5.5 Multicellular Life

VOCABULARY

tissue
organ
organ system
cell differentiation
stem cell

KEY CONCEPT **Cells work together to carry out complex functions.**

MAIN IDEAS

- Multicellular organisms depend on interactions among different cell types.
- Specialized cells perform specific functions.
- Stem cells can develop into different cell types.

Connect to Your World

Each of us enters this world as a helpless infant. At first, your ability to eat solid foods or take your first steps elicits a great deal of praise. Over time, however, your development of normal skills gets far less attention. By the time you reach the age of 18, people want to know what you plan to do with your life. Will you build houses or design clothing or treat patients? What will your specialty be? Cells, too, undergo specialization to carry out the complex functions required by the body.

MAIN IDEA

Multicellular organisms depend on interactions among different cell types.

Within multicellular organisms, cells communicate and work together in groups that form increasingly larger, more complex structures. This arrangement progresses from cells to tissues to organs to organ systems, as shown in **FIGURE 5.1**. **Tissues** are groups of cells that work together to perform a similar function. Groups of tissues that work together to perform a specific function or related functions are called **organs.** For instance, plants have photosynthetic tissues made of chlorophyll-containing cells. Conductive tissues transport sugars, water, and minerals to and from other parts of the plant. Protective tissues help prevent water loss. Together, these and other tissues form a leaf, the plant's food-producing organ.

Organs that carry out similar functions are further grouped into **organ systems.** In plants, the shoot system is above the ground. It includes stems that support the plant, leaves that capture radiant energy, and flowers that aid reproduction. Beneath the ground, the root system has different types of roots and root hairs that anchor the plant and absorb water and minerals.

As organ systems work together, they help an organism maintain homeostasis. For example, plants need to maintain a certain level of water within their cells, or they will wilt and die. They absorb water through their roots and expel it as water vapor through openings in their leaves called stomata. Stomata are controlled by special cells called guard cells, which close the stomata when a plant's water intake cannot keep up with its water loss.

CONNECT TO

HOMEOSTASIS

As you learned in **Biology in the 21st Century,** homeostasis is the maintenance of a stable internal environment. Both an organism's physiology and its behavior help it achieve homeostasis.

Apply **Suppose your family goes out of town and forgets to ask your neighbor to water the plants. Do you think the plants' stomata will be open or closed? Explain.**

FIGURE 5.1 Levels of Organization

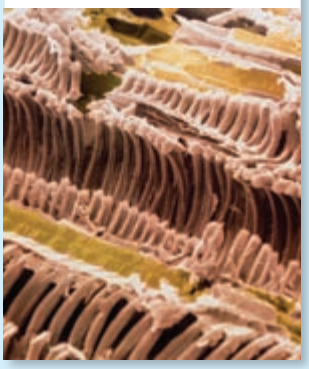
Cells work together in groups that form larger, specialized structures.

CELL

Vessel elements are tube-shaped cells. (colored SEM; magnification 200×)

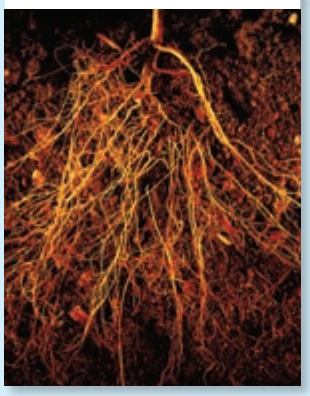
TISSUE

Vessel elements, tracheids, and parenchyma cells form xylem. (colored SEM; magnification 240×)

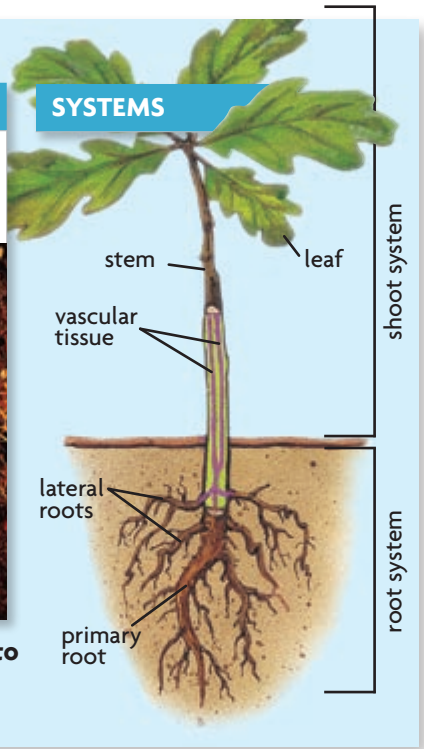


ORGAN

Xylem and other tissues form roots that absorb water and nutrients.



SYSTEMS



Apply **How is the shape of this plant's roots suited to their function?**

MAIN IDEA

Specialized cells perform specific functions.

CONNECT TO

GAMETOGENESIS

As you will learn in **Meiosis and Mendel,** the egg is stocked with organelles and molecules that are necessary for an embryo to grow. Many of these molecules are not evenly distributed throughout the cell; they form gradients.

It is easy to see that a skin cell can divide to make a new skin cell, or that a single bacterium can generate another bacterium. But how does a complex organism like you develop? Your body began as a single fertilized egg. If the egg simply divided to make lots of identical cells, it would not form a baby. To form the intricate structures that make up your body and the bodies of countless organisms around you, cells must specialize.

Cell differentiation is the process by which unspecialized cells develop into their mature forms and functions. While almost every cell in your body has a full set of DNA, each type of cell uses only the specific genes it needs to carry out its function. That is, a cell differentiates among the genes and uses only certain ones. You can think of your DNA as a cookbook. When you want to make a specific dish, you select that recipe and carry out its instructions. If you need to make a dessert, you might bake turtle brownies. If you need to make a main course, you might roast apple-stuffed pork chops or fix a hearty lentil stew. The dishes are very different, but they all come from the same cookbook.

A cell's location within the embryo helps determine how it will differentiate. In plant cells, the first division of a fertilized egg is unequal, or asymmetric, and produces two cells—the apical cell and the basal cell. The apical cell forms most of the embryo, including the growth point for stems and leaves. The major role of the basal cell is to provide nutrients to the embryo; it also creates the growth point for the roots. Plant cells cannot easily migrate because of the cell wall, but they adapt to changing conditions and continue to develop throughout their lifetime. As the plant grows, new cells continue to

differentiate based on their location. For example, cells on the outer layer of a leaf may become epidermal cells that secrete a waxy substance that helps prevent water loss. Cells on the lower leaf surface may become guard cells that control the exchange of water, air, and carbon dioxide.

In animals, an egg undergoes many rapid divisions after it is fertilized. The resulting cells can migrate to a specific area, and the cells quickly begin to differentiate. The early animal embryo generally takes the shape of a hollow ball. As the embryo develops, part of the ball folds inward, forming an inner layer and creating an opening in the outer cell layer. A middle layer of cells then forms between the other two.

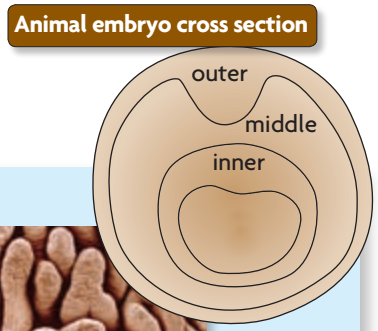
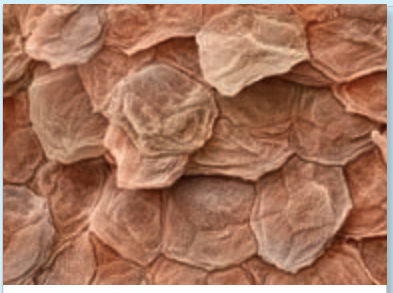
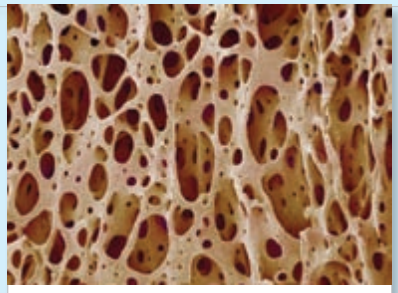


FIGURE 5.2 Cell Differentiation

Cell differentiation in the developing animal embryo is based on location.



Outer Skin cells help prevent infection and dehydration. (colored SEM; magnification 500×)



Middle Bone cells form a hard matrix (shown) that supports and protects organs. (colored SEM; magnification 15×)

Inner Intestinal epithelia have a large surface area that increases absorption. (colored SEM; magnification 25×)

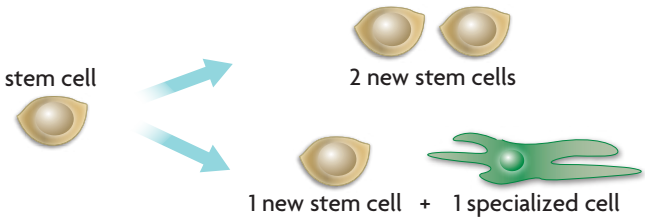
As shown in **FIGURE 5.2,** in vertebrates, the outer cell layer differentiates to form the outer layer of skin and elements of the nervous system, such as the brain and spinal cord. The middle cell layer forms bones, muscles, kidneys, and the inner layer of skin. The inner cell layer forms internal organs, such as the pancreas, lungs, and digestive system lining.

Analyze **Why is regulation of the differentiation process during the early stages of development so critical?**

MAIN IDEA

Stem cells can develop into different cell types.

Stem cells are a unique type of body cell that have the ability to (1) divide and renew themselves for long periods of time, (2) remain undifferentiated in form, and (3) develop into a variety of specialized cell types. When a stem cell divides, it forms either two stem cells or one stem cell and one specialized cell.



CONNECT TO

VOCABULARY

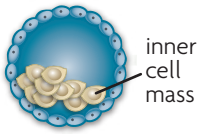
Potent comes from a Latin word meaning "to be able."
The addition of prefixes defines the level of power or ability.
toti- = all
pluri- = more, several
multi- = many

Stem Cell Classification

Stem cells can be categorized by their ability, or potential, to develop into the differentiated cell types of different tissues, as shown in **FIGURE 5.3.** In general, the more differentiated a stem cell already is, the fewer the types of cells it can form.

- Totipotent stem cells can grow into any other cell type. Only a fertilized egg and the cells produced by the first few divisions of an embryo are totipotent.
- Pluripotent stem cells can grow into any cell type except for totipotent stem cells.
- Multipotent stem cells can grow only into cells of a closely related cell family.

FIGURE 5.3 STEM CELL CLASSIFICATION

Class	totipotent	pluripotent	multipotent
Type of cell	fertilized egg 	embryonic stem cell 	adult stem cell (example from blood) 
Can give rise to	all cells	almost any cell	closely related cells
Example	new organism	neurons, skin, muscle, kidney, cartilage, bone, liver, pancreas	red blood cells, platelets, white blood cells

Stem cells are also classified by their origin, as either adult or embryonic. Adult stem cells have been studied for decades, but the ability to grow human embryonic stem cells was not developed until 1998. Since that time, embryonic stem cells have attracted great attention because of their potential to form almost any cell type. Both adult and embryonic stem cells offer unique advantages and challenges to researchers.

Adult Stem Cells

Adult stem cells are partially undifferentiated cells located among the specialized cells of many organs and tissues. They are found all over the body, in the brain, liver, bone marrow, skeletal muscle, dental pulp, and even fat. These stem cells are also found in children and in umbilical cord blood, so the term *somatic stem cell* is more accurate although less frequently used.

A major advantage of adult stem cells is that they can be taken from a patient, grown in culture, and put back into the patient. Thus, the risk of transplant rejection by a patient's immune system is very low. This method also avoids many ethical issues associated with using embryonic stem cells.

Adult stem cells currently pose many disadvantages as well. They are few in number, difficult to isolate, and sometimes tricky to grow. They may also contain more DNA abnormalities than do embryonic stem cells. For years, much evidence suggested that adult stem cells were multipotent. This would mean that a stem cell from fat would produce only fat cells, never muscle cells. Newer data suggest otherwise. Adult stem cells treated with the right combination of molecules may give rise to a completely different type of tissue. This process, called transdifferentiation, remains an active area of research.

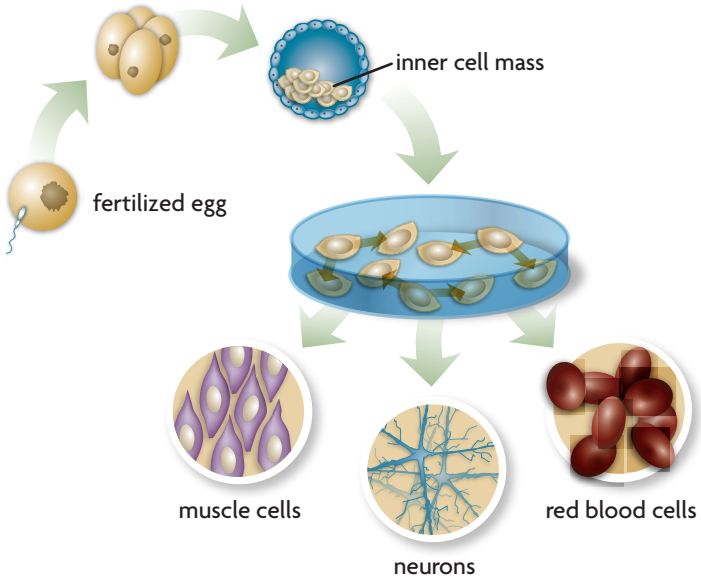
Embryonic Stem Cells

Most embryonic stem cells come from donated embryos grown in a clinic. These embryos are the result of in vitro fertilization, a process by which eggs are fertilized outside a woman's body. The stem cells are taken from a cluster of undifferentiated cells in the three-to-five-day-old embryo.

These cells, called the inner cell mass, do not have the characteristics of any specific cell type. Because they are pluripotent, they can form any of the 200 cell types of the body. They can also be grown indefinitely in culture. These qualities have given people hope that many now devastating diseases will be treatable or even curable in the future.

Embryonic stem cells also have a downside. If these cells are used in treatment, a patient's body might reject them as foreign material. A different possibility is that the stem cells could grow unchecked in a patient's body and form a tumor. The use of embryonic stem cells also raises many ethical questions. **FIGURE 5.4** shows the most common method of getting embryonic stem cells. This method currently involves destruction of the embryo, which some people consider ethically unacceptable.

FIGURE 5.4 HARVESTING EMBRYONIC STEM CELLS



First, an egg is fertilized by a sperm cell in a petri dish. The egg divides, forming an inner cell mass. These cells are then removed and grown with nutrients. Scientists try to control how the cells specialize by adding or removing certain molecules.

Research and Treatment Hope

Stem cells have long been used to treat patients with leukemia and lymphoma, and they offer hope for treating many other diseases as well. For instance, some patients might be cured of diabetes if nonworking cells in the pancreas are replaced with healthy, growing cells. Similarly, damaged organs, such as the heart, might be strengthened by an injection of healthy cells. Research, such as the testing of new drugs, might also benefit. The current research system requires a lot of time and money. Many of the most innovative drugs have little chance of reaching the patient. Potentially, these new compounds could be tested on large numbers of specific cell types grown from stem cells.

Compare and Contrast **List treatment benefits and risks of both types of stem cells.**

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PREMIUM CONTENT

5.5 Formative Assessment

REVIEWING MAIN IDEAS

1. How does communication between cells help maintain homeostasis?
2. Explain why **cell differentiation** is an important part of the development of a multicellular organism.
3. What are the defining characteristics of **stem cells**?

CRITICAL THINKING

4. **Compare** Describe how **tissues, organs,** and **organ systems** are similar.
5. **Evaluate** Explain which factor you think is most important in deciding whether stem-cell research should be legal and government-funded.

CONNECT TO

ANIMAL BEHAVIOR

6. Choose an animal and give an example of the way its behavior reflects its need to maintain homeostasis.