

5.1 The Cell Cycle

VOCABULARY

cell cycle
mitosis
cytokinesis

KEY CONCEPT Cells have distinct phases of growth, reproduction, and normal functions.

MAIN IDEAS

- ▶ The cell cycle has four main stages
- ▶ Cells divide at different rates.
- ▶ Cell size is limited.

Connect to Your World

Many of life's little chores, such as sweeping and dusting, are quietly satisfying and rather fun. Washing dishes by hand, however, is never fun, which is why some clever person made the dishwasher. This handy invention soaks, washes, and rinses your dishes to a spot-free, sanitary sparkle. You unload the dishes, and the machine is ready to start the cycle all over again. A cell goes through a cycle, too. This cycle of growth, DNA synthesis, and division is essential for an organism to grow and heal. If it goes out of control, abnormal cell growth may occur, resulting in cancer cells like those shown on the previous page.

▶ MAIN IDEA

The cell cycle has four main stages.

FIGURE 1.1 Cells grow and copy their DNA during interphase. They also carry out cell-specific functions in G₁ and G₂. During M stage, both the nucleus (in mitosis) and cytoplasm (in cytokinesis) are divided.

Just as all species have life cycles, from tiny chihuahuas to massive beluga whales, cells also have a life cycle. The **cell cycle** is the regular pattern of growth, DNA duplication, and cell division that occurs in eukaryotic cells.

FIGURE 1.1 shows its four main stages: gap 1, synthesis, gap 2, and mitosis.

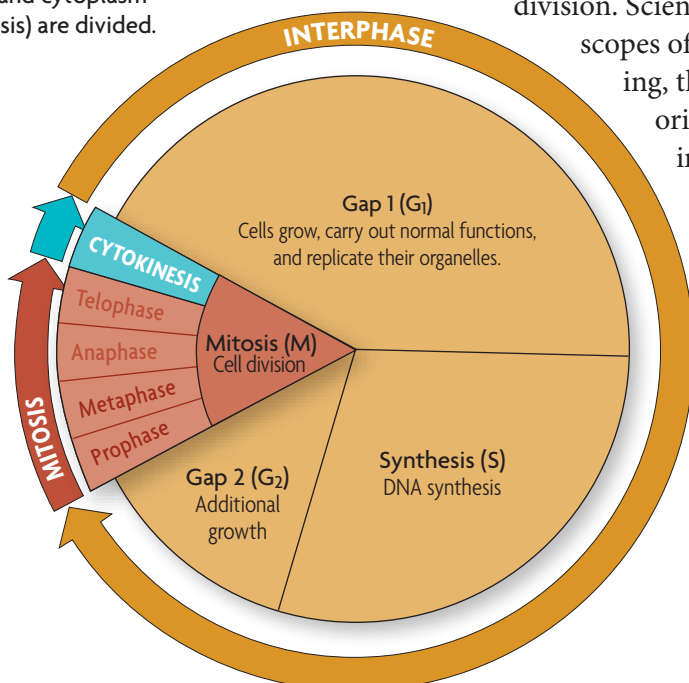
Gap 1, synthesis, and gap 2 together make up what is called interphase.

The stages of the cell cycle get their names from early studies of cell

division. Scientists' observations were limited by the microscopes of the time. When a cell was not actively dividing, they could not see activity in it. Thus, they

originally divided the cell cycle into two parts: interphase, when the cell appeared to be at rest, and mitosis, when the cell was dividing.

Improved techniques and tools later allowed scientists to detect the copying of DNA (DNA synthesis), and they changed their description of the cell cycle to include the synthesis stage. Since they still could not see anything happening during the other parts of interphase, scientists named the periods between mitosis and synthesis "gap 1" and "gap 2." Eventually scientists learned that, during interphase, cells carry out their normal functions and undergo critical growth and preparation for cell division.



Gap 1 (G₁)

The first stage of the cell cycle is gap 1 (G₁). During G₁, a cell carries out its normal functions. If it is a skeletal muscle cell, it contracts to move joints. If it is an adrenal cell, it secretes hormones such as adrenaline. If it is an intestinal cell, it absorbs nutrients. During G₁, cells also increase in size, and organelles increase in number. A cell spends most of its time in the G₁ stage, although the length of this stage varies by cell type.

During G₁, the cell must pass a critical checkpoint before it can proceed to the synthesis stage. Just as it would be dangerous for you to run a marathon if you had not slept or eaten for several days, it would also be dangerous for your cells to continue dividing if certain conditions were not met. For instance, most animal cells need enough nutrition, adequate size, and relatively undamaged DNA to divide successfully. They also need specific signals from other cells, telling them whether more cell division is needed.

Synthesis (S)

The second stage of the cell cycle is the synthesis (S) stage. *Synthesis* means “the combining of parts to make a whole.” During the S stage, the cell makes a copy of its nuclear DNA. In eukaryotes, DNA is located in the nucleus. During interphase, it is loosely organized and appears grainy in photographs. By the end of the S stage, the cell nucleus contains two complete sets of DNA.

Gap 2 (G₂)

Gap 2 (G₂) is the third stage of the cell cycle. During G₂, cells continue to carry out their normal functions, and additional growth occurs. Like G₁, this stage includes a critical checkpoint. Everything must be in order—adequate cell size, undamaged DNA—before the cell goes through mitosis and division.

Mitosis (M)

Mitosis (M), the fourth stage of the cell cycle, includes two processes: mitosis and cytokinesis. **Mitosis** (my-TOH-sihs) is the division of the cell nucleus and its contents. During mitosis, the nuclear membrane dissolves, the duplicated DNA condenses around proteins and separates, and two new nuclei form. Lastly, **cytokinesis** (SY-toh-kuh-NEE-sihs) is the process that divides the cell cytoplasm. The result is two daughter cells that are genetically identical to the original cell.

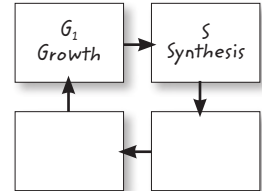
The stages of the cell cycle and the proteins that control it are similar in all eukaryotes. For example, scientists have demonstrated that some of the molecules that regulate checkpoints in the yeast cell cycle can work in human cells, too. Such similarities suggest that eukaryotes share a common ancestry.

Predict What might happen if the G₂ checkpoint stopped working in cells?

READING TOOLBOX

TAKING NOTES

Construct your own cycle diagram to take notes about processes such as the cell cycle.



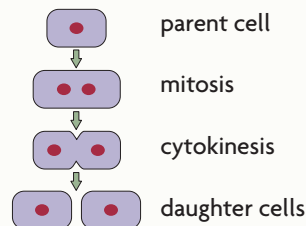
CONNECT TO

DNA REPLICATION

As you will learn in **From DNA to Proteins**, DNA synthesis is also called DNA replication. During this process, the DNA molecule unzips and each strand is used as a pattern for a new DNA strand.

VISUAL VOCAB

Mitosis is the division of the cell nucleus and its contents.



Cytokinesis divides the cell cytoplasm.



Multicellular organisms use cell division for growth and repair.

FIGURE 1.2 CELL LIFE SPAN

CELL TYPE	APPROXIMATE LIFE SPAN
Skin cell	2 weeks
Red blood cell	4 months
Liver cell	300–500 days
Intestine—internal lining	4–5 days
Intestine—muscle and other tissues	16 years

Source: Spaulding et al., *Cell* 122:1.

▶ MAIN IDEA

Cells divide at different rates.

Rates of cell division vary widely, as shown in **FIGURE 1.2**. The prokaryotic cell cycle is similar but not identical to that of eukaryotic cells. Recall that prokaryotes do not have the membrane-bound organelles and cytoskeleton found in eukaryotes. Thus, prokaryotic cells typically divide much faster than do eukaryotic cells.

The rate at which your cells divide is linked to your body's need for those cells. In human cells, the S, G₂, and M stages together usually take about 12 hours. The length of the G₁ stage differs most from cell type to cell type. The rate of cell division is greater in embryos and children than it is in adults. Children have a shorter cell cycle, and many of their organs are still developing. But the rate of cell division also varies within different tissues of the adult body. The internal lining of your digestive tract receives a lot of wear and tear. As a result, cells that line your stomach and intestine are replaced every few days. In contrast, cells that make up the rest of your intestine (mainly smooth muscle) and many of your internal organs, such as lungs, kidney, and liver, divide only occasionally, in response to injury or cell death.

Cells that divide only rarely are thought to enter a stage that some scientists call G₀. In G₀, cells are unlikely to divide, although they continue to carry out their normal functions. Some cells, such as neurons, appear to stay permanently in the G₀ stage. However, some data suggest that neurons actually can divide, and this question continues to be actively researched. Other cells, such as lymphocytes, a type of white blood cell, may remain in G₀ for years until they recognize an invader. Once the invader binds to a lymphocyte receptor, the lymphocyte goes through rapid cell divisions to help fight infection.

Infer Do you think a skin cell would have a long or short G₁ stage? Explain why.

CONNECT TO

LYMPHOCYTES

As you will learn in **Immune System and Disease**, lymphocytes are a part of your immune system. There are two major types of lymphocytes, B and T cells. Both types recognize specific antigens.

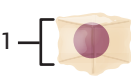
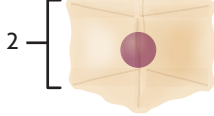
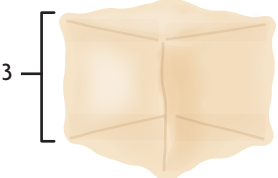
▶ MAIN IDEA

Cell size is limited.

Cells have upper and lower size limits. If cells were too small, they could not contain all of the necessary organelles and molecules. For instance, a cell with too few mitochondria would not have enough energy to live. However, cells cannot grow beyond a certain size, even if surrounded by plenty of nutrients. The upper limit on cell size is due to the ratio of cell surface area to volume. Recall that oxygen, nutrients, and wastes move across the cell membrane, or the surface of the cell. These materials must be transported in adequate amounts and with adequate speed to keep the inside of the cell functioning. But as a cell increases in size, its volume increases faster than its surface area, as shown in **FIGURE 1.3**. Therefore, a further increase in size could result in a surface area too small for the adequate exchange of materials.

FIGURE 1.3 Ratio of Surface Area to Volume in Cells

As a cell grows, its volume increases more rapidly than its surface area. When the surface area-to-volume ratio is too small, the cell cannot move materials into and out of the cell at a sufficient rate or in sufficient quantities.

Relative size			
Surface area (length × width × number of sides)	6	24	54
Volume (length × width × height)	1	8	27
Ratio of surface area to volume	$\frac{6}{1} = 6:1$	$\frac{24}{8} = 3:1$	$\frac{54}{27} = 2:1$

Compare Which cell has the largest surface area? Which cell has the largest surface area-to-volume ratio?

Some cells, however, must be large. A neuron running down a giraffe's neck to its legs may be several meters long, for instance. But it is not shaped like a cube or a sphere. Instead, it is extremely long and thin. This structure gives the neuron a large surface area with a relatively small increase in volume.

To maintain a suitable cell size, growth and division must be coordinated. If a cell more than doubled its size before dividing, the daughter cells would be larger than the original cell. If this happened with each generation, cells would quickly become too large to live. Similarly, if a cell did not double its size before dividing, the daughter cells would be smaller than the original cell. If this happened with each generation, cells would become too small to live.

Connect Which has the larger ratio of surface area to volume, a tennis ball or a soccer ball? Explain your reasoning.

5.1 Formative Assessment

REVIEWING MAIN IDEAS

1. During which stage of the **cell cycle** is the DNA copied?
2. Which stages of the cell cycle generally require about the same amount of time in all human cells?
3. What limits the maximum size of a cell?

CRITICAL THINKING

4. **Infer** Suppose you were to draw a diagram representing the cell cycle of a neuron. Explain where and how you would represent G_0 .
5. **Predict** Suppose you treat cells with chemicals that block **cytokinesis**. Describe what you think the cells would look like.



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PREMIUM CONTENT

CONNECT TO

SCIENTIFIC PROCESS

6. Predict how the rate of cell division would differ between single-celled algae living in a sunny, nutrient-rich pond versus algae living in a shady, nutrient-poor pond. How could you test your prediction?