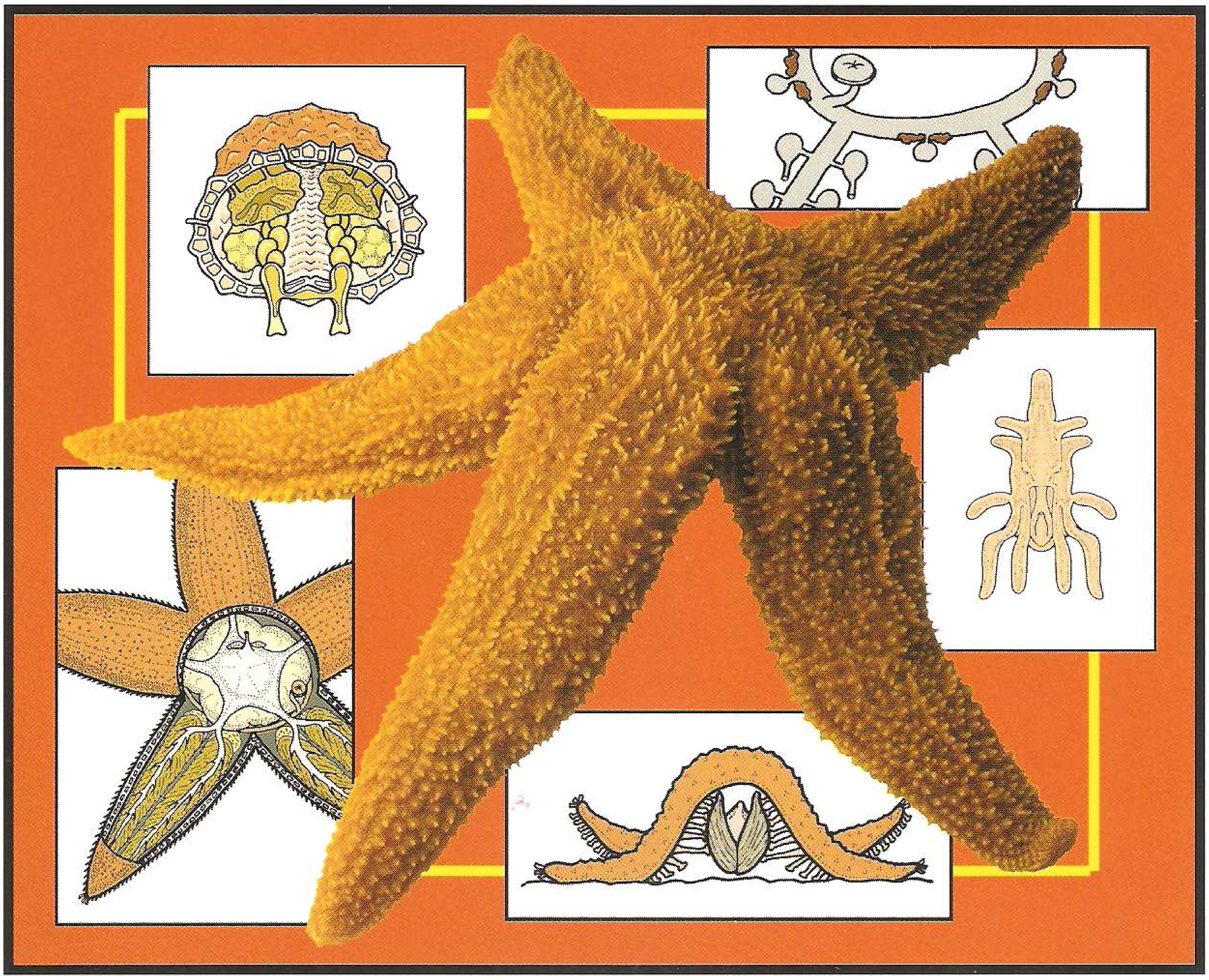
The Taxonomy & Physiology of the

Starfish

A comprehensive, step-by-step dissection guide complete with photographs and illustrations



Text, photographs, and illustrations by Lisa K. Hyatt

How to use this guide:

This guide is intended to introduce the taxonomy of the starfish (also sometimes referred to as the sea star) and to guide the student through its dissection in a step-by-step manner. Dissection instructions are in italics. In general, the photographs may not show all structures because they are too small to be seen, but will show those that are prominent and easily identified. Illustrations are provided that will aid in identification. These figures are designed in a self-quiz manner in which the student may cover up the answers to the numbered structures. Organ systems are summarized throughout the guide. Anatomical terms and key terms are listed in the back of the guide.

Note: The term, "starfish", can be misleading since this animal is not a fish at all. For this reason, some texts refer to it as the "sea star". However, since the term "starfish" is the most commonly used, it will be how we refer to this animal in this guide.

Note: The taxonomy in this guide was the most current available as of 2003. Due to discoveries in genetics, taxonomic categories may change in the future. This has been particularly true for the members of Phylum Echinodermata. There has been debate as to whether there are five or six classes within this phylum.

Starfish Taxonomy

Kingdom: Animalia
Phylum: Echinodermata
Class: Asteroidea
Order: Forcipulatida
Genus: *Asterias*
Species: *forbesi*
Full scientific name: *Asterias forbesi*
Common name: starfish; sea star

figure 1 - Etching of various echinoderms

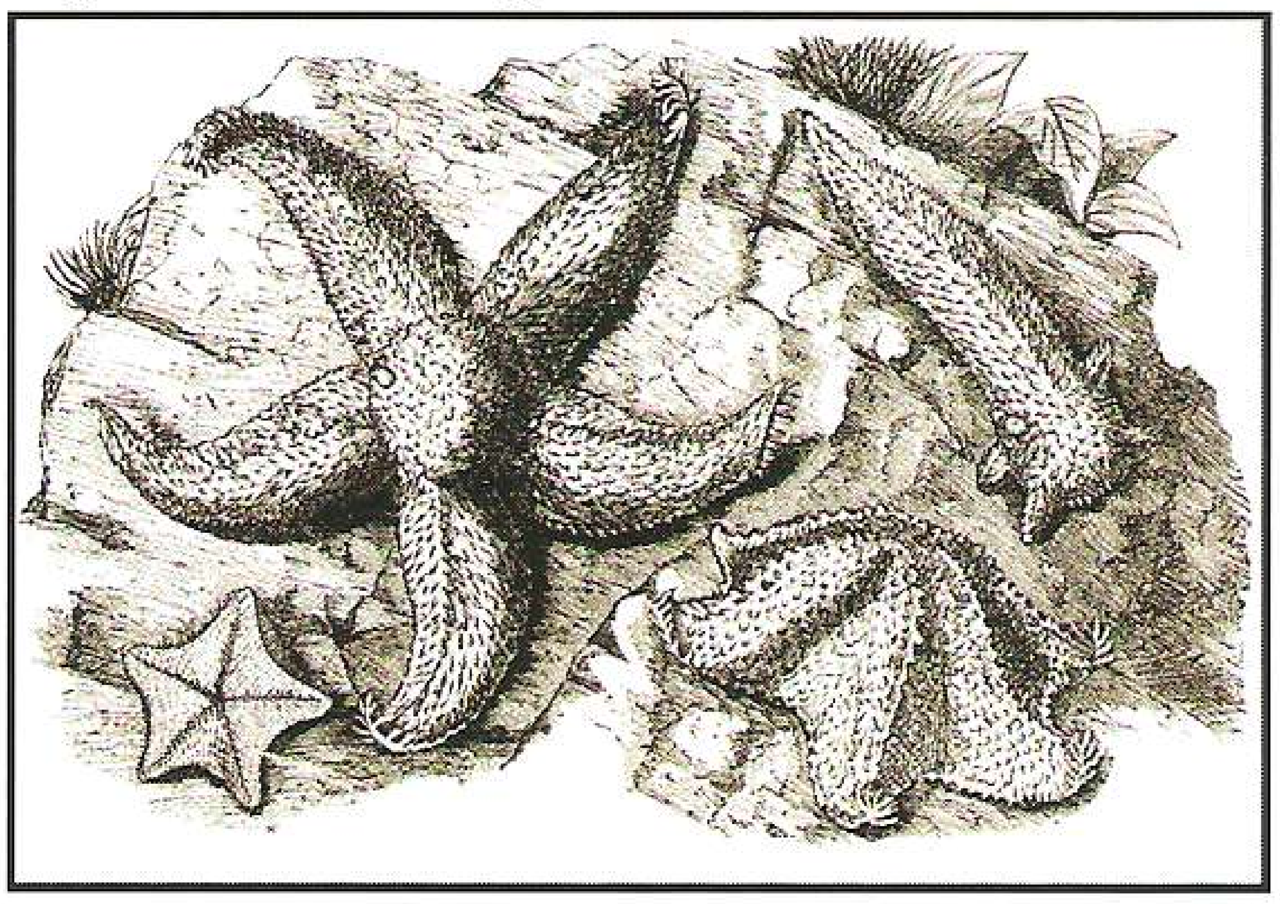
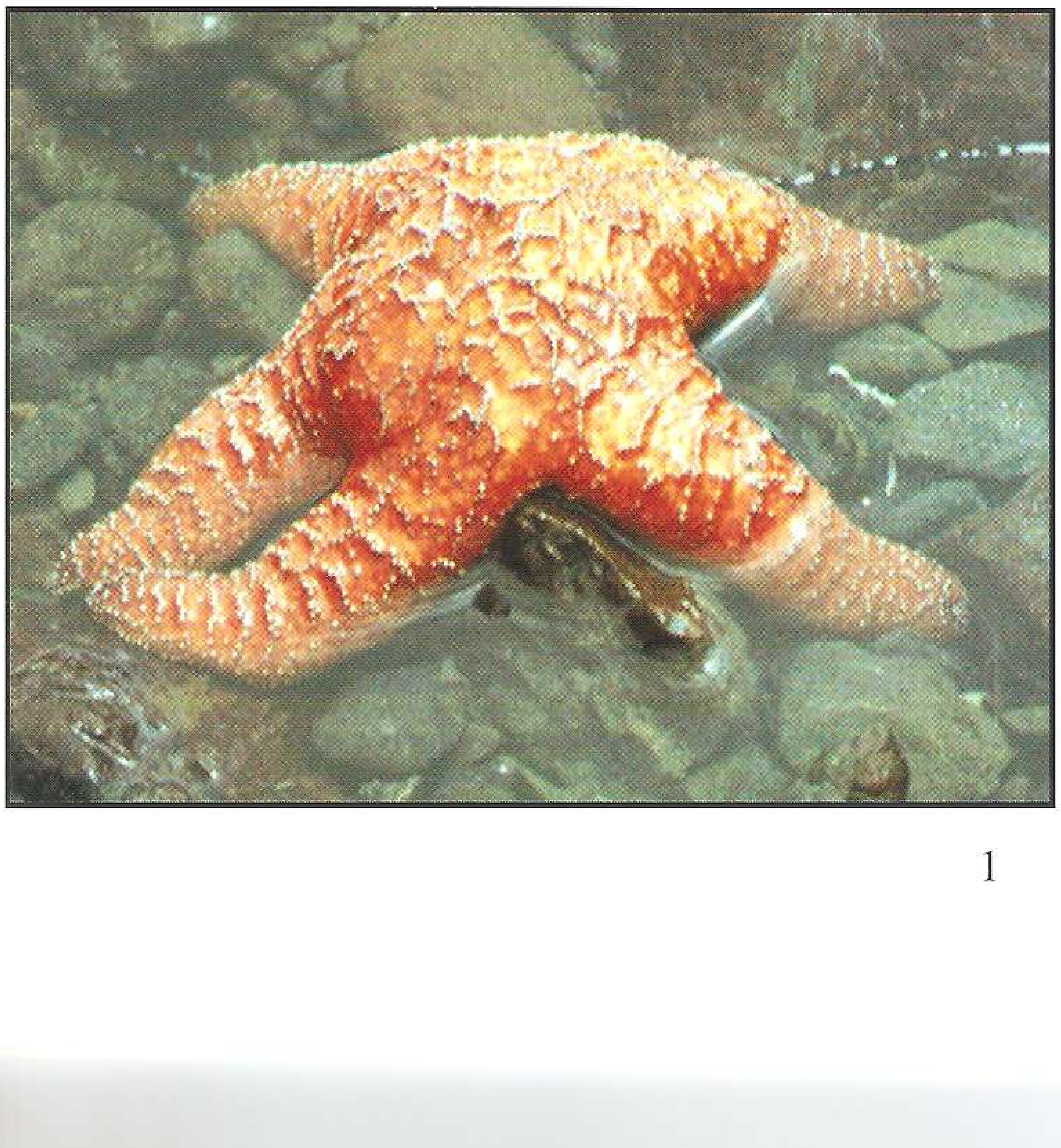
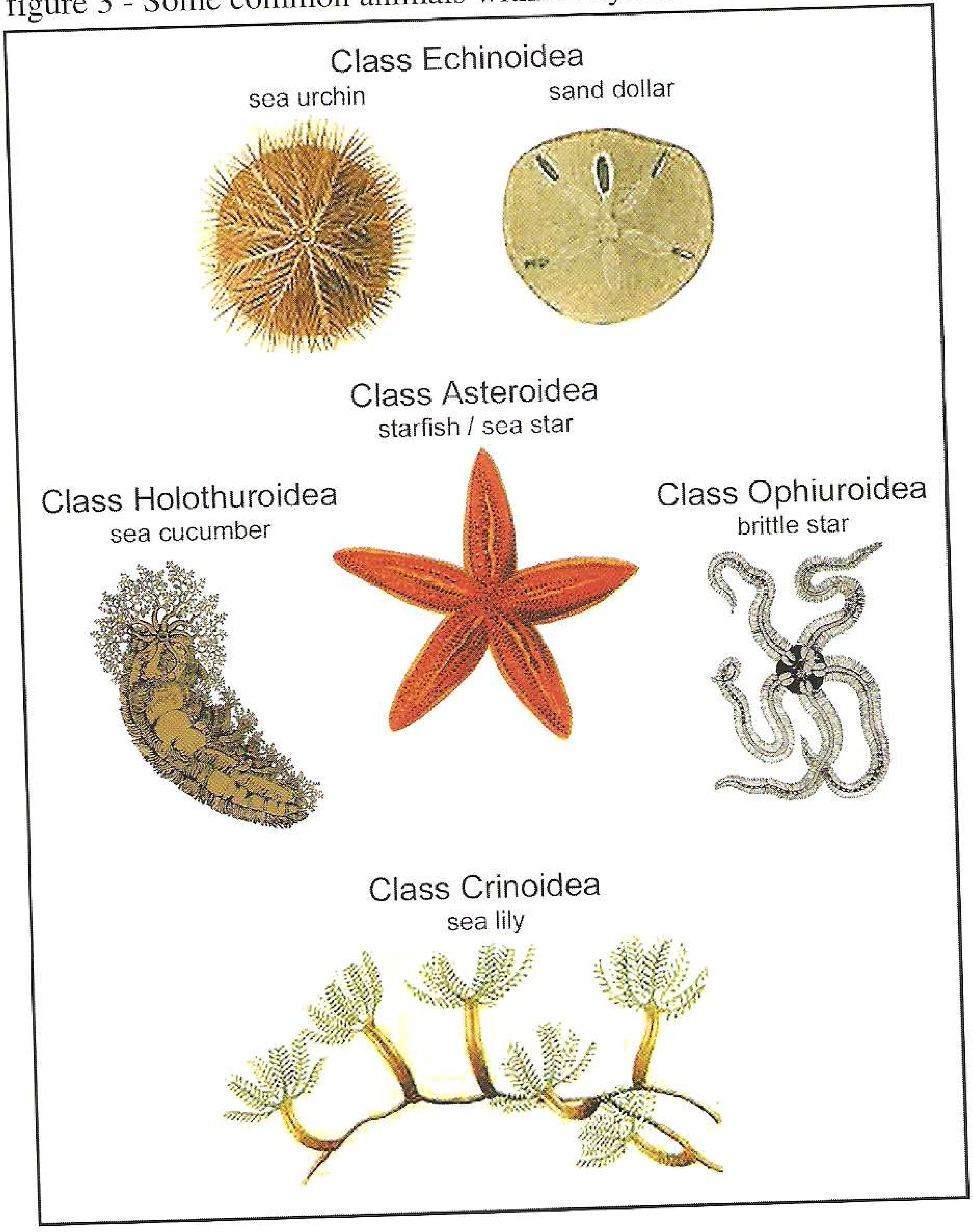


figure 2 - Live starfish in a tide pool



Phylum Echinodermata

The various animals that belong to Phylum Echinodermata may be the strangest in the animal kingdom. This phylum is closely related to Phylum Chordata, the group that includes humans, since both undergo similar embryological development. This fact is not obvious by looking at any echinoderm. Imagine an animal that has its endoskeleton just under the skin, that lacks any noticeable sensory organs (such as eyes) and has no brain. This animal has no clearly defined excretory and circulatory systems. It has a water vascular figure 3 - Some common animals within Phylum Echinodermata



system that aids in movement and feeding. The larval stages of this animal are bilateral, but then it goes through a dramatic metamorphosis into a radial adult. It can even re-grow arms and other organs! What has just been described are the unique characteristics of animals in Phylum Echinodermata. These animals go against many assumptions zoologists sometimes make about the animal world. In many ways, despite extensive research, some features of these strange animals still remain a mystery.

Phylum Echinodermata includes starfish (also called sea stars), brittle stars, basket stars, sea cucumbers, sand dollars, sea urchins, sea lilies, feather stars, and sea daisies (some shown in figure 3). There are approximately 7,000 living species of echinoderms, all of which live in marine environments (they are confined to living in salt water). This is the only phylum that contains strictly **marine** animals. Generally, they are **benthic**, that means that they inhabit the sea bottom. Echinoderms occur in all areas of the ocean, from shallow tide pools (figure 2) to the deep abyssal plains, which can be as deep as 25,000 feet!

As a group, echinoderms are very old, dating all the way back to the early Cambrian Period. There are approximately 13,000 extinct species of various echinoderms. Because of their calcium carbonate skeletons, echinoderms are some of the most numerous fossils that are commonly found.

Characteristics of Echinoderms

Phylum Echinodermata is the phylum which is most closely related to Phylum Chordata (the group that includes humans). Both groups are considered **deuterostomes**, since they undergo similar embryological development. The embryo is **triploblastic**, which means that it develops from three germ layers: the endoderm, the mesoderm, and the ectoderm. Echinoderms possess a true **coelom**, which is a body cavity that is completely lined with mesoderm tissue. They all have an **organ system** level of organization. This means that cells are gathered into tissues, which are then gathered into organs to function in specific ways. However, echinoderms lack some of the organ systems that we commonly think of animals as having.

As mentioned earlier, echinoderms have unique characteristics, some of which include:

* **the water vascular system**
* **hard spiny skin with pedicellaria**
* **dermal endoskeleton of ossicles**
* **the lack of clearly defined excretory and circulatory systems**
* **the absence of a brain**
* **a decentralized nervous system**
* **the ability to regenerate arms and organs**
* **autotomy** (starfish)
* **specialized forms of respiration**
* **complete digestive system** (most echinoderms, including starfish)
* **dioecious** (for most)
* **secondary radial symmetry**

The **water vascular system** is the most defining feature of Phylum Echinodermata. It is a system of channels that function for locomotion, feeding, and may also serve respiratory and excretory functions. *You will learn the details of the water vascular system in the latter portion of this guide.*

The name, "echinoderm", translates into "**spiny skin**", which is another hallmark of this group. The starfish exemplifies this feature especially well. On the skin, are pincer-like elements called **pedicellaria** that prevent other smaller animals from attaching to the body. In this manner, the echinoderm protects itself from ectoparasitism. The pedicellaria also may inhibit some predation.

The dermal endoskeleton is derived from the mesoderm germ layer, and consists of numerous **ossicles** (plates). This endoskeleton is composed of 95% **calcium carbonate**, which explains the abundance of echinoderm fossils (calcium carbonate preserves well). This skeletal system of interlocking plates may be tightly packed, as in the case of the sea urchin, or they can be loosely packed, as with the starfish. *You will see the dermal plates as part of your starfish dissection.* On some echinoderms, such as the sea cucumber, the plates are so reduced that they are microscopic.

Echinoderms lack many of the organ systems and other structures that other animals generally possess. For example, they lack obvious excretory and circulatory organ systems. They do not have a brain, but rather have a **decentralized nervous system** that consists of a network of nerves. This network consists of a **central ring of ganglia** and a **nerve net** with **radial nerves** that extend throughout the body. This is divided into two parts: the **ectoneural system**, which is primarily sensory; and the **endoneural system**, which is the motor system that controls bodily functions.

figure 4 - Multi-armed starfish showing its tube feet against the aquarium glass

One aspect of echinoderms that is unusual is the **regeneration** of lost arms and in some cases, organs. Starfish can readily regenerate an arm that is lost to a predator. Some starfish can employ **autotomy** to avoid predation. Autotomy is the ability to break off part of the body when in danger as a means of escape. The predator gets a small snack (an arm) and the starfish gets away with its life.

Respiration comes in a variety of forms within Phylum Echinodermata. The sea cucumbers from Class Holothuroidea use a structure called a respiratory tree to obtain oxygen from the water. Brittle stars, from Class Ophiuroidea, use bursae to breathe. The starfish of Class Asteroidea use a combination of **dermal branchiae** (skin gills) and **tube feet** for respiration (tube feet shown in figure 4). The dermal branchiae are extensions of the body cavity that create "breathing" pores through the skin (figures 17 &19).

Most members of this group have a **complete digestive system**, which usually consists of the mouth, the cardiac stomach, the pyloric stomach, the intestine, and the anus. Having a complete system means that the animal can be continuously digesting, ingesting new food before the previous meal has been expelled. The digestive process for the starfish employs the **pyloric ceca**, where most of the digestion actually occurs.

Echinoderms are **dioecious**, which means that the male and female reproductive structures are on separate individuals. Despite separate sexes, there is no overt **sexual dimorphism**. *You will not be able to tell if your specimen is male or female.*

All echinoderms have a life cycle that consists of at least three parts:

1. Larval stage(s) with a bilateral body form
2. Metamorphosis
3. Adult stage with a radial body form

Taxonomists use the symmetry of the body as it exists at the larval stage to group animals together. For this reason, echinoderms are technically grouped with other animals that have figure 5 - Starfish brachiolaria larva, displaying bilateral symmetry

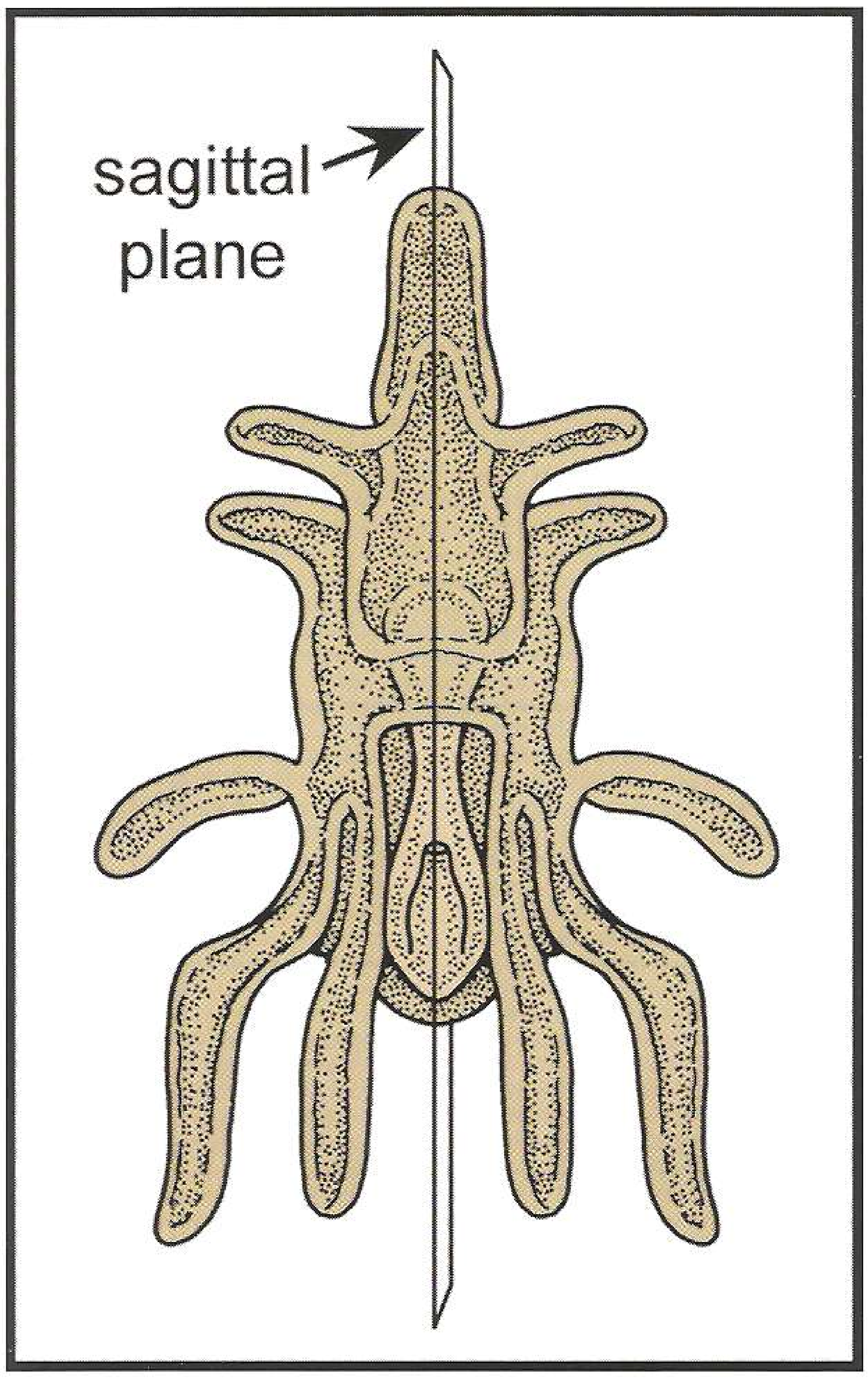


figure 6 - Adult starfish, displaying radial symmetry

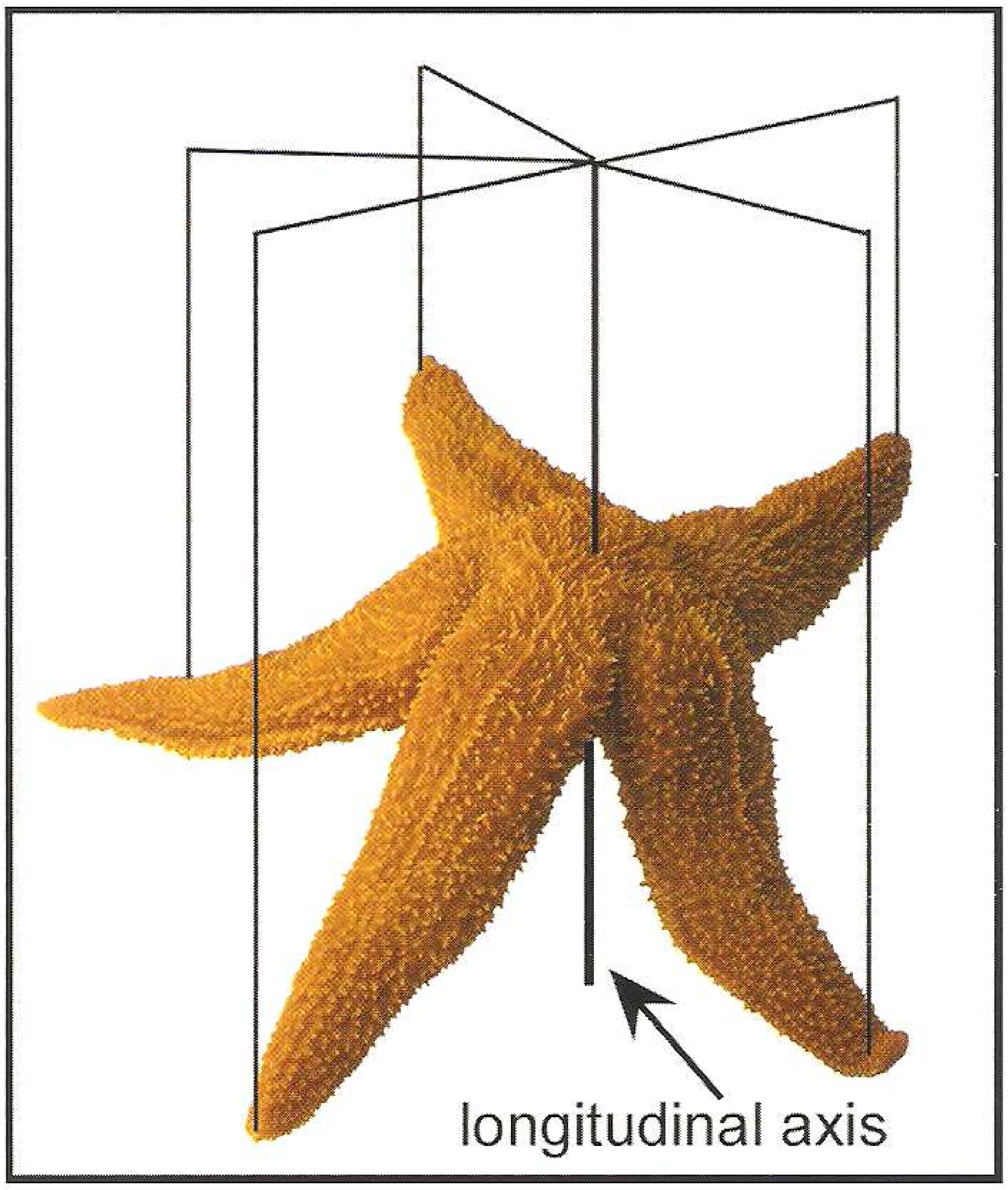
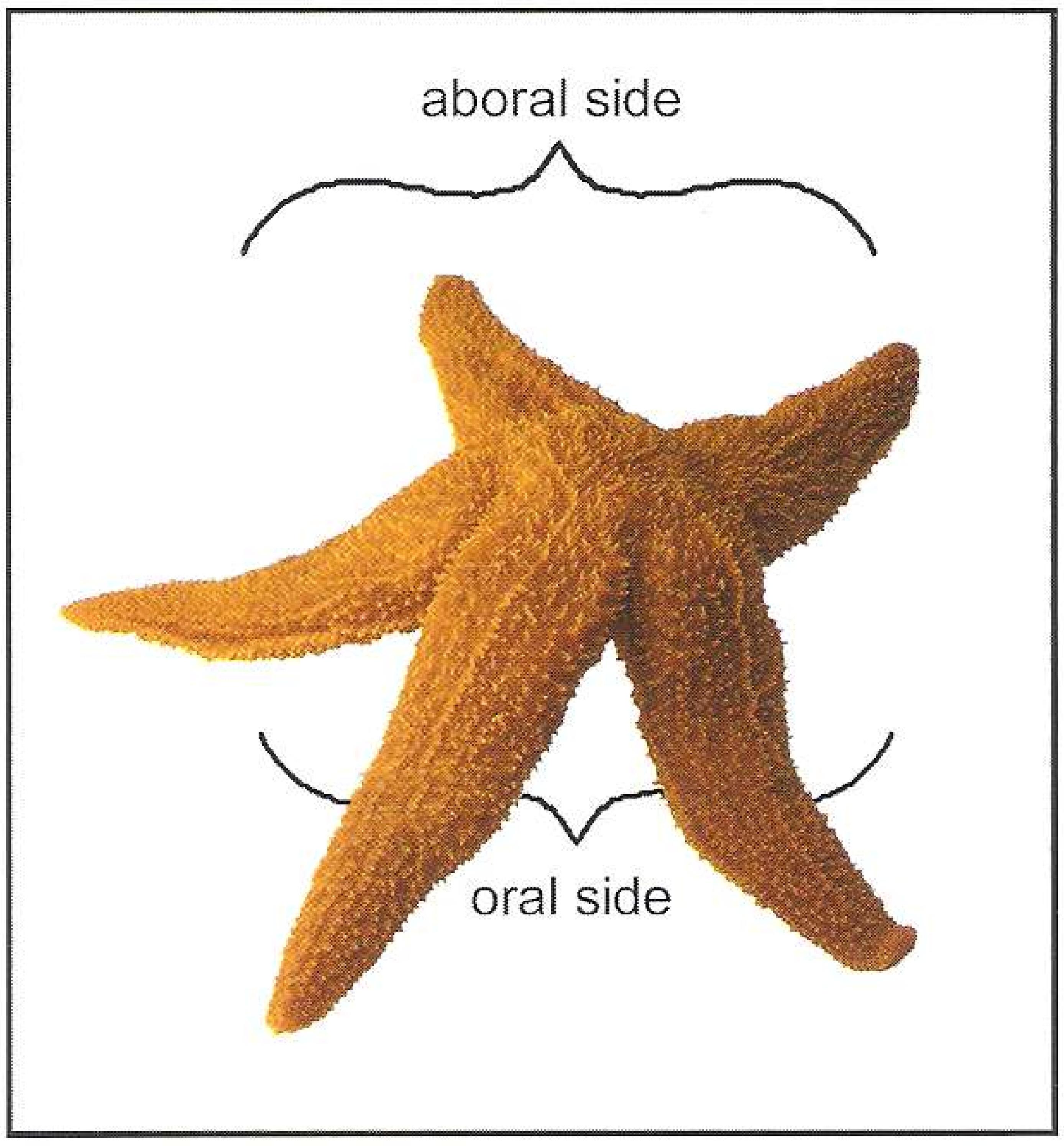


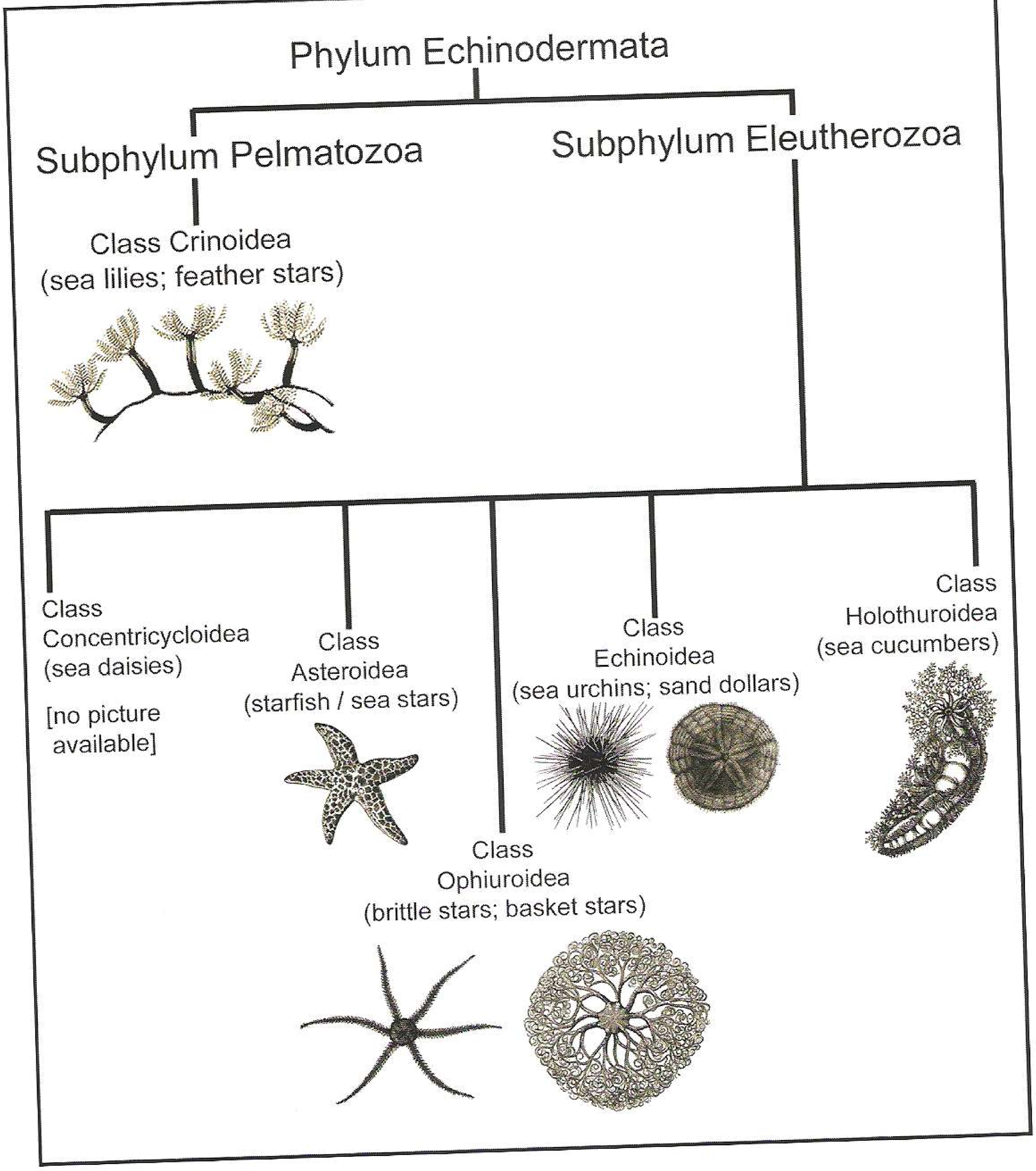
figure 7 - Terms of orientation in an animal with radial symmetry



bilateral symmetry. However, since the adult stage has a body with radial symmetry, echinoderms are referred to as having **secondary radial symmetry**. The larval stages have the body form with bilateral symmetry, in which the body can be divided into an equal mirror image, called the **sagittal plane** (figure 5). In contrast, the adult stage has the body form with radial symmetry, in which the body can be divided into more than two halves by multiple planes through a center longitudinal axis (figure 6). When referring to an animal that is radial, you should be familiar with the following terms of orientation (figure 7):

* Aboral – Refers to the side that does not contain the mouth.
* Oral – Refers to the side that contains the mouth.

figure 8 - Taxonomic divisions within Phylum Echinodermata



The Taxonomy of Phylum Echinodermata – figure 7

Taxonomy, the science of classifying animals, can be controversial. It can change as new discoveries are made in genetics that elucidate the exact relationships between animals in any given group. Phylum Echinodermata is one group that has recently undergone such changes.

Currently, Phylum Echinodermata is divided into 2 subphyla: Subphylum Pelmatozoa and Subphylum Eleutherozoa. Subphylum Pelmatozoa contains Class Crinoidea, which includes the sea lilies and feather stars. This is the most primitive of the classes. Most echinoderm fossils are crinoids from this class.

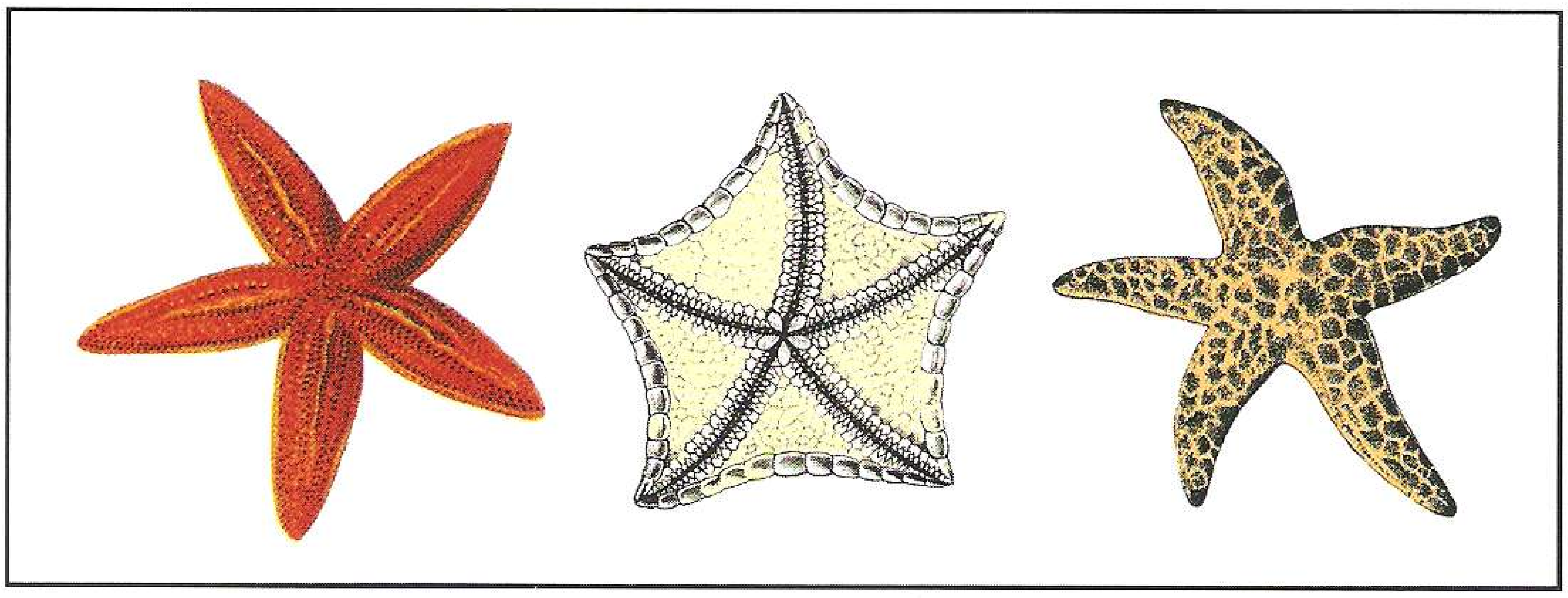
Subphylum Eleutherozoa contains the remaining 5 classes of echinoderms. Class Concentricycloidea, which includes the sea daisies, was added to this subphylum relatively recently. Sea daisies were discovered on the deep sea floor living near decaying wood.

There are only a few species currently known, due to the difficulty of accessing such ocean depths. Some scientists argue that sea daisies should be included in Class Asteroidea. For now, they have their own class as the debate continues.

The other classes in Subphylum Eleutherozoa are widely accepted and free of controversy. Class Asteroidea includes the starfish / sea stars, which often have five arms and can vary in color and body shape (figure 8). However, some starfish can have multiple arms (figure 4) with some species having as many as 42 arms!

Class Ophiuroidea includes the brittle stars and basket stars. The arms of these animals are thinner and more delicate than the starfish of Class Asteroidea. Class Echinoidea includes the sea urchins and sand dollars, which lack any appendages. This class contains some of the most abundant animals commonly found on the ocean floor within Phylum Echinodermata. Class Holothuroidea contains the sea cucumbers, which by their appearance do not seem to belong with the other echinoderms. Upon closer inspection, they actually possess many of the features unique to this phylum.

figure 9 - Various starfish types in Class Asteroidea



More on Class Asteroidea

As mentioned before, Class Asteroidea includes the starfish (sea stars). There are approximately 1600 known extant (living) species of starfish. They are characterized by the star-shaped body that can have 5-42 arms (also called rays). On the underside of each arm are numerous tube feet that contain a sucker, a suction cup-like disc used in locomotion and feeding. Along with the tube feet are the ambulacral ridges, which are distinct on animals in this class. The body of a starfish has a central disc, from which the arms radiate. Typically the body is yellow, orange, or red in color. Size can range from as small as 1 inch to over 3 feet from arm to arm.

External features

The following list of structures and functions refers to figures 10, 11, 12, 13 & 14.

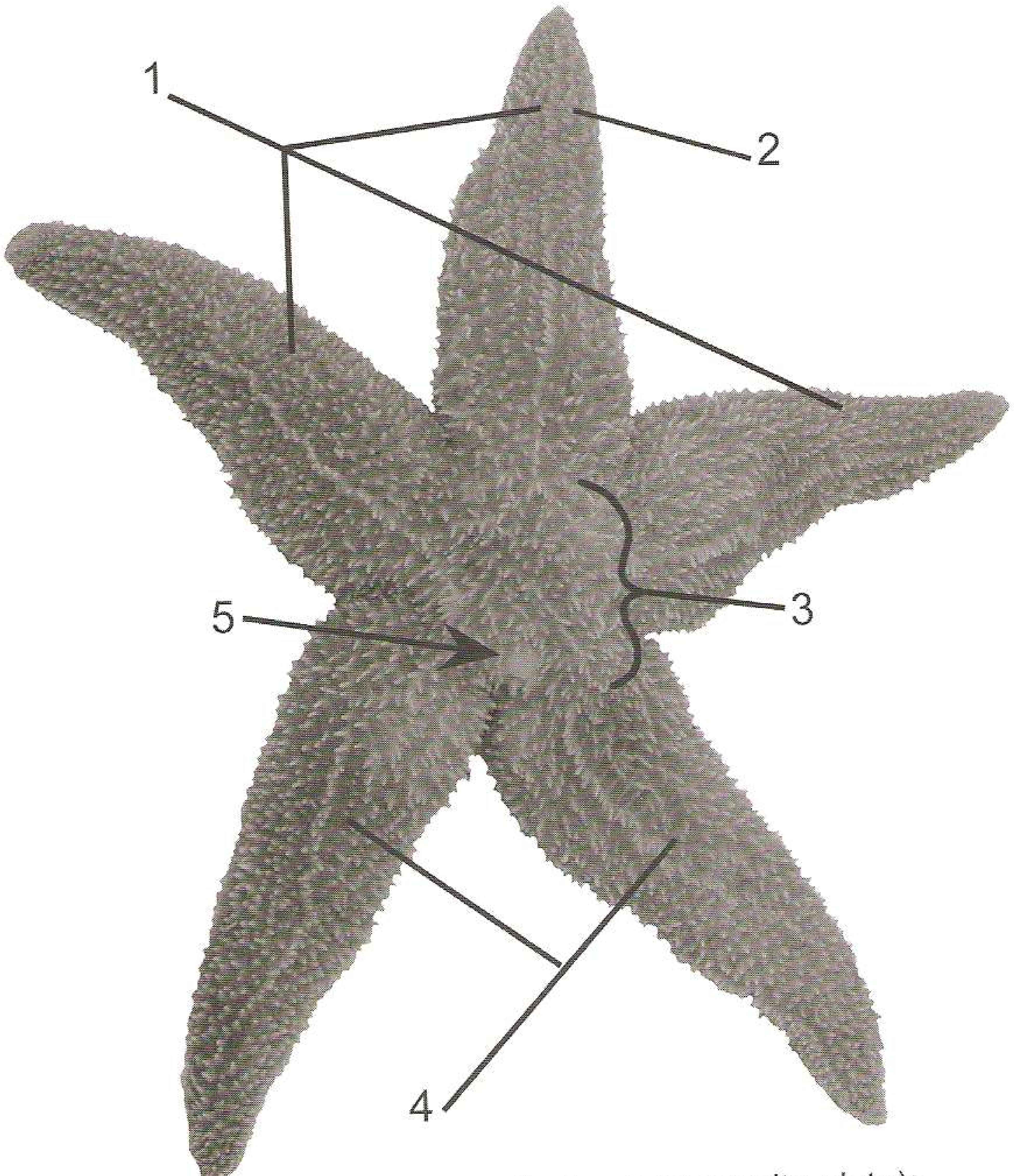
Aboral surface:

* **Madreporite plate** – The madreporite plate serves as the "entrance" to the water vascular system. It contains numerous pores and may function as the hydraulic pressure regulator for this system.

* **Spiny skin** – The skin contains multiple and microscopic pedicellaria. Together these features help inhibit external parasitism.

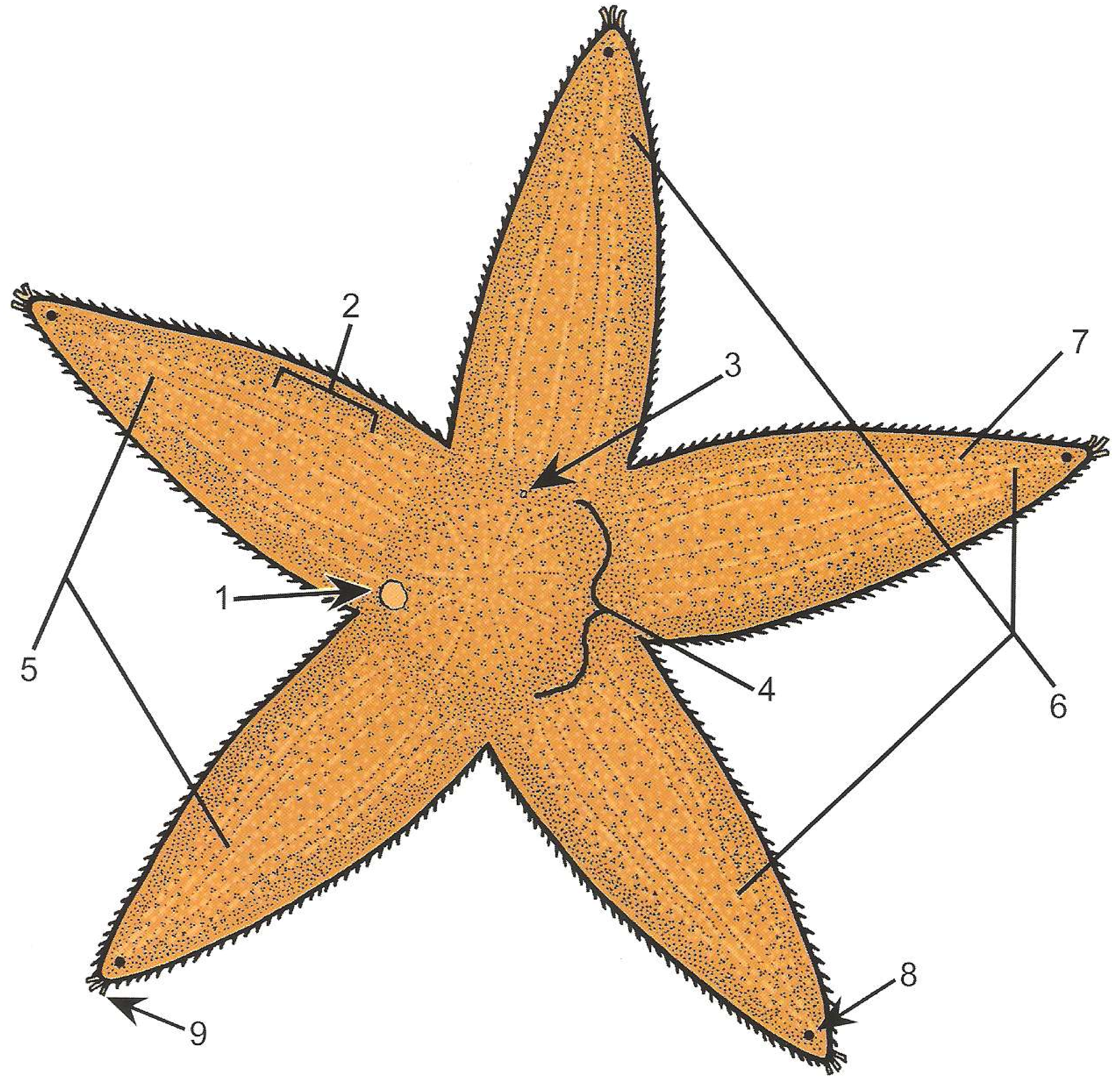
* **Anus** – The anus is a small opening that serves as the exit point for the digestive system. *This structure may be too inconspicuous to be seen.*
* **Central disc** – The central disc is the portion of the body from which the arms radiate. It contains the pyloric stomach, the cardiac stomach, the anus, and the central structures of the water vascular system: the madreporite plate, the stone canal, the ring canal, the Polian vesicles, and the Tiedmann's bodies.
* **Bivium** – The bivium are the two arms adjacent to the madreporite plate.
* **Trivium** – The trivium are the three arms opposite the madreporite plate.
* **Anterior arm** – The anterior arm is the arm directly opposite the madreporite plate.
* **Sensory tentacles** – The sensory tentacles can perceive touch and some chemicals. *Generally, the sensory tentacles are not present on a preserved specimen.*
* **Eyespot** – The eye spots (also called ocelli) are located on the tip of each arm. They contain light sensitive cells. The eye spots can detect light and dark, but not visual images. *The eye spots are not visible on a preserved specimen. If available, view a live specimen. The eye spots will look like a reddish dot above the sensory tentacles on each arm.*

figure 10 - Aboral surface of a preserved starfish

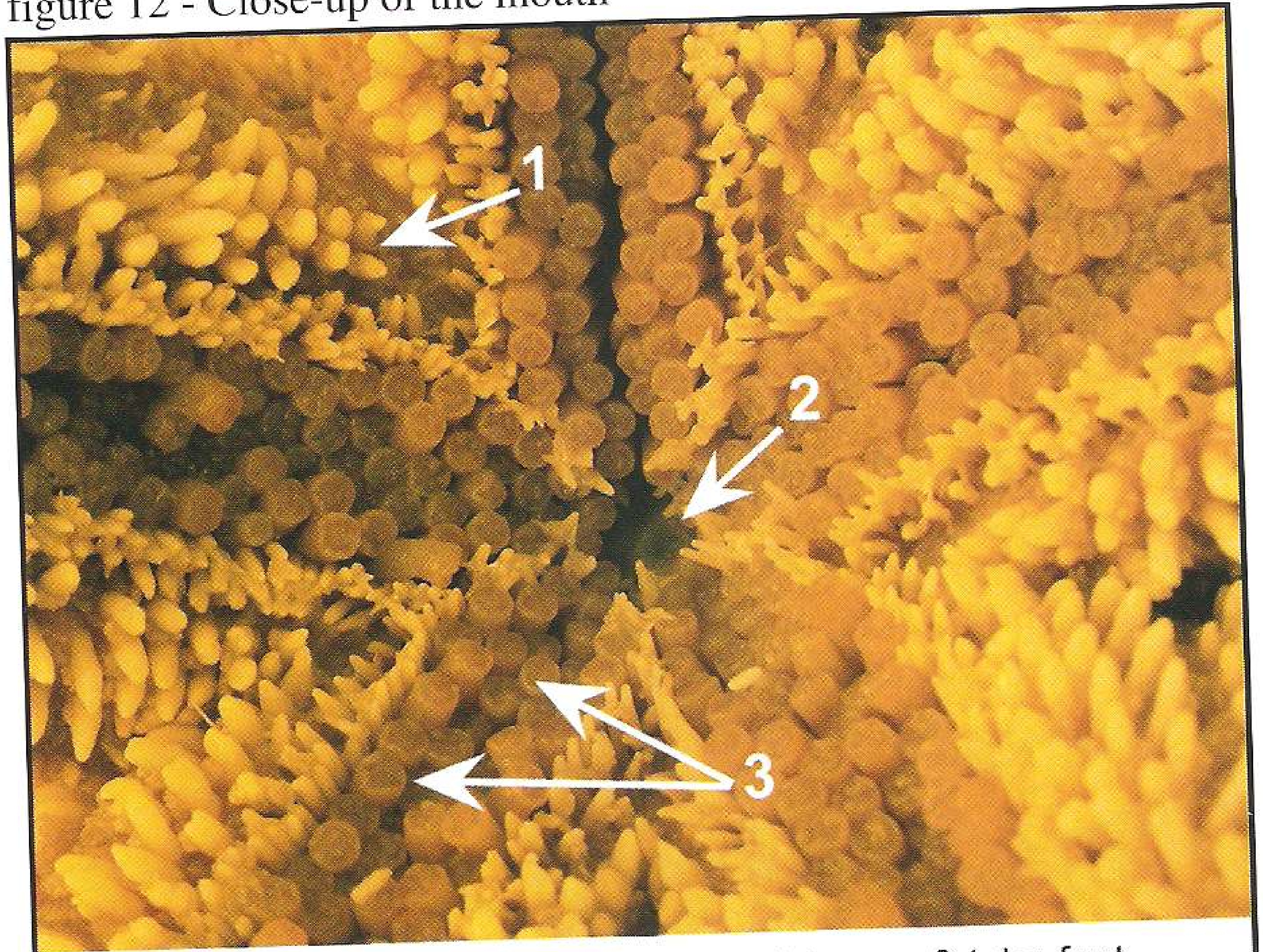


1-trivium (arms opposite the madreporite plate);
2-anterior arm (directly opposite the madreporite plate); 3-central disc;
4-madreporite plate; 5-bivium (arms adjacent to the madreporite plate)

figure 11 - External features on the aboral surface of the starfish

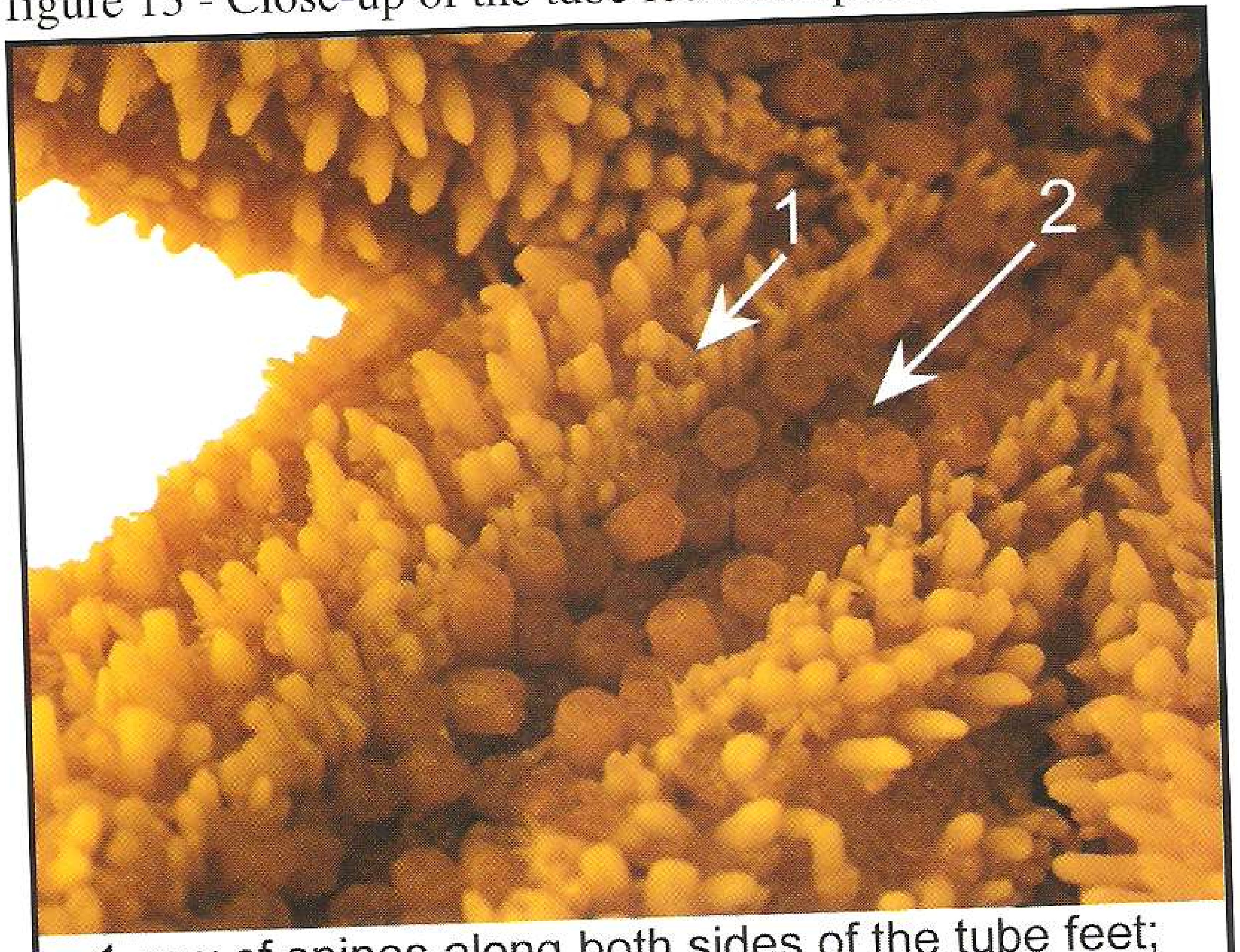


1-madreporite plate; 2-spiny skin; 3-anus; 4-central disc; 5-bivium; 6-trivium; 7-anterior arm; 8-eye spot; 9-sensory tentacles figure 12 - Close-up of the mouth



1-dermal spines; 2-mouth and peristome; 3-tube feet

figure 13 - Close-up of the tube feet and spines



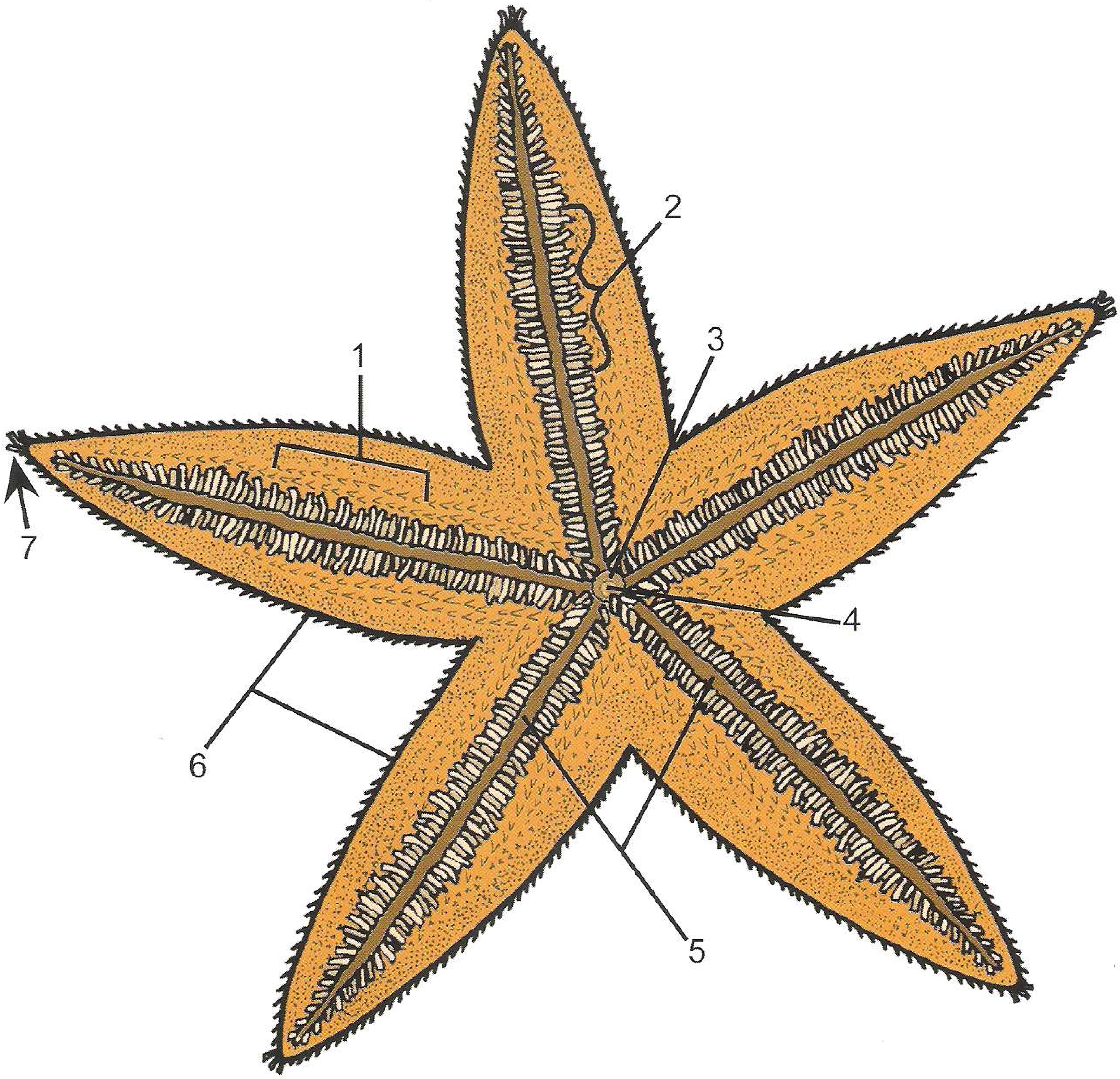
1-row of spines along both sides of the tube feet; 2-tube feet with podium (the body of the foot) and the suckers (at the tips of the foot)

Oral surface:

* **Dermal spines** – (See spiny skin from the previous aboral section).

* **Tube feet** – The rows of tube feet run along the ambulacral ridges in each arm. They function in respiration, feeding, locomotion, and sensing the surrounding environment. Each tube foot consists of a **sucker** to grasp prey and a body called the **podium**. Attached on the interior end of the podium is a balloon-like structure called an **ampulla**. The ampulla works as a water pressure ballast that contracts or extends the tube foot. The tube feet are part of the water vascular system. *Refer to pages 22-23 to learn more about the water vascular system.*

figure 14 - Internal features on the oral surface of the starfish



1-dermal spines; 2-tube feet; 3-peristome; 4-mouth;
5-ambulacral ridges / grooves; 6-arms / rays; 7-sensory tentacles

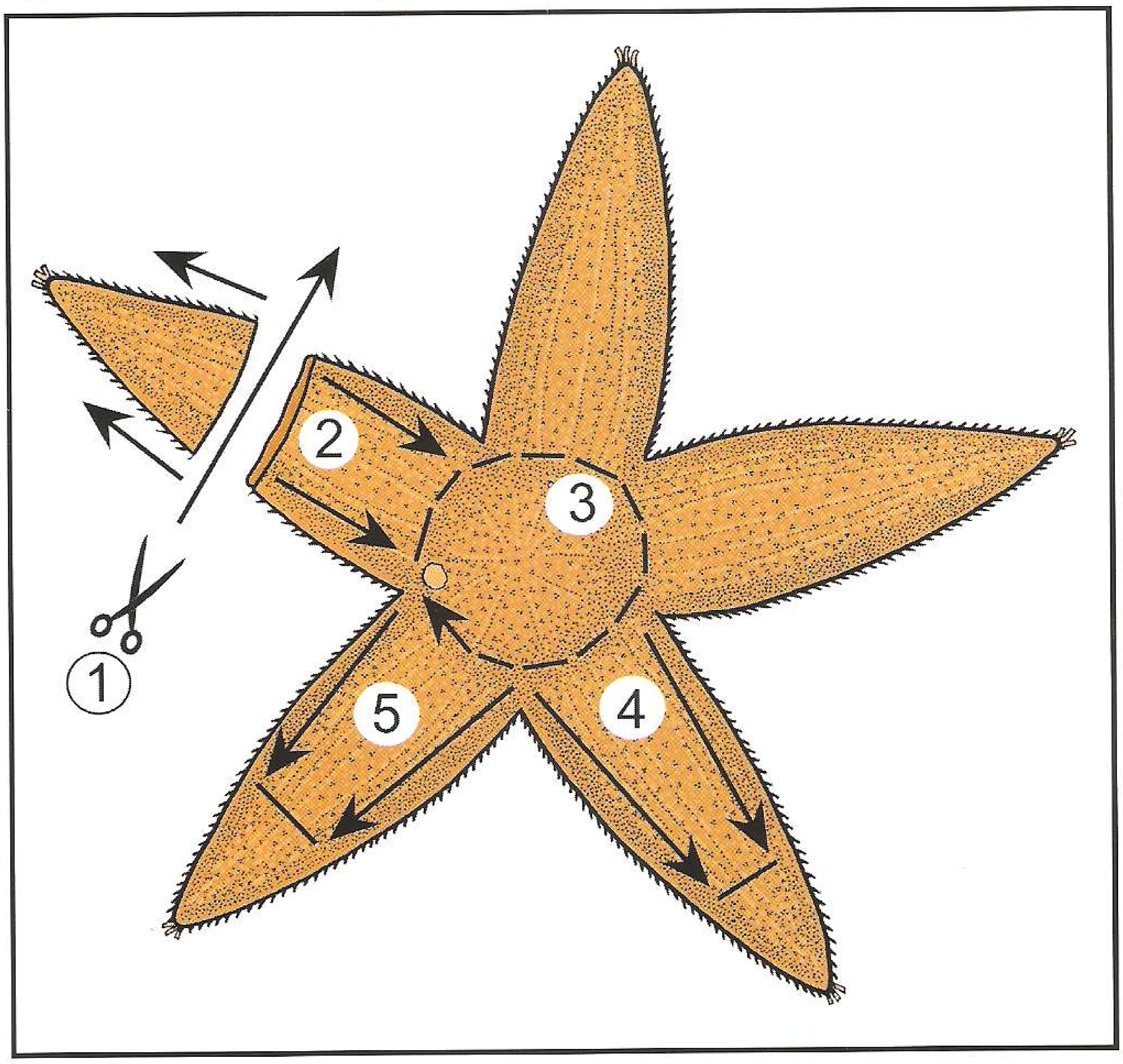
* **Peristome** – The peristome is a fleshy membrane surrounding the mouth. Around the peristome are a series of protective spines.

* **Mouth** – The mouth leads to the cardiac stomach. When feeding on a mollusc, some starfish can evert the cardiac stomach through the mouth in order to secrete digestive enzymes into the mollusc's soft body. In this manner, initial digestion of the prey occurs outside of the starfish's body. The mouth connects to the cardiac stomach through a short esophagus.

* **Ambulacral ridges / grooves** – The ambulacral ridges run along the center oral side of each arm. From these ridges extend the tube feet.

* **Sensory tentacles** – (See "sensory tentacles" from the previous aboral section).

figure 15 - Dissection steps



The Dissection: – figures 15, 16, & 17

Materials

*Starfish	*Dissecting tray	*Protective gloves	*Scalpel	*T-pins
*Probe	*Apron	*Forceps	*Scissors	

Before you begin your dissection, make sure you have seen and identified all of the structures you can using the "External features" section in this guide. If available, use a dissecting microscope to view the spines and pedicellariae on the skin along with other smaller structures. Take note of the shape of the suckers on the tube feet.

Note: Some specimens may have the cardiac stomach extending out from the mouth. If this is the case, make sure to view a specimen where the cardiac stomach is on the interior of the body.

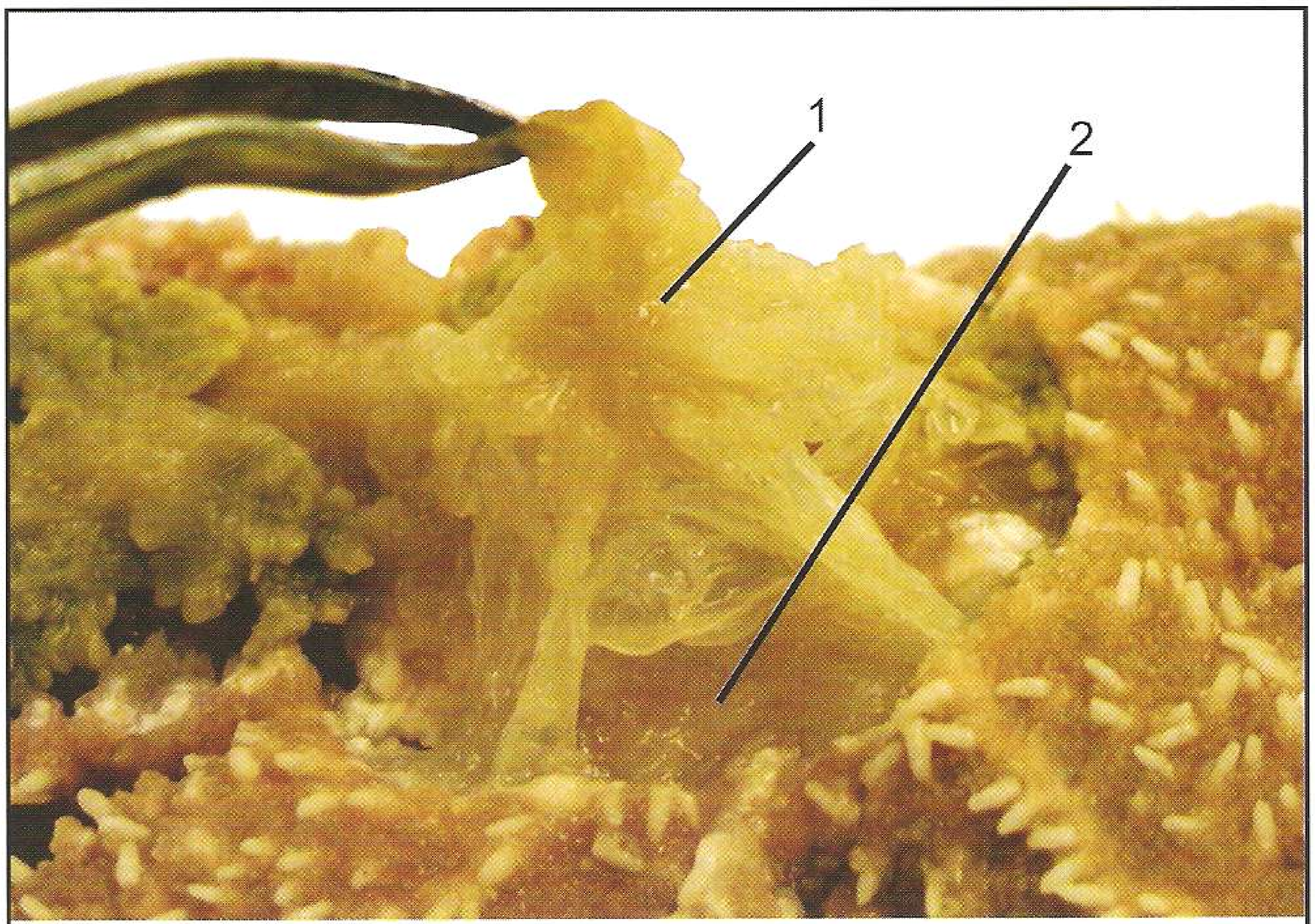
Obtain a starfish, dissection tray, gloves, and other items listed above. When handling a specimen, always wear protective gloves.

1. *Using your scissors, cut off one of the bivium (arms adjacent to the madreporite plate) in the middle of the arm. Save the portion of the arm you have cut off in order to study it and compare it with the structures shown in the cross-section (figure 19). Be careful when cutting, since the dermal endoskeleton of the starfish can be tough.*
2. *Still using your scissors, cut on either side of the arm towards the central disc.*

figure 16 - Cutting the dermal endoskeleton at the junction of the arms

3. *Using your scalpel, cut a circle around the central disc. As you pull up the disc, you will need to carefully scrape it on the underside in order to separate it from the interior organs (specifically, the pyloric stomach). As you lift the central disc, you may need to cut the dermal endoskeleton at the junction of each pair of arms (figure 16).*
4. *Using your scissors, cut down one of the trivium. As you lift the top portion of the arm, scrape down the interior organs (specifically, the pyloric ceca) in order to keep them intact (as shown in figure 15).*
5. *Using your scissors, cut down the other bivium. As you lift the top portion of the arm, scrape down the interior organs (specifically, the pyloric ceca) in order to keep them intact. Using your forceps, carefully remove the pyloric ceca in order to expose the deeper structures: the gonads, the gastric ligaments, the ampullae, and the ambulacral ridge (as shown in figure 15).*
6. *After inspecting the surface structures in the central disc, carefully lift and remove the pyloric stomach using your forceps (figure 17). This will expose the cardiac stomach and gastric ligaments (figure 23).*

figure 17 - Separating the pyloric stomach from the cardiac stomach



1-pyloric stomach; 2-cardiac stomach

Internal features

The following list of structures and functions refers to figures 17-23. Both graphic and photographic views are provided to help you identify the structures on your specimen.

* **Intestinal cecum** – The intestinal cecum (*cecum=singular; ceca=plural*) is located on the intestine. It is a gland that aids in digestion.. *This structure may be too inconspicuous to be seen.*

* **Intestine** – The intestine in the starfish is a short, reduced structure that connects the pyloric stomach with the anus. *This structure may be too inconspicuous to be seen.*

* **Anus** – The anus is a small opening that serves as the exit point for the digestive system. *This structure may be too inconspicuous to be seen.*

* **Pyloric stomach** – The thick-walled pyloric stomach is positioned on the aboral side within the central disc. It leads into 5 distinct pyloric ducts, which branch and lead into the paired pyloric ceca in each arm.

* **Cardiac stomach** – The thin-walled cardiac stomach is positioned on the oral side within the central disc. It has five lobes and is attached to the ambulacral ridges by the paired gastric ligaments in each arm.

* **Dermal endoskeleton** – The dermal endoskeleton is composed of dermal ossicles (plates).

* **Dermal ossicle** – The dermal ossicles are a series of plates made primarily of calcium carbonate that are embedded in the dermis.

* **Spine** – On the surface of the epidermis (outer skin) are numerous defensive spines and pincer-like pedicellaria.

* **Dermis** – The dermis is the thicker interior layer of the body wall. Embedded in the dermis are the ossicles and the dermal branchiae (skin gills).

* **Epidermis** – The epidermis is the thinner exterior layer of the body wall.

* **Peritoneum** – The peritoneum is a thin membrane that lines the interior body wall. It separates the dermis from the coelom (interior body cavity).

* **Papula and dermal branchia** – The papula (*papula=singular; papulae=plural*) is the cone-shaped protrusion of the dermal branchia (*branchia-singular; branchiae=plural*), which is also referred to as the "skin gill". Collectively, the dermal branchiae are one of the sites for gas exchange and respiration.

* **Gonad** – The paired gonads may be testes or ovaries, depending on the gender of the starfish. They have a globular, gelatinous appearance and extend from the central disc into each arm. *You will not be able to determine the gender of your starfish. The gonads can vary in size according to the time of year the starfish were harvested. Gonads will be larger during the mating season and can be greatly reduced during other times of the year.*

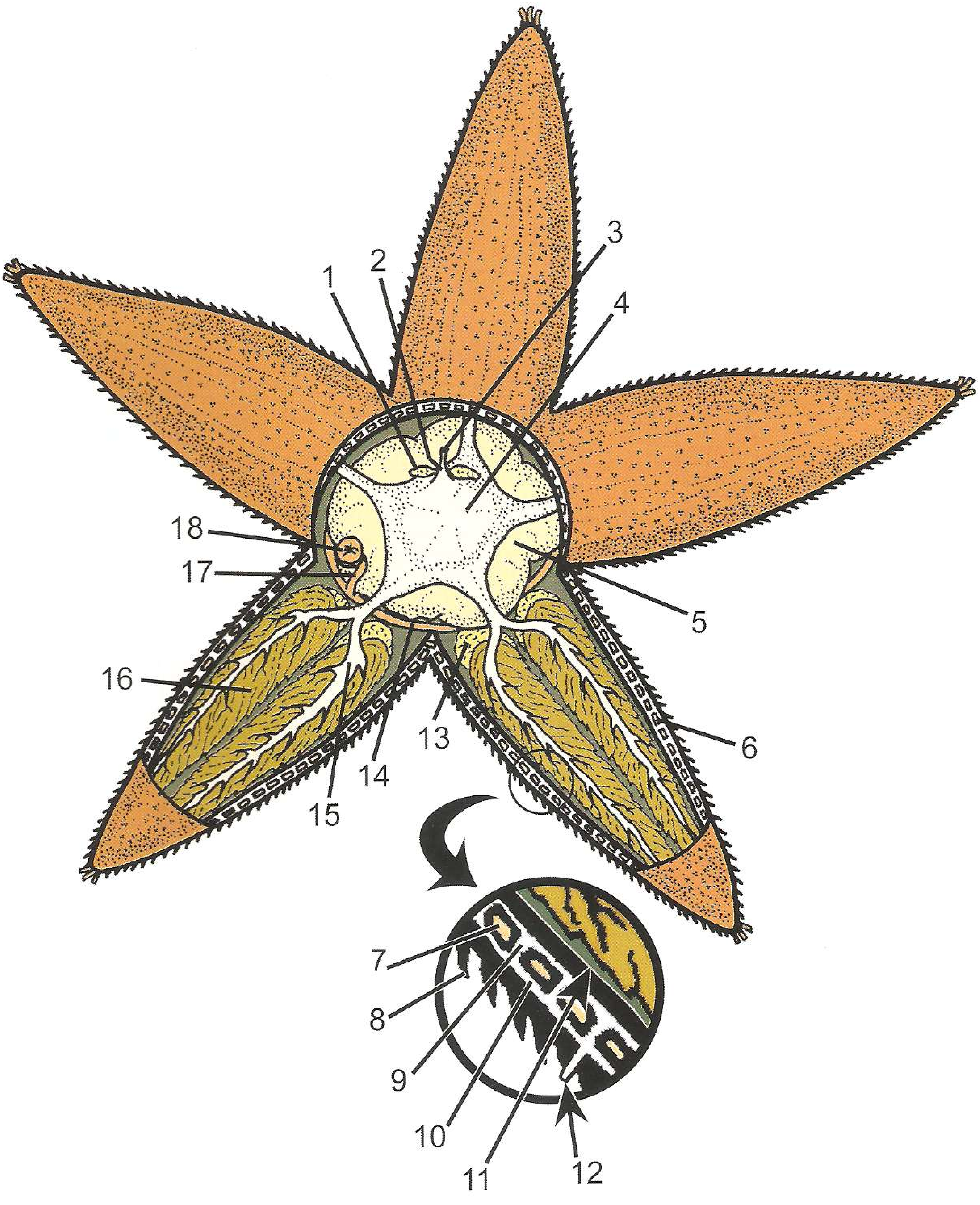
* **Ring canal** – The ring canal is the central part of the water vascular system. *You will learn more about the water vascular system in the next portion of this guide. The ring canal may not be a visible structure.*

* **Pyloric duct** – The five pyloric ducts branch and extend out from the pyloric stomach into the paired pyloric ceca in each arm.

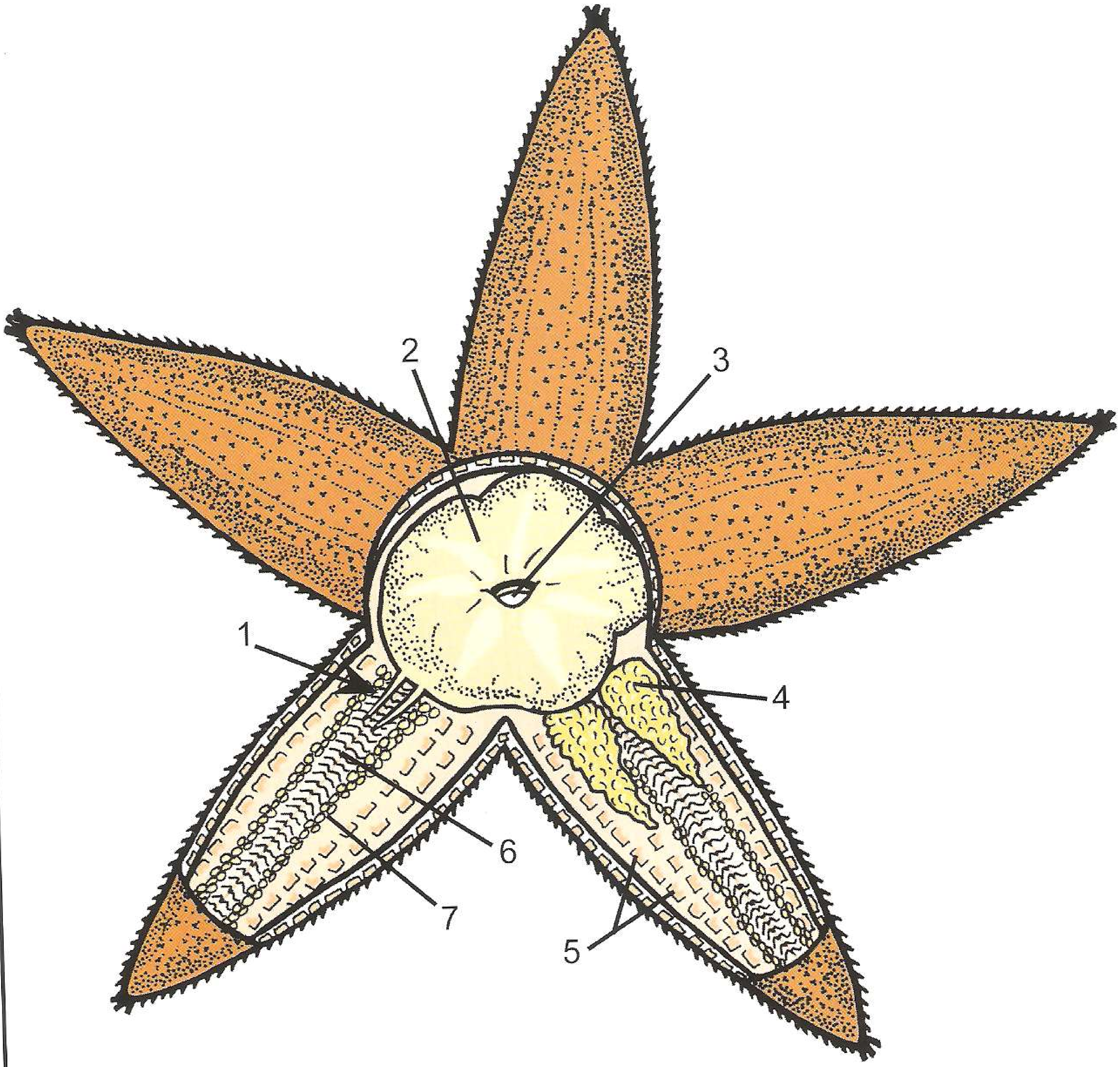
* **Pyloric ceca** – The pyloric ceca (*ceca=singular; cecum=plural*) are the most prominent feature in each arm. These digestive glands secrete enzymes and absorb nutrients. This organ is responsible for the majority of digestion.

* **Stone canal** – The stone canal connects the madreporite plate with the ring canal. It is part of the water vascular system. *You will learn more about the water vascular system in the next portion of this guide. The stone canal may not be a visible structure.*

figure 17 - Initial view of the internal structures



1-intestinal cecum; 2-intestine; 3-anus; 4-pyloric stomach; 5-cardiac stomach; 6-dermal endoskeleton; 7-dermal ossicle; 8-spine; 9-dermis; 10-epidermis; 11-peritoneum; 12-papula and dermal branchia; 13-gonad; 14-ring canal; 15-pyloric duct; 16-pyloric cecum; 17-stone canal; 18-madreporite plate figure 18 - Deeper internal structures (pyloric stomach and pyloric ceca removed)



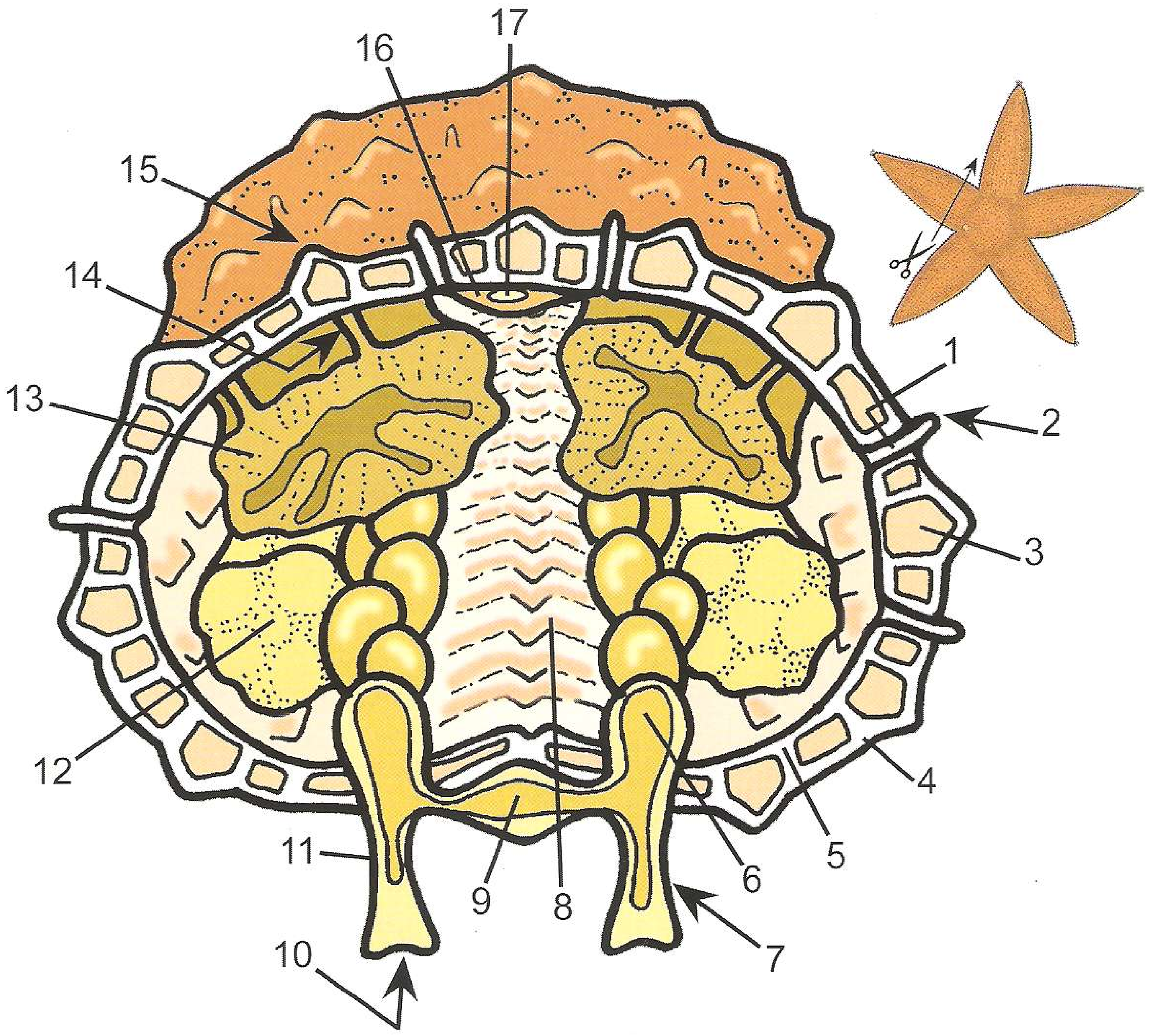
1-gastric ligaments; 2-cardiac stomach; 3-mouth; 4-gonads; 5-dermal plates; 6-ambulacral ridge / groove; 7-ampullae

* **Madreporite plate** – The madreporite plate serves as the "entrance" to the water vascular system. It contains numerous pores and may function as the hydraulic pressure regulator for this system.

* **Gastric ligaments** – The gastric ligaments are attached to the cardiac stomach. These ligaments help pull the cardiac stomach back into the body after it has been everted during feeding. *Refer to the "Feeding and Digestion" section of this guide for more information.*

* **Mouth** – The mouth leads to the cardiac stomach. When feeding on a mollusc, some starfish can evert the cardiac stomach through the mouth in order to secrete digestive enzymes into the mollusc's soft body. In this manner, initial digestion of the prey occurs outside of the starfish's body.

figure 19 - Cross-section of an arm



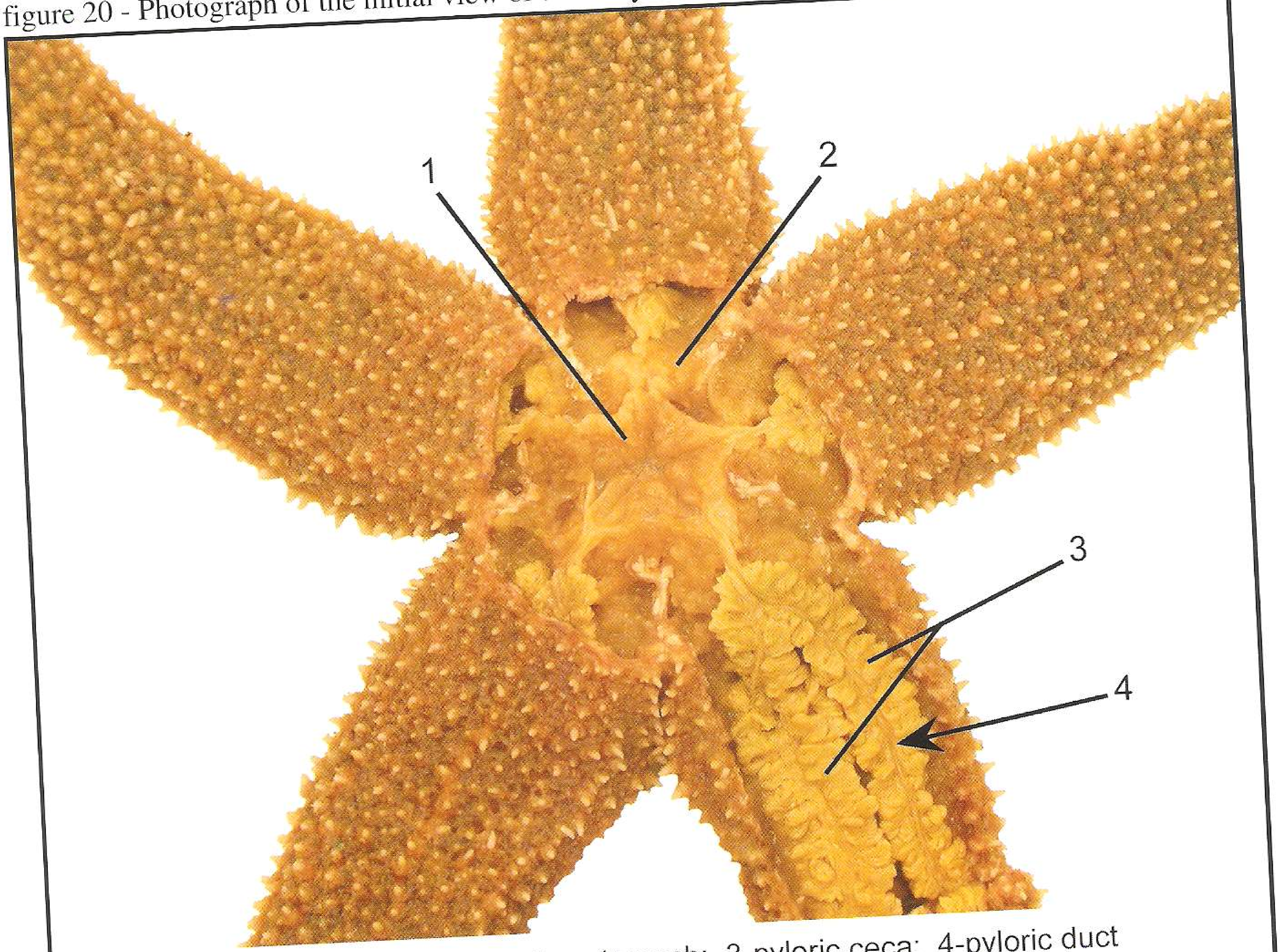
1-dermal branchia; 2-papula; 3-dermal ossicle; 4-epidermis; 5-dermis; 6-ampulla; 7-tube foot; 8-ambulacral ridge; 9-radial canal; 10-sucker; 11-podium; 12-gonad; 13-pyloric cecum; 14-mesentery; 15-spine; 16-apical longitudinal muscle; 17-radial nerve

* **Ambulacral ridge / groove** – The ambulacral ridges run along the center oral side of each arm. From these ridges extend the tube feet.

* **Tube feet** – The rows of tube feet run along the ambulacral ridges in each arm. They function in respiration, feeding, locomotion, and sensing the surrounding environment. Each tube foot consists of a **sucker** to grasp prey and a body called the **podium**. Attached on the interior end of the podium is a balloon-like structure called an **ampulla**. The ampulla works as a water pressure ballast that contracts or extends the tube foot. All of the above mentioned structures are part of the water vascular system.

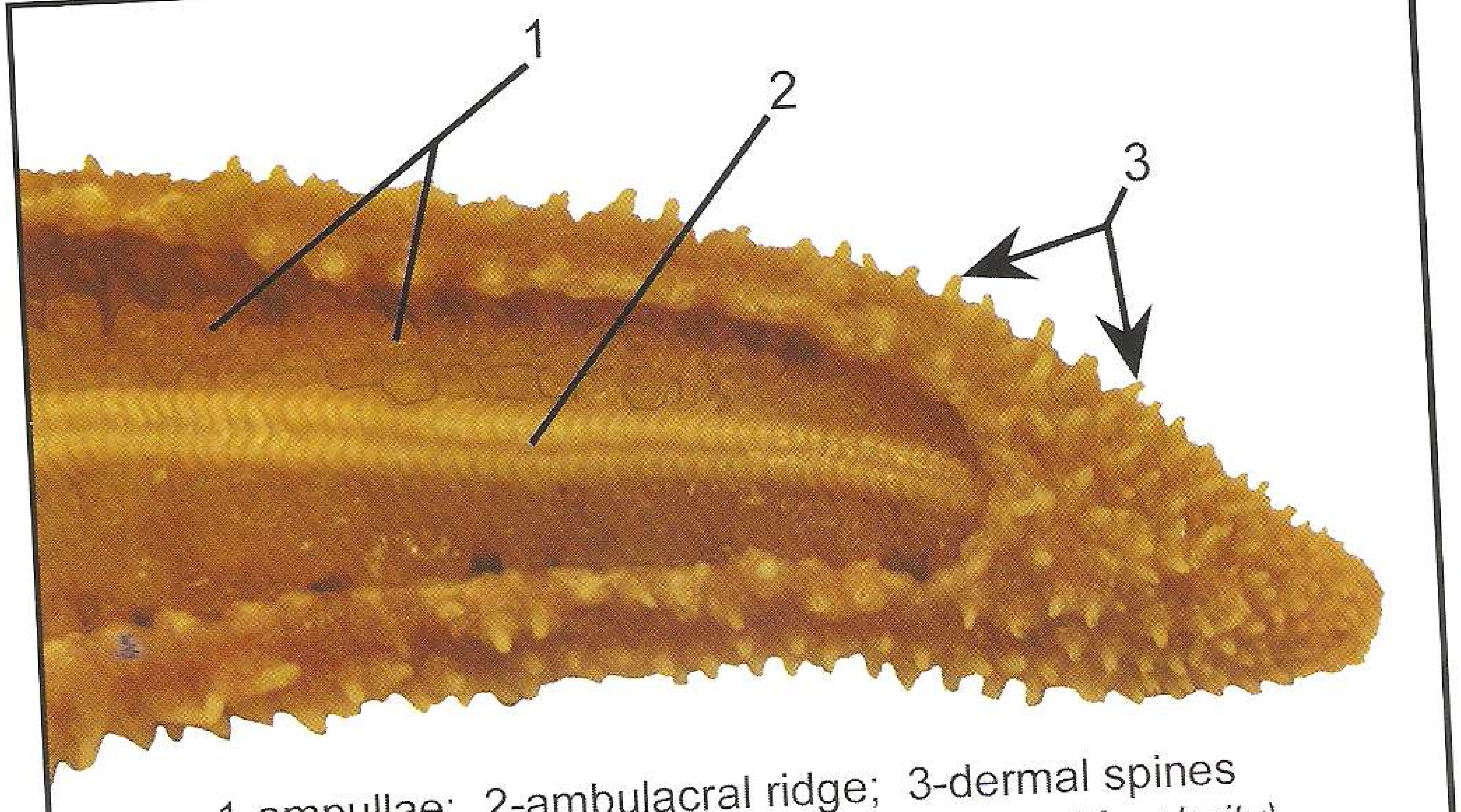
* **Ampullae** – The ampullae (*ampulla=singular; ampullae=plural*) are balloon-like structures that are located along both sides of the ambulacral ridge in each arm. They are connected to the tube feet and are part of the water vascular system. The ampullae serve as ballasts for the hydraulic pressure in the tube feet. When they contract, the tube feet extend. (This could be compared to squeezing one side of a tubular water balloon.)

figure 20 - Photograph of the initial view of the body cavity



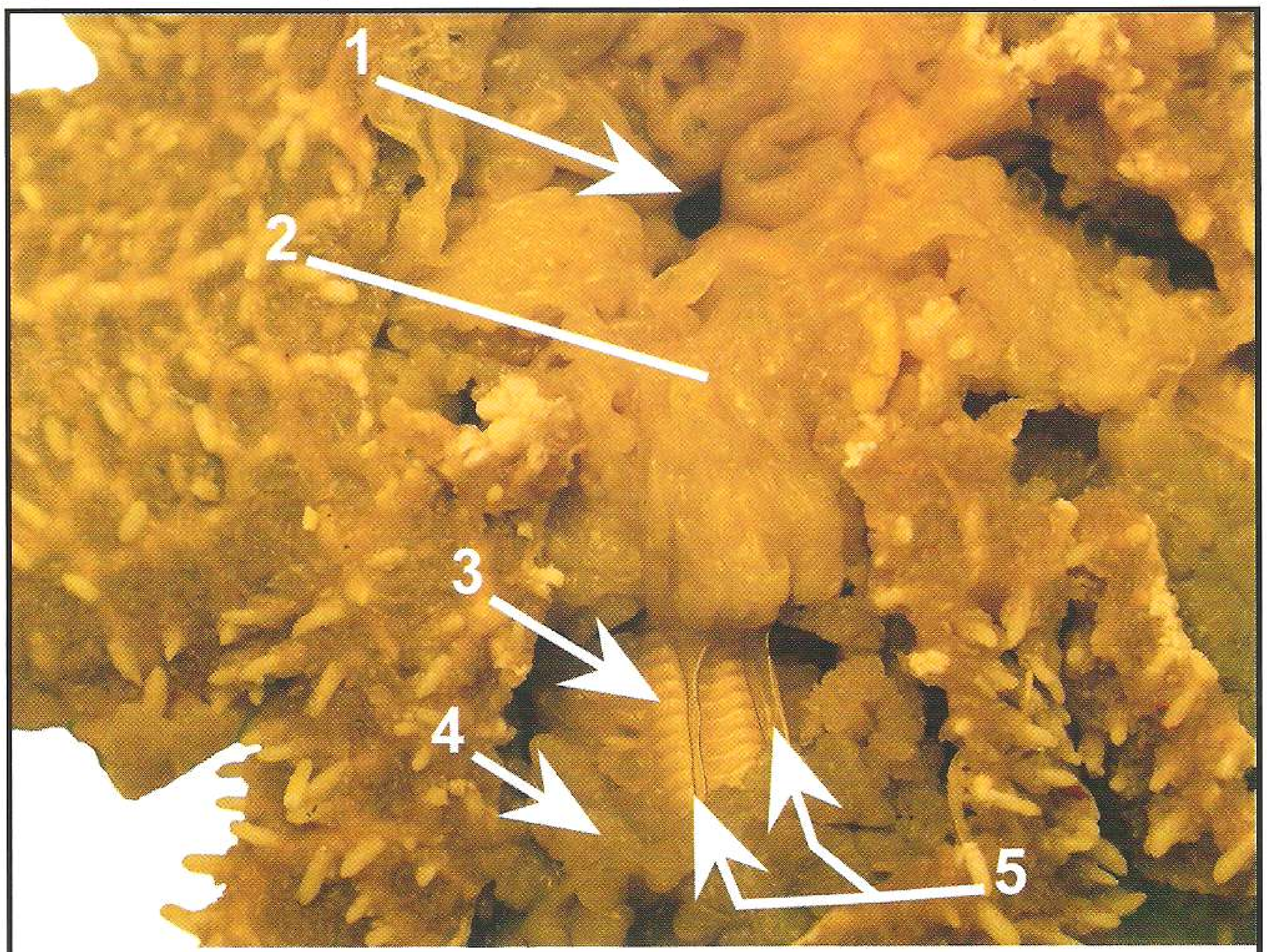
1-pyloric stomach; 2-cardiac stomach; 3-pyloric ceca; 4-pyloric duct

figure 21 - Close-up of the ambulacral ridge and ampullae



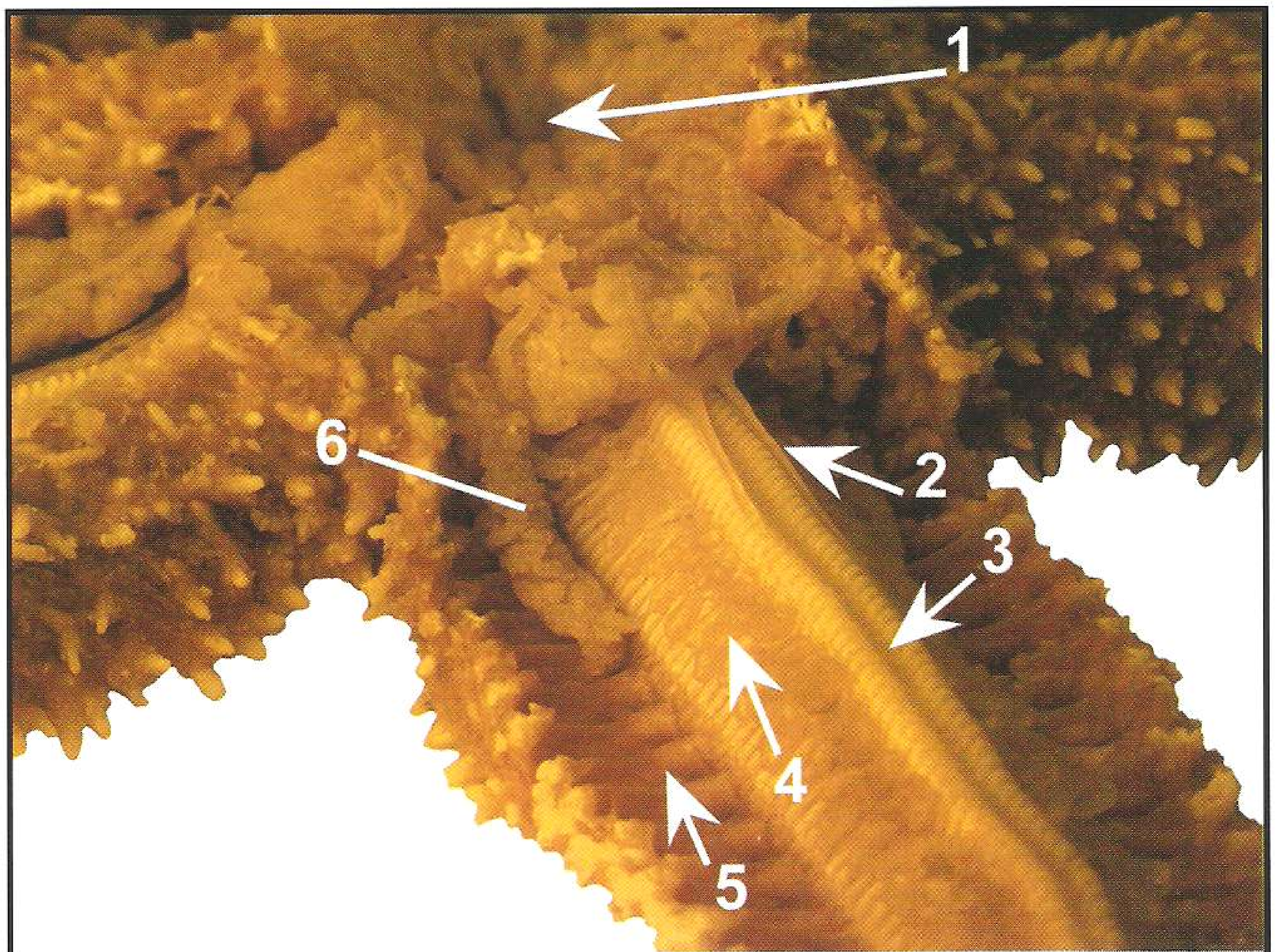
1-ampullae; 2-ambulacral ridge; 3-dermal spines
(note: some of the ampullae have been outlined for clarity)

figure 22 - Close-up of the cardiac and pyloric stomachs and gastric ligaments

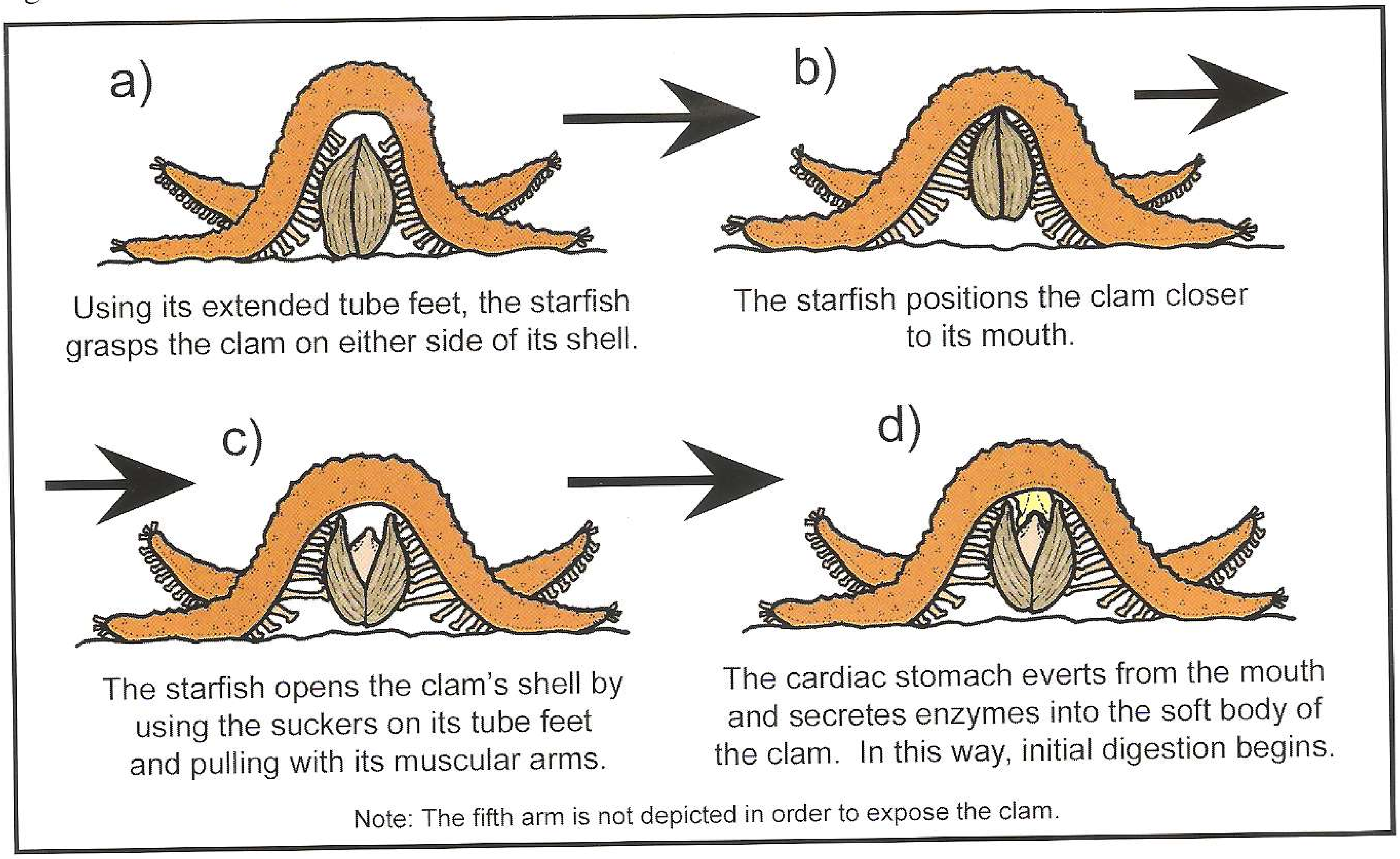


1-mouth; 2-cardiac stomach (pyloric stomach has been removed); 3-ambulacral ridge; 4-pyloric cecum; 5-gastric ligaments

figure 23 - Close-up of some of the deeper internal structures



1-mouth; 2-gastric ligament; 3-ambulacral ridge; 4-ampullae; 5-endoskeletal plates; 6-gonads figure 24 - Clam feeding strategy



Feeding and Digestion – figure 24

Starfish are **carnivorous**, feeding on a variety of marine animals that include molluscs, other echinoderms, small fish, polychaete worms, small crustaceans, and other invertebrates. Molluscs, such as the clam, are a favorite food of many species of starfish. The feeding strategy used for feeding on clams is exceptional. The starfish will approach a clam and using its arms, will position it with the valves of the shell facing up directly under the mouth. By using the hydraulic pressure within the water vascular system, the ampullae contract. This causes the tube feet to extend towards the clam. The suckers on the tips of the tube feet create a secure grasp (figure 23a). The starfish re-positions the clam and lifts it closer to the mouth (figure 23b). Using its muscular arms and tube feet, the starfish pries open the shell of the clam (figure 23c). By contracting the body wall, the cardiac stomach everts out of the mouth and onto the soft body of the clam. Gastric juices and digestive enzymes, which are produced by the pyloric ceca, are released directly onto the clam's body. Digestion begins within the shell. Once the clam's body is partially digested and softened, the starfish begins to feed (figure 23d). Once the starfish is finished feeding, the body wall relaxes and the cardiac stomach retreats back into the body cavity.

Internally, the digestive system consists of the **mouth** connected to the **cardiac stomach** through a short **esophagus**. Attached to the cardiac stomach, on the aboral side of the central disc is the **pyloric stomach**. The **pyloric ceca** extend from the pyloric stomach along the **pyloric ducts** into each arm. The pyloric ceca are responsible for the majority of digestion. On the aboral side of the pyloric stomach are the **intestinal ceca** (also called rectal ceca), the short **intestine**, and the **anus**.

The Dermal Endoskeleton and Body Wall

The dermal endoskeleton consists of numerous **dermal ossicles** (plates) composed primarily of **calcium carbonate**. The ossicles are joined by **connective tissue** and are patterned into a mesh-like network of spaces that is filled with **dermal cells** and various **fibers**. This network is called the **stereom**.

The body wall is mainly composed of the **epidermis**, the **dermal ossicles**, and the **dermis**. Projecting through the skin are the numerous **dermal branchiae**, which are used in respiration. On the surface of the epidermis are the **spines** and pincer-like **pedicellaria**, which protect against external parasites. The ossicles are embedded within the thick dermis. The thinner epidermis protects the starfish from the external environment. The interior of the body wall is lined with a ciliated membrane called **peritoneum**.

The Nervous System and Sensory Organs

The nervous system in the starfish is a **decentralized system** consisting of a **network of nerves** connected by an **epidermal nerve plexus** (a nerve net within the skin). On the central disc of the body is a **central ring of ganglia**, which extends into the arms through the **radial nerves**. Each arm contains a single radial nerve that extends along the radial canal (of the water vascular system). The radial nerves control the muscles in the arm and the action of the tube feet.

The starfish nervous system has two parts:

* **Endoneural system** – The endoneural system is responsible for the motor system that controls bodily functions.
* **Ectoneural system** – The ectoneural system is responsible for the sensory functions of touch, chemoreception, and sensing light.

The sensory organs consist of **sensory cells** that are dispersed on the epidermis and the **eye spots** (ocelli) located at the end of each arm. The eye spots have light sensitive cells that do not perceive images but rather detect light and dark. There are some unspecialized sensory cells on the tube feet that can detect touch, certain chemicals, and some contrasts of light and dark.

One advantage of having this type of decentralized system is that any part of the body can act as the "head". In an animal with radial symmetry that lives in the confined spaces of a coral reef, being able to equally sense food or danger from any direction is a definitive adaptation for survival.

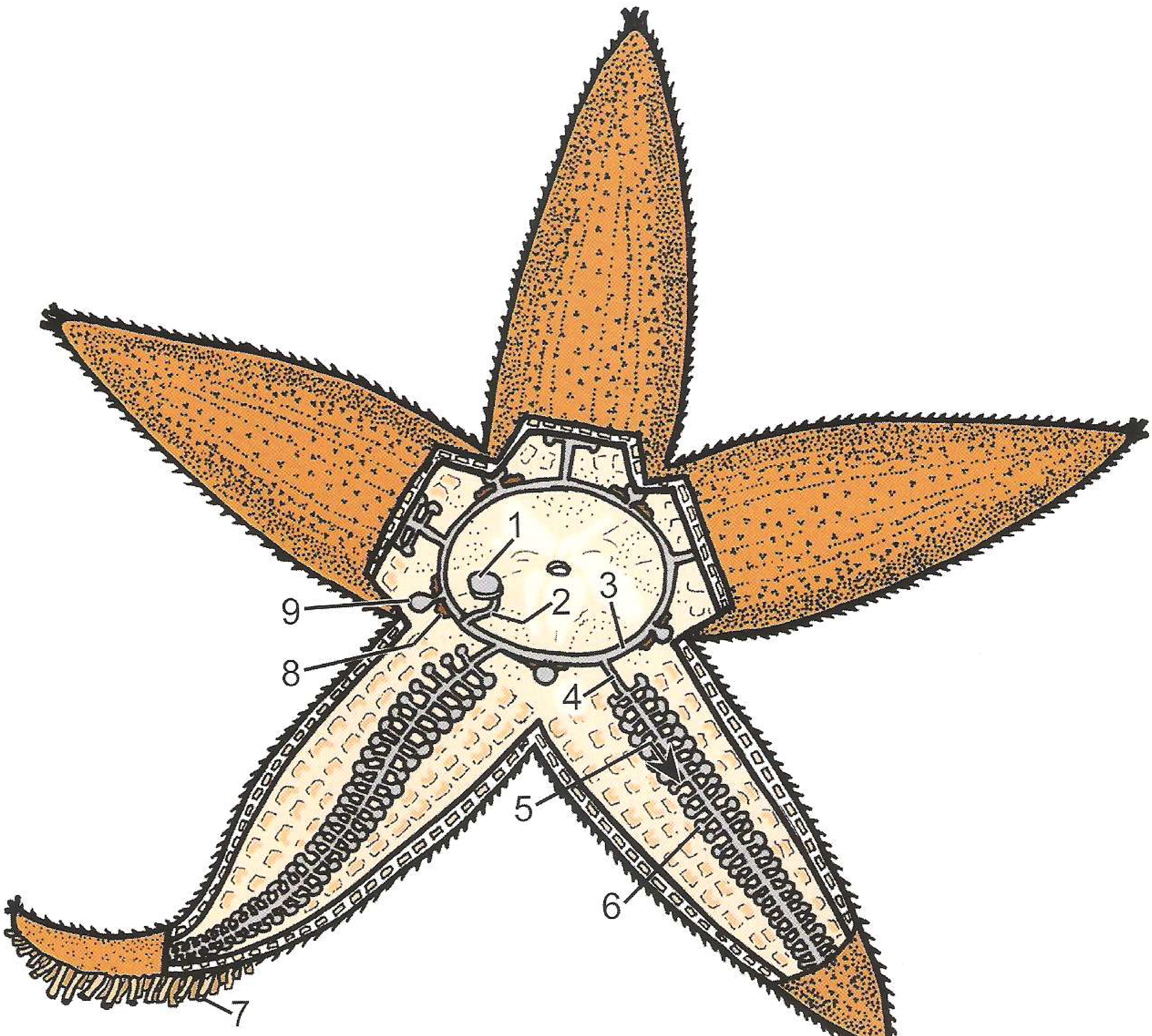
Circulation

Circulation in echinoderms takes place within the **coelom** (the body cavity) in a series of **channels** and **sinuses** (open spaces). The interior of the coelom is lined with epithelial cells that are ciliated. The fine cilia beat in a rhythmic fashion to help create a circulatory current. Floating within the coelom are specialized cells called **amoebocytes**, which are also called coelomocytes. These large cells are capable of **phagocytosis** and function to engulf foreign material and transport nutrients throughout the body. They also store insoluble wastes.

Respiration and Gas Exchange

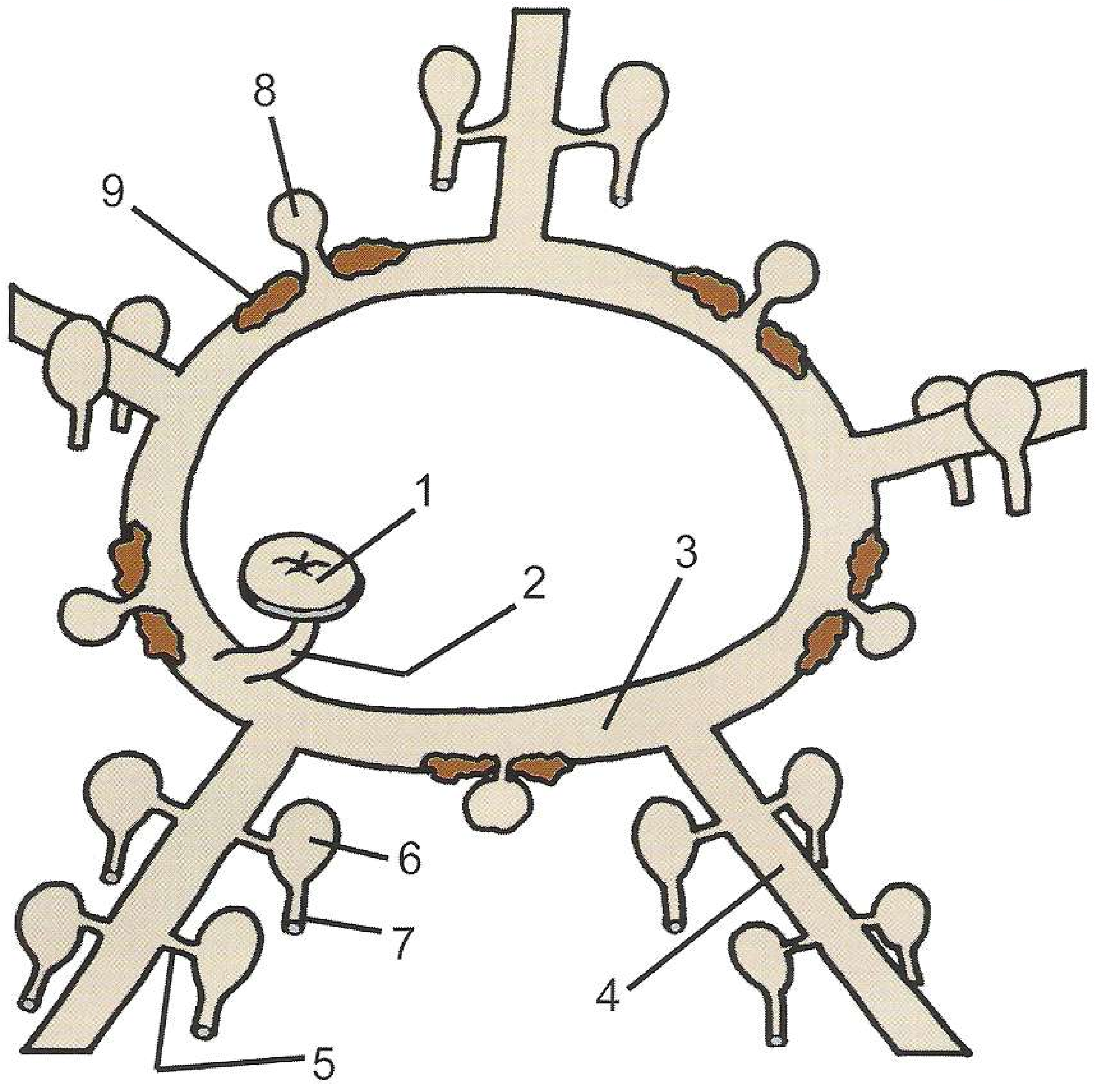
Starfish are capable of **dermal respiration**. Few animals employ this as a means of respiration. Gas exchange (obtaining oxygen) occurs through the **dermal branchiae** (skin gills). These branchiae are extensions of the coelom (body cavity) that create pores through the skin. The numerous pores are located between the dermal ossicles and are lined with **epidermal tissue** on the external surface and **peritoneum** on the interior coelomic surface. The dermal branchiae are evident on the exterior of the skin as small cone-like projections called papulae. In addition to the dermal branchiae, some gas exchange can occur through the **tube feet**, located on the aboral side of the starfish.

figure 25 - The water vascular system in the starfish body



Structures of the water vascular system:
1-madreporite plate; 2-stone canal; 3-ring (circular) canal; 4-radial canal;
5-lateral canal; 6-ampulla; 7-tube feet;
Accessory structures: 8-Tiedmann's body; 9-Polian vesicle

figure 26 - Schematic of the water vascular system

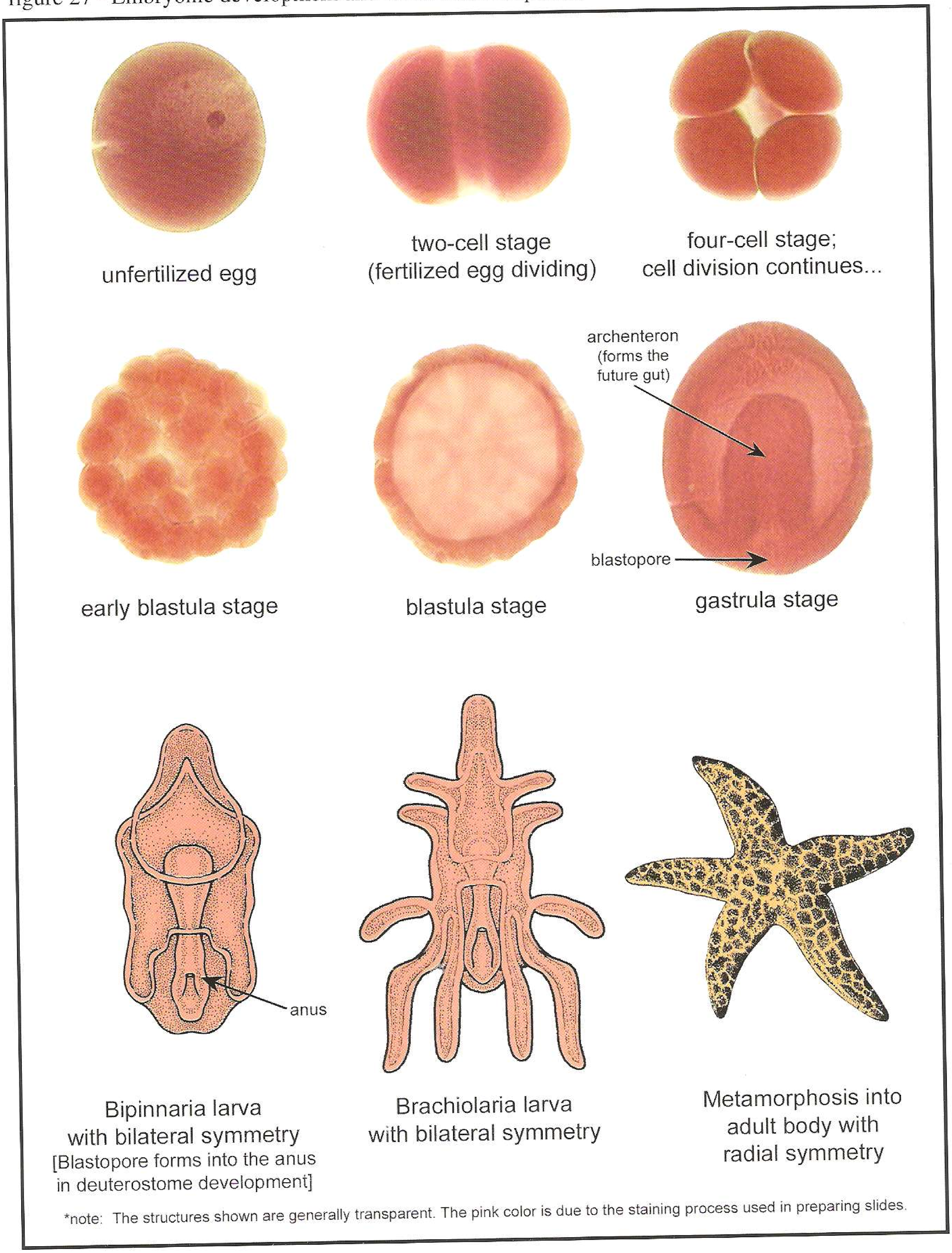


Structures in the water vascular system:
1-madreporite plate; 2-stone canal; 3-ring (circular) canal; 4-radial canal; 5-lateral canal; 6-ampulla; 7-tube foot; Accessory structures: 8-Polian vesicle; 9-Tiedmann's bodies

The Water Vascular System – figure 26

The water vascular system is unique to echinoderms. It functions in respiration, sensory perception, locomotion, and feeding. It may also serve some excretory function. This system consists of a series of water-filled channels that are pressurized. Water enters through the **madreporite plate**, which contains multiple sieve-like pores. It is located on the aboral side of the starfish. The madreporite plate functions as the hydraulic regulator of pressure for the rest of the water vascular system. The fluid that moves through this system is composed of sea water, soluble proteins, and potassium ions. From the madreporite plate the fluid moves through the short **stone canal** and into a circular **ring canal**, located in the central disc of the starfish body. Attached to the ring canal are the **Polian vesicles** and **Tiedmann's bodies**. The Polian vesicles act as pressure regulators and reservoirs. The Tiedmann's bodies produce the **amoebocytes** that move through the circulatory fluid within the coelom. Extending out from the ring canal into each arm are five **radial canals**. Each radial canal runs along the **ambulacral ridge**. Numerous **lateral canals** connect the radial canal with the balloon-like **ampullae**, which are attached to the **tube feet** on the external surface. Each lateral canal contains a regulatory valve that controls hydraulic pressure in each tube foot. The ampullae are balloon-shaped structures that act as water pressure ballasts that extend or contract the tube feet. The ampullae contain circular muscles and the tube feet contain longitudinal muscles. When an individual ampulla contracts, the existing hydraulic pressure forces the tube feet to elongate. Each tube foot consists of a **podium** and a **sucker**, located at the tip. The podium consists of the body of the tube foot. Attached on the interior end of the podium is the ampulla. The sucker is used to grasp prey and to adhere to rocks and coral. Think of the tube foot and ampulla as a tube-shaped water balloon. On one end is the ampulla, in the middle is the podium, and on the end is the sucker. When you squeeze the ampulla end, the middle podium stretches out and gets bigger.

figure 27 - Embryonic development and larval metamorphosis



Reproduction and Embryonic Development - figure 27

Echinoderms are often used as model organisms for deuterostome embryology. For this reason, embryology is included as part of this guide.

Like many aquatic animals, fertilization for the starfish occurs **externally**. Males and females in close proximity release their **sperm** and **eggs** into the surrounding water. There are usually several males congregating around each female. During the breeding season, the gonads for both genders will become enlarged. In the water, once the sperm has fertilized the egg, cell division can begin. In **deuterostome development**, the cell undergoes **radial cleavage** (it divides at right angles). The cell divides progresses from the **2 cell stage**, to the **4 cell stage**, on to the **64 cell stage**. As the cells begin to organize, the forming zygote enters the **blastula stage**. As its shape changes and invagination occurs, the **gastrula stage** begins. Typical for deuterostomes, the **blastopore** forms the future anus and the **archenteron** forms the future gut.

Groups of cells continue to divide and specialize into the various tissues and organs that will make up the future larva. Like many other echinoderms, the starfish goes through more than one larval stage. The first larval stage is that of the free-swimming **bipinnaria larva**, which has a transparent body lined with cilia. These cilia are used for feeding and locomotion. The larval stages of the starfish are microscopic zooplankton that feed many other marine organisms. A starfish lays many eggs to compensate for this level of predation.

The other larval stage is that of the **brachiolaria larva**, which has multiple ciliated arms. Eventually, the brachiolaria larva's arms degenerate, new arms and adhesive suckers are grown, and the larva settles on the bottom of the ocean. Both larval stages have bodies with **bilateral symmetry**. Once the brachiolaria larva has settled, it undergoes the **metamorphosis** into the adult starfish body. This change from a bilateral body form into one that has **radial symmetry** is remarkable. The body is reorganized in a dramatic way. The larval mouth and anus completely disappear. The left side of what was once the brachiolaria larva is transformed into the oral surface of the starfish and a new mouth is grown. The right side of the larva is transformed into the aboral surface, complete with a new anus. Juvenile starfish lack the long arms of the adult. Rather, they have small bodies with stubby podia for arms. As they mature, the body grows larger and the arms elongate.

Symmetry terms

Radial symmetry – A type of symmetry in which the body can be divided into more than two halves by multiple planes through a center longitudinal axis.
Aboral – Refers to the side of an animal with a body type of radial symmetry that does not contain the mouth.
Oral – Refers to the side of an animal with a body type of radial symmetry that contains the mouth.

Bilateral symmetry – A type of symmetry in which the body can be divided into an equal mirror image, called the sagittal plane.
Sagittal plane – Refers to the plane which splits a bilateral animal into two mirror images.

General Anatomical terms:

Anterior – Refers to the head region in bilateral animals.
Cranial – Refers to the head region in many bilateral animals, especially in quadrupeds.

Posterior – Refers to the tail region in bilateral animals.
Caudal – Refers to the tail region in many bilateral animals, especially in quadrupeds.

Dorsal – Refers to the upper surface in bilateral animals.
Superior – Refers to the upper surface in many bilateral animals, especially in quadrupeds.

Ventral – Refers to the under surface in bilateral animals.
Inferior – Refers to the under surface in many bilateral animals, especially in quadrupeds.

Lateral – Refers to the side.
Medial – Refers to the midline.

Proximal – Refers to the attached end of a structure.
Distal – Refers to the free end of a structure.

Key terms

The definitions of the following terms are basic and only described as they pertain to the information in this guide. For further explanations, refer to a biology dictionary or textbook.

Amoebocyte – A term that refers to a cell that resembles an amoeba that floats within the fluids and tissues of an animal. Generally, these cells are capable of phagocytosis and can perform different functions.
Archenteron – A cavity formed from the invagination of the gastrula that forms into the future gut of the animal.
Autotomy – The ability to self-amputate a limb or appendage at will. Usually this strategy is employed when the appendage is trapped or the animal is faced with a predator. In the case of the starfish, the lost arm can later be regenerated.
Benthic – Refers to animals that live on the sea bed or on structures on the sea bed (corals, etc.).
Blastopore – In embryology, the opening to the future gut of the embryo in the gastrula stage.
Blastula – The stage in embryology following cell cleavage in which the cells have arranged themselves to form a fluid filled ball.
Cambrian – Refers to a geologic period. The Cambrian Period is the first of six periods in the Paleozoic Era, dating 600-500 million years ago.
Carnivore – An animal that obtains its nutrients by eating other animals.
Cecum – (*cecum=singular; ceca=plural*) A general term that is used to describe a blind pouch within the digestive system. The starfish has two types of ceca in its body: the pyloric ceca and the digestive ceca.
Coelom – A fluid-filled body cavity that is completely lined with tissue of mesoderm origin. Only animals that are triploblastic have a true coelom.
Complete digestive system – A system of digestion in which food moves through the animal through an entryway (usually the mouth) and an exit-way (usually the anus).
Decentralized nervous system – A type of nervous system in which there is a dispersed network of nerves throughout the body. This is in contrast to the centralized nervous system that humans possess, in which the majority of nervous tissue is centralized in one particular region (i.e.: the brain).
Deuterostome development – In embryological development, the blastopore develops into the anus; exhibits radial and indeterminate cleavage.
Dioecious – Having male and female reproductive organs and related structures on separate male and female individuals. This is in contrast to animals that are monoecious, in which the male and female reproductive organs are on the same individual.
Extant – Term referring to a living group of animals. It is the opposite of extinct, which refers to animals no longer currently living.
Ganglion *(ganglion=singular; ganglia=plural)* – A bundle of nerve cell bodies and the centers for the coordination of nerve impulses in animals.
Gastrula – The stage in embryology following the blastula stage in which the embryo consists of three separate germ layers (endoderm, mesoderm, and ectoderm). The beginnings of some future structures can be seen at this time, such as the future gut shown as a cavity called the archenteron that contains a single opening, the blastopore. The blastopore in deuterostomes forms into the future anus. At this stage, developmental pathways are solidified and cells begin to specialize.

Germ layers – The embryonic germ layers consist of three major types of tissue: the endoderm, the mesoderm, and the ectoderm. From these three germ layers arise all the various tissues and organs in the body.
Gonad – An animal's reproductive organ. It can refer to structures on either male or female animals.
Marine – Restricted to living in salt water.
Insoluble – Not able to dissolve in water.
Metamorphosis – A life stage that occurs between the larval stage and the adult stage. In echinoderms, metamorphosis involves a drastic change in body type: from the bilateral larval stages to the radial adult.
Ocellus – (*ocellus=singular; ocelli=plural*) An eye-like photoreceptor that is light sensitive but does not form images. On the starfish, there is an ocellus on the tip of each arm.
Organ system level of organization – An arrangement of structures in which the cells are gathered into tissues, which are then gathered into organs to function in specific ways.
Peristome – A term used to describe a mouth-like opening. In the starfish, it refers to the fleshy area around the mouth.
Peritoneum – The membrane lining the interior of the body.
Phagocytosis – The process by which a cell engulfs solid particles.
Podium – (*podium=singular; podia=plural*) In starfish, refers to the body of the tube foot.
Secondary radial symmetry – Type of body symmetry defined by having a life cycle in which the larval stages have a body with bilateral symmetry, but the adult stage has a body with radial symmetry. Taxonomists use the larval symmetry when grouping animals together; thus the starfish is included in the informal group of *Bilateria*, which groups together all animals that have a body with bilateral symmetry.
Sexual dimorphism – Showing visible differences between males and females.
Soluble – Able to dissolve in water.
Triploblastic development – Forming three germ layers: endoderm, mesoderm, and ectoderm. Various tissue types can arise from these three germ layers.
Zooplankton – A general term used for a group of animal-like microscopic organisms which include protists, small crustaceans, insect larvae, and other aquatic larvae.