



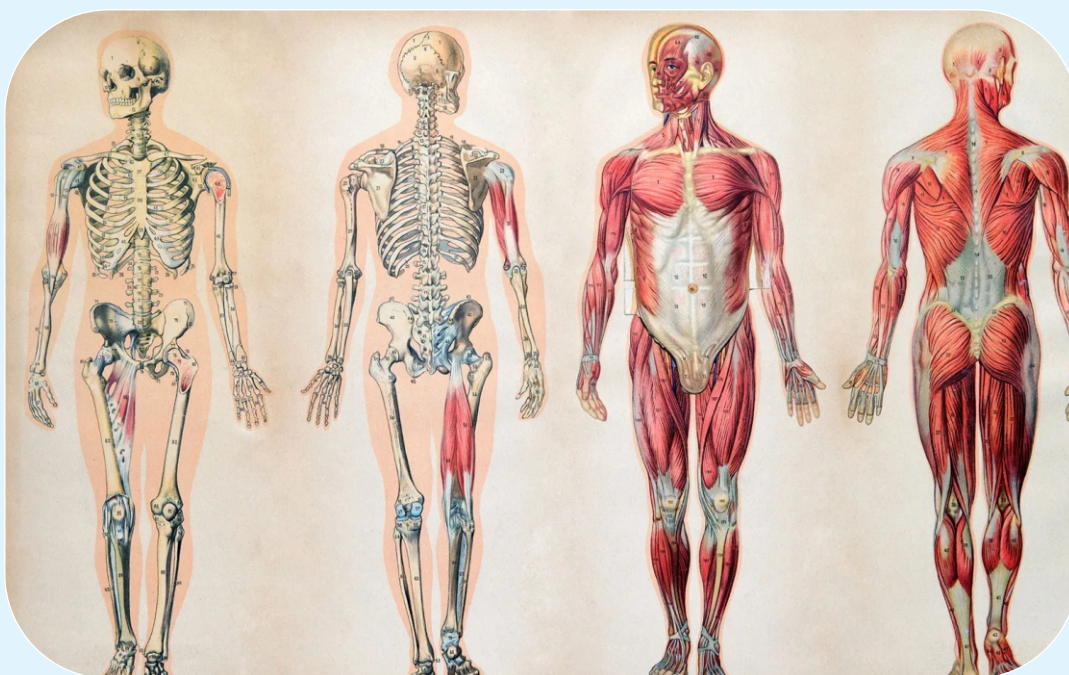
MATS
UNIVERSITY

NAAC
GRADE **A⁺**
ACCREDITED UNIVERSITY

MATS CENTRE FOR DISTANCE & ONLINE EDUCATION

Anatomy & Physiology

**Bachelor of Science (B.Sc.)
Semester - 3**



SELF LEARNING MATERIAL



DSCC302
ZOOLOGY III:
ANATOMY AND PHYSIOLOGY
CODE: ODL/MSS/BSCB/302

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MODULE INTRODUCTION

Course has five Modules. Under this theme we have covered the following topics:

Module 1 Comparative Anatomy of Organ Systems,

Module 2 Comparative Anatomy of Vertebrates

**Module 3 Nervous, Endocrine, And Reproductive Systems In
Vertebrates**

**Module 4 Physiology of Digestion, Circulation, Blood Coagulation,
and Respiration,**

**Module 5 Excretion, Muscle contraction, Nerve Impulse and
sensory systems**

These themes of the Book discuss about the study of the structure and function of the human body. Anatomy is the study of the body's parts, while physiology is the study of how those parts work together. 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 1



ANATOMY & PHYSIOLOGY

COMPARATIVE ANATOMY OF ORGAN SYSTEMS

Objectives:

Understand variations in skeletal, circulatory, excretory, reproductive, and endocrine

systems.

Explore the integumentary system and its derivatives, including skin, scales, hair, and

feathers.

Learn about differences in the alimentary canal, digestive glands, and nutrient

absorption.

Examine the structure and function of respiratory organs across vertebrate groups.

UNIT 1.1:

Comparative Anatomy of Organ Systems:

1.1 Introduction

The study of comparative anatomy explores the similarities and differences in the structure of organs and systems among various groups of animals, with a special focus on tracing evolutionary relationships and functional adaptations. At its core, comparative anatomy helps us understand how a particular organ system has been shaped by ecological pressures, environmental constraints, and the lineage of the organism. In vertebrates, major organ systems—including the integumentary, skeletal, muscular, digestive, respiratory, circulatory, excretory, and nervous systems—show a remarkable combination of conserved features and evolutionary modifications.

Integument and Its Derivatives

The integument is the outer protective covering of the body, comprising skin and associated structures. In most vertebrates, it is composed of an outer epidermis derived from ectoderm and an underlying dermis derived from mesoderm. In fishes, the integument is generally thin and covered with scales, such as placoid scales in cartilaginous fishes or cycloid and ctenoid scales in teleosts. These scales not only reduce friction during



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swimming but also serve as a barrier against pathogens. Amphibians display a smooth, glandular skin that assists in cutaneous respiration and moisture retention, reflecting their dual aquatic and terrestrial lifestyles. In reptiles, the integument is heavily keratinized and forms protective scales that reduce water loss, enabling survival in arid habitats. Birds have evolved feathers—specialized epidermal outgrowths—essential for insulation, camouflage, display, and flight. Mammals, on the other hand, exhibit hair, sebaceous glands, sweat glands, and mammary glands, illustrating a high degree of specialization for thermoregulation and nurturing of offspring.

Skeletal and Muscular Adaptations

The vertebrate endoskeleton provides structural support and a framework for muscle attachment. In fishes, the axial skeleton, comprising the vertebral column and associated elements, is dominant, while the appendicular skeleton remains relatively simple. Amphibians show the first clear adaptation to life on land, with a more robust pectoral and pelvic girdle to support body weight outside water. Reptiles further strengthen these girdles and develop well-formed limbs for terrestrial locomotion. Birds show profound skeletal modifications for flight: a lightweight but strong skeleton with fused clavicles (forming the furcula) and a keeled sternum for flight muscle attachment. Mammals retain a highly ossified skeleton, with diverse modifications depending on locomotor habits—cursorial mammals possess elongated limbs, fossorial mammals show powerful digging forelimbs, and arboreal mammals often have flexible joints and prehensile appendages.

Digestive System Comparisons

The digestive system in vertebrates reflects dietary specialization. In primitive jawless fishes, the gut is a simple straight tube. Cartilaginous and bony fishes possess a more developed gut with a spiral valve increasing surface area for absorption. Amphibians retain a relatively simple stomach and intestine, suitable for their insectivorous or carnivorous diets. Reptiles exhibit longer intestines and more compartmentalization in herbivorous forms. Birds display striking adaptations, such as the crop for storage and the gizzard for grinding food, compensating for the absence of teeth. Mammals demonstrate the greatest variety—ruminants like cows possess a complex four-chambered stomach for cellulose digestion, whereas carnivores have a shorter gut suited for meat digestion. These differences reflect how evolution tailors the same basic plan to distinct ecological niches.

Respiratory Structures and Function

Respiratory organs also display significant evolutionary transitions. Aquatic fishes rely on gills, which are efficient at extracting oxygen from water. Amphibians exhibit a dual mode of respiration, using gills in larval



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stages and simple sac-like lungs in adults, supplemented by cutaneous respiration through their moist skin. Reptiles possess more advanced lungs with greater surface area, permitting a higher metabolic rate and fully terrestrial life. Birds have the most efficient respiratory system among vertebrates, characterized by rigid lungs connected to air sacs, enabling a unidirectional flow of air and continuous oxygen supply even during exhalation—an adaptation vital for the high energy demands of flight. Mammals have highly elastic lungs with intricate alveolar structures, supporting active endothermy and varied lifestyles.

Circulatory and Excretory Correlations

In vertebrates, the circulatory system shows a progressive separation of oxygenated and deoxygenated blood. Fishes exhibit a single circulatory circuit with a two-chambered heart, adequate for aquatic life but limiting in pressure generation. Amphibians develop a three-chambered heart with partial separation, reflecting their intermediate status between water and land. Reptiles retain a three-chambered heart but with a partially divided ventricle that reduces mixing of blood. Birds and mammals independently evolved a four-chambered heart, achieving complete separation and supporting high metabolic rates. The excretory system also adapts to habitat: fishes possess mesonephric kidneys well suited for water balance in aquatic environments, whereas terrestrial vertebrates develop metanephric kidneys with greater efficiency in conserving water. Birds excrete nitrogen as uric acid to minimize water loss, while mammals predominantly excrete urea, balancing water conservation and toxicity.

Nervous System and Sensory Organs

The nervous system retains a common vertebrate plan but undergoes remarkable specialization. Fishes have a brain geared towards basic sensory processing and reflexive motor control, with a well-developed olfactory lobe important for detecting chemical cues in water. Amphibians show a slight increase in cerebral hemispheres, accommodating more complex behaviors. Reptiles possess a larger cerebrum and more advanced optic lobes, aiding in vision-dependent predation. Birds exhibit further enlargement of the cerebellum for flight coordination and highly acute sensory processing. Mammals have the most developed cerebral cortex, enabling higher cognitive functions, learning, and complex social behavior. Correspondingly, sensory organs adapt: lateral line systems in fishes detect water vibrations, amphibians have tympanic membranes for aerial hearing, reptiles develop Jacobson's organs for chemoreception, birds possess superior vision with large eyes, and mammals diversify their senses according to ecological demands.

Circulatory System

The vertebrate heart shows a progression toward complete separation of oxygenated and deoxygenated blood. Fishes have a two-chambered heart



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that pumps blood in a single circuit. Amphibians possess a three-chambered heart, allowing partial separation of blood but still some mixing. Reptiles also have a three-chambered heart, but with a partially divided ventricle that improves efficiency. Birds and mammals each evolved a four-chambered heart independently, enabling a double-circulation system that supports higher activity levels and precise temperature regulation.

Excretory System

The excretory system removes metabolic wastes and maintains osmotic balance. In fishes, mesonephric kidneys function efficiently in aquatic environments, excreting ammonia directly into the surrounding water. Amphibians also use mesonephric kidneys but begin to show adaptations for variable water availability. Reptiles and birds develop metanephric kidneys that conserve water more effectively, with birds excreting nitrogen in the form of uric acid, a paste-like substance that reduces water loss. Mammals have highly advanced metanephric kidneys with loops of Henle that concentrate urine and allow efficient water retention, a key adaptation for survival in diverse habitats.

Reproductive System

Reproductive anatomy exhibits striking evolutionary variation. Most fishes are oviparous, with external fertilization in bony fishes and internal fertilization in cartilaginous fishes, some of which are viviparous. Amphibians typically rely on external fertilization in aquatic environments, producing eggs without extensive protective membranes. Reptiles evolved internal fertilization and lay shelled, amniotic eggs, which can develop on land without desiccation. Birds retain this amniotic egg structure, with calcified shells that protect the embryo while allowing gas exchange. Mammals are characterized by internal fertilization and viviparity; the embryo develops within the uterus, nourished via a placenta in most species, though monotremes like the platypus still lay eggs. This progression reflects increasing protection and resource provision for developing young.

Endocrine System

The endocrine system, though less obvious in anatomy, demonstrates evolutionary refinement in regulating physiology through hormones. In fishes, endocrine organs like the pituitary and thyroid are present but relatively simple, maintaining basic growth and metabolic functions. Amphibians exhibit endocrine regulation critical for metamorphosis; thyroid hormones drive the transition from larval to adult forms. Reptiles



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show further complexity with adrenal and gonadal hormones influencing seasonal reproduction and metabolic adaptation to varied climates. Birds possess highly active thyroid and adrenal glands to support the high metabolic demands of flight. Mammals have the most elaborately regulated endocrine networks, with feedback loops controlling growth, reproduction, stress responses, and homeostasis through glands like the pituitary, thyroid, pancreas, and adrenal cortex.

Evolutionary Significance

Comparing these systems across vertebrate classes underscores how a basic anatomical plan has been modified to meet different ecological challenges. Homologous structures, like the pentadactyl limb or the vertebrate heart, reveal shared ancestry, while their variations illustrate evolutionary innovation. Such comparisons not only deepen our understanding of biology but also provide insights with practical implications in fields like medicine, developmental biology, and paleontology.

SUMMARY:

Comparative anatomy shows how vertebrate organ systems evolved from a common plan but adapted to diverse habitats.

- Integument: from fish scales to amphibian moist skin, reptilian keratinized scales, bird feathers, and mammalian hair/glands.
- Skeleton & Muscles: fish axial support → amphibian girdles for land → reptile stronger limbs → bird flight skeleton → mammal diverse locomotion.
- Digestive & Respiratory: simple gut in fishes → specialization in reptiles, birds (crop & gizzard), and mammals (ruminants); gills in fishes → lungs in amphibians/reptiles → efficient air sac lungs in birds → alveoli in mammals.
- Circulatory & Excretory: fish 2-chambered heart → amphibian/reptile 3-chambered → bird/mammal 4-chambered; excretion shifts from ammonia (fish) → urea (mammals) → uric acid (birds).
- Reproduction & Endocrine: external fertilization in fishes/amphibians → internal fertilization & amniotic eggs in reptiles/birds → viviparity with placenta in mammals; endocrine control becomes increasingly complex.



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A. Multiple Choice Questions (MCQs)

1. Which vertebrate group first shows the presence of a robust pelvic and pectoral girdle for terrestrial life?
 - a) Fishes
 - b) Amphibians
 - c) Reptiles
 - d) Birds

Answer: b) Amphibians

2. Birds compensate for the absence of teeth by developing:
 - a) Ruminant stomachs
 - b) Crop and gizzard
 - c) Jacobson's organ
 - d) Loops of Henle

Answer: b) Crop and gizzard

3. Which type of nitrogenous waste is excreted by birds?
 - a) Ammonia
 - b) Urea
 - c) Uric acid
 - d) Creatinine

Answer: c) Uric acid

4. The four-chambered heart evolved independently in:
 - a) Amphibians and reptiles
 - b) Birds and mammals
 - c) Fishes and amphibians
 - d) Reptiles and fishes

Answer: b) Birds and mammals

5. Which endocrine gland plays a crucial role in amphibian metamorphosis?
 - a) Pancreas
 - b) Pituitary
 - c) Thyroid
 - d) Adrenal

Answer: c) Thyroid

B. Short Answer Questions

1. Compare the structure of fish scales with bird feathers in terms of function and adaptation.
2. Why is the bird respiratory system considered the most efficient among vertebrates?

3. Differentiate between mesonephric and metanephric kidneys with examples.
4. Explain the significance of the amniotic egg in vertebrate evolution.
5. Describe the role of the thyroid gland in amphibians.



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UNIT 1.2:

Integument and its Derivative

1.2 Introduction

The integument is the outer covering of the body that separates and protects the internal environment from the external surroundings. In vertebrates, it is not merely a passive covering but a complex organ system that performs multiple functions. It acts as a mechanical barrier, prevents dehydration, participates in thermoregulation, aids in sensory perception, and often plays a role in communication and camouflage. The integument also gives rise to a wide range of derivatives such as scales, feathers, hairs, nails, claws, and horns, which have evolved to serve specialized functions in different groups of vertebrates.

1.2.1 General Structure of the Integument

In a typical vertebrate, the integument consists of two primary layers: the **epidermis** and the **dermis**, underlaid by a subcutaneous layer.

1. Epidermis:

The epidermis is derived from the ectoderm and is composed mainly of stratified squamous epithelium. In its deepest layer, known as the stratum basale or germinativum, mitotically active cells continuously divide to replace the superficial cells. As these cells migrate outward, they undergo keratinization, a process in which the cytoplasm is gradually replaced by keratin, a tough, fibrous protein. This process provides resistance to mechanical stress and water loss. The outermost layer, the stratum corneum, consists of dead, flattened keratinized cells that are periodically shed.

2. Dermis:

The dermis lies beneath the epidermis and is derived from the mesoderm. It is composed of connective tissue rich in collagen and elastic fibers, blood vessels, lymphatics, and sensory nerve endings. The dermis supports and nourishes the epidermis and houses various glands, pigment cells, and, in some species, muscles that move the integumentary derivatives (for example, the erector muscles of hair in mammals).

The dermis often contains specialized chromatophores (pigment cells) such as melanophores, xanthophores, and iridophores, which are responsible for skin coloration and patterns. In some species, these pigment cells can rapidly expand or contract, producing dynamic changes in color for camouflage or signaling.

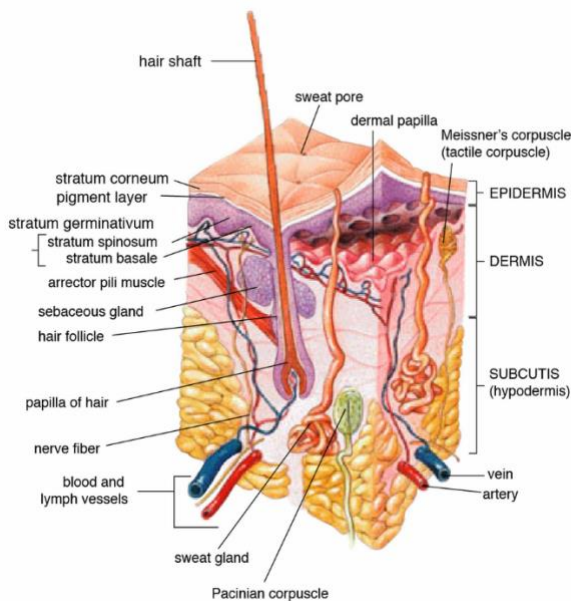


Fig1.1: V.S of skin

1.2.2 Functions of the Integument

The integument serves as a multifunctional organ. It forms the first line of defense against pathogens, provides mechanical protection against injury, and minimizes water loss in terrestrial animals. It participates in the synthesis of vitamin D, contains sensory receptors that detect touch, temperature, and pain, and often houses glands that secrete substances ranging from lubricating oils to toxic or defensive chemicals. In many vertebrates, the integument also functions in thermoregulation by means of sweating, panting, or the erection of hairs or feathers to trap air.

Integumentary Derivatives

Through evolutionary modification, the integument has given rise to a remarkable diversity of structures that aid in survival, reproduction, and adaptation to different environments. These derivatives are usually keratinous in nature and arise as outgrowths of the epidermis, often supported or modified by the dermis.

Epidermal Derivatives

Epidermal derivatives arise purely from the ectodermal epidermal layer. These structures are typically composed of keratin, a resilient protein, and they project outward as protective or functional appendages. In many cases, dermal papillae support their development, but their origin remains epidermal.

Key Epidermal Derivatives:



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- **Epidermal Scales:**

In reptiles and some mammals (such as pangolins), scales are entirely epidermal and keratinized. They form overlapping shields that prevent water loss and provide mechanical protection. Scales are protective structures that cover the body surface of many vertebrates. In fishes, **placoid scales** (in cartilaginous fishes), **ganoid scales** (in primitive bony fishes), and **cycloid or ctenoid scales** (in modern teleosts) are typical. These scales not only protect against injury and predators but also reduce friction during swimming. In reptiles, the scales are entirely epidermal and composed of keratin, forming a tough, overlapping shield that minimizes water loss and provides mechanical protection.

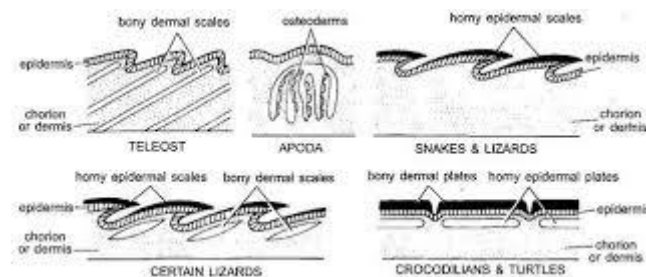


Fig 1.2 various types of scales in vertebrates

Feathers:

Unique to birds, feathers develop from epidermal placodes and are anchored in follicles that dip into the dermis. Feathers are composed of β -keratin, lightweight and strong, providing aerodynamic surfaces for flight, insulation, and ornamental displays. Feathers are highly specialized derivatives unique to birds, arising from the epidermis but intricately supported by dermal papillae. They are primarily composed of keratin and serve a variety of functions, including flight, insulation, display, and camouflage. The complex arrangement of barbs and barbules in contour feathers creates a smooth aerodynamic surface, while down feathers trap air to conserve body heat.

Hair and Fur:

These develop from epidermal downgrowths called hair follicles, which extend into the dermis. The hair shaft is composed of keratin, while associated sebaceous glands lubricate the hair and skin. Hair aids in insulation, sensory detection (vibrissae), and signaling. Hairs are slender keratinous outgrowths of the mammalian epidermis. They develop from invaginations called hair follicles that extend into the dermis. Hairs serve as

insulation, sensory structures (as in vibrissae or whiskers), and sometimes as display elements in social communication. The arrector pili muscles attached to hair follicles enable hairs to stand erect, trapping air for insulation or signaling aggression or fear.

- **Claws, Nails, and Hooves:**

All these are keratinized plates formed by specialized epidermal layers:

- **Claws** (curved) assist in grasping, tearing, or defense.
- **Nails** (flattened) protect sensitive fingertips and enhance tactile sensation.
- **Hooves** (thickened and hardened) withstand friction and impact in running animals.

Cali

- **Beaks (Rhamphotheca):**

In birds and turtles, the jaws are covered with a keratinous epidermal sheath forming a beak or bill. This structure replaces heavy teeth and is adapted for various feeding habits.

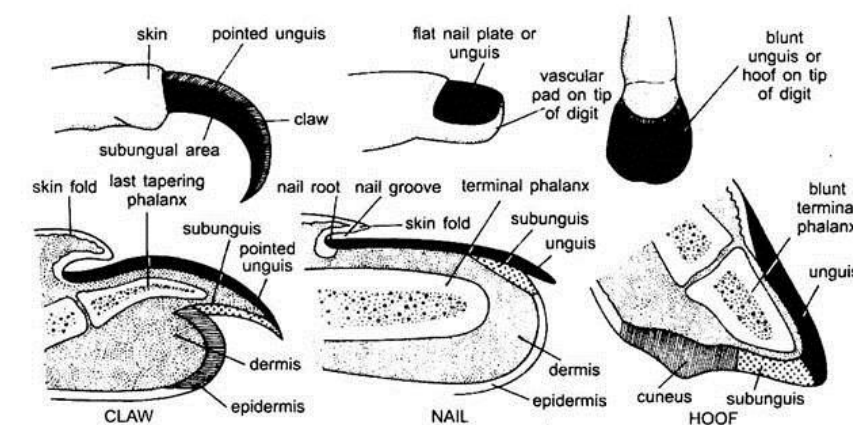


Fig 1.3: Relation between claw, nail and hoof

Horns and Antlers

Horns and antlers are also integumentary derivatives, though they incorporate both epidermal and dermal components:

- **True horns** (such as those of cattle and antelopes) are permanent, keratin-covered dermal projections.



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- **Antlers** (as in deer) are bony outgrowths of the skull that are seasonally shed and regrown, initially covered by a vascularized skin called velvet during their development.

- **Epidermal Glands:**

Several types of glands originate in the epidermis:

- **Sebaceous glands** (mammals) secrete oily sebum.
- **Sweat glands** aid in thermoregulation.
- **Mammary glands** are highly modified sweat glands producing milk.
- **Scent glands** secrete pheromones for communication.

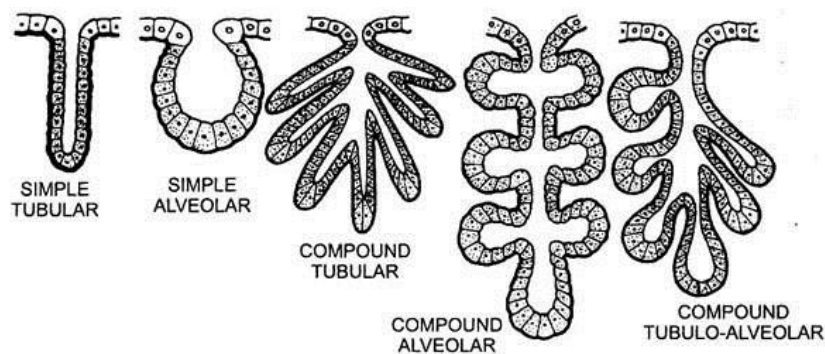


Fig1.4: Epidermal glands

Significance:

Epidermal derivatives are primarily protective and help animals adapt to terrestrial life by reducing water loss, aiding locomotion, or participating in social and reproductive behaviors.

Dermal Derivatives

Dermal derivatives originate from the mesodermal connective tissue of the dermis. These structures often include bone or dentine and are typically found in fishes and some reptiles. In many cases, the epidermis covers these dermal components, but the skeletal material itself is dermal in origin.



Key Dermal Derivatives:

- **Dermal Scales in Fishes:**

Placoid scales (sharks and rays) have a dentine core and an enamel-like surface, making them miniature tooth-like structures embedded in the dermis. Ganoid scales (gars) have a bony base with a shiny ganoine layer, while cycloid and ctenoid scales (teleost fishes) are thin dermal plates providing flexibility and protection.

- **Dermal Bones:**

Many early vertebrates had bony armor plates formed in the dermis, some of which persist in modern species as parts of skull roofing bones or turtle shells (the carapace and plastron are primarily dermal in origin).

- **Horns with Bony Cores:**

In true horns (cattle, sheep, antelopes), the central supportive structure is dermal bone, which is then covered by a keratinous epidermal sheath.

Antlers (deer) are entirely bony dermal outgrowths that are seasonally shed.

- **Osteoderms:**

Found in crocodilians and some lizards, these are bony plates formed within the dermis that contribute to the rigidity and protection of the integument.

Significance:

Dermal derivatives provide strong structural support and defense. In aquatic vertebrates, they help streamline the body, while in reptiles and certain mammals, they offer protection against predators and environmental stress.

Integration of Epidermal and Dermal Components

In many integumentary structures, the epidermis and dermis work together. For instance, in hair follicles and feathers, the epidermis forms the visible structure, while the dermis supplies nourishment and anchorage through dermal papillae. In horns, a dermal bony core is covered by an epidermal sheath. This collaboration illustrates how integumentary derivatives are not isolated inventions but products of the coordinated evolution of the skin's layers.

SUMMARY:

The integument in vertebrates is a complex organ system composed of **epidermis** (ectodermal, keratinized) and **dermis** (mesodermal, connective



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tissue), serving roles in protection, thermoregulation, sensory input, and communication. It gives rise to diverse derivatives:

- **Epidermal derivatives:** scales, feathers, hairs, claws, nails, hooves, beaks, horns (keratin sheath), and glands (sebaceous, sweat, mammary, scent).
- **Dermal derivatives:** placoid, ganoid, cycloid, and ctenoid scales; dermal bones (skull, turtle shell); osteoderms; bony cores of horns; antlers.

Many derivatives are formed by the combined action of epidermis and dermis, illustrating evolutionary cooperation between skin layers.

A. Multiple Choice Questions (MCQs)

1. The stratum basale of the epidermis is primarily responsible for:
 - a) Pigment production
 - b) Keratinization
 - c) Cell division and replacement
 - d) Sensory reception

Answer: c) Cell division and replacement

2. Placoid scales are characteristic of:
 - a) Amphibians
 - b) Cartilaginous fishes
 - c) Birds
 - d) Mammals

Answer: b) Cartilaginous fishes

3. Which of the following integumentary derivatives are unique to mammals?
 - a) Feathers and beaks
 - b) Hair and mammary glands
 - c) Scales and osteoderms
 - d) Antlers and claws

Answer: b) Hair and mammary glands

4. Antlers differ from true horns in that they:
 - a) Have a keratin sheath
 - b) Are permanent structures
 - c) Are entirely bony and shed annually
 - d) Lack a dermal component

Answer: c) Are entirely bony and shed annually

5. Osteoderms are found in:
 - a) Birds
 - b) Mammals only
 - c) Crocodilians and some lizards

d) Amphibians

Answer: c) Crocodilians and some lizard



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B.Short Answer questions

1. Differentiate between epidermal and dermal derivatives with examples.
2. What role do chromatophores play in the integument?
3. Explain how feathers and hair demonstrate epidermal–dermal integration.
4. How do integumentary glands aid in thermoregulation and communication?
5. State two key differences between horns and antlers.



UNIT 1.3:

Alimentary Canal & Digestive Glands

1.3 General Overview

The alimentary canal, also called the digestive tract, is a continuous muscular passage through which food is ingested, processed, and ultimately egested in all vertebrates. It begins at the mouth, where food is received and often mechanically broken down by teeth, beaks, or other structures, and it terminates at an anus or cloaca, through which indigestible material is eliminated. Along its length, the canal is regionally specialized into successive segments, each with a particular role in the complex process of digestion and absorption. The mouth opens into the buccal cavity, which in most vertebrates is lined with mucus and often provided with salivary glands or similar secretory organs that moisten food and, in higher vertebrates, initiate enzymatic digestion. The buccal cavity leads posteriorly to the pharynx, a common chamber shared by both digestive and respiratory systems, from which the food passes through the esophagus, a muscular tube that transports it to the stomach by peristaltic movements. The stomach, typically a distensible sac, is a site for temporary storage and chemical breakdown of food, its walls often lined with glands that secrete acid and proteolytic enzymes. Following the stomach is the intestine, usually differentiated into a small intestine, where most chemical digestion and absorption occur, and a large intestine, which compacts waste and absorbs water. In many vertebrates, the intestine opens into a cloaca—a common chamber for the digestive, urinary, and reproductive tracts—while in others it terminates directly as an anus.

Complementing the canal are associated digestive glands, notably the liver, pancreas, and in higher vertebrates, well-developed salivary glands. These glands secrete bile, pancreatic juices, and other fluids that play vital roles in emulsifying fats, digesting carbohydrates and proteins, and maintaining an alkaline environment for enzymatic activity. Despite following this general plan, the alimentary canal in different vertebrate groups shows striking modifications in shape, length, and complexity, directly related to their dietary habits, metabolic needs, and evolutionary history.

General Overview of Digestive Glands

Alongside the alimentary canal, vertebrates possess several accessory digestive glands that play indispensable roles in the chemical processing of food. These glands do not form part of the food passage but are anatomically connected to it through ducts. They secrete various substances—such as enzymes, mucus, acids, and bile—that facilitate the conversion of complex food materials into absorbable nutrients.



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The most universally present glands are **salivary glands**, **liver**, and **pancreas**. Salivary glands, typically opening into the buccal cavity, moisten food, aid in lubrication for swallowing, and, in higher vertebrates, initiate carbohydrate digestion through enzymes like amylase. The liver, the largest gland in the body, is a metabolic hub as well as a digestive gland; it secretes **bile**, which emulsifies fats and aids their digestion. The **pancreas** secretes a cocktail of digestive enzymes (lipase, amylase, proteases) and bicarbonate ions that neutralize gastric acid and act in the small intestine to break down carbohydrates, proteins, and fats.

Some groups also possess additional specialized glands or modifications of these basic structures, reflecting their ecological and dietary needs. Collectively, these glands work in close coordination with the alimentary canal to ensure efficient digestion and absorption of nutrients.

Fishes

In cyclostomes (like lampreys and hagfishes), the alimentary canal is straight and relatively simple, suited to their parasitic or scavenging habits. The mouth lacks jaws but is provided with rasping structures (in lamprey) or tentacles (in hagfish). There is no true stomach; the esophagus leads directly into an intestine that often has a spiral valve, a helical fold increasing surface area for absorption.

In cartilaginous fishes (sharks and rays), the mouth opens ventrally, leading to a short pharynx with numerous gill slits. The esophagus is wide and muscular, leading to a J-shaped stomach capable of storing large meals. The intestine contains a well-developed spiral valve, an adaptation for efficient absorption in the absence of a long gut. Large digestive glands, particularly a massive liver rich in oil, aid buoyancy and store nutrients, while the pancreas lies diffusely embedded along the intestine and releases enzymes through ducts.

In bony fishes, the alimentary canal shows further specialization. The mouth is usually terminal with varied dentition according to feeding habits—sharp teeth in carnivores, grinding pharyngeal teeth in herbivores. The stomach is usually well defined and may be simple or divided into regions (cardiac, fundic, pyloric). Pyloric caeca, blind outgrowths at the junction of stomach and intestine, are characteristic and secrete digestive enzymes. A compact liver and pancreas contribute bile and pancreatic juices.

Amphibians

Amphibians such as frogs exhibit a more terrestrial adaptation while retaining features from their aquatic ancestors. The mouth is wide, with sticky tongue and simple conical teeth for capturing prey. The pharynx connects to a short esophagus leading to a sac-like stomach. From the



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stomach, the duodenum receives secretions from the liver (via gall bladder and bile duct) and pancreas, aiding in digestion of proteins and fats. The small intestine is relatively long and coiled, facilitating increased absorption compared to fishes. A large intestine terminates in a cloaca. Salivary glands are present in most amphibians and begin carbohydrate digestion in the buccal cavity, a feature absent in fishes.

Reptiles

Reptiles, being fully terrestrial, show further elaboration of the alimentary canal. In most lizards and snakes, the mouth contains well-developed teeth that may be homodont or heterodont, depending on diet. The tongue often plays a sensory role as well as aiding in prey manipulation. The esophagus is long and muscular, allowing storage or slow passage of food, which is especially evident in snakes. The stomach is typically divided into a muscular cardiac part and a glandular pyloric part. Intestinal coils are more complex than in amphibians, with a well-differentiated small and large intestine. Cloacal structure is retained. Digestive glands such as salivary glands may be modified into venom glands in many snakes and some lizards, showing functional specialization. The liver is bilobed and secretes bile; the pancreas is discrete and drains into the duodenum.

Birds

Birds exhibit striking adaptations for flight and high metabolic demands. The beak replaces teeth, but its shape is highly specialized according to diet—seed-crushing, probing, tearing, or filter feeding. The pharynx and esophagus lead to a prominent **crop**, a storage organ in many birds where initial softening of food occurs. The stomach is divided into two distinct regions: the **proventriculus**, a glandular part secreting gastric juices, and the **gizzard** (ventriculus), a thick-walled muscular part that mechanically grinds food, often with ingested grit. The small intestine is long and coiled, allowing thorough absorption. Paired ceca are present at the junction of small and large intestine in many species, aiding fermentation of plant material. The cloaca serves as a common outlet. Accessory glands include a large bilobed liver producing bile, and a pancreas lying in the duodenal loop, contributing enzymes. Salivary glands in birds are well developed to moisten food and, in some species, secrete sticky fluids to capture insects.

Mammals

In mammals, the alimentary canal is most highly specialized, with marked differences in dentition, gut length, and compartmentalization according to diet. The mouth cavity bears heterodont dentition—incisors, canines, premolars, and molars—each adapted for specific functions. Salivary



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glands (parotid, submaxillary, sublingual) are well developed and secrete saliva containing enzymes like amylase, initiating carbohydrate digestion.

The esophagus leads to a stomach that may be simple (as in carnivores and omnivores) or complexly chambered (as in ruminants). In ruminants like cows, the stomach differentiates into rumen, reticulum, omasum, and abomasum, allowing microbial fermentation of cellulose before enzymatic digestion. The small intestine is greatly coiled, with distinct duodenum, jejunum, and ileum, ensuring maximum absorption. The large intestine often has a cecum, especially well developed in herbivores for fermentation. The rectum opens externally through the anus.

The liver in mammals is large and lobed, producing bile and performing multiple metabolic functions. The pancreas is discrete and secretes a broad spectrum of digestive enzymes and bicarbonate, essential for digestion in the small intestine.

Comparative Insights

Across vertebrates, the evolutionary trend is towards greater compartmentalization and increased surface area for absorption. Primitive fishes rely on spiral valves, while higher vertebrates develop longer, more coiled intestines. Accessory glands become more complex and numerous, aiding in pre-digestion (salivary glands) or enzymatic breakdown (pancreas). The liver remains a central organ in all groups, reflecting its early evolutionary origin and multifunctional role. Modifications such as the bird gizzard or the ruminant fore-stomach highlight adaptive divergence shaped by diet and ecology.

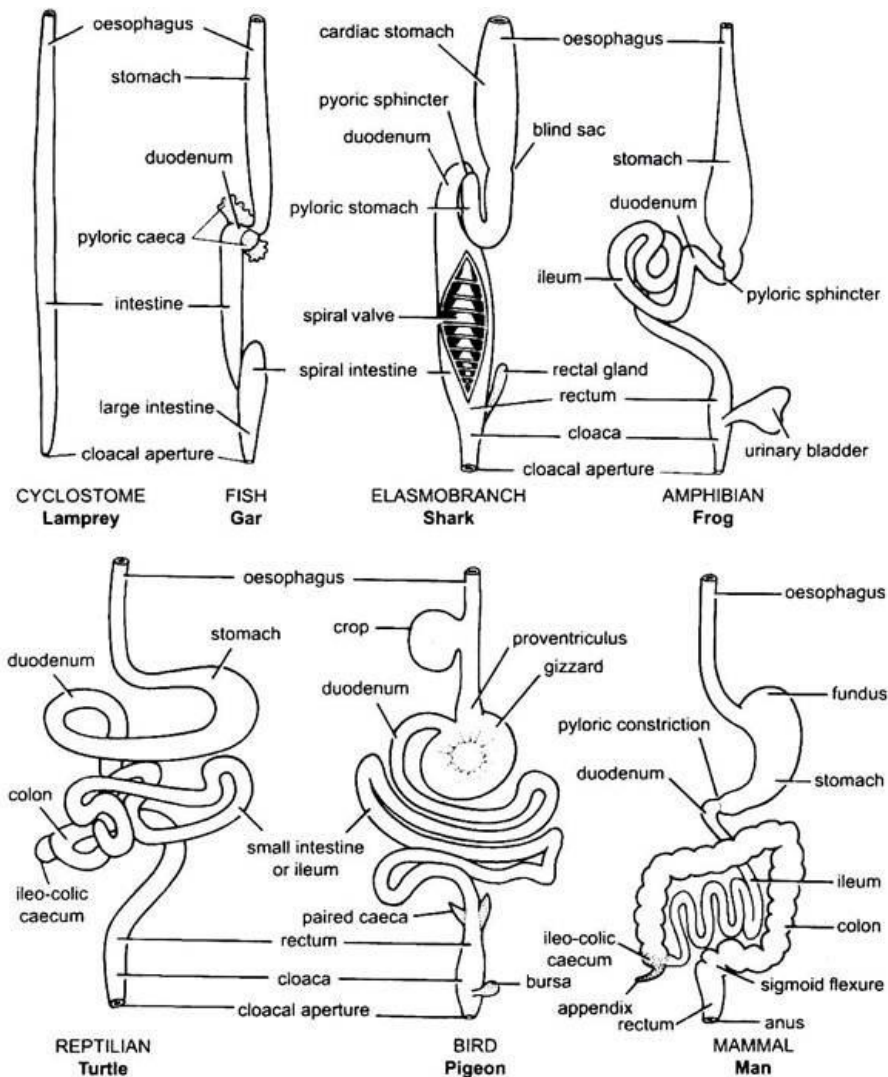


Fig1.5: Digestive Tract of vertebrates

General Overview of Digestive Glands

Alongside the alimentary canal, vertebrates possess several accessory digestive glands that play indispensable roles in the chemical processing of food. These glands do not form part of the food passage but are anatomically connected to it through ducts. They secrete various substances—such as enzymes, mucus, acids, and bile—that facilitate the conversion of complex food materials into absorbable nutrients.

The most universally present glands are **salivary glands**, **liver**, and **pancreas**. Salivary glands, typically opening into the buccal cavity, moisten food, aid in lubrication for swallowing, and, in higher vertebrates, initiate carbohydrate digestion through enzymes like amylase. The liver, the largest gland in the body, is a metabolic hub as well as a digestive gland; it secretes **bile**, which emulsifies fats and aids their digestion. The **pancreas** secretes a cocktail of digestive enzymes (lipase, amylase, proteases) and bicarbonate ions that neutralize gastric acid and act in the small intestine to break down carbohydrates, proteins, and fats.



Some groups also possess additional specialized glands or modifications of these basic structures, reflecting their ecological and dietary needs. Collectively, these glands work in close coordination with the alimentary canal to ensure efficient digestion and absorption of nutrients.

Comparative Account of Digestive Glands in Vertebrates

1. Digestive Glands in Fishes

In jawless fishes (cyclostomes), salivary glands are rudimentary or absent, as their feeding often involves sucking or rasping rather than mastication. The liver is prominent and often rich in lipids, serving both buoyancy and nutritional storage functions. A diffuse pancreas is typically present, embedded in the intestinal tissue, releasing its secretions into the gut through simple ducts. In cartilaginous fishes like sharks, the liver is extraordinarily large and oily, producing bile and contributing to buoyancy. Salivary glands are not distinctly developed, as food manipulation in the mouth is minimal. The pancreas is often lobed and well supplied with ducts leading to the intestine, ensuring enzymatic digestion of proteins and fats. In bony fishes, discrete salivary glands are still uncommon, but mucus cells in the mouth perform lubricating functions. The liver is well developed, often bilobed, and the pancreas is more compact than in cartilaginous fishes, delivering enzymes through one or more ducts into the intestine.

2. Digestive Glands in Amphibians

Amphibians such as frogs and salamanders show more advanced glandular development suited to their terrestrial life. Three pairs of salivary glands—lingual, submaxillary, and palatine—open into the buccal cavity and secrete mucus and, in some species, a small amount of digestive enzymes, helping in prey capture and lubrication. The liver is large and bilobed, producing bile stored in the gall bladder before being released into the duodenum. The pancreas is a distinct gland lying within the mesentery between stomach and duodenum, producing a range of enzymes such as trypsin, lipase, and amylase for intestinal digestion.

3. Digestive Glands in Reptiles

In reptiles, the salivary glands are well developed, often tubular, and produce mucus or serous secretions; in some snakes and lizards, they are modified into venom glands that secrete toxic enzymes for prey immobilization and predigestion. The liver is typically large, lobed, and capable of storing glycogen and lipids, with bile ducts leading to a gall bladder. The pancreas is compact and drains through pancreatic ducts into the duodenum, secreting a wide array of enzymes for protein and lipid digestion. Reptilian glands show a greater degree of functional specialization compared to amphibians.



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4. Digestive Glands in Birds

Birds exhibit salivary glands that are highly variable in size and function depending on diet. Many birds have salivary glands that secrete sticky mucous fluids, useful in capturing insects or binding nest material. In nectar-feeding birds, these glands are particularly well developed. The liver is large and bilobed, situated anterior to the proventriculus, producing bile for fat digestion; the gall bladder is present in most but absent in some birds such as pigeons. The pancreas is well developed and lies in the loop of the duodenum, secreting digestive enzymes and bicarbonates. These glands operate in concert with the highly specialized avian stomach (proventriculus and gizzard) to process food rapidly and efficiently, meeting the high energy demands of flight.

5. Digestive Glands in Mammals

Mammals exhibit the most complex and specialized arrangement of digestive glands. Salivary glands are present in three major pairs—parotid, submaxillary, and sublingual—along with numerous minor buccal glands. Their secretions not only lubricate food but also contain enzymes like salivary amylase (ptyalin) that initiate carbohydrate digestion in the mouth. In some species, additional glands (e.g., labial, palatine) provide supplementary secretions. The liver in mammals is highly lobulated and multifunctional, producing bile, detoxifying blood, storing glycogen, and synthesizing plasma proteins. The pancreas is compact and divided into endocrine and exocrine portions; the exocrine part secretes enzymes such as amylase, lipase, trypsin, and chymotrypsin into the duodenum, while bicarbonate neutralizes gastric acids. In ruminants and other herbivores, these glandular secretions are adapted to handle large volumes of cellulose-rich food, often in conjunction with microbial fermentation.

1.3.1 Comparative Perspective

Across vertebrates, the trend is toward increasing complexity and specialization of digestive glands. Fishes rely mainly on liver and diffuse pancreas, with minimal salivary function. Amphibians show the appearance of true salivary glands and a distinct pancreas. Reptiles introduce further specialization, including venom-modified glands. Birds demonstrate adaptive variability in salivary secretion and maintain highly efficient liver and pancreas function. Mammals, at the apex of glandular evolution, possess multiple, specialized salivary glands and highly functional liver and pancreas suited to diverse diets. These glands illustrate how vertebrate evolution has continuously refined digestion to exploit available food resources effectively.

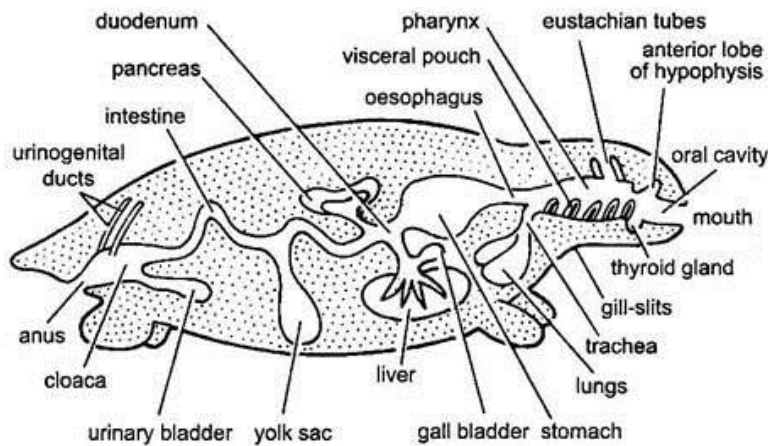


Fig 1.6: Alimentary canal and its chief derivative in vertebrates

SUMMARY:

The vertebrate alimentary canal is a continuous tube from mouth to anus/cloaca, regionally specialized for ingestion, digestion, absorption, and egestion. Associated glands—salivary glands, liver, and pancreas—aid chemical digestion.

- **Fishes:** simple gut, spiral valve, large liver (buoyancy & bile), diffuse pancreas.
- **Amphibians:** true salivary glands appear, simple stomach–intestine, distinct pancreas and liver.
- **Reptiles:** greater specialization; salivary glands modified into venom glands in some species.
- **Birds:** crop, proventriculus (glandular), gizzard (mechanical), paired ceca; glands adapted to diet.
- **Mammals:** most complex—heterodont dentition, long coiled intestines, ruminant chambered stomach, multiple salivary glands, highly functional liver and pancreas.

Evolutionary trend: increasing compartmentalization of gut and specialization of glands for dietary adaptation.

A. Multiple Choice Questions

1. In cyclostomes, the intestine is characterized by:
 - a) Cloaca
 - b) Spiral valve
 - c) Pyloric caeca
 - d) Rumen

Answer: b) Spiral valve



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2. The gizzard in birds is primarily used for:
 - a) Secretion of gastric juices
 - b) Fermentation of cellulose
 - c) Mechanical grinding of food
 - d) Absorption of nutrients**Answer: c) Mechanical grinding of food**
3. In mammals, which enzyme in saliva begins carbohydrate digestion?
 - a) Lipase
 - b) Amylase (ptyalin)
 - c) Pepsin
 - d) Trypsin**Answer: b) Amylase (ptyalin)**
4. The liver of sharks is unusually large because it:
 - a) Stores bile only
 - b) Contributes to buoyancy with oil reserves
 - c) Is the site of cellulose fermentation
 - d) Produces venom**Answer: b) Contributes to buoyancy with oil reserves**
5. Which vertebrates possess venom-modified salivary glands?
 - a) Amphibians
 - b) Reptiles
 - c) Birds
 - d) Mammals**Answer: b) Reptiles**

B.Short Answer Questions

1. Describe the modifications of the alimentary canal in birds and relate them to their high metabolic demands.
2. Compare the digestive glands in fishes, amphibians, reptiles, birds, and mammals.
3. Explain the adaptations of the mammalian ruminant stomach for cellulose digestion.
4. Write short notes on:
 - a) Pyloric caeca in bony fishes
 - b) Venom glands in reptiles
 - c) Role of pancreas in vertebrate digestion

UNIT 1.4:

Respiratory Organs



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1.4 Gills

Introduction

Gills represent one of the most fundamental and ancient respiratory structures in aquatic animals. They are specialized organs that enable gas exchange between the organism and the surrounding water, allowing oxygen uptake and carbon dioxide elimination. Since oxygen is much less abundant in water compared to air, aquatic organisms have evolved complex structural and physiological adaptations to make this process efficient. Gills are therefore not only essential for respiration but also act as multifunctional organs involved in osmoregulation, acid–base regulation, and waste removal. Their evolutionary refinement has allowed aquatic animals, particularly fishes, to thrive in diverse aquatic environments ranging from oxygen-rich rivers to oxygen-poor deep seas.

Structure and Counter-Current Exchange

The basic structure of a gill is designed to maximize the efficiency of diffusion. Each gill arch bears rows of slender filaments that are further divided into secondary lamellae, greatly increasing surface area. Within the lamellae is a dense network of capillaries where blood flows in close proximity to the surrounding water. The epithelial barrier between water and blood is extremely thin, often only a few microns, minimizing the diffusion distance for gases.

A crucial feature of gill function is the counter-current exchange mechanism. Here, water flows across the gill surface in one direction, while blood flows in the opposite direction. This arrangement maintains a concentration gradient along the entire respiratory surface, ensuring that oxygen consistently diffuses from water into blood. Even when the blood leaving the gill approaches equilibrium with the incoming water, the gradient is preserved, allowing oxygen uptake efficiencies as high as 80–85% in some fish species. This system is far superior to parallel or cross-current flow, which would result in much lower efficiency.

External and Internal Gills

External gills are a primitive type of gill seen in amphibian larvae (like tadpoles) and some neotenic amphibians (such as axolotls). These gills extend outward from the head or neck region into the surrounding water and resemble delicate, feathery or lace-like structures. Their position allows direct exposure to water, facilitating rapid gas exchange. However, this advantage comes with drawbacks: external gills are exposed to



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predators, prone to drying if the animal leaves water, and cause drag during swimming. They can also trap debris from the water, reducing efficiency.

In contrast, most fishes have evolved internal gills, which are protected within gill chambers on either side of the pharynx. The gill chambers communicate with the external environment through gill slits or are shielded by opercula (bony covers in teleosts). Internal gills are more efficient and less vulnerable than external ones. The movement of water over internal gills is unidirectional: water is taken in through the mouth, flows across the gill filaments, and exits through gill slits or opercular openings. The pumping action of the mouth and operculum creates pressure differences that drive water flow. This continuous, unidirectional flow prevents the mixing of oxygen-rich and oxygen-depleted water, optimizing gas exchange.

Microscopic Arrangement

At the microscopic level, fish gills display remarkable specialization. Each gill arch supports multiple filaments, and each filament carries rows of thin, plate-like secondary lamellae. The lamellae are the primary sites of gas exchange, containing a dense capillary network that brings deoxygenated blood very close to the water. The epithelial layer separating blood and water is extremely thin, creating a diffusion distance often less than 2–3 microns. This minimal barrier, combined with the enormous surface area provided by the lamellae, makes gill respiration highly efficient.

The arrangement of water and blood in counter-current flow ensures that oxygen always diffuses from water into blood, even as blood becomes progressively oxygenated. This design prevents equilibrium from being reached and allows fish to survive in environments where oxygen levels are relatively low compared to air.

Physiological Roles Beyond Respiration

While gills are primarily respiratory organs, they also perform critical additional physiological functions.

- **Osmoregulation:** In freshwater fishes, specialized chloride cells in the gill epithelium actively absorb ions like sodium and chloride to counteract the constant loss of salts to the hypotonic environment. Marine fishes, on the other hand, face the opposite problem of excess salts, which they excrete through chloride cells in the gills to maintain osmotic balance.
- **Acid–Base Balance:** Gills regulate pH by exchanging hydrogen ions (H^+) and bicarbonate ions (HCO_3^-) with the external



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environment. Enzymes such as carbonic anhydrase facilitate the conversion of carbon dioxide into carbonic acid, which dissociates into H^+ and HCO_3^- . This exchange allows fishes to maintain stable internal pH despite fluctuations in water chemistry.

- **Excretion of Nitrogenous Wastes:** In addition to kidneys, gills also excrete ammonia, the primary nitrogenous waste of fishes. Since ammonia is highly soluble in water, it readily diffuses out across the gill epithelium into the surrounding water.

Together, these roles highlight that gills are multifunctional organs essential for maintaining homeostasis in aquatic environments.

Evolutionary Diversity

Gills have evolved differently across animal groups, reflecting their environmental and evolutionary pressures. Invertebrates display wide variation in gill structures: horseshoe crabs possess book gills, while polychaete worms have elaborate, feathery external gills. Among vertebrates, hagfishes have unique pouch-like gills, while sharks and rays (elasmobranchs) have multiple gill slits that are not covered by opercula. Teleost fishes, the most advanced group, have internal gills protected by opercula and supported by sophisticated pumping mechanisms that regulate water flow.

This evolutionary progression from simple external gills to highly specialized internal gills demonstrates the importance of respiratory efficiency in enabling animals to colonize different aquatic habitats.

Environmental Influence

The efficiency of gill respiration is strongly shaped by environmental conditions. In warm water, oxygen solubility decreases, reducing availability, while metabolic rates of ectothermic animals increase, raising oxygen demand. This dual effect makes respiration more challenging in warmer environments. Similarly, water currents, turbidity, and oxygen concentration all impact the diffusion gradient necessary for gas exchange.

Many aquatic organisms have evolved behavioral and physiological adaptations to cope with these conditions. Some fish actively ventilate their gills by increasing the pumping action of the mouth and operculum, while others, like tuna and some sharks, rely on ram ventilation, swimming continuously to force water across their gills. Some species seek oxygen-rich microhabitats or adjust their activity levels to match oxygen availability. These strategies emphasize the adaptability and importance of gills as survival mechanisms in fluctuating aquatic environments.

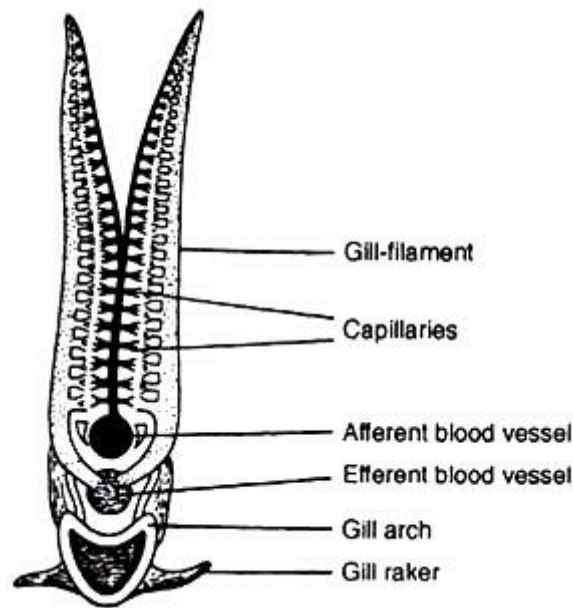


Fig 1.7: sectional view of gill filament

Lungs: Evolutionary Adaptations Across Vertebrates

General Structure

- **Definition:** Lungs are paired, sac-like organs specialized for gaseous exchange with air.
- **Basic Plan:**
 - Internal cavity connected to the external environment via air passages (trachea/bronchi).
 - Thin, vascularized walls allow diffusion of oxygen into blood and carbon dioxide out.
 - Surface area is increased by internal folding, branching, or alveoli depending on the vertebrate group.

Evolutionary Transition of Vertebrate Lungs

The shift from water to land represents a pivotal milestone in vertebrate evolution, largely driven by the development of lungs. These organs enabled early vertebrates to exploit terrestrial habitats by solving the challenge of breathing air. Unlike gills, which extract dissolved oxygen from water, lungs allow direct uptake of atmospheric oxygen, which is far richer—about 21%—compared to the maximum of roughly 1% oxygen available in water under ideal conditions. This transition in respiratory

medium demanded entirely new anatomical and physiological adaptations across vertebrate lineages.

Origins of Vertebrate Lungs

The earliest lungs are found in certain primitive fishes, such as lungfish (*Dipnoi*) and bichirs (*Polypterus*), which evolved as auxiliary organs to gills in oxygen-poor waters. Structurally, these primitive lungs were simple, balloon-like outpocketings of the digestive tract with smooth inner walls. Despite their simplicity, they established the fundamental plan of lung architecture: an internal sac connected to the pharynx, enabling air inflow and outflow for gas exchange.

Amphibian Lungs

Amphibians represent the first vertebrates whose lungs were primarily adapted for breathing air, though cutaneous respiration remains significant. Amphibian lungs show considerable variation in form, reflecting their transitional lifestyle. In frogs and toads, the lungs appear as elongated sacs with a honeycomb-like interior created by shallow septa, providing modestly increased surface area. Amphibians rely on positive-pressure ventilation, a method distinct from the negative-pressure breathing of mammals. Without a diaphragm, they use a buccal pump: air enters via the nostrils into the buccal cavity, and when the nares close, elevation of the buccal floor forces air into the lungs. Exhalation occurs passively through elastic recoil and pressure from surrounding organs. Although adequate for their relatively low metabolic needs, this system restricts prolonged activity.

Reptilian Lungs

Reptiles mark a major step toward full terrestrial adaptation, with lungs that vary widely across species. In the simplest forms (some lizards), lungs resemble those of amphibians but with greater internal compartmentalization. Advanced reptiles, such as crocodilians, evolved complex, multi-chambered lungs with extensive branching that leads to numerous small air chambers called *faveoli*, dramatically increasing respiratory surface area. Most reptiles employ costal (rib-based) breathing, where rib cage expansion and contraction create pressure changes to move air. In turtles and tortoises, the rigid shell necessitated specialized muscular adaptations for ventilation. Reptilian breathing often follows an intermittent pattern—clusters of breaths followed by pauses—reflecting their comparatively lower metabolic requirements.

Avian Lungs

Birds possess one of the most remarkable respiratory systems among vertebrates. Their lungs are small, rigid, and paired with extensive air sacs that create unidirectional airflow, contrasting with the tidal ventilation of mammals and other tetrapods. Gas exchange occurs in parabronchi, which



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contain networks of fine air capillaries interwoven with blood capillaries, maximizing surface area. This cross-current exchange system ensures highly efficient oxygen uptake, even at high altitudes with low oxygen partial pressures. Such efficiency supports the intense metabolic demands of flight and endothermy.

Mammalian Lungs

Mammalian lungs embody the alveolar respiratory model, designed to balance efficiency with the physiological requirements of endothermy and live birth. Ventilation follows a tidal pattern, where the same passages handle both inhalation and exhalation. Structurally, mammalian lungs are arranged in a branching hierarchy: trachea → primary bronchi → secondary bronchi → bronchioles → terminal bronchioles → alveolar ducts ending in alveolar sacs. This design provides an enormous surface area for gas exchange, supporting high metabolic demands.

Comparative Perspective

Tracing lung evolution reveals a clear progression:

- Amphibians rely on simple lungs supplemented by skin respiration, matching their ectothermic metabolism.
- Reptiles exhibit greater compartmentalization and costal breathing, but remain less aerobic than birds and mammals.
- Birds and mammals evolved specialized designs—unidirectional parabronchial flow in birds and alveolar sacs in mammals—each optimized to meet the oxygen requirements of endothermy.

Thus, vertebrate lungs illustrate diverse evolutionary solutions to the common challenge of adapting respiratory structures to ecological contexts and metabolic demands.

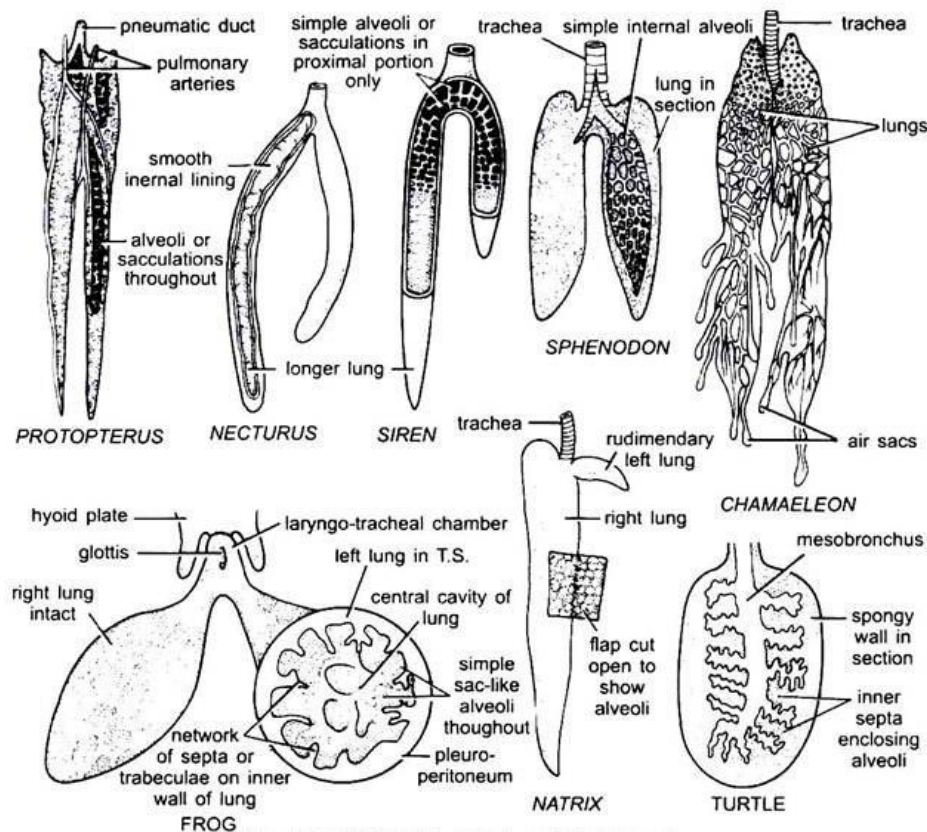


Fig 1.8: Different types of lungs

1.4.2 Air Sacs in Birds: Continuous Airflow System

The Avian Respiratory System

The avian respiratory system represents one of the most striking evolutionary innovations in vertebrates, being fundamentally distinct from all other respiratory designs. Its unique architecture combines rigid lungs with an elaborate system of air sacs, allowing continuous, unidirectional airflow through the gas exchange tissues. This system supports the exceptionally high metabolic demands of flight and endothermy, while also permitting survival at extreme altitudes.

1. Air Sac Complex

At the heart of the avian system lies the **air sac complex**—thin-walled, balloon-like extensions of the airways that revolutionize breathing in birds.

- **Number & Distribution:** Most birds have nine air sacs:
 - Four paired sacs: anterior thoracic, posterior thoracic, abdominal, and cervical
 - One unpaired interclavicular sac
- **Functional Groups:**



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- **Anterior group:** cervical, interclavicular, anterior thoracic
- **Posterior group:** posterior thoracic, abdominal

Although they play almost no direct role in gas exchange due to their thin epithelium and low vascularization, the sacs serve as **bellows** that ventilate the relatively rigid lungs. They expand and contract, storing and moving air, while also pneumatizing bones to reduce skeletal weight and strengthen structures—an adaptation critical for flight.

2. Lungs and Parabronchi

Unlike mammalian lungs, which are elastic and alveolar, **avian lungs are small, stiff, and parabronchial.**

- Air passes continuously through **parabronchi**—tubular passages that branch into networks of fine **air capillaries**, which intertwine with blood capillaries.
- Gas exchange occurs via a **cross-current mechanism**, in which the flow of air and blood run approximately perpendicular. This arrangement ensures oxygen extraction even when the oxygen partial pressure of expired air remains higher than that of the blood, a feat impossible in mammalian alveolar lungs.

3. Ventilation Mechanism

Birds breathe with a **unidirectional airflow** system:

- On inhalation, ~75% of the inspired air bypasses the lungs and enters the **posterior air sacs**, while ~25% passes through the lungs and moves toward the anterior sacs.
- On exhalation, air from the posterior sacs flows into the lungs, while air in the anterior sacs exits the body.
- Thus, fresh air passes through the lungs during both inhalation and exhalation, ensuring continuous gas exchange.

Unlike mammals, birds lack a diaphragm. Instead, expansion and compression of the thoracic and abdominal cavities drive air sac ventilation. This design eliminates dead space and prevents mixing of inspired and expired air, maximizing oxygen availability.

4. Functional Significance

- **Metabolic demands:** Unidirectional flow supports the high oxygen requirements of flight.



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- **High-altitude survival:** Bar-headed geese, for example, can fly over the Himalayas (~9,000 m), where oxygen levels are only about 30% of those at sea level.
- **Efficiency:** Birds extract 25–30% of oxygen from inspired air—comparable to mammals—but with much smaller residual air volumes.
- **Skeletal adaptations:** Pneumatization of bones lightens the skeleton, aids thermoregulation, contributes to resonance in vocalization, and may act as oxygen reservoirs during apnea (e.g., diving).
- **Integration with locomotion:** Wing movements assist ventilation, ensuring increased airflow during flight when metabolic needs peak.

5. Developmental Origins

Embryonic development of the avian respiratory system involves:

- Outgrowths from primitive lung buds forming the air sacs.
- Expansion and positioning of sacs throughout the body cavity.
- Complex branching morphogenesis giving rise to parabronchi and air capillaries.

This developmental program is distinct from mammalian alveolar formation, reflecting a deep evolutionary divergence.

6. Evolutionary Background

- Air sac systems likely originated within **theropod dinosaurs**, where skeletal pneumatization appeared early.
- By the time of **Archaeopteryx** (~150 million years ago), extensive pneumatization was already present, suggesting a primitive air sac system predated powered flight.
- Initial selective advantages may have included thermoregulation and mass reduction, with respiratory efficiency becoming critical as flight evolved.

7. Additional Roles of Air Sacs

Modern research shows that air sacs contribute to multiple functions:



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- **Thermoregulation:** facilitating evaporative cooling during heat stress.
- **Vocalization:** supporting complex sound production in some species.
- **Ecological adaptation:** variation in pneumatization and air sac development reflects diverse ecological niches and locomotor strategies.

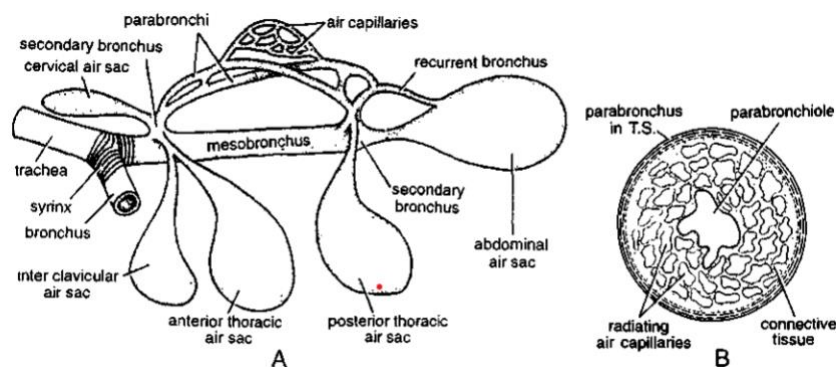


Fig 1.9: Avian Lungs

SUMMARY:

Respiratory adaptations in vertebrates show a clear evolutionary shift from aquatic to terrestrial life.

- **Gills:** Ancient respiratory structures in aquatic animals; highly efficient due to thin lamellae and **counter-current exchange**. Besides gas exchange, they function in osmoregulation, acid–base balance, and ammonia excretion. External gills are primitive (amphibian larvae), while internal gills (protected in chambers with unidirectional flow) dominate fishes.
- **Lungs:** Originated as outpocketings of the pharynx in primitive fishes. Amphibians have simple sac-like lungs (with buccal pumping). Reptiles evolved compartmentalized lungs and costal ventilation. Birds and mammals achieved highly efficient designs: **parabronchial lungs with unidirectional flow** in birds, and **alveolar lungs with tidal flow** in mammals.
- **Avian Air Sac System:** Unique innovation with 9 thin-walled sacs acting as bellows to ventilate rigid lungs. Continuous airflow across parabronchi provides cross-current gas exchange, supporting flight and high-altitude survival. Air sacs also reduce weight (pneumatized bones), assist thermoregulation, and aid in vocalization.



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A. Multiple choice questions

1. Counter-current exchange in fish gills ensures:
 - a) Mixing of oxygenated and deoxygenated water
 - b) Oxygen diffusion only during inhalation
 - c) Maintenance of diffusion gradient along lamellae
 - d) Decreased efficiency of gas exchange**Answer: c) Maintenance of diffusion gradient along lamellae**
2. External gills are primarily seen in:
 - a) Amphibian larvae
 - b) Birds
 - c) Reptiles
 - d) Mammals**Answer: a) Amphibian larvae**
3. Which vertebrate group shows **faveoli** as respiratory structures?
 - a) Amphibians
 - b) Reptiles (advanced)
 - c) Birds
 - d) Mammals**Answer: b) Reptiles (advanced)**
4. The avian respiratory system achieves continuous gas exchange because:
 - a) Birds have alveoli like mammals
 - b) Air sacs create unidirectional airflow
 - c) Air mixes in tidal fashion
 - d) Lungs expand and contract actively**Answer: b) Air sacs create unidirectional airflow**
5. In mammals, the primary site of gas exchange is:
 - a) Bronchi
 - b) Bronchioles
 - c) Alveoli
 - d) Trachea**Answer: c) Alveoli**

B. Short Answer Questions

1. Explain the counter-current exchange mechanism in fish gills.
2. Differentiate between external and internal gills with examples.
3. State two non-respiratory functions of gills.
4. Write short notes on:
 - a) Faveoli in reptiles
 - b) Buccal pumping in amphibians
 - c) Ram ventilation in fishes



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5. What are parabronchi, and how do they function in birds?

SUMMARY:

The **comparative anatomy of organ systems** involves studying the structural and functional similarities and differences of various body systems across animal species, highlighting evolutionary trends and adaptations. The **digestive system** varies with diet; for instance, herbivores like cows have complex stomachs, while carnivores have simpler, shorter digestive tracts. The **respiratory system** shows adaptations from gills in fish to lungs in mammals, with birds possessing air sacs for efficient gas exchange. In the **circulatory system**, lower animals like arthropods have open systems, whereas higher animals like vertebrates have closed systems, with increasing heart complexity from two to four chambers. The **excretory system** also varies: from flame cells in flatworms to kidneys in vertebrates, with special adaptations like the loop of Henle in mammals for water conservation. The **nervous system** ranges from simple nerve nets in cnidarians to highly developed brains and spinal cords in vertebrates, enabling complex behaviors. Lastly, the **reproductive system** shows diversity from asexual reproduction in invertebrates to sexual reproduction with internal fertilization and live births in mammals. This comparative study aids in understanding evolutionary relationships and physiological specializations across the animal kingdom.

A. Multiple Choice Questions (MCQs):

1. **Which part of the nervous system controls reflex actions?**
 - a) Brain
 - b) Spinal cord
 - c) Cranial nerves
 - d) Endocrine glands
2. **The appendicular skeleton primarily consists of:**
 - a) Skull and vertebrae
 - b) Limbs and girdles
 - c) Ribs and sternum
 - d) Brain and spinal cord
3. **Which animal has a three-chambered heart?**
 - a) Fish
 - b) Amphibians
 - c) Mammals
 - d) Birds



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4. **What is the basic functional unit of the kidney?**
 - a) Neuron
 - b) Alveolus
 - c) Nephron
 - d) Osteon
5. **Viviparous animals are characterized by:**
 - a) Laying eggs
 - b) Internal fertilization and live birth
 - c) External fertilization
 - d) Asexual reproduction
6. **The pituitary gland is often referred to as:**
 - a) The master gland
 - b) The digestive gland
 - c) The heat-regulating organ
 - d) The primary excretory organ
7. **What type of scales are found on sharks?**
 - a) Cycloid
 - b) Ctenoid
 - c) Placoid
 - d) Ganoid
8. **Birds have air sacs primarily to:**
 - a) Store oxygen
 - b) Improve buoyancy
 - c) Facilitate unidirectional airflow
 - d) Enhance blood circulation
9. **The cecum is most developed in:**
 - a) Carnivores
 - b) Herbivores
 - c) Amphibians
 - d) Fish
10. **In gills, gas exchange occurs through:**
 - a) Active transport
 - b) Diffusion
 - c) Osmosis
 - d) Secretion

Answer key for MCQs:

1. **b) spinal cord**
2. **b) Limbs and girdles**
3. **b) Amphibians**
4. **c) Nephron**
5. **b) Internal fertilization and live birth**
6. **a) The master gland**



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7. **c) Placoid**
8. **c) Facilitate unidirectional airflow**
9. **b) Herbivores**
10. **b) Diffusion**

B.Short Answer Questions:

1. Compare the structure of the vertebrate brain across different classes.
2. What is the difference between an endoskeleton and an exoskeleton?
3. Describe single vs. double circulation in vertebrates.
4. What is the functional difference between placoid and cycloid scales?
5. How do herbivores and carnivores differ in their digestive tract adaptations?
6. Why do birds have a unidirectional airflow system in their lungs?
7. What is the function of pituitary and adrenal glands in vertebrates?
8. Differentiate between oviparous and viviparous reproduction.
9. What role does the cecum play in digestion, and which animals have a well-developed cecum?
10. How do amphibians perform respiration in different life stages?

C.Long Answer Questions:

1. Explain the structural differences in the vertebrate nervous system, focusing on the brain and spinal cord.
2. Compare the axial and appendicular skeletons across vertebrate classes.
3. Describe the circulatory system in vertebrates, including heart chamber variations and circulation types.
4. How do vertebrate kidneys and nephrons adapt to different environmental conditions?
5. Discuss the reproductive system in vertebrates, with examples of external vs. internal fertilization.
6. Describe the layers of the skin and their functions in vertebrates.



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7. Compare digestive system modifications in herbivores, carnivores, and omnivores.
8. Explain the differences between gills and lungs in gas exchange mechanisms.
9. How do air sacs improve the respiratory efficiency of birds?
10. Discuss the importance of endocrine glands in vertebrate physiological regulation.

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MODULE 2

COMPARATIVE ANATOMY OF VERTEBRATES

Objectives:

- Understand the structure, function, and evolution of the vertebrate endoskeleton.
- Learn about limb modifications, vertebral column variations, and girdle adaptations.
- Explore the circulatory system, focusing on heart evolution and aortic arches.
- Compare the urinogenital system, including kidney types and excretory ducts across vertebrates

UNIT 2.1:

Endoskeleton - Limbs, Girdles, and Vertebrae

2.1 Introduction

The vertebrate endoskeleton is an internal supporting framework composed of cartilage, bone, or a combination of both. It provides shape, mechanical support, protection for delicate organs, and serves as a system of levers for muscle action. Though the basic plan of the endoskeleton is established early in vertebrate evolution, each group has modified it in relation to habitat, locomotor adaptation, and mode of life. A comparative study of limbs, girdles, and vertebrae across different vertebrate classes highlights both the conserved architecture and adaptive modifications.

2.1.1 Limbs: Evolution and Structural Plan

The paired appendages of vertebrates, called **limbs**, are modifications of the primitive fin folds of ancestral aquatic forms. Primitive jawless fishes lacked paired fins, but true paired appendages first appeared in early gnathostomes. The basic tetrapod limb is pentadactyl—comprising a single proximal element, two intermediate elements, several distal elements, and digits.

In **fishes**, the limbs are represented by pectoral and pelvic fins. In cartilaginous fishes like sharks, these fins are supported by basal and radial cartilaginous rods embedded in fin folds. In bony fishes, the rays are dermal in origin but articulated to basal skeletal supports. The fins primarily act as stabilizers and steering organs in water.



With the conquest of land by early tetrapods, fins were transformed into **limbs with joints**—capable of supporting the body against gravity and enabling propulsion on land. In **amphibians**, the limbs are short and laterally placed, bearing four or five digits, suited for walking and swimming. **Reptiles** retain a similar plan but with more robust bones and better joint development for terrestrial locomotion. In **birds**, the forelimbs are modified into wings with fused elements to support feathers and flight muscles, while the hindlimbs are adapted for perching, running, or swimming depending on the species. **Mammals** show the greatest diversity: forelimbs may be adapted for running (cursorial forms like deer and horses), digging (fossorial forms like moles), flying (bats), or swimming (whales and seals). Despite this diversity, the underlying pentadactyl pattern—humerus, radius, ulna, carpals, metacarpals, phalanges in the forelimb and femur, tibia, fibula, tarsals, metatarsals, phalanges in the hindlimb—remains conserved.

The paired appendages of vertebrates—forelimbs and hindlimbs—are evolutionary derivatives of the primitive lateral fin folds seen in ancient aquatic vertebrates. Their structure, mode of attachment, and functional specializations vary widely among different vertebrate groups, yet they retain a common underlying plan known as the **pentadactyl limb** in tetrapods.

General Plan of a Tetrapod Limb

In tetrapods (amphibians, reptiles, birds, and mammals), each limb is typically divided into three regions:

1. **Proximal segment (Stylopodium):**
Forelimb – humerus; Hindlimb – femur.
This segment articulates with the limb girdle and acts as the main lever.
2. **Middle segment (Zeugopodium):**
Forelimb – radius and ulna; Hindlimb – tibia and fibula.
These two parallel bones allow rotation, flexibility, and support.
3. **Distal segment (Autopodium):**
Comprising wrist or ankle bones (carpals/tarsals), hand or foot bones (metacarpals/metatarsals), and digits (phalanges).
In the primitive state, there are five digits (pentadactyl condition).

This basic design is highly conserved, but the shape, proportion, and function of each part have been modified to suit the habitat and lifestyle of each group.



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Limbs in Various Vertebrate Groups

1. Fishes

- Most fishes possess **fins** rather than true limbs.
- **Paired fins** (pectoral and pelvic) act as stabilizers, brakes, and steering organs in water.
- Skeleton is formed of basal cartilaginous elements (propterygium, mesopterygium, metapterygium) and radial elements.
- There are no jointed segments comparable to stylopodium or zeugopodium.

2. Amphibians

- Amphibians mark the first true tetrapod condition with **limbs for terrestrial locomotion**.
- Limbs are typically **short and laterally placed**; most have four digits on forelimbs and five on hindlimbs (e.g., frogs).
- The bones are relatively slender, with well-developed joints to support walking and swimming.
- The pentadactyl pattern is evident, although reduction or fusion of elements can occur in some species.

3. Reptiles

- Reptilian limbs are generally **stronger and more elongated** than those of amphibians.
- They are better suited for life on land, with improved joint surfaces and more efficient levers.
- Most reptiles retain five digits on each limb, though some lineages (snakes) have lost limbs altogether, while others like lizards show reduction in digit number depending on mode of locomotion.
- The limbs are usually placed more directly under the body than in amphibians, improving support and stride.

4. Birds

- Birds exhibit **extreme specialization of the forelimb into wings**.
 - The humerus is short and robust, the radius and ulna are modified, and many carpals and metacarpals fuse to form a rigid support for flight feathers.
 - Digits are reduced in number (usually three) and fused for strength.



- Hindlimbs are adapted for perching, walking, running, or swimming. The femur is short, while the tibiotarsus and tarsometatarsus are elongated, giving the legs great leverage and strength.
- Despite these modifications, the underlying plan remains homologous to that of other tetrapods.

5. Mammals

- Mammalian limbs show **great diversity** related to ecological niches:
 - Cursorial mammals (e.g., horses) show elongation of distal segments and reduction of digits to improve speed.
 - Fossorial mammals (e.g., moles) have short, powerful limbs with strong claws for digging.
 - Arboreal mammals (e.g., monkeys) have highly mobile joints and prehensile digits for climbing.
 - Aquatic mammals (e.g., whales, dolphins) show forelimbs modified into flippers with flattened bones and hindlimbs reduced or lost.
 - Bats possess forelimbs modified into wings, where elongated digits support a flight membrane.
- The pentadactyl pattern is retained even in specialized forms, though digits may be reduced or fused.

Feature	Fishes (fins)	Amphibians	Reptiles	Birds	Mammals
Basic form	Paired fins basal radial elements	True with jointed & limbs, pentadactyl pattern	Robust limbs, pentadactyl	Forelimbs modified as wings; hindlimbs bipedal	Highly diverse: as running, digging, climbing, flying
Stylopodium	Absent as distinct segment	Humerus, Femur	Humerus, Femur	Humerus strong for wing stroke	Highly variable, e.g., long in cursorials
Zeugopodium	Basal fin supports	Radius–Ulna;	Well-formed Radius–	Radius–Ulna reduced	Radius–Ulna; Tibia–Fibula



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Feature	Fishes (fins)	Amphibians	Reptiles	Birds	Mammals
		Tibia– Fibula	Ulna; Tibia– Fibula	& fused with element s	modifications
Autopodium	Fin rays (dermal)	Carpal/Tarsal & digits	Carpal/Tarsal & digits (usually 5)	Carpal element fused; digits reduced (3)	Carpal/Tarsal digits; specialization (e.g., hoof)
Digits	Absent (fin rays)	4 fore/5 hind (typical)	Usually 5	Reduced to 3 in wing	5 in primitive forms; reduction/fusion common
Locomotor adaptation	Swimming, steering	Walking, swimming	Terrestrial walking, climbing	Flying, perching, running	Cursorial, fossorial, arboreal, aquatic, volant

Girdles: Pectoral and Pelvic Supports

The **girdles** anchor the paired limbs to the axial skeleton and provide surfaces for muscular attachment.

Pectoral Girdle:

In fishes, the pectoral girdle is largely cartilaginous or membranous and not directly articulated with the axial skeleton; it often includes dermal elements such as cleithrum and clavicle. This design allows great flexibility in water.

In amphibians and reptiles, the pectoral girdle comprises the scapula and coracoid with a cartilage-filled glenoid cavity for articulation with the humerus. These girdles are not fused to the vertebral column, permitting independent movement of forelimbs.

In birds, the pectoral girdle is specialized for flight and includes the **scapula**, **coracoid**, and **furcula** (wishbone), forming a strong triosseal canal to withstand the stresses of wing flapping.

In mammals, the girdle is reduced to a scapula and clavicle (the clavicle may be reduced or absent in cursorial mammals). The pectoral girdle is



suspended in muscles rather than joined directly to the vertebrae, giving the forelimbs great range of motion.

Pelvic Girdle:

The pelvic girdle in fishes is simple and not attached to the vertebral column, often consisting of small cartilaginous plates.

In amphibians, reptiles, birds, and mammals, the pelvic girdle becomes a solid bony ring firmly attached to the sacral vertebrae. It is formed by the fusion of three paired bones: **ilium**, **ischium**, and **pubis**, meeting at the acetabulum, which articulates with the femur. This girdle transmits the body's weight to the hindlimbs, crucial for terrestrial locomotion. In birds, the pelvic girdle is elongated and fused with synsacral vertebrae to support bipedal stance and flight balance. In mammals, variations exist depending on mode of locomotion, but the general plan is conserved.

The **girdles** are bony or cartilaginous arches that anchor the paired limbs to the axial skeleton and provide broad surfaces for muscle attachment. They form a critical part of the appendicular skeleton. Two girdles are present in most vertebrates:

- **Pectoral girdle** – associated with the forelimbs (or pectoral fins in fishes)
- **Pelvic girdle** – associated with the hindlimbs (or pelvic fins in fishes)

Although their basic plan is conserved, both girdles have undergone significant modifications in different vertebrate groups in response to habitat and mode of locomotion.

Pectoral Girdle

General Plan

The pectoral girdle supports the forelimb and lies in the shoulder region. It usually consists of endochondral elements (scapula, coracoid) and, in many primitive forms, dermal elements (cleithrum, clavicle).

In Fishes

In cartilaginous fishes (e.g., sharks), the pectoral girdle is a simple **U-shaped cartilage** situated ventrolaterally. It is not directly attached to the axial skeleton.

In bony fishes, the pectoral girdle is more elaborate, formed mainly of dermal bones such as the **cleithrum**, **supracleithrum**, and **post-temporal**, with a small endochondral scapulocoracoid region. This arrangement supports the pectoral fins and allows extensive lateral movement.

In Amphibians



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The transition to land necessitated a stronger shoulder support. The pectoral girdle now consists of:

- **Scapula** (dorsal element),
- **Coracoid** (ventral element),
- **Clavicle** (dermal bone),
- An interclavicle or cartilage in some forms. There is still no direct articulation with the vertebral column, allowing the forelimbs to absorb impact when landing from jumps.

In Reptiles

Reptilian pectoral girdles are sturdier. The **scapula and coracoid** are well ossified, and an **interclavicle** is present in many. The clavicles may be reduced or absent. As in amphibians, the girdle is not directly joined to the axial skeleton.

In Birds

The pectoral girdle is highly specialized for flight. It consists of:

- A long, blade-like **scapula**,
- A strong **coracoid** that braces the wing against the sternum,
- A fused pair of clavicles forming the **furcula** (wishbone) which acts as a spring during wing beats. These three elements meet to form the **triosseal canal**, through which the tendon of the supracoracoideus muscle passes, powering the upstroke in flight.

In Mammals

The mammalian pectoral girdle is simplified:

- The **scapula** is large and flat, with a prominent spine for muscle attachment.
- The **clavicle** is present in climbing or digging mammals (e.g., primates, rodents) but reduced or absent in cursorial animals (e.g., horses, deer) to permit greater limb swing.
- The coracoid is reduced to the **coracoid process** of the scapula. The girdle is suspended by muscles and does not articulate directly with the vertebral column, allowing a wide range of forelimb motion.

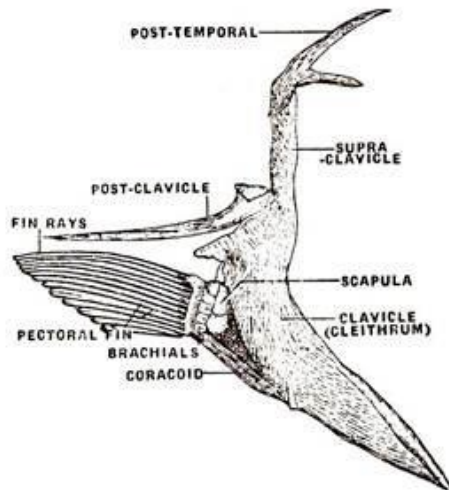


Fig. 26. *Lates* sp. Pectoral girdle

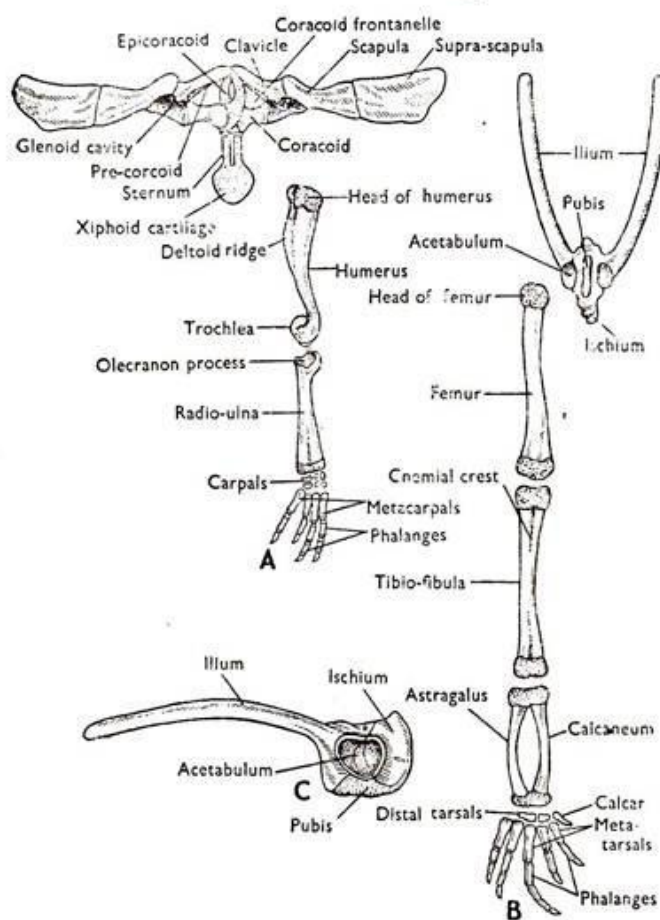


Fig. 27. *Bufo* sp. Appendicular skeleton
A. Pectoral girdle and fore limb bones
B. Pelvic girdle and hind limb bones
C. Pelvic girdle (side view)

Fig 2.1: Pectoral Girldle



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Pelvic Girdle

General Plan

The pelvic girdle supports the hindlimb and lies in the hip region. Unlike the pectoral girdle, it is usually firmly attached to the vertebral column, providing a stable base for locomotion on land.

In Fishes

In cartilaginous and bony fishes, the pelvic girdle is small and consists of paired cartilaginous or bony plates located ventrally. It is **not attached to the vertebral column** and serves only to support the pelvic fins.

In Amphibians

The pelvic girdle becomes a strong arch transmitting weight from the body to the hindlimbs. It is composed of three endochondral bones:

- **Ilium** – extending dorsally to articulate with a single sacral vertebra,
 - **Ischium** – forming the posterior part,
 - **Pubis** – forming the ventral part.
- These three meet at the **acetabulum**, which receives the head of the femur. This structure supports walking and jumping.

In Reptiles

Reptiles show further specialization with a similar tripartite pelvic girdle. However, two or more **sacral vertebrae** articulate with the ilium, providing stronger support for terrestrial movement. The acetabulum is deeper, and the girdle more robust.

In Birds

The pelvic girdle is fused with the synsacrum (a series of fused lumbar, sacral, and caudal vertebrae) to form a rigid structure. The **ilium** is elongated, the **ischium** and **pubis** are directed backward, and the three bones remain separate ventrally, leaving the pubic region open—an adaptation to allow the passage of large eggs.

In Mammals

Mammals also retain the tripartite arrangement (ilium, ischium, pubis) which fuses early in development. The **ilium** is expanded for the attachment of strong hindlimb muscles, the **acetabulum** is deep for firm articulation, and the sacrum usually consists of fused vertebrae for greater stability. Modifications occur depending on locomotor habits (e.g., broad ilia in humans for bipedalism).

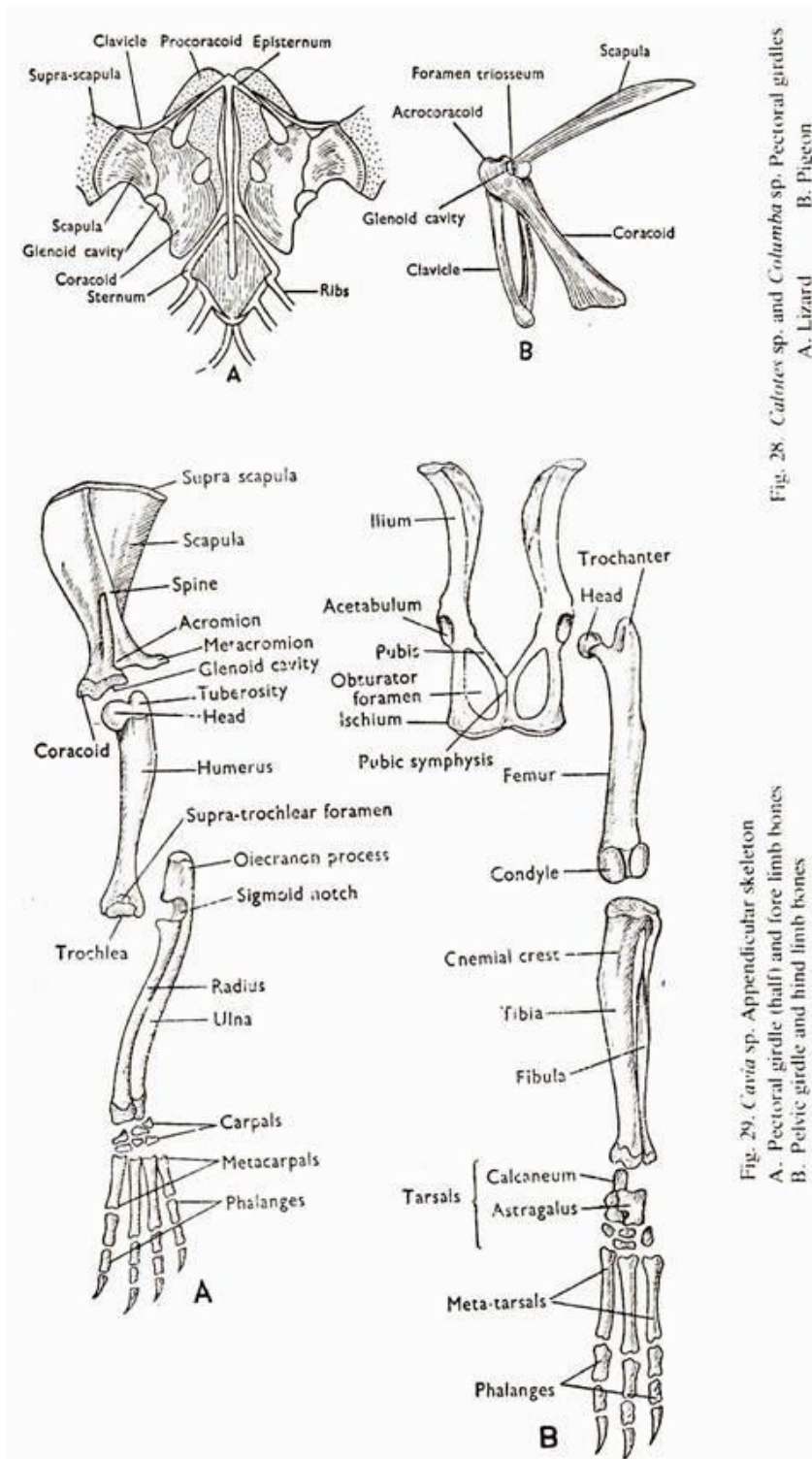


Fig. 28, *Calotes* sp. and *Columba* sp. Pectoral girdles
A. Lizard B. Pigeon

Fig. 29, *Cavia* sp. Appendicular skeleton
A. Pectoral girdle (half) and fore limb bones
B. Pelvic girdle and hind limb bones

Fig 2.2: Pelvic Girdle



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	Fishes	Amphibians	Reptiles	Birds	Mammals
Feature					
Pectoral girdle composition	Cartilaginous or dermal plates supporting fins	Scapula, coracoid, clavicle; not fused with axial skeleton	Scapula and coracoid ossified; interclavicle often present	Scapula, coracoid, and furcula forming triosseal canal	Large scapula; clavicle reduced or absent in runners; coracoid reduced
Pectoral girdle attachment	Not attached to vertebral column	Not attached to vertebral column	Not attached to vertebral column	Braced against sternum but not vertebrae	Suspended in muscles, no direct attachment
Pelvic girdle composition	Small cartilaginous plates supporting pelvic fins	Ilium, ischium, pubis meeting at acetabulum	Tripartite girdle; attached to 2 or more sacral vertebrae	Ilium elongated; ischium and pubis backward fused with synsacrum	Tripartite girdle with broad ilium; deep acetabulum; fused to sacrum
Pelvic girdle attachment	Not attached to vertebral column	Attached to single sacral vertebra	Attached to multiple sacral vertebrae	Fused with synsacrum	Firmly fused with sacrum
Functional adaptation	Supports fins for swimming	Supports for walking and swimming	Strong support for terrestrial movement	Flight for stability and egg laying	Adapted for running, climbing, digging, or bipedalism

- **Pectoral girdle** evolved from simple cartilaginous arches in fishes to complex bony structures supporting flight, running, or climbing in tetrapods.



- **Pelvic girdle** evolved from loosely supported plates to a robust, sacrum-anchored framework transmitting body weight to the hindlimbs.
- **Vertebrae: Axial Modifications and Regional Differentiation**
- The **vertebral column** is the primary axial support and protects the spinal cord. It is composed of a series of **vertebrae**, whose number, shape, and articulations vary greatly across vertebrates.
- In **fishes**, vertebrae are simple and amphicoelous (concave on both ends), adapted for flexibility in swimming. The trunk vertebrae bear ribs, while caudal vertebrae support the tail. The centra are often cartilaginous in primitive forms and ossified in advanced teleosts.
- In early **amphibians**, vertebrae show increased ossification with distinct centra, neural arches, and transverse processes, though they remain numerous and less specialized. Modern amphibians retain a generalized vertebral column with little regional specialization, usually comprising cervical, trunk, sacral, and caudal regions.
- **Reptiles** exhibit further regional differentiation: cervical vertebrae with movable articulations for head movement, dorsal vertebrae with well-developed ribs, sacral vertebrae fused for pelvic support, and caudal vertebrae that may be elongated for balance. The centra are typically procoelous (concave anteriorly, convex posteriorly), offering strength with flexibility.
- **Birds** show extreme specialization. Cervical vertebrae are numerous and heterocoelous (saddle-shaped), providing remarkable flexibility for preening and feeding. Thoracic vertebrae are fused for a rigid trunk, while lumbar, sacral, and some caudal vertebrae are fused with the pelvis to form the **syndesmosis**, providing a sturdy framework for flight. The terminal caudal vertebrae fuse into a pygostyle to support tail feathers.
- **Mammals** exhibit a highly standardized vertebral formula: typically seven cervical vertebrae (regardless of neck length), a variable number of thoracic vertebrae bearing ribs, lumbar vertebrae with robust transverse processes, a sacrum of fused vertebrae articulating with the pelvic girdle, and a variable number of caudal vertebrae forming the tail. The centra are acoelous (flat-ended) to bear compressive loads and provide support for terrestrial locomotion.

The **vertebral column** is the central supporting axis of the vertebrate body. It encloses and protects the spinal cord, provides attachment points for ribs and muscles, and transmits body weight to the limbs through the girdles. Despite enormous diversity in shape and function, all vertebrae share the same fundamental parts: **centrum (body)**, **neural arch**, **neural spine**, and often **transverse processes**.

General Features

- **Centrum (body)**: the main weight-bearing part.
- **Neural arch**: encloses the spinal cord.



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- **Processes:** projections for articulation or muscle attachment (e.g., transverse, zygapophyses).
- **Regional differentiation:** vertebrae may be grouped into cervical, thoracic (or dorsal), lumbar, sacral, and caudal regions in tetrapods.

2.1.2 Vertebrae in Different Vertebrate Groups

Fishes

- Vertebrae are simple and primarily adapted for flexibility in water.
- The centrum is often **amphicoelous** (concave on both ends) allowing side-to-side bending.
- Vertebrae are divided into **trunk vertebrae** (with ribs) and **caudal vertebrae** (bearing haemal arches and supporting the tail).
- Ossification varies: cartilaginous in sharks, bony in teleosts.
- No distinct cervical, lumbar, or sacral regions.

Amphibians

- First true tetrapods with a neck, so they develop a **cervical vertebra** (atlas) for head movement.
- Vertebrae are more ossified than in fishes, with centra, neural arches, and transverse processes clearly formed.
- Regions are weakly differentiated: cervical, trunk (with ribs), a single **sacral vertebra** articulating with the pelvic girdle, and caudal vertebrae forming the tail.
- Centrum shape is usually **amphicoelous** or **opisthocoelous** (concave posteriorly).

Reptiles

- Show greater regional specialization:
 - **Cervical vertebrae:** several, allowing significant head movement.
 - **Dorsal (thoracic) vertebrae:** bearing well-developed ribs.
 - **Sacral vertebrae:** two or more fused to support the pelvic girdle.
 - **Caudal vertebrae:** varying in number, often elongated for balance and tail functions.
- Centrum is usually **procoelous** (concave anteriorly, convex posteriorly) giving strength with flexibility.

Birds

- Highly specialized for flight:
 - **Cervical vertebrae:** numerous (often 13–25), **heterocoelous** (saddle-shaped ends) allowing extreme flexibility for preening and feeding.
 - **Thoracic vertebrae:** some fused to form a rigid trunk.

- **Lumbar and sacral vertebrae:** fused with part of the thoracic and caudal series to form a **synsacrum**, providing a firm attachment for the pelvic girdle.
- **Caudal vertebrae:** distal elements fused into a **pygostyle**, supporting tail feathers.

Mammals

- Show a highly standardized and specialized column:
 - **Cervical:** almost always **7 vertebrae**, regardless of neck length (giraffes and mice both have 7).
 - **Thoracic:** variable (usually 12–15), each bearing a pair of ribs.
 - **Lumbar:** strong and without ribs, with long transverse processes for muscle attachment.
 - **Sacral:** several (usually 3–5) fused to form a sacrum for pelvic support.
 - **Caudal:** variable in number and length depending on tail function (few in apes, many in some mammals).
- Centrum is **acoelous** (flat-ended) for weight bearing and resistance to compression.

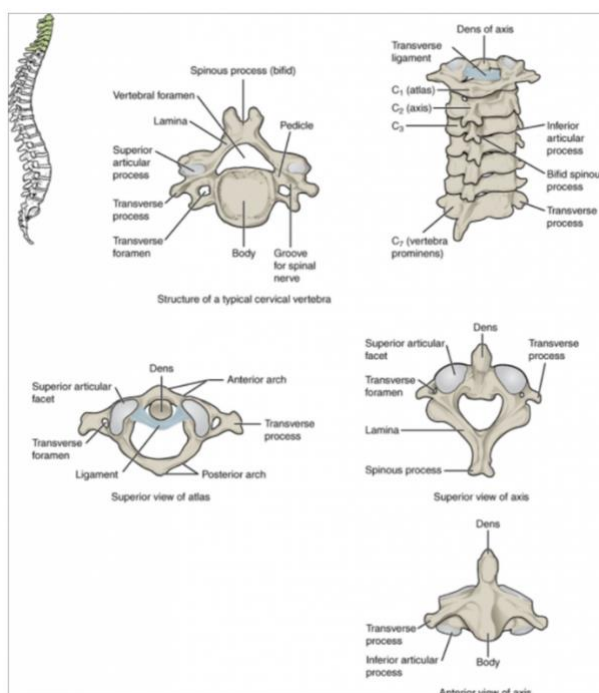


Fig 2.3: Vertebral Column

SUMMARY:

The limbs of vertebrates reflect a remarkable evolutionary transformation from simple fins of aquatic ancestors to the highly specialized limbs of



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terrestrial and aerial forms. Despite their diversity, they all share a conserved developmental blueprint, testifying to a common ancestry. The comparative study of limbs shows how vertebrates have solved similar biomechanical problems in varied habitats through modification of the same basic structure.

The evolution of girdles reflects the transition from aquatic to terrestrial life and the demands of different locomotive strategies.

1. The pentadactyl limb consists of:
 - a) Stylopodium, pterygium, autopodium
 - b) Stylopodium, zeugopodium, autopodium
 - c) Humerus, scapula, femur
 - d) Radius, ulna, fibula**Answer: b) Stylopodium, zeugopodium, autopodium**

2. In fishes, paired fins are supported by:
 - a) Carpals and tarsals
 - b) Basal and radial elements
 - c) Stylopodium and zeugopodium
 - d) Scapula and coracoid**Answer: b) Basal and radial elements**

3. The bird's forelimb modification is characterized by:
 - a) Five separate digits
 - b) Reduced and fused digits (usually three)
 - c) Long femur and short tibiotarsus
 - d) Absence of scapula**Answer: b) Reduced and fused digits (usually three)**

4. Which vertebrate group typically has **procoelous vertebrae**?
 - a) Amphibians
 - b) Reptiles
 - c) Birds
 - d) Mammals**Answer: b) Reptiles**

5. The mammalian vertebral column usually has how many cervical vertebrae?
 - a) Variable (5–15)
 - b) 7 in almost all species
 - c) 12 in most
 - d) None in aquatic mammals**Answer: b) 7 in almost all species**



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PHYSIOLOGY**

Short Answer Questions:

1. Define pentadactyl limb with its general plan.
2. Differentiate between pectoral girdle in fishes and birds.
3. State two modifications of mammalian limbs with examples.
4. What is a synsacrum? Mention its significance in birds.
5. Compare centrum types in fishes, reptiles, and mammals.



UNIT 2.2:

Circulatory System - Evolution of Heart and Aortic Arches

2.2 Introduction

The circulatory system represents one of the most remarkable evolutionary innovations in vertebrate physiology, enabling the efficient transport of oxygen, nutrients, hormones, and waste products throughout increasingly complex bodies. At the center of this system lies the heart, a muscular pump that has undergone dramatic architectural changes across the vertebrate lineage. Alongside it, the aortic arches have evolved from their ancestral origins in fish to form the great vessels of terrestrial vertebrates. This evolutionary journey reveals how progressive adaptations to new environments and physiological demands have shaped the diversity of circulatory systems we observe today.

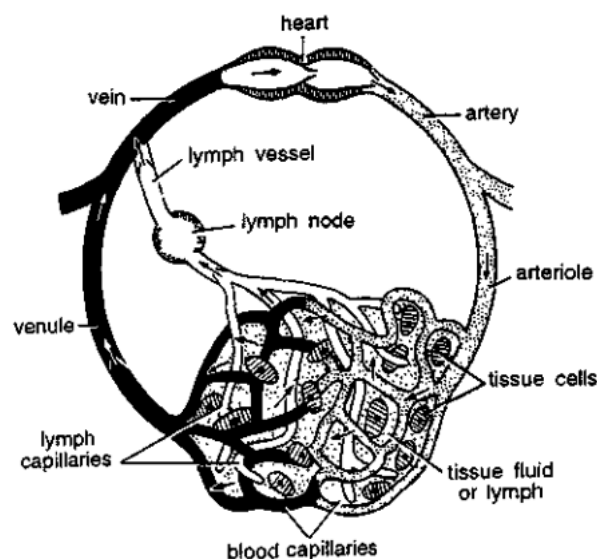


Fig 2.4: Mammalian Circulatory system

2.2.1 Heart Evolution: Structure and Adaptations in Vertebrates

Origin of the Primitive Heart

The earliest vertebrate heart was a simple contractile tube, comparable to that of amphioxus (lancelet). It acted mainly as a pulsating vessel, moving blood forward through peristaltic contractions.

Heart in Cartilaginous Fishes (Chondrichthyans)



In sharks and rays, the heart retains a four-part sequence—sinus venosus, atrium, ventricle, and conus arteriosus. The ventricle is highly muscular, producing strong contractions, while valves in the conus arteriosus prevent backflow, ensuring efficient forward circulation in these active predators.

Heart in Bony Fishes (Osteichthyans)

Teleost fishes show further refinements. The conus arteriosus is reduced, and a new elastic chamber, the **bulbus arteriosus**, acts as a pressure reservoir. This maintains continuous blood flow during ventricular relaxation, supporting the high energy needs of modern ray-finned fishes.

Transition in Lungfishes and Early Tetrapods

In lungfishes and primitive tetrapods, the atrium becomes partially divided, reducing the mixing of oxygenated and deoxygenated blood. This adaptation is significant for air-breathing and higher oxygen demand. Lungfishes, with both gills and primitive lungs, represent an intermediate stage.

Heart in Reptiles

Most reptiles have a three-chambered heart with partial ventricular division, reducing blood mixing. Crocodilians are unique, with a completely divided four-chambered heart, independently evolved from birds and mammals. They also retain special shunts (e.g., foramen of Panizza) for diving adaptations.

Avian Heart Adaptations

Birds possess proportionally larger hearts than mammals of similar size, with thick-walled ventricles and faster intrinsic heart rates. These adaptations meet the extreme metabolic demands of flight.

Mammalian Heart Adaptations

Mammals evolved specialized conduction systems (sinoatrial node, atrioventricular node, Purkinje fibers) for precise heartbeat coordination. The left ventricle is exceptionally muscular, pumping blood into systemic circulation at high pressure.

Developmental and Cellular Evolution

Embryonic heart development begins as a simple tube across all vertebrates, later looping and septating to varying extents. Endothermic vertebrates (birds, mammals) show advanced cardiac myocyte structures with denser mitochondria and organized myofibrils to sustain higher metabolic activity.

Nervous and Hormonal Regulation

Heart regulation became more sophisticated in tetrapods, with autonomic nervous control and hormonal responses (e.g., catecholamines, natriuretic

peptides). These mechanisms are conserved but exhibit lineage-specific adaptations

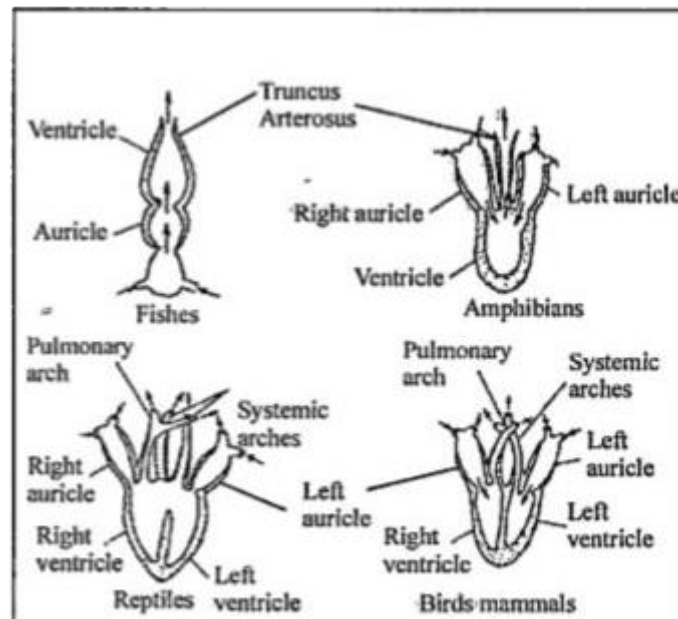


Fig2.5: Evolution of heart

2.2.2 Aortic Arches: Evolution and Function Across Vertebrates

Primitive Vertebrate Condition

In jawless fishes, blood exits the heart via the ventral aorta and flows through six paired aortic arches, supplying gills for oxygenation before merging into the dorsal aorta.

Aortic Arches in Jawed Fishes

- **Cartilaginous fishes:** Arches I and II are reduced for jaw and head circulation, while arches III–VI supply the gills.
- **Bony fishes:** Teleosts develop complex branching within the gills to increase gas exchange efficiency.

Transition in Lungfishes and Amphibians

As lungs evolved, the arches were remodeled. Lungfishes and amphibians show transitional patterns where arches support both gills (in larvae) and lungs. In adult amphibians:

- Arch III → carotid artery (head circulation)
 - Arch IV → systemic arch (body circulation)
 - Arch VI → pulmonary arteries (lung circulation)
- Arches I, II, and V regress.



Aortic Arches in Reptiles

Reptiles typically retain both right and left fourth arches as systemic arches (double aortic arch). Arch III remains the carotid, and arch VI forms the pulmonary arteries.

Aortic Arches in Birds

Birds retain only the **right fourth arch** as the systemic aortic arch. The left fourth arch degenerates.

Aortic Arches in Mammals

Mammals retain the **left fourth arch** as the systemic aortic arch. The right fourth arch contributes to the right subclavian artery. Arch VI forms pulmonary arteries and the ductus arteriosus in the fetus.

Developmental Regulation

Aortic arch development is controlled by conserved signaling pathways (Notch, Wnt, BMP, FGF) and transcription factors (Hox, Tbx). These regulate both the initial symmetrical formation of arches and their lineage-specific remodeling.

Evolutionary Significance

The transformation of gill-supporting arteries into systemic and pulmonary circulation highlights how ancestral structures were repurposed for new functions. Embryonic development recapitulates this evolutionary history, as all vertebrates initially form multiple arches before remodeling them into adult vascular structures.

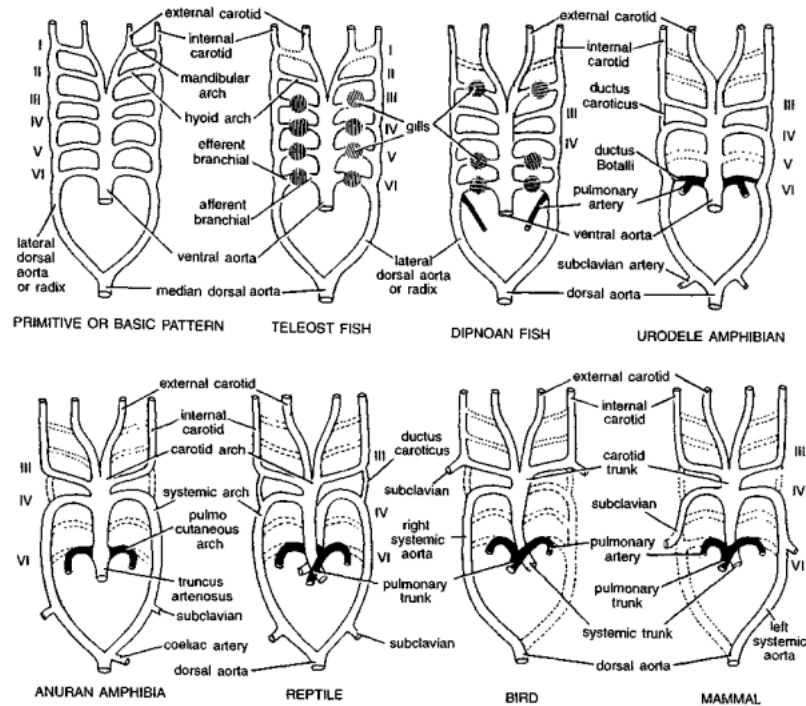


Fig 2.6: Evolution of aortic arches

2.2.3 Circulatory Pathways: Single vs Double Circulation

Introduction

The evolution of circulatory pathways in vertebrates reflects a gradual refinement of oxygen and nutrient delivery systems. This transition spans from the **single circulation of fishes** to the **fully divided double circulation of birds and mammals**, with intermediate forms among amphibians and reptiles offering valuable insight into adaptive trends.

Single Circulation in Fishes

Fishes exhibit the ancestral condition of a **single-loop circulation**. Blood flows:

1. Heart →
2. Gills (oxygenation) →
3. Body tissues →
4. Back to the heart.

While effective in aquatic environments, this system has limitations. Blood pressure drops significantly as blood passes through the gill

capillaries, resulting in **low systemic pressure** and reduced oxygen delivery to tissues. This restricts metabolic capacity.



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Evolutionary Transition to Double Circulation

The emergence of lungs in early tetrapods demanded a **separate pulmonary circuit**. Terrestrial life also brought increased oxygen demands, driving the evolution of **double circulation** with pulmonary and systemic circuits operating in parallel.

Amphibians: Partial Separation

Amphibians have a **three-chambered heart** (two atria, one ventricle). Oxygenated and deoxygenated blood partially mix, but this system is efficient enough given their **low metabolic rates** and the role of **cutaneous respiration** (gas exchange through the moist skin).

Reptiles: Incomplete Double Circulation

Most reptiles retain a **three-chambered heart** with an incompletely divided ventricle.

- **Turtles:** minimal septation.
- **Pythons & some lizards:** nearly complete septation.

This arrangement reduces blood mixing and allows functional separation of circuits, while still permitting **controlled shunting** (e.g., during diving or digestion, when blood can bypass the lungs).

Crocodylians: A Special Case

Crocodiles independently evolved a **fully four-chambered heart**, similar to birds and mammals. However, they retain the **foramen of Panizza** and other arterial shunts, enabling bypass of pulmonary circulation during diving—directing blood flow to vital organs like the brain.

Birds and Mammals: Complete Double Circulation

Endothermic vertebrates (birds, mammals) developed a **fully separated four-chambered heart** with complete pulmonary and systemic circuits. This system supports their high metabolic rates (5–10× greater than ectotherms) by providing efficient oxygen delivery and stable blood pressure.



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Developmental Perspective

During embryogenesis, all vertebrates form a **simple tubular heart**. Through looping and septation, varying levels of chamber separation emerge. Complete atrial and ventricular septation is achieved only in crocodilians, birds, and mammals, reflecting their advanced circulatory specialization.

Physiological Advantages of Double Circulation

- **Efficient oxygen delivery** to tissues.
- Enhanced **nutrient transport** and **waste removal**.
- Improved **immune cell distribution**.
- Better **thermoregulation**, crucial for endotherms.

Blood pressure comparisons highlight these advantages:

- Fishes: **25–30 mmHg**
- Amphibians: **30–40 mmHg**
- Non-crocodilian reptiles: **40–60 mmHg**
- Birds & mammals: **80–120 mmHg (systolic)**

Blood Composition and Oxygen Transport

Blood evolved alongside circulation. Oxygen-carrying capacity (hemoglobin concentration and efficiency) is greater in animals with higher metabolism. Birds, with the highest mass-specific metabolic rates, have **large erythrocytes rich in hemoglobin**, maximizing oxygen delivery during flight.

Regulatory Mechanisms of Circulation

Control of circulation became increasingly complex:

- **Baroreceptors** monitor blood pressure.
- **Chemoreceptors** detect oxygen and CO₂ levels.
- **Autonomic nervous system** adjusts heart rate and contractility.
- **Endocrine factors** (e.g., catecholamines) fine-tune vascular resistance.

These regulatory systems reach their peak sophistication in birds and mammals, supporting their high-energy lifestyles.



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SUMMARY:

The vertebrate circulatory system has undergone significant evolutionary modifications to meet increasing metabolic and environmental demands.

- The heart evolved from a **simple contractile tube** (amphioxus-like) to a **four-chambered heart** in birds and mammals, enabling complete separation of oxygenated and deoxygenated blood.
- **Aortic arches**, originally branchial arteries in fishes, were repurposed into the major systemic and pulmonary arteries in tetrapods, with lineage-specific differences (right systemic arch in birds, left systemic arch in mammals).
- Circulatory pathways shifted from **single circulation in fishes** to **partial double circulation in amphibians and reptiles**, and finally to **complete double circulation** in crocodilians, birds, and mammals.
- These changes enhanced **oxygen delivery, systemic pressure, and regulatory control**, supporting higher metabolic rates, thermoregulation, and complex lifestyles.

A. Multiple Choice Questions (MCQs)

Q1. The primitive vertebrate heart resembled:

- a) Four-chambered mammalian heart
- b) Contractile tube of amphioxus
- c) Crocodilian heart
- d) Bird heart

Answer: b) Contractile tube of amphioxus

Q2. In teleost fishes, the **bulbus arteriosus** functions as:

- a) A pressure reservoir maintaining continuous blood flow
- b) A contractile chamber enhancing pumping
- c) A site of gas exchange
- d) A shunt for diving

Answer: a) A pressure reservoir maintaining continuous blood flow

Q3. Which reptile group has a completely divided four-chambered heart?

- a) Lizards
- b) Turtles
- c) Crocodilians
- d) Snakes

Answer: c) Crocodilians



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Q4. In mammals, the systemic aortic arch is derived from:

- a) Right fourth arch
- b) Left fourth arch
- c) Third arch
- d) Sixth arch

Answer: b) Left fourth arch

Q5. Blood pressure is highest in which vertebrate group?

- a) Fishes
- b) Amphibians
- c) Non-crocodilian reptiles
- d) Birds and mammals

Answer: d) Birds and mammals

Q6. The foramen of Panizza in crocodilians connects:

- a) Left atrium and right atrium
- b) Left ventricle and right ventricle
- c) Systemic and pulmonary arteries
- d) Carotid and subclavian arteries

Answer: c) Systemic and pulmonary arteries

B.Short Answer Questions

1. Describe the role of the bulbus arteriosus in teleost fishes.
2. Why do amphibians have incomplete double circulation?
3. State one evolutionary difference in the aortic arch between birds and mammals.
4. What is the significance of the partial ventricular septum in reptiles?
5. Mention two regulatory mechanisms of vertebrate circulation.

UNIT 2.3:

Urinogenital System - Kidney and Excretory Ducts



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2.3 Kidney Structure and Evolution in Vertebrates

The **urinogenital system** combines excretory and reproductive functions, showing remarkable evolutionary adaptations across different environments. The kidney, the main filtration organ, demonstrates great diversity in structure and function, depending on the habitat, availability of water, and metabolic demands.

Developmental Stages of Kidneys

1. Pronephros (Earliest Kidney Type)

- First to appear during embryonic development in all vertebrates.
- Functions only in larval amphibians and some primitive jawless fishes.
- Composed of segmentally arranged nephrons with nephrostomes that open into the coelom.
- Drained by the pronephric duct, which later contributes to the development of other kidney types.

2. Mesonephros (Intermediate Stage)

- Functions as the adult kidney in **fishes and amphibians**.
- Larger and more complex nephrons than pronephros.
- Each nephron has a **glomerulus with Bowman's capsule** for blood filtration.
- Filtrate passes through tubules for reabsorption/secretion before draining into the **Wolffian (archinephric) duct**.

3. Metanephros (Advanced Kidney Type)

- Found in **amniotes (reptiles, birds, and mammals)**.
- Develops a **new duct – the ureter**, which branches into the collecting system.
- Forms a compact kidney with distinct **cortex (with renal corpuscles and proximal tubules)** and **medulla (with loops of Henle and collecting ducts)**.
- Highly efficient, allowing water conservation in terrestrial life.



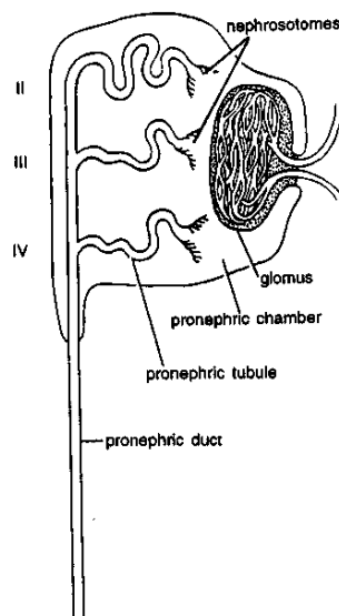
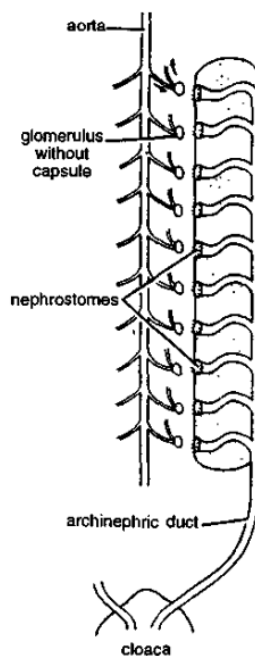
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Nephron Variations Across Vertebrates

- **Fishes:**
 - Marine teleosts: small or absent glomeruli (agglomerular kidneys) to **retain water** in salty environments.
 - Freshwater fishes: large glomeruli with high filtration rates to remove excess water from their hypotonic surroundings.
- **Amphibians:**
 - Kidneys are adaptable to both aquatic and terrestrial life.
 - Aquatic forms excrete dilute urine.
 - Terrestrial forms conserve more water but cannot concentrate urine like mammals.
- **Reptiles:**
 - Possess short loops of Henle.
 - Conserve more water than amphibians.
 - Male reptiles often have a **sexual segment in the kidney** that produces seminal fluid, showing integration of excretory and reproductive systems.
- **Birds:**
 - Kidneys are lobulated with **cortical tissue and medullary cones**.
 - Contain two nephron types:
 - Reptilian-type (short)
 - Mammalian-type (long with loops of Henle).
 - Can produce concentrated urine without a renal pelvis.
- **Mammals:**
 - Most complex kidneys among vertebrates.
 - Two nephron types:
 - Cortical (short-looped)
 - Juxtamedullary (long-looped, extending deep into medulla).
 - Loop of Henle establishes a **countercurrent system** for producing highly concentrated urine.
 - Essential for water conservation in terrestrial and desert environments.

Functional Significance

- **Loop of Henle:** Creates a steep osmotic gradient in the medulla for water reabsorption and urine concentration.
- **Countercurrent Mechanism:**
 - Descending limb: permeable to water.
 - Ascending limb: pumps sodium chloride out, but impermeable to water.
 - Result: concentrated medullary interstitium → highly concentrated urine.



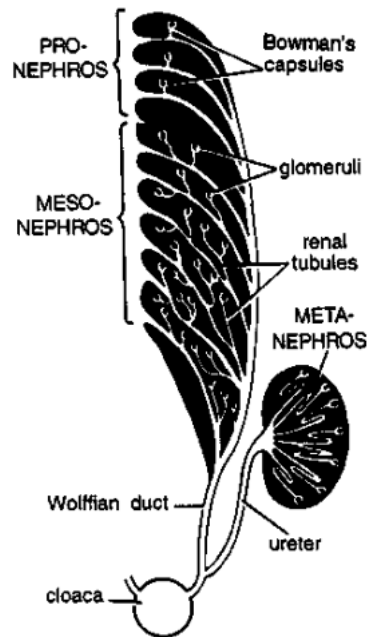


Fig 2.7: Pronephric, Mesonephric and metanephric kidney

2.3.1 Excretory Ducts in Vertebrates

The **excretory ducts** of vertebrates have undergone remarkable evolutionary changes, closely linked with waste elimination and, secondarily, with reproductive functions. Their embryonic development reveals strong evolutionary connections, showing how primitive ducts were modified into specialized urinary and reproductive channels.

1. Primitive Excretory Duct: The Archinephric (Wolffian) Duct

- The **archinephric duct** first appears with the **pronephros**, acting as the earliest urinary passage.
- In **fishes and amphibians (anamniotes)**, this duct remains the **primary urinary pathway**.
- In **males**, it develops into parts of the reproductive system, such as the **epididymis** and **vas deferens**, which transport sperm.
- In **females**, the Wolffian duct degenerates, leaving only small vestigial traces.

2. Mesonephric Tubules and Their Role

- The **mesonephric tubules** drain into the archinephric duct, forming the main urinary duct in **fishes and amphibians**.



- In some **marine teleost fishes**, the ends of these tubules enlarge to function like a bladder—though mainly for **ion balance** rather than urine storage.

3. Variations in Fishes

- In **most teleosts**, the two archinephric ducts join at the posterior to form a **urinary sinus**, which drains into the cloaca or a separate urogenital opening.
- In some marine teleosts, the ducts expand at their ends to form a **urinary bladder** for **osmoregulation** (ionic homeostasis).
- This **paired duct system** that empties into a **urogenital sinus** is a unique feature of fishes.

4. Reptilian Excretory Ducts

- **Ureters** in reptiles usually open directly into the **cloaca**.
- Some reptiles (turtles and lizards) possess a **cloacal bladder**, but others (like crocodilians and some lizards) lack a bladder, especially those with aquatic lifestyles.
- The reptilian cloaca is divided into three specialized chambers:
 - **Coprodeum** – receives feces.
 - **Urodeum** – receives urine and reproductive products.
 - **Proctodeum** – terminal region before excretion.

5. Avian Excretory System

- **Birds lack a urinary bladder** — their ureters open directly into the **urodeum of the cloaca**.
- This adaptation reduces body weight, important for flight.
- Birds mainly excrete **uric acid**, which conserves water and is less toxic than urea or ammonia.
- The **avian cloaca** is multifunctional:
 - Receives urine and feces,
 - Acts as the site of sperm transfer in females,
 - Serves as the exit passage for eggs.



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6. Mammalian Modifications

- **Monotremes** retain a cloaca, similar to reptiles.
- In **marsupials and placental mammals**, the **cloaca is divided**, leading to separate openings for:
 - **Digestive wastes**
 - **Urinary system (urethra)**
 - **Reproductive system (vagina in females)**
- In males, the **urethra carries both urine and sperm**, showing partial integration of excretion and reproduction.
- This evolutionary shift marks a **trend toward specialization** of urinary and reproductive ducts.

7. Histological Structure of Excretory Ducts

- **Ureters:**
 - Lined with **transitional epithelium**, allowing expansion and contraction.
 - Have smooth muscle layers that perform **peristalsis** to move urine.
- **Urinary Bladder:**
 - Wall lined with **transitional epithelium** that changes shape:
 - **Cuboidal** when empty.
 - **Squamous (flat)** when full.
 - Allows large expansion without damage, enabling **urine storage**.

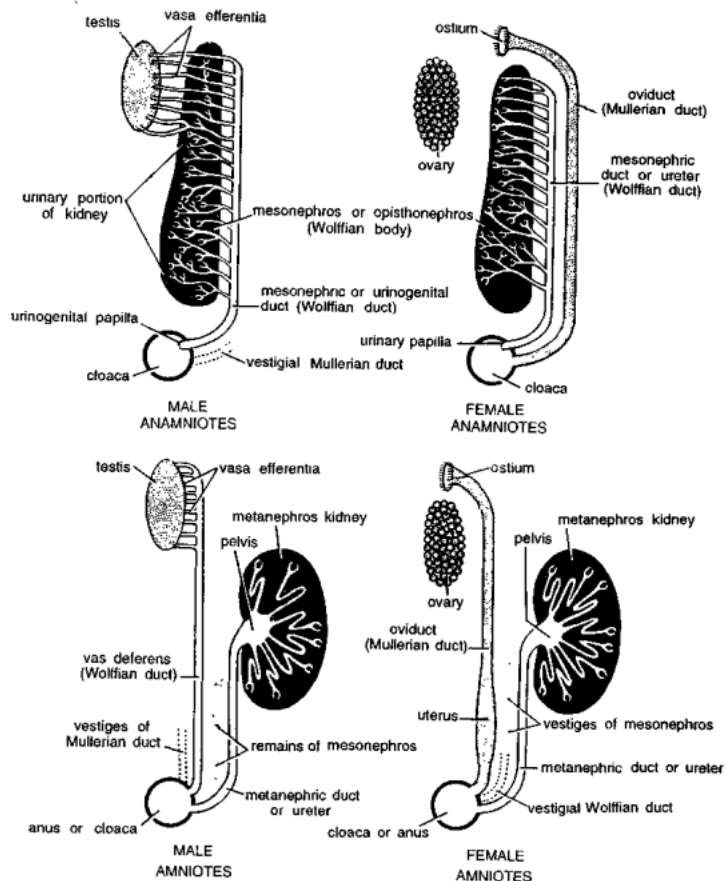


Fig2.8: urinogenital system in vertebrates

SUMMARY:

Endoskeleton

The **endoskeleton** is the internal framework of vertebrates, providing structural support, protection, and anchorage for muscles. Though it serves similar functions across species, it varies significantly in composition, structure, and specialization among different vertebrate groups.

- **Fishes:** The endoskeleton is primarily cartilaginous in **cartilaginous fishes** (e.g., sharks) and bony in **bony fishes** (e.g., teleosts). The vertebral column and skull are well-developed but relatively simple.
- **Amphibians:** Exhibit both aquatic and terrestrial adaptations. The skeleton is lightweight with fewer bones, suited for jumping and swimming.



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- **Reptiles:** Show further ossification and specialization. The skull becomes more complex, and the vertebral column supports crawling.
- **Birds:** Have a lightweight, fused, and pneumatic (air-filled) skeleton for flight. The sternum is keeled to support flight muscles.
- **Mammals:** Possess a highly developed bony skeleton with differentiated vertebrae, complex skull, and limb bones adapted for various modes of locomotion.

Circulatory System

The **circulatory system** in vertebrates is a **closed system** comprising the heart, blood vessels, and blood. It evolves progressively from lower to higher vertebrates to increase efficiency in oxygen and nutrient transport.

- **Fishes:** Have a **single circulatory system** with a **two-chambered heart** (one atrium and one ventricle). Blood passes through the heart once in each circuit.
- **Amphibians:** Possess a **three-chambered heart** (two atria and one ventricle) with **double circulation** that allows partial separation of oxygenated and deoxygenated blood.
- **Reptiles:** Also have a **three-chambered heart**, but with a partially divided ventricle in some species (e.g., crocodiles have a four-chambered heart), allowing more efficient blood separation.
- **Birds and Mammals:** Have a **four-chambered heart** with complete separation of oxygenated and deoxygenated blood, supporting high metabolic rates and endothermy (warm-bloodedness).

A. Multiple Choice Questions (MCQs):

1. **The endoskeleton of vertebrates is primarily made up of:**
 - a) Chitin and calcium carbonate
 - b) Bone and cartilage
 - c) Keratin and silica
 - d) Hemoglobin and collagen
2. **The axial skeleton in vertebrates includes:**
 - a) Limbs and girdles
 - b) Skull, vertebral column, and rib cage
 - c) Forelimbs and hindlimbs
 - d) Claws and feathers
3. **In tetrapods, the pectoral girdle functions to:**
 - a) Connect the hindlimbs to the vertebral column



- b) Attach the forelimbs to the axial skeleton
 - c) Join the ribs to the sternum
 - d) Link the skull to the spine
4. **Which type of vertebrae allows flexible neck movement in birds?**
- a) Cervical vertebrae
 - b) Thoracic vertebrae
 - c) Lumbar vertebrae
 - d) Sacral vertebrae
5. **The evolution of the vertebrate heart shows a significant increase in:**
- a) The number of aortic arches
 - b) The number of heart chambers
 - c) The number of excretory ducts
 - d) The number of lungs
6. **What is the main benefit of double circulation in vertebrates?**
- a) Higher oxygen efficiency
 - b) Faster excretion
 - c) Larger kidney size
 - d) Improved digestion
7. **Which group of vertebrates retains all six aortic arches during early development?**
- a) Mammals
 - b) Birds
 - c) Fish
 - d) Amphibians
8. **What is the functional unit of the kidney called?**
- a) Nephron
 - b) Glomerulus
 - c) Loop of Henle
 - d) Bowman's capsule
9. **The pronephric kidney is predominantly found in:**
- a) Adult amphibians
 - b) Mammals
 - c) Embryonic vertebrates
 - d) Reptiles
10. **In vertebrates, the excretory and reproductive systems are closely linked in:**
- a) Only amphibians
 - b) Only mammals
 - c) Most vertebrates
 - d) Invertebrates



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Answer Key

1. **b) Bone and cartilage**
2. **b) Skull, vertebral column, and rib cage**
3. **b) Attach the forelimbs to the axial skeleton**
4. **a) Cervical vertebrae**
5. **b) The number of heart chambers**
6. **a) Higher oxygen efficiency**
7. **c) Fish**
8. **a) Nephron**
9. **c) Embryonic vertebrates**
10. **c) Most vertebrates**

B.Short Answer Questions:

1. Differentiate between the axial and appendicular skeleton.
2. Describe the evolutionary modifications of limbs in vertebrates.
3. What is the function of the pectoral and pelvic girdles?
4. Compare the vertebral column structure in fish and mammals.
5. Describe the evolution of the vertebrate heart, from fish to mammals.
6. What are the differences between single and double circulation?
7. How do aortic arches change in vertebrate evolution?
8. What are the different types of kidneys found in vertebrates?
9. Explain the function of nephrons in the kidney.
10. How do the excretory ducts differ across vertebrate groups?

C.Long Answer Questions:

1. Explain the structure and function of the vertebrate endoskeleton, including bones, cartilage, and skeletal divisions.
2. Discuss the evolution of limbs in vertebrates and the modifications seen in different groups.
3. Compare the pectoral and pelvic girdles in vertebrates and their role in locomotion.



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4. Describe the structure, types, and evolutionary modifications of vertebrae across vertebrate species.
5. Explain the evolution of the heart from a two-chambered to a four-chambered structure.
6. Compare the aortic arches in fish, amphibians, reptiles, birds, and mammals.
7. Discuss the difference between single and double circulation with examples.
8. Describe the structure and function of kidneys across different vertebrate groups.
9. Explain how the urinogenital system has evolved in vertebrates.
10. Compare the excretory and reproductive systems in fish, amphibians, reptiles, birds, and mammals.

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MODULE 3

NERVOUS, ENDOCRINE, AND REPRODUCTIVE SYSTEMS IN VERTEBRATES

Objectives:

- Learn about the classification, histology, and function of endocrine glands in different vertebrates.
- Study the structure, function, and differentiation of gonads and genital ducts across species.
- Explore the evolution of reproductive strategies, including internal and external fertilization.

UNIT 3.1

Nervous System - General Plan of Brain and Spinal Cord

3.1 Basic Plan of the Vertebrate Brain

All vertebrates, from fishes to humans, share a **common structural framework** for the brain, which reflects both embryonic development and evolutionary history.

Embryonic Development

- In the early embryo, the brain begins as **three primary vesicles**:
 1. **Prosencephalon (forebrain)**
 2. **Mesencephalon (midbrain)**
 3. **Rhombencephalon (hindbrain)**
- These primary vesicles divide into **five secondary vesicles**:
 - **Telencephalon** and **Diencephalon** (from the forebrain)
 - **Mesencephalon** (remains undivided)
 - **Metencephalon** and **Myelencephalon** (from the hindbrain)

This developmental pattern gives rise to the major subdivisions of the adult vertebrate brain.

The Forebrain (Prosencephalon)

The forebrain is the most highly developed part of the brain in higher vertebrates and includes the **telencephalon** and **diencephalon**.

Telencephalon



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- Forms the **cerebrum** (the largest part of the brain).
- Key components:
 - **Cerebral cortex** – outer layer responsible for perception, memory, learning, and decision-making.
 - **Basal ganglia** – motor control and voluntary movement.
 - **Hippocampus** – learning and memory.
 - **Amygdala** – emotional responses.

In mammals, the **cortex** expands enormously, becoming folded into **gyri (ridges)** and **sulci (grooves)**, which maximize surface area without increasing skull size.

Functional Lobes in Humans

- **Frontal lobe:** executive functions, reasoning, personality.
- **Parietal lobe:** sensory integration and spatial awareness.
- **Temporal lobe:** hearing, memory, language comprehension.
- **Occipital lobe:** visual processing.

Diencephalon

- Includes the **thalamus** (sensory relay), **hypothalamus** (homeostasis, hormone regulation), and **epithalamus** (pineal gland – biological rhythms).

The Midbrain (Mesencephalon)

- Contains the **optic tectum** (important in vision and reflexes in fishes and amphibians).
- In mammals, it becomes the **superior and inferior colliculi**, coordinating visual and auditory reflexes.

The Hindbrain (Rhombencephalon)

Divided into **metencephalon** and **myelencephalon**:

Metencephalon

- **Pons:** relays information between cerebrum and cerebellum; regulates sleep and breathing.
- **Cerebellum:** coordinates balance, posture, and movement. In higher vertebrates, it also contributes to learning and cognition.

Myelencephalon



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- **Medulla oblongata:** controls vital life functions such as heartbeat, blood pressure, and breathing. It is also the transition to the spinal cord.

Evolutionary Trends in Vertebrate Brain Development

The brain shows several evolutionary patterns:

1. **Expansion of the telencephalon** – especially in reptiles, birds, and mammals.
2. **Increase in cerebellar complexity** – associated with motor skill sophistication (e.g., flight in birds, tool use in primates).
3. **Specialization of sensory regions** – species relying on smell, vision, or hearing show enlargement of corresponding brain areas.
4. **Emergence of new cortical structures** – e.g., neocortex in mammals.

Comparative Brain Anatomy Across Vertebrates

Fishes

- Brain is **simple and linear**, reflecting the three vesicles.
- **Telencephalon:** primarily olfactory (smell-based).
- **Optic tectum:** major visual processing center.
- **Cerebellum:** size varies; large in active swimmers (e.g., sharks), small in sedentary fishes.

Amphibians

- **Telencephalon:** more expanded than in fishes, beginning of cortical development.
- **Optic tectum:** still dominant, highlighting reliance on vision.
- **Cerebellum:** small, consistent with limited locomotor complexity.

Reptiles

- **Telencephalon:** larger, with **dorsal ventricular ridge (DVR)** for sensory processing.
- **Cortex** begins to divide into specialized regions.
- Active reptiles (like crocodiles) have more developed cerebellums than sedentary lizards.

Birds



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- **Telencephalon:** very large, despite lacking a mammalian-style layered cortex.
- Possess a highly developed **DVR** and a **Wulst** – both critical for vision and sensory processing.
- **Cerebellum:** large and complex, supporting fine motor skills needed for flight.

Mammals

- **Telencephalon:** develops into a **six-layered neocortex** – a major evolutionary innovation.
- In primates and humans:
 - Neocortex forms ~80% of brain mass.
 - Highly folded cerebrum (gyri & sulci).
- **Cerebellum:** multilobed and genetically organized, contributing to both motor and cognitive functions.
- **Prefrontal cortex:** especially large in humans, supporting advanced reasoning, planning, and language.

Unity and Diversity in Vertebrate Brains

Despite differences, all vertebrate brains share common features:

- Three-part division (forebrain, midbrain, hindbrain).
- Presence of cerebral hemispheres, cerebellum, and brainstem.
- Conservation of neurotransmitter systems and neural pathways.

These shared traits highlight the **common ancestry** of vertebrates, while expansions and specializations in certain regions explain their **diverse adaptations** to environment, movement, and social behavior.

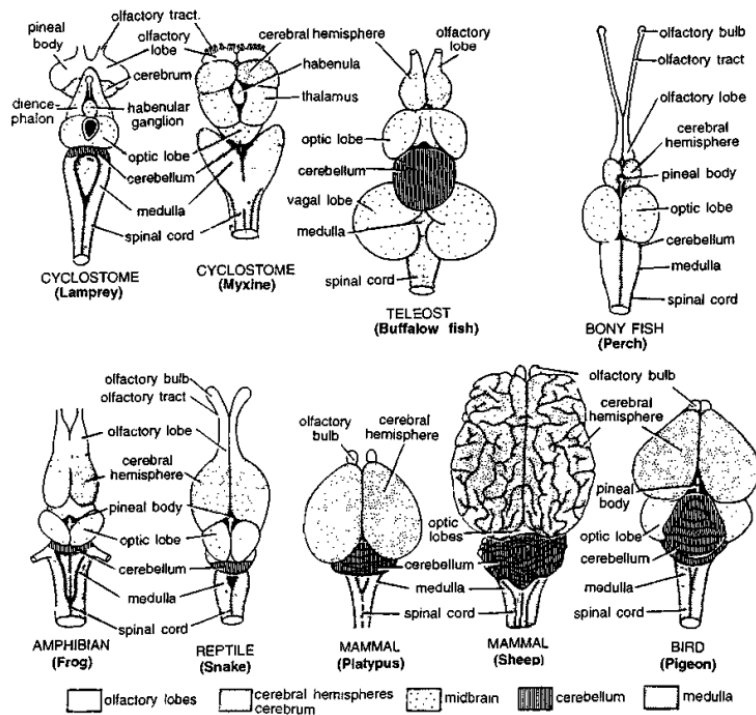
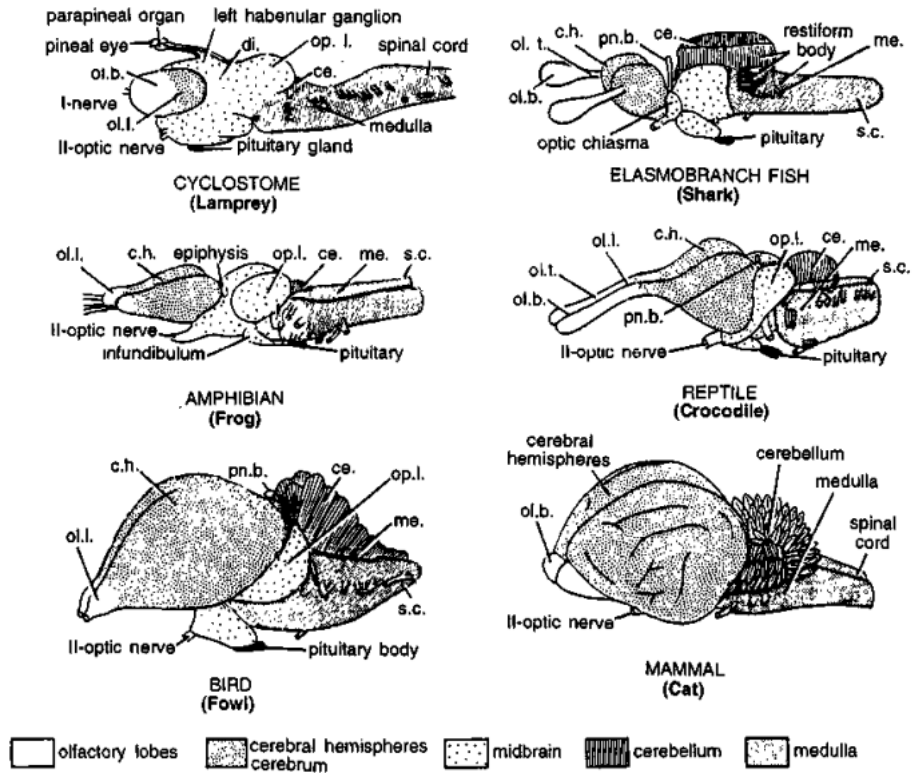


Fig3.1: Brain of vertebrates



3.1.1 Spinal Cord Structure: Anatomy, Segmentation, and Functional Significance

Introduction

The spinal cord is a vital part of the central nervous system that connects the brain with the rest of the body. It acts both as a **communication pathway** and as a **processing center** for reflexes and motor control. Importantly, its structure is not the same throughout its length. Different regions show **specialized enlargements** and **variations in gray and white matter**, which reflect their functions.

Regional Differences in the Spinal Cord

- The spinal cord has **two major enlargements**:
 - **Cervical Enlargement (C3–T1)**: Supplies nerves to the upper limbs.
 - **Lumbosacral Enlargement (L1–S3)**: Supplies nerves to the lower limbs.
- These enlargements contain **more gray matter** (neuron cell bodies) because more neurons are required to control limb muscles.
- The **ratio of gray to white matter** changes along the cord:
 - **Cervical region**: More white matter, since it carries many ascending (sensory) and descending (motor) fibers.
 - **Lumbosacral region**: More gray matter, as fewer long tracts are present lower down.

Functions of the Spinal Cord

The spinal cord performs two main roles:

1. **Conduction Pathway**: It carries information between the brain and the periphery.
 2. **Integration Center**: It controls reflexes without needing brain involvement.
- **Simple Reflexes (Monosynaptic Reflexes)**:
Example: Knee-jerk (stretch) reflex. Involves one or two neurons and stays within a single segment.
 - **Complex Reflexes (Polysynaptic Reflexes)**:
Example: Withdrawal reflex from a painful stimulus. Involves many neurons and several spinal segments.



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Central Pattern Generators (CPGs)

- The spinal cord contains **neural circuits** called central pattern generators.
- These circuits can produce rhythmic movements like **walking, running, or swimming**, even without brain input.
- The brain usually **initiates, modulates, and coordinates** these patterns to make movement smooth and adaptive.

Evolutionary and Species Adaptations

- In **tetrapods** (four-limbed vertebrates), spinal cord enlargements match limb function.
- **Legless vertebrates** (e.g., snakes) have a more uniform spinal cord.
- **Birds** have a very large lumbosacral enlargement, and some species possess a unique structure called the **glycogen body**, whose function is not yet clear.

Increasing Complexity of Spinal Pathways

- In **primates**, the **corticospinal tract** is highly developed. This allows fine motor control, such as writing or tool use.
- In **non-mammalian vertebrates**, motor control depends more on brainstem pathways, which are less specialized.
- **Mammals** show highly organized **ascending sensory tracts**, with separate channels for different sensations (touch, pain, temperature, etc.), leading to greater sensory precision.

3.1.2 Structure of the Ventricular System

The **ventricular system** is a set of interconnected cavities inside the brain, filled with **cerebrospinal fluid (CSF)**. It is continuous with the **central canal** of the spinal cord.

- During development, the central canal is open (patent) along the spinal cord, but in adults, especially in the upper segments, it may close or become vestigial.
- At the lower end of the spinal cord, the canal may dilate slightly to form a small cavity called the **terminal ventricle**.

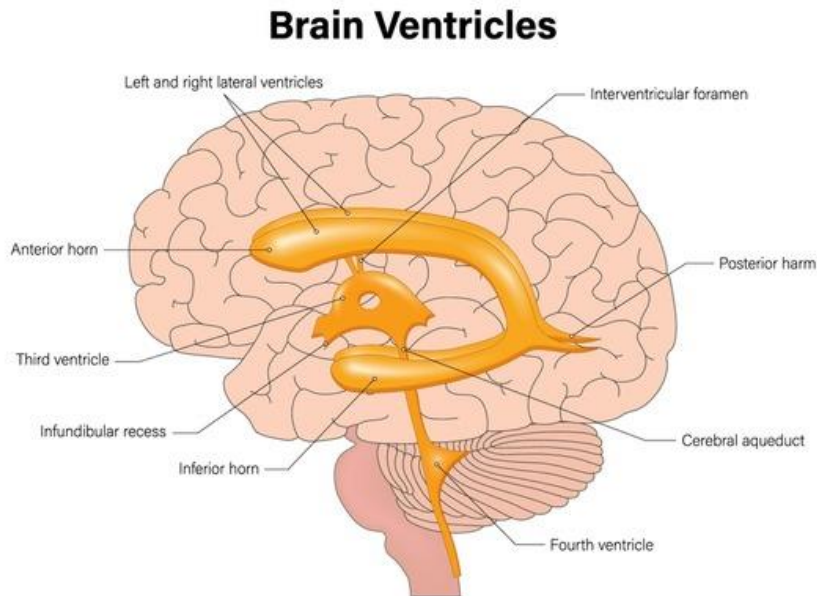


Fig 3.2: Brain ventricles

2. Cerebrospinal Fluid (CSF): Properties and Functions

CSF is a clear, colorless liquid present in both the **ventricular system** and the **subarachnoid space** (between the arachnoid mater and pia mater).

Main functions:

1. **Mechanical Protection** – Acts as a cushion or shock absorber for the brain, protecting it from injury.
2. **Buoyancy** – Reduces the effective weight of the brain inside the skull.
3. **Chemical Stability** – Maintains ion balance, provides nutrients, and removes waste products.
4. **Waste Clearance** – Helps eliminate toxic byproducts from brain tissue.
5. **Developmental Role** – Transports growth factors and signaling molecules important for brain development.

Quantity and turnover:

- Around **150 ml** of CSF is present at any time in humans (25 ml in the ventricles, rest in the subarachnoid space).
- It is produced continuously by the **choroid plexus**, about **500 ml per day** (i.e., the CSF is renewed about **3 times daily**).



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3. Comparative Anatomy of the Ventricular System

- **Fishes and Amphibians:** Ventricles are simple, with little division, reflecting less complex hemispheres.
- **Ectothermic vertebrates (cold-blooded):** Cerebral aqueduct is short and wide.
- **Birds:** Possess a unique modification where the ventricular system extends into the **rhomboid sinus** at the lumbosacral spinal cord, probably helping balance during bipedal walking.
- **Mammals:** Show the most diversity. The **lateral ventricles** expand with cerebral lobe growth, producing distinct horns. Mammalian CSF has **low protein content** and **high turnover rates**, especially in smaller, more active animals.

3.1.3 Nerve Pathways and Reflex Arc

1. Types of Neural Pathways

The nervous system communicates through **neural pathways**, broadly classified as:

- **Sensory (afferent) pathways:** Carry information from sensory organs to the brain.
- **Motor (efferent) pathways:** Carry signals from the brain to muscles and glands.
- **Integrative pathways:** Process and integrate sensory and motor information.

Examples:

- **Visual pathway:** Retina → Optic nerve → Optic chiasm (partial crossing) → Occipital cortex.
- **Auditory pathway:** Signals pass through multiple brainstem stations before reaching auditory cortex.
- **Olfactory pathway:** Bypasses thalamus, projecting directly to olfactory cortex.
- **Autonomic pathways:**
 - **Sympathetic system:** Thoracolumbar origin → ganglia → target organs.
 - **Parasympathetic system:** Brainstem and sacral origin → ganglia close to target organs.



2. Reflex Arc and Neural Circuitry

A **reflex arc** is the basic unit of neural circuitry responsible for reflex actions. It usually involves:

- **Sensory neuron** (detects stimulus)
- **Interneuron(s)** (processing in spinal cord)
- **Motor neuron** (activates response)

Example – Withdrawal Reflex:

- Touching something painful activates sensory neurons.
- These stimulate interneurons in the spinal cord, which:
 1. **Excite flexor muscles** (pulling the limb away).
 2. **Inhibit extensor muscles** (preventing opposite movement).
- This may also cause **crossed extension**: the opposite limb extends to maintain balance.

Neural principles in reflexes:

- **Divergence**: One sensory input activates many motor outputs.
- **Convergence**: Multiple inputs combine on one neuron.
- **Inhibition**: Balances activity between opposing muscle groups.
- **Descending modulation**: Brain can enhance or suppress reflexes depending on context.

3. Comparative Aspects of Neural Pathways

- **Primates**: Have highly developed **corticospinal tracts**, allowing fine hand control.
- **Non-mammalian vertebrates**: Rely more on brainstem pathways for movement.
- **Species adaptations**:
 - **Nocturnal species**: Strong auditory and olfactory systems.
 - **Diurnal species**: More advanced visual systems.
 - **Aquatic vertebrates**: Special lateral line system for detecting water movements.



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SUMMARY:

The nervous system is the body's communication network, coordinating activities and responding to stimuli. It is divided into:

- **Central Nervous System (CNS):** brain and spinal cord, responsible for processing information.
- **Peripheral Nervous System (PNS):** nerves linking CNS with the body.
- **Autonomic Nervous System (ANS):** controls involuntary actions (sympathetic and parasympathetic). Basic units are **neurons**, which transmit impulses through electrical and chemical signals. Protection is provided by meninges, cerebrospinal fluid, and the blood-brain barrier.

A. Multiple Choice Questions

1. The central nervous system consists of:
 - a) Brain and cranial nerves
 - b) Brain and spinal cord
 - c) Spinal nerves and ganglia
 - d) Autonomic nerves
2. The “fight or flight” response is controlled by:
 - a) Somatic nervous system
 - b) Parasympathetic nervous system
 - c) Sympathetic nervous system
 - d) Central nervous system
3. Which of the following carries signals from receptors to the CNS?
 - a) Motor neurons
 - b) Sensory neurons
 - c) Interneurons
 - d) Effectors

B.Short Answer Questions

1. Differentiate between CNS and PNS.
2. What is the role of sympathetic and parasympathetic divisions of the ANS?

UNIT 3.2:

Endocrine Glands - Classification and Histology



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3.2 Introduction

The endocrine system is one of the body's main control systems, along with the nervous system, that helps maintain homeostasis and coordinate complex biological functions. Whereas the nervous system conveys information via electrical impulses traveling down a physical network of neurons, the endocrine system communicates via chemical signals, called hormones, that travel through the bloodstream until they reach their target tissues. This integrated system of ductless glands and specialized cells generates, stores, and secretes these hormones directly into the circulatory system, facilitating distinct long-range signaling and regulation through the body. Here we present a comprehensive review of the endocrine glands, alongside their classification, histological characteristics, products (hormones), regulation and comparative aspects across vertebrate species. Exploring both the microarchitecture and functional properties of these specialized tissues reveals the stunning complexity and precision of endocrine regulation in action.

3.2.1 Classification of Endocrine Glands

Endocrine glands can be classified using various criteria, including their histological organization, embryological origin, chemical nature of their secretions, and functional roles. Understanding these classification systems provides a framework for comprehending the diversity and specialization within the endocrine system.



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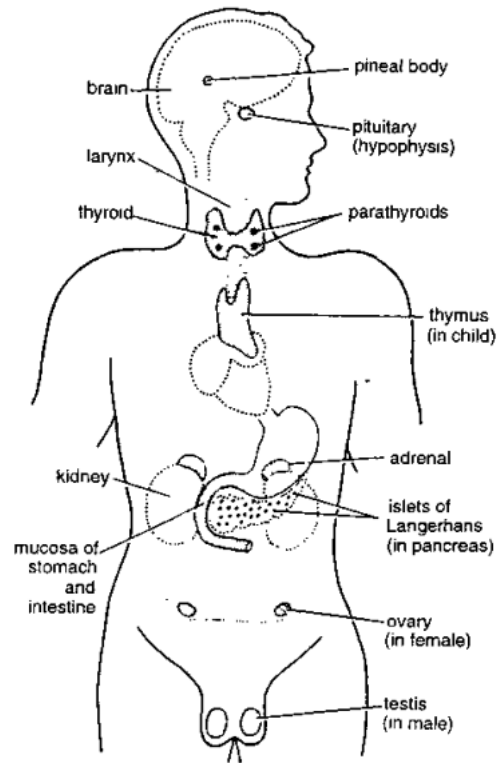


Fig3.3: Endocrine glands in human

Classification Based on Structural Organization

Pure Endocrine Glands

Pure endocrine glands function exclusively in hormone production and secretion. These glands lack ducts and release their secretory products directly into the bloodstream. Examples include:

1. **Parathyroid glands:** Produce parathyroid hormone, which regulates calcium homeostasis.
2. **Adrenal glands:** Consist of the cortex and medulla, secreting steroid hormones and catecholamines, respectively.
3. **Pineal gland:** Produces melatonin, which regulates circadian rhythms.

Mixed Glands

Mixed glands perform both endocrine and exocrine functions, containing both ductless endocrine components and ducted exocrine components. Major examples include:

1. **Pancreas:** Contains exocrine acini that secrete digestive enzymes into the digestive tract via ducts, and endocrine islets of Langerhans that release hormones directly into the bloodstream.



2. **Gonads (testes and ovaries):** Produce gametes (exocrine function) and sex hormones (endocrine function).
3. **Placenta:** Serves as an interface for maternal-fetal exchange (exocrine function) and produces hormones like human chorionic gonadotropin (hCG) and estrogen (endocrine function).

Diffuse Endocrine System

Also known as the enteroendocrine system, this consists of isolated hormone-producing cells dispersed throughout tissues that primarily serve other functions, particularly within epithelial linings. Examples include:

1. **Enteroendocrine cells:** Scattered throughout the gastrointestinal tract, producing hormones like gastrin, secretin, and cholecystokinin.
2. **Neuroendocrine cells:** Found in the respiratory epithelium and other tissues.

Classification Based on Embryological Origin

Neural Crest Derivatives

1. **Adrenal medulla:** Develops from neural crest cells that migrate to the adrenal region.
2. **Paraganglion system:** Includes chromaffin cells and carotid bodies.

Ectodermal Derivatives

1. **Anterior pituitary:** Develops from Rathke's pouch, an outgrowth of oral ectoderm.
2. **Skin-derived endocrine elements:** Vitamin D production in the skin has endocrine implications.

Endodermal Derivatives

1. **Thyroid gland:** Derives from the floor of the primitive pharynx.
2. **Parathyroid glands:** Develop from the pharyngeal pouches.
3. **Pancreatic islets:** Arise from endodermal cells of the developing pancreatic buds.
4. **Enteroendocrine cells:** Differentiate from the endoderm of the primitive gut tube.

Mesodermal Derivatives

1. **Gonads:** Develop from the urogenital ridge.
2. **Adrenal cortex:** Arises from the coelomic mesoderm.



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3. **Placenta:** Develops from trophoblastic cells of mesodermal origin.

Classification Based on Chemical Nature of Hormones

Protein and Peptide Hormone-Producing Glands

1. **Anterior pituitary:** Secretes growth hormone, prolactin, adrenocorticotrophic hormone (ACTH), thyroid-stimulating hormone (TSH), follicle-stimulating hormone (FSH), and luteinizing hormone (LH).
2. **Parathyroid glands:** Produce parathyroid hormone.
3. **Pancreatic islets:** Release insulin, glucagon, somatostatin, and pancreatic polypeptide.

Steroid Hormone-Producing Glands

1. **Adrenal cortex:** Secretes glucocorticoids, mineralocorticoids, and adrenal androgens.
2. **Gonads:** Produce sex steroids (estrogen, progesterone, testosterone).
3. **Placenta:** Synthesizes estrogen and progesterone during pregnancy.

Amine Hormone-Producing Glands

1. **Thyroid gland:** Produces thyroid hormones (thyroxine and triiodothyronine), which are iodinated amino acids.
2. **Adrenal medulla:** Secretes catecholamines (epinephrine and norepinephrine).
3. **Pineal gland:** Synthesizes melatonin, an indoleamine.

Histological Features of Major Endocrine Glands

The histological organization of endocrine glands reflects their specialized functions in hormone production and secretion. Each gland exhibits unique microscopic features that facilitate its specific endocrine role.

Pituitary Gland (Hypophysis)

The pituitary gland, approximately the size of a pea (≈ 0.5 -1 cm in diameter) and weighing about 0.5 grams, resides in the sella turcica of the sphenoid bone at the base of the brain. It consists of two main portions with distinct embryological origins, histological structures, and functional properties.

Anterior Pituitary (Adenohypophysis)



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The anterior pituitary develops from Rathke's pouch, an ectodermal outgrowth from the roof of the embryonic oral cavity. Histologically, it displays the following characteristics:

1. **Cellular organization:** Arranged in cords and clusters of epithelial cells separated by fenestrated sinusoidal capillaries, allowing for efficient hormone release into the bloodstream.
2. **Cell types:** Contains five distinct hormone-producing cell types, identifiable by specific staining properties and immunohistochemical markers:
 - **Somatotrophs:** Constitute approximately 40-50% of anterior pituitary cells, appear as large, acidophilic cells with prominent secretory granules containing growth hormone (GH).
 - **Lactotrophs:** Comprise about 15-20% of cells, are acidophilic, and produce prolactin (PRL).
 - **Corticotrophs:** Make up 15-20% of cells, display basophilic properties due to their glycoprotein content, and secrete adrenocorticotrophic hormone (ACTH) and related peptides derived from pro-opiomelanocortin (POMC).
 - **Thyrotrophs:** Represent 5% of cells, are basophilic, and produce thyroid-stimulating hormone (TSH).
 - **Gonadotrophs:** Constitute 10% of cells, are basophilic, and secrete follicle-stimulating hormone (FSH) and luteinizing hormone (LH).
3. **Vascular supply:** Receives blood via the hypophyseal portal system, which connects the hypothalamus to the anterior pituitary, enabling hypothalamic releasing and inhibiting hormones to regulate pituitary hormone secretion.

Intermediate Lobe

This thin layer between the anterior and posterior pituitary is prominent in many vertebrates but rudimentary in humans. It produces melanocyte-stimulating hormone (MSH) and contains:

1. **Melanotrophs:** Cells that process POMC to produce α -MSH.
2. **Colloid-filled cysts:** Remnants of Rathke's pouch lumen.

Posterior Pituitary (Neurohypophysis)

The posterior pituitary develops as a downward extension of the hypothalamus (neural ectoderm) and exhibits the following histological features:



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1. Cellular components:

- **Pituicytes:** Modified glial cells that provide structural support.
- **Herring bodies:** Axonal dilations containing neurosecretory granules, representing storage sites for hormones produced in the hypothalamus.

2. Vascular arrangement: Rich sinusoidal capillary network that facilitates hormone release into the systemic circulation.

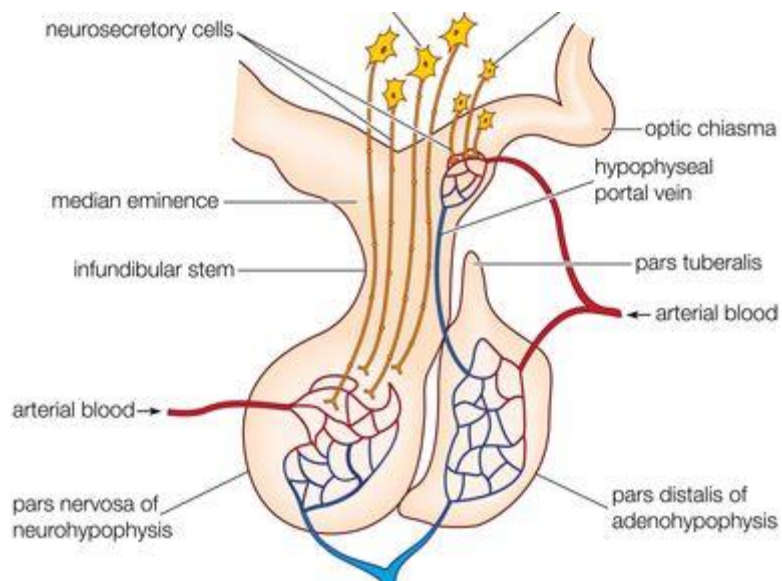


Fig 3.4: Hypothalamus

Adrenal Glands (Suprarenal Glands)

The paired adrenal glands sit atop each kidney, each weighing 4-5 grams in adults. They are composite organs with distinct cortical and medullary regions of different embryological origins, histological organization, and functional properties.

Adrenal Cortex

The adrenal cortex derives from mesoderm and constitutes about 80-90% of the gland. It is arranged in three concentric zones, each producing different steroid hormones:

1. Zona glomerulosa:

- The outermost layer (15% of cortical volume).
- Cells arranged in arched clusters or glomeruli.
- Cells are small, columnar to pyramidal, with basophilic cytoplasm containing lipid droplets.



- Uniquely expresses aldosterone synthase.

2. Zona fasciculata:

- The middle and widest layer (75% of cortical volume).
- Cells arranged in straight cords perpendicular to the capsule.
- Contains large, polyhedral cells with abundant cytoplasm filled with lipid droplets (spongiocytes).
- Produces glucocorticoids, predominantly cortisol, which regulate metabolism and stress responses.
- Rich in smooth endoplasmic reticulum for steroid synthesis.

3. Zona reticularis:

- The innermost cortical layer (10% of cortical volume).
- Cells arranged in an anastomosing network.
- Smaller cells with fewer lipid droplets and abundant lipofuscin pigment.
- Produces adrenal androgens, mainly dehydroepiandrosterone (DHEA) and androstenedione.
- Contains lysosomes and lipofuscin granules, especially in older individuals.

Adrenal Medulla

The adrenal medulla develops from neural crest cells and constitutes 10-20% of the gland's volume. Its histological features include:

1. Chromaffin cells:

- Large, polygonal to columnar cells arranged in cords and clusters.
- Contain numerous membrane-bound granules that store catecholamines (epinephrine and norepinephrine).
- Named for their affinity for chromium salts, which produce a brown coloration.
- Can be differentiated into epinephrine-producing (80%) and norepinephrine-producing (20%) cells by histochemical techniques.

2. Ganglion cells:

- Scattered sympathetic postganglionic neurons.



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- Large cells with prominent nucleoli and Nissl substance.

3. Vascular features:

- Extensive sinusoidal capillary network.
- Receives arterial blood both directly and after it has perfused the cortex.

4. Innervation:

- Rich sympathetic innervation via preganglionic fibers of the splanchnic nerves.
- Synapses directly on chromaffin cells, allowing neural control of catecholamine release.

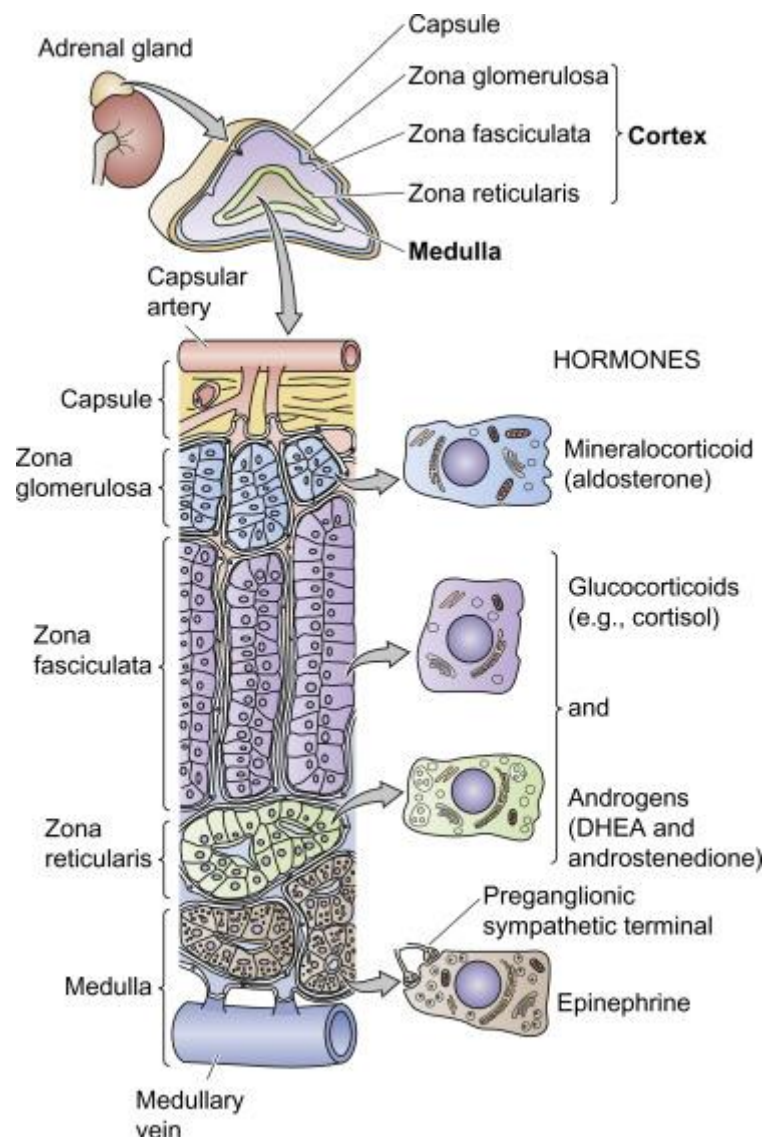


Fig 3.5: Adrenal Gland

Pancreatic Islets (Islets of Langerhans)



The endocrine pancreas consists of approximately 1-2 million small clusters of cells—the islets of Langerhans—scattered throughout the exocrine pancreatic tissue. These islets constitute only 1-2% of the pancreatic volume but play crucial roles in metabolic regulation.

Histological Organization

1. Structure and distribution:

- Spherical to oval clusters ranging from 50-300 μm in diameter.
- Richly vascularized with fenestrated capillaries.

2. Cellular composition: Contains four main cell types identifiable by immunohistochemistry and specific staining techniques:

- **Beta (β) cells:**
 - Most abundant (60-70% of islet cells).
 - Typically located in the central portion of the islet.
 - Produce insulin, which decreases blood glucose levels.
 - Contain characteristic granules with crystalline cores visible by electron microscopy.
- **Alpha (α) cells:**
 - Secrete glucagon, which increases blood glucose levels.
 - Contain electron-dense secretory granules.
- **Delta (δ) cells:**
 - Comprise 5-10% of islet cells.
 - Distributed throughout the islet.
 - Produce somatostatin, which inhibits both insulin and glucagon secretion.
 - Contain large, electron-lucent granules.
- **PP cells (F cells):**
 - Represent 1-2% of islet cells, more abundant in the head of the pancreas.
 - Secrete pancreatic polypeptide, which regulates pancreatic exocrine secretion.

3. Vascular arrangement:



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- Arterioles enter the islet and branch into fenestrated capillaries.
- Blood flows from the center to the periphery, allowing insulin to influence glucagon secretion.
- Efferent venules drain into the portal system, delivering hormones directly to the liver.

4. Innervation:

- Rich autonomic innervation with both sympathetic and parasympathetic fibers.
- Neurotransmitters modulate hormone secretion from islet cells.

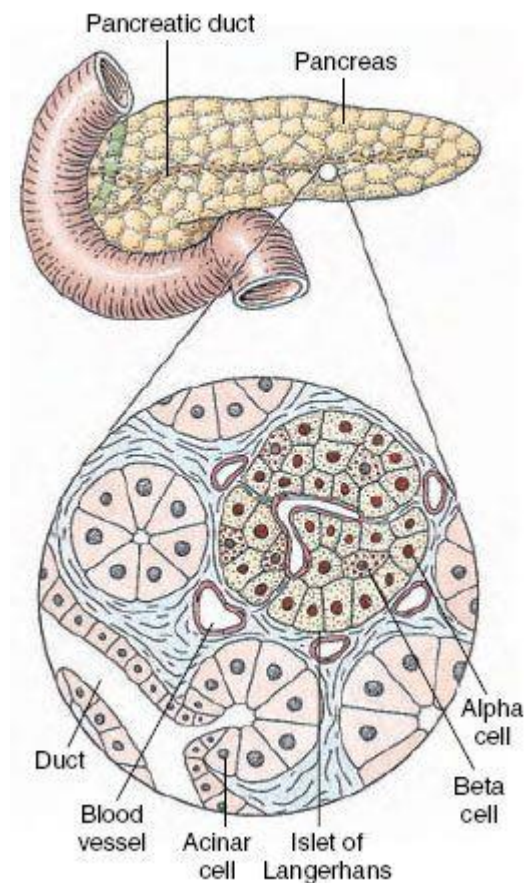


Fig3.6: Pancreas

Pineal Gland (Epiphysis Cerebri)

The pineal gland is a small, pine cone-shaped neuroendocrine organ located in the epithalamus, between the two cerebral hemispheres. It weighs approximately 100-180 mg and measures about 5-8 mm in length.

Histological Features

1. Cellular components:



- **Pinealocytes:** The principal parenchymal cells, accounting for about 95% of the cellular elements. These are modified photoreceptor cells with:
 - Large, pale nuclei with prominent nucleoli.
 - Abundant cytoplasm containing lipid droplets.
 - Long processes that terminate near blood vessels.
 - Secretory vesicles containing melatonin and other indoleamines.
- **Interstitial cells (astrocyte-like cells):**
 - Stellate cells with processes that form a supporting network.
 - Express glial fibrillary acidic protein (GFAP).
 - May participate in regulatory functions.

2. Structural organization:

- Cells arranged in cords or pseudofollicular structures.
- Absence of true glandular organization.
- Progressive calcification with age, forming concretions called "brain sand" or corpora arenacea.

3. Vascular features:

- Rich capillary network without a blood-brain barrier.
- Direct exposure to cerebrospinal fluid.

4. Innervation:

- Sympathetic innervation via the superior cervical ganglia, which regulates melatonin synthesis.
- Absence of direct photosensitivity in mammals, unlike in lower vertebrates.

Gonads (Testes and Ovaries)

The gonads serve dual functions: gametogenesis (exocrine function) and hormone production (endocrine function). Their histological organization reflects this functional duality.

Testes

1. Structural organization:

- Interstitial spaces between tubules house the endocrine components.



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2. Endocrine components:

- **Leydig cells (interstitial cells):**
 - Large, polygonal cells with eosinophilic, lipid-rich cytoplasm.
 - Contain abundant smooth endoplasmic reticulum for steroid synthesis.
 - Produce testosterone and other androgens.
- **Sertoli cells:**
 - Tall columnar cells within the seminiferous tubules.
 - Produce inhibin, which regulates FSH secretion from the pituitary.
 - Also serve exocrine functions by supporting spermatogenesis.

3. Vascular and lymphatic features:

- Rich vascular network in the interstitial spaces.
- Blood-testis barrier formed by tight junctions between Sertoli cells.

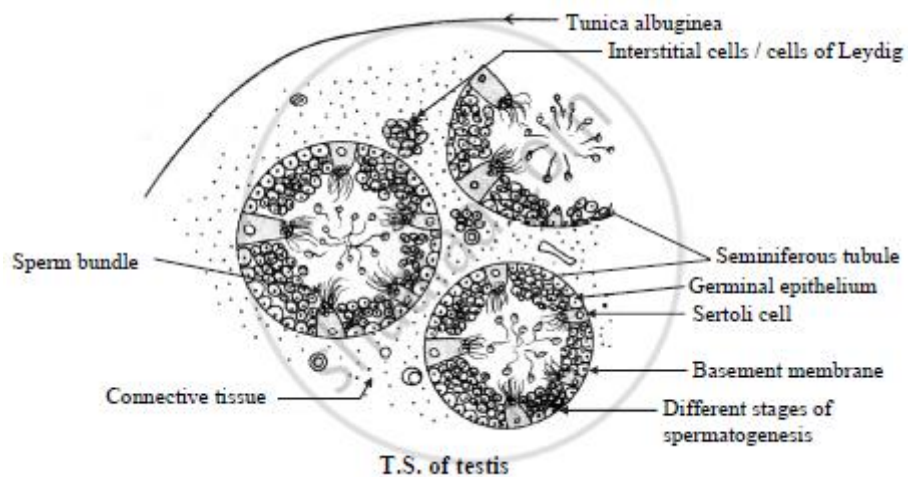


Fig 3.7: T.S. of Testis

Ovaries

1. Structural organization:

- Covered by a modified mesothelium (germinal epithelium).
- Divided into outer cortex (containing follicles) and inner medulla (vascular stroma).



2. Endocrine components:

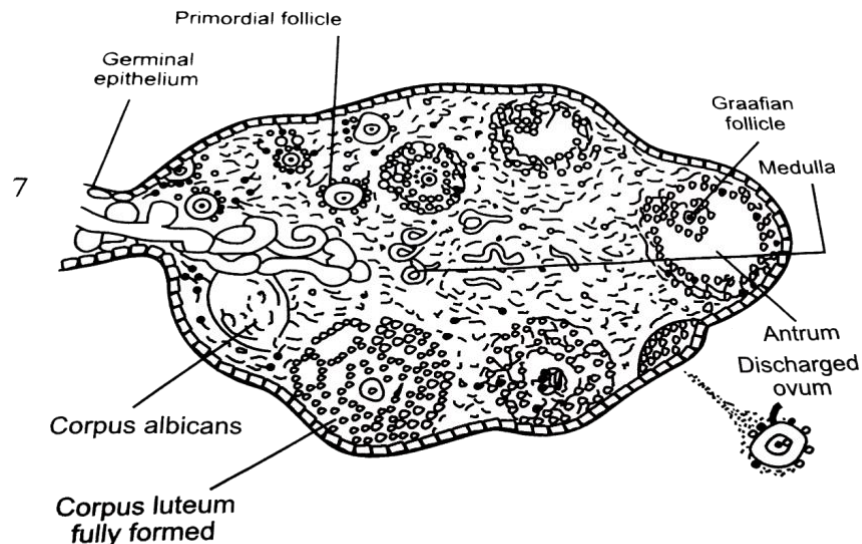
- **Granulosa cells:**
 - Surround developing oocytes in ovarian follicles.
 - Produce estradiol from androgens via aromatase activity.
 - Form the membrane granulosa of mature follicles.
- **Theca cells:**
 - Differentiate from stromal cells around growing follicles.
 - Divided into theca interna (steroidogenic) and theca externa (fibrous).
 - Theca interna cells produce androgens that serve as substrates for estrogen synthesis by granulosa cells.
- **Corpus luteum:**
 - Forms after ovulation from remaining follicular cells.
 - Contains luteinized granulosa cells and theca cells.
 - Produces progesterone and estrogens.
 - Degenerates into corpus albicans if pregnancy does not occur.

3. Follicular development:

- Primordial follicles: Oocyte surrounded by a single layer of flattened granulosa cells.
- Primary follicles: Growing oocyte with cuboidal granulosa cells.
- Secondary follicles: Multiple layers of granulosa cells, developing theca layers.
- Tertiary (antral) follicles: Contains fluid-filled antrum, well-developed theca layers.
- Graafian (preovulatory) follicle: Large antrum, eccentric oocyte within cumulus oophorus.

4. Vascular features:

- Rich vascular supply, particularly to developing follicles and corpora lutea.
- Spiral arteries that accommodate follicular growth.



Structure of Human Ovary

Fig 3.8: T.S. of Ovary

Placenta

While temporary and present only during pregnancy, the placenta functions as a critical endocrine organ that maintains pregnancy and prepares the mother for lactation.

Histological Features

1. Structural organization:

- Discoid structure composed of maternal (decidua) and fetal (chorion) components.
- Divided into cotyledons, the functional units of maternal-fetal exchange.

2. Cellular components with endocrine functions:

- **Syncytiotrophoblast:**
 - Multinucleated outer layer of the chorionic villi.
 - Principal site of hormone production.
 - Contains abundant rough endoplasmic reticulum and mitochondria.
 - Produces human chorionic gonadotropin (hCG), human placental lactogen (hPL), estrogens, and progesterone.
- **Cytotrophoblast:**



- Inner layer of mononucleated cells.
- Serves as stem cells for syncytiotrophoblast.
- Decreases in prominence as pregnancy advances.

3. Vascular arrangement:

- Fetal blood vessels within chorionic villi.
- Maternal blood in intervillous spaces.
- Hemochorial arrangement where maternal blood directly contacts trophoblast.

4. Temporal changes:

- First trimester: Prominent cytotrophoblast, active proliferation.
- Second and third trimesters: Predominant syncytiotrophoblast, increased vascularization, formation of terminal villi.

Thyroid Gland – Structure, Function, and Comparative Account in Vertebrates

The thyroid gland is one of the most important endocrine glands in vertebrates, regulating basal metabolism, growth, and development through the secretion of iodinated hormones. Its origin, structure, and physiological significance have evolved in close relation to the metabolic demands of different vertebrate groups, and a comparative study reveals both fundamental similarities and marked adaptations.

Embryological Origin and General Features:

The thyroid arises as an endodermal thickening on the ventral floor of the pharynx, usually near the level of the second or third gill pouch. This thickening grows downward to form a bilobed or paired gland that ultimately becomes richly vascularized and encapsulated by connective tissue. In all vertebrates, the gland is composed of secretory epithelial cells arranged around colloid-filled follicles. The colloid is rich in thyroglobulin, a glycoprotein precursor of thyroid hormones. Two principal hormones, **thyroxine (T₄)** and **triiodothyronine (T₃)**, are synthesized and stored in the colloid and released into circulation under the control of pituitary thyroid-stimulating hormone (TSH). These hormones increase oxygen consumption, elevate basal metabolic rate, influence carbohydrate and lipid metabolism, and are indispensable for normal growth and differentiation of tissues.

Comparative Anatomy and Location:

In **cyclostomes** such as lampreys, the thyroid is not a discrete encapsulated organ but a diffuse mass of endostylar tissue in larval stages that later reorganizes into follicular thyroid tissue in adults. This



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transition is significant, as it demonstrates an evolutionary link between primitive mucous-secreting endostyle and true thyroid tissue.

In **fishes**, the thyroid typically appears as a pair of irregular masses or follicles scattered around the ventral aorta and branchial arteries rather than as a single compact gland. This diffuse arrangement is especially evident in teleosts and elasmobranchs. Despite the scattered structure, the follicles produce the same iodinated hormones, reflecting conservation of function across vertebrates.

In **amphibians**, the gland becomes a more compact bilobed structure located ventral to the larynx and trachea. Amphibian metamorphosis is critically dependent on thyroid hormones; in frogs, for example, thyroxine triggers resorption of the tail, development of limbs, and remodeling of internal organs. Ablation or inhibition of thyroid function arrests metamorphosis, illustrating the gland's deep evolutionary role in life-history transitions.

In **reptiles**, the thyroid is typically more compact and lies close to the base of the neck near the heart and great vessels. Although reptiles do not undergo metamorphosis like amphibians, thyroid hormones regulate seasonal cycles of growth, molting (in snakes and lizards), and reproductive activity, demonstrating adaptive modulation of endocrine rhythms in response to environmental cues.

In **birds**, the thyroid is paired and usually situated near the carotid arteries, often at the thoracic inlet. Avian thyroids are highly vascular and play an important role in regulating basal metabolic rate to meet the high energetic demands of endothermy and flight. Thyroid activity also influences molting cycles, gonadal activity, and thermogenesis.

In **mammals**, the thyroid is typically a bilobed structure connected by an isthmus and located anterior to the trachea, just below the larynx. It is enclosed in a capsule and receives an abundant blood supply and rich sympathetic innervation. The mammalian thyroid exhibits the most advanced regulatory mechanisms, with feedback loops involving the hypothalamic–pituitary–thyroid axis ensuring precise hormonal balance. The presence of parafollicular cells (C cells) producing calcitonin, a hormone involved in calcium homeostasis, adds another layer of endocrine complexity.

Histology and Function:

In all vertebrates, the fundamental unit is the **thyroid follicle**, a sphere lined by cuboidal or low columnar epithelial cells. The lumen contains colloid, within which iodination of tyrosine residues occurs to form monoiodotyrosine (MIT) and diiodotyrosine (DIT). Coupling of these residues forms T_3 and T_4 , which are stored extracellularly in the colloid—a unique feature among endocrine glands. Upon stimulation by TSH, the follicular epithelium engulfs colloid droplets, processes them, and releases free hormones into circulation. These hormones act on

nearly all tissues, increasing mitochondrial biogenesis, enhancing oxidative phosphorylation, stimulating protein synthesis, and regulating carbohydrate and lipid turnover.



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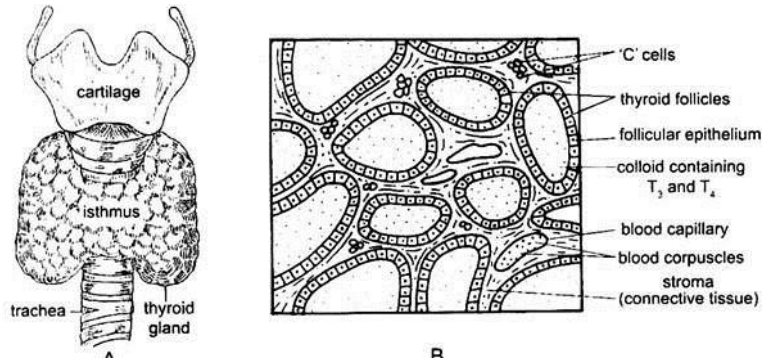


Fig 3.9: Thyroid gland

Regulatory Mechanisms in Hormone Secretion

Negative Feedback

The most common regulatory mechanism involves negative feedback loops, where the end product of a pathway inhibits earlier steps:

1. **Short-loop negative feedback:** A hormone inhibits the secretion of its regulatory hormone. For example, cortisol inhibits ACTH release from the pituitary.
2. **Long-loop negative feedback:** End-organ hormones inhibit hypothalamic or pituitary hormone secretion. For example, thyroid hormones suppress TSH and TRH release.

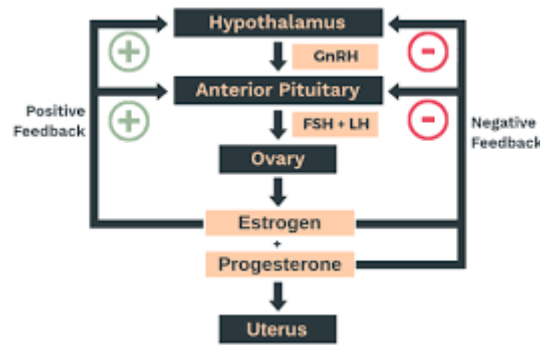
Positive Feedback

In certain cases, hormones stimulate their own production or the production of hormones that further enhance the initial response:

1. **Reproductive examples:** Estrogen initially suppresses LH secretion but then triggers the LH surge that induces ovulation.
2. **Parturition:** Oxytocin stimulates uterine contractions, which trigger more oxytocin release.



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3.10: Hormonal Regulation

Neural Regulation

The nervous system directly influences hormone secretion through:

1. **Direct neural innervation:** Sympathetic stimulation of the adrenal medulla or pancreatic islets.
2. **Neurosecretion:** Hypothalamic nuclei producing releasing and inhibiting hormones that regulate pituitary function.
3. **Neuroendocrine reflexes:** Sensory inputs (osmolality, blood pressure, stress) triggering specific hormone responses.

Chemical Signals

Local metabolites, ions, and nutrients can directly influence hormone secretion:

1. **Glucose levels:** Directly affect insulin and glucagon release from pancreatic islets.
2. **Calcium levels:** Regulate parathyroid hormone secretion through calcium-sensing receptors.
3. **Oxygen tension:** Modulates erythropoietin production by the kidneys.

Hormonal Regulation of Growth

Growth involves both an increase in cell number (hyperplasia) and cell size (hypertrophy), coordinated by multiple hormones acting in concert.

Growth Hormone (GH) Axis

Growth hormone, produced by somatotrophs in the anterior pituitary, represents the central hormone regulating postnatal growth:

1. **Regulation of GH secretion:**
 - **Somatostatin:** Hypothalamic peptide that inhibits GH release.
 - **Feedback regulation:** IGF-1 suppresses GH secretion.

2. Mechanism of action:

- **Direct effects:** GH directly promotes lipolysis, protein synthesis, and glucose production.

3. Physiological effects:

- **Longitudinal bone growth:** Stimulates chondrocyte proliferation in growth plates.
- **Organ growth:** Promotes hyperplasia and hypertrophy of various tissues.
- **Metabolic effects:** Protein anabolism, lipolysis, mild insulin resistance.

Thyroid Hormones

Thyroid hormones (T3 and T4) play essential roles in growth and development:

1. Developmental effects:

- **Central nervous system:** Critical for neuronal proliferation, migration, and myelination.
- **Skeletal maturation:** Required for normal bone development and growth.
- **Congenital hypothyroidism:** Results in cretinism with severe growth and developmental delays if untreated.

2. Growth mechanisms:

- **Synergy with GH:** Enhances GH receptor expression and IGF-1 production.
- **Metabolic stimulation:** Increases basal metabolic rate, supporting energy-intensive growth processes.
- **Direct gene regulation:** Modulates expression of genes involved in development.

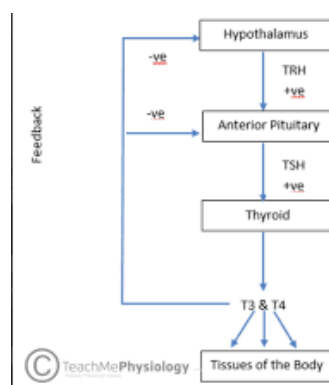


Fig3.11: Hypothalamic-pituitary-thyroid Axis



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Sex Steroids

Sex hormones exert profound influences on growth, particularly during puberty:

1. Estrogens:

- Initially promote long bone growth during the pubertal growth spurt.
- Eventually induce epiphyseal closure, terminating linear growth.
- Shape the female body composition and fat distribution.

2. Androgens:

- Stimulate protein anabolism and muscle development.
- Promote bone growth and mineralization.
- Contribute to the male pubertal growth spurt.
- Eventually lead to epiphyseal closure.

Insulin

While primarily a metabolic hormone, insulin significantly impacts growth:

1. Anabolic effects:

- Promotes protein synthesis and inhibits protein catabolism.
- Enhances cellular nutrient uptake required for growth.
- Stimulates lipogenesis and glycogen storage.

2. Growth interactions:

- Shares signaling pathways with IGF-1.
- Necessary for normal IGF-1 production and action.
- Growth retardation occurs in untreated type 1 diabetes mellitus.

SUMMARY:

The endocrine glands are ductless glands that secrete hormones directly into the bloodstream to regulate various physiological processes such as growth, metabolism, reproduction, and homeostasis. Major endocrine glands include the pituitary (master gland controlling others), thyroid (regulating metabolism), parathyroid (calcium balance), adrenal glands (stress response and metabolism), pancreas (blood glucose regulation), pineal gland (biological rhythms), thymus (immune function), and gonads (sex hormones and reproduction). Each gland releases specific hormones

that act on target organs or tissues, maintaining internal stability (homeostasis) and coordinating body functions through chemical signaling.



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A. Multiple Choice Questions

1. Which gland is known as the "master gland" of the endocrine system?
a) Thyroid
b) Pituitary
c) Adrenal
d) Pancreas
Answer: b) Pituitary
2. Which hormone regulates blood glucose by lowering its level?
a) Glucagon
b) Cortisol
c) Insulin
d) Adrenaline
Answer: c) Insulin
3. The adrenal medulla secretes which of the following hormones?
a) Aldosterone and Cortisol
b) Insulin and Glucagon
c) Adrenaline and Noradrenaline
d) Thyroxine and Calcitonin
Answer: c) Adrenaline and Noradrenaline
4. The parathyroid gland primarily regulates:
a) Sodium balance
b) Calcium levels
c) Blood pressure
d) Thyroxine secretion
Answer: b) Calcium levels

B. Short Answer Questions

1. Define endocrine glands and explain how they differ from exocrine glands.
2. Describe the role of the pituitary gland in regulating other endocrine glands.
3. Write short notes on the hormones of the adrenal gland and their functions.
4. Discuss the role of pancreas as both an endocrine and exocrine gland.



UNIT 3.3:

Gonads and Genital Ducts

3.3 Introduction

The reproductive system is one of the most critical physiological systems of vertebrates, which make their contribution to the proliferation of future generations. Central to this system are the gonads and genital ducts, structures that have undergone impressive specializations during evolution across the vertebrate lineage. Overall, reproductive anatomy is an evolutionary story of the consolidation of necessary features alongside dramatic adaptations made for specialized reproductive strategies, from the primitive cyclostomes to the highly cosmopolitan mammals. A comprehensive rediction of gonad structure, function, and development; the process of sex differentiation; comparative anatomy of genital ducts; and reproductive cycles of vertebrates, including the evolutionary adaptations of gonads of both external and internal fertilizing vertebrates.

Gonads: Anatomy, Physiology, and Embryogenesis

Gonads are the main reproductive organs that generate gametes and sex hormones. In vertebrates, they usually arise as paired structures from the intermediate mesoderm of the embryo. The fundamental structural organization of gonads consists of a cortex (outer region) and medulla (inner region), but the relative development of these regions has notable differences between males and females and across vertebrate classes.

The fundamental components of mature gonads include:

1. Germ cells (oogonia/spermatogonia): The precursors of gametes that undergo meiosis and differentiation
2. Somatic cells: Supporting cells that provide structural and functional support for germ cell development

3.3.1 Male Gonads: Testes

The testes have two main functions: 1. Spermatogenesis (the production of male gametes); and 2. Steroidogenesis (sex hormone synthesis, predominantly testosterone). The basic organization of the vertebrate testis is highly conserved among species but adapted to specific roles.

Structural Organization

Sertoli cells line the seminiferous tubules from basement membrane to lumen. Tight junctions between Sertoli cells establish the blood-testis barrier, which divides the tubule into basal and adluminal compartments. This barrier shields developing germ cells from immune surveillance and preserves a unique microenvironment essential for spermatogenesis. In



non-mammalian vertebrates, the testicular structure shows variations while maintaining these essential components:

1. In teleost fish, testes typically exhibit a lobular or tubular organization, with seminiferous tubules or lobules containing cysts of synchronously developing spermatogenic cells.
2. Amphibian testes consist of seminiferous tubules or ampullae arranged in a lobular pattern, often with seasonal variations in size and activity.
3. Reptilian testes generally contain seminiferous tubules with a seasonal cycle of spermatogenic activity corresponding to their breeding patterns.
4. Avian testes, while structurally similar to mammalian testes, typically undergo dramatic seasonal enlargement during breeding periods, sometimes increasing up to 300 times in size.

Spermatogenesis

Spermatogenesis is the process by which haploid spermatozoa are produced from diploid spermatogonia. This process occurs within the seminiferous tubules and progresses through several stages:

1. Mitotic proliferation: Spermatogonial stem cells undergo mitosis to produce more stem cells and differentiating spermatogonia.
2. Meiosis: Spermatocytes undergo meiotic division to reduce chromosome number and produce haploid spermatids.
3. Spermiogenesis: Spermatids undergo dramatic morphological transformations to become streamlined, motile spermatozoa.

The timing and efficiency of spermatogenesis vary across vertebrate classes. In mammals, it is a continuous process taking approximately 64 days in humans. In contrast, many non-mammalian vertebrates exhibit seasonal spermatogenesis synchronized with environmental cues and mating opportunities.

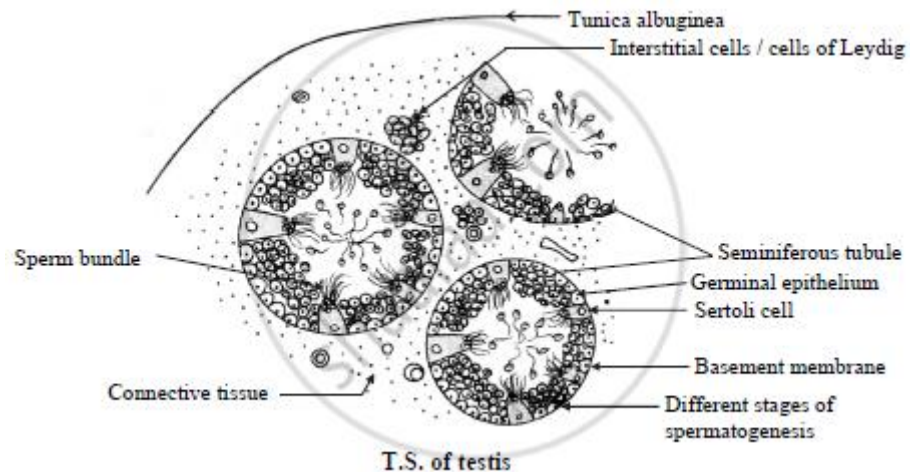


Fig3.12: T.S. of Testis

3.3.2Female Gonads: Ovaries

The ovaries are these that perform oogenesis (the creation of female gametes) and the production of female sex hormones, mainly estrogens and progesterone. In contrast to the relatively conserved architecture of testes, ovarian morphology varies considerably across vertebrate classes.

Structural Organization

In mammals, ovaries usually exhibit a distinct cortex and medulla. The cortex is composed of ovarian follicles in different stages of development, and the medulla consists of connective tissue, blood vessels, lymphatics, and nerves. The ovary is enclosed by a modified peritoneum known as the germinal epithelium (although it does not have germ cells in adults).

The fundamental functional unit of the mammalian ovary is the ovarian follicle, consisting of:

1. An oocyte (developing egg cell)
2. Surrounding granulosa cells that provide nutritional and hormonal support
3. Theca cells (in more developed follicles) that form around the granulosa cells and participate in steroid hormone production

Non-mammalian vertebrates exhibit diverse ovarian structures:

1. Fish ovaries typically show one of three patterns: gymnovarian (eggs released directly into the coelom), cystovarian (eggs released into an ovarian lumen continuous with the oviduct), or intermediate types.
2. Amphibian ovaries generally consist of a thin cortex containing developing oocytes and a medulla with blood vessels and connective tissue.

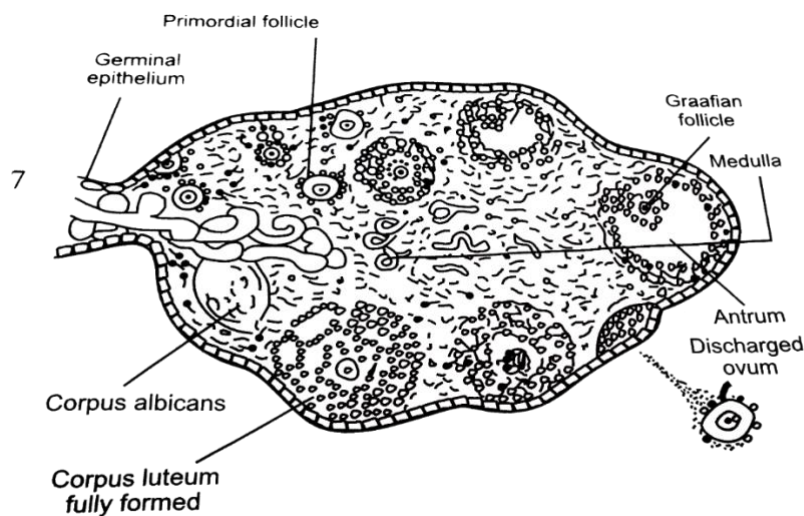
3. Reptilian ovaries typically contain follicles arranged in a cortical region, with size and activity varying seasonally.

Oogenesis

Oogenesis is the process of female gamete formation, characterized by several key features:

1. Primordial germ cells migrate to the developing gonad and differentiate into oogonia.
2. Oogonia proliferate mitotically and begin meiosis to become primary oocytes.
3. Primary oocytes arrest at prophase I of meiosis until hormonal stimulation triggers further development.

A critical difference between spermatogenesis and oogenesis is the asymmetrical division during meiosis in oogenesis, resulting in one large ovum and small polar bodies, thus preserving cytoplasmic resources for the developing embryo. In mammals, all oogonia enter meiosis during fetal development, establishing a finite oocyte reserve. In contrast, many non-mammalian vertebrates maintain oogonial stem cells capable of generating new oocytes throughout reproductive life.



Structure of Human Ovary

Fig3.13: Structure of Human Ovary

Gonadal Development

The development of gonads follows a complex sequence of events beginning with the formation of the undifferentiated gonadal primordium.

Formation of the Undifferentiated Gonad

In all vertebrates, gonadal development begins with the formation of the genital ridge, a thickening of the coelomic epithelium on the ventromedial



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surface of the mesonephros. This ridge is colonized by primordial germ cells (PGCs) that originate extragonadally and migrate to the developing gonad.

The timing of PGC migration varies across vertebrates:

1. In birds, PGCs arise from the epiblast, enter the germinal crescent, and reach the gonads via the circulatory system.
2. In amphibians, PGCs derive from the vegetal pole and migrate through the dorsal mesentery.
3. In teleost fish, PGCs originate extraembryonically and migrate along specific pathways guided by chemokine signals.

Once colonized by PGCs, the genital ridge consists of:

1. Coelomic epithelium: The surface epithelium that will contribute to gonadal structure
2. Underlying mesenchyme: Derived from the mesonephros and intermediate mesoderm
3. Primordial germ cells: The future gamete precursors

At this stage, the gonad is considered bipotential or undifferentiated, capable of developing into either testes or ovaries depending on genetic and hormonal signals.

Male Genital Ducts

The male genital duct system undergoes significant modification across vertebrate lineages, reflecting adaptations to different reproductive strategies.

Mammals

In male mammals, the genital duct system consists of:

1. Rete testis: A network of tubules that receive sperm from the seminiferous tubules
2. Efferent ductules: Coiled tubes connecting the rete testis to the epididymis
3. Epididymis: A highly convoluted tube where sperm undergo maturation and gain motility

Additional glands contribute to the formation of semen:

1. Seminal vesicles: Secrete a fructose-rich fluid that provides energy for sperm



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2. Prostate gland: Produces an alkaline fluid that neutralizes acidic vaginal secretions
3. Bulbourethral glands: Secrete a clear fluid that neutralizes urinary acid and provides lubrication

The mammalian system shows adaptations for internal fertilization, with specializations for sperm storage, maturation, and transport.

Birds

Male birds possess:

1. Rete testis and efferent ductules similar to mammals
2. Epididymis: Usually less elaborate than in mammals
3. Ductus deferens: Often convoluted and expanded near its termination to form a sperm storage area
4. Urodeum of the cloaca: The common chamber receiving sperm and excretory products

Many male birds lack accessory glands comparable to mammals, though some species possess a rudimentary prostate-like structure. In some species, the terminal portion of the ductus deferens forms a specialized seminal glomerus for sperm storage.

Reptiles

The male reptilian duct system includes:

1. Rete testis and efferent ductules
2. Epididymis: Variable in complexity, more developed in species with internal fertilization
3. Ductus deferens: Terminates in the urodeum of the cloaca

Some reptiles possess accessory glands:

1. Crocodilians have structures analogous to mammalian seminal vesicles.
2. Some squamates possess a segment of the ductus deferens modified as an ampulla for sperm storage.

Amphibians

In male amphibians:

1. Sperm travels through the rete testis to the efferent ductules.
2. The anterior portion of the mesonephric kidney often serves dual excretory and reproductive functions.



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3. The mesonephric (Wolffian) duct transports both sperm and urine in many species.
4. In some salamanders, specialized cloacal glands produce spermatophores for indirect sperm transfer.

The duct system shows variations between anurans (frogs and toads) and urodeles (salamanders), with the latter often having more specialized structures for courtship and sperm transfer.

Fish

Male teleost fish exhibit considerable diversity:

1. In some species, sperm ducts derive from extensions of the testicular tissue rather than from mesonephric ducts.
2. The sperm ducts may fuse posteriorly to form a common spermduct or remain separate.
3. In viviparous species, specialized portions of the duct may form intromittent organs.

Chondrichthyans (sharks and rays) possess modified posterior mesonephric ducts as sperm ducts, often with specialized regions for sperm storage.

Modifications for Reproduction

Male genital ducts show adaptations reflecting reproductive strategies:

1. Internal fertilizers typically have more complex duct systems with regions specialized for sperm storage and maturation.
2. Species practicing external fertilization often have simpler ducts primarily serving as conduits.
3. Species with seasonal reproduction may have specialized storage regions where sperm can be maintained until mating.

Female Genital Ducts

Female genital ducts exhibit remarkable diversity across vertebrates, reflecting various reproductive strategies from massive egg production to viviparity.

Mammals

In female mammals, the Müllerian ducts develop into:

1. Fallopian tubes (oviducts): Ciliated funnels that capture ova released from the ovary and serve as the site of fertilization
2. Uterus: A muscular organ for embryo implantation and development



- Duplex: Completely paired uteri (e.g., rodents)
 - Bipartite: Partially fused uteri with two horns (e.g., dogs, pigs)
 - Bicornuate: Two uterine horns joining to form a single body (e.g., primates except higher apes and humans)
 - Simplex: Single uterine cavity (e.g., humans, higher apes)
3. Cervix: The neck of the uterus leading to the vagina
 4. Vagina: The birth canal and female copulatory organ

This system shows adaptations for internal fertilization, embryo implantation, and placental development, with variations reflecting differing reproductive strategies (e.g., number of offspring, duration of gestation).

Birds

Female birds typically possess:

1. Left oviduct only (right regresses during development in most species)
2. Infundibulum: The funnel-shaped opening that receives the ovulated egg
3. Magnum: Where albumen (egg white) is secreted
4. Vagina: A muscular tube connecting to the cloaca

This specialized system accommodates the formation of the complex avian egg with its multiple layers and calcified shell.

Reptiles

Female reptiles show diversity in oviduct structure:

1. Infundibulum: Often with ciliated cells to capture ova
2. Various regions specialized for:
 - Albumen secretion
 - Shell membrane formation
 - Shell formation (more elaborate in egg-laying species)
3. Vagina or terminal oviduct: Opens into the cloaca

Viviparous reptiles exhibit modifications including:

1. Thinner eggshells or absence of calcified shells
2. Specialized regions for placental or paraplacental structures



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3. Modifications for gas exchange and nutrient transfer

Amphibians

Female amphibian oviducts typically consist of:

1. Ostium: The ciliated opening near the ovary
2. Oviduct proper: Usually coiled and glandular, secreting jelly layers around eggs
3. Ovisac: An expanded terminal region that serves as temporary egg storage
4. Connection to the cloaca

The degree of oviductal specialization correlates with reproductive mode:

1. Species with aquatic eggs typically have simpler oviducts.
2. Species with terrestrial eggs or direct development show more specialized secretory regions.
3. Viviparous species (some salamanders and caecilians) have regions modified for maternal-fetal exchange.

Fish

Female teleost fish show three main patterns:

1. Gymnovanians: Lack oviducts; ova released into the coelom and exit via the genital pore
2. Cystovanians: Possess hollow ovaries continuous with short oviducts
3. Semi-cystovanians: Intermediate condition

In viviparous fish, oviducts may be modified for:

1. Egg retention and embryo development
2. Specialized regions for nutrient transfer
3. Superficial placental-like structures in some species

Chondrichthyans (sharks and rays) possess paired Müllerian ducts that develop into oviducts with specialized regions for egg capsule formation in oviparous species or placental structures in viviparous species.

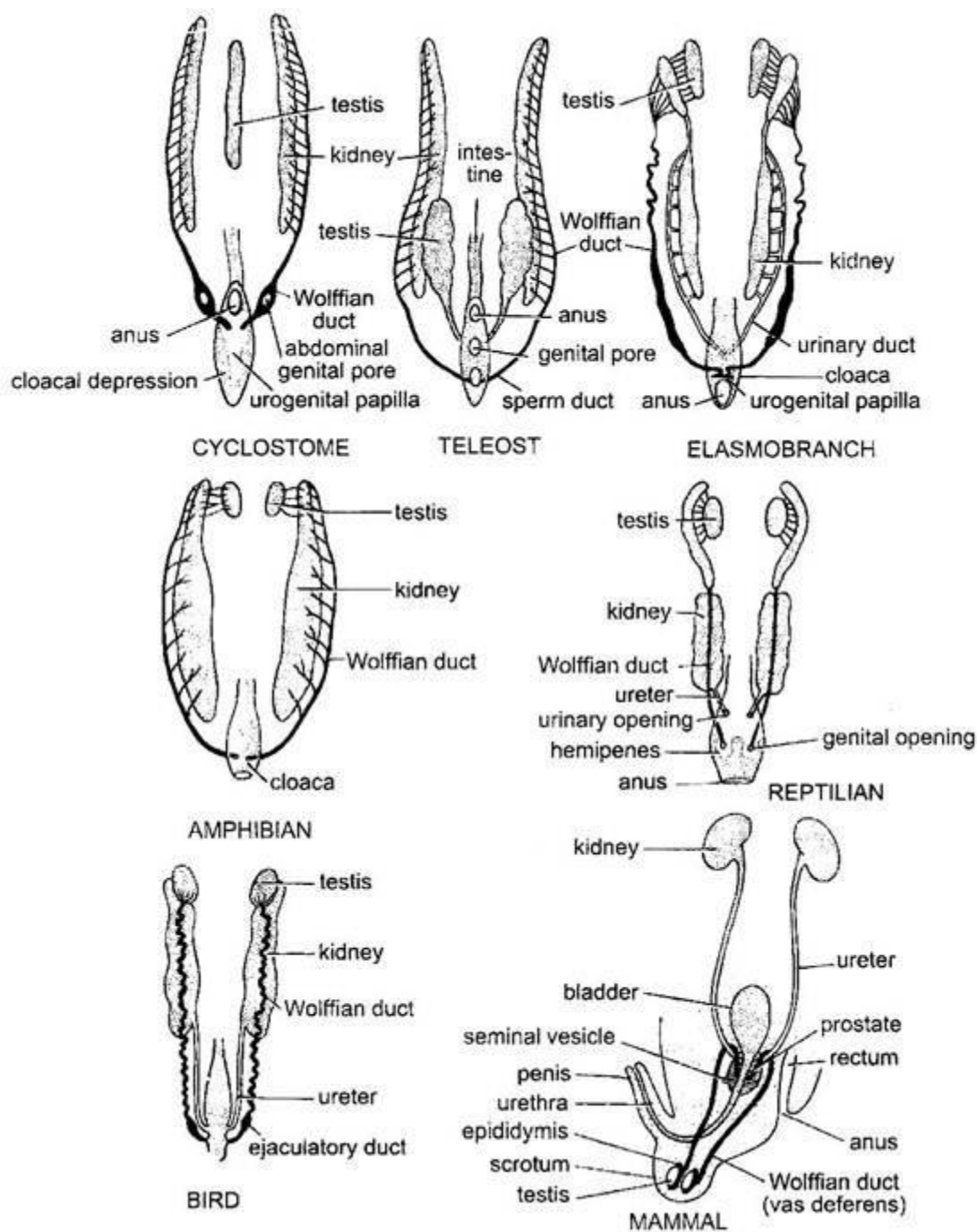


Fig 3.14: Genital and Urinary ducts in male vertebrates

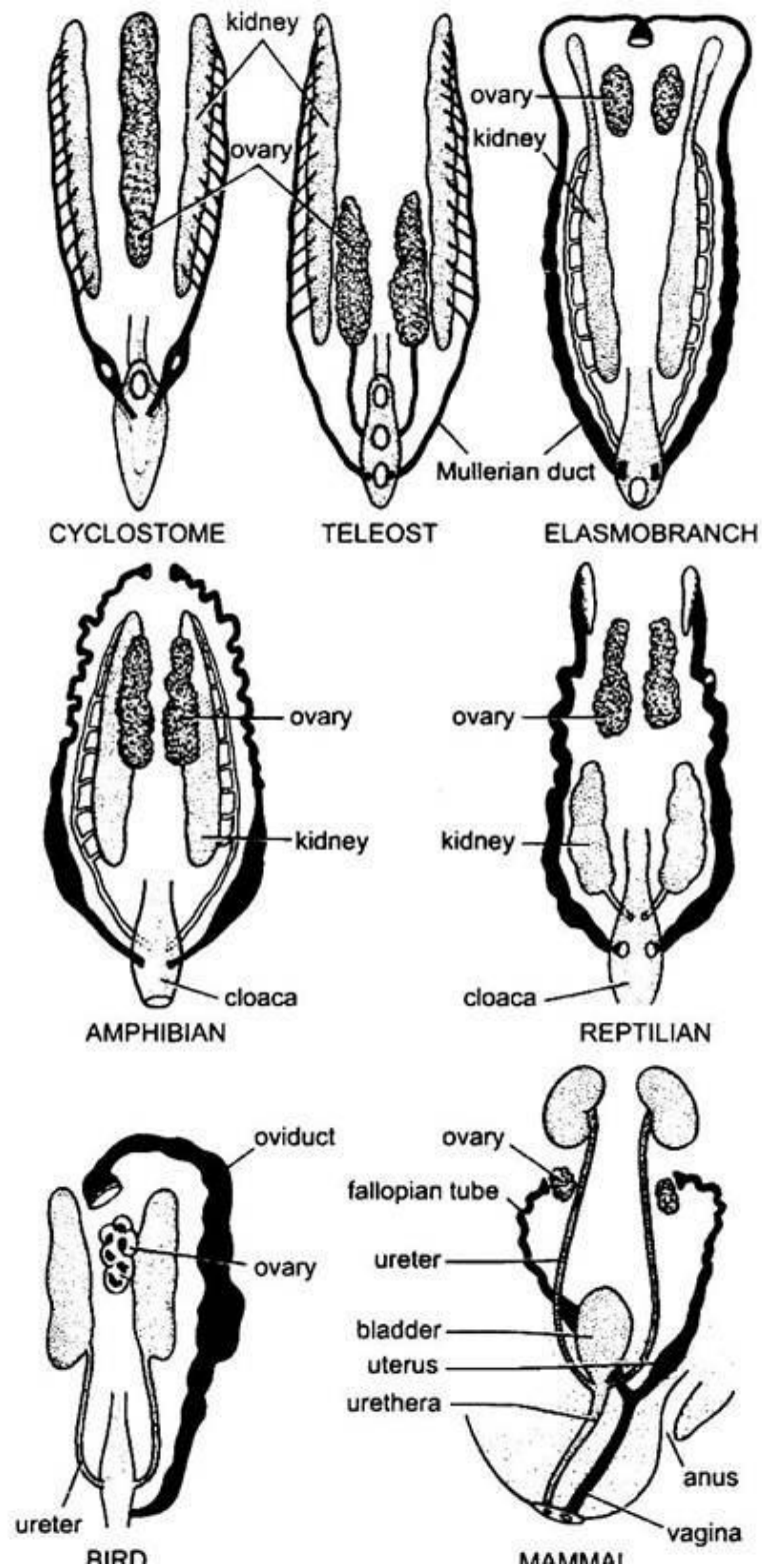


Fig 3.15: Genital and Urinary ducts in female vertebrates



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SUMMARY:

The **gonads** (testes in males, ovaries in females) are primary reproductive organs. They produce **gametes** (sperm and ova) and secrete **sex hormones** (testosterone, estrogen, progesterone) that regulate reproductive functions, sexual development, and secondary sexual characteristics.

The **genital ducts** are accessory structures that transport gametes. In males, the ducts include **epididymis, vas deferens, ejaculatory duct, and urethra**, which store and deliver sperm. In females, the ducts include **oviducts (fallopian tubes), uterus, and vagina**, which aid in the transport of ova, fertilization, implantation, and childbirth. Together, gonads and genital ducts ensure reproduction and continuity of species.

A. Multiple Choice Questions

1. Which of the following hormones is secreted by the testes?
 - a) Estrogen
 - b) Progesterone
 - c) Testosterone
 - d) Prolactin

Answer: c) Testosterone

2. The oviduct in females is primarily the site of:
 - a) Implantation
 - b) Fertilization
 - c) Ovulation
 - d) Menstruation

Answer: b) Fertilization

3. Which of the following is *not* a male genital duct?
 - a) Vas deferens
 - b) Ejaculatory duct
 - c) Urethra
 - d) Fallopian tube

Answer: d) Fallopian tube

B. Short Answer Questions

1. What are the dual functions of gonads?
2. Name the major genital ducts in males and their roles.
3. How do oviducts and uterus differ in function in females?
4. Explain the role of sex hormones in secondary sexual characteristics.



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SUMMARY:

The **nervous system** is a rapid control system that senses stimuli, processes information, and coordinates responses using **neurons** and **glial cells**.

- **CNS:** Brain (thoughts, memory, voluntary actions) and spinal cord (reflexes, communication).
- **PNS:** Nerves outside CNS, divided into **somatic** (voluntary control) and **autonomic** (involuntary—sympathetic & parasympathetic).
- **Reflex Arc:** Direct sensory → spinal cord → motor pathway.
- In higher vertebrates, the brain shows advanced development (cerebrum, cerebellum).

The **endocrine system** is slower but long-lasting, using hormones secreted into blood to regulate **growth, metabolism, reproduction, and homeostasis**.

- Major glands: **Pituitary** (master gland), **hypothalamus** (nervous link), **thyroid & parathyroid** (metabolism, calcium), **adrenal** (stress response), **pancreas** (blood sugar), **gonads** (sex hormones), **pineal & thymus** (sleep cycle, immunity).
- Nervous and endocrine systems coordinate through the **hypothalamus–pituitary axis** to maintain homeostasis.

The **gonads**—testes in males and ovaries in females—are primary reproductive organs with dual roles in **gamete production** and **hormone secretion**. Testes produce **sperm** and secrete **testosterone**, which regulates male sexual development, secondary sexual characters, and fertility. Ovaries produce **ova** and release **estrogen** and **progesterone**, hormones essential for female reproductive cycles, pregnancy, and the development of secondary sexual traits. Thus, gonads play a central role in reproduction and the maintenance of sexual dimorphism in vertebrates.

A. Multiple Choice Questions (MCQs):

1. **The central nervous system (CNS) is composed of:**
 - a) Brain and spinal cord
 - b) Nerves and ganglia
 - c) Sensory and motor pathways
 - d) Cranial and spinal nerves
2. **Which part of the brain controls coordination and balance?**
 - a) Cerebrum
 - b) Cerebellum



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- c) Medulla oblongata
- d) Thalamus
- 3. **Cerebrospinal fluid (CSF) is primarily located in:**
 - a) The brain ventricles and spinal canal
 - b) Bones and muscles
 - c) Lungs and heart
 - d) Liver and kidneys
- 4. **The reflex arc is responsible for:**
 - a) Voluntary body movements
 - b) Conscious decision-making
 - c) Involuntary responses to stimuli
 - d) Growth regulation
- 5. **Which of the following is classified as an endocrine gland?**
 - a) Sweat gland
 - b) Salivary gland
 - c) Adrenal gland
 - d) Sebaceous gland
- 6. **The pituitary gland is known as the "master gland" because it:**
 - a) Produces digestive enzymes
 - b) Controls the nervous system
 - c) Regulates other endocrine glands
 - d) Pumps blood throughout the body
- 7. **Which hormone is primarily responsible for regulating metabolism?**
 - a) Insulin
 - b) Thyroxine
 - c) Oxytocin
 - d) Progesterone
- 8. **In most vertebrates, the male gonads function to produce:**
 - a) Ova
 - b) Sperm
 - c) Hormones only
 - d) Placenta
- 9. **The primary role of genital ducts is to:**
 - a) Absorb nutrients
 - b) Excrete waste
 - c) Transport gametes
 - d) Produce hormones
- 10. **External fertilization is most commonly observed in:**
 - a) Mammals
 - b) Amphibians and fish



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- c) Reptiles and birds
- d) Insects

ANSWER KEY

1. **a) Brain and spinal cord**
2. **b) Cerebellum**
3. **a) The brain ventricles and spinal canal**
4. **c) Involuntary responses to stimuli**
5. **c) Adrenal gland**
6. **c) Regulates other endocrine glands**
7. **b) Thyroxine**
8. **b) Sperm**
9. **c) Transport gametes**
10. **b) Amphibians and fish**

B.Short Answer Questions:

1. Differentiate between CNS and PNS in vertebrates.
2. What are the main regions of the vertebrate brain, and what are their functions?
3. How does the spinal cord function in vertebrates?
4. What is the role of cerebrospinal fluid (CSF)?
5. Compare sensory and motor nerve pathways in vertebrates.
6. Name three major endocrine glands and their functions.
7. What is the role of the pituitary gland in growth and reproduction?
8. Define gonads and their functions in male and female vertebrates.
9. What is sex differentiation, and how is it controlled?
10. Compare internal and external fertilization in vertebrates.

C.Long Answer Questions:

1. Describe the general structure of the vertebrate nervous system, including CNS and PNS.
2. Explain the comparative evolution of the brain in vertebrates.



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3. Describe the anatomy and function of the spinal cord, including nerve pathways and reflexes.
4. Discuss the role of cerebrospinal fluid (CSF) in vertebrate nervous system protection and function.
5. Compare the structure, function, and histology of major endocrine glands across vertebrates.
6. How do hormones regulate growth, metabolism, and reproduction in vertebrates?
7. Explain the differences in reproductive structures and genital ducts among vertebrate groups.
8. Describe the hormonal regulation of reproductive cycles in male and female vertebrates.
9. Discuss the evolution of reproductive strategies, including adaptations for internal and external fertilization.
10. Compare and contrast the gonadal structures and functions in fish, amphibians, reptiles, birds, and mammals.

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MODULE 4

PHYSIOLOGY OF DIGESTION, CIRCULATION, BLOOD COAGULATION, AND RESPIRATION



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Objectives:

- Study the blood coagulation process, including clotting mechanisms and disorders.
- Explore the mechanism and control of breathing, along with comparative respiratory adaptations.

UNIT 4.1:

Digestion and Absorption of Dietary Components

4.1 Introduction

Digestion is the process by which food is broken down into smaller, soluble forms that can be absorbed into the body. In vertebrates, it involves two main actions:

1. **Mechanical digestion** – physical breakdown of food by chewing, grinding, and churning.
2. **Chemical digestion** – breakdown of complex molecules into simple ones by enzymes and digestive juices.

Although the basic steps are the same in all vertebrates, differences in **diet (carnivory, herbivory, omnivory)** and **habitat (aquatic vs. terrestrial)** have led to special adaptations in the **alimentary canal, digestive glands, and enzymes**.

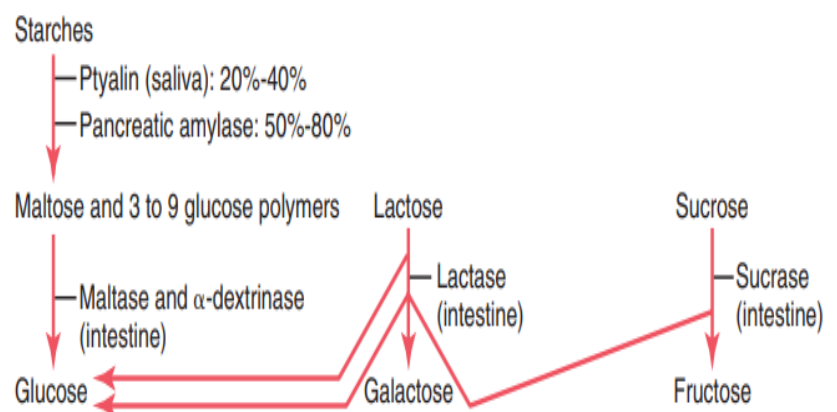
Digestion in the Oral Cavity

- Digestion starts in the **mouth**, where food is ingested, chewed, and mixed with saliva.
- **Teeth and feeding adaptations:**
 - **Fishes & Amphibians:** Simple, uniform (homodont) teeth mainly for grasping prey, not chewing.
 - **Reptiles:** Similar dentition; in herbivorous species (tortoises, iguanas), teeth or beak-like structures crop vegetation.



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- **Birds:** Lack true teeth. Food is seized with the beak and later ground in the **gizzard**.
- **Mammals:** Show **heterodont teeth** (incisors, canines, premolars, molars) for cutting, tearing, and grinding food, allowing thorough chewing (mastication).
- **Role of saliva:**
 - Contains **mucus** to moisten and lubricate food.
 - In **mammals and some birds**, saliva has **amylase**, which begins starch digestion.
 - In most **fishes and amphibians**, saliva does not have digestive enzymes; it mainly helps in swallowing.

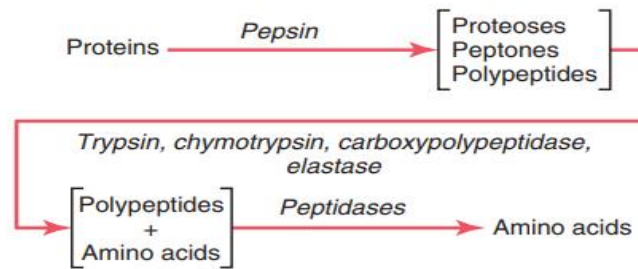


Pharynx, Esophagus, and Stomach

After swallowing, food passes through the **pharynx** and **esophagus** into the **stomach**, where protein digestion begins.

- **Structure:** Most vertebrates have a **J-shaped stomach** lined with gastric glands.
- **Secretions:**
 - **Hydrochloric acid (HCl)** – makes stomach acidic, kills microbes, denatures proteins.

- **Pepsinogen** → **Pepsin** – enzyme that digests proteins into smaller peptides.



4.1.1 Adaptations in different groups:

- **Carnivorous fishes, amphibians, reptiles:** Highly acidic stomachs with strong proteolytic activity for protein-rich diets.
- **Birds:** Have a two-part stomach:
 - **Proventriculus** – secretes gastric juice.
 - **Gizzard** – muscular chamber that grinds food (often with swallowed stones).
- **Mammals:**
 - **Ruminants** (cows, goats, deer) – 4-chambered stomach (rumen, reticulum, omasum, abomasum) where microbes help digest cellulose.
 - **Non-ruminant herbivores** (horses, rabbits) – single-chambered stomach but enlarged **cecum and colon** for hindgut fermentation.

Small Intestine: Main Site of Digestion and Absorption

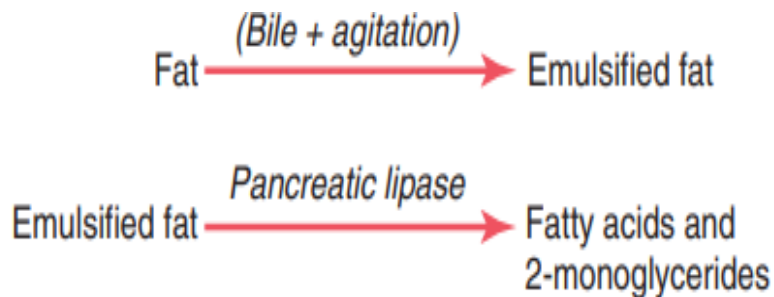
The **small intestine** is the most important organ for nutrient digestion and absorption.

- **Length and structure:**
 - **Carnivores** – short intestines (meat digests easily).
 - **Herbivores** – long, coiled intestines (plants are fibrous and require more time to digest).
- **Digestive juices:**



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- **Bile** (from liver, stored in gallbladder) – emulsifies fats into tiny droplets for easier digestion by lipase.
- **Pancreatic juice** – contains enzymes:
 - **Amylase** – breaks starch into simple sugars.
 - **Lipase** – digests fats into fatty acids and glycerol.
 - **Proteases (trypsin, chymotrypsin)** – digest proteins into amino acids.



Absorption of nutrients:

- The lining of the small intestine has **villi and microvilli**, which greatly increase the surface area.
- **Sugars** (like glucose) and **amino acids** – absorbed into blood capillaries.
- **Fats** – absorbed into lymphatic vessels (lacteals) in mammals; in fishes, lipids enter blood directly.
- **Vitamins and minerals** – absorbed at specific sites (e.g., vitamin B12 in ileum, calcium and iron in upper intestine).

Large Intestine and Hindgut

The **large intestine** absorbs water, salts, and prepares waste for elimination.

- **Carnivores:** Short, simple large intestine.
- **Herbivores:** Enlarged or specialized large intestine for microbial fermentation.



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- **Birds:** Have **paired ceca** for fermentation.
- **Rabbits and horses:** Large **cecum** for fermentation of cellulose.
- **Reptiles:** Some herbivorous reptiles have long colons with symbiotic bacteria.

Comparative Adaptations in Vertebrates

- **Fishes & Amphibians:** Simple guts, short intestines, mainly digest proteins.
- **Reptiles:** Variable – simple in carnivores, complex in herbivores.
- **Birds:** Compact system adapted for flight, with specialized structures (gizzard, ceca).
- **Mammals:** Highly diverse – ruminants with foregut fermentation, non-ruminants with hindgut fermentation, omnivores with versatile digestive systems.

SUMMARY:

In vertebrates, digestion and absorption involve breaking down food into simpler molecules for use by the body. Digestion begins in the mouth, where food is chewed (in mammals) or held by simple teeth or beaks (in fishes, amphibians, reptiles, and birds). The stomach secretes acid and enzymes to digest proteins, with special adaptations such as the gizzard in birds and the four-chambered stomach in ruminant mammals. The small intestine is the main site of chemical digestion and absorption, aided by bile from the liver and enzymes from the pancreas. Its length varies with diet—short in carnivores, long in herbivores. Nutrients are absorbed through villi into blood or lymph, while the large intestine reabsorbs water and, in herbivores, supports microbial fermentation. These differences reflect evolutionary adaptations to diet and habitat.

A. Multiple Choice Questions

1. In mammals, the enzyme that begins starch digestion in the mouth is:
 - a) Pepsin
 - b) Amylase
 - c) Lipase



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d) Trypsin

Answer: b) Amylase

2. Which vertebrate group uses a gizzard to grind food?

a) Fishes

b) Amphibians

c) Birds

d) Mammals

Answer: c) Birds

3. The four-chambered stomach is a feature of:

a) Amphibians

b) Ruminant mammals

c) Reptiles

d) Birds

Answer: b) Ruminant mammals

B.Short Answer Questions

1. Why do herbivores have longer intestines than carnivores?
2. What is the function of bile in digestion?
3. Name two special digestive adaptations in birds.
4. How is protein digestion initiated in the stomach?

UNIT 4.2:

Physiology of the Heart, Cardiac Cycle, and ECG



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4.2 Introduction

The heart is a hollow, muscular organ situated in the thoracic cavity, usually enclosed within a double-walled protective sac called the pericardium. In vertebrates, it lies slightly to the left of the midline and is positioned between the lungs, resting on the diaphragm. Its shape is roughly conical, with a broad base directed upwards and a tapered apex pointing downwards and to the left. The size of the heart varies among species but is generally proportional to the body size; in humans, it is approximately the size of a clenched fist and weighs about 250–300 grams in females and 300–350 grams in males.

4.2.1 Structure of heart

Structurally, the heart is divided internally into chambers by muscular septa and equipped with valves to maintain unidirectional blood flow. In higher vertebrates, such as birds and mammals, the heart is four-chambered, consisting of two thin-walled atria located superiorly and two thick-walled ventricles situated inferiorly. The right side of the heart deals with deoxygenated blood, receiving it from systemic veins into the right atrium and pumping it through the right ventricle into the pulmonary circulation. The left side of the heart handles oxygenated blood, receiving it from the pulmonary veins into the left atrium and then pumping it through the left ventricle into the systemic circulation. The septum that separates the atria is called the interatrial septum, and that separating the ventricles is known as the interventricular septum.

The heart wall itself is composed of three distinct layers. The outermost layer, the **epicardium**, is a thin serous membrane that forms part of the pericardium. Beneath it lies the **myocardium**, the thick muscular middle layer responsible for the contractile activity of the heart. The innermost layer, the **endocardium**, is a smooth endothelial lining that reduces friction as blood flows through the heart chambers. The myocardium is notably thicker in the left ventricle than in the right because it must generate higher pressures to pump blood through the entire systemic circuit.

Valvular structures ensure one-way flow. The atrioventricular (AV) valves lie between atria and ventricles: the tricuspid valve on the right side and the bicuspid (mitral) valve on the left. These valves are tethered by chordae tendineae to papillary muscles, which prevent their prolapse during ventricular contraction. Semilunar valves guard the exits of the ventricles: the pulmonary valve at the opening of the pulmonary artery and the aortic



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valve at the opening of the aorta. These valves open and close passively in response to pressure changes within the heart.

A specialized conduction system is embedded within the heart's architecture. The sinoatrial (SA) node, located in the right atrial wall near the opening of the superior vena cava, serves as the primary pacemaker. The atrioventricular (AV) node lies at the junction of the atria and ventricles, while the bundle of His and Purkinje fibers penetrate the ventricular walls, ensuring rapid and coordinated transmission of electrical impulses.

The heart is richly supplied with blood by the coronary circulation. The right and left coronary arteries arise from the base of the aorta and branch extensively over the heart's surface to provide oxygen and nutrients to the myocardium. Venous drainage occurs through the cardiac veins, which empty into the coronary sinus and then into the right atrium.

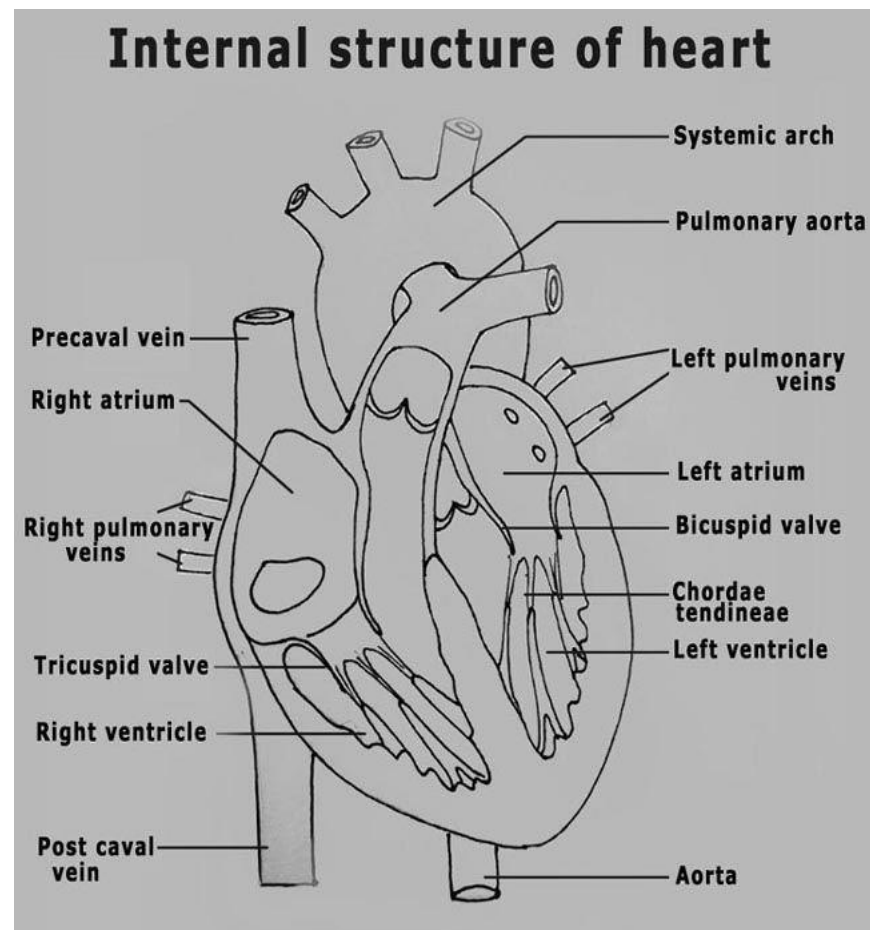


Fig 4.1: Structure of heart



4.2.2 Physiology of the Heart

The heart's anatomy is intricately linked to its physiology, enabling it to function as an efficient pump. Its rhythmic activity arises from the unique properties of cardiac muscle cells and the conduction system. The heart functions through a repeating pattern known as the **cardiac cycle**, comprising phases of contraction (systole) and relaxation (diastole), which together ensure continuous blood flow.

The sequence begins with atrial systole, where the atria contract to complete the filling of the ventricles. This is followed by ventricular systole, during which the ventricles contract powerfully, expelling blood into the pulmonary artery and aorta. After this ejection, the ventricles relax during diastole, allowing them to refill with blood and prepare for the next cycle. This cycle, occurring about 70–75 times per minute in a resting human heart, is finely tuned to maintain adequate cardiac output.

Electrical impulses generated by the SA node spread across the atria, causing their coordinated contraction, and then reach the AV node. The slight delay at the AV node ensures that the ventricles fill completely before contracting. The impulse then travels through the bundle of His and Purkinje fibers, resulting in synchronized ventricular contraction. This intrinsic conduction system makes the heart self-exciting, capable of beating even when isolated from neural input.

Although the heart has automaticity, its function is modulated by extrinsic factors. The sympathetic division of the autonomic nervous system increases heart rate and contractility through the action of norepinephrine, preparing the body for increased activity. The parasympathetic division, primarily via the vagus nerve, exerts a calming influence, slowing the heart rate and reducing the force of contraction. Hormones such as epinephrine and thyroxine can also influence cardiac activity over longer durations.

Coronary circulation is critical because the myocardium relies almost exclusively on aerobic metabolism. Oxygen-rich blood flows through the coronary arteries primarily during diastole. Any obstruction to this flow can result in ischemia and compromise the heart's pumping ability.

The heart's physiology ensures a dynamic balance between blood supply and the metabolic demands of tissues. During exercise or stress, cardiac output can increase several folds through a combination of elevated heart rate and stronger contractions. Conversely, during rest, the heart conserves energy by slowing its rhythm. This adaptability highlights the heart's central role in maintaining homeostasis across varied physiological states.

The heart functions as a dual pump that works continuously to maintain circulation. Its activity is governed by intrinsic properties of cardiac muscle and the specialized conduction system, yet it remains highly



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responsive to neural and hormonal influences that adapt its performance to the body's demands.

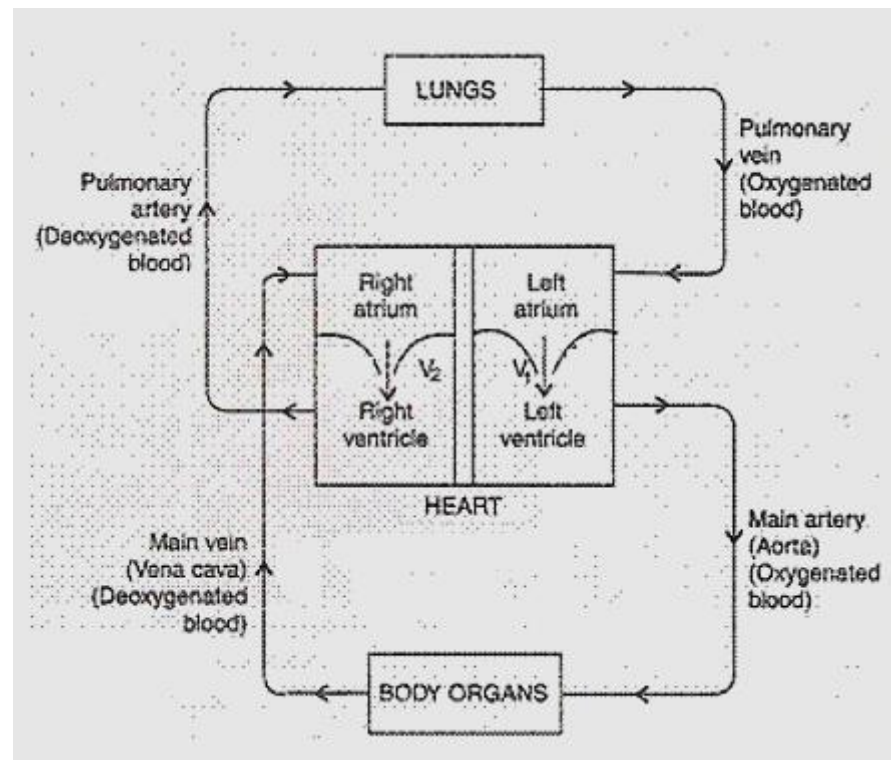


Fig 4.2: Circulation of blood

The Cardiac Cycle

The working of the heart is best understood through the **cardiac cycle**, which is the sequence of mechanical and electrical events in one heartbeat. A complete cycle lasts about 0.8 seconds in a healthy adult at rest and consists of the following phases:

1. Atrial Systole:

The SA node initiates an electrical impulse, causing both atria to contract almost simultaneously. This atrial systole lasts about 0.1 seconds and pushes additional blood into the relaxed ventricles, ensuring maximal filling.

2. Ventricular Systole:

Following a brief delay at the AV node (to allow ventricles to fill completely), the electrical impulse travels through the bundle of His and Purkinje fibers, causing the ventricles to contract. This ventricular systole lasts about 0.3 seconds.

- As intraventricular pressure rises, the AV valves (tricuspid and bicuspid) close, producing the first heart sound (S1, “lub”).

- When ventricular pressure exceeds the pressure in the pulmonary artery and aorta, the semilunar valves open, and blood is ejected.

3. Ventricular Diastole:

After contraction, the ventricles relax, and intraventricular pressure falls below the pressure in the great arteries. This causes the semilunar valves to close, producing the second heart sound (S2, “dup”). Ventricular diastole lasts about 0.4 seconds, during which the AV valves reopen and the ventricles passively fill with blood from the atria, preparing for the next cycle.

Throughout the cycle, pressure changes and valve operations maintain a strict one-way flow of blood. The coordinated action of systole and diastole ensures efficient pumping with minimal energy wastage.

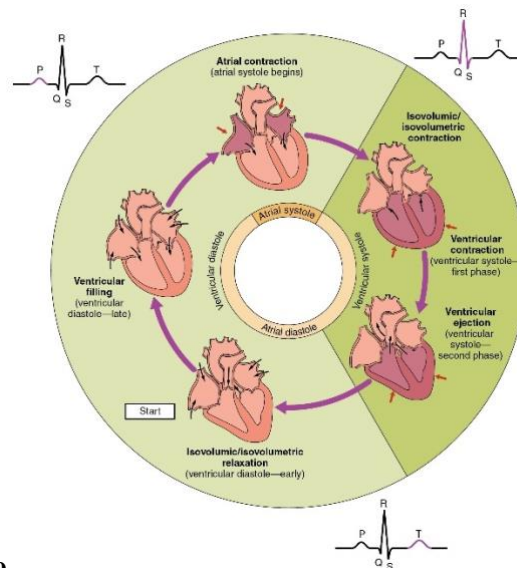


Fig4.3: Cardiac Cycle

Electrical Conduction and Pacemaker Activity

The **sinoatrial (SA) node**, located in the right atrial wall, is the natural pacemaker. Its cells have the unique ability to depolarize spontaneously, initiating each heartbeat. The impulse spreads across the atrial myocardium, causing atrial contraction, and reaches the **atrioventricular (AV) node**, where a slight conduction delay allows the ventricles to complete filling. From the AV node, the impulse travels rapidly down the **bundle of His** and into the **Purkinje fibers**, which distribute the signal to the ventricular myocardium, triggering a strong and coordinated contraction.

This conduction system ensures the heart beats in a synchronized manner, with atria contracting first, followed by ventricles, optimizing the efficiency of blood ejection.



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Neural and Hormonal Regulation

While the heart has intrinsic rhythmicity, its rate and force are modulated by external factors.

- **Sympathetic stimulation** (via cardiac accelerator nerves) releases norepinephrine, increasing the rate (positive chronotropy) and force of contraction (positive inotropy), which is essential during exercise or stress.
- **Parasympathetic stimulation** (via the vagus nerve) releases acetylcholine, slowing the heart rate and reducing contractility during rest or recovery.
- Hormones like **epinephrine** (from the adrenal medulla) and **thyroid hormones** can also enhance cardiac output over longer time frames.

Coronary Circulation and Metabolic Requirements

The myocardium relies almost exclusively on aerobic metabolism and requires a constant supply of oxygen and nutrients. The **coronary arteries** provide this supply, with most blood flow occurring during diastole, when the myocardium is relaxed. Venous blood is returned to the right atrium through the coronary sinus. Any interruption in coronary blood flow can lead to ischemia or infarction, severely affecting the heart's pumping ability.

Functional Significance

The heart's physiology is a remarkable example of biological efficiency and adaptability. Under resting conditions, an adult human heart pumps about 5 liters of blood per minute. During exercise, this can increase four- to five-fold due to higher heart rate and enhanced stroke volume. This adaptability ensures that tissues receive an adequate supply of oxygen and nutrients during varying metabolic demands, maintaining homeostasis and supporting life processes.

4.2.3 The Electrocardiogram (ECG)

An essential tool in studying the physiology and working of the heart is the **Electrocardiogram (ECG or EKG)**. It is a graphic representation of the electrical activity of the heart recorded from the surface of the body over time. Because the heart's rhythmic contractions are initiated and coordinated by electrical impulses, these currents spread through the



cardiac muscle and can be detected by electrodes placed on the skin. The ECG provides invaluable information about the heart's rhythm, conduction pathways, and functional integrity.

Principles of ECG Recording

When the heart depolarizes or repolarizes, a wave of electrical activity spreads through the myocardium, generating voltage differences that can be detected externally. Standard ECG recording uses **three limb leads** (I, II, and III) forming Einthoven's triangle, along with augmented limb leads and precordial (chest) leads for more detailed evaluation. The electrical signals are amplified and plotted against time, producing characteristic waveforms.

Components of a Normal ECG

A normal ECG tracing consists of recurring deflections corresponding to specific electrical events in the cardiac cycle:

- **P Wave:**
Represents atrial depolarization. It occurs just before atrial contraction (atrial systole) and is usually small and rounded. The duration and shape of the P wave give clues about atrial size and conduction.
- **PR Interval:**
The time from the start of the P wave to the beginning of the QRS complex. It reflects the conduction time from the SA node through the AV node and into the ventricles. A prolonged PR interval may indicate AV block.
- **QRS Complex:**
A sharp, large deflection representing rapid ventricular depolarization. Because the ventricles have a large muscle mass, the QRS complex is more prominent than the P wave. Abnormalities in its width or shape can suggest conduction defects, hypertrophy, or myocardial damage.
- **ST Segment:**
The flat section between the end of the QRS complex and the beginning of the T wave. It corresponds to the time when the ventricles are fully depolarized and actively contracting. Elevation or depression of the ST segment is clinically significant, often indicating ischemia or myocardial infarction.
- **T Wave:**
A broad, smooth deflection representing ventricular repolarization. It occurs after ventricular systole. Abnormalities in T wave shape or polarity may signal electrolyte imbalances, ischemia, or other pathological conditions.



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- **QT Interval:**

Extends from the beginning of the QRS complex to the end of the T wave. It reflects the total time for ventricular depolarization and repolarization. Prolongation of the QT interval may predispose to arrhythmias.

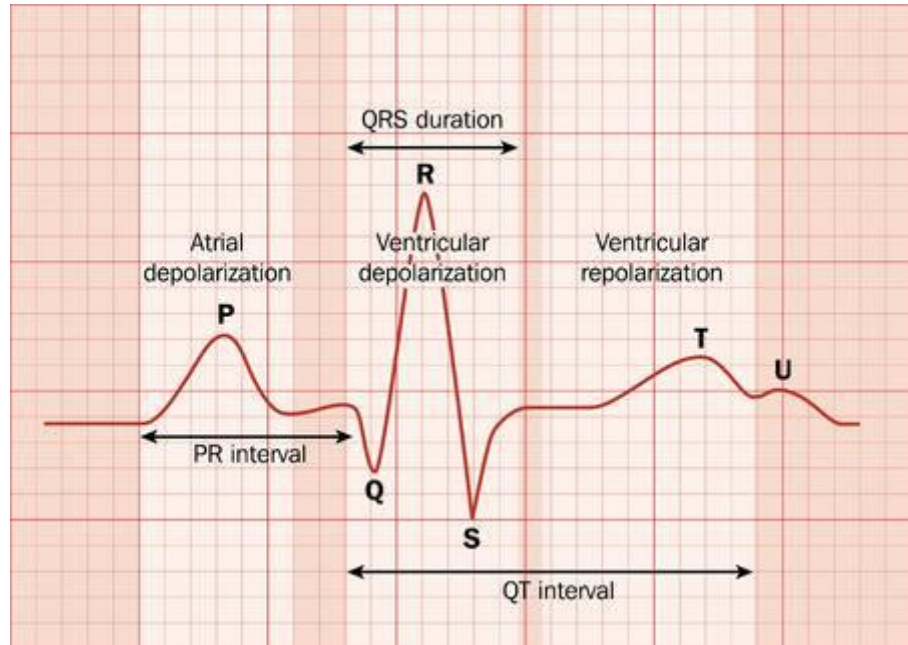


Fig4.4: ECG

Significance of ECG in Physiology

The ECG does not directly show mechanical contraction or blood flow, but it precisely reflects the **electrical events** that trigger those mechanical actions. By analyzing the pattern, amplitude, and duration of the waves and intervals, one can determine:

- The heart rate and rhythm (normal sinus rhythm, bradycardia, tachycardia, arrhythmias).
- The conduction pathways (identifying AV blocks, bundle branch blocks).
- Evidence of myocardial hypertrophy or damage.
- Effects of drugs, electrolyte disturbances, or systemic diseases on the heart.

Clinical and Experimental Use

In clinical practice, the ECG is a routine, non-invasive test to monitor cardiac health, diagnose disease, and evaluate treatment outcomes. In experimental physiology, it is used to study cardiac electrophysiology,

assess effects of various interventions, and understand comparative heart function in different vertebrates.



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Integration with Cardiac Physiology

The ECG serves as a bridge between the **electrical activity** and the **mechanical events** of the cardiac cycle. For example:

- The P wave precedes atrial contraction (seen in atrial systole).
- The QRS complex precedes ventricular contraction (ventricular systole).
- The T wave occurs during ventricular relaxation (early diastole).

By correlating these deflections with heart sounds and pressure changes, physiologists can construct a comprehensive understanding of how the heart functions in health and disease.

SUMMARY:

The **heart** is a muscular pumping organ that circulates blood throughout the body, supplying oxygen and nutrients while removing wastes. Its physiology is explained through the **cardiac cycle**, which includes systole (contraction) and diastole (relaxation) phases, ensuring unidirectional blood flow through atria and ventricles. The cycle is regulated by specialized tissues like the **sinoatrial (SA) node** (natural pacemaker) and atrioventricular (AV) node, which generate and transmit impulses. The heart's electrical activity is recorded in an **electrocardiogram (ECG)**, which shows characteristic waves: **P wave** (atrial depolarization), **QRS complex** (ventricular depolarization), and **T wave** (ventricular repolarization). Together, the heart, cardiac cycle, and ECG illustrate the coordination of electrical and mechanical events that sustain life.

A. Multiple Choice Questions:

1. The natural pacemaker of the heart is:
 - a) AV node
 - b) SA node
 - c) Purkinje fibers
 - d) Bundle of His**Answer:** b) SA node
2. The QRS complex in an ECG represents:
 - a) Atrial depolarization
 - b) Ventricular depolarization
 - c) Atrial repolarization



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d) Ventricular repolarization

Answer: b) Ventricular depolarization

3. During systole, the ventricles:

a) Relax and fill with blood

b) Contract and pump blood

c) Both atria contract

d) Valves remain open

Answer: b) Contract and pump blood

B.Short Answer Questions

1. Explain the phases of the cardiac cycle.
2. Describe the role of the SA node in regulating heartbeat.
3. What information can be obtained from an ECG?
4. How do systole and diastole contribute to circulation?



UNIT 4.3:

Blood Coagulation

4.3 Introduction

Blood coagulation, also referred to as clotting of blood, is a crucial defense mechanism of vertebrate physiology that prevents excessive bleeding when a blood vessel is injured. Under normal conditions, blood remains fluid inside the vascular system, circulating freely without clotting. However, when the vascular integrity is disrupted due to trauma, surgery, or pathological injury, the body immediately initiates a protective process that transforms liquid blood into a gel-like semisolid mass called a clot. This clot effectively seals the site of injury, stops further blood loss, and provides a scaffold for tissue repair.

The essence of coagulation is a series of biochemical reactions in which a set of plasma proteins, known as clotting factors, are sequentially activated—usually by proteolytic cleavage—resulting in the formation of insoluble fibrin strands. These strands entangle blood cells and platelets, producing a stable clot. Importantly, this process is tightly regulated so that clot formation is localized only to the damaged area and does not occlude normal blood flow elsewhere in the circulatory system.

4.3.1 Factors Involved in Blood Coagulation

Coagulation is orchestrated by a group of plasma proteins called **coagulation factors**. Most of these factors are synthesized in the liver and circulate in an inactive form (zymogens) until they are activated in response to vascular injury. They are traditionally numbered in Roman numerals (I to XIII) in the order of their discovery, not their sequence in the reaction cascade. Several cofactors, ions, and cellular surfaces are also essential. The principal factors are:

- **Factor I – Fibrinogen:** A soluble plasma glycoprotein converted to fibrin by thrombin.
- **Factor II – Prothrombin:** A vitamin K–dependent plasma protein, activated to thrombin by prothrombinase.
- **Factor III – Tissue Factor (Thromboplastin):** A membrane protein released by damaged tissues; initiates the extrinsic pathway.
- **Factor IV – Calcium Ions (Ca^{2+}):** Essential cofactor in multiple steps of both intrinsic and extrinsic pathways.
- **Factor V – Labile Factor:** Cofactor that accelerates prothrombinase activity.



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- **Factor VII – Stable Factor:** Vitamin K–dependent, activated in the presence of tissue factor and Ca^{2+} .
- **Factor VIII – Anti-hemophilic Factor A:** Cofactor for Factor IX; its deficiency causes hemophilia A.
- **Factor IX – Christmas Factor or Anti-hemophilic Factor B:** Vitamin K–dependent; deficiency leads to hemophilia B.
- **Factor X – Stuart–Prower Factor:** Common pathway protease that converts prothrombin to thrombin.
- **Factor XI – Plasma Thromboplastin Antecedent:** Part of the intrinsic pathway.
- **Factor XII – Hageman Factor:** Activated upon contact with negatively charged surfaces; initiates intrinsic pathway.
- **Factor XIII – Fibrin Stabilizing Factor:** Cross-links fibrin strands to form a stable clot.

Additional elements include **platelet phospholipids**, **von Willebrand factor (vWF)** which aids platelet adhesion and stabilizes factor VIII, and **cofactors like protein C, protein S, and antithrombin III** that regulate and limit clot formation. Vitamin K is indispensable for the hepatic synthesis of several factors (II, VII, IX, X) in their functional, carboxylated form.

Physiology and Mechanism of Coagulation

The physiology of blood coagulation involves a sequence of well-coordinated steps collectively termed **hemostasis**, which is classically divided into three overlapping phases: vascular constriction, formation of a temporary platelet plug, and activation of the coagulation cascade leading to fibrin clot formation.

1. Vascular Phase (Vasoconstriction):

Immediately after injury, the smooth muscle in the vessel wall contracts (vasospasm), which reduces local blood flow and limits blood loss. This response is transient but provides time for the subsequent steps of coagulation to occur.

2. Platelet Phase (Primary Hemostasis):

Platelets, small cytoplasmic fragments in the blood, play a crucial role. On exposure to subendothelial collagen and tissue factor, they adhere via von Willebrand factor and become activated. Activated platelets change shape, release ADP, serotonin, and thromboxane A_2 , which recruit and activate additional platelets. These aggregate to form a soft, temporary platelet plug at the site of injury.



3. Coagulation Phase (Secondary Hemostasis):

The platelet plug is mechanically weak and is stabilized by the deposition of a fibrin mesh. This is achieved through the **coagulation cascade**, a series of enzymatic reactions in which inactive zymogens are converted into active enzymes.

The Coagulation Cascade

The cascade operates through two initial pathways that converge into a common final pathway:

a. Intrinsic Pathway:

This pathway is triggered when blood comes into contact with a negatively charged surface (such as exposed collagen or glass in vitro). It involves sequential activation of factors XII, XI, IX, and VIII. Activated factor IX, along with its cofactor VIII and calcium ions, activates factor X.

b. Extrinsic Pathway:

This is initiated by tissue damage that exposes tissue factor (factor III). Tissue factor forms a complex with activated factor VII in the presence of calcium to directly activate factor X.

c. Common Pathway:

Activated factor X (Xa) combines with factor V, calcium, and phospholipid surfaces to form the **prothrombinase complex**, which converts prothrombin (factor II) into active thrombin. Thrombin, in turn, is a key effector enzyme:

- It converts fibrinogen (factor I) into insoluble fibrin monomers.
- It activates factor XIII, which cross-links fibrin strands into a stable mesh.
- It provides positive feedback by further activating factors V, VIII, and XI, amplifying its own production.

As a result, a dense fibrin network forms around the platelet plug, trapping red and white blood cells, thus forming a stable clot. This clot effectively seals the injury, restoring the barrier function of the vessel.

Regulation and Fibrinolysis

Blood coagulation is tightly regulated to ensure that clotting occurs only where needed. **Antithrombin III** neutralizes excessive thrombin and other activated factors, while the **protein C–protein S system** inactivates factors Va and VIIIa. Once vessel healing occurs, **fibrinolysis** dissolves the clot: plasminogen embedded in the clot is converted to plasmin by



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tissue plasminogen activator (tPA), and plasmin digests fibrin into soluble fragments, restoring normal blood flow.

The process of coagulation occurs through a **cascade of enzymatic activations**, traditionally divided into **intrinsic** and **extrinsic** pathways, both of which converge into a **common pathway** leading to the formation of fibrin.

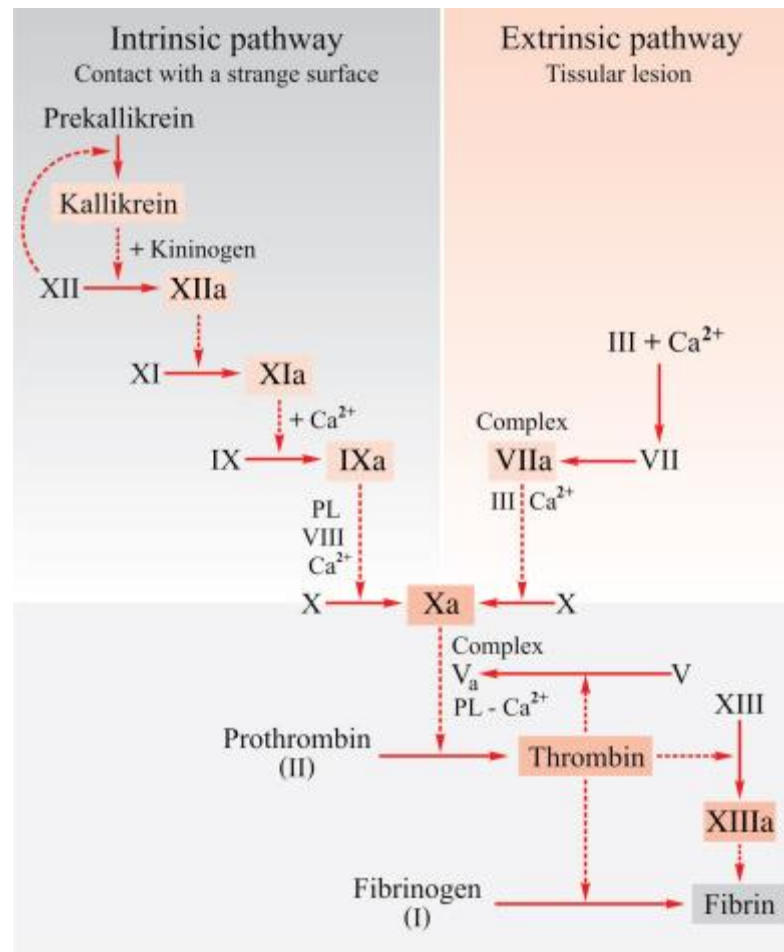


Fig 4.5: Blood coagulation

Intrinsic Pathway

The **intrinsic pathway** is so called because all the factors required for its activation are present within the blood itself. It is triggered by the contact of blood with negatively charged surfaces, such as exposed subendothelial collagen, basement membrane components, or even glass in experimental conditions.

1. When Factor XII (Hageman factor) encounters such surfaces, it becomes activated to Factor XIIa.
2. Factor XIIa activates Factor XI to XIa.



3. Factor XIa, in the presence of calcium ions, activates Factor IX to IXa.
4. Activated Factor IX, together with its cofactor Factor VIIIa (derived from Factor VIII activated by thrombin), calcium ions, and platelet phospholipids, forms the intrinsic tenase complex.
5. This complex efficiently converts Factor X to Factor Xa.

The intrinsic pathway is slower compared to the extrinsic pathway but plays a crucial role in amplifying clot formation and sustaining it.

Extrinsic Pathway

The **extrinsic pathway** is initiated by factors outside the blood, primarily when tissues are damaged. It is rapid and provides an immediate response to vascular injury.

1. Damaged tissues expose and release **Tissue Factor (Factor III)**.
2. Tissue Factor forms a complex with Factor VII in the presence of calcium, converting Factor VII to its active form, Factor VIIa.
3. The Tissue Factor–Factor VIIa complex then directly activates Factor X to Factor Xa.

Because tissue factor is abundant at sites of injury, the extrinsic pathway is the major initiator of coagulation in vivo, quickly generating a small amount of thrombin that then feeds into and accelerates the intrinsic pathway.

SUMMARY:

Blood coagulation, or clotting, is a vital hemostatic process that prevents excessive blood loss following vascular injury. It involves a cascade of enzymatic reactions where inactive plasma proteins (clotting factors) are sequentially activated. The process occurs in three major stages: **(1) Formation of prothrombin activator** via the intrinsic (within blood) and extrinsic (tissue injury) pathways, **(2) Conversion of prothrombin to thrombin** in the presence of calcium ions, and **(3) Conversion of soluble fibrinogen into insoluble fibrin strands** by thrombin, which stabilize the clot. Platelets, vascular endothelium, and plasma factors work in concert to regulate coagulation, while anticoagulants like heparin and plasmin ensure the clotting process remains localized and prevent intravascular thrombosis. The balance between clot formation and fibrinolysis maintains circulatory integrity.



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A. Multiple Choice Questions

1. Which ion is essential for blood coagulation?
 - a) Sodium
 - b) Potassium
 - c) Calcium
 - d) Magnesium

Answer: c) Calcium

2. The extrinsic pathway of coagulation is initiated by:
 - a) Platelet aggregation
 - b) Tissue factor (thromboplastin) release
 - c) Activation of Hageman's factor
 - d) Fibrinogen breakdown

Answer: b) Tissue factor (thromboplastin) release

3. Which enzyme converts fibrinogen into fibrin during coagulation?
 - a) Plasmin
 - b) Prothrombin
 - c) Thrombin
 - d) Fibrinase

Answer: c) Thrombin

B.Short Answer Questions

1. Describe the intrinsic and extrinsic pathways of blood coagulation and explain how they converge.
2. Discuss the role of thrombin in blood coagulation and fibrinolysis.
3. Write a note on natural anticoagulants and their significance in maintaining blood fluidity.



UNIT 4.4:

Respiration - Mechanism and Control of Breathing

4.4 Introduction

Respiration: This is one of the most basic physiological functions observed in living beings as they exchange gases with their surrounding environment. Such movement is part of a complex interplay that describes not just the mechanics of breathing but also the biochemical exchanges that take place at both cellular and tissue levels. Ventilatory systems, found in vertebrates, have evolved some impressive adaptations to gas exchange across evolution and environment; water versus land, in fact: in stunning natural ingenuity. This review focuses on how we breathe, how we regulate our respiratory pattern, and how vertebrate evolution has shaped our respiratory system through shared or derived innovations.

4.4.1 The Breathing Mechanism

Pulmonary ventilation, or the process of breathing, involves two main phases: inspiration (inhalation) and expiration (exhalation). This pumping action is characterized by rhythmic contraction and relaxation, moving air into the lungs and out again; this is where gas exchange takes place via the respiratory surfaces. The mechanics behind these processes are contingent on the physical principles driving respiration.

Inspiration

During this process, the elasticity of the lungs forces important role. The lungs are inherently elastic and collapse inward, away from the thoracic wall. They are however apposed with one another in close proximity to the thoracic wall, by the cohesive force between the visceral and parietal pleura which are separated by a small layer of pleural fluid. This setup produces a small negative pressure (intrapleural pressure) that keeps the lungs from collapsing during normal respiration. During inspiration, the elastic recoil of the lungs serves to store potential energy that comes to play during expiration.

Expiration

When you are expiring forcibly (e.g., when exercising or during voluntary deep inspiration), it is also a muscular contraction that increases this movement. The internal intercostal muscles pull the ribs down and in more strongly. At the same time, the muscles in the abdomen (including



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the rectus abdominis, external and internal obliques and transversus abdominis) contract, raising intra-abdominal pressure. This increased pressure forces the diaphragm further up and into the thoracic cavity, decreasing thoracic volume more sharply and forcing more air out.

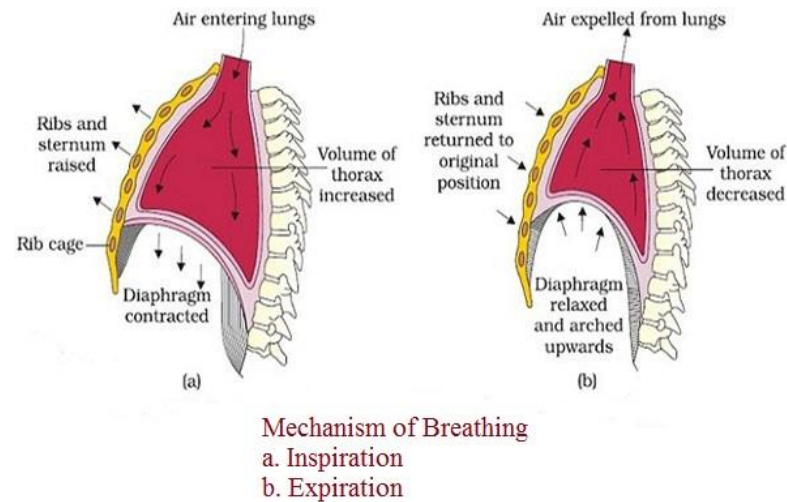


Fig 4.6: Mechanism of breathing

Lung Ventilation and Respiratory Volumes

Several lung volumes and capacities are measured by spirometry to quantify complex definitions of ventilation. These help us understand respiratory function and diagnose respiratory disorders. The ventilation rate, commonly expressed as minute ventilation, is defined as the total amount of air that enters and exits the lungs per unit of time. It is determined by the tidal volume times the respiratory rate (frame per minute). At rest, with a tidal volume of 500 mL and a respiratory rate of 12 breaths per min, minute ventilation is about 6,000 mL/min. During exercise, this value is unchanged but both the tidal volume and the respiratory rate increase to increase the compliance of the body for the respiratory and cardiovascular systems to meet the demands increases of active tissues.

Principles of Gas Exchange

The transfer of gases across the respiratory membrane occurs according to Fick's law of diffusion; the diffusion of a gas is directly proportional to the concentration gradient, the surface area available for diffusion, and the gas's diffusion coefficient, and inversely proportional to the membrane thickness. The system has evolved over the years to take care of these factors. There are around 300 million alveoli in the lungs, they have a surface area of 50–100 m² for gas exchange. The diffusion distance being minimized by a thinner respiratory membrane and the ability of respiratory gases to dissolve in the membrane components allow for their passage.

Oxygen Transport

After entering the blood, oxygen is carried on the whole primarily attached to hemoglobin, within red blood cells, with a little free in plasma. A molecule of hemoglobin can carry as many as four molecules of oxygen, resulting in oxyhemoglobin. The relationship between PO_2 and hemoglobin oxygen saturation is described by the oxygen-hemoglobin dissociation curve, which shows a characteristic sigmoidal shape because of the cooperative binding behavior of hemoglobin. This S-shape has tremendous physiologic importance. In the pulmonary capillaries, PO_2 is high, and small increases in PO_2 cause a large increase in oxygen saturation, facilitating effective oxygen loading. In contrast, at lower PO_2 in peripheral tissues, small reductions in PO_2 promote the release of large quantities of O_2 from hemoglobin to match tissue demand. At normal arterial PO_2 (approximately 100 mmHg), hemoglobin is about 97-98% saturated with oxygen. The oxygen-hemoglobin dissociation curve is affected by a number of variables. The curve shifts right with higher temperature, higher levels of carbon dioxide (the Bohr effect), lower pH, and higher concentrations of 2,3-diphosphoglycerate (2,3-DPG), promoting release of oxygen in metabolically active tissues. On the other hand, lower temperature, low carbon dioxide, high pH, and low 2,3-DPG shift the curve to the left, which increases binding of oxygen in the lungs or during hypothermia.

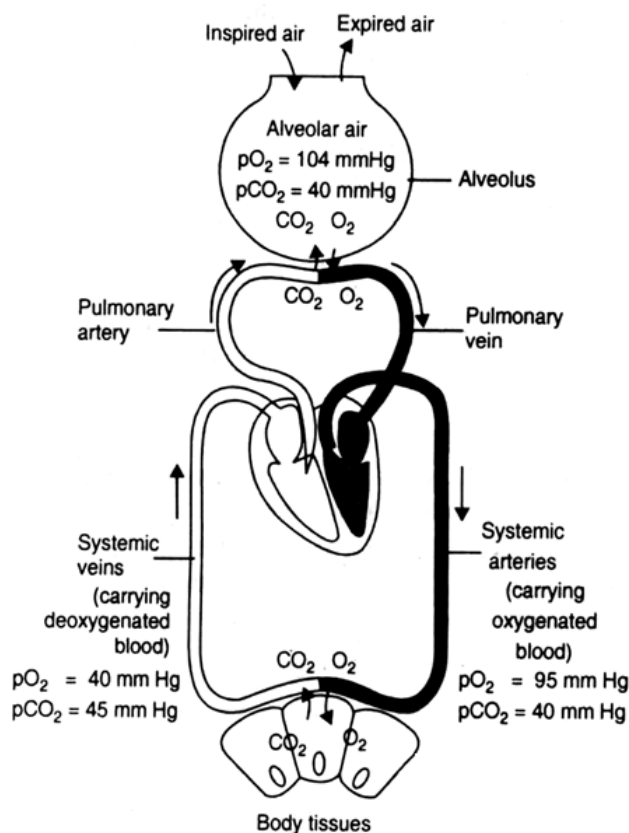


Fig 4.7: Circulation of blood



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Control of Breathing: Medulla Oblongata & Chemoreceptors

The stunning precision with which respiration modulates to metabolic demands, from restful gasping to strenuous panting, foreshadows the sophistication of its regulatory systems. In contrast to the heart that can self-generate a basal rhythm through its intrinsic pacemaker activity, the respiratory muscles need to be innervated continuously in order to contract. In addition to a variety of feedback systems to optimize ventilation for metabolic needs during different physiological states, the central control coordinates this as a whole.

Central Control of Breathing

These neural networks generate the fundamental respiratory rhythm composed of alternating periodic inspiratory and expiratory phases. In the case of quiet breathing, the inspiratory neurons have a discharge pattern that ramps up gradually (inspiratory ramp) in order to drive the inspiratory musculature. This activity abruptly ends at the point of inspiration and passive expiration then ensues. At this stage the precise mechanisms that create this rhythm involve complex interactions including intrinsically rhythmic neurons, reciprocal inhibition and multiple neurotransmitter systems.

Chemical Control of Breathing

The basic rhythm of respiration is generated in the brainstem; however, arterial blood gases and pH are constantly monitored by chemoreceptors, with feedback ensuring respiratory patterns accommodate for metabolic need. Based on their site of action, these chemoreceptors are classified as central and peripheral. Neurons in this area, the central chemoreceptors, are sensitive to the concentration of hydrogen ions in the CSF and the brain extracellular fluid as it bathes the central chemoreceptors located just deep on the ventral surface of the medulla oblongata. In fact, these receptors primarily respond to changes in hydrogen ion concentration and react to carbon dioxide indirectly, since carbon dioxide easily diffuses across the blood-brain barrier and reacts with water to form carbonic acid, which dissociates to yield hydrogen and bicarbonate ions. Thus, increased blood carbon dioxide level (hypercapnia) amplifies hydrogen ions concentration in brain extracellular fluid, which excites central chemoreceptors and enhances ventilation.

Different chemoreceptor systems are sensitive to different stimuli. Under normal physiological conditions, carbon dioxide is the main driver of ventilation. Each 1 mmHg rise in arterial PCO_2 normally stimulates 2–3 L/min of ventilation. This high sensitivity allows for tight regulation of arterial PCO_2 and blood pH, with a corresponding increase in ventilation (except when hypoventilation, a consequence of the WOB definition is involved). Unlike O_2 , arterial PO_2 must fall below roughly 60 mmHg before the peripheral chemoreceptors signal a major change in



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ventilation. At this level of PO_2 and above, the oxygen-hemoglobin dissociation curve allows for an adequate hemoglobin saturation with oxygen, despite minor alterations in the PO_2 . This preferential sensitivity reflects the different physiological consequences of carbon dioxide accumulation and oxygen deficit. High carbon dioxide effects are immediate because they drastically change blood pH, disrupting many biochemical pathways, while the same cells can withstand even moderate oxygen decrements for a limited time without direct cellular injury. However, in severe hypoxemia the ventilatory response to low oxygen increases greatly, which is critical for coping with critical oxygen deficiency.

SUMMARY:

Respiration is the biological process through which oxygen is taken into the body and carbon dioxide is expelled, ensuring energy production at the cellular level. It involves two main phases: **external respiration** (exchange of gases between alveoli and blood) and **internal respiration** (exchange between blood and tissues). The **mechanism of breathing** consists of inspiration and expiration, regulated by changes in thoracic volume and pressure. During **inspiration**, contraction of the diaphragm and external intercostal muscles expands the thoracic cavity, reducing intrapulmonary pressure and allowing air to flow in. During **expiration**, these muscles relax, the thoracic cavity decreases in volume, intrapulmonary pressure rises, and air is expelled. Forced breathing additionally involves accessory muscles (sternocleidomastoid, abdominal muscles). Breathing is regulated by the respiratory centers in the medulla and pons, sensitive to CO_2 concentration and blood pH, ensuring homeostasis.

A. Multiple Choice Questions

1. Which structure is the primary muscle of inspiration?
 - a) External oblique
 - b) Diaphragm
 - c) Sternocleidomastoid
 - d) Internal intercostal**Answer:** b) Diaphragm
2. Expiration under normal resting conditions is:
 - a) Active process
 - b) Passive process
 - c) Involuntary only
 - d) Always active**Answer:** b) Passive process
3. Respiratory rhythm is primarily controlled by:
 - a) Hypothalamus



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- b) Cerebral cortex
 - c) Medullary respiratory center
 - d) Cerebellum
- Answer:** c) Medullary respiratory center

B.Short Answer Questions

1. Explain the mechanism of inspiration and expiration with reference to thoracic pressure changes.
2. Discuss the role of respiratory centers in regulation of breathing.
3. Differentiate between external respiration, internal respiration, and cellular respiration.

SUMMARY:

Digestion is the process by which complex food substances are broken down into simpler absorbable forms through mechanical and chemical means. It begins in the mouth with the action of saliva, continues in the stomach with gastric juices digesting proteins, and is completed in the small intestine where bile and pancreatic enzymes help in breaking down carbohydrates, proteins, and fats into glucose, amino acids, and fatty acids respectively. The absorbed nutrients enter the bloodstream, while water is reabsorbed in the large intestine. The heart, a four-chambered muscular organ, maintains circulation by pumping oxygenated and deoxygenated blood through pulmonary and systemic circuits. Its rhythmic contractions, regulated by the sinoatrial node (the natural pacemaker), ensure continuous blood flow throughout the body. The cardiac cycle includes phases of contraction (systole) and relaxation (diastole), crucial for maintaining pressure and flow. Respiration, on the other hand, involves the exchange of gases—oxygen and carbon dioxide—primarily in the lungs. The mechanism of breathing includes inhalation (intake of air by diaphragm contraction and rib expansion) and exhalation (release of air by relaxation). Gas exchange occurs in the alveoli where oxygen diffuses into the blood and carbon dioxide is expelled, while cellular respiration in body cells converts glucose into energy (ATP), enabling all physiological functions.

A.Multiple Choice Questions (MCQs):

1. **The central nervous system (CNS) is composed of:**
 - a) Brain and spinal cord
 - b) Nerves and ganglia



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- c) Sensory and motor pathways
 - d) Cranial and spinal nerves
2. **Which part of the brain controls coordination and balance?**
- a) Cerebrum
 - b) Cerebellum
 - c) Medulla oblongata
 - d) Thalamus
3. **Cerebrospinal fluid (CSF) is primarily located in:**
- a) The brain ventricles and spinal canal
 - b) Bones and muscles
 - c) Lungs and heart
 - d) Liver and kidneys
4. **The reflex arc is responsible for:**
- a) Voluntary body movements
 - b) Conscious decision-making
 - c) Involuntary responses to stimuli
 - d) Growth regulation
5. **Which of the following is classified as an endocrine gland?**
- a) Sweat gland
 - b) Salivary gland
 - c) Adrenal gland
 - d) Sebaceous gland
6. **The pituitary gland is known as the "master gland" because it:**
- a) Produces digestive enzymes
 - b) Controls the nervous system
 - c) Regulates other endocrine glands
 - d) Pumps blood throughout the body
7. **Which hormone is primarily responsible for regulating metabolism?**
- a) Insulin
 - b) Thyroxine
 - c) Oxytocin
 - d) Progesterone
8. **In most vertebrates, the male gonads function to produce:**
- a) Ova
 - b) Sperm
 - c) Hormones only
 - d) Placenta
9. **The primary role of genital ducts is to:**
- a) Absorb nutrients
 - b) Excrete waste



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- c) Transport gametes
- d) Produce hormones

10. External fertilization is most commonly observed in:

- a) Mammals
- b) Amphibians and fish
- c) Reptiles and birds
- d) Insects

Answer Key:

1. **a) Brain and spinal cord**
2. **b) Cerebellum**
3. **a) The brain ventricles and spinal canal**
4. **c) Involuntary responses to stimuli**
5. **c) Adrenal gland**
6. **c) Regulates other endocrine glands**
7. **b) Thyroxine**
8. **b) Sperm**
9. **c) Transport gametes**
10. **b) Amphibians and fish**

B.Short Answer Questions:

1. What are the main functions of digestion in vertebrates?
2. Define the role of enzymes in digestion and absorption.
3. How is the cardiac cycle regulated in the human heart?
4. What are the major components of an ECG waveform?
5. Describe the difference between intrinsic and extrinsic coagulation pathways.
6. How do platelets help in wound healing?
7. What is the role of chemoreceptors in respiration?
8. How does the autonomic nervous system regulate heart rate?
9. Compare the mechanisms of gas exchange in fish and amphibians.
10. Explain how breathing is controlled by the nervous system.

C.Long Answer Questions:



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1. Describe the digestive process from ingestion to absorption, highlighting key enzymes and organs.
2. Compare the digestive adaptations of herbivores, carnivores, and omnivores.
3. Explain the structure and function of the vertebrate heart, including its conduction system.
4. Discuss the phases of the cardiac cycle and their physiological importance.
5. Explain the electrical activity of the heart, including the interpretation of an ECG.
6. Describe the coagulation cascade, including the role of platelets and clotting factors.
7. Compare respiratory adaptations in aquatic and terrestrial vertebrates.
8. Explain the mechanism of breathing, including the roles of inspiration and expiration.
9. Describe the transport of oxygen and carbon dioxide in the blood.
10. How does comparative physiology of circulation and respiration differ across vertebrate groups?

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MODULE 5

EXCRETION, MUSCLE CONTRACTION, NERVE IMPULSE, AND SENSORY SYSTEMS

Objectives:

- Understand the physiology of excretion and the role of the kidney in osmoregulation.
- Learn about muscle contraction mechanisms and neuromuscular function.
- Explore the physiology of nerve impulse transmission and synaptic signaling.
- Study the structure and function of the eye and ear in vertebrates.
- Compare vertebrate adaptations in excretion, muscle function, nerve conduction, and sensory systems.

UNIT 5.1:

Excretion - Physiology of Excretion, Osmoregulation

5.1 Structure of the Kidney

In vertebrates, the kidneys are the chief excretory organs, typically a pair of reddish-brown, bean-shaped structures located in the dorsal part of the abdominal cavity, one on each side of the vertebral column. They are retroperitoneal, meaning they lie behind the peritoneum, and are richly supplied with blood vessels to perform their regulatory and excretory functions.

Each kidney is covered by a tough fibrous capsule and is organized into two main regions: the **outer cortex** and the **inner medulla**. The cortex appears granular because of the presence of numerous renal corpuscles and convoluted tubules, whereas the medulla appears striated due to the presence of straight tubules and collecting ducts. The medulla is further arranged into conical structures known as **renal pyramids**, whose apices (renal papillae) project into minor calyces that drain urine into major calyces and then into the **renal pelvis**, a funnel-shaped chamber that narrows to form the **ureter**. The ureters carry urine to the urinary bladder, where it is stored until expelled through the urethra.

The functional unit of the kidney is the **nephron**, and each human kidney contains about one million nephrons. A nephron consists of two major parts:

Renal Corpuscle:

This lies in the cortex and comprises **Bowman's capsule** (a cup-shaped

epithelial structure) enclosing a tuft of capillaries known as the **glomerulus**. The glomerulus receives blood via an **afferent arteriole** and drains through an **efferent arteriole**, maintaining high hydrostatic pressure within the capillary bed to favor filtration.

Renal Tubule:

This arises from Bowman's capsule and extends into the medulla before returning to the cortex, forming several specialized regions:

- **Proximal Convoluted Tubule (PCT)** – highly coiled, located in the cortex, with cells rich in mitochondria and microvilli to facilitate active reabsorption.
- **Loop of Henle** – descends into the medulla (descending limb) and then ascends back (ascending limb); plays a critical role in creating an osmotic gradient.
- **Distal Convoluted Tubule (DCT)** – again in the cortex; involved in selective secretion and reabsorption under hormonal control.
- **Collecting Duct** – several nephrons empty into a single collecting duct, which traverses the medulla and opens at the renal papilla into the minor calyx.

The close association of nephrons with blood vessels forms a highly efficient filtration and reabsorption system. The efferent arterioles form a network of **peritubular capillaries** and, in nephrons with long loops of Henle, specialized **vasa recta**, which help maintain the medullary osmotic gradient.

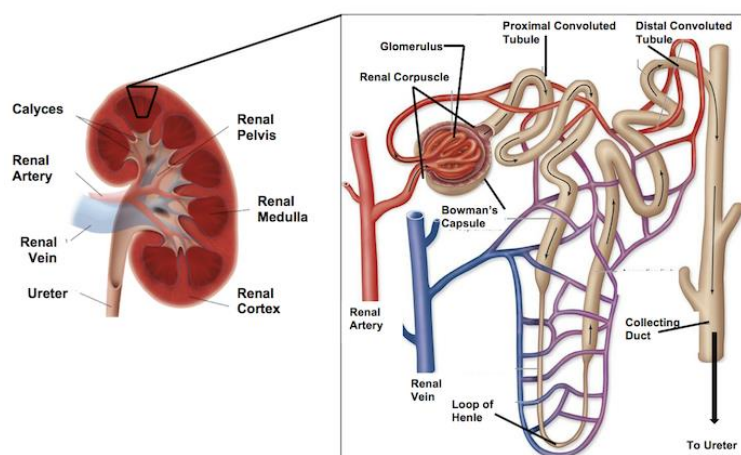


Fig5.1: Structure of kidney and nephron

5.1.1 Mechanism of Excretion

The process of urine formation in the kidney is a combination of three sequential mechanisms—**glomerular filtration**, **tubular reabsorption**,



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and **tubular secretion**—followed by the final step of **concentration and collection** before excretion.

1. Glomerular Filtration

Blood entering the glomerulus is under high pressure because the afferent arteriole is wider than the efferent arteriole. This hydrostatic pressure forces water and small solutes such as urea, glucose, amino acids, salts, and vitamins out of the blood and into Bowman's capsule. Large molecules like plasma proteins and blood cells are retained. The resulting fluid in Bowman's capsule is called the **glomerular filtrate**, which is essentially plasma devoid of proteins. This ultrafiltration is non-selective and forms about 170–180 liters of filtrate per day in humans.

2. Tubular Reabsorption

As the filtrate passes through the renal tubule, essential substances are reabsorbed back into the bloodstream.

- In the **proximal convoluted tubule**, most glucose, amino acids, vitamins, and about 65% of water and sodium are actively or passively reabsorbed. This segment has a brush border epithelium to maximize reabsorptive capacity.
- In the **loop of Henle**, the descending limb is permeable to water but not salts, allowing water to leave into the hyperosmotic medulla. The ascending limb is impermeable to water but actively transports Na^+ , K^+ , and Cl^- out into the interstitium, contributing to the medullary concentration gradient.
- In the **distal convoluted tubule** and **collecting duct**, reabsorption is under hormonal control. **Antidiuretic hormone (ADH)** increases water permeability, allowing additional water reabsorption, while **aldosterone** increases sodium reabsorption in exchange for potassium secretion.

3. Tubular Secretion

Certain substances are actively secreted from the peritubular capillaries into the tubular fluid to maintain homeostasis and remove additional wastes. These include hydrogen ions (important for acid–base balance), potassium ions, ammonia, creatinine, and some drugs. Secretion occurs mainly in the distal convoluted tubule and, to a lesser extent, in the proximal tubule.

4. Concentration of Urine and Excretion

The combined processes create a final urine that is hyperosmotic or hypoosmotic depending on the body's needs. The medullary osmotic gradient established by the loop of Henle and maintained by the **vasa recta** allows for fine regulation of water conservation. When ADH levels are high, the collecting ducts become permeable to water, resulting in

concentrated urine. When ADH is low, the ducts remain relatively impermeable, and dilute urine is excreted.

The final urine, containing urea, uric acid, excess salts, and water, flows from the collecting ducts to the minor and major calyces, then to the renal pelvis, and is carried by the ureters to the urinary bladder for storage. Periodically, the bladder empties through the urethra in the process known as **micturition**, which is a reflex action controlled by both voluntary and involuntary neural pathways.

Excretion is a fundamental physiological process through which an organism removes nitrogenous waste products and other metabolic by-products from its body to maintain the internal chemical equilibrium. In vertebrates, continuous metabolic activity results in the production of compounds that, if accumulated, would become toxic. Chief among these are nitrogenous wastes such as ammonia, urea, and uric acid, which are formed primarily by the catabolism of proteins and nucleic acids. Besides nitrogenous wastes, salts, excess water, pigments, and certain hormones also need to be eliminated. The physiological mechanisms that carry out this elimination while maintaining water and electrolyte balance constitute the excretory system.

In vertebrates, excretion is closely integrated with **osmoregulation**—the regulation of water and ionic composition of the internal milieu. Different vertebrate groups have evolved specific excretory strategies depending on their habitat and evolutionary history. Aquatic vertebrates, for instance, often excrete highly soluble ammonia directly, as water is abundant and its dilution poses no problem. Terrestrial vertebrates have evolved mechanisms to convert ammonia into less toxic forms such as urea or uric acid, thus conserving water while still eliminating nitrogenous wastes efficiently.

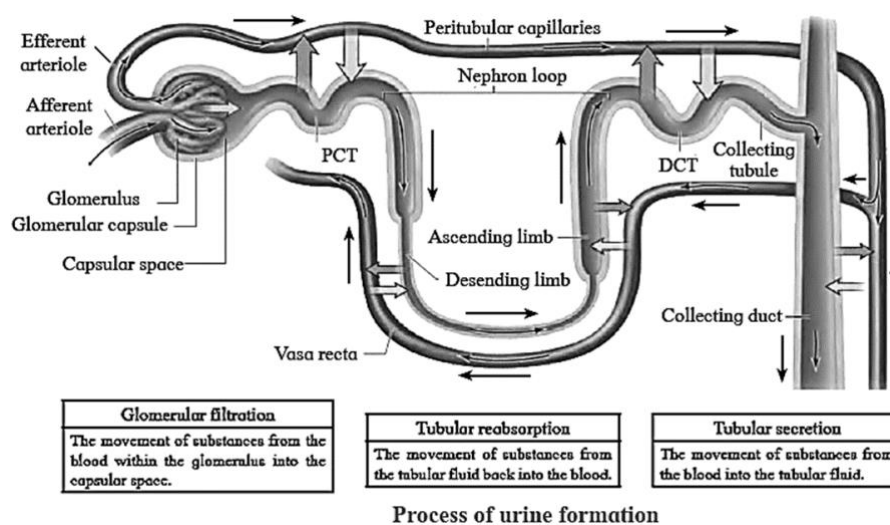


Fig 5.2 process of urine formation



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Organs and Mechanisms of Excretion

The principal organs of excretion in vertebrates are the **kidneys**, paired structures derived from mesodermal tissues of the embryo. They are responsible not only for the removal of waste products but also for the precise regulation of water balance, pH, and the concentrations of various ions such as sodium, potassium, chloride, and bicarbonate. The functional unit of the kidney is the **nephron**, a complex tubular structure specialized for filtration, selective reabsorption, and secretion.

Blood is delivered to each nephron through a tuft of capillaries known as the **glomerulus**, which is surrounded by Bowman's capsule. The glomerular walls are highly permeable to water and small solutes but impermeable to cells and large proteins, allowing the formation of an ultrafiltrate of plasma. This process is known as **glomerular filtration** and represents the first step in urine formation.

The filtrate then enters the **renal tubule**, which consists of the proximal convoluted tubule, the loop of Henle, the distal convoluted tubule, and the collecting duct. Along these segments, an intricate series of physiological processes occur:

- In the **proximal convoluted tubule**, a large fraction of water, glucose, amino acids, and essential ions are actively or passively reabsorbed into the peritubular capillaries. Simultaneously, certain substances such as hydrogen ions, ammonium, and drugs are secreted into the lumen to fine-tune acid-base balance and eliminate additional waste products.
- In vertebrates with a loop of Henle (notably mammals and birds), the **loop of Henle** establishes a countercurrent multiplier system. The descending limb is permeable to water but not solutes, allowing water to leave and concentrating the filtrate. The ascending limb actively transports salts out but is impermeable to water, creating an osmotic gradient in the medulla that is crucial for the production of concentrated urine.
- The **distal convoluted tubule** and **collecting duct** are sites of hormonal regulation. Under the influence of antidiuretic hormone (ADH), the walls of the collecting duct become more permeable to water, allowing additional reabsorption and producing hyperosmotic urine when water conservation is required. Aldosterone, secreted by the adrenal cortex, stimulates sodium reabsorption and potassium secretion, thus maintaining electrolyte balance.

Nitrogenous Waste Products and Adaptations

The form in which nitrogen is excreted varies among vertebrate groups and reflects both evolutionary lineage and habitat. **Ammonotelic**



organisms, such as most freshwater fishes and amphibian larvae, excrete ammonia directly into the surrounding water. **Ureotelic** animals, such as mammals and many adult amphibians, convert ammonia into urea in the liver through the ornithine–urea cycle; urea is far less toxic and highly soluble, allowing its excretion in a more concentrated form with less water loss. **Uricotelic** animals, including birds, reptiles, and many insects, excrete uric acid, a relatively insoluble compound that precipitates as a paste or solid with minimal water expenditure—an adaptation particularly advantageous in arid environments or for embryos developing in cleidoic eggs.

Integration with Other Systems

The physiology of excretion is tightly integrated with other body systems. The **circulatory system** delivers metabolic wastes to the kidneys and carries away reabsorbed substances. The **endocrine system** regulates kidney function through hormones such as ADH, aldosterone, and atrial natriuretic peptide, coordinating the excretory process with overall fluid and electrolyte homeostasis. The **nervous system** influences renal blood flow and can modulate the rate of filtration in response to stress or changes in blood pressure.

5.1.2 Osmoregulation

Osmoregulation is a vital physiological process by which animals maintain the osmotic pressure and ionic balance of their body fluids within narrow limits despite wide fluctuations in the osmotic conditions of the external environment. In vertebrates, the maintenance of water and electrolyte balance is essential for the proper functioning of cells, as even minor deviations in osmolality can lead to changes in cell volume, altered enzyme activity, and disruption of metabolic processes. Vertebrates inhabit a wide range of environments—from marine habitats with high salt concentrations, to freshwater systems with very low salt content, and terrestrial regions where water availability is often limited. Consequently, they have evolved diverse osmoregulatory mechanisms suited to their ecological niches.

In aquatic vertebrates, osmoregulation depends largely on the permeability of their integument and the osmotic gradient between their body fluids and the surrounding water. Freshwater teleost fishes live in an environment that is hypotonic to their body fluids. Water continuously enters their bodies by osmosis through the gill epithelium and skin, while salts tend to diffuse outward. To counteract this, freshwater fishes rarely drink water, produce large volumes of dilute urine, and actively uptake essential ions such as Na^+ and Cl^- through specialized chloride cells in their gills. By contrast, marine teleosts are surrounded by hypertonic seawater. They lose water by osmosis and tend to gain salts. To maintain osmotic balance, they drink seawater and excrete the excess salts through chloride cells in their gills, while producing only small quantities of concentrated urine to



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minimize water loss. Elasmobranchs like sharks and rays adopt a different strategy by retaining urea and trimethylamine oxide in their body fluids, making them slightly hyperosmotic to seawater, thus reducing water loss while excreting excess salts through the rectal gland.

Amphibians, which are tied to moist environments for part of their life cycle, show interesting adaptations. Their permeable skin facilitates cutaneous water exchange. In freshwater, they gain water osmotically and excrete dilute urine, while in drier habitats they can reduce cutaneous water loss by secreting mucus and by behavioral adjustments such as seeking shade or burrowing. Some amphibians can even reabsorb water stored in their urinary bladder to maintain hydration during periods of scarcity.

Reptiles, birds, and mammals, being primarily terrestrial, face the continuous challenge of water conservation in an environment that tends to dehydrate them. Reptiles possess relatively impermeable skin with scales that minimize water loss and produce uric acid as a nitrogenous waste, which is excreted as a paste with minimal water. Birds, too, excrete uric acid, which allows them to conserve water, and many species have specialized nasal salt glands to eliminate excess sodium chloride. Mammals, with their highly efficient kidneys containing loops of Henle, are able to produce concentrated urine, an adaptation critical for life in arid regions. The degree of urine concentration depends on the length and complexity of the loop of Henle, which creates a countercurrent multiplier system enabling water reabsorption from the collecting ducts. Desert mammals such as kangaroo rats rarely drink free water; they rely on metabolic water and the production of highly concentrated urine to survive.

At the cellular level, osmoregulation is orchestrated by various transport proteins and hormonal controls. Antidiuretic hormone (ADH or vasopressin) plays a central role in mammals and birds by increasing water reabsorption in the kidney's collecting ducts. Aldosterone regulates sodium reabsorption and potassium secretion, thus indirectly influencing water balance. In fishes, hormones like cortisol and prolactin modulate the activity of gill ionocytes, adjusting ion transport according to whether the animal is in freshwater or seawater.

Therefore, osmoregulation is not a single mechanism but a dynamic interplay of anatomical structures, physiological processes, and hormonal regulation tailored to the animal's environment. It ensures that the internal milieu remains constant, allowing enzymatic and metabolic processes to function optimally despite changes in the external world. This ability to maintain osmotic homeostasis is a hallmark of vertebrate physiology and one of the key factors enabling vertebrates to colonize a vast diversity of habitats across the planet.

Hormonal Control of Excretion and Osmoregulation



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Aldosterone, a mineralocorticoid produced by the adrenal cortex, primarily regulates sodium and potassium balance. Its secretion increases in response to elevated potassium levels, angiotensin II, and adrenocorticotrophic hormone (ACTH). Within principal cells of the distal tubule and collecting duct, aldosterone binds to mineralocorticoid receptors and promotes the expression and activity of epithelial sodium channels (ENaC) and sodium-potassium ATPase pumps. This results in enhanced sodium reabsorption and potassium secretion. The increased sodium reabsorption promotes water retention through osmotic forces, expanding extracellular fluid volume and contributing to blood pressure regulation. Aldosterone also stimulates hydrogen ion secretion in intercalated cells, contributing to acid-base balance maintenance. Calcitonin, secreted by parafollicular cells of the thyroid gland in response to elevated plasma calcium levels, exerts effects opposite to those of PTH. It inhibits bone resorption and enhances renal calcium excretion, helping lower plasma calcium levels. In the kidney, calcitonin reduces calcium and sodium reabsorption in the thick ascending limb of the loop of Henle and distal tubule, promoting calciuria. This hormone plays a particularly important role during periods of hypercalcemia, such as during pregnancy or lactation, when calcium metabolism undergoes significant alterations.

SUMMARY:

Excretion is the biological process by which organisms remove **nitrogenous wastes, excess salts, and metabolic byproducts** to maintain internal homeostasis. In vertebrates, the **kidneys** are the chief excretory organs, filtering blood through nephrons where processes of **ultrafiltration, reabsorption, and tubular secretion** occur to form urine. Nitrogenous wastes are excreted in different forms across species—**ammonia (ammonotelism), urea (ureotelism), or uric acid (uricotelism)**—depending on habitat and water availability. Human urine formation involves the glomerulus, proximal and distal tubules, loop of Henle, and collecting ducts, finely regulated by hormones like **ADH and aldosterone**. Besides kidneys, organs such as skin, lungs, and liver also assist in excretion.

A. Multiple Choice Questions:

1. The structural and functional unit of the kidney is:
 - a) Nephron
 - b) Glomerulus
 - c) Bowman's capsule
 - d) Collecting duct

Answer: a) Nephron



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2. Ureotelic animals excrete nitrogen mainly in the form of:
 - a) Ammonia
 - b) Uric acid
 - c) Urea
 - d) Creatinine

Answer: c) Urea

3. Which hormone increases water reabsorption in kidneys?
 - a) Aldosterone
 - b) Cortisol
 - c) ADH
 - d) Insulin

Answer: c) ADH

B.Short Answer Questions

1. Describe the process of urine formation in human kidneys.
2. Differentiate between ammonotelic, ureotelic, and uricotelic modes of excretion with examples.
3. Explain the role of ADH and aldosterone in regulating kidney function.

UNIT 5.2:

Physiology of Muscle Contraction



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5.2 Introduction

Muscle contraction represents one of the most fundamental physiological processes in vertebrate organisms, enabling movement, posture maintenance, and various internal functions from blood circulation to digestion. At its core, muscle contraction is a complex interplay of cellular, molecular, and electrical mechanisms that convert chemical energy into mechanical force. The ability of muscles to contract and generate force is essential for virtually all aspects of animal life, from basic mobility to complex behaviors like predation, reproduction, and adaptation to environmental challenges. This remarkable physiological system has evolved diverse specializations across different vertebrate groups while maintaining fundamental operational principles.

5.2.1 Types of Muscle: Structure and Contraction Mechanisms

Vertebrate organisms possess three distinct types of muscle tissue: skeletal, cardiac, and smooth muscle. Each type exhibits unique structural and functional characteristics that reflect their specialized physiological roles.

Skeletal Muscle Structure

Skeletal muscle, attached to bones via tendons, is responsible for voluntary movements and postural control. The hierarchical organization of skeletal muscle begins with individual muscle fibers, which are elongated, multinucleated cells formed during development through the fusion of myoblasts. Each muscle fiber contains numerous myofibrils arranged in parallel, giving skeletal muscle its characteristic striated appearance when viewed microscopically. These striations result from the highly ordered arrangement of contractile proteins within repeated functional units called sarcomeres. Beyond actin and myosin, skeletal muscle contains regulatory proteins crucial for contraction control. Tropomyosin, a rod-shaped protein that runs along the actin filament, works in concert with the troponin complex (comprising troponin T, troponin I, and troponin C) to regulate actin-myosin interaction in response to calcium signaling. Additionally, structural proteins like α -actinin, desmin, and dystrophin form a cytoskeletal network that maintains cellular architecture and transmits contractile forces to the extracellular matrix and ultimately to the skeletal system.

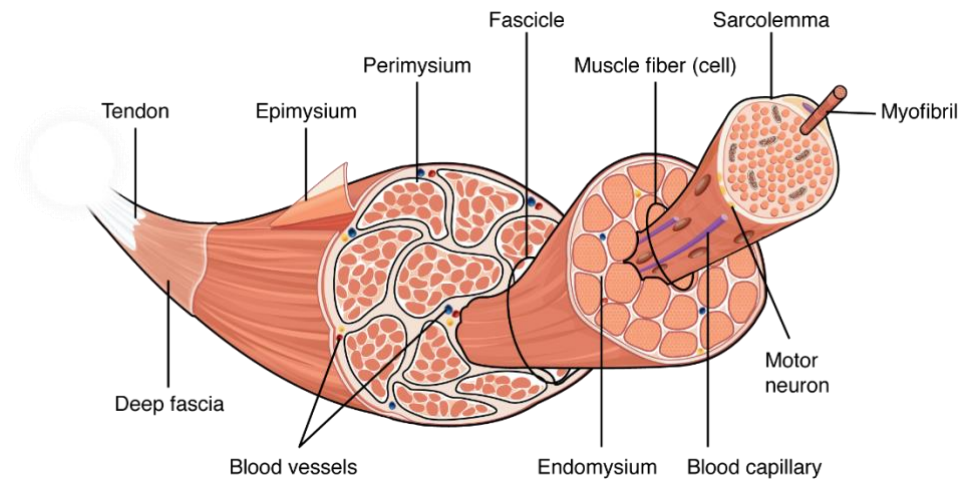


Fig5.3: Structure of skeletal Muscle

Skeletal Muscle Contraction Mechanism

The process of skeletal muscle contraction is elegantly explained by the sliding filament theory, which describes how thick and thin filaments slide past each other without changing their individual lengths, resulting in sarcomere shortening and macroscopic muscle contraction. This molecular dance begins with neural stimulation and calcium release, and proceeds through a series of precisely coordinated steps governed by ATP-dependent mechanisms. Initiation of skeletal muscle contraction occurs when motor neurons release acetylcholine at the neuromuscular junction, generating an action potential that propagates along the sarcolemma (muscle cell membrane) and into the transverse tubules (T-tubules). These tubular invaginations of the sarcolemma extend deep into the muscle fiber, ensuring rapid transmission of electrical signals throughout the cell volume. When an action potential reaches the T-tubules, it activates voltage-gated dihydropyridine receptors (DHPRs), which mechanically couple with ryanodine receptors (RyRs) in the adjacent sarcoplasmic reticulum membrane. This coupling triggers calcium release from the sarcoplasmic reticulum into the sarcoplasm, dramatically increasing cytosolic calcium concentration.

The rate and force of skeletal muscle contraction depend on several factors, including the frequency of neural stimulation, the number of motor units recruited, and the fiber type composition of the muscle. Motor units, consisting of a motor neuron and all muscle fibers it innervates, are recruited according to the size principle—smaller motor units controlling slow-twitch fibers activate first, followed by progressively larger units controlling fast-twitch fibers as greater force is required. This recruitment pattern optimizes force production while minimizing fatigue. Relaxation of skeletal muscle occurs when neural stimulation ceases, leading to a series of events that reverse the contractile process. Without continued action potentials, calcium release from the sarcoplasmic reticulum stops, and active calcium transport systems (primarily the sarco/endoplasmic

reticulum Ca^{2+} -ATPase or SERCA) rapidly sequester calcium back into the sarcoplasmic reticulum. As cytosolic calcium levels decrease, calcium dissociates from troponin C, allowing tropomyosin to return to its blocking position on actin filaments. With myosin-binding sites once again covered, cross-bridge cycling ceases, and the muscle relaxes. Titin plays a crucial role during relaxation, providing elastic recoil that helps return sarcomeres to their resting length.

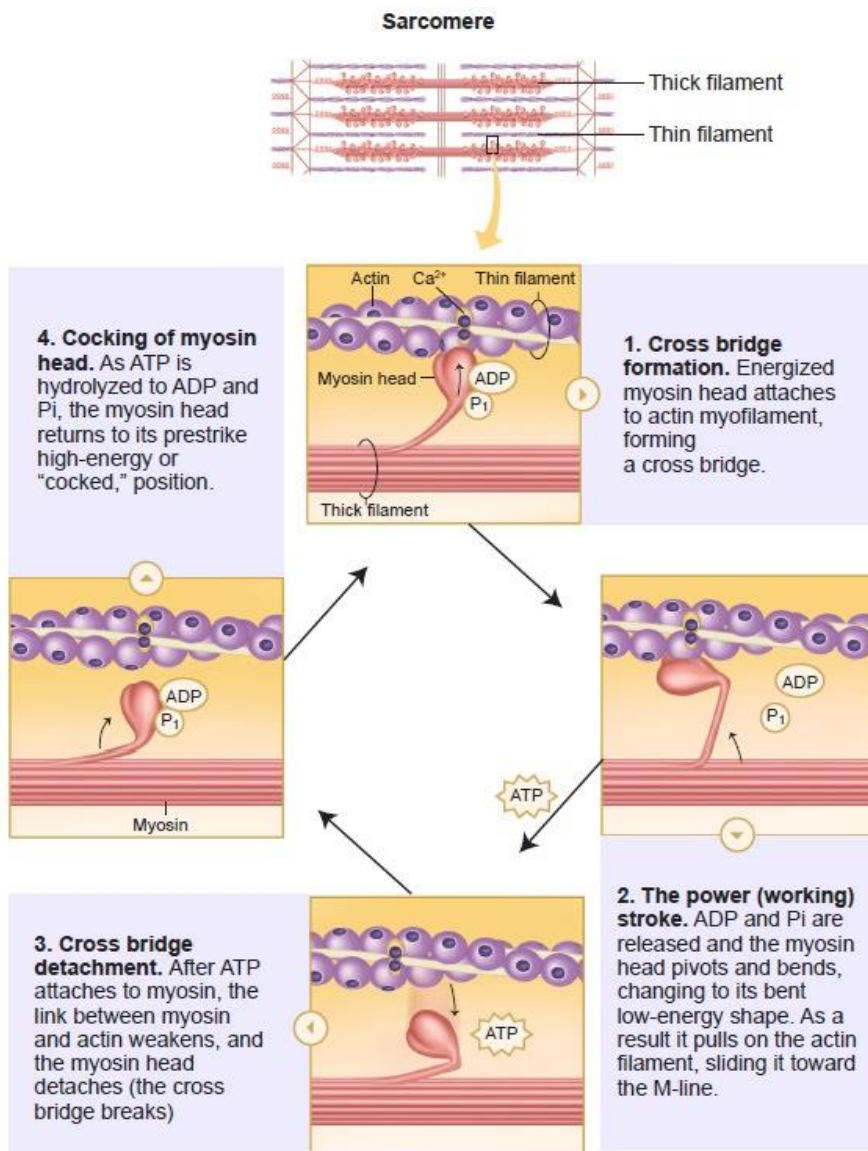


Fig 5.4: Cross Bridge Cycle

Cardiac Muscle Structure and Contraction

Cardiac muscle, found exclusively in the heart, shares many structural similarities with skeletal muscle but possesses unique adaptations for its specialized role in maintaining continuous, rhythmic contractions. Like skeletal muscle, cardiac muscle is striated due to the organized



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arrangement of sarcomeres, but cardiac muscle cells (cardiomyocytes) are typically smaller, branched, and contain only one or two centrally located nuclei rather than the multiple peripheral nuclei seen in skeletal muscle fibers. The contractile apparatus in cardiac muscle largely resembles that of skeletal muscle, with sarcomeres composed of interdigitating actin and myosin filaments. However, cardiac muscle possesses unique isoforms of contractile and regulatory proteins, including cardiac-specific myosin heavy chains, troponin I, and troponin T. Additionally, cardiac muscle contains more mitochondria than skeletal muscle, reflecting its high energy demands and reliance on aerobic metabolism. The sarcoplasmic reticulum in cardiac muscle is less extensive than in skeletal muscle, and cardiac myocytes contain numerous T-tubules to ensure efficient calcium signaling throughout the cell.

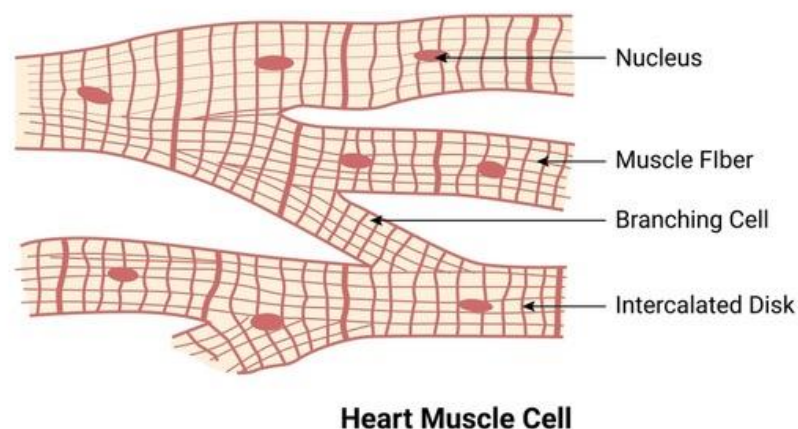


Fig 5.5: Heart Muscle Cell

Cardiac muscle contraction follows the same basic sliding filament mechanism as skeletal muscle but with important differences in initiation, regulation, and duration. Unlike skeletal muscle, which requires neural stimulation to contract, cardiac muscle exhibits autorhythmicity—the ability to generate action potentials spontaneously. This intrinsic rhythmicity originates in specialized pacemaker cells of the sinoatrial node and is modulated by autonomic innervation rather than directly controlled by it. Regulation of cardiac muscle contraction involves both intrinsic and extrinsic mechanisms. Intrinsically, the Frank-Starling mechanism enables the heart to adjust contractile force based on ventricular filling—increased stretching of cardiac fibers enhances calcium sensitivity and contractile force, optimizing cardiac output. Extrinsically, the autonomic nervous system modulates heart rate and contractility, with sympathetic stimulation increasing both parameters through β -adrenergic receptor activation and parasympathetic stimulation decreasing heart rate via muscarinic receptors.

Relaxation of cardiac muscle requires calcium removal from the cytosol, which occurs through four pathways: reuptake into the sarcoplasmic



reticulum via SERCA, extrusion across the sarcolemma via the sodium-calcium exchanger, uptake by mitochondria, and binding to cytosolic buffers like calmodulin. The balance between these pathways varies among species and can be altered in pathological conditions such as heart failure.

Smooth Muscle Structure and Contraction

The contractile apparatus of smooth muscle contains unique isoforms of contractile proteins adapted for its specialized functions. Smooth muscle myosin II differs from skeletal muscle myosin in its ATPase activity and regulation. The thin filaments contain actin along with the regulatory proteins caldesmon and calponin rather than the troponin complex found in striated muscles. Additionally, the protein ratio of actin to myosin is higher in smooth muscle (approximately 15:1) compared to skeletal muscle (about 2:1), contributing to its distinctive contractile properties. Contraction of smooth muscle proceeds more slowly and sustains for longer periods than in striated muscles, with significantly lower energy consumption—characteristics that make it ideal for maintaining vascular tone and regulating the diameter of hollow organs. The primary mechanism of smooth muscle contraction centers on calcium-dependent phosphorylation of the regulatory light chain of myosin rather than the troponin-mediated system of striated muscles.

The contractile process in smooth muscle begins with an increase in cytosolic calcium concentration, which can result from various stimuli including neural input (primarily autonomic), hormones, local factors, or mechanical stretch. This calcium elevation occurs through influx from extracellular fluid via voltage-gated or receptor-operated calcium channels and release from intracellular stores in the sarcoplasmic reticulum through IP_3 receptors following G-protein coupled receptor activation. Elevated calcium binds to calmodulin, forming a calcium-calmodulin complex that activates myosin light chain kinase (MLCK). Activated MLCK phosphorylates the regulatory light chain of myosin, inducing a conformational change that enables myosin to interact with actin and generate force through cross-bridge cycling. Unlike striated muscle, where tropomyosin physically blocks myosin binding sites on actin, smooth muscle regulation occurs primarily through this phosphorylation-dependent activation of myosin itself.

An important feature of smooth muscle contraction is the latch state—a condition where force is maintained with reduced cross-bridge cycling and ATP consumption. This state results from dephosphorylation of attached myosin by myosin light chain phosphatase (MLCP), which decreases myosin's detachment rate without significantly affecting its attachment to actin. The balance between MLCK and MLCP activities, regulated by various signaling pathways including Rho kinase and protein kinase C, determines the level of myosin phosphorylation and thus contractile



activity. Relaxation of smooth muscle occurs when cytosolic calcium levels decrease through active transport back into the sarcoplasmic reticulum or out of the cell, leading to dissociation of the calcium-calmodulin complex, inactivation of MLCK, and predominance of MLCP activity. This results in myosin dephosphorylation and cessation of cross-bridge cycling. Various physiological relaxants including nitric oxide, prostaglandins, and β -adrenergic agonists induce smooth muscle relaxation through mechanisms involving cAMP or cGMP, which ultimately reduce cytosolic calcium or decrease myosin phosphorylation through kinase-mediated effects on calcium handling proteins or MLCP activity.

5.2.2 Neuromuscular Junction: Structure and Role of Acetylcholine

The neuromuscular junction (NMJ) represents a specialized synapse where motor neurons communicate with skeletal muscle fibers, translating neural impulses into mechanical contraction. This remarkable structure has evolved to ensure rapid, reliable signal transmission, as failure at this critical interface would compromise movement and survival. The NMJ exhibits exquisite molecular organization and employs acetylcholine as its primary neurotransmitter, enabling precisely timed activation of the postsynaptic muscle fiber.

Structural Organization of the Neuromuscular Junction

The neuromuscular junction comprises three main components: the presynaptic motor nerve terminal, the synaptic cleft, and the postsynaptic muscle membrane. Each component displays specialized adaptations that collectively optimize neuromuscular transmission. The presynaptic nerve terminal represents the expanded distal end of a motor neuron axon, containing numerous mitochondria that support the high energy demands of neurotransmission. Within the terminal, synaptic vesicles loaded with acetylcholine cluster near specialized regions of the presynaptic membrane called active zones. These active zones contain voltage-gated calcium channels and a complex protein network including SNARE proteins (synaptobrevin, syntaxin, and SNAP-25), Munc13, Munc18, and Rab3, which collectively mediate calcium-dependent exocytosis of neurotransmitter vesicles. Additionally, the presynaptic terminal contains machinery for endocytosis and vesicle recycling, ensuring sustained neurotransmitter release during repetitive stimulation. The synaptic cleft separates the nerve terminal from the muscle fiber by approximately 50-100 nm and contains a specialized extracellular matrix rich in laminins, collagens, and proteoglycans. This matrix includes acetylcholinesterase (AChE), the enzyme responsible for rapid degradation of acetylcholine, anchored to the basal lamina by collagen Q. The structured organization of the synaptic cleft facilitates diffusion of acetylcholine while providing mechanical stability to the junction and contributing to synapse development and maintenance.

The postsynaptic muscle membrane exhibits elaborate folding patterns forming junctional folds, which dramatically increase surface area and concentrate acetylcholine receptors (AChRs) at the fold crests. The density of AChRs at the NMJ is remarkably high—approximately 10,000 receptors/ μm^2 , compared to virtually none in extrajunctional regions of the sarcolemma. This clustering results from an intricate developmental process involving agrin, a proteoglycan released from motor nerve terminals, which activates the muscle-specific kinase (MuSK) via the LRP4 co-receptor. MuSK activation triggers a signaling cascade involving DOK7 and rapsyn, ultimately leading to AChR aggregation at the postsynaptic membrane. The junctional folds also contain voltage-gated sodium channels concentrated in the depths of the folds, strategically positioned to initiate action potentials in response to endplate potentials generated by AChR activation. The mature NMJ maintains its structural integrity through bidirectional signaling between motoneuron and muscle fiber. Retrograde signals from the muscle, including neurotrophic factors like GDNF and cytokines like interleukin-6, influence presynaptic differentiation and function. Conversely, anterograde signals from the nerve, including agrin, neuregulin, and various growth factors, regulate postsynaptic specialization and gene expression. This reciprocal communication ensures precise alignment of pre- and postsynaptic components and adaptation to changing physiological demands.

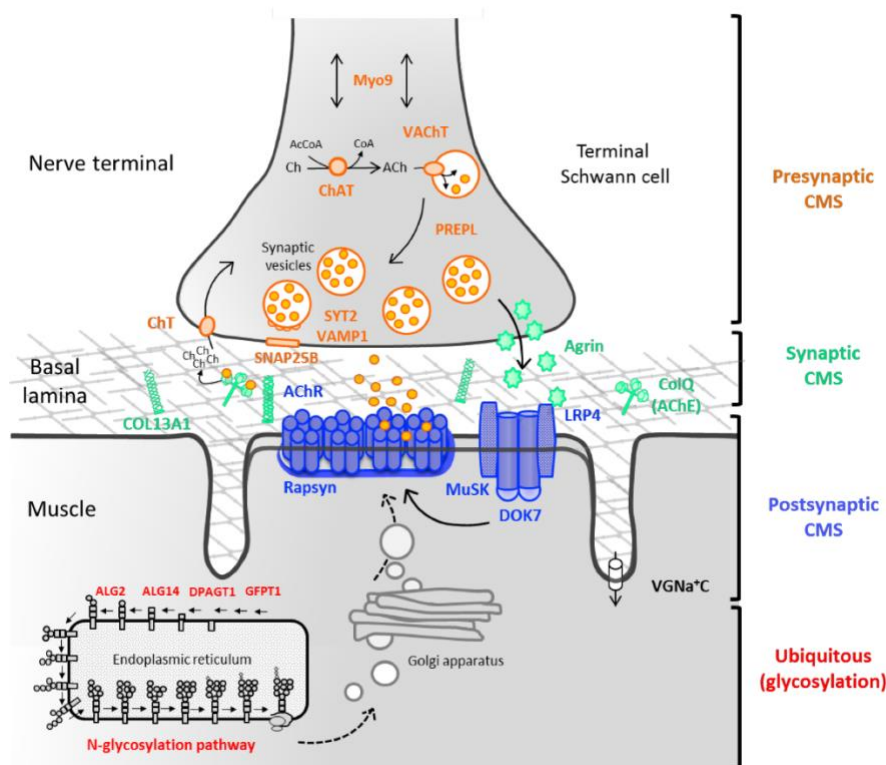


Fig 5.6: Nerve impulse transmission across synapse



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Acetylcholine: Synthesis, Release, and Function

Acetylcholine (ACh) serves as the principal neurotransmitter at the neuromuscular junction, mediating the rapid and precise signaling essential for skeletal muscle contraction. The life cycle of acetylcholine at the NMJ encompasses synthesis, storage, release, receptor binding, and degradation—all tightly regulated processes critical for normal neuromuscular function. Once synthesized, acetylcholine is packaged into synaptic vesicles by the vesicular acetylcholine transporter (VACHT), which uses a proton gradient generated by the vesicular H^+ -ATPase to drive ACh accumulation. Each synaptic vesicle contains approximately 5,000-10,000 ACh molecules, representing a quantum of neurotransmitter released during exocytosis. The filled vesicles either join the reserve pool, which contains the majority of vesicles anchored to the cytoskeleton via synapsin proteins, or the readily releasable pool positioned at active zones, primed for immediate release.

Release of acetylcholine follows a calcium-dependent exocytotic process triggered by action potential arrival at the nerve terminal. When an action potential propagates into the presynaptic terminal, it depolarizes the membrane and activates voltage-gated calcium channels (predominantly P/Q-type or Cav2.1), allowing calcium influx into the terminal. This localized calcium elevation is detected by synaptotagmin, the primary calcium sensor for neurotransmission, which interacts with SNARE proteins to initiate membrane fusion and vesicle exocytosis, releasing acetylcholine into the synaptic cleft. Under resting conditions, spontaneous release of individual vesicles occurs randomly, generating miniature endplate potentials (MEPPs) of approximately 0.5-1 mV amplitude. These subthreshold events reflect the quantal nature of neurotransmission first described by Katz and colleagues. During normal neuromuscular transmission, an action potential typically triggers the synchronous release of 20-300 vesicles (depending on the species and specific NMJ), resulting in an endplate potential (EPP) sufficient to reach threshold and generate a muscle action potential.

Upon release into the synaptic cleft, acetylcholine diffuses rapidly across the narrow gap and binds to nicotinic acetylcholine receptors (nAChRs) concentrated on the postsynaptic membrane. The adult nAChR at the mammalian NMJ is a pentameric ligand-gated ion channel composed of two α , one β , one δ , and one ϵ subunit arranged around a central ion pore. This adult receptor isoform replaces the embryonic receptor (containing a γ subunit instead of ϵ) during postnatal development, resulting in channels with shorter open times and higher conductance, suited for mature neuromuscular transmission. Binding of two acetylcholine molecules to the α subunits induces a conformational change that opens the receptor channel, allowing simultaneous influx of sodium and efflux of potassium



ions. This ionic current generates a localized depolarization called the endplate potential (EPP). At the normal NMJ, the EPP substantially exceeds the threshold for action potential generation, providing a safety factor that ensures reliable neuromuscular transmission even under fatiguing conditions. Once initiated, the muscle action potential propagates along the sarcolemma and into the T-tubule system, triggering the excitation-contraction coupling process described earlier. The termination of acetylcholine signaling is crucial for precise temporal control of neuromuscular transmission and occurs primarily through hydrolysis by acetylcholinesterase (AChE) anchored in the synaptic basal lamina. This enzyme cleaves acetylcholine into acetate and choline with remarkable efficiency—each AChE molecule can hydrolyze up to 5,000 ACh molecules per second. The released choline is recaptured by the high-affinity choline transporter in the presynaptic terminal for recycling into new acetylcholine molecules. This rapid clearance of ACh prevents prolonged receptor activation and desensitization, enabling high-frequency neuromuscular transmission at rates exceeding 100 Hz in some fast muscles.

Neuromuscular Transmission Modulation

Neuromuscular transmission exhibits plasticity in response to various physiological and pathological conditions, with multiple mechanisms modulating the efficacy of signaling at the NMJ. Understanding these regulatory processes provides insight into both normal muscle function and diseases affecting neuromuscular transmission. Short-term plasticity at the NMJ includes facilitation, depression, and post-tetanic potentiation. Facilitation occurs when closely spaced action potentials lead to enhanced neurotransmitter release due to residual calcium in the nerve terminal. Conversely, depression results from depletion of the readily releasable vesicle pool during high-frequency stimulation. Post-tetanic potentiation represents enhanced transmitter release following a tetanic stimulation period, attributed to increased calcium sensitivity of the release machinery and mobilization of vesicles from the reserve pool. Long-term plasticity at the NMJ involves structural and functional adaptations to chronic changes in activity patterns. Increased neuromuscular activity leads to expansion of the presynaptic terminal, enhanced neurotransmitter release capacity, and refinement of postsynaptic specializations. Conversely, disuse results in retraction of nerve terminals, reduced vesicle release, and dispersal of postsynaptic AChRs. These adaptations involve changes in gene expression mediated by activity-dependent transcription factors and retrograde signaling between muscle and nerve.

Presynaptic modulation of acetylcholine release occurs through multiple mechanisms. Adenosine, released during high-frequency stimulation, activates presynaptic A₁ receptors that inhibit neurotransmitter release through reduced calcium influx. Various neuropeptides co-released with acetylcholine, including calcitonin gene-related peptide (CGRP) and



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substance P, modulate synaptic transmission over longer timescales. Additionally, muscarinic acetylcholine receptors on the presynaptic membrane provide negative feedback regulation, reducing ACh release during intense activity. Postsynaptic sensitivity to acetylcholine varies with muscle fiber type, innervation pattern, and physiological state. Fast-twitch fibers typically exhibit greater quantal content and larger safety factors compared to slow-twitch fibers, reflecting their different functional requirements. During development and after denervation, extrajunctional regions of the muscle membrane express AChRs, increasing sensitivity to acetylcholine throughout the muscle fiber—a phenomenon exploited diagnostically in certain neuromuscular disorders. Glial cells at the NMJ, specifically terminal Schwann cells, actively participate in synaptic function rather than merely providing structural support. These cells detect neuronal activity through purinergic and other receptors, respond with calcium signaling, and release modulatory factors that influence both presynaptic release and postsynaptic sensitivity. Following nerve injury, terminal Schwann cells guide regenerating axons to original synaptic sites, facilitating functional recovery.

Neuromuscular transmission can be compromised by various pathological conditions and toxins that target specific components of the NMJ. Myasthenia gravis, an autoimmune disorder featuring antibodies against acetylcholine receptors or related proteins, reduces postsynaptic sensitivity and causes fatiguable muscle weakness. Lambert-Eaton myasthenic syndrome involves autoantibodies against presynaptic calcium channels, reducing quantal release. Various neurotoxins specifically target the NMJ, including botulinum toxin (inhibiting ACh release by cleaving SNARE proteins), α -bungarotoxin (irreversibly binding AChRs), and fasciculins (inhibiting AChE), further highlighting the critical importance of this synapse for normal muscle function.

SUMMARY:

Muscle contraction is a highly coordinated physiological process based on the **sliding filament theory**, where thin **actin filaments** slide over thick **myosin filaments** within the sarcomere, causing shortening of muscle fibers. The process begins with an **action potential** transmitted via motor neurons, releasing **acetylcholine** at the neuromuscular junction, which triggers depolarization of the sarcolemma and release of **calcium ions** from the sarcoplasmic reticulum. Calcium binds to **tropo**nin, causing tropomyosin to shift and expose active sites on actin. Myosin heads, energized by **ATP hydrolysis**, form cross-bridges with actin and pull filaments inward. Relaxation occurs when calcium is pumped back into the sarcoplasmic reticulum and ATP causes detachment of myosin from actin. This cycle ensures precise control of skeletal, cardiac, and smooth muscle movements.



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A. Multiple Choice Questions:

1. The sliding filament theory of muscle contraction was proposed by:
 - a) Darwin and Wallace
 - b) Huxley and Hanson
 - c) Schleiden and Schwann
 - d) Watson and Crick

Answer: b) Huxley and Hanson

2. Which ion is essential for initiating muscle contraction?
 - a) Sodium
 - b) Potassium
 - c) Calcium
 - d) Magnesium

Answer: c) Calcium

3. The neurotransmitter at the neuromuscular junction is:
 - a) Dopamine
 - b) Acetylcholine
 - c) Serotonin
 - d) Adrenaline

Answer: b) Acetylcholine

4. During contraction, which band of the sarcomere shortens?
 - a) A band
 - b) I band
 - c) H zone
 - d) Both b and c

Answer: d) Both b and c

5. The energy for muscle contraction is directly supplied by:
 - a) GTP
 - b) ATP
 - c) Creatine phosphate
 - d) Glucose

Answer: b) ATP

B. Short Answer Questions

1. Explain the sliding filament theory of muscle contraction with a neat diagram.
2. Describe the role of calcium ions and ATP in muscle contraction and relaxation.
3. Differentiate between skeletal, cardiac, and smooth muscle contraction.



UNIT 5.3:

Physiology of Nerve Impulse, Synaptic Transmission

5.3 Introduction

The Neuron The nervous system is composed of nerve cells or neurons, surrounded by a delicate web of connective tissue called neuroglia.

Neuron or neurone is the structural as well as functional unit of nervous system. According to the 'neuron theory', each neuron is a distinct anatomical unit, having no protoplasmic continuity with other neurons. It is also physiologically distinct, so that damage or destruction of a neuron may not affect adjacent neurons. The neuron, rather than the nerve, transmits the nerve impulse.

5.3.1 Structure of a neuron

Neurons are of different shapes, but each consists of an irregular cytoplasmic cell body called cyton. with a number of branching cell processes or fibres.

1. Cyton. Cyton contains a nucleus and several small basophilic Nissl granules or tigroid bodies that readily stain with methylene blue. These granules are made of ribonucleic acid (RNA) and take part in protein synthesis. Cytoplasm of cyton also contains a network of fine, thread-like neurofibrillae. A group or mass of cell bodies within the gray matter of brain or spinal cord is called a nucleus, while outside the central nervous system it is called a ganglion.

Nerve fibres. Two types of fibres are differentiated on the basis of the direction of nerve impulse conducted by them.

(a) Dendrites. These are shorter, usually several, much branched, with Nissl granules, and carry impulses towards or into the cell body.

(b) Axon. It is longer, usually single, without branches and Nissl granules, and normally conducts impulses away from the cell body. A nerve fibre consists of a central thin cytoplasmic strand, called axis cylinder, which is continuous with the cell body. All nerve fibres outside brain and spinal cord, are covered by a thin delicate membrane, the Schwann sheath or neurilemma. In most long nerve fibres, there is a layer of lipid or fatty material, called myelin or medullary sheath, between axis cylinder and neurilemma. Such fibres are termed myelinated or medullated and appear white. Myelin substance is not continuous uniformly but becomes interrupted at intervals by circular constrictions termed nodes of Ranvier. Part of nerve fibres between two adjacent nodes is called an internode. Nerve fibres which lack the fatty sheath are called non-myelinated or non-



medullated and are gray in appearance. Just below neurilemma is a thin cytoplasmic layer with scattered flat nuclei, forming sheath cells or Schwann cells. They secrete the myelin sheath and neurilemma. Each internode is covered usually by a single Schwann cell. Collateral branches may arise at right angles from long fibres or axons.

Synapses. Neurons form pathways for conduction of nerve impulses, but cytoplasm of one neuron is not continuous with that of another. Electron microscope has shown that branches of an axon end in terminal buttons full of mitochondria. These lie in close proximity but without actual organic connection with terminal branches of a dendrite of another neuron. The small gap thus left between the juxtaposed processes is called a synapse or synapsis. Only the branches of an axon form a synapse with the dendrites of another neuron. The whole nervous system in fact represents chains of neurons linked together by synapses in a complicated web.

Nature of Nerve Impulse The nature of nerve impulses passing along a nerve fibre is partly physical and partly chemical (Fig. 3). A wave of electric change or disturbance accompanies the nerve impulse. This electric charge, known as the action current, can be recorded with a galvanometer. While transmitting an impulse, the nerve consumes more O₂, produces more CO₂ and generates a minute but measurable amount of heat, than a resting nerve. These factors clearly indicate the physico-chemical nature of the nerve impulse.

The synapse has a polarity, that is, like a 'physiological valve', it allows an impulse to travel in one direction only, from axon of one neuron to the dendrite of other. In fact, an impulse does not travel through a synapse, but a fresh impulse is induced on its other side. On reaching the terminal buttons of an axon, the impulse induces them to produce a small amount of a chemical transmission neurotransmitter, therefore, all synapses are called cholinergic. Acetyl choline is highly unstable as it is readily neutralized by an enzyme acetyl cholinesterase. One process it splits into processes. One of these processes is to the periphery and the other goes to the central nervous system. Such cells are found in all final ganglia. Unipolar neurones. These cells have a number of dendrites and an axon. They have various shapes depending mainly on the number and position of the dendrites, usually acetylcholine, which sets up a fresh impulse in the next neuron. On the other hand, terminations of sympathetic fibres release sympathin, a substance like adrenalin, and which is antagonistic to acetylcholine. These neuro-hormones may continue to stimulate the other neuron, but they are quickly inactivated by an enzyme, cholinesterase. A neuron is able to transmit an electric impulse very rapidly, at a speed of 100 metres per second in man. Medullated fibres conduct impulses much faster than the non-medullated fibres. It travels at a uniform



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speed with the same intensity for a long time and does not spread to adjacent tissues due to insulation provided by myelin sheaths. A refractive period usually occurs when the depolarized nerve fibre cannot carry another stimulus. It is believed that the nerves are never tired. Impulses are conducted on the basis of 'all or none' principle .

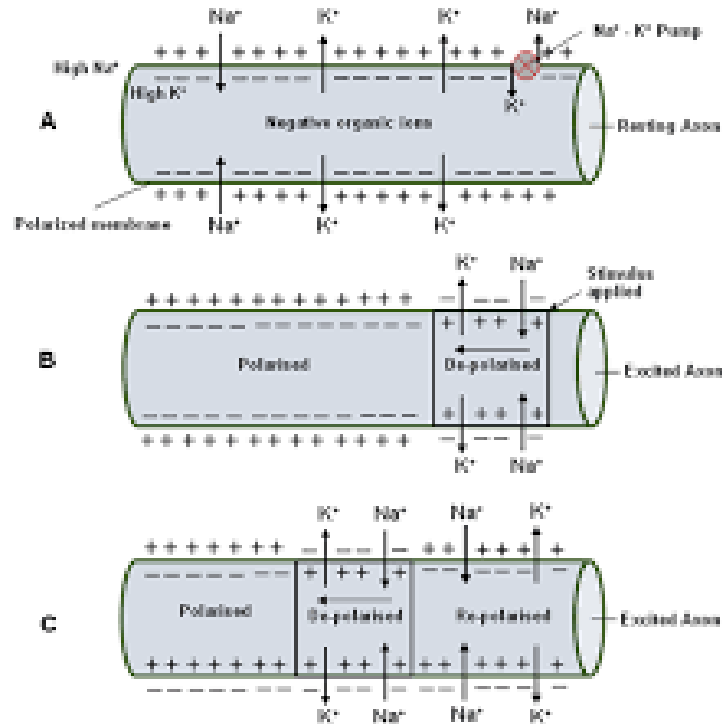


Fig5.7: Nerve Impulse Transmission

SUMMARY:

Nerve impulse transmission is the process by which neurons communicate through rapid electrical signals called **action potentials**. In a resting neuron, the **resting membrane potential** (about -70 mV) is maintained by the sodium–potassium pump and selective ion permeability. When a stimulus reaches threshold, **voltage-gated sodium channels open**, causing sodium influx and **depolarization**. This is followed by **repolarization** as potassium channels open and K^+ ions exit the cell. A brief **refractory period** ensures unidirectional conduction. The action potential travels along the axon, faster in **myelinated fibers** due to **saltatory conduction** at the nodes of Ranvier. At the synapse, the impulse triggers release of **neurotransmitters** like acetylcholine into the synaptic cleft, which bind to receptors on the postsynaptic membrane, initiating a new impulse. This mechanism allows rapid, controlled communication in the nervous system.



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A. Multiple Choice Questions:

1. The resting membrane potential of a typical neuron is about:
a) +30 mV
b) -70 mV
c) 0 mV
d) -90 mV
Answer: b) -70 mV
2. During depolarization of a neuron, which ion primarily enters the cell?
a) K^+
b) Na^+
c) Ca^{2+}
d) Cl^-
Answer: b) Na^+
3. Saltatory conduction occurs in:
a) Non-myelinated axons
b) Myelinated axons
c) Both a and b
d) Dendrites only
Answer: b) Myelinated axons
4. The refractory period ensures:
a) Faster conduction
b) Backward conduction of impulse
c) Unidirectional conduction of impulse
d) Inhibition of neurotransmitter release
Answer: c) Unidirectional conduction of impulse
5. The neurotransmitter at the neuromuscular junction is:
a) Dopamine
b) Serotonin
c) Acetylcholine
d) Noradrenaline
Answer: c) Acetylcholine

B. Short Answer Questions

1. Explain the sequence of events in the generation and conduction of an action potential.
2. Describe the differences between saltatory and continuous conduction.
3. Discuss the role of neurotransmitters in synaptic transmission.



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SUMMARY:

Excretion is the biological process of eliminating metabolic wastes and maintaining the body's internal environment (homeostasis). In vertebrates, the primary excretory organs are the kidneys, which filter nitrogenous wastes like urea from the blood and regulate water and salt balance through the formation of urine. The muscle contraction mechanism involves the sliding filament theory, where the proteins actin and myosin interact in the presence of calcium ions and energy-rich ATP, enabling muscles to contract and produce movement. Contraction is initiated by nerve impulses that stimulate the release of calcium from the sarcoplasmic reticulum within muscle fibers. A nerve impulse is an electrical signal transmitted along neurons, beginning with a stimulus that causes depolarization of the neuron membrane. This generates an action potential that travels down the axon and results in neurotransmitter release at the synapse, enabling communication between neurons or between a neuron and a muscle cell. The sensory systems are specialized to detect changes in the internal or external environment. These include receptors for vision, hearing, taste, smell, and touch. Each sensory organ (like the eye, ear, skin, tongue, and nose) converts specific stimuli into electrical signals that are transmitted via sensory neurons to the brain for interpretation, allowing organisms to respond appropriately to their surroundings.

A. Multiple Choice Questions (MCQs):

1. **The functional unit of the kidney responsible for filtration is:**
 - a) Nephron
 - b) Alveolus
 - c) Osteon
 - d) Synapse
2. **Osmoregulation in freshwater fish primarily involves:**
 - a) Excreting concentrated urine
 - b) Drinking seawater
 - c) Actively absorbing salts through gills
 - d) Retaining water and excreting salts
3. **Which hormone plays a key role in maintaining water balance in the body?**
 - a) Insulin
 - b) Antidiuretic hormone (ADH)
 - c) Adrenaline
 - d) Thyroxine
4. **The primary neurotransmitter involved in muscle contraction at the neuromuscular junction is:**
 - a) Dopamine
 - b) Acetylcholine
 - c) Serotonin
 - d) Epinephrine



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5. **Which ion is essential for muscle contraction?**
 - a) Sodium
 - b) Potassium
 - c) Calcium
 - d) Chloride
6. **The resting membrane potential of a neuron is maintained by:**
 - a) The sodium-potassium pump
 - b) Passive diffusion of glucose
 - c) Myelin sheath destruction
 - d) Release of neurotransmitters
7. **Synaptic transmission occurs primarily through:**
 - a) Electrical signals only
 - b) Direct ion exchange between neurons
 - c) Chemical neurotransmitters crossing the synaptic cleft
 - d) Protein synthesis
8. **The inner ear is responsible for:**
 - a) Filtering sounds
 - b) Detecting vibrations
 - c) Balance and hearing
 - d) Maintaining eye movement
9. **The retina of the eye contains:**
 - a) Hair cells
 - b) Rods and cones
 - c) Nephrons
 - d) Synapses
10. **Which of the following is a common eye disorder?**
 - a) Hypertension
 - b) Cataracts
 - c) Osteoporosis
 - d) Parkinson's disease

ANSWER KEY

1. **a) Nephron**
2. **c) Actively absorbing salts through gills**
3. **b) Antidiuretic hormone (ADH)**
4. **b) Acetylcholine**
5. **c) Calcium**
6. **a) The sodium-potassium pump**
7. **c) Chemical neurotransmitters crossing the synaptic cleft**
8. **c) Balance and hearing**



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9. b) Rods and cones

10. b) Cataracts

B.Short Answer Questions:

1. Describe the role of nephrons in kidney function.
2. What are the main differences between freshwater and marine osmoregulation?
3. How does ADH (antidiuretic hormone) regulate urine concentration?
4. What are the three types of muscle tissue, and where are they found?
5. Explain the role of calcium in muscle contraction.
6. What is a neuromuscular junction, and how does it function?
7. Describe the process of action potential generation in neurons.
8. What is the difference between excitatory and inhibitory neurotransmitters?
9. How do rods and cones contribute to vision?
10. Compare the function of the cochlea and semicircular canals in the ear.

C.Long Answer Questions:

1. Describe the mechanism of urine formation, including filtration, reabsorption, and secretion.
2. Explain how different vertebrates adapt to osmoregulation in marine and freshwater environments.
3. Describe the structure and function of muscle fibers, and explain the sliding filament theory of contraction.
4. Explain the role of the neuromuscular junction, including the function of acetylcholine.
5. Compare the process of synaptic transmission in excitatory vs. inhibitory neurons.
6. Explain the phases of an action potential, including depolarization, repolarization, and hyperpolarization.
7. Describe the structure of the human ear, including its role in hearing and balance.
8. Explain how light is processed by the eye, including the role of the retina and optic nerve.
9. Discuss the evolutionary adaptations of vertebrate sensory systems in different environments.
10. Describe common disorders of the eye and ear, including their causes and effects on perception.



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