TAXONOMY OF SEA CUCUMBERS

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Introduction

Sea cucumbers are popularly called holothurians, belong to the phylum Echinodermata, which is a distinct phylum in the animal kingdom and are significant members of benthic invertebrate communities occurring in all of the major oceans and seas of the world. Echinoderms possess radial symmetry (generally pentamerous), an intradermic skeleton consisting of closely fitted plates, articulated plates, or ossicles, and a peculiar water vascular system of fluid-filled tubes. The phylum is divided into five classes of very different appearance :

- The crinoids (or feather stars)
- Holothuroids (or sea cucumbers)
- Echinoids (or sea urchins)
- Asteroids (or sea stars)
- Ophiuroids (or brittle stars)

As a significant benthic invertebrate community, sea cucumbers have more critical effects on the physicochemical processes of soft-bottom and reef ecosystems. Commercially exploited sea cucumbers provide income to millions of coastal fishers worldwide and nutrition to Asian consumers (Purcell et al., 2013). The processed product from sea cucumber is called 'beche-de-mer' in French, 'iriko' in Japanese, 'haisom' in Chinese and 'trepang ' in Indonesian. It has a very high export value to Southeast Asian countries because of its higher protein and nutrients such as vitamins, amino acids, trace metals and minerals (Bordbar et al., 2011). Sea cucumbers are an integral part of traditional Chinese medicine, in addition to that recent research indicated their essential source of several bioactive compounds of anti-angiogenic, anticancer, anticoagulant, anti-hypertension, anti-inflammatory, antimicrobial, antioxidant, antithrombotic, antitumor and wound healing properties. Sea cucumbers have a more significant role in ecosystem functioning by contributing to sediment health via bioturbation, recycling of nutrients, and influencing seawater chemistry. Sea cucumbers host many parasitic and commensal symbionts from several phyla, thereby enhancing ecosystem biodiversity. Many taxa prey on them, thereby transferring animal tissue and nutrients (derived from detritus and microalgae) to higher trophic levels forming energy transfer pathways in food chains, etc (Purcell et al, 2016).

Morphology of sea cucumbers

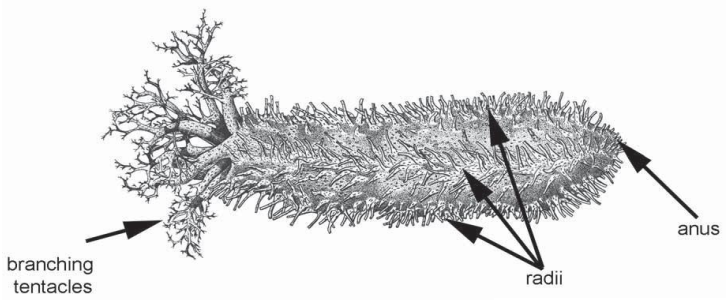

Fig1. A holothurian (adapted from Pawson, et al., 2010)

Holothurians have an orally-aborally elongated body (Fig.1) formed like a short or long cylinder, with the mouth at the anterior end encircled by tentacles and the anus at the posterior end often edged by papillae. Holothurians usually lay on the substrate with their ventral surface or trivium, formed by the radii. This creeping sole bears the locomotory podia, while on the dorsal surface, or bivium, the podia are often represented by sensory papillae (Conand, 1998). The mouth is terminal or displaced dorsally, surrounded by a thin buccal membrane, and generally bordered by a circle of tentacles (Fig. 1). Tentacles are buccal podia containing extensions from the water vascular system serve various functions related to feeding, sensory perception, and manipulation of food particles. The types of oral tentacles found in sea cucumbers can vary depending on the species and ecological adaptations.

Tentacles are significant in identifying sea cucumbers due to their diverse morphology, arrangement, and specialized functions. The morphology of tentacles can vary widely among different species of sea cucumbers. Characteristics such as tentacles' shape, size, length, and surface texture can be diagnostic features used to differentiate between species. The number and arrangement of tentacles around the mouth are often species-specific traits. Some sea cucumbers have a single ring of tentacles, while others may have multiple rows or clusters. Oral tentacles' presence, absence, or arrangement can aid species identification.

Types of tentacles

i. Peltate tentacles: Peltate tentacles are characterized by a broad, flattened disc-shaped structure at the distal end, resembling a small paddle or leaf (Fig.2). These tentacles are often found in species that are specialized filter feeders, as the broad surface area aids in capturing suspended food particles from the water column.

ii. Digitate tentacles**:** Digitate tentacles are slender and elongated, resembling fingers or digits. They may have a tapered or rounded tip. These tentacles are versatile and can be used for feeding and sensory perception. They are commonly found in generalist feeders that consume various food types.

iii.. Papillate tentacles**:** Papillate tentacles are covered with small, finger-like projections or papillae along their surface. These tentacles are often associated with species that feed on organic detritus or fine particulate matter. The papillae increase the surface area for efficient absorption of nutrients.

iv. Fusiform tentacles**:** Fusiform tentacles are cylindrical or spindle-shaped, with a uniform diameter along their length. They may be found in species that feed by selective deposit feeding, targeting specific types of organic matter or microorganisms in sediments.

v. Branched tentacles**:** Some sea cucumbers have oral tentacles that are branched or subdivided into smaller segments, resembling a tree-like structure (Fig.2). Branched tentacles may increase the surface area available for feeding or sensory perception, allowing sea cucumbers to efficiently capture food particles or detect chemical cues in the environment.

vi. Tentacular bulb: In certain sea cucumber species, particularly those in the family Synaptidae, the oral tentacles may be modified into a bulbous structure called a tentacular bulb. The tentacular bulb is used for burrowing into sediments and capturing prey buried within the substrate. It may also aid in respiration and gas exchange in some species.

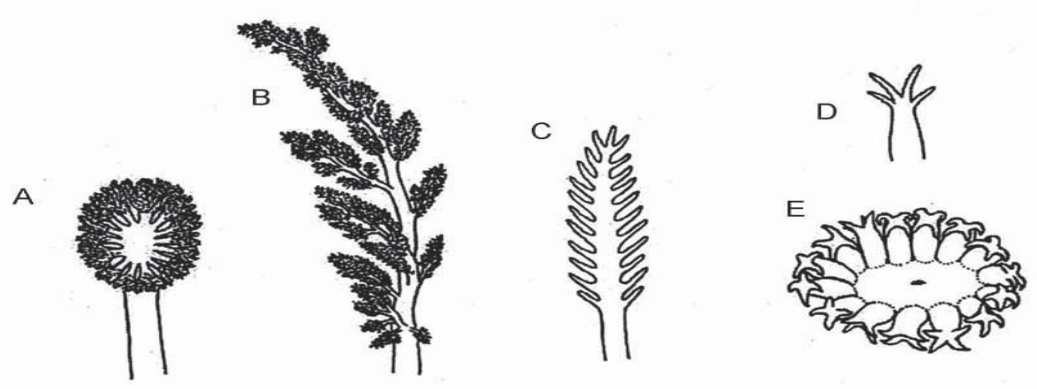

Fig.2. Hoolothurian tentacles. A, shield-shaped (Order Aspidochirotida); B, branching (O. Dendrochirotida); C, pinnate (O. Apodida); D, digitate (O. Apodida, O. Molpadiida); E, digitate (O. Molpadiida) (adapted from Pawson, et al., 2010).

Calcareous rings

The calcareous rings are skeletal structures found within the body wall of sea cucumbers, serving as a support framework for the internal organs and muscles. These rings comprise calcareous ossicles, small calcareous plates or pieces arranged in a circular or ring-like fashion around the oesophagus, forming a rigid structure. Calcareous rings play vital roles in the taxonomy and classification of sea cucumbers. They provide valuable insights into their taxonomy, phylogeny, species diversity, and functional ecology. By examining the morphology and characteristics of calcareous rings, researchers can enhance our understanding of these fascinating marine organisms' evolutionary history and ecological diversity.

The morphology and arrangement of calcareous rings are highly variable among different species of sea cucumbers. Taxonomists use the characteristics of

calcareous rings, such as the number, shape, size, and arrangement of ossicles, as diagnostic features for species identification and classification.

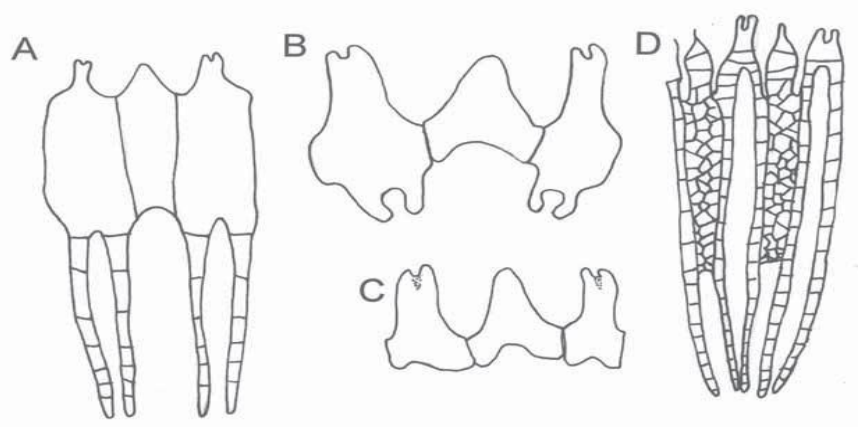

Fig.3. Calcareous rings; A, B, C with two radial pieces and one interradial piece, D with two interradial pieces and two notched radial pieces. A, ring with medium posterior projections; B, ring with short posterior projections; C, ring with no posterior projections; D, tubular ring with long, complex, posterior projections (adapted from Hyman, 1955).

Body wall and Spicules

The body wall is a thick layer of collagenous connective tissue dermis with a thin epidermis outside the dermis. The sea cucumber skeleton lies in the dermis, taking the form of vast microscopic ossicles called spicules. They display a profusion of beautiful geometric shapes that vary with species and age and are essential in taxonomy (Slater and Chen, 2015).

Spicules are composed primarily of calcium carbonate, which provides structural support and reinforcement to the soft tissues of these organisms. The exact composition of spicules may vary, with some sea cucumbers incorporating magnesium or other trace elements into their skeletal structures. Spicules may vary in shape, size, and surface ornamentation, ranging from simple rod-like structures to elaborate forms with branching or ornamented surfaces. Common types of spicules found in sea cucumbers include:

1. Table Spicules: Table spicules are flat, disc-shaped structures with a central perforation. These spicules support the body wall and contribute to the overall rigidity of the sea cucumber's skeleton.
2. Anchor Spicules: Anchor spicules are elongated structures with one or more pointed ends resembling miniature anchors. These spicules anchor the body wall to surrounding tissues and substrates, enhancing stability and preventing collapse.
3. Wheel Spicules: Wheel spicules are wheel-shaped structures with radiating spokes or arms. These spicules are thought to play a role in reinforcing specific regions of the body wall and may contribute to locomotion and burrowing behaviour in some species.

4. Cylinder Spicules: Cylinder spicules are elongated, cylindrical structures with smooth or ornamented surfaces. These spicules provide structural support and flexibility to the body wall, allowing sea cucumbers to withstand mechanical stresses and deformations.

Spicules serve multiple ecological functions in sea cucumbers. They can act as physical deterrents against predators by making the body wall of sea cucumbers more rigid and resistant to deformation or compression, and also help sea cucumbers to burrow into sediments.

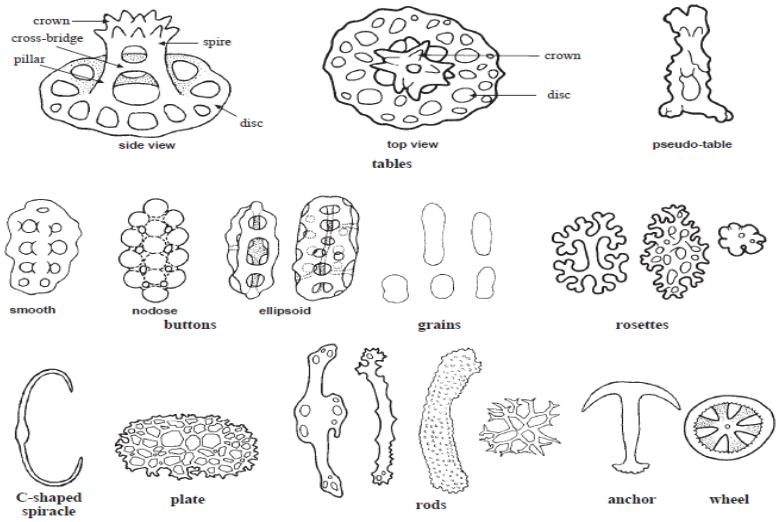

Fig.4. Basic types of spicules (adapted from Conand,1998)

Species identification of sea cucumbers

The sea cucumber species can be identified through the examination of the skeletal elements (ossicles) found in various parts of the body, especially those embedded in the body wall, papillae, podia and tentacles of live, dried or preserved animals and can be isolated by the following method (adapted from Purcell et al, 2023).

1. Small pieces (e.g. a few square mm) of tissue removed from different body parts and can be placed into separate small labelled vials.
2. Add the required volume (e.g. 0.5 ml) of sodium hypochlorite (concentrated household bleach) or sodium hydroxide to each vial to dissolve the organic tissue. The soft tissue will be dissolved in 20–30 minutes, leaving the hard ossicles in the bottom of the vial.
3. The spicules settled can be separated after decanting, or pipetting, out the bleach and are washed five times in distilled water and carefully sucking the liquid out of the vial with a pipette. Rinse the pipette in fresh water each time to not contaminate a sample with the ossicles from another.
4. The isolated ossicles can then be rinsed in alcohol and placed onto a microscope slide with a drop of a mountant (e.g. Euparal medium) for microscopic observation (scanning electron microscope (SEM) stub.

Characteristics of orders under the class - Holothuroidea

There are five orders in the class Holothuroidea (Dendrochirotida, Aspidochirotida, Molpadiida, Apodida and Elasipoda). The description is given below (adapted from Pinn, 2013).

Order	Description
Dendrochirotida	There were 10-30 tentacles highly branched or shaped in the form of dendritic, occasionally digitate. Ten calcareous plates form a simple or complex posterior process calcareous ring. They are usually sedentary, attached or burrowing. Introvert and retractor muscles are present.
Aspidochirotida	Very large group with very diverse and abundant in shallow tropical habitats. Tentacles always in the shape of peltate. Respiratory trees present. Introvert and retractor muscles absent.
Elaspodida	Lack of respiratory tree in body cavity. Strongly bilaterally symmetrical with commonly complicated and elaborate projections like frills, veils and sails on their gelatinous body. Only found in deep sea at abyssal depths.
Apodida	One of the simplest forms of sea cucumber. It has a very long and worm-like cylindrical body. .Body wall without any tube feet, except for the tentacles, hence have soft smooth and soft body. Respiratory trees and anal papillae absent. Ossicles often include wheels, or anchors....
Molpadiida	Tentacles are digitate. Stouted fusiform body with some slightly curved body to some curved liken a ball with tapering to a more or less conspicuous tail. No tube feet are present in the body wall and are mostly find in soft muddy substrates. Respiratory trees present; anal papillae may be present. Ossicles not wheel-shaped

Key to the shallow-water families of Aspidochirotida (adapted from James and James 1994).

1a. Body with trivium (sole) usually flattened and dorsal bivium convex; gonads forming a single tuft appended to the left dorsal mesentery; Cuvierian organs present or absent; dominant spicules of form of tables, buttons (simple or modified), and rods (excluding C- and S-shaped rods) . . . . . **Holothuriidae.**

1b. Body square-shaped or trapezoidal in cross-section; Cuvierian organs always absent; gonads forming two tufts appended on each side of the dorsal mesentery; dominant spicules in form of branched rods and C-and S-shaped rods . . . . . **Stichopodidae**

Field keys to the commercially important genera of holothurians

1. Anal opening surrounded by five teeth-like structure *Actinopyga*

1'. Anal opening not surrounded by teeth-like structure ...2
2. Anal opening surrounded by five groups of papillae....***Bohadschia***
2'. Anal opening not surrounded by five groups of papillae 3
3. Body more or less quadrangular with distinct papillae....***Stichopus***
3'. Body not quadrangular, but tubular, sometimes loaf-shaped 4
4. Body massive up to 800 mm in length, dorsal papillae resembling leaf-like strucutre ***Thelenota***
4'.Body moderate in length up to 600 mm; papillae not expanded into leaf-like structures ***Holothuria***

Genus *Actinopyga* Bronn, 1861

Species belonging to this genus are either of medium value or low value.

Field key to the species of *actinopyga*

1. Colour completely black ***A. miliaris***
1'. Colour brown or brown and white
2. Colour brown on the upper side and white on the lower side; often found near low water mark ***A. mauritiana***
2'. Colour completely brown with often sand deposits on the upper side of body; mostly found in deeper waters ... ***A. echinites***

Genus *Bohadschia* Jaeger, 1833

Massive forms with distinct anal papillae, often buried or covered with a fine coat of mud. Because of the Cuvierian tubules (sticky threads) processing is difficult. Species belonging to this genus have moderate commercial value.

Field key to the species of *Bohadschia*

1. Colour black or brown with distinct 'eye' like spots all over the body ***B. argus***
1'. Colour variable, usually light brown with black spots ***B. marmorata***

Genus *Stichopus* Brandt, 1835

Some species belonging to this genus reach a massive length of 900 mm. Body will disintegrates and becomes gelatinous when taken out of water.

Field key to the species of *stichopus*

1. Body quadrangular with four rows of large finger-like processes. Colour dark green, appearing almost black in some shades of light ***S. chloronotus***
2. Body massive and loaf-like with irregular brown patches on yellow grey background ***S. variegatus***

Genus *Thelenota* Brandt, 1833

Very massive forms with numerous large pointed teats in groups of two or three all over the upper surface.

Genus *Holothuria* Linnaeus, 1764

This is by far the most important genus for processing. Over one hundred species are known under this genus.

Key to the species of *Holothuria*

1. Body like a loaf with very thick body wall. In the living condition about six pairs of lateral teat-like projections are seen; body with black and white patches ***Holothuria nobilis***

1'. Body tubular, body wall not very thick. No lateral projections in the living condition 2

2. Body completely black in colour; red colour comes off when live specimens are handled ***Holothuria atra***

2'.The colour not completely black and no red colour comes off when live specimens are handled 3

3. Yellow transverse bands on the upper side of the body, lower side white with a number of black dots ***Holothuria scabra***

3'. Body uniformly brown in colour; small stiff projections all over the body; highly burrowing form ***H. spinifera***

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