Carolina Biological Supply Company
Presents

The Anatomy of the Starfish

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Abstract. This program facilitates a study of the anatomy of the starfish as a representative echinoderm.

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Narrative

Starfish belong to a unique group of marine animals—the echinoderms. Other members of the phylum Echinodermata are sea urchins, sand dollars, sea cucumbers, brittle stars, and crinoids, or sea lilies. These were among the earliest echinoderms to appear, and they comprise a large proportion of the fossils of this ancient phylum.

The name Echinodermata, which means "spiny-skinned," refers to one of the most prominent features of these animals. Dermal spines extend from the body surface of most echinoderms. The spines are most pronounced in sea urchins, but are also clearly seen in starfish. Another prominent feature of echinoderms is **radial symmetry**, with similar body parts radiating out from a central axis. In most cases, the radial symmetry is **pentamerous**, or five-part. Echinoderms are also characterized by a **water vascular system** used in moving and feeding.

Echinoderms are especially interesting to biologists because the phylum seems to be closely related to the chordates, the phylum that includes humans. Superficially, these two groups bear little resemblance, but their embryological development suggests that they had common ancestors. The common Atlantic starfish, *Asterias,* well illustrates the major features of the echinoderms.

THE EXTERNAL ANATOMY

The most striking feature of the starfish is its radial symmetry. Observe the five **arms** radiating out from a **central disk**. If the arms are of unequal size, the starfish may be undergoing **regeneration**, the replacement of damaged parts. Starfish grow new arms to replace severed ones.

The underside of the starfish is referred to as the **oral surface** because the mouth is located there, in its center. Running along the midline of each arm on the oral surface is an **ambulacral groove**, protected by two rows of moveable spines. Inside each ambulacral groove are two double rows of **podia**, or **tube feet**, used in locomotion and in grasping prey. On a preserved specimen, the tube feet are usually contracted, but they can be seen easily on a live specimen, on which it may also be easier to see the **peristome**, a circular membrane surrounding the mouth. Like the ambulacral grooves, the mouth area can be closed off by specialized moveable spines to protect the starfish's soft tissues.

The upper side of the starfish is called the **aboral surface**. Located off-center on the central disk is the conspicuous **sieve plate**, or **madreporite**. This is the opening to the starfish's water vascular system,

which we'll explore later. In the center of the central disk is the tiny **anus**, another structure that is easier to find on a living specimen.

Located at the tip of each arm is a pigmented ocellus, or **eyespot**, and a terminal **tentacle**. Both are sensory organs. The eyespot and tentacle are often not visible on preserved specimens.

The madreporite provides a reference point for identifying the arms of the starfish. The two arms beside the madreporite make up the **bivium**. The other three are the **trivium**. The arm opposite the madreporite is designated as the **anterior arm**, even though a starfish moves equally well in any direction.

Scattered over the surface of the starfish are many spines. These external projections from the calcareous endoskeleton help protect the starfish from potential predators. The spines are most conspicuous in a dried specimen. A closer look at the spines shows that many are ringed with smaller projections, called **pedicellariae**. Pedicellariae are tiny claws of various shapes scattered over the starfish's surface. Under the microscope, some of them resemble pliers. The pedicellariae help clean fallen debris and parasites off the starfish's body surface.

The surface of the starfish, including the spines, is covered with a skin of ciliated epidermal cells. The waving cilia move water along the skin, aiding waste removal and gas exchange.

Between the starfish's spines are the delicate dermal branchiae, or **papulae,** that function as gills in gas exchange. These fleshy protrusions would be very vulnerable without the surrounding spines and pedicellariae to protect them.

THE INTERNAL ANATOMY

To examine the internal anatomy of the starfish, we need a sharp scalpel, dissecting scissors, and a blunt probe. We can begin the dissection by cutting the tip off the anterior arm with a pair of scissors. Then we cut along both sides of the anterior arm and across the top at the arm's junction with the central disk. This allows us to remove the body wall on the aboral side of the arm.

Notice that the internal organs are attached to the body wall by **mesenteries**, thin folds of tissue lining the starfish's large body cavity, or **coelom**. The entire lining, or **peritoneum**, is a sheet of ciliated epithelial cells that circulate fluids within the starfish.

A close look at the portion of body wall we removed shows the basic structure of the endoskeleton. Bony, calcified **ossicles** are embedded in the leathery dermis, or **perisome**. The dermal cells secrete the calcite crystals that make up the ossicles. The skeletal network formed by the ossicles can be seen throughout the inner surface of the body wall. Since the many ossicles are held in place by the perisome, rather than being

tightly joined to each other, the starfish's body wall is very flexible. In some other echinoderms, such as the sand dollar, platelike ossicles are fused, forming a solid, nonflexible skeleton.

Beneath the internal organs in the dissected arm is the conspicuous **ambulacral ridge**, which forms a roof over the ambulacral groove on the oral surface of the arm.

The largest internal organs in each arm of the starfish are the paired digestive glands, or **hepatic caeca**. The hepatic caeca produce digestive enzymes and play a role in the absorption and storage of nutrients. Beneath the hepatic caeca are the **gonads**, which we'll explore later.

By removing the aboral body wall from the other two arms of the trivium and from the central disk up to the madreporite, we can expose much of the digestive system. To remove this portion of body wall, we have to sever the short **intestine**, through which food passes from the stomach to the anus. Tiny, dark pouches called **rectal caeca** are situated at the junction of the intestine and the anus. They may function in the temporary storage of waste.

Most of the space in the central disk is occupied by the starfish's stomach,which is divided into two portions. The **pyloric stomach** is the aboral compartment that connects to each pair of hepatic caeca through a branching **pyloric duct**. This pattern is repeated in each arm of the starfish.

By cutting through the pyloric duct on the anterior arm and removing the hepatic caeca, we can reveal the edge of the **cardiac stomach** beneath them. A short **esophagus** leads from the mouth to the cardiac stomach. The starfish can extend its cardiac stomach through its mouth inside out so that digestive juices dissolve prey outside the body. Then, cilia lining the cardiac stomach carry the liquified food up into the pyloric stomach. After feeding, the starfish retracts its everted stomach by means of paired **cardiac retractor muscles** in each arm.

Oysters, mussels, and other bivalve molluscs are common prey of *Asterias*. The starfish uses its arms and tube feet to open the shells wide enough to insert part of its everted stomach.

The starfish's tube feet are part of its **water vascular system**, an anatomical feature unique to echinoderms. To observe the water vascular system fully, we must expose the rest of the central disk, making sure to cut carefully around the madreporite, the opening to the system. Below the madreporite is the **stone canal**, a short tube so named because of its hard covering. To trace the path of the stone canal, we must remove both compartments of the stomach. The stone canal empties into the **ring canal**, which lies beneath a sturdy ring of ossicles. On the ring canal are nine pouches called **Tiedemann's bodies**. These structures are thought to produce the amoeboid cells called **coelomo-**

cytes that move through the water vascular system. Five **radial canals** branch off the ring canal, one extending along the ambulacral ridge of each arm, directly beneath the ossicles.

In this cross section of a starfish's arm, we can identify the ambulacral ridge and the radial canal. A short, lateral canal connects each **tube foot** with the radial canal. A valve in each lateral canal enables each tube foot to work somewhat independently. A bulbous **ampulla** is at the top of each tube foot. The ampullae are located within the body wall, while the tube feet protrude into the ambulacral groove on the oral surface of the starfish.

A tube foot operates by a combination of muscle contractions and hydraulic pressure. Contraction of a tiny, circular muscle around the ampulla sqeezes water down, elongating the tube foot. Connective tissue in the tube-foot wall prevents lateral expansion. A partial contraction of the longitudinal muscles in the tube foot forces enough water back into the ampulla to cup the adhesive pad, or **sucker**, at the base of the tube foot. The resulting suction enables starfish to hold onto rocks or other hard objects and to grasp prey. Complete contraction of the longitudinal muscles forces most water back into the ampulla, and the tube foot shortens, pulling the starfish along a hard substrate.

By means of uneven contraction of the longitudinal muscles in each tube foot, the starfish can also move across a soft **substrate**. All the movements of the hundreds of tube feet are coordinated by the starfish's nervous system.

Like most of its anatomy, a starfish's nervous system is radially arranged. A **circumoral nerve ring** is located around the periphery of the peristome. From this nerve ring a **radial nerve** extends down the center of the ambulacral groove of each arm. The placement of the radial nerve is easily seen in a cross section of a starfish's arm.

The circumoral nerve ring and radial nerves are mainly sensory. Fibers connect these nerves with the **ectoneural plexus**, a network of nerve fibers that innervates the entire epidermis of the starfish, as well as the spines and the pedicellariae. There is also an **entoneural plexus** that innervates the perisome and the coelomic lining. Another nerve network, consisting primarily of motor fibers, controls the muscles of the starfish's arm and those of the tube feet and ampullae.

The only differentiated sensory organs of starfish are the light-sensitive **ocellus** and the terminal tentacle at the tip of each arm. Starfish often orient these structures upward as they move along. Sensory cells scattered throughout the epidermis are also able to detect light.

Circulation in starfish occurs primarily through ciliary action in the main coelomic cavity and the water vascular system. The papulae extend from the main cavity, and the tube feet from the water vascular system, so their surfaces provide the main link between the internal

organs and the external environment of the starfish. Oxygen, carbon dioxide, and nitrogenous wastes diffuse through them.

Echinoderms have a blood vascular system, but in starfish it is much reduced and has little importance in circulation. Called a **hemal system**, it is much more loosely organized than the circulatory system typical of vertebrates. The only component of the hemal system usually seen in a dissection is the **axial sinus**, a membranous sac surrounding the stone canal. This sinus connects with a hemal ring around the peristome, from which a lacuna, or channel, branches down each arm. One of these **radial hemal lacunae** is seen aboral to the radial nerve in a cross section of an arm. The starfish's blood is watery and contains no special oxygen-carrying molecule like vertebrate hemoglobin.

The starfish's reproductive system is also relatively simple. Each arm contains a pair of **gonads**, or reproductive organs. In preserved specimens, male and female gonads appear identical. To distinguish one sex from another, we must cut a piece off the gonad and macerate it in a drop of water on a microscope slide. Under the microscope, eggs appear large and ovoid, while sperm are much smaller. Under high magnification, the flagella of the sperm cells are visible.

Each gonad has a **gonoduct** leading to a **gonopore** through which millions of eggs or sperm are released into sea water, where fertilization occurs. The gonopores, situated between the arms, are so tiny that they are usually not visible externally.

Starfish, as well as sea urchins, are often used for studies of fertilization and embryology since their reproductive cycles make fertilization easy to control in the lab. The embryos are maintained in sea water and observed as they develop.

Several early developmental features of echinoderms are so similar to those of chordates that echinoderms are considered the chordates' closest invertebrate relatives. After these early stages, starfish typically develop through two distinct larval stages. The free-swimming **bipinnaria** larva clearly illustrates the bilateral symmetry of larval echinoderms. During the next larval stage, the **brachiolaria**, the young starfish develops a sucker and settles to the bottom. Then, it undergoes its final metamorphosis, during which it develops the radial symmetry, the endoskeleton, and the water vascular system characteristic of the adult echinoderms, our unlikely kin.

GLOSSARY

Aboral. Toward or on the opposite side or end from the mouth. The aboral surface of a starfish is the functional upper surface.

Ambulacral ridge. The raised line that projects upward into the body cavity along the midline of the oral surface of each arm of a starfish.

Ambulacral groove. The fissure along the midline of the oral surface of each arm of a starfish, where most of the tube feet are housed.

Amoeboid. Shaped like and moving like an amoeba (with pseudopodia) and capable of engulfing particles, as of food.

Ampulla. The bulb atop each tube foot. The ampulla lies within the coelom while the attached tube foot projects through the body wall.

Anterior arm. The arm of a starfish opposite the madreporite.

Anus. The opening to the digestive system through which undigested matter is expelled.

Arms. The lateral projections from the central disk of a starfish or brittle star, usually occurring in multiples of five; often called "rays."

Axial sinus. A connecting structure between the oral and aboral hemal rings in the blood vascular system of a starfish.

Bilateral symmetry. Arrangement of anatomical features such that division along one medial plane would result in halves that are mirror images.

Bipinnaria. A larval stage in the development of the starfish; literally means "double-winglike." The bipinnaria larva is the form most like the larvae of some protochordates and is thus cited as evidence that the echinoderms and chordates are closely related.

Brachiolaria. Larval stage of starfish development transitional between the bipinnaria and the adult. The brachiolaria larva settles to the bottom and undergoes metamorphosis, developing radial symmetry, a water vascular system, and an endoskeleton, to become an adult starfish less than one mm in diameter.

Bivium. Two of the five arms of a starfish; the madreporite is between these two.

Cardiac retractor muscles. Muscles that pull the extruded cardiac stomach back into the central disk.

Cardiac stomach. The extensible, lower stomach of a starfish; the portion that can be extruded through the mouth and retracted.

Central disk. The central portion of a starfish from which the arms or rays radiate.

Chordates. Phylum of animals exhibiting, at least during some stage

of development, a notochord, a dorsal hollow nerve cord, and pharyngeal clefts. The chordate phylum includes all the vertebrates.

Cilia. Tiny cellular projections.

Circumoral nerve ring. Circular nerve in the starfish's central disk from which radial nerves branch off.

Coelom. A membrane-lined body cavity surrounded by mesodermal tissue.

Coelomocyte. One of the relatively undifferentiated amoeboid cells found in the coelom and the water vascular system of starfish. The coelomocytes aid in the transport of food and wastes.

Dermal branchiae. Papulae; tiny extensions from the starfish's coelomic cavity that project through the body wall. Due to their function (gas exchange), they are sometimes called dermal "gills."

Diffusion. Movement of particles from areas of higher concentration to areas of lower concentration, such as movement of carbon dioxide or oxygen molecules across membranes.

Ectoneural plexus. A network of nerve fibers that innervates the entire epidermis of a starfish.

Entoneural plexus. A network of nerve fibers that innervates the inner surface of the body wall of a starfish.

Esophagus. Short tube connecting the starfish's mouth with the cardiac stomach.

Excretion. Elimination of nitrogenous metabolic wastes from the body.

Eyespot. Ocellus; light-sensitive organ at the tip of each arm of a starfish.

Gonads. Organs that produce and/or store sex cells (eggs and/or sperm).

Gonoduct. Tube through which eggs or sperm pass from a starfish's gonads to the gonopore and thence into seawater.

Gonopore. External opening of the gonoduct through which a starfish's eggs or sperm pass into the surrrounding seawater.

Hepatic caeca. Large digestive glands occupying most of the space in a starfish's arms.

Hemal system. The lacunar blood vascular system of echinoderms; develops as a specialized portion of the coelom.

Intestine. In starfish, the short tube connecting the pyloric stomach and the anus.

Lacuna. A cavity or canal in an anatomical structure. The starfish blood vascular system is said to be "lacunar" because it consists of canals and enfoldings of the coelom.

Lange's nerve. The most conspicuous nerve of the starfish's deep, or hyponeural nervous system. One runs down the center of each arm and innervates the muscles of the arm and of the tube feet.

Madreporite. Sieve plate; the intake for the water vascular system of a starfish; found off-center in the central disk.

Mesentery. Membranes that surround interal organs and hold them in place within the coelom.

Ocellus. Eyespot; the light-sensitive organ at the tip of each arm of a starfish.

Oral surface. The functional lower surface of a starfish, where the mouth is located.

Ossicles. Separate calcareous skeletal elements making up the endoskeleton of echinoderms.

Papulae. Dermal branchiae; protrusions of the starfish's coelom that function in gas exchange.

Pedicellaria. A tiny claw or pincer on the external surface of an echinoderm.

Pentamerous. Made up of five parts.

Perisome. The starfish's dermis; the leathery matrix of the starfish's body wall in which the skeletal ossicles are embedded.

Peristome. The disk of thin, elastic tissue surrounding the mouth of a starfish.

Peritoneum. The thin, mesodermal lining of the coelomic cavity.

Podia. Tube feet of echinoderms.

Pyloric stomach. The aboral portion of a starfish's stomach, connected by ducts to the five pairs of hepatic caecae.

Pyloric ducts. Tubes connecting the pyloric stomach and the hepatic caecae.

Radial canal. Portion of the water vascular system that runs from the ring canal along the midline of each arm of a starfish.

Radial hemal lacuna. Branch of starfish's blood vascular system; one extends along the ambulacral ridge of each arm.

Radial nerve. Nerve cord that runs along the midline of the ambulacral groove in each arm of a starfish.

Radial symmetry. Arrangement of body parts around a central axis.

Rectal caeca. Dark, lumpy pouches situated near the terminus of the intestine in starfish; may funtion in temporary storage of waste before its expulsion through anus.

Regeneration. The growing of new parts to replace those lost or broken.

Ring canal. Portion of water vascular system that encircles the mouth; radial canals branch from it.

Sieve plate. Madreporite; intake to the water vascular system in echinoderms.

Sinus. A cavity or space in body tissue.

Spines. Echinoderm skeletal elements that project externally through the body wall, but are covered by the thin epidermis.

Stone canal. Calcified portion of the water vascular system of a starfish that connects the madreporite with the ring canal.

Substrate. The surface on which an organism lives or over which it moves.

Sucker. The suction pad at the terminus of each tube foot of many starfish species.

Tentacle. A terminal, suckerless, sensory tube foot on each arm of a starfish.

Tiedemann's bodies. Swellings on the ring canal of starfish, possibly where coelomocytes are formed.

Trivium. The three arms of a starfish that include the anterior arm (opposite the madreporite) and the arm to each side of it.

Tube feet. Podia; extensions from echinoderms' water vascular system; used in locomotion, food-gathering, and respiration.

Water vascular system. System of tubes derived from the coelom, unique to echinoderms, enabling them to use hydraulic pressure to aid in food gathering and/or locomotion.

THE ANATOMY OF THE STARFISH

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