The Cell Cycle

In this topic we will examine the cell cycle, the series of changes that a cell goes through from one division to the next.

We will pay particular attention to how the genetic material is passed on from parent cell to daughter cells during the cell cycle.

Objective # 1

Compare the amount and organization of genetic material in prokaryotic cells with the amount and organization of genetic material in eukaryotic cells.

Objective 1

An average eukaryotic cell has about 1,000 times more DNA than an average prokaryotic cell.

Prokaryotes have a single, circular DNA molecule. It is sometimes called “naked” because the DNA is not combined with proteins.

The DNA in a eukaryotic cell is organized into several linear chromosomes. Each chromosome normally contains one DNA molecule which is combined with special proteins called histones.

Objective 1

<table>
<thead>
<tr>
<th>DNA structure</th>
<th>Prokaryotes</th>
<th>Eukaryotes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>single, naked, circular DNA molecule</td>
<td>many linear chromosomes, each made of 1 DNA molecule joined with protein</td>
</tr>
<tr>
<td>location</td>
<td>in an area of the cytoplasm called the nucleoid</td>
<td>inside a membrane-bound nucleus</td>
</tr>
</tbody>
</table>

Objective # 2

Describe the process of cell division in prokaryotic cells.
Objective 2

Prokaryotes use a type of cell division called binary fission:
1) First, the single, circular DNA molecule replicates, producing two identical copies of the original.
2) Next, the 2 DNA molecules move to opposite ends of the cell.

3) Finally, the cytoplasm divides in half, producing 2 daughter cells which each have one copy of the original DNA molecule. Therefore, the 2 new cells are genetically identical to each other and to the original cell.

Objective # 3

Describe the structure of both unduplicated and duplicated eukaryotic chromosomes; and distinguish between chromosome, chromatid, centromere, and chromatin.

Eukaryotic chromosomes are made of chromatin, a complex of DNA and protein.
Each unduplicated chromosome contains one DNA molecule, which may be several inches long.

How can such long molecules fit inside a microscopic nucleus?
- Every 200 nucleotide pairs, the DNA wraps twice around a group of 8 histone proteins to form a nucleosome.
- Higher order coiling and supercoiling also help condense and package the chromatin inside the nucleus:
For much of the cell cycle, most of the chromatin is loosely coiled. During this time, the individual chromosomes cannot be seen inside the nucleus.

Prior to cell division each chromosome duplicates itself. All the duplicated chromosomes then condense into short rod-like structures that can be seen and counted under the microscope:

Because of duplication, each condensed chromosome consists of 2 identical chromatids joined by a centromere. Each duplicated chromosome contains 2 identical DNA molecules (unless a mutation occurred during duplication), one in each chromatid:
Objective 3

- The centromere is a constricted point on the chromosome containing a specific DNA sequence, to which is bound 2 discs of protein called kinetochores.
- Kinetochores serve as points of attachment for microtubules that move the chromosomes during cell division.

Objective # 4

Explain what karyotypes are and how they are useful.

Objective 4

- The particular array of chromosomes in a eukaryotic cell is called its karyotype.
- To examine a karyotype, the chromosomes are photographed when they are highly condensed, then photos of the individual chromosomes are cut out and arranged in order of decreasing size:
Objective 4

- Karyotypes are used to study the number and structure of the chromosomes present in a cell.
- They can also be used to detect chromosomal abnormalities that may be associated with specific genetic traits or defects.

Objective # 5

Distinguish between a haploid cell and a diploid cell.
Distinguish between identical chromosomes, homologous chromosomes, and non-homologous chromosomes.

Objective 5

- In eukaryotes, every species requires a specific number of chromosomes to code for all the polypeptides produced by the organism. These chromosomes make up 1 complete set.
- Each chromosome in a set controls the production of a different group of polypeptides.

Objective 5

- Cells that contain 1 complete set of chromosomes are called haploid.
- \( n \) or \( N \) represents the number of chromosomes in a haploid cell.
- Cells that contain 2 complete sets of chromosomes are called diploid.
- \( 2n \) or \( 2N \) represents the number of chromosomes in a diploid cell.

Objective 5

- For example, 23 different chromosomes are needed to code for all the polypeptides produced by humans.

- Therefore, in humans:
  \[ N = 23 \]
  \[ 2N = 46 \]

Objective 5

- We will use different shapes to represent the different chromosomes that make up a set, and different colors to represent different sets of chromosomes.
In a diploid cell, the chromosomes occur in pairs. The 2 members of each pair are called homologous chromosomes or homologues.

Under the microscope, homologous chromosomes look identical.

In addition, because they code for the same polypeptides, they control the same traits.

However, homologous chromosomes are not identical because they may code for different forms of each trait:

- Red eyes
- Short wings
- Tan body
- White eyes
- Long wings
- Tan body

Identical chromosomes:
- Look the same under the microscope (have the same shape and color on our diagrams)
- Control the same traits
- Code for the same form of each trait
- Common origin – both descended from the same original chromosome

Homologous chromosomes:
- Look the same under the microscope (have the same shape but different colors on our diagrams)
- Control the same traits
- May code for different forms of each trait
- Independent origin - each was inherited from a different parent
Objective 5
- Non-homologous chromosomes:
  - Look different under the microscope (have different shapes on our diagrams)
  - Control different traits

Objective 5
Duplicated Chromosomes
- Haploid Cell, $N = 3$
- Diploid Cell, $2N = 6$

Objective # 6
Define and be able to use the following terms correctly: gene, gene locus, and allele.

Objective 6
- Gene – a section of a DNA molecule that contains the code for making one polypeptide.
- Gene locus – the location of a gene along the length of a chromosome
- Alleles – genes that can occupy the same gene locus (on different chromosomes)

Objective # 7
Identify the stages of the eukaryotic cell cycle, and describe the events of each stage.
Objective 7

- The cell cycle refers to the sequence of events that occur as a cell grows and divides. It is divided into 2 main stages:
  - Interphase – chromosomes are not visible. Involves cell growth and duplication of the genetic material.
  - Cell division – includes division of the duplicated chromosomes (mitosis) and division of the cytoplasm (cytokinesis).

Objective 7

- Interphase is subdivided into 3 stages:
  - G1 is the primary growth phase of the cell cycle
  - S is when the cell synthesizes a copy of its chromosomes (DNA duplication).
  - G2 is the second growth phase, during which preparations are made for cell division.

Objective 7

- Mitosis is subdivided into 4 stages:
  - Prophase
  - Metaphase
  - Anaphase
  - Telophase

Objective #8

- List, describe, diagram, and identify the stages of mitosis.

Objective 8

- Mitosis:
  - some haploid and some diploid cells may divide by mitosis.
  - each new cell receives one copy of every chromosome that was present in the original cell.
  - produces 2 new cells that are both genetically identical to the original cell.
Objective 8, Mitosis in a Diploid Cell (2N=6)

DNA duplication during interphase

Mitosis

Objective 8, Mitosis in a Haploid Cell (N=3)

DNA duplication during interphase

Mitosis

Objective 8, Stages of Mitosis

- **Prophase:**
  - nuclear membrane disintegrates
  - nucleolus disappears
  - duplicated chromosomes condense
  - mitotic spindle begins to form
  - kinetochores begin to mature and attach to mitotic spindle

Objective 8, Stages of Mitosis

- **Metaphase:**
  - kinetochores attach duplicated chromosomes to mitotic spindle
  - chromosomes line up, in single file, along metaphase plate at equator of cell
Objective 8, Stages of Mitosis

- **Anaphase:**
  - Centromeres split so that each duplicated chromosome becomes 2 identical, unduplicated chromosomes
  - Kinetochore microtubules shorten, pulling identical chromosomes to opposite poles
  - Polar microtubules elongate preparing cell for cytokinesis

- **Telophase:**
  - Chromosomes reach poles of cell
  - Kinetochore disappear
  - Polar microtubules continue to elongate, preparing cell for cytokinesis
  - Nuclear membrane reforms
  - Nucleolus reappears
  - Chromosomes decondense
Objective # 9

Describe the process of cytokinesis and distinguish between mitosis and cytokinesis.

Objective 9

- Cytokinesis refers to division of the cytoplasm during cell division, while mitosis refers to division of the genetic material (chromosomes).

- Although cytokinesis generally follows mitosis, this isn’t always the case.

Objective 9

- In animal cells and other eukaryotic cells that lack a cell wall, cytokinesis is achieved by means of a constricting belt of actin filaments.

- As the filaments slide past each other, they create a cleavage furrow which deepens and eventually pinches the cell in half:
Objective 9

- Plant cells possess a cell wall which is too rigid to be squeezed in half by actin filaments.
- Instead, a new cell membrane, called a cell plate, is assembled in the middle of the cell. As this expands outward, it effectively divides the cell in two.

Objective 10

Explain what cancer is, and describe how cancer can result when control of the eukaryotic cell cycle breaks down.

Cancer is the uncontrolled growth and division of cells.

- Most cancers result from mutations in one of two types of growth-regulating genes:
  - proto-oncogenes
  - tumor-suppressor genes

Objective 10

- Proto-oncogenes code for proteins involved in stimulating cell division.
- Mutated proto-oncogenes that stimulate a cell to divide when it shouldn’t are called oncogenes (cancer-causing genes).

Objective 10

- Tumor-suppressor genes code for proteins involved in inhibiting cell division.
- Mutated tumor-suppressor genes that do not inhibit cell division when they should can also cause cancer.