# Section 2: Body Plan and Anatomy

**Symmetry and Structure**

Echinoderms exhibit **pentaradial symmetry** as adults, a hallmark of their body plan. While their larvae display bilateral symmetry, a transformation occurs during metamorphosis, resulting in the radial organization. This symmetry is most apparent in sea stars and brittle stars, where five arms radiate from a central disc. In other groups, such as sea cucumbers and sea urchins, the symmetry is less obvious externally but is evident internally through the arrangement of their body parts, including tube feet, ambulacral grooves, and skeletal plates. Pentaradial symmetry enhances their interaction with the environment, allowing them to feed, move, and sense stimuli in all directions.

**Water Vascular System**

The **water vascular system**, unique to echinoderms, is a complex hydraulic network critical for locomotion, feeding, gas exchange, and sensory perception. Water is drawn into the system through the **madreporite**, a sieve-like structure on the surface that filters particles and regulates pressure. From the madreporite, water travels down the **stone canal**, which connects to the **ring canal** encircling the central body. From there, water is distributed to the **radial canals**, which extend into the arms (or rows in sea cucumbers). The radial canals branch into smaller **lateral canals** that lead to the **ampullae** and **tube feet**, the system's functional units.

* **Ampullae and Tube Feet Mechanics**  
   The ampullae are bulb-like structures connected to the tube feet. Each ampulla contains muscles that contract to push water into the corresponding tube foot, causing it to extend. Tube feet themselves have longitudinal muscles that control movement, allowing precise directional adjustments. This hydraulic and muscular interaction enables the tube feet to act like **water balloons**, becoming rigid when filled with fluid, and pliable when relaxed. Echinoderms use this mechanism for walking, climbing, burrowing, and even capturing prey.
* **Polian Vesicles**  
   Polian vesicles are specialized sacs within the water vascular system that act as reservoirs, maintaining pressure and compensating for volume changes. These structures ensure that the system remains functional even during prolonged activity or minor damage.

**Functions of the Water Vascular System**  
 The hydraulic precision of the water vascular system allows echinoderms to grip surfaces, manipulate objects, and move with remarkable control. In sea stars, tube feet enable locomotion across uneven terrain, while in sea urchins, they help stabilize the body in wave-swept zones. This system also aids in respiration and sensory perception, as tube feet often contain chemosensory and mechanosensory cells.

### Species Profile: Sea Cucumber (Enypniastes eximia)

Commonly known as the "Headless Chicken Monster" due to its appearance, Enypniastes eximia exhibits a unique adaptation within the water vascular system. This deep-sea sea cucumber has developed enlarged, wing-like structures derived from its tube feet, enabling it to swim above the ocean floor. This capability allows it to evade predators and relocate to areas with abundant detritus for feeding. Its transparent body reveals internal organs, and it can secrete bioluminescent mucus when threatened, deterring potential predators. Enypniastes eximia inhabits abyssal plains worldwide, typically at depths exceeding 4,000 meters.

**Mutable Collagenous Tissue (MCT)**

Echinoderms possess **mutable collagenous tissue**, a unique adaptation that allows them to rapidly alter the stiffness of their connective tissues. This remarkable capability is under neural control, enabling the animal to transition between soft, flexible states and rigid, immovable ones almost instantly.

**Examples of MCT in Action**

1. **Anchoring Against Predation**:  
    A sea star moving across rocks can keep its tissues pliable to maximize flexibility and efficiency. However, if a predator attempts to pry it off the substrate, the sea star can instantly stiffen its tissues, making its grip almost unbreakable. This anchoring prevents predators from easily removing it without causing serious damage to both predator and prey. Attempting to forcibly detach a sea star in this state can harm the animal, as the rigid tissue can fracture or tear.
2. **Energy-Efficient Feeding**:  
    When feeding on bivalves, sea stars use their tube feet to apply steady force to pull the shells apart. Clams have powerful adductor muscles that can resist this force, but sea stars employ MCT to maintain the pulling pressure without expending continuous muscular energy. Once the sea star’s arms stiffen, it can hold the shell in a strained position indefinitely until the clam’s muscles fatigue and the shell opens. This strategy allows sea stars to outlast prey with significantly greater muscle strength.

* **Ecological and Functional Significance**  
   MCT allows echinoderms to conserve energy while adapting to environmental pressures. This tissue also facilitates autotomy, the voluntary shedding of body parts (e.g., arms in brittle stars), by softening specific regions for easy detachment. Such adaptations have allowed echinoderms to thrive in diverse marine environments, from turbulent intertidal zones to the calm depths of the ocean floor.

These combined adaptations of the water vascular system and MCT illustrate the extraordinary versatility and efficiency of echinoderm physiology, highlighting their evolutionary success as marine invertebrates.

**Feeding Mechanisms**

**Asteroidea (Sea Stars)**

Sea stars have a remarkable feeding strategy, utilizing their two stomachs—the cardiac and pyloric stomachs—located centrally on the underside of their bodies. The **cardiac stomach** can be everted, protruding through the mouth to externally digest prey, such as bivalves, by secreting digestive enzymes. This allows sea stars to consume prey larger than their mouth openings. In some cases, they pull food into their stomachs for internal digestion, completing the process within the **pyloric stomach**. This dual-stomach arrangement enables them to exploit a wide range of prey. Their ability to pry open bivalve shells, combined with the use of their tube feet to anchor and manipulate prey, highlights their predatory efficiency.

### Species Profile: Harlequin Sea Star (Hymenicera picta)

The Harlequin Sea Star, also known as the Harlequin Starfish, is renowned for its specialized feeding behavior. Unlike many sea stars that evert their stomachs to digest prey externally, the Harlequin Sea Star feeds exclusively on coral polyps. It uses its tube feet to pry open the coral's calcareous exoskeleton and inserts its stomach into the cavity to consume the soft tissues. This method allows it to exploit a specific niche within coral reef ecosystems. Its vibrant coloration serves as camouflage among the corals, aiding in both predation and protection from potential predators.

**Echinoidea (Sea Urchins and Sand Dollars)**

Sea urchins are grazers that scrape algae and biofilms from rocky substrates using the **Aristotle’s lantern**, one of the most intricate feeding structures in the animal kingdom. This apparatus comprises five calcareous teeth, arranged in a pentaradial symmetry, housed within a complex skeletal and muscular framework. Each tooth is self-sharpening and can grow continuously, compensating for wear from scraping surfaces.

The radial symmetry of the Aristotle’s lantern is not only a functional adaptation for feeding but also a striking anatomical feature that reinforces the echinoid body plan. Sea urchins use this system to excavate grooves into hard rock, often creating depressions where they embed themselves for stability and protection. These "urchin homes" can be seen on rocky reefs where large populations of urchins thrive. Sand dollars, in contrast, lack the robust scraping capabilities of sea urchins and instead feed by sifting sediment for organic particles, using cilia on their aboral surface to transport food to the mouth.

**Holothuroidea (Sea Cucumbers)**

Sea cucumbers are divided into **deposit feeders** and **suspension feeders**, each employing a distinct feeding strategy using mucus-covered tentacles surrounding their mouths. Deposit feeders ingest sediment in bulk, digesting the organic material and expelling cleaned sediment as waste, which enhances nutrient recycling in the substrate. Suspension feeders, on the other hand, extend their tentacles into the water column to trap plankton and organic debris. These tentacles are periodically retracted into the mouth for cleaning and ingestion, enabling them to feed efficiently in nutrient-rich currents.

**Ophiuroidea (Brittle Stars and Basket Stars)**

Brittle stars have a unique feeding strategy that sets them apart from sea stars. Instead of positioning their mouths over food, brittle stars use their flexible, slender arms to capture prey or gather organic particles. The food is then passed down the **ambulacral grooves** using tube feet and pedicellariae until it reaches the central mouth. This method allows brittle stars to feed on detritus, small prey, or plankton without requiring direct mouth contact with the substrate. Basket stars, with their intricately branched arms, employ a similar approach but specialize in suspension feeding, capturing plankton from water currents and using the entire arm to transport food to the mouth.

**Crinoidea (Feather Stars and Sea Lilies)**

Crinoids rely on suspension feeding, using their feather-like, mucus-covered arms to trap plankton and organic particles. Once food is captured, the entire arm is pulled inward, bringing the food to the central mouth located on the calyx. This feeding behavior is a key distinguishing feature of crinoids, setting them apart from brittle stars. By retracting their long arms for every feeding event, crinoids ensure the efficient transport of food while minimizing energy expenditure.

**Epidermis and Pedicellariae**

**Epidermis**

The epidermis of echinoderms is a living, multifunctional layer that encases their calcareous endoskeleton, including spines, pedicellariae, and other surface structures. This layer is composed of glandular cells, sensory cells, and a protective cuticle, playing roles in defense, respiration, and interaction with the environment.

* **Spines**:  
   Spines are prominent extensions of the endoskeleton covered by the epidermis, giving echinoderms their characteristic texture and appearance. These spines are not fixed; they are **musculated**, meaning they can move to provide defense against predators, aid in anchoring to substrates, or assist in digging into sediment or rocks. For instance, in sea urchins, spines contribute to burrowing and the creation of "urchin homes" in rocky environments. The epidermis surrounding the spines maintains their hydration and prevents fouling, highlighting its protective role.
* **Papulae**:  
   Papulae (or dermal branchiae) are soft, finger-like projections of the body wall connected to the water vascular system. These structures increase the surface area for gas exchange and waste elimination, functioning as respiratory organs. Papulae are most prominent in sea stars, where they extend between ossicles, and their exposed position makes them vulnerable. However, they are often guarded by surrounding spines and pedicellariae, providing them with indirect protection.

**Pedicellariae**

Pedicellariae are small, specialized appendages unique to sea stars and sea urchins, varying in form and function. Found embedded within the epidermis and associated with spines, pedicellariae enhance the effectiveness of the echinoderm's external defenses.

1. **Defensive Pedicellariae**:  
    Some pedicellariae are stalked or extendable, allowing them to pinch or grab at predators or fouling organisms. These structures act as the first line of defense for echinoderms like sea stars, deterring potential threats with minimal effort.
2. **Toxic Pedicellariae**:  
    In sea urchins, certain pedicellariae contain venom sacs capable of delivering toxins to predators. These venomous pedicellariae can immobilize small attackers or provide a painful deterrent to larger predators.
3. **Cleaning Pedicellariae**:  
    Many pedicellariae are adapted for maintenance, removing debris, algae, and parasites from the body surface. This function is vital for preventing fouling and maintaining the health of the epidermis and underlying structures.

Pedicellariae exemplify the adaptability of echinoderms, working in concert with spines and papulae to support survival in diverse marine environments.

### Species Profile: Flower Sea Urchin (Toxopneustes pileolus)

The Flower Sea Urchin is both beautiful and dangerous. Its name derives from the numerous flower-like pedicellariae covering its body. These pedicellariae are highly toxic, capable of delivering venom that can cause severe pain, paralysis, and even be fatal to humans. The venom contains contractin A, a protein that induces muscle contraction, and peditoxin, a neurotoxin affecting nerve function. When threatened, the Flower Sea Urchin employs these venomous pedicellariae as a defense mechanism, deterring predators with their potent sting. This species inhabits shallow waters of the Indo-Pacific region, often concealed among coral reefs and rocky substrates.

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