaged when different types of histones interact
   a. Histone (H1) associates with the linker histone
   b. Creates 30 nm diameter fibers
3. Fibers form loops held together by scaffolding proteins
4. These interact to form the condensed chromosome seen in metaphase

E. Chromosomes of different species differ in number and information content
1. Humans and several other species of organisms have 46 chromosomes
   a. The karyotype provides a visualization of the condensed chromosomes
   b. The average number of chromosomes is between 10 and 50
2. The number of chromosomes does not provide information about the organism
III.  Cell Cycle

A.  Interphase
1.  Metabolic or growth phase
   a.  From cell formation until cell division
   b.  All non-replication activities
   c.  90% of the cell cycle
2.  Preparation for division
3. **Subphases:**
   a. **G\(_1\):** growth phase with little cell division related activities
      i. Can last minutes to years (G\(_0\))
   b. **S:** synthetic phase; DNA replicates
   c. **G\(_2\):** brief period of growth where enzymes and other proteins necessary for division are synthesized
      i. Very brief

4. DNA replication (Do not need to know molecular events)

**IV. Mitotic Cell Division**

**A. Characteristics**
1. Daughter cells (2) are identical to mother cell
2. No gain or loss of genetic material
3. Series of continuous events
4. Lasts about two hours

**B. Phases of mitosis**
1. Cellular characteristics at end of G\(_2\)
   a. Nucleus with nuclear membrane
   b. Nucleoli present
   c. Two centrosomes present
      i. Closely affiliated with nucleus
   d. Pair of centrioles present in each centrosome
   e. Aster is around each centriole pair
      i. Array of microtubules
   f. Genetic material is still in chromatin form

![Images of interphase, prophase, and prometaphase cells with annotations explaining the processes and characteristics.](image-url)
2. Characteristics of Prophase
   a. Nucleus
      i. Nucleoli disappear
      ii. Chromatin condenses to form chromosomes
      iii. Chromatids are joined at centromeres to form sister chromatids
   b. Cytoplasm
      i. Mitotic spindles (microtubules) form
      ii. Centrosomes migrate toward the poles along the nuclear surface
      iii. Spindles lengthen

3. Characteristics of Prometaphase
   a. Nuclear membrane disappears and spindles interact with chromosomes
   b. Spindles extend from each pole toward the cell’s equator

(a) One end of each microtubule of this animal cell is associated with one of the poles. Astral microtubules (green) radiate in all directions, forming the aster. Kinetochore microtubules (red) connect the kinetochores to the poles, and polar (non-kinetochore) microtubules (blue) overlap at the midplane.
c. Kinetochores attach to sister chromatids
   i. Microtubules attach to the kinetochores

d. Non-kinetochore microtubules radiate from the centrosomes toward the metaphase plate
   i. Microtubules overlap with those of the opposite pole

4. Characteristics of Metaphase
   a. Chromosomes move to the metaphase plate
      i. Centromeres align on the metaphase plate
   b. Kinetochores of sister chromatids face the opposite poles
      i. Identical chromatids are attached to kinetochore fibers radiated from opposite ends of the cell
   c. Spindle
      i. Structure that includes non-kinetochore microtubules plus the kinetochore tubules

5. Characteristics of Anaphase
   a. Centromeres of each chromosome move apart
      i. Sister chromatids split into separate chromosomes
   b. Characteristic “V” shape
      i. Kinetochore fibers move ahead of the remaining chromosome
   c. Kinetochore microtubules shorten at the kinetochore end
      i. Chromosomes move toward poles
   d. Cell elongates
      i. Poles move farther apart
      ii. Non-kinetochore microtubules push poles apart
   e. End of Anaphase
      i. Two poles have identical chromosomes
6. Characteristics of Telophase
   a. Poles are pushed further apart
   b. Nuclei begin to reform at poles
      i. Nuclear envelope is formed from parent nuclear membrane and ER
   c. Nucleoli reappear
   d. Chromatin uncoils
      i. Chromosomes disappear

7. Characteristics of Cytokinesis
   a. Cleavage furrow forms near metaphase plate
   b. Contractile ring of actin on cytoplasmic side forms
   c. Actin contracts until the cells pinch apart
V. **Sexual Life Cycles**

A. Require mechanisms to reduce the chromosome number

B. Asexual reproduction
   1. Splitting, budding, or fragmentation of the parent
   2. Offspring are clones of the parent

B. Sexual reproduction
   1. Union of gametes to form a zygote
   2. Offspring of sexual reproduction are genetically unique from the parents

C. Chromosome composition of cells
   1. Somatic cells contain homologous chromosomes
      a. Genetic material may be from more than one source
      b. Diploid cells contain two sets of chromosomes (2n)
         i. Each set is from a different genetic source
      c. Haploid cells have only one set of chromosomes (n)
      d. Human diploid number is 46
   2. Polyploid cells contain more than two sets of chromosomes (e.g., 3n)
      a. Polyploidy is important in plant evolution
VI. Meiosis

A. Characteristics
1. Meiosis haploid cells
   a. Up to four cells

B. Meiosis produces haploid cells with unique gene combinations
1. Meiosis involves two separate divisions
   a. Genetic material is copied only once
2. Daughter cells are haploid
3. Haploid cells have unique gene combinations
   a. Gametes produced by meiosis differ genetically
C. **Nuclear divisions**

1. **Two divisions: Meiosis I and meiosis II**
2. **Each include four phases**
   a. Prophase, metaphase, anaphase, and telophase
3. **Prophase I includes synapsis and crossing-over**

![Image of nuclear divisions](image)

(a) LM of a tetrad during late prophase I of a male meiotic cell (spermatocyte) from a salamander.

(b) A drawing showing the structure of the tetrad. The paternal chromatids are blue, and the maternal chromatids are red.

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a. Homologous chromosomes pair and undergo synapsis
   i. Maternal homologue
   ii. Paternal homologue
b. Synapsis is the association of four chromatids
   i. Tetrad
c. Synaptonemal complex forms between the members of the tetrad
   i. Genetic material is exchanged by crossing over
d. Crossing-over results in great genetic variation
e. Homologous chromosomes are held together at chiasmata
   i. Site of crossing over
f. (See discussion of mitosis for remaining details)

4. **Separation of homologous chromosomes**
   a. Tetrads align at the equator in metaphase I
   b. 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
   i. DNA synthesis does not occurs

4. **Chromatids separate in meiosis II**
   a. Prophase II
      i. Recondensation of the chromosomes
      ii. Similar to those of prophase in mitosis
   b. Chromosomes line up at the equator in metaphase II
c. Chromatids separate in anaphase II
   i. Now called chromosomes
d. In telophase I, there is one copy of each homologous chromosome at each pole
e. End product is typically 4 haploid cells
VI. **Comparative 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 synapsis and independent separation of sister chromatids, a great deal of genetic diversity results

C. The position of meiosis in the life cycle varies among groups
   1. Germ line cells undergo gametogenesis
      a. Spermatogenesis produces sperm
      b. Oogenesis 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
         i. The diploid stage is the sporophyte generation
         ii. The haploid stage is the gametophyte generation
         iii. In higher plants, the dominant stage is the sporophyte generation

VII. **Regulation of the Cell Cycle**

A. Cell-cycle control system
   1. Components
      a. Cell-cycle molecular clock
      b. Checkpoints
         i. Ensure appropriate conditions exist prior to advancing onto the next phase of the cell cycle
         ii. Checkpoints exist at G₁, G₂, and M phases
         iii. Conditions include environmental conditions—intracellular and extracellular

B. Molecular controls
   1. Cyclic changes in the activity and presence of various molecules
      a. Protein kinases
         i. Phosphorylate target proteins
         ii. Activate or inactivate these proteins
      b. Cyclins control kinase activity
         i. Cyclin concentration change cyclically during the cell cycle
         ii. Protein kinases that regulate the cell cycle are cyclin-dependent (Cdks)
         iii. The kinase level does not change but as cyclin levels change, the corresponding activity of the Cdks does
         iv. Cyclin complexes with the kinase to make it active
   2. Activated regulatory molecules control events during specific phases of the cell cycle