SB3. Students will derive the relationship between single-celled and multi-celled organisms and the increasing complexity of systems. **SB5.** Students will evaluate the role of natural selection in the development of the theory of evolution. **Also covers: SCSh1, SCSh3, SCSh4, SCSh6, SCSh9, SB4**

CHAPTER 27

Echinoderms and Invertebrate Chordates

Section 1
Echinoderm Characteristics

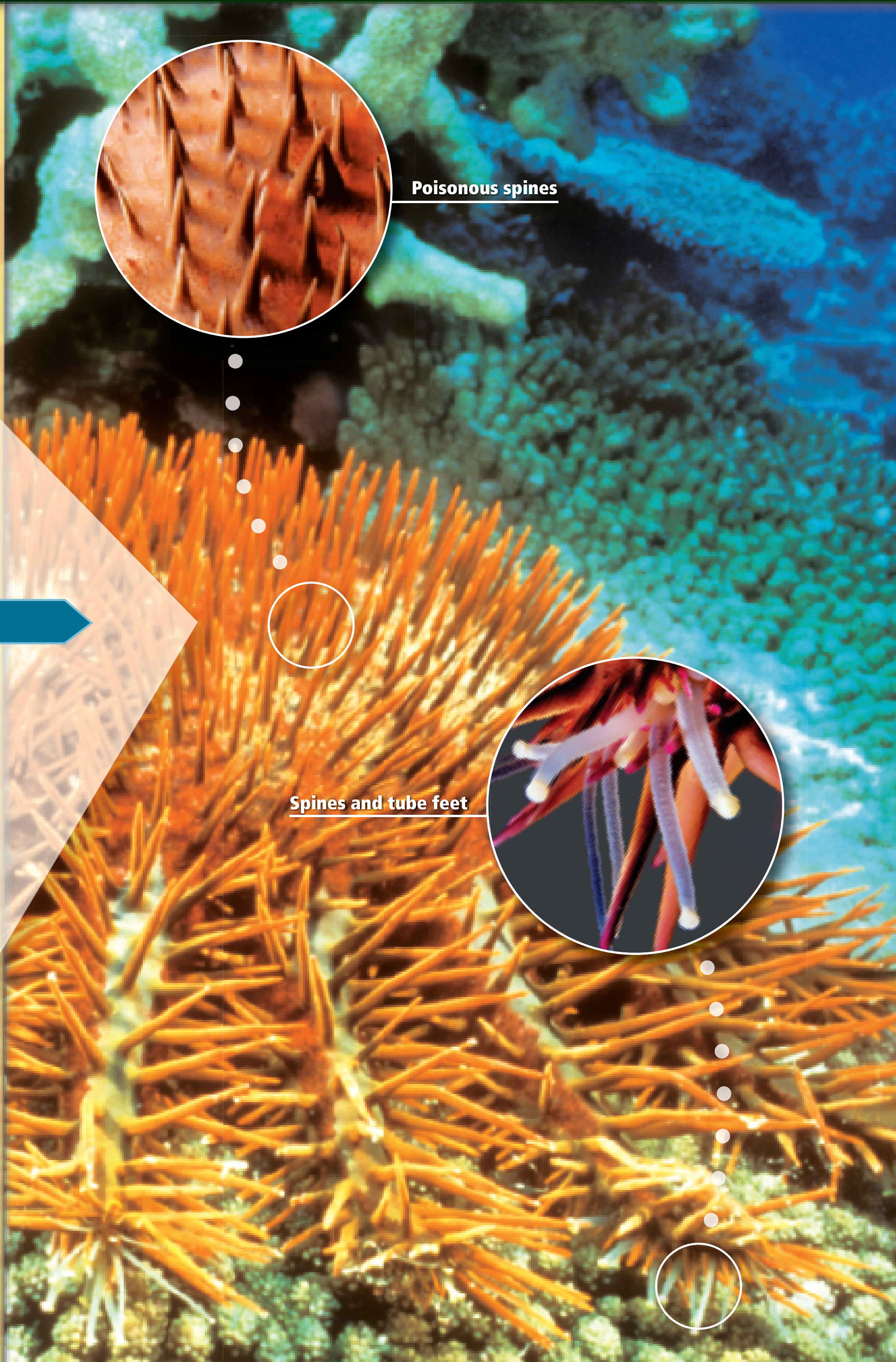
MAIN Idea Echinoderms are marine animals with spiny endoskeletons, water-vascular systems, and tube feet; they have radial symmetry as adults.

Section 2
Invertebrate Chordates

MAIN Idea Invertebrate chordates have features linking them to vertebrate chordates.

BioFacts

- A single crown-of-thorns sea star eats 2–6 m^2 of coral per year.
- Crown-of-thorns sea stars have spines that are covered with poison-filled skin.
- Another echinoderm, the sea cucumber, protects itself by changing the consistency of its skin from near liquid to solid and back again.



(t)Chris Newbert/Minden Pictures, (b)Chris Newbert/Minden Pictures, (bkgd)Franklin Viola/Animals Animals

Start-Up Activities

LAUNCH Lab

Why are tube feet important?

Like all echinoderms, the crown-of-thorns sea star in the opening photo has structures called tube feet. In this lab, you will observe tube feet and determine their function.

Procedure

1. Read and complete the lab safety form.
2. Place a **live sea star** in a **petri dish** filled with **water from a saltwater aquarium.** **WARNING:** ***Treat the sea star in a humane manner at all times.***
3. Observe the ventral side of the sea star under a **dissecting microscope.** Look for the rows of tube feet that run down the middle of each arm, and draw a diagram of the structures.
4. Gently touch the end of a tube foot with a **glass probe.** Record your observations.
5. Return the sea star and water to the aquarium.

Analysis

1. **Describe** the structure of the sea star's tube feet.
2. **Infer** Based on your observations, what is the function of an echinoderm's tube feet?

Biology Online

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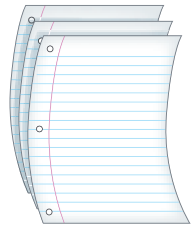
- study the entire chapter online
- explore Concepts in Motion, the Interactive Table, Microscopy Links, and links to virtual dissections
- access Web links for more information, projects, and activities
- review content online with the Interactive Tutor and take Self-Check Quizzes

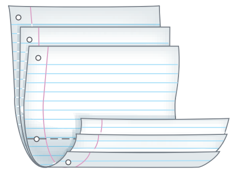
FOLDABLES Study Organizer

Describing Invertebrate Chordates Make the following Foldable to help you understand the physical features that link invertebrate chordates to vertebrate chordates.

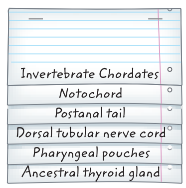
STEP 1 Collect three sheets of paper and layer them about 1.5 cm apart vertically. Keep the edges level.



STEP 2 Fold up the bottom edges of the paper to form six tabs.



STEP 3 Crease well along the fold to hold the tabs in place. Staple along the fold. Rotate the paper so the fold is at the top, and label each tab as shown.



FOLDABLES **Use this Foldable with Section 27.2.** As you read the section, record information about the physical features of invertebrate chordates that link them to vertebrate chordates.

Section 27.1

SB3b. Compare how structures and function vary between the six kingdoms (archaebacteria, eubacteria, protists, fungi, plants, and animals). SB5b. Explain the history of life in terms of biodiversity, ancestry, and the rates of evolution. Also covers: SCSh3a, SCSh4b, SCSh9c, SB4f

Echinoderm Characteristics

Objectives

- **Summarize** the characteristics common to echinoderms.
- **Evaluate** how the water-vascular system and tube feet are adaptations that enable echinoderms to be successful.
- **Distinguish** between the classes of echinoderms.

Review Vocabulary

endoskeleton: an internal skeleton that provides support and protection and can act as a brace for muscles to pull against

New Vocabulary

pedicellaria
water-vascular system
madreporite
tube foot
ampulla

MAIN Idea **Echinoderms are marine animals with spiny endoskeletons, water-vascular systems, and tube feet; they have radial symmetry as adults.**

Real-World Reading Link To take a blood-pressure reading, a health care professional squeezes a bulb that forces air through a tube and into the blood-pressure cuff around your arm. The cuff remains tight around your arm until the pressure is released when the air is let out. Some animals use this same kind of system to obtain food and move.

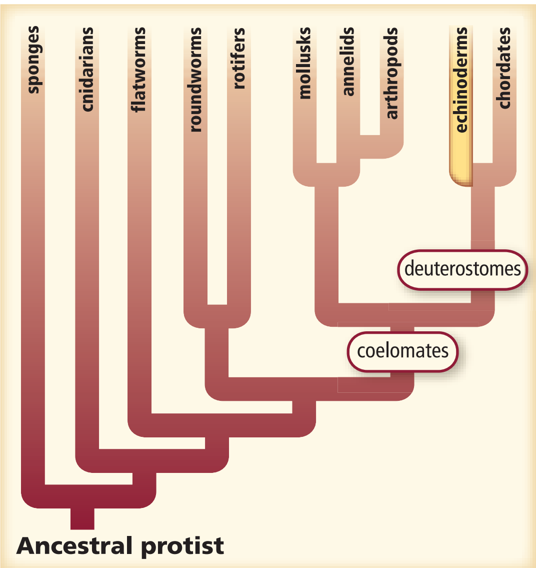
Echinoderms Are Deuterostomes

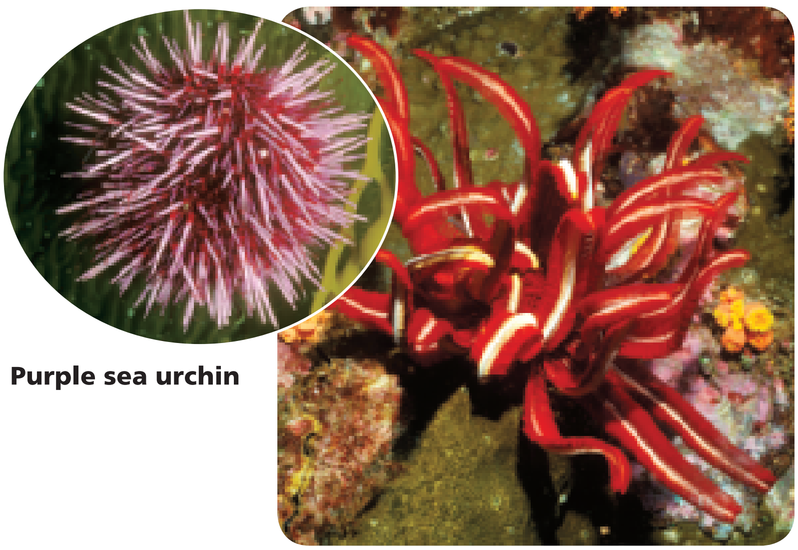
As shown in the evolutionary tree in **Figure 27.1,** echinoderms (ih KI nuh durmz) are deuterostomes—a major transition in the phylogeny of animals. Notice how the evolutionary tree branches at deuterostome development.

The mollusks, annelids, and arthropods you studied in previous chapters are protostomes. Recall that during development, a protostome's mouth develops from the opening on the gastrula, while a deuterostome's mouth develops from elsewhere on the gastrula. This might not seem important, but consider that only echinoderms and the chordates that evolved after echinoderms have this kind of development. Echinoderms and chordates are related more closely than groups that do not develop in this way. You are related more closely to the sea star in the opening photo than you are to a beetle or a clam.

The approximately 6000 living species of echinoderms are marine animals and include sea stars, sea urchins and sand dollars, sea cucumbers, brittle stars, sea lilies and feather stars, and sea daisies. Two echinoderms are shown in **Figure 27.1.**

Figure 27.1 Echinoderms are marine animals and are the first animals in evolutionary history to have deuterostome development and an endoskeleton.





Purple sea urchin

Feather star

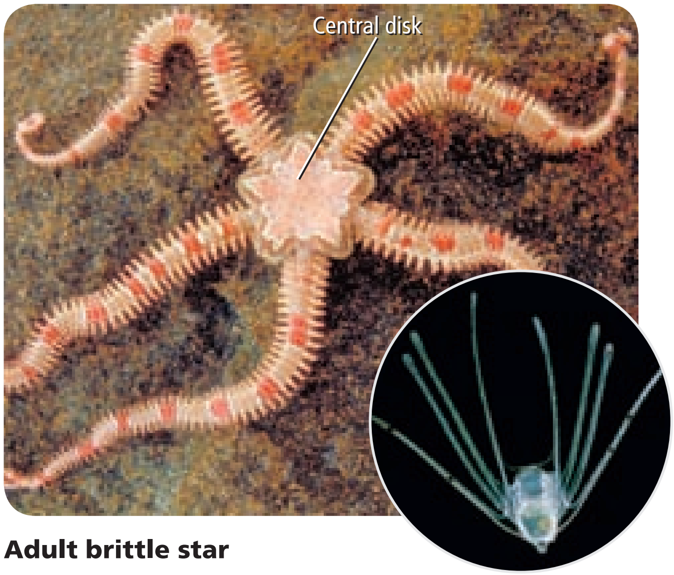
Body Structure

The brittle star is an example of an echinoderm with the spiny endoskeleton that is characteristic of the organisms in this phylum. Echinoderms are the first group of animals in evolutionary history to have endoskeletons. In echinoderms, the endoskeleton consists of calcium carbonate plates, often with spines attached, and is covered by a thin layer of skin. On the skin are **pedicellariae** (PEH dih sih LAHR ee uh), small pincers that aid in catching food and in removing foreign materials from the skin.

All echinoderms have radial symmetry as adults. In **Figure 27.2,** you can see this feature in the five arms of the brittle star radiating out from a central disk. However, echinoderm larvae have bilateral symmetry, as shown in **Figure 27.2.** In the next chapter, you will learn how bilateral symmetry shows an embryonic link to the vertebrate animals that evolved later.

No other animals with the complex organ systems of echinoderms have radial symmetry. Scientists theorize that the ancestors of echinoderms did not have radial symmetry. Primitive echinoderms might have been sessile, and radial symmetry developed, to enable them to carry on a successful stationary existence. Free-moving echinoderms might have evolved from the sessile animals. Investigate the features of echinoderms in **MiniLab 27.1.**

Reading Check **Infer** how radial symmetry is important to animals that cannot move quickly.



Adult brittle star

Brittle star larva

■ **Figure 27.2** Brittle star larvae have bilateral symmetry and can be divided along only one plane into mirror-image halves. Adult brittle stars have radial symmetry and can be divided through a central axis, along any plane, into equal halves.

MiniLab 27.1

Observe Echinoderm Anatomy

What are the characteristics of echinoderms? Although they have many shapes and sizes, all echinoderms have some features in common.

Procedure

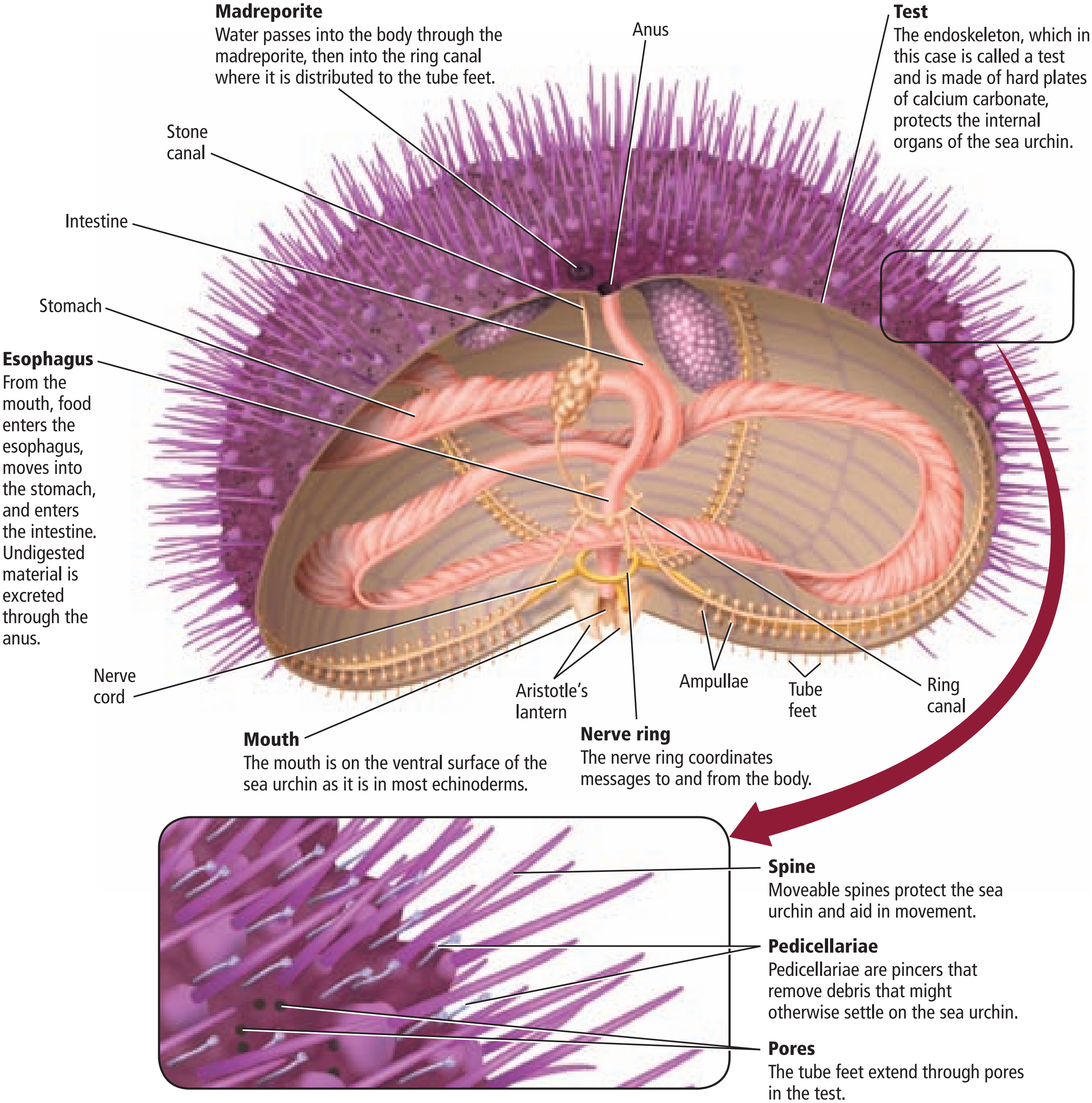
1. Read and complete the lab safety form.
2. Study preserved specimens of **a sand dollar, a sea cucumber, a sea star,** and **a sea urchin.**
3. Create a data table to record your observations. Complete the table by describing the major features of each specimen. Include a sketch of each specimen.
4. Label any external features you can identify.
5. Clean all equipment and return it to the appropriate place. Wash your hands thoroughly after handling preserved specimens.

Analysis

1. **Compare** the external features of the echinoderms you studied. Can your observations completely justify why these four organisms are classified in the same phylum? Explain.
2. **Observe and Infer** What features are most important in helping echinoderms avoid being eaten by predators?

Visualizing an Echinoderm

Figure 27.3
Sea urchins can be found in tidal areas of the sea. They burrow into crevices in rocks to hide, and they scrape algae with a hard five-plated structure, called Aristotle's lantern, in their mouths. Imagine that these plates are like teeth that move.



Concepts in Motion **Interactive Figure** To see an animation of echinoderm features, visit biologygmh.com

Biology Online

Water-vascular system Another feature of echinoderms is their **water-vascular system**—a system of fluid-filled, closed tubes that work together to enable echinoderms to move and get food. The strainerlike opening to the water-vascular system, shown in **Figure 27.3,** is called the **madreporite** (MA druh pohr it). Water is drawn into the madreporite, then moves through the stone canal to the ring canal. From there, the water moves to the radial canals and eventually to the tube feet.

Tube feet are small, muscular, fluid-filled tubes that end in suction-cup-like structures and are used in movement, food collection, and respiration. The opposite end of the tube foot is a muscular sac, called the **ampulla** (AM pyew luh). When muscles contract in the ampulla, water is forced into the tube foot and it extends. Imagine holding a small, partly inflated balloon in your hand and squeezing it. The balloon will extend from between your thumb and forefinger, which is similar to the way the tube foot extends. The suction-cup-like structure on the end of the tube foot attaches it to the surface. This hydraulic suction enables all echinoderms to move and some, such as sea stars, to apply a force strong enough to open the shells of mollusks, as illustrated in **Figure 27.4.**

■ **Figure 27.4** A sea star uses its tube feet to open the two shells of a clam.
Describe *the sea star's feeding method.*

Feeding and digestion Echinoderms use a great variety of feeding strategies in addition to tube feet. Sea lilies and feather stars extend their arms and trap food. Sea stars prey on a variety of mollusks, coral, and other invertebrates. Many species of sea stars can push their stomachs out of their mouths and onto their prey. They then spread digestive enzymes over the food and use cilia to bring the digested material to their mouths. Brittle stars can be active predators or scavengers, and they can trap organic materials in mucus on their arms. Most sea urchins use teethlike plates, shown in **Figure 27.3,** to scrape algae off surfaces or feed on other animals. Many sea cucumbers extend their branched, mucus-covered tentacles to trap floating food.

LAUNCH Lab

Review Based on what you've read about the water-vascular system, how would you now answer the analysis questions?

Respiration, circulation, and excretion Echinoderms also use their tube feet in respiration. Oxygen diffuses from the water through the thin membranes of the tube feet. Some echinoderms carry out diffusion of oxygen through all thin body membranes in contact with water. Others have thin-walled skin gills that are small pouches extending from the body. Many sea cucumbers have branched tubes, called respiratory trees, through which water passes and oxygen moves into the body.

Circulation takes place in the body coelom and the water-vascular system, while excretion of cellular wastes occurs by diffusion through thin body membranes. Cilia move water and body fluids throughout these systems aided by pumping action in some echinoderms. In spite of the simplicity of these organs and systems, echinoderms maintain homeostasis effectively with adaptations that are suited to their way of life.

Reading Check **Summarize** the functions of an echinoderm's tube feet.

VOCABULARY

ACADEMIC VOCABULARY

Aid:
To give assistance or to help.
Echinoderms capture food aided by their tube feet.

■ **Figure 27.5** A sea star lifts the end of an arm to sense light and movement.

Response to stimuli Echinoderms have both sensory and motor neurons with varying degrees of complexity in different species. In general, a nerve ring surrounds the mouth with branching nerve cords connecting to other body areas.

Sensory neurons respond to touch, chemicals dissolved in the water, water currents, and light. At the tips of the arms of sea stars are eyespots, clusters of light-sensitive cells, illustrated in **Figure 27.5.** Many echinoderms also sense the direction of gravity. For example, a sea star will return to an upright position after being overturned by a wave or current.

Movement Echinoderm locomotion is as varied as echinoderm body shapes. The structure of the endoskeleton is important for determining the type of movement an echinoderm can undertake. The movable bony plates in the endoskeletons of echinoderms enable them to move easily. Feather stars move by grasping the soft sediments of the ocean bottom with their cirri—long, thin appendages on their ventral sides—or by swimming with up-and-down movements of their arms. Brittle stars use their tube feet and their arms in snakelike movements for locomotion. Sea stars use their arms and tube feet for crawling. Sea urchins move by using tube feet and burrowing with their movable spines. Sea cucumbers crawl using their tube feet and body wall muscles.

Reading Check **Summarize** In addition to using their tube feet, in what other ways do echinoderms move?

VOCABULARY

SCIENCE USAGE V. COMMON USAGE

Structure

Science usage: the arrangement of parts of an organism.

The structure of an insect's mouth determines how it functions.

Common usage: something that is constructed, such as a building.

The workers built the structure in three months.

Reproduction and development Most echinoderms reproduce sexually. The females shed eggs and the males shed sperm into the water where fertilization takes place. The fertilized eggs develop into free-swimming larvae with bilateral symmetry. After going through a series of changes, the larvae develop into adults with radial symmetry. Recall that echinoderms have deuterostome development, making them an important evolutionary connection to vertebrates.

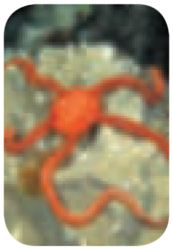
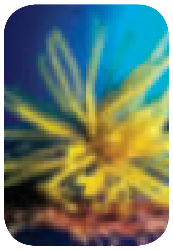
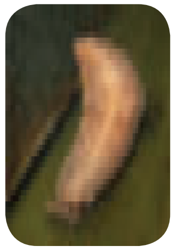
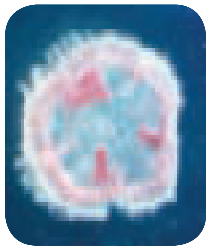
The sea star in **Figure 27.6** illustrates an echinoderm regenerating a lost body part. Many echinoderms can drop off an arm when they are attacked, enabling them to flee while the predator is distracted. Others can expel part of their internal organ systems when threatened, an action that might surprise and deter predators. All of these body parts can be regenerated.

■ **Figure 27.6** This sea star is regenerating one of its arms, a process that can take up to one year.
Explain ***how regenerating body parts helps echinoderms survive.***

Concepts In Motion

Interactive Table To explore more about echinoderms, visit biologygmh.com.

Table 27.1 Classes of Echinoderms

Class	Asteroidea	Ophiuroidea	Echinoidea	Crinoidea	Holothuroidea	Concentricycloidea
Examples						
Class Members	Sea stars	Brittle stars	Sea urchins, Sand dollars	Sea lilies, Feather stars	Sea cucumbers	Sea daisies
Distinctive Features	• Often five-armed • Tube feet used for feeding and movement	• Often five-armed • Arms break off easily and can be regenerated • Move by arm movement • Tube feet have no suction cups	• Body encased in a test with spines • Sea urchins burrow in rocky areas. • Sand dollars burrow in sand.	• Sessile for some part of life • Sea lilies have long stalks. • Feather stars have long branching arms.	• Cucumber shape • Leathery outer body • Tube feet modified to tentacles near mouth	• Less than 1 cm in diameter • No arms • Tube feet located around a central disk

Echinoderm Diversity

The major classes of living echinoderms include Asteroidea (AS tuh ROY dee uh), the sea stars; Ophiuroidea (OH fee uh ROY dee uh), the brittle stars; Echinoidea (ih kihn OY dee uh), the sea urchins and sand dollars; Crinoidea (kri NOY dee uh), the sea lilies and feather stars; Holothuroidea (HOH loh thuh ROY dee uh), the sea cucumbers; and Concentricycloidea (kahn sen tri sy CLOY dee uh), the sea daisies. Recall that they all are marine animals with radial symmetry as adults, a water-vascular system with tube feet, endoskeletons often bearing spines, and larvae with bilateral symmetry. The classes of echinoderms are summarized in **Table 27.1.**

Sea stars If you ever have seen an echinoderm, it probably was a sea star. Most species of sea stars have five arms arranged around a central disk. Some, such as the one in **Figure 27.7,** have more than five arms. Sea stars can be found in shallow water near the shore and in tide pools when the tide recedes. They can be found in groups clinging to rocks by means of their tube feet. A single tube foot can exert a pull of 0.25–0.30 N. This is equal to the force required to lift 25–30 large paper clips. Because a sea star might have as many as 2000 tube feet, it can exert quite a large force as it crawls or opens mollusks for food. Sea stars are important predators in marine ecosystems, feeding on clams and other bivalves. Because of their spiny skin, sea stars usually are not food for other marine predators.

Figure 27.7 Sunflower stars can have twenty or more arms.

■ **Figure 27.8** One type of brittle star, the basket star, extends its branched arms into the current to filter feed.

Analyze ***How are brittle stars different from sea stars?***

Brittle stars Like sea stars, most brittle stars have five arms, but the brittle star's arms are thin and very flexible, as shown in **Figure 27.8.** They do not have suckers on their tube feet, so they cannot use them for movement as sea stars do. Brittle stars move by rowing themselves quickly over the bottom rocks and sediments or by snakelike movements of their arms. When attacked by a predator, a brittle star can release an arm and make a quick getaway. The missing arm will be regenerated later. Brittle stars hide in the crevices of rocks by day and feed at night. They feed on small particles suspended in the water or catch suspended materials on mucous strands between their spines.

Some brittle stars respond to light. The spherical structures covering the body of these brittle stars might function as light-gathering lenses. Brittle stars are more abundant and have more numbers of species than any other class of echinoderm.

Reading Check **Compare and contrast** the locomotion of sea stars and brittle stars.

Sea urchins and sand dollars Burrowing is a key characteristic of sea urchins and sand dollars. Sand dollars can be found in shallow water burrowing into the sand, while sea urchins burrow into rocky areas. These echinoderms each have a compact body enclosed in a hard endoskeleton, called a test, that looks like a shell. The tube feet extend through pores in the test. Closely fitting plates of calcium carbonate make up the test. Sea urchins and sand dollars lack arms, but their tests reflect the five-part pattern of arms in sea stars and brittle stars. Spines also are an important feature of this class, as seen in **Figure 27.9.** Some sea urchin spines and pedicellariae contain venom and are used for fending off predators. The poison in pedicellariae can paralyze prey. Sea urchins also can be herbivorous grazers, scraping algae from rocks, while sand dollars filter organic particles from the sand in which they are partially buried.

■ **Figure 27.9** Sea urchins burrow themselves into rocky crevices with their sharp, movable spines. Sand dollars burrow themselves into the sand, where they filter out small food particles.

Sea urchins

Sand dollar


Aristotle's lantern


Five-sided lantern

■ **Figure 27.10** Aristotle's lantern is a five-sided mouthpart similar in shape to a five-sided lantern. The force of a sea urchin's chewing plates is so strong that it has been known to chew through concrete.

Connection to History Most sea urchins have a chewing apparatus inside their mouths consisting of five hard plates, similar to teeth. This structure, shown in **Figure 27.10,** is called Aristotle's lantern. It was named after a description written by Aristotle, a Greek philosopher, in his book *Historia Animalium* (The History of Animals). In the fourth century B.C., which is when Aristotle lived, people used five-sided lanterns with side panels made of thin, translucent horn, called horn lanterns. Aristotle thought the mouth of a sea urchin looked like a horn lantern without the panels.

Sea lilies and feather stars Fossil records show that sea lilies and feather stars are the most ancient of the echinoderms and were abundant before other echinoderms evolved. They are different from other echinoderms in that they are sessile for part of their lives. As shown in **Figure 27.11,** sea lilies have a flower-shaped body at the top of a long stalk, while the long-branched arms of feather stars radiate upward from a central area. Though they might stay in one place for a long time, sea lilies and feather stars can detach themselves and move elsewhere. Both sea lilies and feather stars capture food by extending their tube feet and arms into the water, where they catch suspended organic materials.

Reading Check **Compare** How are feather stars and sea lilies similar?

■ **Figure 27.11** This fossil illustrates how a sea lily's body is flower-shaped at the tip of a long stalk. A feather star extends its arms from a central point where they are attached.
Infer ***How is the shape of the arms of feather stars adapted to a lifestyle that includes little movement?***


Sea lily


Feather star

■ **Figure 27.12** Some of the sea cucumber's tube feet are modified into tentacles that trap food particles from the water.
Identify ***What substance coats the tentacles and helps trap food particles?***

CAREERS IN BIOLOGY

Marine Biologist Scientists in this field study plants and animals, such as echinoderms, that live in the ocean. They also study how pollution affects the marine environment. For more information on biology careers, visit biologygmh.com.

Sea cucumbers Sea cucumbers don't look like other echinoderms. Some might say they don't even look like animals. Can you guess why they are called sea cucumbers? They look like cartoon cucumbers creeping over the ocean floor. Their elongated bodies move sluggishly by means of tube feet assisted by contractions in their muscular body wall. Their calcium carbonate plates are reduced in size and do not connect as they do in other echinoderms, so their outer bodies generally appear leathery. Some of their tube feet are modified to form tentacles which extend from around their mouths to trap suspended food particles, as shown in **Figure 27.12.** The tentacles are covered with mucus, which increases their ability to trap food. Once food has been trapped on a tentacle, it is drawn into the mouth where the food is sucked off. This process is similar to licking your finger after putting it in a bowl of pudding.

Sea cucumbers are the only echinoderms to have respiratory organs in the form of respiratory trees. These many-branched tubes pump in seawater through the anus for oxygen extraction. The respiratory tree also functions in excretion by removing cellular wastes.

When a sea cucumber is threatened, it can cast out some of its internal organs through its anus. A potential predator might be confused by this action and move on. The sea cucumber can regenerate its lost parts. Even though the sea cucumber's adaptations might seem odd, it is important to remember that this animal maintains homeostasis with adaptations that fit its way of life in its particular habitat.

■ **Figure 27.13** Sea daisies are tiny disc-shaped echinoderms.

Sea daisies Discovered in 1986 off the coast of New Zealand, sea daisies have been difficult to classify and study, because so few have been found. They are less than 1 cm in diameter and are disc-shaped with no arms. Their tube feet are located around the edge of the disc. **Figure 27.13** shows that they have five-part radial symmetry, as do other echinoderms. Notice the daisy pattern of petals, or tube feet, around the edges of the disc.

Reading Check **Infer** What characteristics place sea daises in the phylum Echinodermata?

Ecology of Echinoderms

Sea cucumbers and sea urchins are sources of food for people in some Asian countries. The muscles of certain sea cucumbers are eaten as sushi, and dried sea cucumbers are added to flavor soups, vegetables, and meat. The egg masses of sea urchins are eaten raw or slightly cooked.

Commensal relationships exist between some echinoderms and other marine animals. Recall from Chapter 2 that commensalism is a relationship in which one organism benefits and the other organism is neither helped nor harmed. For example, some species of brittle stars live inside sponges. The brittle star leaves the protective interior of the sponge and feeds on materials that have settled on the sponge.

Echinoderm benefits Marine ecosystems also depend on some echinoderms. When populations of echinoderms decline, a change in the ecosystem often is noted. For example, a sea urchin species that lives in the Caribbean and the Florida keys declined in numbers by more than 95 percent in 1983 due to disease. After this, algae increased greatly on the coral reefs and virtually destroyed the reefs in many areas. Sea urchins and sea cucumbers are bioturbinators, organisms that stir up sediment on the ocean floor. This action is important to the entire marine ecosystem, as it makes nutrients in the seafloor available to other organisms.

Echinoderm harm Some echinoderms can harm marine ecosystems. The crown-of-thorns sea star shown in the photo at the beginning of this chapter feeds on coral polyps. When these sea stars increase in numbers, coral reefs are destroyed. Although the causes of the population explosions of these sea stars continue to be debated, the numbers seem to decline on their own. At a later time, they might increase again with no apparent explanation. Sea urchins are a favorite food of sea otters, as shown in **Figure 27.14.** The number of sea otters in California has declined in recent years, leading to an increase in the number of sea urchins. The sea urchins are eating the kelp forests, destroying the habitat of fish, snails, and crabs.

Figure 27.14 Without enough sea otters to keep the sea urchin population under control, sea urchins will continue to increase in number, threatening the kelp forests on which they feed.

Section 27.1 Assessment

Section Summary

- Adult echinoderms can be identified by four main structural features.
- Larval echinoderms have features that link them to relatives that evolved after them.
- Echinoderms have a water-vascular system and tube feet.
- Echinoderms have a variety of adaptations for feeding and movement.
- There are six major classes of living echinoderms.

Understand Main Ideas

1. MAIN Idea **Identify** the four main features that distinguish adult echinoderms.
2. **Explain** how a water-vascular system works.
3. **Sketch** line drawings that represent each of the six classes of echinoderms.
4. **Suggest** how feeding and movement are related to each other in echinoderms.

Think Scientifically

5. *Hypothesize* A certain species of red-and-white-striped shrimp often is found on a species of colorful brittle stars. Form a hypothesis about the relationship between the shrimp and the brittle stars.
6. MATH in Biology If it takes a force of 20 N to pull apart a bivalve's shells, how many tube feet will it take to pull apart a bivalve if each tube foot has a pull of 0.25 N?

Biology Online **Self-Check Quiz** biologygmh.com