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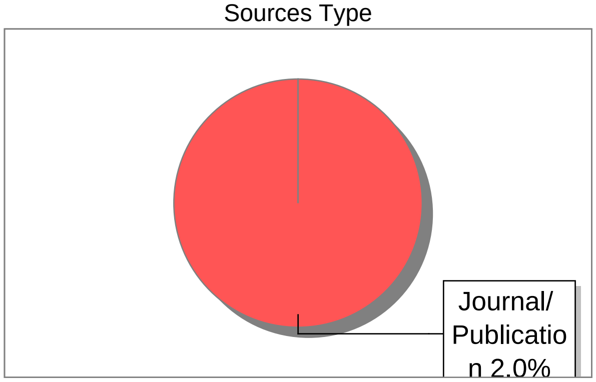


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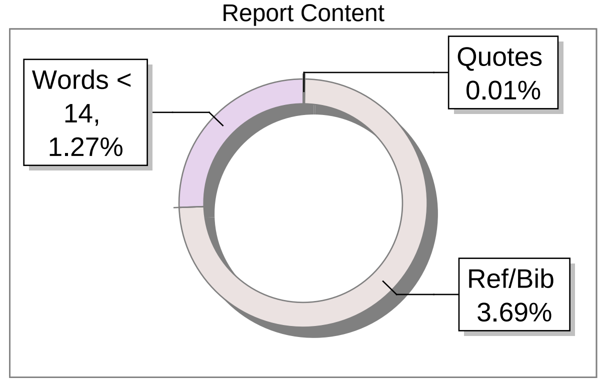


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# DSCC202
# ZOOLOGY II:
# VERTEBRATE PHYSIOLOGY

MATS University

## VERTEBRATE PHYSIOLOGY
## CODE: ODL/MSS/BSCB/202

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## MODULE INTRODUCTION

Course has five MODULEs. Under this theme we have covered the following topics-



The central themes in vertebrate physiology revolve around structurefunction relationships, homeostasis, adaptation, and feedback control systems. These themes explain how vertebrates maintain internal stability, adapt to their environments, and how their physiological functions are linked to their structures. This book is designed to help you think about the topic of the particular MODULE.

We suggest you do all the activities in the MODULEs, even those which you find relatively easy. This will reinforce your earlier learning.

# MODULE I

# CHORDATES

**Objectives:**

- Understand the diagnostic features of phylum Chordata.
- Differentiate between nonchordates and chordates with examples.
- Study the general organization of chordates (notochord, dorsal nerve cord, pharyngeal gill slits, postanal tail, endostyle/thyroid).
- Examine the subdivision of chordates into Protochordates and Vertebrates.
- Analyze the evolutionary significance and relationships among lower chordates (Cephalochordata, Urochordata).
  Develop skills to identify chordate features in specimens and diagrams.

## UNIT 1: Origin and classification of Chordates

### Introduction

The Phylum Chordata is a highly diverse and complex group of animals that includes all vertebrates (like mammals, birds, reptiles, amphibians, and fishes), as well as some invertebrate relatives. Chordates are distinguished by having a **notochord**, **dorsal hollow nerve cord**, **pharyngeal slits**, **post-anal tail**, and an **endostyle or thyroid gland** at some point in their life cycle. This group represents a crucial evolutionary link between invertebrates and vertebrates.

### Origin of Chordates

### Evolutionary Background

Chordates are believed to have evolved over **540 million years ago during the Cambrian Explosion**. Their origin is a key chapter in the evolutionary history of animals, marking the emergence of complex body structures and centralized nervous systems.

### Ancestral Lineage

There are three main hypotheses regarding the ancestry of chordates:

**(a) Echinoderm Ancestry Hypothesis**

- Chordates are closely related to **echinoderms** (like starfish and sea urchins) based on embryological similarities.
- Both are deuterostomes, meaning their embryonic development follows a similar pattern.
- Larval forms of echinoderms (like **dipleurula**) show similarities with primitive chordate larvae.

**(b) Hemichordate Hypothesis**

- Suggests chordates evolved from **hemichordates**, a group of marine animals with a body plan partly similar to chordates.
- Hemichordates possess a **stomochord**, once thought to be similar to the notochord.

**(c) Urochordate Hypothesis**

- Currently the most accepted theory.
- Proposes that chordates evolved from **urochordates** (like sea squirts), especially the **larval form of tunicates**, which shows all chordate features.
- Through a process called **"paedomorphosis"** (retention of larval traits in adults), a free-swimming tunicate larva could have given rise to vertebrate ancestors.

**Fundamental Characteristics of Chordates**

All chordates exhibit the following features at some stage of development:

1. **Notochord**: A flexible rod-like structure that provides support.
2. **Dorsal hollow nerve cord**: Runs along the back; gives rise to the brain and spinal cord in vertebrates.
3. **Pharyngeal slits**: Openings in the pharynx used in filter-feeding or respiration.
4. **Post-anal tail**: An extension of the body beyond the anus.
5. **Endostyle/Thyroid gland**: Involved in metabolism or filter feeding.

**Classification of Chordates**

The Phylum Chordata is divided into **three subphyla**, based on the presence and development of the notochord and other structures.

**Subphylum: Urochordata (Tunicata)**

- **Common Name**: Sea squirts

- **Habitat**: Marine
- **Characteristics**:
  - Notochord and nerve cord present only in the larval stage.
  - Adults are sessile and lack chordate features.
  - Covered by a **tunic** made of cellulose-like material.
- **Examples**: *Ascidia*, *Ciona*, *Salpa*

**Subphylum: Cephalochordata**

- **Common Name**: Lancelets
- **Habitat**: Marine, burrowing
- **Characteristics**:
  - Retain notochord and nerve cord throughout life.
  - Fish-like in shape but lack a true vertebral column.
  - Transparent body with segmented muscles.
- **Examples**: *Branchiostoma* (also known as *Amphioxus*)

**Subphylum: Vertebrata (Craniata)**

- **Common Name**: Vertebrates
- **Habitat**: Aquatic and terrestrial
- **Characteristics**:
  - Notochord replaced by vertebral column in adults.
  - Well-developed brain enclosed in a cranium.
  - Advanced organ systems and sensory structures.

**Classification of Vertebrata**

Vertebrates are further classified into **two major groups**:

**A. Agnatha (Jawless Vertebrates)**

- **Characteristics**:
  - No jaws or paired fins.
  - Cartilaginous skeleton.
  - Notochord persists throughout life.
- **Examples**: *Petromyzon* (lamprey), *Myxine* (hagfish)

**B. Gnathostomata (Jawed Vertebrates)**

This group is further divided into:

**(i) Pisces (Fishes)**

- Aquatic vertebrates with gills, scales, and fins.

1. **Chondrichthyes (Cartilaginous fishes)**
    - Skeleton made of cartilage
    - No swim bladder
    - Examples: *Shark*, *Skate*, *Ray*
2. **Osteichthyes (Bony fishes)**
    - Skeleton made of bone
    - Have swim bladders for buoyancy
    - Examples: *Rohu*, *Catla*, *Perch*

**(ii) Tetrapoda (Four-limbed vertebrates)**

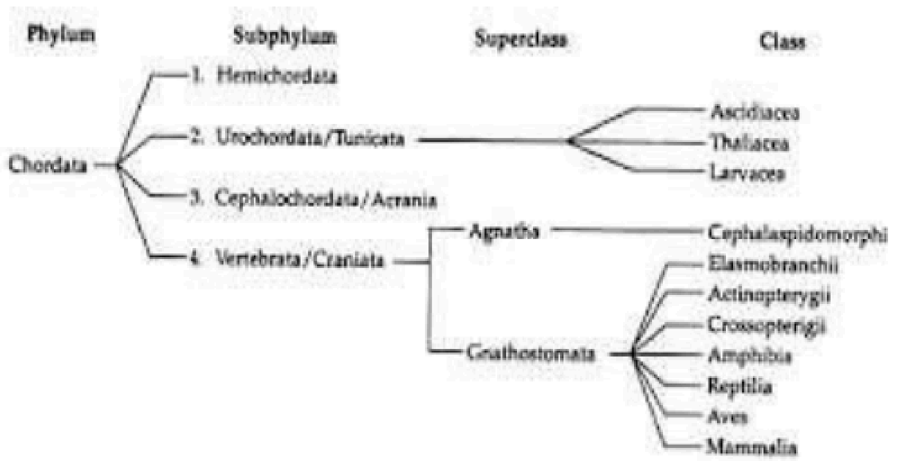
Adapted for life on land. Includes:

1. **Amphibia**
    - Dual life: aquatic larvae and terrestrial adults
    - Moist skin, no scales
    - Examples: *Frog*, *Toad*, *Salamander*
2. **Reptilia**
    - Dry, scaly skin
    - Lay shelled eggs on land
    - Examples: *Lizard*, *Snake*, *Turtle*
3. **Aves (Birds)**
    - Feathers, beaks, and wings
    - Endothermic (warm-blooded)
    - Examples: *Sparrow*, *Eagle*, *Pigeon*
4. **Mammalia**
    - Hair/fur and mammary glands
    - Most give birth to live young

- Examples: *Human*, *Tiger*, *Bat*, *Whale*

**Evolutionary Tree of Chordates**

(Include a diagram showing a phylogenetic tree with Urochordata, Cephalochordata, and Vertebrata branching from a common ancestor)




Notes

**Origin and classification of Chordates**

## UNIT 2: Protochordate- Type study Amphioxus

### Introduction

Amphioxus, also known as **lancelet**, belongs to the subphylum **Cephalochordata** of the phylum **Chordata**. It serves as an important model organism in evolutionary biology because it shares features with both **invertebrates and vertebrates**, thus acting as a connecting link between the two. The commonly studied genus is **Branchiostoma** (formerly *Amphioxus*), particularly *Branchiostomalanceolatum*.

### Classification

| Category | Details |
|---|---|
| Kingdom | Animalia |
| Phylum | Chordata |
| Subphylum | Cephalochordata |
| Genus | Branchiostoma |
| Common Name | Amphioxus, Lancelet |

### Habitat and Distribution

- Found in **shallow marine waters**, especially in **sandy or muddy sea bottoms**.
- Common in **temperate and tropical seas**.
- Bury themselves in the sand with only the anterior end protruding.

### Morphology

- Body is **elongated, fish-like, and laterally compressed**.
- Measures about **5–8 cm in length**.
- **Transparent body** with no paired fins or head.
- **Dorsal and caudal fins** are continuous and supported by fin rays.
- **No eyes**, but sensitive to light via simple pigment spots.

### Key Anatomical Features



**a. Notochord:**

- Present throughout life.

- Extends from head to tail and serves as the main axial support.

**b. Dorsal Nerve Cord:**

- Lies above the notochord.
- Hollow and runs along the dorsal side of the body.

**c. Pharyngeal Gill Slits:**

- Numerous and arranged in pairs.
- Used for **filter-feeding** and **respiration**.

**d. Post-anal Tail:**

- Tail extends beyond the anus, aiding in locomotion.

**Circulatory and Respiratory Systems**

- **Closed circulatory system**.
- **No heart**; blood is pumped by contractile vessels.
- **No red blood cells** (thus, no hemoglobin).
- **Respiration occurs through pharyngeal slits**, not lungs or gills.

**Digestive System**

- Complete digestive tract: mouth ! pharynx ! intestine ! anus.
- **Filter-feeding** mechanism:
    - Water enters through the **buccal cirri** and passes through the **pharynx**.
    - Food particles are trapped in mucus and transported to the gut.
    - Waste is expelled through the **anus**, located just in front of the tail fin.

**Excretory and Nervous System**

- Excretory organs: **protonephridia** with flame cells.
- Nervous system consists of a **dorsal nerve cord**.
- **No true brain**, but an anterior swelling called the **cerebral vesicle** acts as a primitive brain.

**Reproduction and Development**

- **Dioecious** (separate sexes).
- External fertilization in water.
- **Indirect development** through a **tornaria-like larva**.
- Larvae undergo **metamorphosis** before becoming adults.

**Significance in Evolution**

- Amphioxus retains all fundamental **chordate characteristics** throughout life:
    - Notochord
    - Dorsal nerve cord
    - Pharyngeal slits
    - Post-anal tail
- Considered a **living model of the ancestral chordate**.
- Serves as a **link between invertebrates and vertebrates**, showing how simpler chordate features could have evolved into complex vertebrate structures.

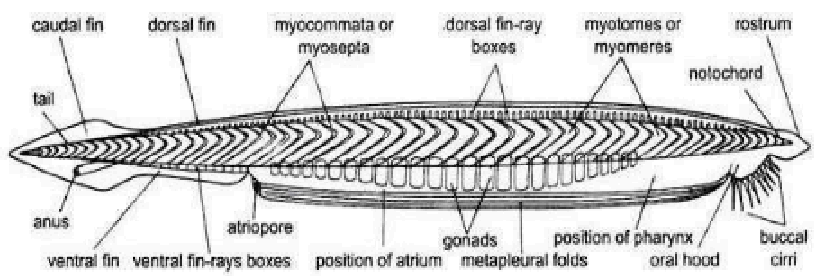



**Fig. 6.1.** *Branchiostoma*. Entire animal in right side view.

## UNIT 3: A comparative account of Petromyzon and Myxine

### Introduction:

*Petromyzon* (lamprey) and *Myxine* (hagfish) are the only extant representatives of the superclass **Cyclostomata**, a group of jawless, eel-like vertebrates. Both are primitive agnathans (jawless vertebrates), but they show notable differences in their anatomy, physiology, and behavior. This comparative account highlights the similarities and differences between *Petromyzon* and *Myxine* for a clear understanding of their evolutionary and ecological distinctions.

### Classification:

| Feature | *Petromyzon* (Lamprey) | *Myxine* (Hagfish) |
|---|---|---|
| Class | Cephalaspidomorphi | Myxini |
| Order | Petromyzontiformes | Myxiniformes |
| Habitat | Anadromous (marine and freshwater) | Marine only |
| Lifestyle | Ectoparasitic (on fish) | Scavenger and predator |

### External Morphology:

| Feature | *Petromyzon* | *Myxine* |
|---|---|---|
| Body Shape | Elongated, cylindrical | Slender, eel-like |
| Mouth | Circular, sucker-like with keratinized teeth | Terminal, jawless with barbels |
| Number of Eyes | Well-developed, lateral eyes | Rudimentary, buried in skin |
| Barbels | Absent | Present (3 pairs) |
| Gill Openings | 7 pairs of separate round pores | 1 to 15 pairs (usually 5–14), often in a common duct |
| Fins | Dorsal and caudal fins present | Fins rudimentary or absent |
| Nasal Opening | Single, dorsal (nostril) | Single, dorsal |

### Skeleton and Notochord:

| Feature | *Petromyzon* | *Myxine* |
|---|---|---|
| Vertebral Column | Rudimentary cartilaginous elements; persistent notochord | No true vertebrae; persistent notochord |

| | | |
|---|---|---|
| Cranium | Cartilaginous braincase | Cartilaginous skull (not fully enclosed) |
| Notochord | Persistent and prominent | Persistent and prominent |

**Digestive and Feeding Habits:**

| **Feature** | ***Petromyzon*** | ***Myxine*** |
|---|---|---|
| Feeding Mode | Parasitic – feeds on body fluids of fishes | Scavenger – feeds on dead or dying animals |
| Teeth | Horny teeth in buccal funnel | Tooth-like structures on tongue |
| Digestive System | Straight gut without stomach | Straight gut without stomach |

**Circulatory and Respiratory Systems:**

| **Feature** | ***Petromyzon*** | ***Myxine*** |
|---|---|---|
| Heart | Four-chambered: sinus venosus, atrium, ventricle, conus arteriosus | Similar four-chambered heart |
| Accessory Hearts | Absent | Present (portal heart, cardinal heart, etc.) |
| Respiration | Through gills | Through gills and skin |
| Blood | Contains nucleated RBCs | Contains nucleated RBCs |

**Nervous System and Sense Organs:**

| **Feature** | ***Petromyzon*** | ***Myxine*** |
|---|---|---|
| Brain | Well-developed | Poorly developed |
| Eyes | Functional, image-forming | Degenerate and covered by skin |
| Lateral Line System | Present | Present (less developed) |
| Chemoreceptors | Present | Well-developed |

**Reproduction and Development:**

| Feature | *Petromyzon* | *Myxine* |
|---|---|---|
| Gonads | Single, unpaired | Single, unpaired |
| Reproductive Mode | Oviparous | Oviparous |
| Larval Stage | Ammocoete larva (metamorphosis into adult) | Direct development (no larva) |
| Fertilization | External | External |
| Sexual Dimorphism | Absent | Absent |

**Ecological Role and Importance:**

| Feature | *Petromyzon* | *Myxine* |
|---|---|---|
| Ecological Niche | Ectoparasite – affects fish populations | Scavenger – cleans ocean floor |
| Economic Impact | Harmful to fisheries (parasitism) | Beneficial – decomposer |
| Research Importance | Model for vertebrate development | Model for early vertebrate evolution |

**Summary of Key Differences:**

| Characteristic | *Petromyzon* | *Myxine* |
|---|---|---|
| Habitat | Freshwater & marine | Marine only |
| Eye Development | Well-developed | Rudimentary |
| Feeding Strategy | Parasitic | Scavenging |
| Larval Stage | Ammocoete larva | No larval stage |
| Accessory Hearts | Absent | Present |
| Barbels | Absent | Present |

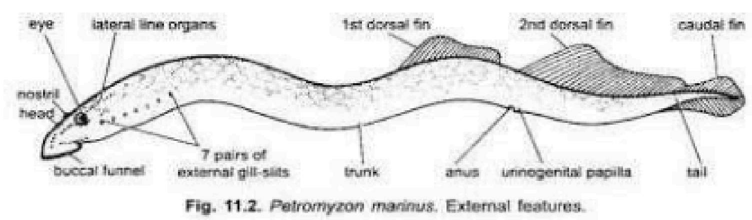



Fig: Petromyzon

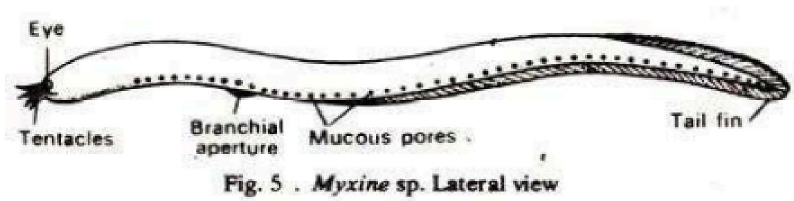



Fig: Myxine

**Question bank:**

**Very Short Answer Questions**

1. Define notochord.
2. What is the pharyngeal gill slit?
3. Name any one urochordate and one cephalochordate.
4. What is the function of the endostyle?
5. To which phylum does amphioxus belong?
6. What is the mode of feeding in amphioxus?
7. Name the larval stage of amphioxus.
8. How many gill slits are present in *Petromyzon*?
9. What type of eye is present in *Myxine*?
10. Is *Petromyzon* a parasite or a scavenger?

**Short Answer Questions**

1. Mention three fundamental characteristics that define a chordate.
2. Distinguish between chordates and non-chordates.

3. Explain the significance of notochord and dorsal hollow nerve cord in chordates.

4. Write a short note on the classification of chordates up to classes.

5. Give three anatomical features that make amphioxus a true chordate.

6. Compare the feeding mechanisms of amphioxus and *Petromyzon*.

7. List any three similarities and three differences between *Petromyzon* and *Myxine*.

8. What are the main ecological roles of *Petromyzon* and *Myxine*?

9. Describe the locomotion in amphioxus.

10. Differentiate between the respiratory systems of *Petromyzon* and *Myxine*.

**Long Answer Questions**

1. Discuss the origin and evolutionary relationships of chordates with examples.

2. Give a detailed classification of chordates and explain characteristics of each subphylum.

3. Describe the external and internal morphology of amphioxus. Why is it considered a connecting link?

4. Explain the structural and functional adaptations of amphioxus for its mode of life.

5. Provide a comparative account of *Petromyzon* and *Myxine* with respect to external features, feeding, sense organs, and reproduction.

6. Discuss the evolutionary significance of cephalochordates in vertebrate ancestry.

7. Compare the nervous and circulatory systems of amphioxus and cyclostomes (*Petromyzon* and *Myxine*).

8. Describe the reproductive features and larval development in amphioxus and *Petromyzon*.

## MODULE II

## VERTEBRATA I

**Objectives:**

- Learn the classification of vertebrates up to class level.
- Study the diagnostic characters of Cyclostomata (lampreys, hagfishes) and Pisces (cartilaginous and bony fishes).
- Understand the structural adaptations of fishes for respiration, circulation, and locomotion.
- Explore migration, parental care, and economic importance of fishes.
- Compare primitive vertebrate features with advanced vertebrates.
- Develop observation skills through study of preserved specimens and fish skeletons.

# UNIT 4: Fishes: Skin, Scale, Migration and Parental care

## Fish: Skin

### Introduction

Fish skin is an essential component of the integumentary system and serves as the first line of defense against the external environment. It plays a critical role in protection, respiration, osmoregulation, sensory perception, and locomotion. Understanding fish skin structure and function is vital in the fields of fish biology, aquaculture, and biotechnology.

### Structure of Fish Skin

Fish skin consists of **two primary layers**:

**a) Epidermis**

- The outermost, non-keratinized layer.
- Composed mainly of **epithelial cells**, **mucous cells (goblet cells)**, and **club cells**.
- Lacks a stratum corneum (unlike mammalian skin).
- Constantly regenerates and sheds.
- Secretes mucus to reduce friction and provide a chemical barrier against pathogens.

**b) Dermis**

- Lies beneath the epidermis.
- Divided into:
    - **Stratum spongiosum** (upper layer): Contains **blood vessels**, **pigment cells (chromatophores)**, **nerve fibers**, and **connective tissue**.
    - **Stratum compactum** (lower layer): A dense collagenous layer that provides structural strength.

**c) Scales**

- Embedded in the dermis.
- Provide mechanical protection and hydrodynamic efficiency.
- Types include:
    - **Placoid scales** (e.g., sharks)
    - **Cycloid and ctenoid scales** (e.g., bony fishes)

- **Ganoid scales** (e.g., gars, sturgeons)

### Functions of Fish Skin

**a) Protection**

- Physical barrier against injuries and pathogens.
- Mucus contains **lysozymes**, **antibodies**, and **antimicrobial peptides**.

**b) Osmoregulation**

- Regulates the movement of water and ions between the fish and its environment.
- Plays a crucial role in freshwater vs. marine osmoregulation.

**c) Respiration**

- In some species (e.g., eels, mudskippers), the skin facilitates **cutaneous respiration**, especially under low oxygen conditions.

**d) Sensation**

- Rich in sensory cells and nerve endings that detect **pressure**, **temperature**, and **chemical changes** in water.

**e) Coloration and Camouflage**

- Chromatophores (melanophores, iridophores, xanthophores) provide pigmentation.
- Used in camouflage, warning coloration, sexual display, and stress indication.

### Mucus and Immune Function

- **Mucus layer** contains **immunoglobulins (IgM)**, **complement proteins**, **antimicrobial peptides**, and **proteases**.
- Acts as a **chemical defense** by trapping and neutralizing pathogens.
- Plays a role in **wound healing**, **regeneration**, and **immune response modulation**.



### Regeneration and Healing

- Fish skin shows a high degree of **regenerative capability**.

- **Re-epithelialization** occurs rapidly after injury.
- Some species regenerate scales and dermal tissue, making fish models useful in **regenerative biology** research.

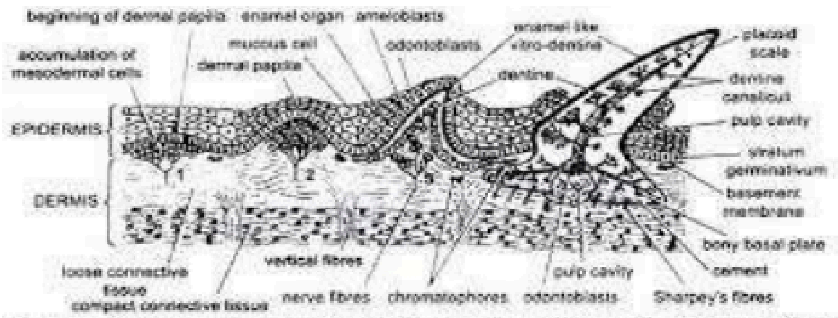


Fig. 14.5. *Scoliodon*. V. S. of skin showing development of placoid scale. 1. Accumulation of dermal cells; 2. Formation of dermal papilla; 3. Growing spine; 4. V. S. of a fully formed scale.

**Fish: scale and its types**

**Introduction**

Fish scales are small, rigid plates that grow out of the skin of most fish species. These structures are part of the **integumentary system** and serve various functions, such as protection, streamlining body movement in water, and in some species, age determination. The term **BSC** stands for **Bony Scale Covering**, emphasizing the calcified or ossified nature of most fish scales.

**Structure of Fish Scales**

Fish scales originate from the **mesodermal layer** of the skin and are embedded in the **dermis**, although they may be visible through the outer **epidermis**. Each scale typically consists of:

- **Basal plate** – embedded in the skin
- **Exposed part** – visible on the surface
- **Growth rings (circuli)** – similar to tree rings, which can indicate age
- **Radii** – lines that radiate from the center outward

## Types of Fish Scales

Fish scales can be categorized into two broad groups: **Placoid scales** (found in cartilaginous fish) and **Bony scales** (found in bony fish). Bony scales are further divided into:

### 1. Cosmoid Scales

- Found in extinct lobe-finned fishes and coelacanths
- Thick, multi-layered: bone, dentine, and enamel
- Rare in modern fish

### 2. Ganoid Scales

- Found in fishes like gars and bichirs
- Hard, rhomboid shape
- Composed of **ganoine** (a shiny enamel-like substance), dentine, and bone

### 3. Cycloid Scales

- Found in soft-rayed fish-like salmon and carp
- Smooth, circular, overlapping
- Flexible, with growth rings

### 4. Ctenoid Scales

- Found in spiny-rayed fishes like perch and sunfish
- Similar to cycloid but with tiny comb-like projections (**ctenii**) on the posterior edge
- Improve hydrodynamics and reduce drag

## Functions of Fish Scales

- **Protection**: Shields against predators, parasites, and mechanical injury
- **Hydrodynamics**: Reduces friction, enhances smooth movement in water
- **Camouflage**: Reflective or pigmented scales aid in blending with the environment
- **Sensory Function**: Scales work alongside lateral line systems to detect vibrations
- **Age Determination**: Growth rings provide a method for estimating fish age (important in fisheries biology)

### Development and Growth

Fish scales grow as the fish grows. The concentric rings (**circuli**) on scales expand outward, and the number of annuli (groups of circuli) can correspond to the fish's age in years. Environmental factors like temperature and food availability affect growth rate and ring formation.

### Differences Between Scale Types

| **Feature** | **Cycloid** | **Ctenoid** | **Ganoid** | **Placoid** |
|---|---|---|---|---|
| Edge Shape | Smooth | Toothed (ctenii) | Rhomboid | Spiny |
| Composition | Bone | Bone | Bone & ganoine | Dentine & enamel |
| Found In | Soft-rayed fish | Spiny-rayed fish | Primitive fish | Cartilaginous fish |
| Flexibility | High | Moderate | Low | Low |

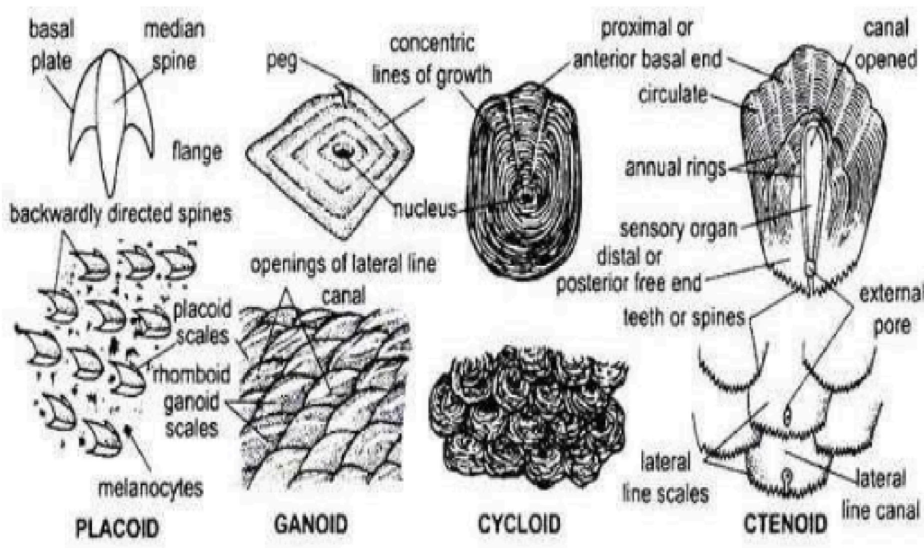



Fig. 17.5. Different types of dermal scales found in fishes. Lower row shows parts of skin with numerous scales. Upper row shows single scales.

Fig: Fish: types of scales

Notes

**Fish: Migration**

**Introduction**

Fish migration is the regular, often seasonal, movement of fish from one habitat to another for the purpose of feeding, reproduction, or environmental conditions. It plays a crucial role in the life cycle of many fish species and has significant ecological, economic, and conservation implications.

**Definition of Fish Migration**

**Fish migration** is defined as the **habitual movement of fish from one part of a water body to another, or between different water bodies**, which is often cyclic and involves return journeys.

**Key Characteristics:**

- Periodic or seasonal
- Directional and purposeful
- Involves large-scale movement
- Triggered by environmental cues (temperature, photoperiod, salinity, etc.)

**Types of Fish Migration**

Fish migration is classified based on the origin and destination of movement, especially in relation to freshwater and marine environments.

**a) Anadromous Migration**

- Fish are born in freshwater, migrate to the sea to grow, and return to freshwater to spawn.
- **Examples**: Salmon (*Salmo salar*), Sturgeon (*Acipenser spp.*)

**b) Catadromous Migration**

- Fish are born in the sea, migrate to freshwater to grow, and return to the sea to spawn.
- **Example**: European Eel (*Anguilla anguilla*), American Eel (*Anguilla rostrata*)

**c) Amphidromous Migration**

- Migration between freshwater and marine environments occurs, but not necessarily for breeding.

- **Example**: Gobies (*Sicyopterus spp.*), some species of Galaxiids

**d) Potamodromous Migration**

- Fish migrate entirely within freshwater systems such as rivers or lakes.
- **Example**: Mahseer (*Tor putitora*), Carps

**e) Oceanodromous Migration**

- Fish migrate entirely within marine environments.
- **Example**: Tuna (*Thunnus spp.*), Mackerel (*Scomber spp.*)

**Purposes of Fish Migration**

**a) Spawning Migration**

- Movement to specific sites for reproduction.
- Involves physiological changes (gonadal development, hormonal changes).

**b) Feeding Migration**

- Fish migrate in search of better feeding grounds.
- Often seen in pelagic species.

**c) Shelter or Habitat Migration**

- Movement in response to environmental changes like temperature, salinity, oxygen concentration.

**d) Juvenile Migration**

- Movement of young fish to nursery areas for growth and survival.

**Mechanisms and Orientation**

Fish use various biological and environmental cues to orient themselves during migration:

**a) Environmental Cues**

- Temperature, salinity, photoperiod, water current, lunar cycle.

**b) Sensory Mechanisms**

- **Olfaction (smell)**: Used for homing, especially in salmon.
- **Vision**: Assists in short-distance navigation.
- **Magnetoreception**: Detection of Earth's magnetic fields.

- **Sun and Star Navigation**: Used by some pelagic fish.

### Physiological Adaptations

Migratory fish undergo a series of physiological and anatomical changes:

- Development of osmoregulatory systems to adjust to salinity changes.
- Increase in energy reserves (fat and glycogen).
- Hormonal changes involving cortisol, prolactin, and thyroxine.

### Ecological and Economic Significance

**a) Ecological Roles**

- Nutrient transfer between ecosystems (e.g., marine to freshwater).
- Supports food chains in both marine and freshwater ecosystems.

**b) Economic Importance**

- Major source of commercial and recreational fishing.
- Migration routes are critical for fisheries management.

### Threats to Fish Migration

- **Dams and barriers**: Obstruct migratory routes.
- **Pollution**: Affects water quality and fish health.
- **Climate Change**: Alters migration timing and patterns.
- **Overfishing**: Reduces spawning population

### Conservation Measures

- **Fish ladders and bypass systems**: Allow passage around barriers.
- **River restoration**: Reestablishing natural flow regimes.
- **Protected areas**: Conservation of critical habitats.
- **Monitoring and tagging**: Understanding migration behaviour.

| Fish Species | Migration Type | Migration Distance | Notable Features |
|---|---|---|---|
| Salmon (*Salmo salar*) | Anadromous | Up to 3,000 km | Precise homing ability |

Eel (*Anguilla spp.*) Catadromous Up to 6,000 km Migrate to Sargasso Sea for spawning

Tuna (*Thunnus spp.*) Oceanodromous Over 4,000 km High-speed swimmers, long-range travel



## Fish: Parental Care

### Introduction

Parental care in fishes refers to the investment made by one or both parents to ensure the survival of their offspring after fertilization. Although the reproductive strategies of fishes are highly diverse, ranging from the production of millions of eggs with no subsequent care to intensive guarding and nurturing behaviors, parental care represents an advanced evolutionary strategy aimed at enhancing offspring survival.

In the aquatic environment, the risks faced by eggs and larvae—such as predation, disease, and environmental fluctuation—are significant. Parental care acts as a buffer against these threats by increasing the chances of successful development and recruitment into the adult population. It is an important aspect of fish ethology and evolutionary biology.

### Types of Parental Care in Fishes

Fish exhibit a broad spectrum of parental care behaviors. These can be broadly categorized based on who provides the care (male, female, or both) and the nature of the care (guarding, brooding, or provisioning).

### No Parental Care (Broadcast Spawning)

In many species, especially among marine fishes, eggs and sperm are released into the water column without any post-spawning care. This is typical in pelagic spawners such as tuna, mackerel, and cod. Although this strategy relies on sheer numbers for survival, it is inherently risky and wasteful, with high larval mortality.

### Male Parental Care

Contrary to mammals and birds, male parental care is common in fishes. This may involve nest building, guarding of eggs, fanning to oxygenate the eggs, or even mouthbrooding.

- **Nest Building and Guarding**: In species such as the three-spined stickleback (*Gasterosteus aculeatus*), the male constructs a nest using plant material and mucous secretions. After courtship and egg deposition by the female, the male fertilizes and guards the eggs, fanning them with his fins to maintain oxygen flow.

- **Mouthbrooding**: Seen in cichlids like *Tilapia* spp., where the male carries fertilized eggs in his mouth until they hatch. This behavior protects the eggs from predators and environmental hazards.
- **Pouch Brooding**: In seahorses (*Hippocampus* spp.) and pipefishes, the male has a specialized brood pouch where the female deposits her eggs. Fertilization occurs internally, and the male incubates the eggs until live young are released.

**Female Parental Care**

Female-only care is less common but does occur in some species.

- **Mouthbrooding**: Some African cichlids, such as *Haplochromis* spp., involve the female holding fertilized eggs in her mouth until hatching. She may even continue to protect the fry post-hatching.
- **Egg Carrying**: In the case of catfish such as *Aspredoaspredo*, eggs are attached to the ventral surface of the female's body, where she carries them until hatching.

**Biparental Care**

In certain fish species, both male and female contribute to caring for the offspring. This is typically observed in more behaviorally advanced groups such as cichlids.

- **Guarding and Fanning**: In species like *Amatitlanianigrofasciata* (convict cichlid), both parents share responsibilities such as cleaning, guarding, and fanning the eggs.
- **Feeding and Protection**: In some rare cases, like the discus fish (*Symphysodon* spp.), parents secrete a nutritious mucus on their skin which the fry feed on during their early life stages.

**Mechanisms of Parental Care**

Parental care in fishes involves various behavioral and physiological adaptations. These include:

1. **Nest Construction**: Males of species like gouramis and sticklebacks construct nests from aquatic plants or bubbles to house and protect eggs.
2. **Egg Oxygenation**: Many parents, particularly males, fan the eggs with their fins to ensure a constant supply of oxygenated water, preventing fungal growth and suffocation.

3. **Predator Deterrence**: Aggressive territorial behavior is often displayed by fish parents to deter predators and rival males from approaching their brood.

4. **Cleaning**: Parents clean the eggs to remove debris, fungus, or dead eggs, maintaining a hygienic environment crucial for egg survival.

5. **Transporting Eggs or Fry**: Some catfish and cichlids have been observed carrying eggs or fry to new locations if a threat is perceived or if environmental conditions change.

6. **Hiding or Shelter Provision**: Parents may lead fry to safe areas with cover or construct shelters where the offspring can hide.

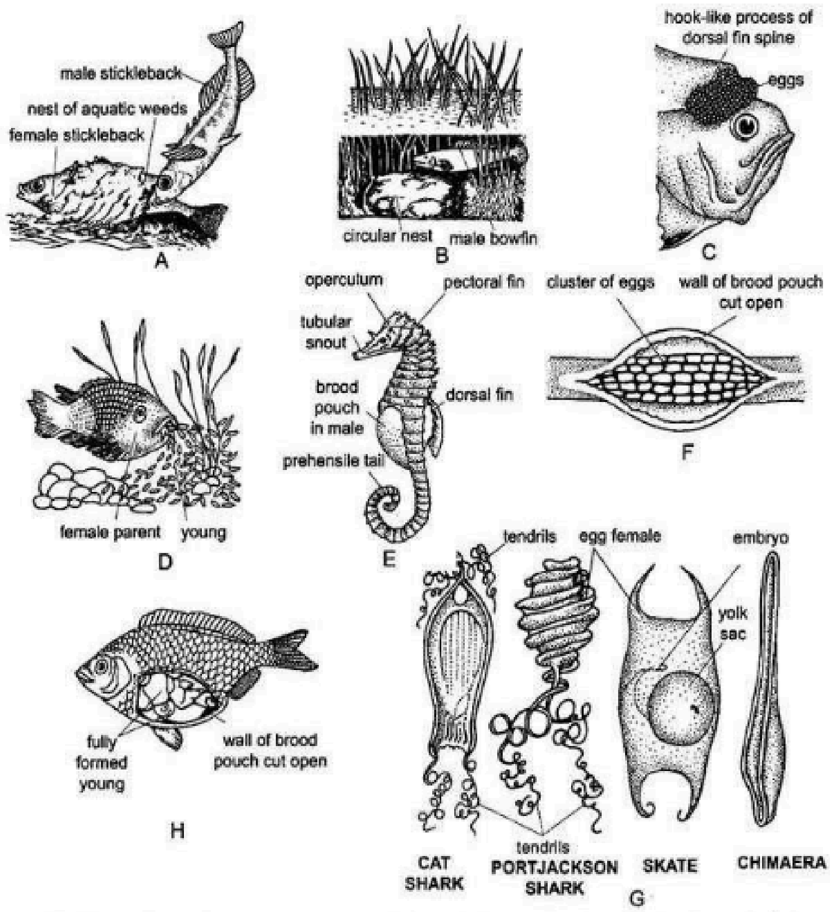



**Fig. 17.9.** Some interesting examples of parental care in fishes. A–Male stickleback (*Gasterosteus aculeatus*) muzzles female at the base of tail to stimulate her to lay eggs in a nest of dead aquatic plants; B–Male bowfin (*Amia calva*) guarding over circular nest; C–The male Australian *Kurtus* incubates eggs on its forehead; D–Very young of *Tilapia massambica* take refuge in female parents buccal cavity in times of danger; E–A male *Hippocampus* carrying brood pouch; F–Brood pouch of male *Syngnathus* opened to show eggs; G–Mermaids purses for eggs; H–Body cavity of *Cymatogaster aggregatus* cut open to show a fully formed young ready for hatching.

Fig: Parental care in Fishes

**UNIT 5: Amphibia: Parental care and Neoteny**



**Parental Care in Amphibia**

Parental care refers to the behavioral and physiological activities of the parents that increase the survival chances of their offspring. Among vertebrates, amphibians exhibit a remarkable diversity of parental care strategies, ranging from complete abandonment of eggs to highly specialized and complex methods of nurturing. The evolution of parental care in Amphibia is particularly fascinating due to their semi-terrestrial life, small body size, and high predation pressure on eggs and larvae.

**Introduction to Amphibian Reproduction and the Need for Parental Care**

Amphibians are poikilothermic vertebrates that typically lay eggs in moist environments to prevent desiccation. Due to their soft, gelatinous, and non-calcified eggs, they are vulnerable to environmental hazards and predation. Consequently, various species have evolved parental care strategies to increase the chances of survival and reduce mortality of offspring. Amphibian parental care may be carried out by the male, the female, or both, and includes behaviors such as guarding, transporting, brooding, and even feeding.

**Types and Mechanisms of Parental Care in Amphibians**

Amphibian parental care can be broadly classified based on the type of behavior and the level of involvement. The most common types include:

**Egg Attendance and Guarding**

In many amphibians, either parent may stay near the eggs to guard them against predators, fungal infections, or desiccation. This form of care is often observed in frogs and toads, where the parent stays close to the egg mass until hatching.

- **Example**: *Alytes obstetricans* (the midwife toad) male carries the fertilized eggs wound around its hind legs until they are ready to hatch. During this period, the male frequently bathes in water to keep the eggs moist.
- **Example**: In *Rana clamitans*, the male guards eggs laid in shallow water from predators and intruders.

**Moisture Maintenance and Oxygen Supply**

Since amphibian eggs are prone to drying and require a constant supply of oxygen, some species engage in behaviors aimed at regulating environmental conditions around the eggs.

- **Example**: In *Chiromantisxerampelina* (gray foam-nest tree frog), the female secretes a foam around the eggs, which helps maintain moisture and allows gas exchange. The foam also provides some protection from predators and parasites.
- **Example**: In *Ichthyophisglutinosus*, a caecilian, the female coils around the egg clutch and secretes a mucus layer to keep the eggs moist.

**Egg and Larval Transport**

Several amphibian species actively transport eggs or larvae from the site of deposition to water bodies or safe locations, thereby increasing the chances of survival.

- **Example**: *Dendrobates* and *Phyllobates* (poison dart frogs) exhibit elaborate transport behaviors. After hatching, the male carries tadpoles on his back to small water-filled tree holes or bromeliads, where the tadpoles complete development.
- **Example**: In *Rhinoderma darwinii* (Darwin's frog), the male picks up the fertilized eggs into his vocal sacs. The eggs hatch and the tadpoles complete metamorphosis inside the sac, after which the young emerge as miniature frogs.

**Brooding in Specialized Structures**

Some amphibians have evolved specialized anatomical structures to carry or incubate their offspring, a highly derived form of parental care.

- **Example**: *Gastrotheca* species (marsupial frogs) possess a dorsal pouch in the female's back where fertilized eggs are placed and develop until hatching.
- **Example**: In *Pipa pipa* (Surinam toad), fertilized eggs are embedded into the skin of the female's back. The skin forms protective capsules around the eggs, where the young develop directly into miniature toads before emerging.
- **Example**: The caecilian *Ichthyophis* not only guards its eggs but also exhibits maternal dermatophagy, where the larvae feed on the mother's skin, which becomes rich in lipids and proteins.

**Viviparity and Direct Development**

In some amphibians, parental care involves internal development of the young, bypassing the free-living larval stage. This is a rare but highly advanced adaptation.

- **Viviparity**: Observed in some caecilians such as *Typhlonectes*, where the young develop inside the oviduct and are born as fully formed juveniles. During development, they feed on secretions or scrape the oviduct lining for nourishment.

- **Direct Development**: Seen in several terrestrial frog species like *Eleutherodactylus*, where eggs develop directly into miniature frogs without a tadpole stage. Such strategies eliminate the vulnerable aquatic larval phase.

### Feeding and Nutritional Provisioning

Although rare, some amphibians provide nourishment to their offspring beyond the yolk supply in the eggs.

- **Example**: In certain poison dart frogs, the female lays unfertilized eggs that are consumed by the developing tadpoles as a nutrient source. This is known as **trophic egg feeding**.
- **Example**: In caecilians, as mentioned earlier, the mother's skin becomes nutrient-rich and is consumed by the larvae in a behavior called **maternal dermatotrophy**.

### Sex Roles in Parental Care

Parental care in amphibians can be male-biased, female-biased, or biparental:

- **Male-dominant care** is more common in species like *Alytes obstetricans* and *Dendrobates*.
- **Female-dominant care** is seen in *Gastrotheca* and *Ichthyophis*.
- **Biparental care**, though rare, exists in some species where both parents cooperate in guarding or transporting eggs and larvae.

This diversity is shaped by ecological pressures, reproductive strategies, and sexual selection.

### Evolutionary Significance of Parental Care in Amphibians

The evolution of parental care in amphibians is a classic example of how reproductive success is maximized in response to environmental constraints and predation. Key evolutionary advantages include:

1. **Increased Offspring Survival**: Protection from predators, desiccation, and infections leads to higher hatching success.
2. **Habitat Flexibility**: Enables reproduction in diverse habitats, including arboreal or terrestrial ecosystems, away from large water bodies.
3. **Reduced Fecundity**: Species that invest in parental care usually lay fewer eggs, but the survival rate per offspring is higher, representing a shift from r-strategy to K-strategy.

4. **Sexual Selection and Mate Choice**: In species where males exhibit care, females may select mates based on their ability to provide protection or transport for the young.

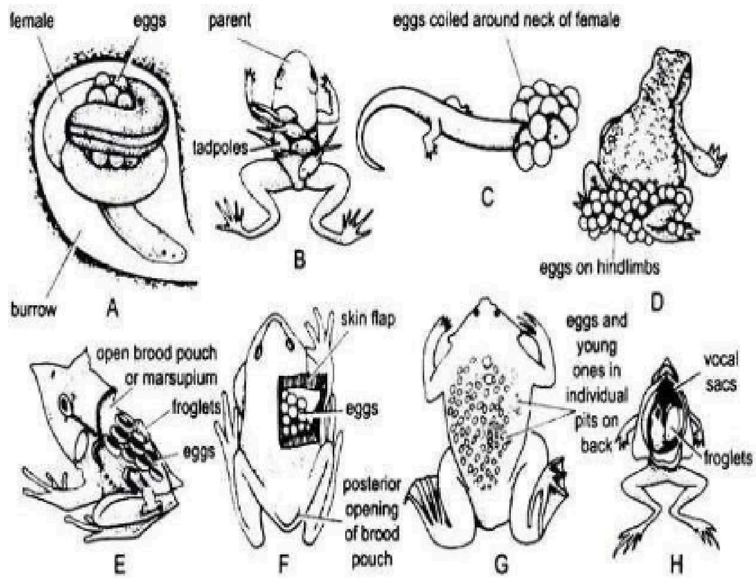



**Fig. 20.2.** Direct parental care in Amphibia. A–Female *Ichthyophis* coiling round eggs; B–Transportation of tadpoles attached to back of a parent; C–*Desmognathus fuscus* with eggs; D–*Alytes obstetricans* carrying eggs around his thighs; E–A marsupial frog with eggs exposed in open brood pouch on back; F–*Nototrema* or *Gastrotheca*, with flap of dorsal brood sac cut open to show eggs; G–In *Pipa*, eggs develop completely into individual capsules on back of female; H–Froglets inside vocal sacs cut open of female *Rhinoderma darwinii*.

Fig: Parental Care in amphibians

**Neoteny in Amphibians**

**Introduction**

Neoteny, also known as **paedomorphosis**, is a fascinating biological phenomenon where an organism retains juvenile or larval characteristics even after attaining sexual maturity. In the animal kingdom, neoteny is most prominently observed among amphibians, especially within certain orders like **Urodela (Caudata)**, which includes newts and salamanders. In these organisms, the adult form may continue to exhibit traits typically associated with the larval stage, such as gills, tail fins, or aquatic habits, even while being reproductively active. This retention of larval traits provides key insights into the processes of evolution, development (ontogeny), and adaptation.

**Definition of Neoteny**

The term **neoteny** is derived from the Greek words *neos* (young) and *teinein* (to stretch or extend), referring to the prolongation of juvenile characteristics into the adult stage. In developmental biology, neoteny is one of the forms of **heterochrony**, which involves changes in the timing of developmental events. More specifically, neoteny refers to the **slowing down or retardation of somatic development** while **sexual development proceeds normally or at an accelerated pace**.

In amphibians, this results in an adult that is **sexually mature but morphologically larval**. This phenomenon is especially common in certain environments where metamorphosis would be disadvantageous due to ecological constraints.

**Types of Neoteny in Amphibians**

Amphibian neoteny can be broadly categorized into two types:

1. **Obligate Neoteny (Permanent Neoteny):**
   This occurs when an organism **never undergoes metamorphosis** and remains in its larval form throughout life. Even though it does not undergo the usual transformation into a terrestrial adult, it reaches sexual maturity and is capable of reproduction. Obligately neotenic species exhibit **fully functional larval features** such as gills and tail fins throughout their lifespan.
   - **Example:** *Necturus maculosus* (Mudpuppy) and *Proteus anguinus* (Olm). These species are entirely aquatic and neotenic throughout their lives.
2. **Facultative Neoteny (Temporary or Partial Neoteny):**
   In facultative neoteny, an organism **may remain neotenic under certain environmental conditions**, but has the potential to metamorphose into a typical adult form if conditions become favorable. This type of neoteny is an **adaptive response** to environmental factors such as temperature, iodine concentration, and habitat stability.
   - **Example:** *Ambystoma tigrinum* (Tiger Salamander). In some populations, individuals may remain aquatic and neotenic, while in others they metamorphose into terrestrial adults.

**Mechanisms Underlying Neoteny**

The mechanisms controlling neoteny in amphibians are both **physiological and environmental**. Some key mechanisms include:

Notes

Vertebrate Physiology

1. **Endocrine Regulation:**
   - The **thyroid gland** plays a central role in amphibian metamorphosis. The hormone **thyroxine (T)** and its active form **triiodothyronine (T)** initiate and control the process of metamorphosis.
   - In neotenic amphibians, there may be a **lack of thyroid hormone secretion**, an **insensitivity of tissues to thyroid hormones**, or **inhibition of the pituitary-thyroid axis**.
   - For instance, neotenic salamanders often show underdeveloped thyroid glands or reduced levels of thyroid-stimulating hormone (TSH).
2. **Environmental Factors:**
   - **Temperature:** Lower temperatures can inhibit thyroid activity, thereby delaying or preventing metamorphosis.
   - **Iodine deficiency:** Iodine is a critical component of thyroid hormones. A lack of iodine in the water can prevent the synthesis of T and T, resulting in neoteny.
   - **Aquatic habitat stability:** In stable aquatic environments, there may be **no selective pressure to leave the water**, favoring neotenic traits.
   - **Oxygen concentration:** In some cases, hypoxic (low oxygen) water conditions favor the development of gills, promoting neoteny.
3. **Genetic Control:**
   - Certain species have **genetic predispositions** for neoteny. For example, the **axolotl** (*Ambystoma mexicanum*) remains permanently neotenic under natural conditions due to a mutation in the gene responsible for initiating metamorphosis. However, under laboratory conditions, metamorphosis can be artificially induced by injecting thyroid hormones.

**Examples of Neotenic Amphibians**

1. **Axolotl (*Ambystoma mexicanum*):**
   Native to lakes near Mexico City, the axolotl remains in its larval form throughout life, retaining external gills and a dorsal fin. It is capable of reproduction while still in this form and is a model organism for studying regeneration and development.
2. **Mudpuppy (*Necturus maculosus*):**
   Found in North American freshwater bodies, this species is permanently aquatic and retains larval traits such as external gills and a laterally compressed tail.

3. **Olm (*Proteus anguinus*):**
   An obligate neotenic amphibian found in the subterranean waters of the Dinaric Alps in Europe. It exhibits adaptations to a cave-dwelling lifestyle, including loss of pigmentation and underdeveloped eyes.

4. **Tiger Salamander (*Ambystoma tigrinum*):**
   This species shows facultative neoteny. In arid or high-altitude environments, it often remains aquatic and neotenic. In more favorable terrestrial conditions, it may metamorphose.

**Significance and Adaptive Value of Neoteny**

Neoteny in amphibians serves several adaptive advantages:

1. **Environmental Specialization:**
   Neoteny allows organisms to **exploit stable aquatic environments** without the need to transition to land, which might be harsh or unpredictable.

2. **Energy Conservation:**
   Metamorphosis is an **energy-intensive process**. By avoiding it, neotenic species conserve energy and resources that can instead be allocated to reproduction and survival.

3. **Reproductive Strategy:**
   Early sexual maturity, even in larval form, allows for **faster reproduction**, which can be advantageous in stable but resource-limited environments.

4. **Evolutionary Insight:**
   Neoteny provides a window into **evolutionary developmental biology (evo-devo)** by showing how changes in developmental timing can lead to significant morphological diversity.

5. **Conservation Relevance:**
   Many neotenic species are **sensitive to environmental changes** such as pollution and habitat destruction, making them important indicators of ecological health.

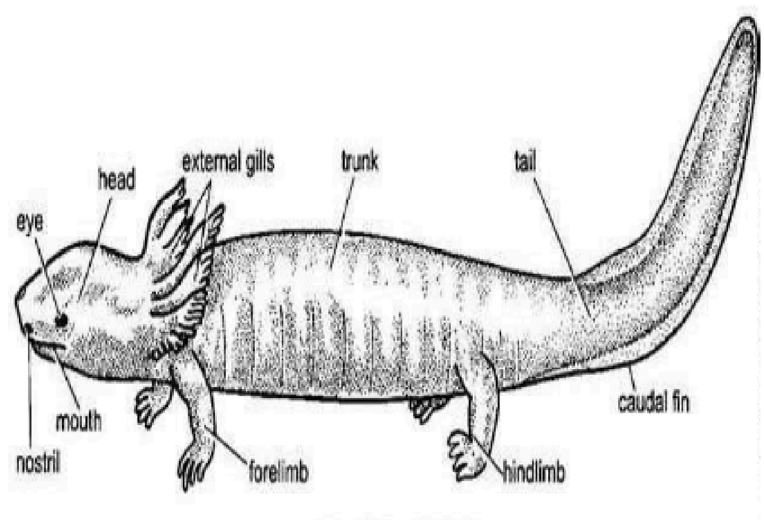



Fig. 19.4. *Necturus.*

Fig: Necturus

## UNIT 6: Reptilia: Poisonous and non- poisonous snakes

### Poison Glands in Reptilia

Among reptiles, a unique adaptation is found in some members of the order **Squamata** (particularly in certain snakes and a few lizards): the development of **poison glands**. These are specialized **modified salivary glands** that secrete toxic substances used primarily for immobilizing prey and, secondarily, for defense. While the majority of reptiles are nonpoisonous, the presence of poison glands in certain groups represents a significant evolutionary advancement for efficient predation.

### Origin and Structure

The poison glands of reptiles are modified labial or salivary glands situated in the upper jaw region. In venomous snakes (such as cobras, vipers, and kraits), these glands are located beneath and behind the eyes, embedded in the upper jaw musculature. The gland itself is **alveolar or tubular** in structure and is surrounded by a strong capsule of connective tissue. From this capsule extend septa that divide the gland into numerous lobules.

The glandular epithelium consists of secretory cells capable of producing a complex mixture of proteins, enzymes, and other bioactive molecules. A welldeveloped **duct system** carries the secretion from the gland to the base of a specialized **grooved or tubular fang**. In frontfanged snakes like cobras and vipers, the duct opens near the tip of the fang, enabling the direct injection of venom into prey. In rearfanged species (opisthoglyphous snakes), the grooves in the posterior maxillary teeth conduct the secretion into the wound as the prey is chewed.

### Mechanism of Venom Delivery

The poison gland is associated with powerful compressor muscles—often termed **compressor glandulae**—derived from the adductor mandibulae externus superficialis. When the snake strikes, these muscles contract sharply, forcing venom through the duct into the fang and finally into the prey's tissues. The entire mechanism is remarkably fast and efficient, representing a fine-tuned predatory adaptation.

### Composition of Venom

Venom produced by these glands is a complex cocktail of enzymes (such as phospholipases, proteases, and hyaluronidase), polypeptides, and other toxins. Depending on the species, the venom may be:

- **Neurotoxic** – primarily affecting the nervous system, leading to paralysis (e.g., in cobras and kraits).
- **Hemotoxic** – destroying blood cells and tissues, causing hemorrhage and necrosis (e.g., in vipers and pit vipers).
- **Cytotoxic or myotoxic** – causing extensive local tissue damage.

The adaptive value of venom lies in its ability to rapidly subdue active or dangerous prey and initiate the process of digestion even before swallowing.

**Lizard Venom Glands**

While most lizards are nonvenomous, certain species like the **Gila monster** (*Heloderma suspectum*) and the **Mexican beaded lizard* (*Heloderma horridum*) also possess venom glands in their lower jaws. In these lizards, the venom is delivered through grooved teeth, but the mechanism is less efficient than in advanced snakes.

**Functional and Evolutionary Significance**

The development of poison glands marks a major evolutionary step in reptilian predation. By chemically immobilizing prey, venomous reptiles minimize the risk of injury from struggling or aggressive animals. This adaptation has allowed these reptiles to occupy ecological niches where rapid prey subjugation is essential. Over evolutionary time, venom systems have diversified, leading to a wide variety of toxic compounds, some of which have become invaluable in biomedical research and drug development.

**Types of Venom in Reptiles**

Venom is a complex secretion containing a cocktail of enzymes, toxins, and other bioactive compounds. The composition and action of venom vary depending on the species and ecological adaptations. Based on their primary physiological effects, **venoms are categorized into several types**:

**1. Neurotoxic Venom**

- **Action**: Affects the nervous system by blocking synaptic transmission, paralyzing respiratory muscles, and ultimately causing death due to asphyxiation.
- **Mechanism**: Interferes with acetylcholine release or receptor binding at neuromuscular junctions.
- **Example Species**:
    - **Elapidae family**: Cobras (*Naja*), kraits (*Bungarus*), mambas (*Dendroaspis*).

- **Symptoms in prey/humans**: Ptosis (drooping eyelids), blurred vision, difficulty breathing, respiratory failure.
- **Medical Use**: Some neurotoxins are studied for potential applications in neurology and anesthesia.

**2. Hemotoxic Venom**

- **Action**: Damages blood cells, disrupts blood clotting, and breaks down capillary walls, leading to hemorrhage and tissue necrosis.
- **Mechanism**: Contains enzymes such as proteases and metalloproteinases that degrade cellular components.
- **Example Species**:
    - **Viperidae family**: Russell's viper (*Daboia russelii*), saw-scaled viper (*Echis carinatus*).
- **Symptoms in prey/humans**: Swelling, intense pain, internal bleeding, blood clotting disorders, kidney damage.
- **Medical Use**: Certain hemotoxins are used in blood pressure research and anticoagulant drug development.

**3. Cytotoxic Venom**

- **Action**: Destroys local cells and tissues at the bite site.
- **Mechanism**: Includes phospholipases and other enzymes that rupture cell membranes and cause necrosis.
- **Example Species**: Spitting cobras (*Naja nigricollis*) and some vipers.
- **Symptoms**: Severe tissue damage, blistering, gangrene, and in severe cases, limb amputation if untreated.
- **Note**: This venom type is often accompanied by either neurotoxic or hemotoxic components.

**4. Myotoxic Venom**

- **Action**: Specifically targets muscle cells, leading to muscle breakdown (rhabdomyolysis).
- **Mechanism**: Disrupts muscle cell membranes and mitochondrial function.
- **Example Species**: Some sea snakes and Australian elapids.
- **Symptoms**: Muscle pain, weakness, dark-colored urine due to myoglobin release, possible kidney failure.

**5. Cardiotoxic Venom**

- **Action**: Affects the heart muscle directly, causing arrhythmias or cardiac arrest.

**Notes**

- **Mechanism**: May act by modulating ion channels in cardiac tissue.
- **Example**: Rare in most snakes but observed in some elapids and sea snakes.

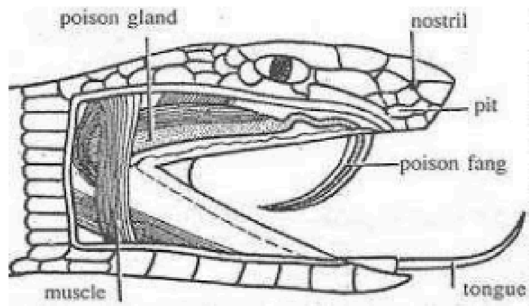



Fig: Poison apparatus in snake

**Antivenin (Cure of Snake Bite):**The best cure for snake bite is an antivenom serum or antivenin which is injected into the body of the victim to counteract snake venom. Different antivenins are required against different snakes due to differences in the qualities of their venoms. An antivenin is prepared by injecting a horse with gradually increasing doses of a snake venom until the horse becomes fully immunized to any amount of venom injected. Now blood serum of horse is collected and preserved. This is antivenom serum or antivenin which has developed sufficient antibodies to neutralize the effect of that particular snake venom.

## Notes

**Reptilia: Poisonous and non- poisonous snakes**

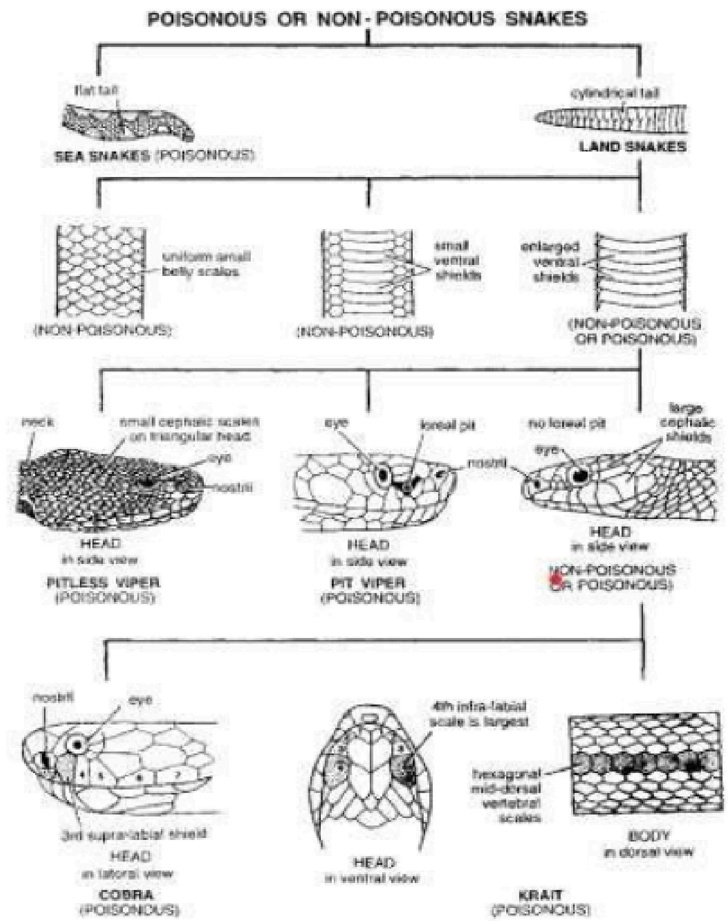


*Table I.* **Key to Identify Poisonous from Non-poisonous Snakes of India.**

| Structures | | Characters | Nature | Snakes |
|---|---|---|---|---|
| 1. Tail | (a) | Tail laterally compressed, oar-like | Poisonous | Sea snakes *Hydrophis, Enhydrina* |
| | (b) | Tail cylindrical, tapering | Poisonous or nonpoisonous Examine further | Land snakes |
| 2. Belly scales or ventrals | (a) | Belly scales small, continuous with dorsals | Non-poisonous | |
| | (b) | Ventrals not fully broad to cover belly | Non-poisonous | Pythons |
| | (c) | Ventrals broad, fully covering belly | Examine further | |
| 3. Head scales, loreal pit, sub-caudals | (a) | Head scales small. Head triangular. No loreal pit | Poisonous | Pitless vipers |
| | | (i) Subcaudals double | " | *Vipera russelli* |
| | | (ii) Subcaudals single | " | *Echis carinata* |
| | (b) | Head scales small. A loreal pit present between nostril and eye | Poisonous | Pit vipers *Lachesis, Ancistrodon* |
| | (c) | Head with large shields. No loreal pit | Examine further | |
| 4. Vertebrals, 4th infralabial, 3rd supralabial | (a) | Vertebrals enlarged, hexagonal 4th infra-labial largest | Poisonous | Krait, *Bungarus* |
| | (b) | Vertebrals not enlarged. 3rd supra-labial touches eye and nostril | Poisonous | |
| | | (i) Neck with a hood and spectacle mark | " | Cobra, *Naja* |
| | | (ii) Hood absent. Coral spots on belly | " | Coral snakes, *Callophis* |
| | (c) | No such characters | Nonpoisonous | |

**Question Bank:**

**Very Short Answer Questions (VSAQ)**

(Answer in one or two sentences)

1. Name the different types of fish scales.
2. What is the main function of mucus on fish skin?
3. Define anadromous and catadromous migration.
4. Give one example of a fish that shows parental care.
5. What is neoteny?
6. Name an amphibian that exhibits neoteny.
7. Mention any two methods of parental care in amphibians.
8. Name one poisonous and one non-poisonous snake.
9. What is the role of Jacobson's organ in snakes?
10. What kind of fangs do vipers have?

**Short Answer Questions (SAQ)**

(Answer in about 60–80 words)

1. Describe the structure and function of fish skin.

2. Write a short note on different types of fish scales.
3. Differentiate between cycloid and ctenoid scales.
4. Explain the importance of fish migration. Give examples.
5. Describe any two parental care behaviors in fishes.
6. What is neoteny? How does it benefit amphibians?
7. Explain two examples of parental care in amphibians.
8. How do poisonous and non-poisonous snakes differ in dentition?
9. Explain the mechanism of venom delivery in snakes.
10. Write a note on the structure and function of snake fangs.

**Long Answer Questions (LAQ)**

(Answer in about 150–200 words or more)

1. Describe the structure of fish skin and the different types of scales with labeled diagrams.
2. Discuss migratory behavior in fishes. Distinguish between anadromous and catadromous migration with examples.
3. Explain various types of parental care observed in fishes with suitable examples.
4. What is neoteny in amphibians? Discuss its causes and evolutionary significance.
5. Describe in detail the various parental care mechanisms found in amphibians.
6. Explain the differences between poisonous and non-poisonous snakes with reference to their fangs, belly scales, and head structure.
7. Describe the venom apparatus in snakes. Add diagrams to support your answer.
8. Discuss the classification of snake venom and its physiological effects.
9. Compare parental care in fishes and amphibians with examples.
10. Write an account on adaptations in fishes, amphibians, and reptiles for their respective environments.

## MODULE III:

## VERTEBRATA II

**Objectives:**

- Study the general characters and classification of Amphibia, Reptilia, Aves, and Mammalia.
- Understand adaptive modifications in skin, limbs, and respiratory systems across these groups.
- Examine evolutionary trends leading from amphibians to reptiles, and from reptiles to birds and mammals.
- Identify flight adaptations in birds and parental care strategies in amphibians and reptiles.
- Compare excretory, circulatory, and nervous systems across major vertebrate classes.
- Develop comparative analytical skills in identifying homologous structures.

## UNIT 7: Aves: Flight adaptations in birds

### Flight Adaptation in Birds

Flight in birds represents one of the most extraordinary evolutionary achievements in the animal kingdom. Birds, as members of class Aves, have evolved a wide array of morphological, physiological, and behavioral features that enable them to take to the skies. The evolutionary drive for flight has shaped virtually every aspect of a bird's anatomy and metabolism. The adaptations observed in birds are not singular features, but a coordinated complex of modifications that together reduce body weight, enhance aerodynamic efficiency, increase muscular power, and ensure high metabolic output.

### Morphological Adaptations

#### a) Feathers and Body Contour

Feathers are perhaps the most distinctive adaptation for flight. They are lightweight, yet strong, and provide the necessary surface area for lift and propulsion. The two main types of flight feathers are:

- *Remiges* (wing feathers): These aid in propulsion and lift.
- *Rectrices* (tail feathers): These assist in steering and stability.

The contour of the bird's body is streamlined (fusiform), reducing air resistance. The arrangement of feathers contributes to this aerodynamic shape, allowing smooth airflow over the body during flight.

#### b) Wings as Modified Forelimbs

Birds' forelimbs are highly modified into wings, which act as the primary organs of flight. The wing structure includes:

- A humerus, radius, and ulna adapted for support.
- Fused carpal and metacarpal bones to provide rigidity.
- Elongated and stiff primary feathers anchored to the hand and secondaries attached to the forearm.

The wing operates as an airfoil, generating lift through differences in air pressure above and below the wing surface.

#### c) Lightweight Skeleton

One of the most critical adaptations is skeletal lightness. Birds possess:

- Pneumatized (air-filled) bones that reduce weight without sacrificing strength.
- A large, keeled sternum (carina) to support flight muscles.

- Fused bones (e.g., synsacrum, pygostyle, furcula) which enhance rigidity and efficiency during flight.
- Reduction in the number of bones, such as in the tail and digits.

**d) Beak Without Teeth**

Birds have evolved toothless beaks, which are significantly lighter than a jaw with teeth. Beaks vary in shape and size depending on diet, but all contribute to weight reduction, facilitating flight.

**Muscular Adaptations**

Flight requires an immense amount of muscular power, particularly from the pectoral region.

**a) Powerful Pectoral Muscles**

- The *pectoralis major* is the largest flight muscle, responsible for the downstroke during flight, accounting for up to 25–35% of the bird's body mass.
- The *supracoracoideus* muscle, located just beneath the pectoralis, is responsible for the upstroke. It uses a pulley system formed by the coracoid bone and triosseal canal to lift the wings efficiently.

These muscles are anchored on the large keel of the sternum, providing maximum leverage for wing movement.

**Respiratory Adaptations**

Flight demands a highly efficient respiratory system to meet oxygen requirements.

**a) Air Sac System**

Birds possess an advanced respiratory system that includes:

- A set of nine air sacs connected to the lungs.
- Unidirectional airflow through the lungs, ensuring a continuous supply of fresh, oxygen-rich air.
- Air sacs also help in thermoregulation and reduce body weight.

**b) Parabronchial Lungs**

Unlike the alveolar lungs of mammals, bird lungs are small and rigid, consisting of parabronchi. Gas exchange occurs continuously during both inhalation and exhalation, ensuring a highly efficient oxygen uptake vital for sustaining flight.

## Circulatory Adaptations

To supply sufficient oxygen and nutrients to flight muscles, birds have a highly adapted circulatory system.

### a) Large Four-Chambered Heart

- Birds have a large, powerful heart relative to their body size, often twice as large as a mammal's of similar mass.
- The four-chambered heart ensures complete separation of oxygenated and deoxygenated blood, increasing metabolic efficiency.

### b) High Blood Pressure and Rapid Circulation

- A high cardiac output allows rapid delivery of oxygen and glucose to tissues.
- The resting and active heart rates of birds are significantly higher than in most vertebrates, supporting their high energy demands.

## Digestive and Excretory Adaptations

To reduce weight and allow for high metabolic turnover, birds show unique modifications in their digestive and excretory systems.

### a) Rapid Digestion and High Metabolic Rate

- Birds digest food quickly to obtain energy rapidly and avoid carrying excess weight.
- Some birds (like hummingbirds) feed constantly due to their high metabolic rate during flight.

### b) No Urinary Bladder

- Birds excrete nitrogenous waste as uric acid, which is semi-solid and requires minimal water, reducing body mass.
- The absence of a urinary bladder prevents accumulation of waste, further conserving weight.

## Nervous and Sensory Adaptations

Flight requires excellent coordination, balance, and vision.

### a) Large Cerebellum and Optic Lobes

- The cerebellum is well-developed for coordinating muscular movements and maintaining balance during complex aerial maneuvers.

- Enlarged optic lobes process visual information rapidly, which is crucial for navigation and obstacle avoidance.

**b) Keen Vision**

- Birds possess acute eyesight, often with binocular or panoramic vision depending on the species.
- The presence of a pecten (a vascular structure in the eye) helps nourish the retina without obstructing vision, enhancing clarity.

**Reproductive Adaptations**

Minimizing body weight extends even to reproductive biology.

**a) Seasonal Gonads**

- Gonads enlarge only during the breeding season and shrink afterward to reduce body mass.
- Most female birds have only one functional ovary (left), reducing weight.

**Behavioral and Ecological Adaptations**

Behavior also plays a key role in enhancing flight efficiency.

**a) Migratory Behavior**

Many birds migrate long distances to exploit seasonal food sources and breeding grounds. Their bodies are adapted for endurance flight with features such as:

- Increased fat reserves before migration.
- Changes in muscle and organ size during long flights.

**b) Flight Patterns and Wing Types**

Birds exhibit different flight styles (gliding, flapping, soaring, hovering), each supported by wing shapes:

- Elliptical wings (e.g., sparrows) offer maneuverability in forests.
- High aspect ratio wings (e.g., albatrosses) are suited for soaring over oceans.
- Hovering wings (e.g., hummingbirds) allow stationary flight.

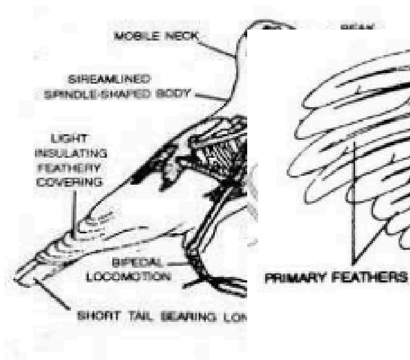



Fig. 6.1. Stream-lined b

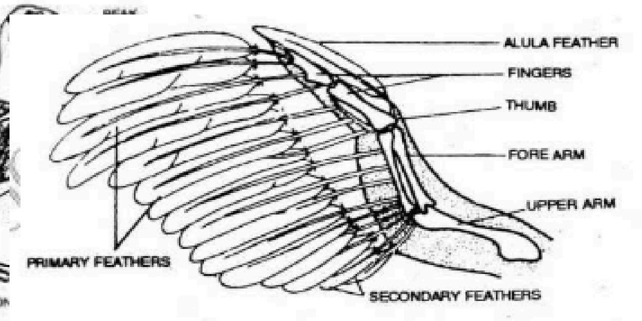



Fig. 6.2. A wing

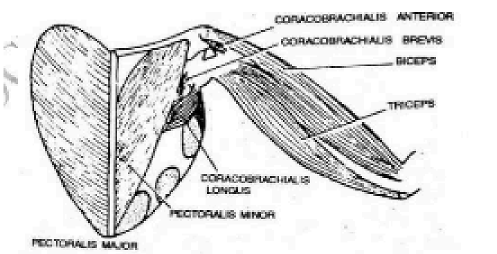



Fig. 6.3. Flight muscles.

Notes

**Aves: Flight adaptations in birds**

## UNIT 8: Birds as Glorified reptiles

### Introduction

The idea of birds being "glorified reptiles" is one of the most fascinating concepts in evolutionary biology and vertebrate zoology. This notion, first popularized by Thomas Huxley in the 19th century, is supported today by a wealth of fossil, anatomical, embryological, and molecular evidence. Understanding how birds evolved from reptiles—more specifically, from a group of theropod dinosaurs—offers deep insights into the processes of evolution, adaptation, and functional morphology.

### Evolutionary Background

Birds (class *Aves*) are now universally accepted as the direct descendants of a particular lineage of bipedal, carnivorous dinosaurs called theropods, which fall within the clade *Dinosauria* of the phylum Chordata. This lineage includes well-known dinosaurs like *Velociraptor* and *Tyrannosaurus rex*. Among theropods, a group known as maniraptorans shows the closest relationship to modern birds. The transition from non-avian theropods to avian forms occurred during the Mesozoic Era, primarily in the Jurassic period, and is best documented by fossils such as *Archaeopteryx*.

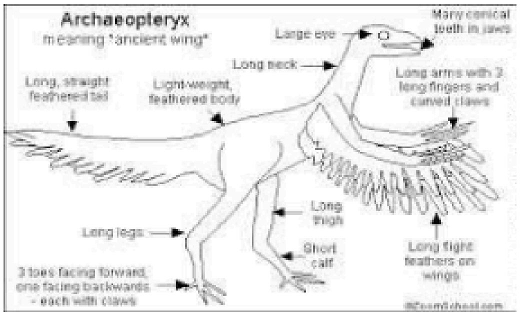
The term "glorified reptiles" refers to the fact that birds, while distinct in many ways due to their flight adaptations and endothermy (warm-bloodedness), retain many characteristics that are unmistakably reptilian in origin. In essence, birds are reptiles that have undergone significant evolutionary specialization.

### Fossil Evidence – The Case of *Archaeopteryx*

The discovery of *Archaeopteryx lithographica* in the late 19th century in the Solnhofen limestone of Germany provided the first clear evidence linking birds to reptiles. This transitional fossil, dated to around 150 million years ago, exhibits a mixture of avian and reptilian features:

- **Avian features**: feathers, wings, furcula (wishbone), and a lightly built skeleton.
- **Reptilian features**: toothed jaws, a long bony tail, clawed fingers, and abdominal ribs.

This mosaic of characters makes *Archaeopteryx* a classic example of a transitional fossil, bridging the gap between non-avian dinosaurs and modern birds. Subsequent discoveries of feathered dinosaurs in China, such as *Microraptor*, *Caudipteryx*, and *Sinosauropteryx*, further solidified the dinosaur-bird connection.




**Anatomical Similarities Between Birds and Reptiles**

Modern birds share numerous structural features with reptiles, particularly with their theropod ancestors. These similarities include:

- **Skeletal Structure**: Birds have a diapsid skull like reptiles, with two temporal openings. Their limb bones and digits, especially in the hindlimbs, mirror those of theropod dinosaurs.
- **Vertebral Column and Tail**: Both reptiles and early birds like *Archaeopteryx* have a long tail composed of individual vertebrae. In modern birds, the tail has become shortened and fused into a pygostyle.
- **Scales**: While birds have feathers, their legs and feet are covered in scales made of keratin, similar to those of reptiles.
- **Cloaca**: Birds and reptiles share a common opening for the digestive, excretory, and reproductive tracts known as the cloaca.
- **Reproduction**: Both are oviparous (egg-laying), and their eggs are encased in a hard, calcified shell.
- **Nucleated Red Blood Cells**: Unlike mammals, both reptiles and birds have red blood cells with nuclei.

**Feathers: A Reptilian Legacy?**

Feathers, once considered unique to birds, are now known to have evolved in non-avian dinosaurs. Fossils of theropods such as *Velociraptor* and *Anchiornis* show various stages of feather development, from simple filaments to complex structures with barbs and vanes. It is now understood that feathers likely evolved for purposes such as insulation, display, and species recognition before they were adapted for flight. Thus, feathers are modified reptilian scales, showcasing an excellent example of evolutionary repurposing.

**Physiological and Behavioral Evidence**

Beyond anatomy, birds share many physiological and behavioral traits with reptiles:

- **Egg-laying and Parental Care**: Like many reptiles, birds lay eggs. However, birds exhibit far more advanced parental care, including incuba-

## Notes

**Birds as Glorified reptiles**

tion and feeding of the young—practices that are also seen in some dinosaur fossils.

- **Metabolic Features**: Birds are endothermic, unlike most reptiles, which are ectothermic. However, recent studies suggest that some theropod dinosaurs had elevated metabolic rates, hinting at a possible transition to endothermy.
- **Lung Structure and Air Sacs**: Both birds and theropods have a unique flow-through lung system aided by air sacs, allowing highly efficient gas exchange. This system is distinct from the tidal lung system of mammals and evolved to support high activity levels, such as flight or active predation.
- **Sleeping Postures and Nesting Behavior**: Fossils of dinosaurs like *Mei long* show bird-like sleeping postures, with the head tucked under the wing, and others demonstrate evidence of brooding behavior—sitting on nests to incubate eggs—just like modern birds.

**Genetic and Embryological Evidence**

Advances in molecular biology have further confirmed the deep evolutionary link between birds and reptiles. Comparative genomics shows that birds share a high degree of DNA similarity with crocodilians, their closest living relatives among reptiles. Both birds and crocodilians belong to the group Archosauria, which also includes extinct dinosaurs.

Embryological studies also support this relationship. For instance, bird embryos show the development of a long tail and digits in the forelimb, which later regress or fuse into the structures seen in adult birds. These developmental patterns mirror those of reptilian embryos, particularly theropods.

**Transformation from Reptile to Bird**

The evolutionary transition from reptile to bird involved several major modifications:

- **Forelimbs into Wings**: The forelimbs became adapted for flight, with elongated digits supporting feathers.
- **Reduction of Teeth**: Most modern birds have beaks without teeth, although ancestral birds had toothy jaws.
- **Fusion of Bones**: Many skeletal elements, such as the clavicles (forming the furcula) and vertebrae, became fused to reduce weight and increase strength.
- **Enhanced Sensory Systems**: Birds developed keen vision, a large brain relative to body size, and specialized balance organs—critical for flight.
- **Flight Musculature**: The development of a keeled sternum provided an anchor for powerful flight muscles.

## Unit 9: Mammals: comparative account of prototheria, metatheria and eutheria

### Mammals: An Overview

Mammals are a class of vertebrate animals belonging to the phylum Chordata and subphylum Vertebrata, under the class Mammalia. They are highly evolved, warm-blooded (endothermic) animals that are characterized by the presence of mammary glands, which are specialized for the production of milk to nourish their young. Mammals are distributed across almost all types of terrestrial and aquatic habitats and exhibit remarkable adaptations that contribute to their evolutionary success. The class Mammalia includes a vast range of animals from tiny shrews to enormous whales, and it encompasses over 6,400 known species.

The term "mammal" is derived from the Latin word *mamma*, meaning breast, highlighting one of their most defining features—lactation. Fossil records indicate that mammals evolved from synapsid ancestors during the late Triassic period, approximately 200 million years ago. These early mammals were small, nocturnal, insectivorous creatures that gradually diversified after the extinction of the non-avian dinosaurs at the end of the Cretaceous period.

### General Characteristics of Mammals

Mammals exhibit several unique anatomical and physiological traits. One of the most prominent features is the presence of hair or fur, composed of keratin, which provides insulation and plays roles in sensory perception and camouflage. The skin contains various glands, including sweat glands that aid in thermoregulation, sebaceous glands that produce oils, and the aforementioned mammary glands in females.

Another distinguishing feature is the presence of a neocortex in the brain, which is involved in higher-order brain functions such as sensory perception, cognition, and motor command. Mammals have a four-chambered heart that ensures complete separation of oxygenated and deoxygenated blood, which supports their high metabolic rate. The respiratory system includes a diaphragm, a muscular partition that assists in efficient ventilation of the lungs. The circulatory and respiratory systems are intricately coordinated to sustain the energy demands of endothermy.

Skeletal and dental characteristics are also highly specialized. Most mammals possess a heterodont dentition, meaning they have teeth of different shapes and functions—incisors, canines, premolars, and molars. This dental specialization is closely linked to their dietary adaptations. The lower jaw is composed of a single bone, the dentary, which articulates directly with the squamosal part of the skull, a trait that differentiates mammals from reptiles. The three ossicles of the middle ear—the malleus, incus, and stapes—are another mammalian innovation, derived from the bones of the jaw and contributing to acute hearing.

### Comparative Account of Prototheria, Metatheria, and Eutheria

Mammals, the warm-blooded vertebrates characterized by the presence of mammary glands, body hair, and a well-developed brain, are divided into three major groups based on their reproductive structures, modes of development, and evolutionary features. These three subdivisions are **Prototheria (monotremes)**, **Metatheria (marsupials)**, and **Eutheria (placental mammals)**. Each of these groups represents a significant evolutionary pathway in mammalian history and showcases diverse adaptations in morphology, physiology, and embryology.

### Prototheria: The Primitive Egg-laying Mammals

**Prototheria**, commonly referred to as **monotremes**, represent the most primitive group of living mammals. They are unique in being the only extant mammals that lay eggs instead of giving birth to live young. This group includes species such as the **platypus (Ornithorhynchus anatinus)** and **echidnas or spiny anteaters (genus Tachyglossus and Zaglossus)**, all of which are native to **Australia and New Guinea**.

Anatomically, prototherians exhibit a combination of reptilian and mammalian features. One of their most distinguishing traits is the **cloaca**, a single opening for excretion and reproduction, reminiscent of reptiles and birds. Unlike the more advanced mammals, prototherians **lack nipples**; instead, they secrete milk through specialized mammary gland ducts that open directly onto the skin or into shallow grooves where the young lap it up. The skeletal structure of the skull and pectoral girdle in prototherians also retains many primitive characteristics. For example, their pectoral girdle includes elements such as the **coracoid and interclavicle**, bones typically found in reptiles.

Developmentally, prototherians lay **leathery-shelled eggs** and exhibit external embryonic development. The young are hatched in a relatively undeveloped state and are dependent on maternal care for an extended period. The **absence of a true placenta** is a hallmark of the group, which sets them apart from other mammals.

### Metatheria: The Intermediate Marsupials

**Metatheria**, commonly known as **marsupials**, represent an intermediate stage in mammalian evolution between the egg-laying monotremes and the more advanced placental mammals. Marsupials are best known for their mode of reproduction, where the young are born at a very early stage of development and are then carried and suckled in an external pouch called the **marsupium**. This group is especially diverse in **Australia**, where they occupy a wide range of ecological niches, but some species like **opossums** are also found in **North and South America**.

Marsupials give birth to **altricial young**, meaning the offspring are extremely immature at birth. Despite the absence of a complex placenta like in eutherians, marsupials possess a **choriovitelline placenta**, which is less efficient and temporary. After a brief gestation period, the neonates crawl into the marsupium and latch onto a nipple, where they continue their development for several weeks or months. The marsupium is not universal among marsupials; in some species, it is reduced or even absent.

Morphologically, marsupials differ from both prototherians and eutherians in several skeletal and dental features. They typically possess a larger number of incisors and have a unique pattern of tooth replacement. Their brain is generally less convoluted compared to eutherians, indicating relatively simpler neural development.

Marsupials are considered adaptive radiators, meaning they have diversified into many forms to fill a variety of ecological roles. Examples include the **kangaroo (Macropus)**, **koala (Phascolarctos)**, **wombat (Vombatus)**, and the **Tasmanian devil (Sarcophilus)**.

### Eutheria: The Advanced Placental Mammals

**Eutheria**, or **placental mammals**, constitute the most diverse and widespread group of mammals, with representatives found in nearly every terrestrial and aquatic ecosystem on Earth. This group includes humans, elephants, whales, bats, rodents, and carnivores, among many others. The key distinguishing feature of eutherians is the presence of a **complex and long-lasting placenta**, which enables extended internal development of the embryo.

Eutherian mammals exhibit **viviparous reproduction**, where fertilization and the entire development of the embryo occur inside the mother's uterus. The placenta facilitates nutrient exchange, gas exchange, and waste elimination between the mother and the developing embryo. This results in a **prolonged gestation period** and the birth of relatively well-developed offspring. Consequently, the need for a marsupium or postnatal pouch is eliminated.

Anatomically, eutherians possess several advanced characteristics. Their **brain is highly developed**, with increased cortical folding and compartmentalization. The **skull structure is more compact**, and they possess a single bone in the lower jaw—the **dentary**—which articulates directly with the squamosal bone of the skull. The **mammary glands** are well developed and equipped with nipples, ensuring efficient nursing.

Eutherians exhibit tremendous variation in body size, locomotion, dietary habits, and reproductive strategies. They have diversified into several orders such as **Primates**, **Carnivora**, **Cetacea**, **Chiroptera**, and **Rodentia**, making them the most ecologically successful group of mammals.

### Evolutionary Significance and Adaptational Trends

The evolutionary trajectory from prototherians to metatherians and finally to eutherians illustrates the increasing complexity in reproductive strategies and physiological adaptations. Prototherians represent the basal stock, retaining many ancestral traits such as egg-laying, a cloaca, and reptilian skeletal features.

Metatherians demonstrate a partial evolutionary advancement with internal fertilization, a rudimentary placenta, and postnatal care through the marsupium. Eutherians have perfected viviparity with the evolution of a fully functional placenta, allowing them to occupy a broader range of habitats and ecological niches.

One of the evolutionary advantages seen in eutherians is the ability to produce fewer but more viable and independent offspring, as compared to the high dependence and vulnerability of marsupial neonates. Furthermore, the development of the placenta in eutherians is considered a major adaptive innovation, enabling more effective maternal-fetal interaction and control over gestational timing.

Table: Comparative account of Prototheria, Metatheria and Eutheria

| **Feature** | **Prototheria (Monotremes)** | **Metatheria (Marsupials)** | **Eutheria (Placentals)** |
|---|---|---|---|
| **Representative Animals** | Platypus, Echidnas | Kangaroos, Koalas, Opossums | Humans, Dogs, Elephants, Whales |
| **Geographical Distribution** | Australia, New Guinea | Australia, Americas | Worldwide |
| **Reproduction** | Oviparous (lay eggs) | Viviparous with short gestation | Viviparous with long gestation |
| **Egg/Embryo Development** | Eggs with leathery shell; external incubation | Embryo born at early stage, completes development in pouch | Embryo develops fully inside uterus |
| **Placenta Type** | Absent | Yolk-sac placenta (primitive) | Chorio-allantoic placenta (complex) |
| **Nipples** | Absent (milk secreted through skin) | Present, inside pouch or exposed | Well-developed nipples |
| **Young at Birth** | Hatch as very immature young | Born highly altricial | Born relatively developed |
| **Parental Care** | Yes, with incubation and milk feeding | Extended care in pouch | Extended care, but without pouch |
| **Cloaca** | Present (single opening for excretion and reproduction) | Partially divided, but present | Absent (separate urinary, reproductive, and anal openings) |
| **Brain Structure** | Small, no corpus callosum | Moderately developed, rudimentary corpus callosum | Large, with well-developed corpus callosum |
| **Dentition** | Absent in adults or rudimentary; horny plates | Varied and often complex | Highly specialized for diet (heterodont) |
| **Epipubic Bones** | Present | Present | Absent |

| | | | |
|---|---|---|---|
| **Mammary Glands** | Without teats; milk secreted onto skin | With teats, often inside marsupium | With teats, well-developed |
| **Limb Posture** | Sprawling or semi-erect | Erect, adapted for hopping/climbing | Erect, highly varied (running, flying, swimming, etc.) |
| **Adaptive Radiation** | Limited | Moderate | Extensive across all ecological niches |

**Question Bank:**

**Long Answer Questions (LAQs)**

1. Explain the various anatomical and physiological adaptations in birds that enable them to fly.
2. Discuss how birds exhibit reptilian features, justifying the statement "Birds are glorified reptiles."
3. Compare the major characteristics of Prototheria, Metatheria, and Eutheria with respect to reproduction, development, and anatomy.
4. Give an account of the skeletal and muscular modifications in birds that facilitate flight.
5. Describe how the evolutionary link between reptiles and birds is supported by fossil and anatomical evidence.
6. Prepare a comparative table showing distinguishing features of Prototheria, Metatheria, and Eutheria.
7. Explain the role of the avian respiratory and circulatory systems in supporting high metabolic demands of flight.
8. Trace the evolutionary significance of birds and mammals from reptilian ancestors.

**Short Answer Questions (SAQs)**

1. What is the role of pneumatic bones in bird flight?
2. State any four reptilian characters retained in birds.
3. Distinguish between Metatheria and Eutheria with two examples each.
4. How does a bird's four-chambered heart contribute to efficient oxygen supply during flight?
5. Mention any two anatomical features that support the idea that birds evolved from reptiles.

6. List three features of Prototherians that make them primitive among mammals.
7. Why are marsupials mostly found in Australia?
8. Write a short note on the evolutionary importance of Archaeopteryx.
9. How do Metatherian mammals care for their young after birth?
10. State the function of alula in flight.

**Very Short Answer Questions (VSAQs)**

1. Which of the following is a flight muscle in birds?
2. Name one egg-laying mammal.
3. Birds evolved from which group of reptiles?
4. What is the function of the keeled sternum in birds?
5. Which subclass of mammals has a placenta?
6. Archaeopteryx had teeth and feathers. True/False?
7. Define "Marsupium."
8. Which group has the most advanced brain and parental care?
9. Which organ in birds allows unidirectional airflow?
10. Name any one-character common to both reptiles and birds.

## MODULE IV

## INTRODUCTION TO EMBRYOLOGY



**Objectives:**

- Define embryology and explain its scope in biological sciences.
- Study gametogenesis (spermatogenesis and oogenesis) and fertilization events.
- Understand cleavage, blastulation, and gastrulation with reference to chick and frog embryos
- Learn the formation of three primary germ layers and their significance.
- Analyze the role of yolk distribution in patterns of cleavage.
- Develop interpretation skills using embryological slides and diagrams.

**UNIT 10: Gametogenesis, Fertilization and Parthenogenesis**

## Gametogenesis

### Introduction

Gametogenesis is the biological process through which diploid precursor cells undergo cellular and nuclear changes to form mature haploid gametes—spermatozoa in males and ova in females. This process is essential for sexual reproduction, as it ensures the maintenance of chromosome number across generations and contributes to genetic variability through recombination and independent assortment.

The term *gametogenesis* encompasses two distinct but related processes:

1. **Spermatogenesis** – formation of male gametes (sperm).
2. **Oogenesis** – formation of female gametes (ova or eggs).

Both processes occur through meiotic cell division, but they differ significantly in timing, cellular mechanisms, and outcomes. Gametogenesis begins during embryonic development with the formation of **primordial germ cells (PGCs)** and concludes at sexual maturity, when mature gametes are produced.

### Primordial Germ Cells and Migration

Gametogenesis originates from a small population of cells known as **primordial germ cells**. These cells are specified early in embryonic development. In mammals, PGCs are first recognized in the yolk sac or epiblast region and later migrate through the developing embryo to the **gonadal ridges**, the precursors of testes and ovaries.

Once in the gonads, PGCs undergo mitotic divisions to increase in number. They eventually differentiate into **spermatogonia** in males and **oogonia** in females. These cells are still diploid (2n) at this stage and serve as the foundational stem cells for further gamete development.

### Spermatogenesis

Spermatogenesis occurs in the seminiferous tubules of the testes and continues throughout the reproductive life of a male. It can be broadly divided into three sequential phases:

#### 1. Multiplication Phase

In this phase, spermatogonia (diploid stem cells) located at the basal membrane of the seminiferous tubules undergo multiple rounds of **mitotic divisions** to maintain the germ cell pool. Some spermatogonia remain as stem cells (type A cells), while others differentiate into type B spermatogonia, which are committed to becoming sperm.

**2. Growth Phase**

Type B spermatogonia enlarge and become **primary spermatocytes**. This stage involves an increase in cytoplasmic volume and duplication of DNA, preparing the cells for meiotic division. Primary spermatocytes are still diploid (2n), but each chromosome has two sister chromatids.

**3. Maturation Phase**

The maturation phase includes **two successive meiotic divisions**:

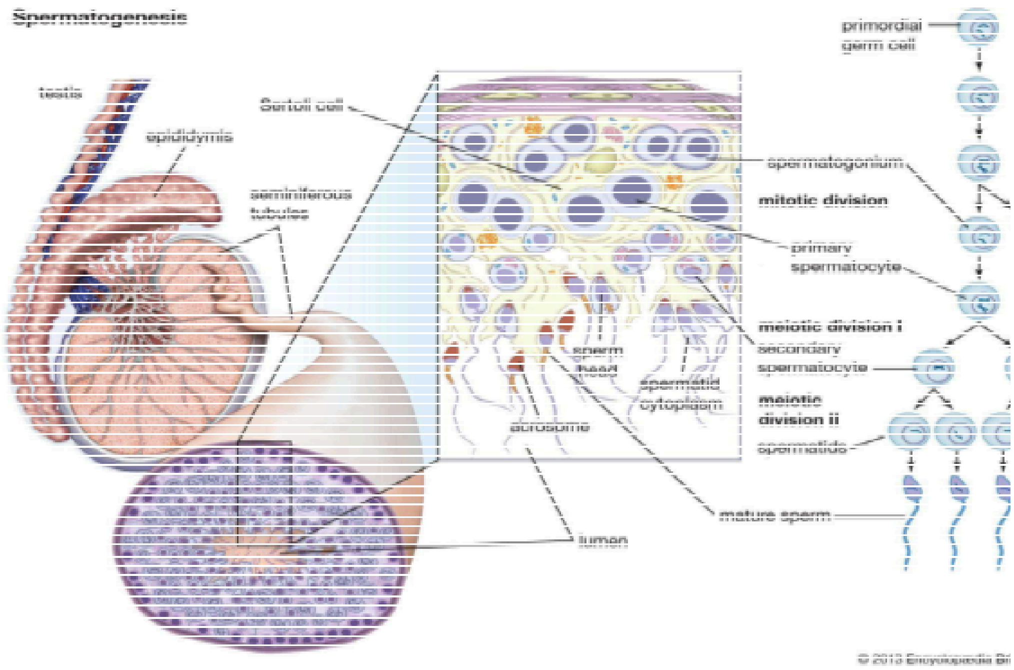
- **Meiosis I**: Each primary spermatocyte undergoes meiosis I to produce two **secondary spermatocytes**, each with a haploid (n) number of chromosomes. However, each chromosome still consists of two chromatids.
- **Meiosis II**: Each secondary spermatocyte rapidly enters meiosis II to form two **spermatids**, resulting in a total of four haploid spermatids from one primary spermatocyte.

**4. Spermiogenesis**

Spermiogenesis is the process of transforming round, non-motile spermatids into highly specialized, motile **spermatozoa**. This transformation involves:

- **Condensation of chromatin** within the nucleus.
- Formation of an **acrosome** from the Golgi apparatus, which helps the sperm penetrate the ovum.
- Development of a **flagellum** for motility.
- Shedding of excess cytoplasm as residual bodies.

The mature sperm are then released into the lumen of the seminiferous tubules through a process known as **spermiation**. They are transported to the **epididymis**, where they acquire motility and are stored until ejaculation.




## Oogenesis

Oogenesis occurs in the ovaries and differs significantly from spermatogenesis in timing, duration, and outcome. It is characterized by the formation of a single mature ovum from each primary oocyte, accompanied by the production of polar bodies.

### 1. Multiplication Phase

During fetal development, oogonia undergo repeated **mitotic divisions** to increase their number. However, this proliferation stops well before birth. By the time of birth, all oogonia have entered the early stages of meiosis I and are now referred to as **primary oocytes**.

### 2. Growth Phase

Primary oocytes grow in size due to accumulation of yolk and cytoplasmic materials, including RNA, proteins, and organelles. The growth is supported by surrounding **follicular cells**, forming a structure called the **primary follicle**.

The oocyte becomes arrested in **prophase I** of meiosis—a stage that can last for years, until puberty.

### 3. Maturation Phase

At the onset of puberty, under hormonal influence (FSH and LH), selected primary oocytes resume meiosis I during each menstrual cycle. This process produces:

- One large **secondary oocyte** (haploid), and
- One small, non-functional **first polar body**.

The secondary oocyte immediately begins **meiosis II** but is arrested at **metaphase II**. It completes meiosis II only upon **fertilization** by a sperm cell, producing:

- One large **ovum** (functional haploid gamete), and
- One **second polar body** (non-functional).

Thus, from one primary oocyte, only **one functional ovum** is produced, in contrast to spermatogenesis where four functional sperm arise from one primary spermatocyte.

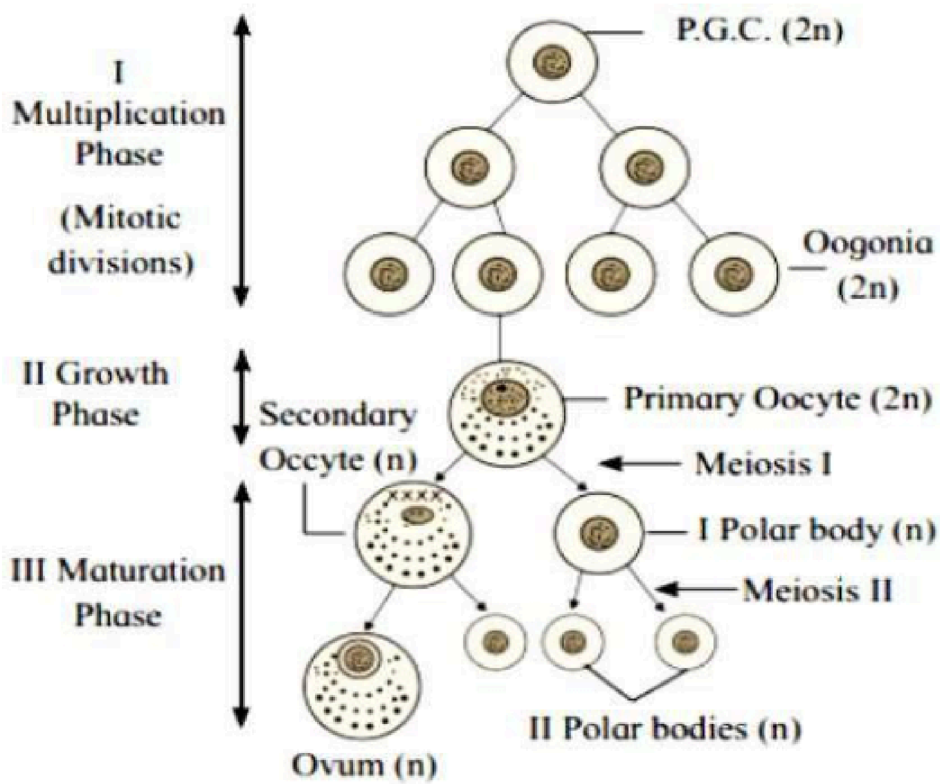



**Table: Comparison Between Spermatogenesis and Oogenesis**

| **Feature** | **Spermatogenesis** | **Oogenesis** |
|---|---|---|
| Site | Seminiferous tubules of testes | Ovaries |

| | | |
|---|---|---|
| Onset | Begins at puberty | Begins during fetal life |
| Duration | Continuous throughout life | Discontinuous; ends at menopause |
| Outcome | Four functional sperm per precursor | One ovum and three polar bodies per precursor |
| Arrest Phase | No long arrest; continuous process | Arrests at prophase I (birth) and metaphase II (ovulation) |
| Size of Gamete | Small, motile sperm | Large, non-motile egg with nutrients |
| Cytoplasm Distribution | Equally divided | Unequally divided |

**Hormonal Regulation of Gametogenesis**

Gametogenesis is under the control of the **hypothalamic-pituitary-gonadal (HPG) axis**. The **hypothalamus** secretes **gonadotropin-releasing hormone (GnRH)**, which stimulates the anterior **pituitary gland** to release:

- **Follicle-stimulating hormone (FSH)** – promotes development of gametes.
- **Luteinizing hormone (LH)** – stimulates Leydig cells in males and ovulation in females.

In males, LH induces **testosterone** production by Leydig cells, which is essential for spermatogenesis. In females, LH triggers **ovulation**, and FSH stimulates follicular growth and estrogen secretion. The interplay of these hormones orchestrates the complex timing of gamete production.

**Significance of Gametogenesis**

Gametogenesis serves several vital functions in biology and evolution:

- **Restoration of diploidy**: Fusion of haploid gametes ensures that the offspring has the correct chromosome number.
- **Genetic variation**: Through recombination and independent assortment during meiosis, gametogenesis introduces genetic diversity, which is crucial for evolution and adaptation.
- **Sexual reproduction**: It is the cornerstone of sexual reproduction, enabling the combination of genetic material from two parents.



**Fertilization**

Fertilization is the fundamental biological process through which two specialized reproductive cells, the male gamete (sperm) and the female gamete (ovum or egg), fuse to form a new diploid organism. It is a highly coordinated event that restores the diploid number of chromosomes, activates the developmental program of the zygote, and initiates the formation of a new individual. Far from being a single moment, fertilization is a series of sequential steps that begin with the approach of sperm towards the egg and culminate in the formation of a genetically unique zygote.



**Definition and Significance**

Fertilization may be defined as the union of a haploid sperm nucleus and a haploid ovum nucleus to form a diploid zygote. In sexually reproducing organisms, this process not only ensures genetic continuity between generations but also contributes to genetic variability through the random combination of gametes. By restoring the diploid condition, fertilization completes the sexual cycle that alternates between haploid gametogenesis and diploid development.

**Prefertilization Events**

Before fertilization occurs, several preparatory events take place. In animals, spermatozoa are usually produced in large numbers and undergo maturation in the male reproductive tract. When introduced into the female reproductive system (as in internal fertilization) or released into the environment (as in external fertilization), sperm must remain motile and viable for a certain period. The ovum, on the other hand, matures within the ovary and is often surrounded by accessory layers such as the **zona pellucida** and the **corona radiata** in mammals, or the **vitelline membrane** in many invertebrates. These structures play crucial roles in sperm recognition and binding.

**Mechanism of Fertilization**

The process of fertilization unfolds through a series of interrelated steps:

1. **Sperm Approach and Chemotaxis**
   Sperm are guided towards the egg by a combination of chemical signals (chemotaxis), temperature gradients, and mechanical factors. In marine organisms like sea urchins, the egg releases specific chemoattractants that direct sperm swimming patterns. In mammals, the oviductal environment and follicular fluid facilitate sperm migration towards the ovum.

2. **Sperm Binding and Acrosome Reaction**
   On reaching the egg, the sperm must recognize and bind to species-specific molecules on the egg's outer layers. In mammals, glycoproteins of the zona pellucida such as ZP3 mediate this binding. The sperm then undergoes the **acrosome reaction**, where the acrosomal vesicle at the tip of the sperm

head releases hydrolytic enzymes. These enzymes locally digest the protective layers, allowing the sperm to traverse the zona pellucida.

3. **Penetration of Egg Envelopes**
   Following the acrosome reaction, the sperm's plasma membrane fuses with the egg's plasma membrane. The sperm's nucleus and centriole are introduced into the egg cytoplasm, while the rest of the sperm structures are typically degraded. This membrane fusion is a highly specific event ensuring that only one sperm successfully fertilizes the egg.

4. **Cortical Reaction and Polyspermy Block**
   To prevent multiple sperm from entering (polyspermy), the egg triggers rapid changes immediately after the first sperm penetrates. An initial **fast block** involves a change in membrane potential of the egg surface, which transiently prevents further sperm fusion. This is followed by the **cortical reaction**, wherein cortical granules beneath the egg membrane release enzymes into the perivitelline space. These enzymes modify the egg's extracellular matrix (such as hardening the zona pellucida), creating a permanent block to polyspermy.

5. **Activation of the Egg**
   Entry of the sperm also initiates metabolic activation of the egg. There is a surge in intracellular calcium levels, leading to the resumption of the egg's arrested meiotic division (usually at metaphase II in mammals) and preparation for embryonic development. The cytoplasm becomes reorganized, and maternal mRNAs stored in the egg are translated to support early development.

6. **Pronuclear Formation and Fusion**
   The sperm nucleus decondenses to form the **male pronucleus**, while the egg nucleus completes meiosis and forms the **female pronucleus**. Both pronuclei migrate toward each other, guided by microtubules. Eventually, they fuse, combining their genetic material to produce the **zygote nucleus** with a full diploid complement of chromosomes.

### Types of Fertilization

- **External Fertilization:** Common in many aquatic animals such as amphibians and most fish. Gametes are released into the surrounding water, where fertilization occurs outside the body. Although it involves high gamete wastage and is influenced by environmental factors, it allows fertilization to take place in a medium where gametes can easily meet.

- **Internal Fertilization:** Seen in terrestrial animals including reptiles, birds, and mammals. Sperm is deposited directly into the female reproductive tract, increasing the chances of successful fertilization and protecting gametes from desiccation.

**Cytological and Genetic Consequences**

Fertilization restores the diploid state of the organism, combining paternal and maternal genetic material. It introduces genetic variation through:

- Random assortment of chromosomes,
- Independent gamete selection,
- Occasional recombination events during gametogenesis.

These variations are fundamental for evolution and adaptation, giving rise to unique genetic identities in offspring.

**Physiological Importance**

Beyond genetic combination, fertilization is also the moment when the egg is metabolically activated. It sets in motion the early developmental program, including cleavage, blastula formation, and subsequent embryogenesis. Fertilization ensures that only one sperm contributes its genetic material, maintaining genomic stability. Additionally, many species exhibit mechanisms that ensure species-specific fertilization, which preserves reproductive isolation.

**Parthenogenesis**

Parthenogenesis is a fascinating reproductive phenomenon in which an egg develops into a complete individual without the act of fertilization by a male gamete. In simpler terms, it is a process of reproduction that does not require the fusion of sperm and ovum. The word itself is derived from the Greek words *parthenos* (meaning "virgin") and *genesis* (meaning "origin" or "creation"), and together they describe the development of a new organism from an unfertilized egg. Parthenogenesis occurs naturally in many invertebrates and some vertebrates, although its frequency, mechanism, and biological significance vary greatly across different groups.

In animals, parthenogenesis can be considered an alternative strategy to sexual reproduction. While sexual reproduction allows for genetic variation through recombination, parthenogenesis offers the advantage of producing offspring rapidly in environments where mates are scarce or conditions favor quick population growth. This is why it is frequently observed in insects, certain crustaceans, some reptiles, and even a few species of birds and fishes.

### Types and Mechanisms

Parthenogenesis is not a single uniform process; rather, it encompasses a variety of mechanisms depending on how the egg develops and what ploidy level the offspring exhibit. Broadly, it can be classified as **natural parthenogenesis** and **artificial parthenogenesis.**

**Natural parthenogenesis** occurs spontaneously and is part of the normal life cycle of some species. A classic example is seen in honeybees. In the colony of *Apis mellifera*, the queen lays two kinds of eggs. Fertilized eggs develop into female workers or queens, while unfertilized eggs, by parthenogenesis, develop into haploid male drones. This type is called *arrhenotoky* (male-producing parthenogenesis). Other insects, such as aphids, show a seasonal pattern known as *cyclical parthenogenesis*, in which females produce several generations of offspring parthenogenetically during favorable seasons, and only later in the year do they switch to sexual reproduction to produce eggs that can overwinter.

**Artificial parthenogenesis** can be induced experimentally under laboratory conditions. Here, an unfertilized egg is stimulated to develop by mechanical, chemical, or physical means such as pricking the egg with a fine needle, subjecting it to temperature shocks, or treating it with certain salts or chemicals. While the offspring produced in such experiments are often abnormal or do not survive to adulthood, these studies have been crucial in understanding embryology and cellular physiology.

## Development of Frog up to Formation of the Three Germ Layers

The development of the frog (*Rana tigrina* or *Rana hexadactyla* as commonly studied) is a classic example of embryology among vertebrates. The frog is a **mesolecithal oviparous amphibian**, meaning that its eggs contain a moderate amount of yolk that is unevenly distributed, concentrated more towards the vegetal pole. The early development proceeds through a series of welldefined stages, beginning with fertilization and culminating in the establishment of three primary germ layers—**ectoderm, mesoderm, and endoderm**—which later give rise to all tissues and organs.

### Fertilization and Zygote Formation

In frogs, fertilization is **external**. During the breeding season (usually after rains), the male clasps the female in amplexus, and as the female lays eggs, the male releases sperm over them in water. A sperm penetrates the egg through the animal pole. The point of sperm entry plays a role in establishing the **dorsoventral axis** of the embryo. After fertilization, the egg becomes a zygote with a cortical rotation of its cytoplasm, resulting in the formation of the **gray crescent**, a critical region opposite to the point of sperm entry. This gray crescent marks the future dorsal side of the embryo and is a signalingcenter for further development.

### Cleavage and Formation of Blastula

Cleavage in the frog is **holoblastic but unequal** because of the presence of yolk in the vegetal hemisphere.

- The first cleavage is **meridional**, passing through both animal and vegetal poles, dividing the zygote into two equal blastomeres.
- The second cleavage, also meridional, is at right angles to the first, producing four blastomeres.
- The third cleavage is **horizontal**, but because the yolk-laden vegetal region divides more slowly, this results in four smaller cells in the animal region (micromeres) and four larger yolk-rich cells in the vegetal region (macromeres).

With successive cleavages, a multicellular structure called the **morula** is formed, which later undergoes rearrangement to form a **blastula**.
The **blastula** in frog consists of:



- An upper region of small cells (animal hemisphere),

- A lower region of larger yolk-laden cells (vegetal hemisphere),
- And a fluid-filled cavity called the **blastocoel** located eccentrically towards the animal pole.

The blastula is not a simple ball of cells but is already polarized due to the distribution of yolk and cytoplasmic determinants. This stage sets the stage for **gastrulation**.

### Gastrulation and Formation of Germ Layers

Gastrulation is the process by which the single-layered blastula is reorganized into a multilayered structure called the **gastrula**. This involves a complex series of cell movements—**invagination, involution, epiboly, and migration**—through specific regions such as the dorsal lip of the blastopore.

**a. Initiation at the Dorsal Lip**
At the site of the gray crescent, cells begin to migrate inward. This region becomes the **dorsal lip of the blastopore**. The dorsal lip acts as an organizer and orchestrates the movements of cells.

**b. Involution and Invagination**

- Cells from the surface of the blastula roll over (involute) at the dorsal lip and move inside, spreading along the roof of the blastocoel.
- These migrating cells displace the original yolk-laden cells and form the **mesodermal mantle**.
- Simultaneously, cells of the animal pole spread over the surface by **epiboly**, gradually covering the embryo.

**c. Formation of Blastopore and Yolk Plug**
As gastrulation proceeds, a circular blastopore is formed with dorsal, lateral, and ventral lips. The remaining yolk cells protrude through the blastopore as a **yolk plug**, which later gets internalized.

### Establishment of the Three Germ Layers

By the end of gastrulation, the frog embryo is transformed from a simple blastula into a complex gastrula with three distinct germ layers:

1. **Ectoderm (outer layer):**
    - Derived from the cells that remain on the outside after epiboly.
    - It will form the future epidermis of the skin, nervous system (brain and spinal cord), sense organs, and related structures.

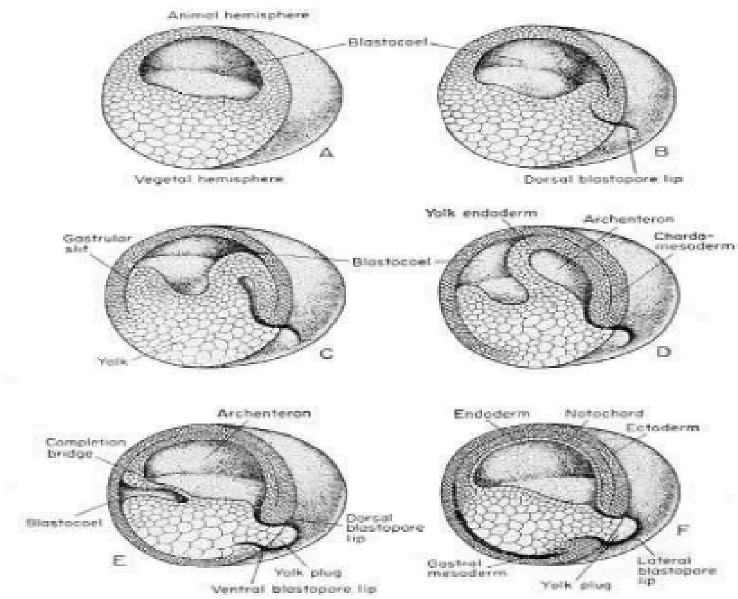
2. **Mesoderm (middle layer):**
   - Formed by the involuting cells that migrate between the ectoderm and endoderm.
   - This layer gives rise to muscles, skeleton, circulatory system, excretory system, and the notochord.
3. **Endoderm (inner layer):**
   - Composed of the yolk-rich cells that line the archenteron (the newly forming gut cavity).
   - It will form the lining of the digestive tract, respiratory organs, and associated glands.

**Significance of Germ Layer Formation**

The formation of germ layers marks the transition from a simple cellular arrangement to a structurally organized embryo. Each germ layer has distinct developmental fates:

- The **ectoderm** protects and interfaces with the environment while contributing to neural development.
- The **mesoderm** acts as the foundation for internal support and movement.
- The **endoderm** ensures internal physiological functions like digestion and respiration.

These layers set the stage for **organogenesis**, where specific tissues and organs develop through further differentiation.




**Question Bank:**

**Very Short Answer / Objective Type**

1. Name the type of fertilization in frogs.
2. In oogenesis, the ovum is arrested at which stage before ovulation?
3. What is the fate of the grey crescent in frog development?
4. Which germ layer gives rise to the nervous system?
5. Tick the correct answer:
    - **Cleavage in frog is:**
      (a) Meroblastic
      (b) Discoidal
      (c) Holoblastic unequal
      (d) Superficial

**Short Answer Questions**

1. Differentiate between **spermatogonia and oogonia**.
2. Write short notes on:
    - Primary oocyte and secondary oocyte
    - Vitellogenesis
    - Types of eggs based on yolk content (isolecithal, telolecithal, etc.)

3. Define and explain:
    - Internal fertilization
    - External fertilization (with example of frog)
4. What is **cortical granule reaction**? Why is it important?
5. How is **egg polarity** established in frog eggs?
6. What are **grey crescent** and its significance in frog development?
7. Differentiate between **meroblastic** and **holoblastic** cleavage. Which one is seen in frog?
8. Define **parthenogenesis** and mention two animals where it occurs naturally.

**Long Answer Questions**

1. Describe **spermatogenesis** in detail with a neat, labelled diagram.
2. Explain the **process of oogenesis** in vertebrates. How does it differ from spermatogenesis?
3. Write an essay on **fertilization** in amphibians. Discuss the events of prefertilization, fertilization, and postfertilization stages.
4. With the help of diagrams, explain **cleavage in frog's egg** up to the formation of the blastula.
5. Describe the **gastrulation process in frog** and explain how the three germ layers (ectoderm, mesoderm, endoderm) are formed.
6. Discuss the phenomenon of **parthenogenesis** with suitable examples and its biological significance.
7. Explain the **role of cortical reaction and block to polyspermy** during fertilization in amphibians.

# MODULE V

## EMBRYOLOGY II

**Objectives:**

- Understand the concept of embryonic induction and organizers.
- Study the development and functions of extraembryonic membranes (amnion, chorion, yolk sac, allantois).
- Examine the structure, types, and functional significance of placenta in mammals.
- Learn organogenesis: early formation of neural tube, notochord, somites, and coelom.
- Appreciate the evolutionary and developmental significance of embryology in vertebrates.
- Build skills in correlating embryological structures with their adult derivatives.

### UNIT 12: Development of chick upto formation of three germ layers

### Development of Chick up to the Formation of Three Germ Layers

The development of the chick embryo has been one of the most extensively studied events in vertebrate embryology because of the relatively large size of the egg, ease of observation, and similarity to higher vertebrate development. The hen's egg is a **telolecithal egg**, meaning that it contains a large amount of yolk concentrated towards one pole (vegetal pole) while the cytoplasm and nucleus are displaced towards the opposite pole (animal pole). Fertilization in birds occurs internally, in the upper part of the oviduct, prior to the deposition of albumen and shell. By the time the egg is laid, **cleavage has already started**, and the embryo is at a very early stage of development called the **blastoderm**.

**Cleavage and Formation of the Blastoderm**

Cleavage in the chick is **meroblastic and discoidal**, meaning that only the small disc of cytoplasm at the animal pole undergoes division while the yolk remains uncleaved. Rapid mitotic divisions produce a thin cap of cells, the **blastodisc**, which spreads over the yolk. This blastodisc soon organizes into two distinct regions:

1. **Area pellucida** – the central, transparent region where cells have separated from the yolk beneath.
2. **Area opaca** – the peripheral, opaque region where cells remain in contact with the underlying yolk.

A space, called the **subgerminal cavity**, forms between the blastoderm and the yolk. This stage is known as the **blastula stage** in chick development. Unlike amphibians, there is no true hollow blastocoel; instead, the subgerminal cavity performs a similar function in permitting cellular movements during gastrulation.

**Initiation of Gastrulation**

Gastrulation in birds is the process through which the simple blastoderm transforms into a structure with **three primary germ layers**—ectoderm, mesoderm, and endoderm. Gastrulation begins with the formation of a crucial structure called the **primitive streak**.

At about **6 to 8 hours of incubation**, cells in the posterior part of the area pellucida begin to proliferate and migrate medially. These migrating cells converge towards the midline and sink downwards, forming a thickened linear band—the primitive streak. This streak elongates rapidly towards the head end of the embryo and establishes the body axis. The anterior end of the streak forms a localized thickening called the **primitive knot or Hensen's node**.

**Formation of the Three Germ Layers**

The primitive streak is the chief site of cell migration and germ layer formation. Cells in the blastoderm undergo epithelial-to-mesenchymal transition and move inward through the primitive streak to create new layers beneath the epiblast. The process can be described in three main phases:

1. **Formation of Endoderm**
   The first wave of ingressing cells moves downward through the

primitive streak to displace the original hypoblast (a layer of cells initially underlying the epiblast). These displaced cells spread laterally and anteriorly beneath the epiblast to form a definitive layer known as the **endoderm**. This future endoderm will later give rise to the epithelial lining of the gut and its associated glands, as well as portions of the respiratory tract.

2. **Formation of Mesoderm**
   A second wave of cells continues to migrate through the primitive streak, but these cells do not move as deeply. Instead, they spread between the overlying epiblast (future ectoderm) and the newly formed endoderm. This middle layer is the **mesoderm**, which later differentiates into structures such as muscles, connective tissues, blood, notochordal tissue, and components of the urogenital system. Around the primitive streak and Hensen's node, mesodermal cells also migrate anteriorly to form the notochordal process and the prechordal plate, which are critical in inducing neural development.

**3. Formation of Ectoderm**

The remaining cells of the epiblast, after the migration of endodermal and mesodermal precursors, do not ingress through the primitive streak. These surface cells spread and flatten to form the **ectoderm**, the outermost layer that will give rise to the epidermis, nervous system, and neural crest derivatives.

**Establishment of the Germ Layers and Body Axis**

As the primitive streak elongates and then regresses, the embryo begins to show clear anterior–posterior and dorsal–ventral polarity. Hensen's node acts as an organizing center, inducing the formation of the notochord and initiating neurulation. By the end of gastrulation (about **24 hours of incubation**), the blastoderm has been fully reorganized into a trilaminar structure:

- **Ectoderm** on the surface
- **Mesoderm** in the middle
- **Endoderm** lining the interior

This trilaminar disc forms the basis of all subsequent organogenesis.

## Significance of Germ Layer Formation

The formation of the three germ layers marks a critical milestone in chick development. It sets the stage for **neurulation**, the folding and closure of the neural plate to form the neural tube, as well as for segmentation of the mesoderm into somites and the establishment of extraembryonic membranes such as the amnion, chorion, and yolk sac. Because of the large yolk, these processes occur in a flattened disc rather than a spherical embryo, but the fundamental mechanisms are homologous to other vertebrates.

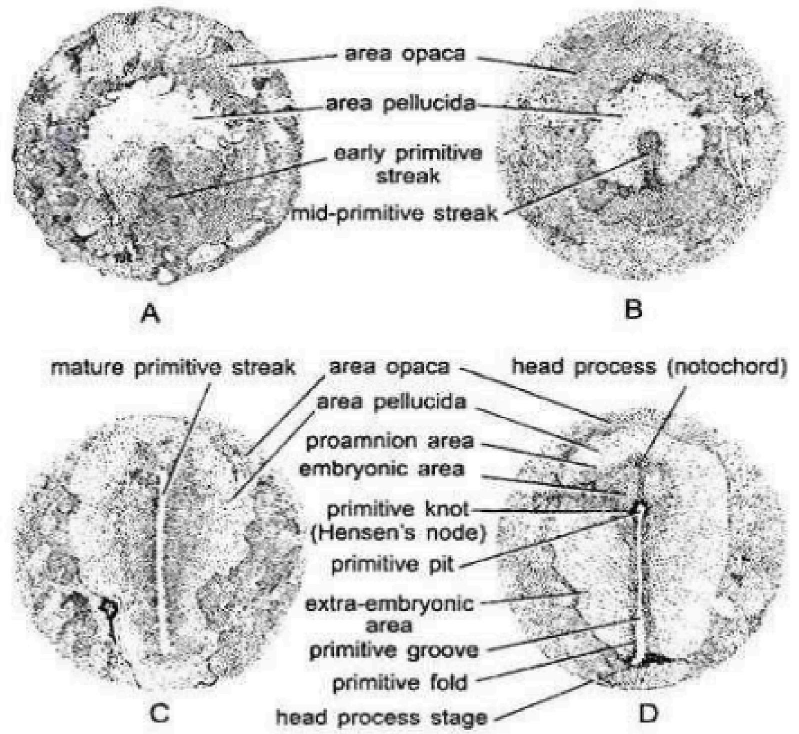



**Fig. 38.5.** Surface view of chick blastoderm showing development of primitive streak (gastrulation) and head process (neurulation). A–Initial streak (stage 2); B–Intermediate streak (stage 3); C–Definitive streak (stage 4); D–Head process stage (stage 5 embryo of 19 to 22 hours of incubation).

**Notes**

**Development of chick upto formation of three germ layers**

## UNIT 13: Extra embryonic membrane

### ExtraEmbryonic Membranes

During the development of vertebrate embryos, certain specialized membranes are formed outside the embryo proper. These are known as **extraembryonic membranes**, and they play vital roles in protecting, nourishing, and assisting the developing embryo. Unlike the tissues that become part of the adult body, these membranes arise from embryonic layers but exist transiently to meet the physiological demands of the growing embryo within its environment—whether inside an egg or within the maternal uterus.

### Origin and General Significance

Extraembryonic membranes develop from the outer regions of the germ layers—**ectoderm, endoderm, and mesoderm**—without contributing directly to the tissues of the embryo itself. Their appearance is a key evolutionary advancement seen in **amniotes** (reptiles, birds, and mammals). These membranes enable the embryo to develop on land by providing an aquatic microenvironment, managing gas exchange, storing wastes, and protecting it from desiccation or mechanical injury.

In contrast, amphibians and fishes, which lay their eggs in water, have little or no need for such membranes, as the surrounding medium itself facilitates respiration, waste dilution, and protection. Thus, the origin of extraembryonic membranes is closely tied to the adaptation of vertebrates to terrestrial life.

The four principal extraembryonic membranes in amniotes are: **amnion**, **chorion**, **yolk sac**, and **allantois**. Although their structure and function vary slightly between reptiles, birds, and mammals, the fundamental plan remains remarkably conserved.

### 1. Amnion – The Protective Water Sac

The **amnion** is a thin, delicate membrane that forms a fluidfilled sac directly surrounding the embryo. It is derived from the somatopleure (ectoderm plus somatic mesoderm) and grows upward around the embryo, eventually enclosing it completely.

Inside this sac is the **amniotic fluid**, a clear, slightly viscous liquid that provides a buoyant environment. This fluid performs several crucial functions:

- It cushions the embryo against mechanical shocks, preventing injury as the mother moves or external forces act on the egg.
- It prevents desiccation by keeping the embryonic tissues moist in a land environment.

- It allows free movement of the developing embryo, preventing adhesion to surrounding membranes and ensuring symmetrical growth.

In oviparous reptiles and birds, the amnion is relatively simple, whereas in mammals it becomes highly vascular and participates in exchange processes.

#### 2. Chorion – Interface with the External Environment

The **chorion** forms the outermost envelope of the developing embryo and is also derived from the somatopleure. It lies just beneath the shell in birds and reptiles, or in mammals it forms part of the interface with the maternal tissues.

The chorion is often richly supplied with blood vessels and works in conjunction with the allantois to form the **chorioallantoic membrane**. This specialized membrane is spread out against the inner surface of the eggshell or uterine wall and functions as the primary site of gaseous exchange. Oxygen diffuses in, and carbon dioxide diffuses out, ensuring the embryo's respiratory needs are met despite being enclosed.

In mammals, the chorion develops chorionic villi—fingerlike projections that penetrate the uterine lining. These villi facilitate the development of the **placenta**, through which nutrients, gases, and waste products are exchanged between maternal and fetal bloodstreams.

#### 3. Yolk Sac – The Nutrient Reservoir

The **yolk sac** arises from the splanchnopleure (endoderm plus splanchnic mesoderm) and extends around the yolk mass in eggs rich in yolk, such as those of reptiles and birds.

Its primary role is to absorb and transport nutrients from the yolk to the developing embryo. Blood vessels from the embryo spread over the yolk sac, forming a vitelline circulation system that carries digested yolk to the embryonic tissues.

In placental mammals, where the yolk content is minimal, the yolk sac does not serve as a major nutrient source. Instead, it takes on other important roles, such as contributing to early blood cell formation (hematopoiesis) and forming part of the primitive gut during early embryonic stages.

#### 4. Allantois – Storage and Gas Exchange

The **allantois** is another splanchnopleuric derivative that buds out from the posterior part of the embryonic gut. In eggs with a hard shell, it acts as a reservoir for nitrogenous wastes (mainly uric acid in birds and reptiles) that cannot be eliminated immediately.

Moreover, the allantois fuses with the chorion to form the **chorioallantoic membrane**, which is extensively vascularized and is the primary site for respiratory exchange. This membrane's rich capillary network lies close to the porous eggshell, facilitating oxygen uptake and carbon dioxide release.

Notes

In mammals, the allantois is involved in the early development of the urinary bladder and contributes to the formation of the umbilical cord vessels, playing a part in placental circulation.

**Evolutionary and Functional Significance**

The evolution of these extraembryonic membranes marked a major step in vertebrate adaptation to terrestrial life. By creating a selfcontained aquatic environment (amnion), developing systems for nutrient mobilization (yolk sac), enabling effective respiration (chorion and allantois), and managing waste, embryos could be laid in dry land environments without the risk of desiccation or insufficient gas exchange.

In mammals, these membranes have been further modified and integrated with maternal tissues to form the **placenta**, a complex organ that allows internal gestation, extended embryonic development, and more efficient nutrient and waste management.

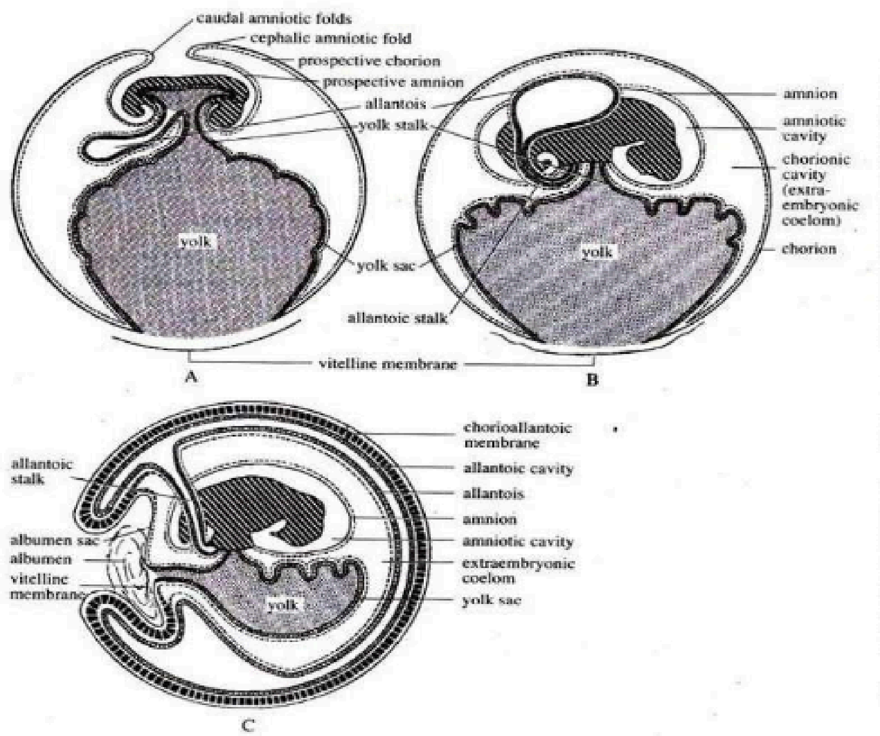



Fig. 5.48 : Development of the extraembryonic membranes in chick. (A) Early stage, (B) Later stage; (C) Fully matured stage.

Fig: extraembryonic membranes

## UNIT 14: Placenta in mammals

### Placenta in Mammals

The placenta is a remarkable, transient organ that develops in most mammals during pregnancy, forming an intimate structural and functional connection between the developing embryo (or fetus) and the maternal tissues of the uterus. It is not merely a passive attachment but a highly specialized interface through which the nourishment, protection, and regulation of the embryo are maintained until birth. Its evolutionary significance lies in allowing viviparity—birth of fully developed young—by ensuring continuous exchange of materials between mother and fetus while maintaining immunological and physiological barriers.

### Formation and Structure

In mammals, the formation of the placenta begins soon after the implantation of the blastocyst into the endometrial lining of the uterus. Cells from the trophoblast (the outer layer of the blastocyst) proliferate and invade the maternal endometrium. These trophoblastic cells differentiate into two main layers: an inner cytotrophoblast and an outer syncytiotrophoblast. The syncytiotrophoblast penetrates deeply into the maternal tissue and establishes contact with maternal blood vessels, while the cytotrophoblast contributes to villous structures that increase the surface area of exchange.

As development proceeds, fingerlike projections called **chorionic villi** arise from the fetal chorion. These villi penetrate into maternal tissue and are bathed in maternal blood within spaces known as **intervillous sinuses**. Each villus contains fetal blood vessels derived from the umbilical arteries and veins, allowing fetal blood to come very close to maternal blood without mixing directly. The placenta thus becomes a dualorigin organ, partly maternal (uterine tissue and blood) and partly fetal (chorionic villi and associated membranes).

### Functions of the Placenta

The placenta performs a multitude of essential functions that sustain fetal life. Nutritionally, it mediates the transfer of oxygen, glucose, amino acids, fatty acids, vitamins, and minerals from the maternal circulation to the fetus. Simultaneously, it removes carbon dioxide and nitrogenous wastes from fetal blood to be eliminated by the maternal system. Beyond nutrition and excretion, the placenta also serves as a temporary **endocrine gland**, secreting hormones such as progesterone, estrogens, human chorionic gonadotropin (hCG), and placental lactogens. These hormones maintain the uterine lining, regulate maternal metabolism, and prepare mammary glands for lactation.

An additional critical function of the placenta is **immunological regulation**. Although the fetus is genetically distinct from the mother, the placenta forms a selective barrier that limits direct immune confrontation. Specialized trophoblastic cells and local immune mechanisms prevent maternal lymphocytes from attacking the fetus while still allowing essential antibodies (particularly IgG) to pass through, conferring passive immunity to the newborn.

### Types of Placenta Based on Structure

Mammalian placentas are classified according to the pattern of contact between chorionic villi and the uterine wall:

- In **diffuse placentas** (e.g., in pigs and horses), villi are distributed uniformly over the entire chorionic surface.
- In **cotyledonary placentas** (e.g., ruminants like cows and sheep), villi are grouped into discrete patches called cotyledons that interlock with caruncles in the uterine lining.
- In **zonary placentas** (e.g., in carnivores such as dogs and cats), villi form a band or girdle around the middle of the chorion.
- In **discoidal placentas** (e.g., in primates and rodents), villi are concentrated in one or two disclike regions, forming a highly efficient exchange site. The human placenta belongs to this category.

### Types Based on Tissue Layers Between Fetal and Maternal Blood

Another important classification is based on the histological layers separating fetal and maternal blood:

- **Epitheliochorial placenta** (e.g., in horses and pigs): All maternal tissue layers are retained, and the exchange is less intimate.
- **Endotheliochorial placenta** (e.g., in carnivores): Maternal epithelium and connective tissue are eroded, allowing closer apposition.
- **Hemochorial placenta** (e.g., in primates and rodents): Maternal blood is in direct contact with the chorionic epithelium, ensuring the most efficient exchange.

### Special Adaptations and Significance

The mammalian placenta is not a static structure. It undergoes dynamic changes throughout gestation, constantly remodeling its villous architecture to meet the growing demands of the fetus. It also plays a protective role by metabolizing certain toxic substances and acting as a partial barrier to pathogens. Furthermore, the placenta stores glycogen and iron, buffering the fetal environment against fluctuations in maternal supply.

The significance of the placenta extends beyond gestation. By regulating the timing of parturition through hormonal signals and by ensuring the fetus is optimally developed at birth, the placenta underpins the reproductive success of mammals. Evolutionarily, the development of a complex placenta is linked to the diversity and adaptive radiation of eutherian mammals, enabling them to exploit varied ecological niches.

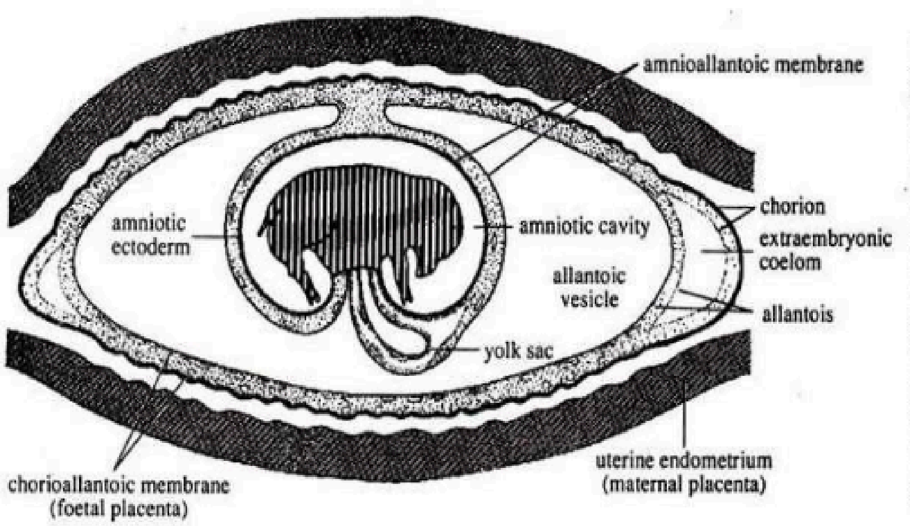



Fig. 5.51 : The mature extraembryonic membranes of the foetal pig, showing composition of foetal placenta (chorioallantoic membrane) and relation to endometrium of uterus.

Fig: structure of placenta

**Functions in Detail**

The placenta fulfills numerous functions essential for fetal development:

- **Respiratory Function:** Although the fetal lungs are nonfunctional in utero, gas exchange occurs across the placenta. Oxygen from maternal blood diffuses through the placental barrier into fetal blood, while carbon dioxide diffuses in the opposite direction to be expelled by the mother.

- **Nutritive Function:** Glucose, amino acids, fatty acids, vitamins, and minerals are transferred from mother to fetus. The placenta is not merely a passive conduit; it actively transports certain substances against concentration gradients and even synthesizes glycogen and other nutrients to supplement fetal supply.

- **Excretory Function:** Nitrogenous wastes such as urea and uric acid produced by the fetus diffuse into maternal circulation for elimination through maternal kidneys.
- **Endocrine Function:** The placenta becomes a temporary but powerful endocrine organ. In humans, it secretes **human chorionic gonadotropin (hCG)** soon after implantation, which maintains the corpus luteum and sustains progesterone production in early pregnancy. Later, the placenta itself secretes **progesterone** and **estrogens**, which maintain the uterine lining, support fetal growth, and prepare maternal tissues for lactation. It also produces **human placental lactogen (hPL)**, which modulates maternal metabolism to favor nutrient supply to the fetus.
- **Immunological Function:** The placenta protects the fetus, which is genetically different from the mother, from being attacked by maternal immune cells. Specialized trophoblast cells express limited antigens and secrete immunosuppressive factors, creating a localized immune tolerance. Moreover, the selective transfer of maternal IgG antibodies provides the fetus with passive immunity, which continues to protect the newborn in the early months after birth.

### Adaptive Features and Evolutionary Perspective

The placenta is not only a structure of exchange but also an organ of adaptation. Its surface area expands enormously as gestation progresses, and its villi branch extensively to accommodate the growing needs of the fetus. It also plays a role in controlling the timing of parturition through the release of signals that initiate uterine contractions when the fetus is mature. From an evolutionary viewpoint, the development of a placenta allowed mammals to produce fewer, betterdeveloped offspring with higher survival rates, compared to oviparous ancestors that relied on external eggs with limited resources.

UNIT 15: Embryonic Induction, Organisers and Differentiation



## Introduction

The journey from a singlecelled zygote to a fully formed multicellular organism is one of biology's most fascinating transformations. Embryology seeks to explain how identical genetic material in all cells leads to an array of distinct tissues and organs arranged in precise patterns. Among the key principles guiding this process are **embryonic induction**, **organisers**, and **cellular differentiation**. These are not isolated phenomena but interdependent mechanisms that collectively shape the architecture of the developing embryo.

In the early 20th century, experimental embryologists began transplanting tissues in amphibian embryos and noticed surprising effects: certain transplanted regions could redirect surrounding cells to form entirely new structures. These classic findings laid the foundation for our modern understanding of developmental signals and patterning.

## Embryonic Induction: The Language of Cellular Communication

**Definition:**
Embryonic induction is the process by which one group of cells (inducing tissue) influences the developmental fate of another group of cells (responding tissue) through chemical or physical signals.

**Mechanism:**
Induction requires two key elements:

1. **Inducer:** A tissue that produces signaling molecules.
2. **Responder:** A tissue that is competent—capable of interpreting those signals.

The responding tissue must be at the right developmental stage to perceive and act on the signals. For example, in amphibians, only the early ectoderm can respond to neural induction cues; after a certain point in development, it loses competence.

**Classical Evidence:**
Spemann and Mangold's 1924 experiment is a landmark in developmental biology. They transplanted the dorsal lip of the blastopore (from a donor newt gastrula) into the ventral region of a host embryo. Instead of just forming tissue typical of that region, the host developed a *secondary embryo* with a complete neural axis. This demonstrated that the transplanted region had not only formed new structures itself but also *induced* host cells to form additional structures.

**Types of Induction:**

- **Permissive induction:** The responding tissue requires a signal to continue its developmental pathway (e.g., lens formation in the eye).
- **Instructive induction:** The inducing tissue provides specific information that determines a new fate (e.g., neural induction by the dorsal lip).

**Organisers: Embryonic SignalingCenters**

**Concept and Discovery:**
The term *organiser* was coined by Spemann to describe regions of the embryo that have a dominant and organizing influence on neighboring tissues. The **Spemann–Mangold organiser** (the dorsal lip of the amphibian gastrula) is the classical example.

**Properties of Organisers:**

- They are *self-differentiating*: they contribute directly to specific structures (like the notochord).
- They are *inductive*: they signal surrounding tissues to adopt new fates.
- They generate *patterned structures*: signals from organisers create gradients that pattern tissues spatially.

**Molecular Basis:**
Organisers function through secreted molecules:

- **Noggin, Chordin, Follistatin:** These molecules inhibit Bone Morphogenetic Proteins (BMPs) in the surrounding ectoderm, shifting its fate from epidermis to neural tissue.
- **Cerberus and Dickkopf:** These inhibit Wntsignaling, further shaping head formation.
- **Sonic Hedgehog (Shh):** Secreted by the notochord and floor plate, it patterns the ventral neural tube.

**Other Examples of Organisers:**

- **Zone of Polarizing Activity (ZPA):** In the limb bud, it secretes Shh, creating anterior–posterior digit identity.
- **Apical Ectodermal Ridge (AER):** In the limb, it maintains outgrowth and provides positional cues.
- **Midbrain–Hindbrain Boundary:** Acts as an organiser to pattern regions of the developing brain.

**Differentiation: From Potential to Identity**

Once induction and organiser signals are received, cells begin to **differentiate**, acquiring unique structural and functional characteristics.

**Stages of Differentiation:**

1. **Competence:** Cells are pluripotent and receptive.
2. **Specification:** Cells are biased toward a fate but not irreversibly committed.
3. **Determination:** Cells become irreversibly committed; even if transplanted, they follow the chosen fate.
4. **Terminal Differentiation:** Cells exhibit specialized structures and functions (e.g., neuron with axon and dendrites, muscle fiber with myofibrils).

**Molecular Control:**

- Transcription factors (e.g., Pax6 for eye development, MyoD for muscle) turn on gene networks that define identity.
- Epigenetic modifications (DNA methylation, histone acetylation) lock in stable gene expression patterns.
- Feedback loops maintain cell fate over time.

**Examples:**

- In the neural tube, gradients of Shh from the notochord and BMP from the roof plate create zones of progenitors that differentiate into motor neurons, sensory neurons, or interneurons.
- In somites, signals from surrounding tissues lead to formation of sclerotome (bone), myotome (muscle), and dermatome (dermis).

**Experimental Insights and Modern Applications**

Embryonic induction and organiser studies have profoundly influenced modern biology:

- **Regenerative Medicine:** Understanding signals like BMP inhibitors and Wnt pathways helps in directing stem cells to become desired cell types.
- **Organ Culture:** Scientists recreate inductive environments in vitro to grow organoids (mini-organs) for research and therapy.

- **Evolutionary Developmental Biology (Evo-Devo):** Comparative studies of organisers reveal how variations in signaling can lead to diverse body plans across species.

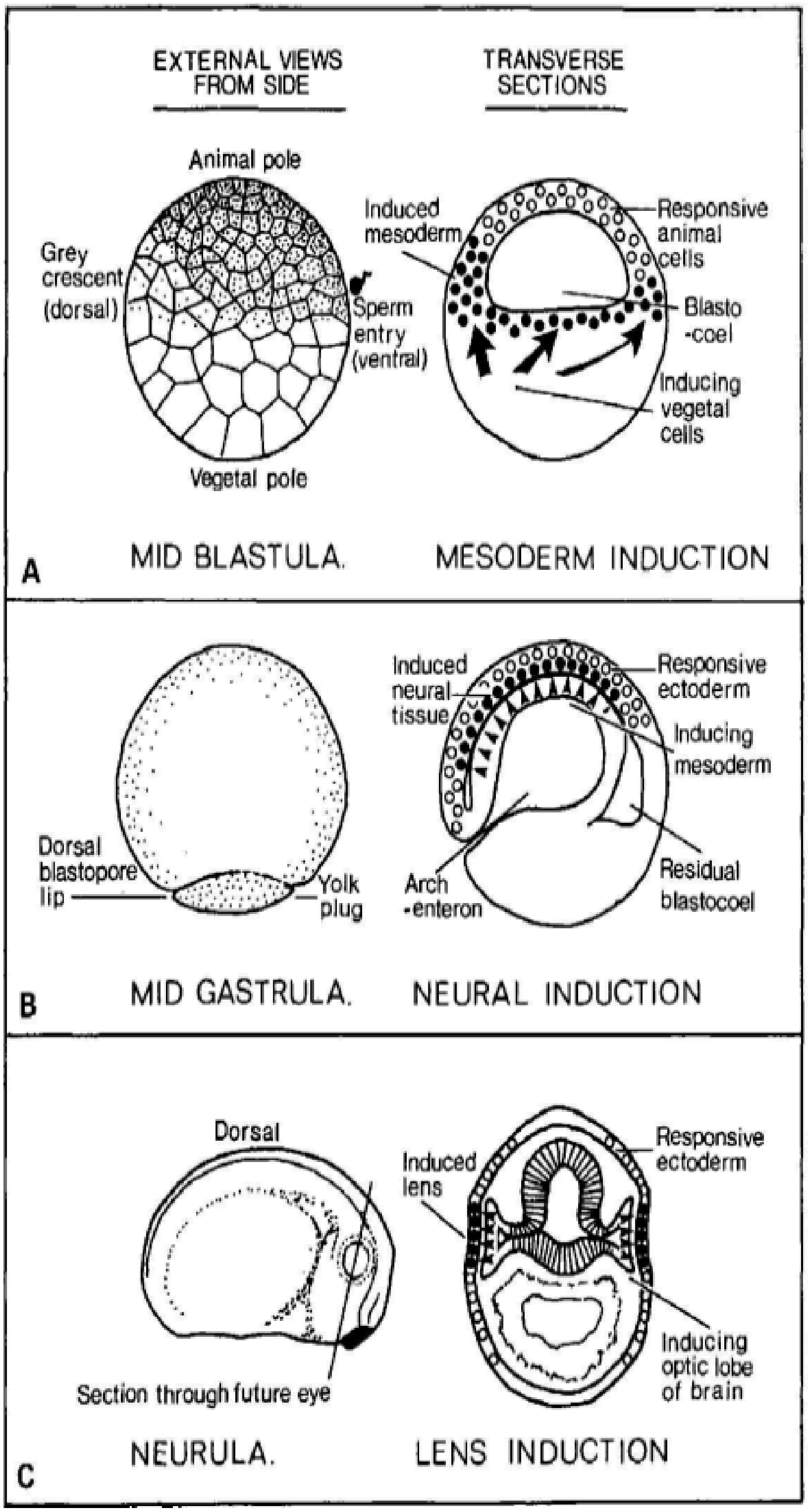
  For instance, zebrafish, chick, and mouse embryos have organisers with homologous functions, showing that these principles are conserved. Additionally, manipulation of these pathways in experimental embryos has shown how subtle changes can lead to profound morphological differences.

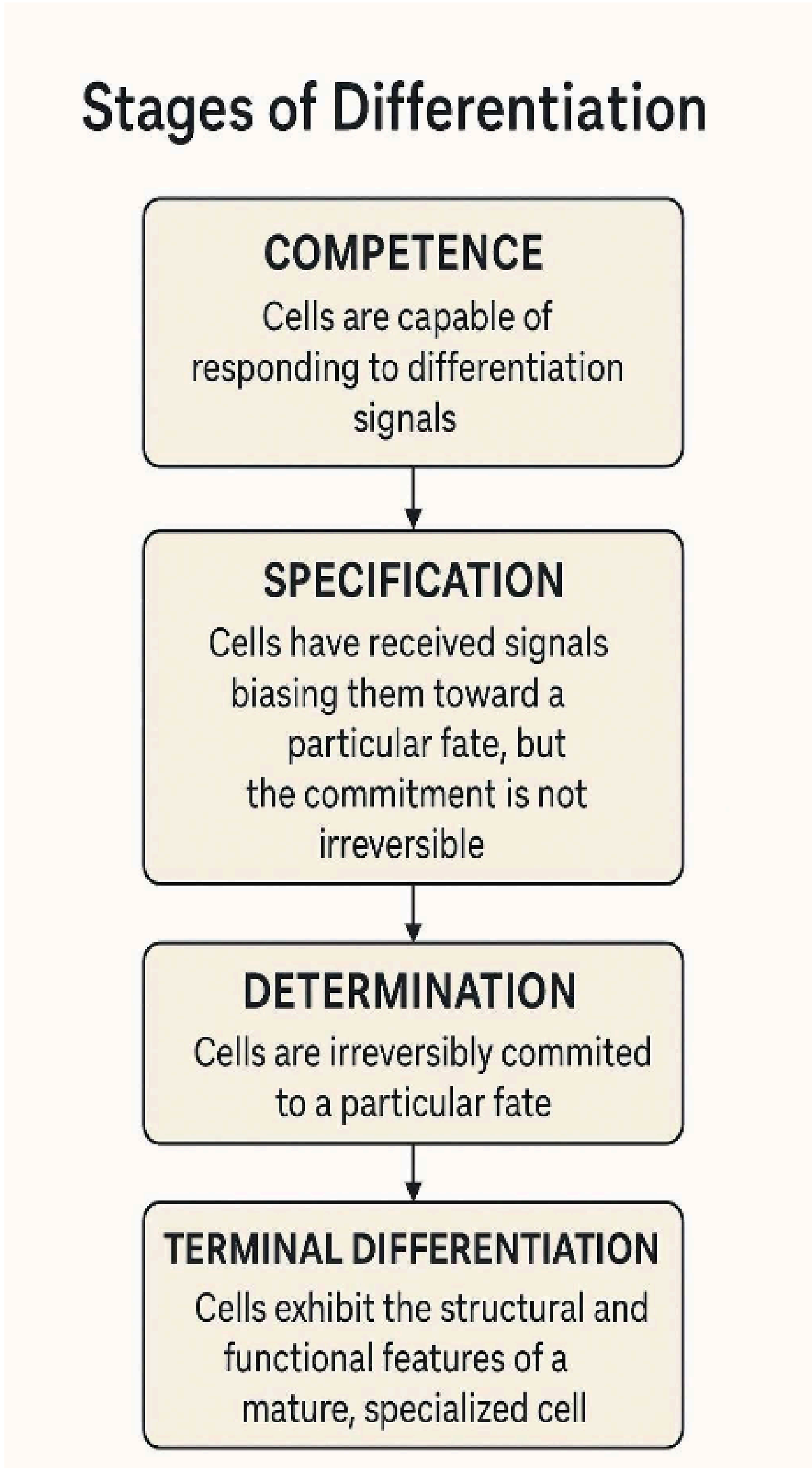
**Integration of Concepts**

In a developing embryo, no single process acts in isolation. Induction provides the instructions, organisers coordinate those instructions into a body-wide plan, and differentiation executes them. A fertilized egg contains all the genetic information, but without these intercellular dialogues, it would remain a disorganized mass of cells.

Consider the eye as an example:

- The optic vesicle (inducer) contacts surface ectoderm.
- The surface ectoderm (responder) forms the lens.
- The lens in turn induces the optic cup to form the retina.
- Within these tissues, cells differentiate into photoreceptors, lens fibers, and supporting structures—each step guided by organisers and inductive cues.


EXTERNAL VIEWS FROM SIDE
TRANSVERSE SECTIONS
Animal pole
Grey crescent (dorsal)
Sperm entry (ventral)
Vegetal pole
Induced mesoderm
Responsive animal cells
Blasto -coel
Inducing vegetal cells
A
MID BLASTULA.
MESODERM INDUCTION
Dorsal blastopore lip
Yolk plug
Induced neural tissue
Responsive ectoderm
Inducing mesoderm
Arch -enteron
Residual blastocoel
B
MID GASTRULA.
NEURAL INDUCTION
Dorsal
Section through future eye
Induced lens
Responsive ectoderm
Inducing optic lobe of brain
C
NEURULA.
LENS INDUCTION


Stages of Differentiation
COMPETENCE
Cells are capable of responding to differentiation signals
SPECIFICATION
Cells have received signals biasing them toward a particular fate, but the commitment is not irreversible
DETERMINATION
Cells are irreversibly commited to a particular fate
TERMINAL DIFFERENTIATION
Cells exhibit the structural and functional features of a mature, specialized cell

**Question Bank:**

**Very Short Answer Question**

1. What is placenta?
2. Name any two types of placenta based on shape.
3. Define embryonic induction.
4. Give one example of an organizer in embryology.
5. Mention the primary extraembryonic membranes in chick.
6. What is the function of yolk sac?
7. Name the three primary germ layers.
8. What is the function of the allantois in chick?
9. State one function of the chorion.
10. Which layer forms the nervous system in embryo?
11. Define histotrophic nutrition.
12. What is the amniotic cavity?
13. Give an example of an epitheliochorial placenta.
14. What is the primitive streak?
15. Which extraembryonic membrane helps in gaseous exchange?

**Short Answer Questions**

1. Differentiate between epitheliochorial and hemochorial placenta.
2. Write a short note on the role of the **Spemann organizer** in embryonic induction.
3. Describe the formation of **amnion** in chick.
4. Explain the function of the **chorion** in extraembryonic membranes.
5. Draw and label a diagram of a **villous placenta**.
6. How do primary germ layers arise during chick development?
7. List the derivatives of ectoderm in the chick embryo.
8. Write short notes on **amnion and yolk sac**.

9. Differentiate between **deciduate** and **nondeciduate** placenta.

10. What is the role of **Hensen's node** in induction?

11. Write a short note on the origin of mesoderm in chick.

12. Explain the functions of extraembryonic membranes as a whole.

13. Mention the differences between **allantoic** and **yolk sac placenta**.

14. Outline the significance of three germ layers.

15. Explain how gastrulation leads to the formation of germ layers.

**Long Answer Questions**

1. **Describe the structure and types of placenta in detail.**
   - Include classification based on shape, distribution of villi, and maternal contact.
   - Add neat labeled diagrams.
2. **Explain embryonic induction with suitable experiments and examples.**
   - Include Spemann and Mangold's experiment.
   - Discuss primary and secondary organizers.
   - Highlight its significance in organogenesis.
3. **Discuss the development of extraembryonic membranes in chick up to the formation of three germ layers.**
   - Explain the formation of amnion, chorion, yolk sac, and allantois.
   - Include diagrams showing their development stages.
4. **Describe the process of gastrulation in chick embryo and how three germ layers are established.**
   - Explain primitive streak, Hensen's node, and migration of cells.
   - Add diagrams showing germ layer formation.
5. **Write an essay on the functional significance of extraembryonic membranes in chick.**
   - Include roles in protection, nutrition, respiration, and excretion.
6. **Discuss the comparative significance of different types of placenta in mammals.**
   - Correlate structure with function.

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