19.5: DNA Replication in Eukaryotic Cells and the Eukaryotic Cell Cycle

Skills to Develop

1. Briefly describe the process of DNA replication.
2. Compare prokaryotic and eukaryotic DNA replication in terms of origins of replication.
3. Define telomeres and state whether they are found in prokaryotic or eukaryotic DNA.
4. Name the stages of mitosis and state what happens during each.

As in prokaryotes, the linear chromosomes of eukaryotes replicate by strand separation and complementary base pairing of free deoxyribonucleotides with those on each parent DNA strand. As with prokaryotes, DNA replication in eukaryotic cells is bidirectional. However, unlike the circular DNA in prokaryotic cells that usually has a single origin of replication, the linear DNA of a eukaryotic cell contains multiple origins of replication (Figure 11).

![Bidirectional DNA Replication in Eukaryotic Cells](https://bio.libretexts.org/Bookshelves/Microbiology/Book%3A_Microbiology_(Kaiser)/Unit_7%3A_Microbial_Genetics_and_Microbial_Metabolism/19%3A_Review_of_Molecular_Genetics/19.5%3A_DNA_Replication_in_Eukaryotic_Cells_and_the_Eukaryotic_Cell_Cycle)

Figure 11: Bidirectional DNA Replication in Eukaryotic Cells. DNA replication (arrows) occurs in both directions from multiple origins of replication in the linear DNA found in eukaryotic cells.

As discussed earlier under prokaryotic DNA replication, DNA can only be synthesized in a 5' to 3' direction and all DNA polymerase requires a primer. To solve this problem, the ends of the linear eukaryotic DNA strands, called **telomeres**, have short, repetitive, noncoding DNA base sequences. A unique enzyme called **telomerase** binds to the telomeric DNA at the 3' end. The telomerase contains a small RNA template as a cofactor which is copied by DNA nucleotides to extend...
the 3' end. Once the extension is long enough, primase can assemble a short RNA primer on the lagging strand and DNA replication can proceed in a manner similar to the lagging strand of prokaryotic DNA.

**Animation:** Replication of DNA by Complementary Base Pairing. As the DNA strands unwind and separate, new complementary strands are produced by the hydrogen bonding of free DNA nucleotides with those on each parent strand. As the new nucleotides line up opposite each parent strand by hydrogen bonding, enzymes called DNA polymerases join the nucleotides by way of phosphodiester bonds. The DNA polymerase responsible for these events is not shown here.

Once the chromosomes have replicated, the nucleus divides by mitosis (see Figure 12 through 16). The eukaryotic cell cycle is divided into two major phases: interphase and cell division.

### Interphase

Ninety percent or more of the cell cycle is spent in interphase. During interphase, cellular organelles double in number, the DNA replicates, and protein synthesis occurs. The chromosomes are not visible and the DNA appears as uncoiled chromatin.

Interphase in a plant cell: see Figure 17
Interphase in a Plant Cell. Ninety percent or more of the cell cycle is spent in interphase. During interphase, cellular organelles double in number, the DNA replicates, and protein synthesis occurs. The chromosomes are not visible and the DNA appears as uncoiled chromatin. These are cells found in the root tip of an onion plant.

Interphase in an animal cell: see Figure 18

Interphase in an Animal Cell. Ninety percent or more of the cell cycle is spent in interphase. During interphase, cellular organelles double in number, the DNA replicates, and protein synthesis occurs. The chromosomes are not visible and the DNA appears as uncoiled chromatin. These are cells from a whitefish.

Interphase is divided into the following stages: G₁, S, and G₂.

1. **G₁ phase:** During G₁ phase, the period that immediately follows cell division, the cell grows and differentiates. New organelles are made but the chromosomes have not yet replicated in preparation for cell division.
2. **S phase:** DNA synthesis occurs during S phase. The chromosomes replicate in preparation for cell division.
3. **G₂ phase:** During G₂ phase, molecules that will be required for cell replication are synthesized.

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**Cell Division**

Cell division consists of nuclear division and cytoplasmic division. Nuclear division is referred to as mitosis while cytoplasmic division is called cytokinesis.

1. **Mitosis (nuclear division)**

Mitosis is the nuclear division process in eukaryotic cells and ensures that each daughter cell receives the same number of chromosomes as the original parent cell. Mitosis can be divided into the following phases: prophase, metaphase, anaphase, and telophase.
a. Prophase: During prophase, the chromatin condenses and the chromosomes become visible. Also the nucleolus disappears, the nuclear membrane fragments, and the spindle apparatus forms and attaches to the centromeres of the chromosomes.

Prophase in a plant cell: see Figure 19 and Figure 20

Prophase in an animal cell: see Figure 21 and Figure 22

b. Metaphase: During metaphase, the nuclear membrane fragmentation is complete and the duplicated chromosomes line up along the cell's equator.

Metaphase in a plant cell: see Figure 23

Metaphase in an animal cell: see Figure 24

c. Anaphase: During anaphase, diploid sets of daughter chromosomes separate and are pushed and pulled toward opposite poles of the cell. This is accomplished by the polymerization and depolymerization of the microtubules that help to form the spindle apparatus.

Anaphase in a plant cell: see Figure 25 and Figure 26

Anaphase in an animal cell: see Figure 27

d. Telophase: During telophase, the nuclear membrane and nucleoli reform, cytokinesis is nearly complete, and the chromosomes eventually uncoil to chromatin. Usually cytokinesis occurs during telophase.

Telophase in a plant cell: see Figure 28 and Figure 29

Telophase in an animal cell: see Figure 30

YouTube movie illustrating mitosis.

2. Cytokinesis (cytoplasmic division)

During cytokinesis, the dividing cell separates into two diploid daughter cells. In animal cells, which lack a cell wall and are surrounded only by a cytoplasmic membrane, microfilaments of actin and myosin attached to the membrane form constricting rings around the central portion of the dividing cell and eventually divide the cytoplasm into two daughter cells. In the case of plant cells, which are surrounded by a cell wall in addition to the cytoplasmic membrane, carbohydrate-filled vesicles accumulate and fuse along the equator of the cell forming a cell plate that separates the cytoplasm into two daughter cells.

Summary

1. During DNA replication, each parent strand acts as a template for the synthesis of the other strand by way of complementary base pairing.
2. Complementary base pairing refers to DNA nucleotides with the base adenine only forming hydrogen bonds with nucleotides having the base thymine (A-T). Likewise, nucleotides with the base guanine can hydrogen bond only with nucleotides having the base cytosine (G-C).

3. Each DNA strand has two ends. The 5’ end of the DNA is the one with the terminal phosphate group on the 5’ carbon of the deoxyribose; the 3’ end is the one with a terminal hydroxyl (OH) group on the deoxyribose of the 3’ carbon of the deoxyribose.

4. To synthesize the two chains of deoxyribonucleotides during DNA replication, the DNA polymerase enzymes involved are only able to join the phosphate group at the 5’ carbon of a new nucleotide to the hydroxyl (OH) group of the 3’ carbon of a nucleotide already in the chain.

5. While the two strands of DNA are complementary, they are oriented in opposite directions to each other. One strand is said to run 5’ to 3’; the opposite DNA strand runs antiparallel, or 3’ to 5’.

6. Unlike the circular DNA in prokaryotic cells that usually has a single origin of replication, the linear DNA of a eukaryotic cell contains multiple origins of replication.

7. Because DNA can only be synthesized in a 5’ to 3’ direction and all DNA polymerase requires a primer, the ends of the linear eukaryotic DNA strands, called telomeres, have short, repetitive, noncoding DNA base sequences. A unique enzyme called telomerase binds to the telomeric DNA at the 3’ end. The telomerase contains a small RNA template as a cofactor which is copied by DNA nucleotides to extend the 3’ end. Once the extension is long enough, primase can assemble a short RNA primer on the lagging strand and DNA replication can proceed in a manner similar to the lagging strand of prokaryotic DNA.

8. Once the chromosomes have replicated, the nucleus divides by mitosis.

9. During interphase, cellular organelles double in number, the DNA replicates, and protein synthesis occurs. The chromosomes are not visible and the DNA appears as uncoiled chromatin.

10. During G1 phase, the period that immediately follows cell division, the cell grows and differentiates and new organelles are made.

11. DNA synthesis (chromosome replication) occurs during S phase.

12. During G2 phase, molecules that will be required for cell replication are synthesized.

13. Nuclear division is referred to as mitosis while cytoplasmic division is called cytokinesis.

14. During prophase, the chromatin condenses and the chromosomes become visible, the nucleolus disappears, the nuclear membrane fragments, and the spindle apparatus forms and attaches to the centromeres of the chromosomes.

15. During metaphase, the nuclear membrane fragmentation is complete and the duplicated chromosomes line up along the cell's equator.

16. During anaphase, diploid sets of daughter chromosomes separate and are pushed and pulled toward opposite poles of the cell.

17. During telophase, the nuclear membrane and nucleoli reform, cytokinesis is nearly complete, and the chromosomes eventually uncoil to chromatin.

18. During cytokinesis, the dividing cell separates into two diploid daughter cells.

Contributors

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