Section 9.1

Reading Preview

Objectives

- **Explain** why cells are relatively small.
- **Summarize** the primary stages of the cell cycle.
- **Describe** the stages of interphase.

Review Vocabulary

selective permeability: process in which a membrane allows some substances to pass through while keeping others out

New Vocabulary

cell cycle
interphase
mitosis
cytokinesis
chromosome
chromatin

Cellular Growth

MAIN Idea Cells grow until they reach their size limit, then they either stop growing or divide.

Real-World Reading Link If you've ever played a doubles match in tennis, you probably felt that you and your partner could effectively cover your half of the court. However, if the court were much larger, perhaps you could no longer reach your shots. For the best game, the tennis court must be kept at regulation size. Cell size also must be limited to ensure that the needs of the cell are met.

Cell Size Limitations

Most cells are less than 100 μm (100×10^{-6} m) in diameter, which is smaller than the period at the end of this sentence. Why are most cells so small? This section investigates several factors that influence cell size.

Ratio of surface area to volume The key factor that limits the size of a cell is the ratio of its surface area to its volume. The surface area of the cell refers to the area covered by the plasma membrane. Recall from Chapter 7 that the plasma membrane is the structure through which all nutrients and waste products must pass. The volume refers to the space taken by the inner contents of the cell, including the organelles in the cytoplasm and the nucleus.

Connection to Math To illustrate the ratio of surface area to volume, consider the small cube in **Figure 9.1,** which has sides of one micrometer (μm) in length. This is approximately the size of a bacterial cell. To calculate the surface area of the cube, multiply length times width times the number of sides (1 μm × 1 μm × 6 sides), which equals 6 μm^2. To calculate the volume of the cell, multiply length times width times height (1 μm × 1 μm × 1 μm), which equals 1 μm^3. The ratio of surface area to volume is 6:1.

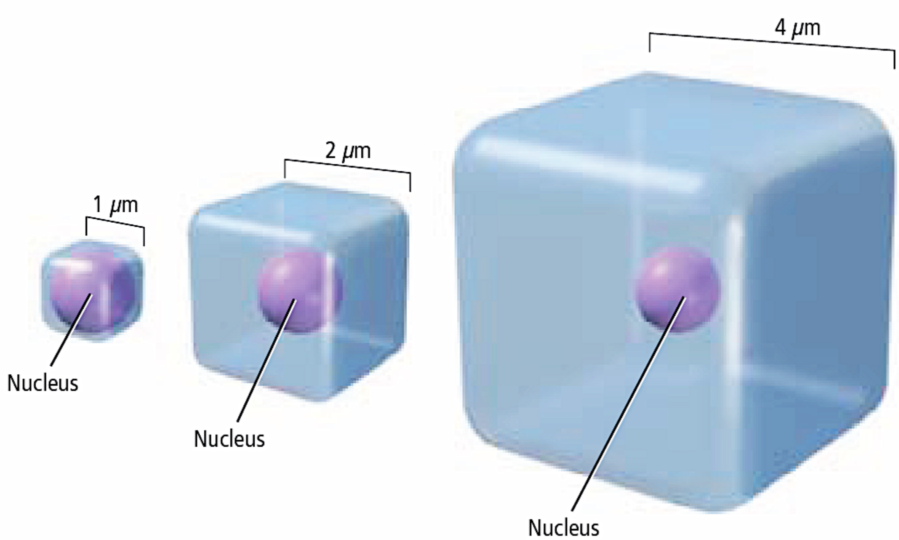

Figure 9.1 The ratio of surface area to volume decreases as a cell gets bigger. The smallest cube shown has a ratio of 6 (1 μm × 1 μm × 6 sides) to 1 (1 μm × 1 μm × 1 μm), while the largest cube has a ratio of 96 (4 μm × 4 μm × 6 sides) to 64 (4 μm × 4 μm × 4 μm) or 3:2.

If the cubic cell grows to 2 µm per side, as represented in **Figure 9.1,** the surface area becomes 24 μm^2 and the volume is 8 μm^3. The ratio of surface area to volume is now 3:1, which is less than it was when the cell was smaller. If the cell continues to grow, the ratio of surface area to volume will continue to decrease, as shown by the third cube in **Figure 9.1.** As the cell grows, its volume increases much more rapidly than the surface area. This means that the cell might have difficulty supplying nutrients and expelling enough waste products. By remaining small, cells have a higher ratio of surface area to volume and can sustain themselves more easily.

Reading Check **Explain** why a high ratio of surface area to volume benefits a cell.

Transport of substances Another task that can be managed more easily in a small cell than in a large cell is the movement of substances. Recall that the plasma membrane controls cellular transport because it is selectively permeable. Once inside the cell, substances move by diffusion or by motor proteins pulling them along the cytoskeleton. Diffusion over large distances is slow and inefficient because it relies on random movement of molecules and ions. Similarly, the cytoskeleton transportation network, shown in **Figure 9.2,** becomes less efficient for a cell if the distance to travel becomes too large. Therefore, cells remain small to maximize the ability of diffusion and motor proteins to transport nutrients and waste products. Small cells maintain more efficient transport systems.

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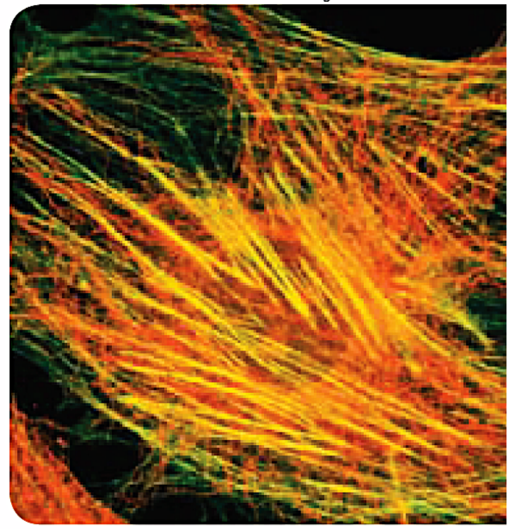


Figure 9.2 In order for the cytoskeleton to be an efficient transportation railway, the distances substances must travel within a cell must be limited.

MiniLab 9.1

Investigate Cell Size

Could a cell grow large enough to engulf your school? What would happen if the size of an elephant were doubled? At the organism level, an elephant cannot grow significantly larger, because its legs would not support the increase in mass. Do the same principles and limitations apply at the cellular level? Do the math!

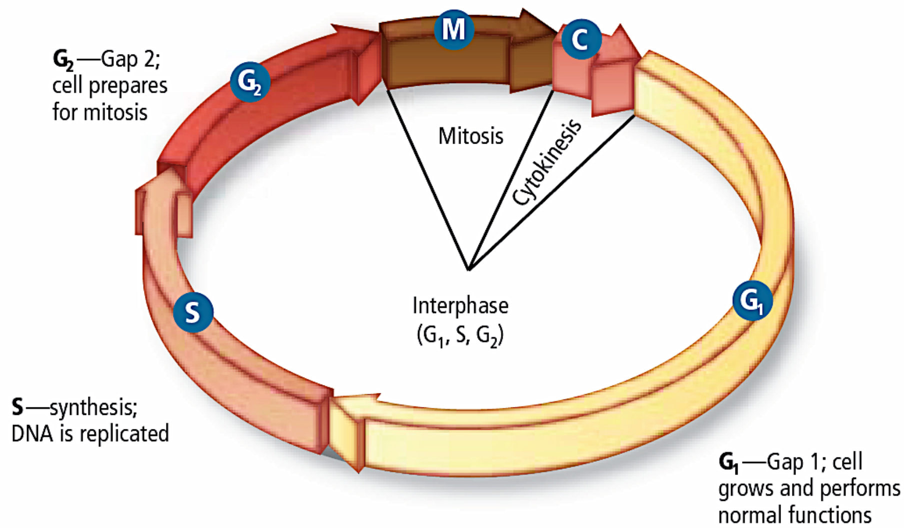
Procedure

1. Read and complete the lab safety form.
2. Prepare a data table for surface area and volume data calculated for five hypothetical cells. Assume the cell is a cube. (Dimensions given are for one face of a cube.)
   Cell 1: 0.00002 m (the average diameter of most eukaryotic cells)
   Cell 2: 0.001 m (the diameter of a squid's giant nerve cell)
   Cell 3: 2.5 cm
   Cell 4: 30 cm
   Cell 5: 15 m
3. Calculate the surface area for each cell using the formula: length × width × number of sides (6).
4. Calculate the volume for each cell using the formula: length × width × height.

Analysis

1. **Cause and Effect** Based on your calculations, confirm why cells don't become very large.
2. **Infer** Are large organisms, such as redwood trees and elephants, large because they contain extra large cells or just more standard-sized cells? Explain.

Figure 9.3 The cell cycle involves three stages—interphase, mitosis, and cytokinesis. Interphase is divided into three substages.
Hypothesize ***Why does cytokinesis represent the smallest amount of time a cell spends in the cell cycle?***



Cellular communications The need for signaling proteins to move throughout the cell also limits cell size. In other words, cell size affects the ability of the cell to communicate instructions for cellular functions. If the cell becomes too large, it becomes almost impossible for cellular communications, many of which involve movement of substances and signals to various organelles, to take place efficiently. For example, the signals that trigger protein synthesis might not reach the ribosome fast enough for protein synthesis to occur to sustain the cell.

The Cell Cycle

Once a cell reaches its size limit, something must happen—either it will stop growing or it will divide. Most cells will eventually divide. Cell division not only prevents the cell from becoming too large, but it is also the way the cell reproduces. Cellular reproduction allows you to grow and heal certain injuries. Cells reproduce by a cycle of growing and dividing called the **cell cycle.** Each time a cell goes through one complete cycle, it becomes two cells. When the cell cycle is repeated continuously, the result is a continuous production of new cells. A general overview of the cell cycle is presented in **Figure 9.3.**

There are three main stages of the cell cycle. **Interphase** is the stage during which the cell grows, carries out cellular functions, and replicates, or makes copies of its DNA in preparation for the next stage of the cycle. Interphase is divided into three substages, as indicated by the segment arrows in **Figure 9.3.** **Mitosis** (mi TOH sus) is the stage of the cell cycle during which the cell's nucleus and nuclear material divide. Mitosis is divided into four substages. Near the end of mitosis, a process called cytokinesis begins. **Cytokinesis** (si toh kih NEE sis) is the method by which a cell's cytoplasm divides, creating a new cell. You will read more about mitosis and cytokinesis in Section 9.2.

VOCABULARY
WORD ORIGIN
Cytokinesis
cyto– prefix; from the Greek word *kytos,* meaning *hollow vessel*
–kinesis from the Greek word *kinetikos,* meaning *putting in motion*

The duration of the cell cycle varies, depending on the cell that is dividing. Some eukaryotic cells might complete the cycle in as few as eight minutes, while other cells might take up to one year. For most normal, actively dividing animal cells, the cell cycle takes approximately 12–24 hours. When you consider all that takes place during the cell cycle, you might find it amazing that most of your cells complete the cell cycle in about a day.

The stages of interphase During interphase, the cell grows, develops into a mature, functioning cell, duplicates its DNA, and prepares for division. Interphase is divided into three stages, as shown in **Figure 9.3:** G_1, S, and G_2, also called Gap 1, synthesis, and Gap 2.

The first stage of interphase, G_1, is the period immediately after a cell divides. During G_1, a cell is growing, carrying out normal cell functions, and preparing to replicate DNA. Some cells, such as muscle and nerve cells, exit the cell cycle at this point and do not divide again.

The second stage of interphase, S, is the period when a cell copies its DNA in preparation for cell division. **Chromosomes** (KROH muh sohmz) are the structures that contain the genetic material that is passed from generation to generation of cells. **Chromatin** (KROH muh tun) is the relaxed form of DNA in the cell's nucleus. As shown in **Figure 9.4,** when a specific dye is applied to a cell in interphase, the nucleus stains with a speckled appearance. This speckled appearance is due to individual strands of chromatin that are not visible under a light microscope without the dye.

The G_2 stage follows the S stage and is the period when the cell prepares for the division of its nucleus. A protein that makes microtubules for cell division is synthesized at this time. During G_2, the cell also takes inventory and makes sure it is ready to continue with mitosis. When these activities are completed, the cell begins the next stage of the cell cycle—mitosis.

Mitosis and cytokinesis The stages of mitosis and cytokinesis follow interphase. In mitosis, the cell's nuclear material divides and separates into opposite ends of the cell. In cytokinesis, the cell divides into two daughter cells with identical nuclei. These important stages of the cell cycle are described in Section 9.2.

Prokaryotic cell division The cell cycle is the method by which eukaryotic cells reproduce themselves. Prokaryotic cells, which you have learned are simpler cells, reproduce by a method called binary fission. You will learn more about binary fission in Chapter 18.

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Figure 9.4 The grainy appearance of this nucleus from a rat liver cell is due to chromatin, the relaxed material that condenses to form chromosomes.

Section 9.1 Assessment

Section Summary

- The ratio of surface area to volume describes the size of the plasma membrane relative to the volume of the cell.
- Cell size is limited by the cell's ability to transport materials and communicate instructions from the nucleus.
- The cell cycle is the process of cellular reproduction.
- A cell spends the majority of its lifetime in interphase.

Understand Main Ideas

1. MAIN Idea **Relate** cell size to cell functions, and explain why cell size is limited.
2. **Summarize** the primary stages of the cell cycle.
3. **Describe** what happens to DNA during the S stage of interphase.
4. **Make a diagram** of the stages of the cell cycle and describe what happens in each.

Think Critically

5. **Hypothesize** what the result would be if a large cell managed to divide, despite the fact that it had grown beyond an optimum size.

MATH in Biology

6. If a cube representing a cell is 5 µm on a side, calculate the surface area-to-volume ratio, and explain why this is or is not a good size for a cell.