Unit 1: Introduction

1. Historical perspective and basic concepts: Phases of development, Cell-cell interaction, Pattern formation, Differentiation and growth, Differential gene expression
2. Cytoplasmic determinants and asymmetric cell division

Unit 2: Early Embryonic Development

1. Gametogenesis: Spermatogenesis, Oogenesis; Types of eggs, Egg membranes
2. Fertilization (External and Internal): Changes in gametes, Blocks to polyspermy; Planes and patterns of cleavage
3. Types of Blastula; Fate maps (including Techniques);
4. Early development of frog and chick up to gastrulation;
5. Embryonic induction and organizers

Unit 3: Late Embryonic Development

1. Fate of Germ Layers – Fate Map
2. Extra-embryonic membranes in birds and mammals
3. Implantation of embryo in humans, Placenta (Structure, types and functions of placenta)

Unit 4: Post Embryonic Development

1. Metamorphosis: Changes, hormonal regulations in amphibians and insects;
2. Regeneration: Modes of regeneration, epimorphosis, morphallaxis and compensatory regeneration (with one example each);
3. Ageing: Concepts and Theories

Unit 5: Implications of Developmental Biology

1. Teratogenesis: Teratogenic agents and their effects on embryonic development;
2. *In vitro* fertilization,
3. Stem cell (ESC), Amniocentesis

INTRODUCTION

CONCEPT OF DEVELOPMENTAL BIOLOGY

Dr. R. Prasad
Department of Zoology,
Eastern Karbi Anglong College,
Sarihajan

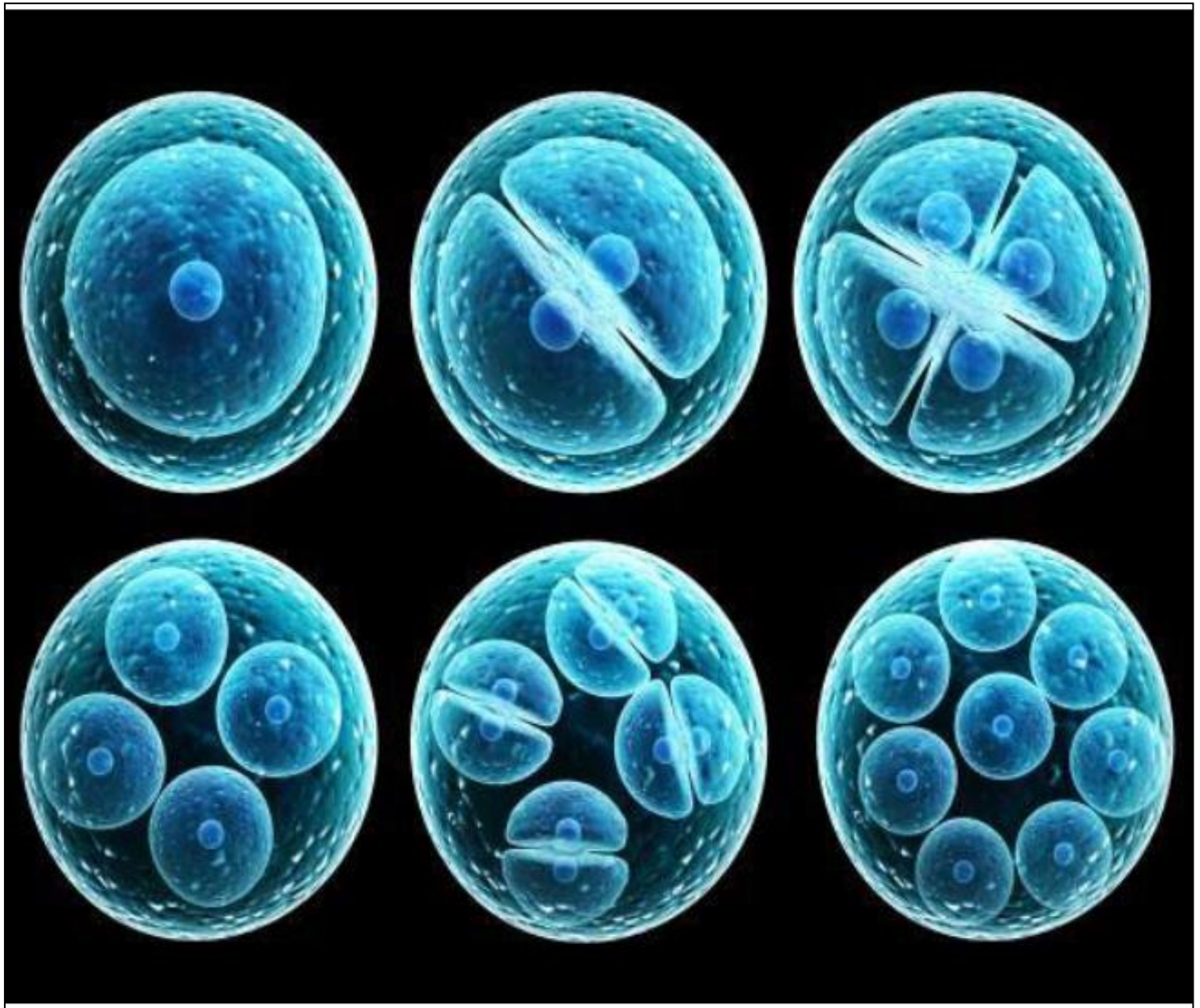

Fig. 1.1: Developmental stages

From the patterns in development, developmental biology evolved and became one of the old and young disciplines in biology; it originated in the 1950 and formally formed an independent discipline in the 1970.

A new discipline gradually was formed in the process of learning molecular embryology which also comprehensively strengthened and further developed this discipline

Since the 1980s, due to the development of disciplines such as genetics, cell biology, and molecular biology, a large number of new research methods were also applied, and developmental biology made great progress.

The research content of this subject includes the occurrence and formation of gametes, fertilization process, cell differentiation, and morphogenesis. It also includes how different cell groups in the development process are reconfigured and specialized.

The emergence of various cell types, the appearance of the final organ phenotypic characteristics, the establishment of special functions, the expression, control, and regulation of genes at different developmental stages, the causal relationship between genotype and phenotypic expression, the relationship between nucleus and cytoplasm during development, interrelationships between cells, and the effects of external factors on embryonic development were predominantly seen. Among them, cell differentiation became a core problem in the process of developmental biology.

HISTORY OF DEVELOPMENT

It originated in the 1950 and formally formed an independent discipline in the 1970. A new discipline gradually formed in the process of learning molecular embryology which is also a comprehensive and further developed discipline.

The multidisciplinary approach to the study of development first arose before the turn of the Twentieth Century as integration of embryology (initially the descriptive study of embryonic development) with cytology (the study of cellular structure and function) and later with genetics (the study of inheritance).

The leading cytologists of that time (primarily E.B. Wilson at Columbia University in New York City) recognized that the development of the embryo is a manifestation of changes in individual cells and that an understanding of the fundamental principles of development would come from studying cellular structure and function.

Wilson recognized that the characteristics of an organism gradually emerge by utilization of the inherited information that is located on the chromosomes. Therefore, it was important to comprehend the nature of that information and how it is utilized during development. However, in the absence of concrete evidence, there was a great deal of rampant speculation as to how the chromosomes participate in development. The German embryologist Wilhelm Roux was the source of much of this speculation.

Roux believed that the fertilized egg receives substances that represent different characteristics of the organism, which - as cell division occurs - become linearly aligned on the chromosomes and are subsequently distributed unequally to daughter cells.

This "qualitative division" fixes the fate of the cells and their descendants because some of the determinants are lost to a cell at each division.

Roux (1888) appeared to have confirmed his theories through an experiment he conducted on frog eggs.

Another German embryologist, Hans Driesch (1892), approached the problem differently with sea urchin embryos. Instead of destroying one of the cells of the two-celled embryo, he separated the cells from one another and found that isolated cells at the four-cell stage also develop normally. Thus, Driesch concluded that each cell retains all the developmental potential of the zygote.

The conflict between these two opposing views of development has been settled in favor of Driesch's interpretation by numerous cell separation experiments.

The Role of the Hereditary Material in Development

Although the equal distribution of hereditary information to all cells had been established in the late 1800s, its role in development remained an enigma. Two key contributions at the dawn of the Twentieth Century provided the impetus for additional progress:

• In 1900, the significance of Gregor Mendel's work on heredity was finally appreciated.

• The other contribution was made by Theodor Boveri, who in a paper published in 1902 demonstrated that normal development is dependent upon the normal combination of chromosomes. Each chromosome must have qualitatively unique effects on development.

Developmental biology is one of the important basic branches of biological sciences. The research content is infiltrated by many other disciplines, especially genetics, cell biology, and molecular biology.

It uses modern science and technology to study and analyze the processes and mechanisms of organisms from spermatogenesis and egg development, fertilization, growth, aging, and death from the molecular level, sub-microscopic level, and cellular level.

Although there are many species of animals, the development of embryos still has a similar pr ocess, which can be divided into stages of fertilization, cleavage, morula, blastocyst, gastrula, and organ formation.

In addition, during the embryonic development of vertebrates, the characteristics common to various animals will appear first (such as the skin), and then specialized structures (such as fish scales) will be developed.

In general, the ectoderm forms the epidermis and nerve tissue. The endoderm forms the intestinal epithelium and the digestive gland epithelium, which forms bone, muscle, blood, lymph, and other connective tissues. Others are derived from the mesoderm. But there are exceptions: the sphincter of the eye iridescence does not come from the mesoderm, nor from the mesenchyme, but from a part of the retina, that is, from the ectoderm.

The smooth muscle of the sweat gland is not from the mesoderm, but from the ectoderm; the mesenchyme itself is unclear, as it may come from the ectoderm or the mesoderm, or even from the endoderm. Research on developmental biology needs further advancement, which will help to understand the developmental mechanisms of organisms.

PRINCIPLE FEATURES AND PATTERNS OF DEVELOPMENT

Developmental biology is the study of the process by which animals and plants grow and develop. Developmental biology also encompasses the biology of regeneration, asexual reproduction, metamorphosis, and the growth and differentiation of stem cells in the adult organism.

Developmental biology includes the production of gametes, fertilization, and development of the embryo, emergence of the adult organism, senescence, and death. Developmental biologists in the department attempt to understand the molecular, genetic, cellular, and integrative aspects of building an organism.

The main processes involved in the embryonic development of animals are tissue patterning (via regional specification and patterned cell differentiation); tissue growth; and tissue morphogenesis.

The regional specification refers to the processes that create a spatial pattern in a ball or sheet of initially similar cells. This generally involves the action of cytoplasmic determinants, located within parts of the fertilized egg, and of inductive signals emitted from signaling centers in the embryo.

The early stages of the regional specification do not generate functional differentiated cells, but cell populations committed to developing to a specific region or part of the organism. These are defined by the expression of specific combinations of transcription factors.

Cell differentiation relates specifically to the formation of functional cell types such as nerve, muscle, secretory epithelia, etc. Differentiated cells contain large amounts of specific proteins associated with cell function.

Morphogenesis relates to the formation of three-dimensional shapes. It mainly involves the orchestrated movements of cell sheets and individual cells. Morphogenesis is important for creating the three germ layers of the early embryo (ectoderm, mesoderm, and endoderm) and for building up complex structures during organ development.

Tissue growth involves both an overall increase in tissue size, and also the differential growth of parts (allometry) which contributes to morphogenesis. Growth mostly occurs through cell proliferation but also through changes in cell size or the deposition of extracellular materials.

The development of plants involves similar processes to that of animals. However, plant cells are mostly immotile so morphogenesis is achieved by differential growth, without cell movements. Also, the inductive signals and the genes involved are different from those that control animal development.

1.4.1 COELOM

All animal has a cavity. Different animals use these cavities for different purposes. A vast fluid-filled area between the body wall and the internal organs is typically referred to as a body cavity. The alimentary canal is located between the body wall and the coelom, a perivisceral cavity. The coelom develops during embryonic development as a split in the mesoderm, which divides into two layers: a somatic layer that surrounds the endoderm and a splanchnic layer that lies close to the epidermis.

The coelomic epithelium, which secretes coelomic fluid, surrounds the coelom. On one end, the excretory organs open into the coelom, and on the other, they open to the outside. Coelomoducts, which transport sperms or eggs from the coelom to the outside, are produced by the coelom wall, which also gives rise to reproductive cells. The per visceral cavity, also known as the splanchnocoel, is formed by the majority of the coelom and houses the visceral organs. The gonocoel and nephrocoel, whose coelomic character can only be appreciated if their developmental histories are followed, are examples of confined cavities that are formed when specific areas of the perivisceral cavity are cut off from it. The first animals with a real coelom are annelids.

Coeloms evolved from acoelomates, then pseudocoelomates, and finally coelomates. The absence or presence of peritoneum or epithelial lining distinguishes a pseudocoelomate from a coelomate animal. It exists in coelomate animals but not in pseudocoelomate ones. A real coelom might have different embryological origins. It is referred to as schizocoelous if it arises from a split in mesoderm cells. It is referred to as enterocoelous if it arises from out pocketing from the embryonic gut.

According to the mode of coelom formation, there are generally two types of animals:

(A) Schizocoelomate: When coelom arises by the splitting of mesodermal bands or masses during embryonic development, it is called schizocoel, and animals are called schizocoelomates (Fig. 1.2). The animals belonging to the phylum Mollusca, Annelida, Arthropoda, and Onychophora are schizocoelomates.

(B) Enterocoelomate: When coelom is formed by the evagination from the embryonic archenteron and the pouch-like structures are detached from the archenteron and gradually occupy the whole body by enlargement, called enterocoel (Fig. 1.2). The animals having enterocoel are called enterocoelomate. The animals belonging to phylum Echinochordata, Hemichordata, and Chordata are enterocoelomates.

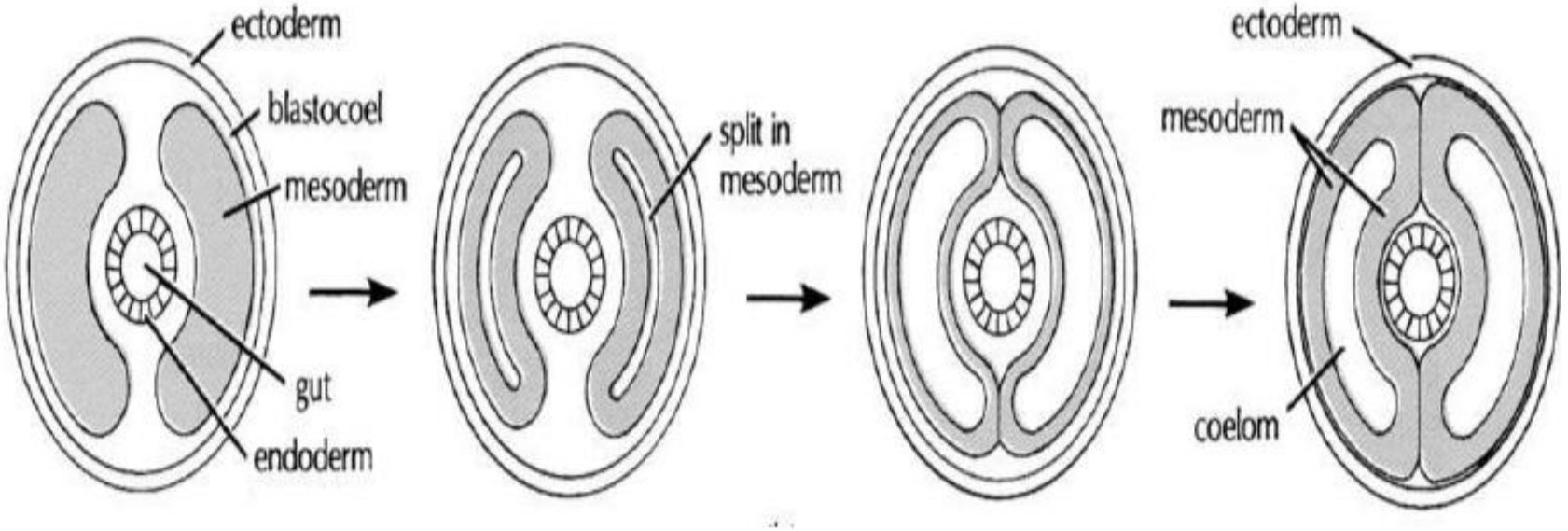

Fig.1.2 Coelomformation by the splitting of mesoderm

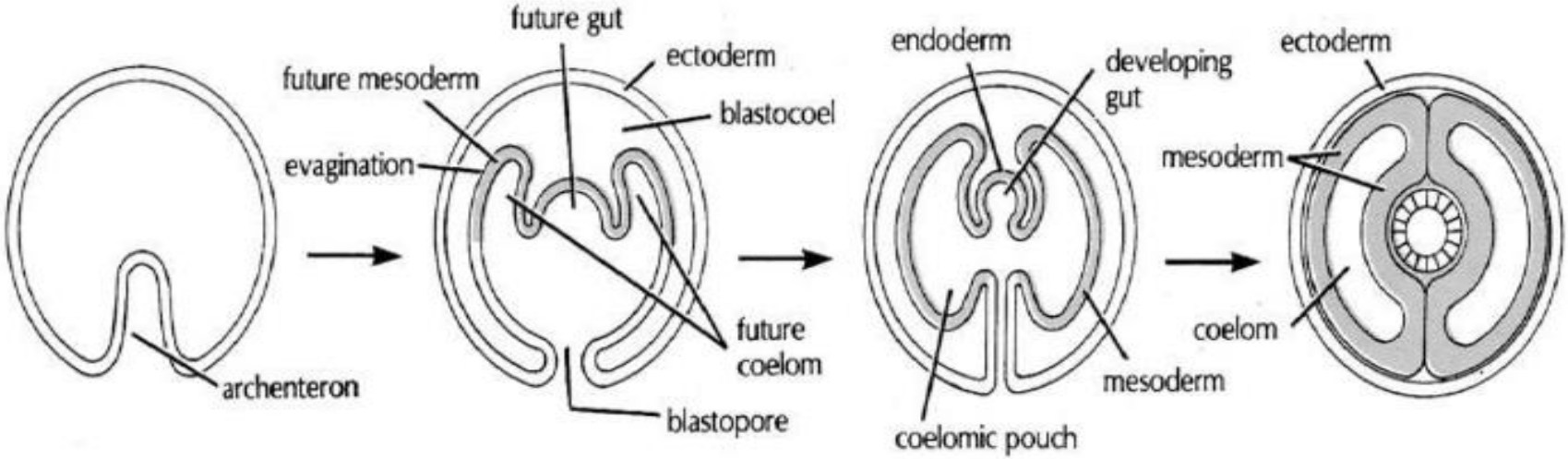

Fig 1.3 Coelom formation by out pocketing of the primitive gut

1.4.2 SEGMENTATION

Segmentation is a difficult process to satisfactorily define. Many taxa (for example the mollusks) have some form of serial repetition in their units but are not conventionally thought of as segmented. Segmented animals are those considered to have organs that were repeated, or to have a body composed of self-similar units, but usually, it is the parts of an organism that are referred to as being segmented.

Segmentation in animals typically falls into three types, characteristic of different arthropods, vertebrates, and annelids. Arthropods such as the fruit fly form segments from a field of equivalent cells based on transcription factor gradients. Vertebrates like the zebra fish use oscillating gene expression to define segments known as somites. Annelids such as the leech use smaller blast cells budded off from large teloblast cells to define segments.

1.4.3 SOMITES

The somites (outdated term: primitive segments) are a set of bilaterally paired blocks of paraxial mesoderm that form in the embryonic stage of somitogenesis, along the head-to-tail axis in segmented animals. In vertebrates, somites subdivide into the sclerotomes, myotomes, syndetomes, and dermatomes that give rise to the vertebrae of the vertebral column, rib cage, part of the occipital bone, skeletal muscle, cartilage, tendons, and skin (of the back).

The word *somite* is sometimes also used in place of the word *metamere*. In this definition, the somite is a homologously-paired structure in an animal body plan, such as is visible in annelids and arthropods.

The mesoderm forms at the same time as the other two germ layers, the ectoderm and endoderm. The mesoderm at either side of the neural tube is called the paraxial mesoderm. It is distinct from the mesoderm underneath the neural tube which is called the chordamesoderm that becomes the notochord. The paraxial mesoderm is initially called the "segmental plate" in the chick embryo or the "unregimented mesoderm" in other vertebrates. As the primitive streak regresses and neural folds gather (to eventually become the neural tube), the paraxial mesoderm separates into blocks called somites.

Formation: The pre-somitic mesoderm commits to the somitic fate before the mesoderm becomes capable of forming somites. The cells within each somite are specified based on their location within the somite. Additionally, they retain the ability to become any kind of somite-derived structure until relatively late in the process of somitogenesis.

The development of the somites depends on a clock mechanism as described by the clock and wavefront model. In one description of the model, oscillating Notch and Wnt signals provide the clock. The wave is a gradient of the FGF protein that is rostral to caudal (nose to tail gradient). Somites form one after the other down the length of the embryo from the head to the tail, with each new somite forming on the caudal (tail) side of the previous one.

The timing of the interval is not universal. Different species have different interval timing. In the chick, embryo somites are formed every 90 minutes. In the mouse, the interval is 2 hours.

For some species, the number of somites may be used to determine the stage of embryonic development more reliably than the number of hours post-fertilization because the rate of development can be affected by temperature or other environmental factors. The somites appear on both sides of the neural tube simultaneously. Experimental manipulation of the developing somites will not alter the rostral/caudal orientation of the somites, as the cell fates have been determined before somitogenesis. Somite formation can be induced by *Noggin*-secreting cells. The number of somites is species-dependent and independent of embryo size (for example, if modified via surgery or genetic engineering). Chicken embryos have 50 somites; mice have 65, while snakes have 500.

As cells within the paraxial mesoderm begin to come together, they are termed somitomeres, indicating a lack of complete separation between segments. The outer cells undergo a mesenchymal-epithelial transition to form an epithelium around each somite. The inner cells remain as mesenchyme.

1.4.4 DIPLOBLAST

Diploblasty is a condition of the blastula in which there are two primary germ layers: the ectoderm and endoderm. Diploblastic organisms are organisms that develop from such a blastula and include cnidaria and ctenophore, formerly grouped in the phylum Coelenterate, but later understanding of their differences resulted in their being placed in separate phyla. The endoderm allows them to develop true tissue. This includes tissue associated with the gut and associated glands. The ectoderm, on the other hand, gives rise to the epidermis, the nervous tissue, and if present, nephridia.

Simpler animals, such as sea sponges, have one germ layer and lack true tissue organization.

All the more complex animals (from flatworms to humans) are triploblastic with three germ layers (a mesoderm as well as ectoderm and endoderm). The mesoderm allows them to develop true organs. Groups of diploblastic animals alive today include jellyfish, corals, sea anemones, and comb jellies.

Features of the diploblastic animal

a) They consist of jelly-like noncellular mesenchyma or coagulated mesoglea in the middle among ectoderm and endoderm.
b) They show radial symmetry, biradial, or rotational symmetry.
c) A lesser degree of specialization.

d) No proper transport system.

e) Absence of coelom.

f) Sac-like digestive system and gastrovascular cavity.

g) Diploblastic creatures might have cell types that serve different capabilities, for example, epitheliomuscular cells, which act as a covering as well as contractile cells.

h) The endoderm of diploblastic animals has true tissues and intestines. A non-living layer named mesoglea is present between the ectoderm and endoderm.

i) Mesoglea helps in protecting the gut lining and body.

j) These animals do not develop organs.

Examples: Phylum Porifera and Cnidaria.

1.4.5 PROTOSTOMES AND DEUTEROSTOMES

The creation of the mouth first or the anus can be used to separate the bilateral metazoans into two major assemblages. Protostomes are metazoans in which the animal's anus and mouth are formed largely by the blastopore, and Deutrostomes in which the animal's anus and mouth are formed mostly by the blastopore. The next subsections will provide your study material on these two groupings.

Protostomia: The metazoans in which the mouth is derived from blastopore on the anterior end and anus that appears later to complete the alimentary canal are included in Protostomia. As the mouth forms first, their animals are included in the 'Protostomia" (Mouth first) division of the animal kingdom. The nerve cord is ventral in protostomes.

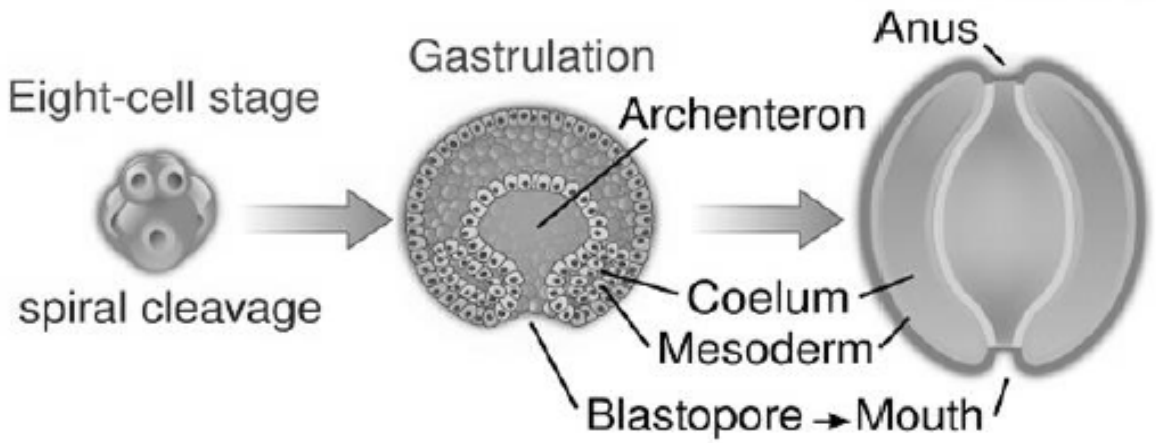

Fig. 1.4 Diagram showing the development of mouth from the blastopore

The developmental characteristics of protostomes are as follows.

1. **The pattern of embryonic cleavage:** Cleavage is spiral in protostomes, i.e., the axis of the cleavage plane is oblique, so blastomeres have a spiral arrangement in which one tier of cells alternates with the next tier of cells. The spiral cleavage is masked at the 6th cleavage 64-cell stage.
2. **The fate of embryonic blastomeres:** The fate of blastomeres is determined very early during holoblastic cleavage. This is called determinate or mosaic cleavage, which means blastomeres are destined to form a particular organ in the very early stage of cleavage. In Figure 1.4 just after the first cleavage ablation of one of the cells takes place it leads to the loss of head structure in the embryo that drives from it. Such a type of development is said to be mosaic.
3. **Fate of blastopore:** The blastopore either becomes mouth (e.g., Mollusca) or gives rise to both mouth and anus (e.g., some mollusks, polychaetes, and onychophorans) in adults.
4. **Formation of mesoderm:** Mesoderm originates from the fourth cell, named mesentoblast (also called as '4d' cell) which increases in number by proliferation.
5. **Formation of coelom:** Coelom originates from the splitting of the mesodermal cell mass. This process of coelom formation is known as schizocoely and coelom are called schizocoelom ('schizo' means split). **Examples:** Coelomate protostomes include Sipuncula, Echiura, Annelida, Pogonophora, Mollusca, Onychophora, Tardigrada, Pentastomida, and some groups of arthropods.

Deuterostomia: The metazoans in which anal opening are derived from blastopore during embryonic development and represents the posterior end of the body and mouth are formed later are included in deuterostomia. As the anus forms first and the mouth is formed secondarily, these animals are grouped in deuterostomia (Mouth second). The nerve cord is dorsal in deuterostomes.

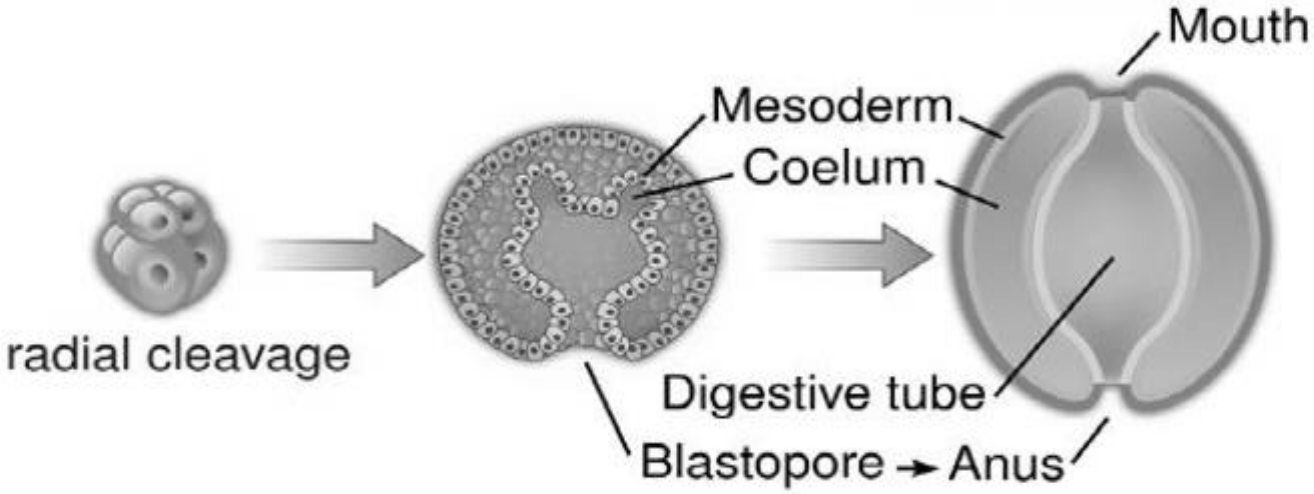

Fig. 1.5 Diagram showing the development of the anus from the blastopore

The developmental characteristics of deuterostomes are as follows.

1. Pattern of embryonic cleavage: The radial pattern of embryonic cleavage occurs in which the cleavage plane is either parallel or at a right angle to the polar axis. Blastomeres are arranged directly above or below one another.

2. Fate of embryonic blastomeres:

Cleavage is indeterminate and if blastomeres are separated at 4 cell stages, each one will develop into a complete individual. Cleavage is regulative because each of the blastomeres if separated can regulate its development (Fig 1.6). In figure 1.6, if ablation of one cell takes place, then the descendants of the remaining cell can give rise to the structure in the embryo that would have developed from the lost cell. In this case, the green cell can regenerate the head structure as well as the trunk region. Such development is said to be regulative.

3. Fate of blastopore: Blastopore becomes the adult anus and then the formation of the mouth takes place from a second opening on the dorsal surface of the embryo.

4. Formation of mesoderm: Mesodermal tissue is formed by the outgrowth of the endodermal wall of the archenteron.

5. Formation of coelom: Coelom is formed by evagination of pouches from the wall of the archenteron and each diverticulum becomes separated from the archenteron and develops an independent coelomic pouch. This process of formation of the coelom is called enterocoely and the coelom is called enterocoelom.

Examples: Deuterostomes include Echinoderms, Chordates, Pogonophores, Hemichordates, and some minor phyla.