

## Chapter 12

### Overview: The Key Roles of Cell Division

- The ability of organisms to produce more of their own kind best distinguishes living things from nonliving matter
- The continuity of life is based on the reproduction of cells, or **cell division**
- In unicellular organisms, division of one cell reproduces the entire organism
- Multicellular organisms depend on cell division for
  - Development from a fertilized cell
  - Growth
  - Repair
- Cell division is an integral part of the **cell cycle**, the life of a cell from formation to its own division

### Concept 12.1: Most cell division results in genetically-identical daughter cells

- Most cell division results in daughter cells with identical genetic information, DNA
- The exception is meiosis, a special type of division that can produce sperm and egg cells

### Cellular Organization of the Genetic Material

- All the DNA in a cell constitutes the cell's **genome**
- A genome can consist of a single DNA molecule (common in prokaryotic cells) or a number of DNA molecules (common in eukaryotic cells)
- DNA molecules in a cell are packaged into **chromosomes**
- Eukaryotic chromosomes consist of **chromatin**, a complex of DNA and protein that condenses during cell division
- Every eukaryotic species has a characteristic number of chromosomes in each cell nucleus
- **Somatic cells** (nonreproductive cells) have two sets of chromosomes
- **Gametes** (reproductive cells: sperm and eggs) have half as many chromosomes as somatic cells

### Distribution of Chromosomes During Eukaryotic Cell Division

- In preparation for cell division, DNA is replicated and the chromosomes condense
- Each duplicated chromosome has two **sister chromatids** (joined copies of the original chromosome), which separate during cell division
- The **centromere** is the narrow “waist” of the duplicated chromosome, where the two chromatids are most closely attached
- During cell division, the two sister chromatids of each duplicated chromosome separate and move into two nuclei
- Once separate, the chromatids are called chromosomes
- Eukaryotic cell division consists of
  - **Mitosis**, the division of the genetic material in the nucleus
  - **Cytokinesis**, the division of the cytoplasm
- Gametes are produced by a variation of cell division called **meiosis**
- Meiosis yields nonidentical daughter cells that have only one set of chromosomes, half as many as the parent cell

**Concept 12.2: The mitotic phase alternates with interphase in the cell cycle**

- In 1882, the German anatomist Walther Flemming developed dyes to observe chromosomes during mitosis and cytokinesis

**Phases of the Cell Cycle**

- The cell cycle consists of
  - **Mitotic (M) phase** (mitosis and cytokinesis)
  - **Interphase** (cell growth and copying of chromosomes in preparation for cell division)
- Interphase (about 90% of the cell cycle) can be divided into subphases
  - **G<sub>1</sub> phase** (“first gap”)
  - **S phase** (“synthesis”)
  - **G<sub>2</sub> phase** (“second gap”)
- The cell grows during all three phases, but chromosomes are duplicated only during the S phase
- Mitosis is conventionally divided into five phases
  - **Prophase**
  - **Prometaphase**
  - **Metaphase**
  - **Anaphase**
  - **Telophase**
- Cytokinesis overlaps the latter stages of mitosis

**The Mitotic Spindle: A Closer Look**

- The **mitotic spindle** is a structure made of microtubules that controls chromosome movement during mitosis
- In animal cells, assembly of spindle microtubules begins in the **centrosome**, the microtubule organizing center
- The centrosome replicates during interphase, forming two centrosomes that migrate to opposite ends of the cell during prophase and prometaphase
- An **aster** (a radial array of short microtubules) extends from each centrosome
- The spindle includes the centrosomes, the spindle microtubules, and the asters
- During prometaphase, some spindle microtubules attach to the kinetochores of chromosomes and begin to move the chromosomes
- **Kinetochores** are protein complexes associated with centromeres
- At metaphase, the chromosomes are all lined up at the **metaphase plate**, an imaginary structure at the midway point between the spindle’s two poles
- In anaphase, sister chromatids separate and move along the kinetochore microtubules toward opposite ends of the cell
- The microtubules shorten by depolymerizing at their kinetochore ends
- Nonkinetochore microtubules from opposite poles overlap and push against each other, elongating the cell
- In telophase, genetically identical daughter nuclei form at opposite ends of the cell
- Cytokinesis begins during anaphase or telophase and the spindle eventually disassembles

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### **Cytokinesis: A Closer Look**

- In animal cells, cytokinesis occurs by a process known as **cleavage**, forming a **cleavage furrow**
- In plant cells, a **cell plate** forms during cytokinesis

### **Binary Fission in Bacteria**

- Prokaryotes (bacteria and archaea) reproduce by a type of cell division called **binary fission**
- In binary fission, the chromosome replicates (beginning at the **origin of replication**), and the two daughter chromosomes actively move apart
- The plasma membrane pinches inward, dividing the cell into two

### **The Evolution of Mitosis**

- Since prokaryotes evolved before eukaryotes, mitosis probably evolved from binary fission
- Certain protists exhibit types of cell division that seem intermediate between binary fission and mitosis

### **Concept 12.3: The eukaryotic cell cycle is regulated by a molecular control system**

- The frequency of cell division varies with the type of cell
- These differences result from regulation at the molecular level
- Cancer cells manage to escape the usual controls on the cell cycle

### **Evidence for Cytoplasmic Signals**

- The cell cycle appears to be driven by specific chemical signals present in the cytoplasm
- Some evidence for this hypothesis comes from experiments in which cultured mammalian cells at different phases of the cell cycle were fused to form a single cell with two nuclei

### **The Cell Cycle Control System**

- The sequential events of the cell cycle are directed by a distinct **cell cycle control system**, which is similar to a clock
- The cell cycle control system is regulated by both internal and external controls
- The clock has specific **checkpoints** where the cell cycle stops until a go-ahead signal is received
- For many cells, the G<sub>1</sub> checkpoint seems to be the most important
- If a cell receives a go-ahead signal at the G<sub>1</sub> checkpoint, it will usually complete the S, G<sub>2</sub>, and M phases and divide
- If the cell does not receive the go-ahead signal, it will exit the cycle, switching into a nondividing state called the **G<sub>0</sub> phase**

***The Cell Cycle Clock: Cyclins and Cyclin-Dependent Kinases***

- Two types of regulatory proteins are involved in cell cycle control: **cyclins** and **cyclin-dependent kinases (Cdks)**
- Cdks activity fluctuates during the cell cycle because it is controlled by cyclins, so named because their concentrations vary with the cell cycle
- **MPF** (maturation-promoting factor) is a cyclin-Cdk complex that triggers a cell's passage past the G<sub>2</sub> checkpoint into the M phase

***Stop and Go Signs: Internal and External Signals at the Checkpoints***

- An example of an internal signal is that kinetochores not attached to spindle microtubules send a molecular signal that delays anaphase
- Some external signals are **growth factors**, proteins released by certain cells that stimulate other cells to divide
- For example, platelet-derived growth factor (PDGF) stimulates the division of human fibroblast cells in culture
- A clear example of external signals is **density-dependent inhibition**, in which crowded cells stop dividing
- Most animal cells also exhibit **anchorage dependence**, in which they must be attached to a substratum in order to divide
- Cancer cells exhibit neither density-dependent inhibition nor anchorage dependence

**Loss of Cell Cycle Controls in Cancer Cells**

- Cancer cells do not respond normally to the body's control mechanisms
- Cancer cells may not need growth factors to grow and divide
  - They may make their own growth factor
  - They may convey a growth factor's signal without the presence of the growth factor
  - They may have an abnormal cell cycle control system
- A normal cell is converted to a cancerous cell by a process called **transformation**
- Cancer cells that are not eliminated by the immune system form tumors, masses of abnormal cells within otherwise normal tissue
- If abnormal cells remain only at the original site, the lump is called a **benign tumor**
- **Malignant tumors** invade surrounding tissues and can **metastasize**, exporting cancer cells to other parts of the body, where they may form additional tumors
- Recent advances in understanding the cell cycle and cell cycle signaling have led to advances in cancer treatment